PROCEEDINGS, INDONESIAN PETROLEUM ASSOCIATION
Thirty-First Annual Convention and Exhibition, May 2007

CENTRAL JAVA, INDONESIA – A "TERRA INCOGNITA" IN PETROLEUM EXPLORATION: NEW CONSIDERATIONS ON THE TECTONIC EVOLUTION AND PETROLEUM IMPLICATIONS

Awang H. Satyana*

ABSTRACT

Central Java, in the middle part of Java Island, Indonesia, shows a conspicuous re-entrant or indentation of its coastline compared to those of the western and eastern parts of Java Island. This indentation is considered to express wrench segmentation. Two major Paleogene strike-slip faults with opposing trends and slips are responsible for the indentation. The faults are called (1) the Muria-Kebumen Fault, left-lateral, trending southwest-northeast; and (2) the Pamanukan-Cilacap Fault, right-lateral, trending northwest-southeast. The two faults cross Central Java, separated in the northern area but meeting in the southern area.

The two faults are considered to cause significant geologic changes in Central Java. The faults caused: uplift of the Serayu Range and exposure of the pre-Tertiary Luk Ulo mélange complex, subsidence of the northern part of Central Java and indentation of the northern coastline, subsidence of the Southern Mountains of Java in southern Central Java and indentation of the southern coastline, and northward shifting of the Quaternary volcanic arc in Central Java.

The petroleum potential of Central Java is not yet fully understood, in contrast with its counterparts in the West Java and East Java basins which have been known to be very prolific since the late 1800s. Central Java has seen a definite lack of exploration making it a "terra incognita" in petroleum exploration. The tectonics of Central Java are unique relative to West and East Java and this is considered to affect its petroleum geology. The presence of two opposite regional strike-slip faults crossing each other in southern Central Java has configured the petroleum geology of Central Java. Southern Central Java was uplifted (the Serayu Range); the uplift was compensated isostatically by the subsidence of two areas to the north and south of the uplifted area: a northern area (North Serayu) and a southern area (South Serayu / Banyumas). The subsided area became basins within which petroleum system elements and processes are operating as manifested by numerous oil and gas seepages within the basins. Gravity tectonics of toe-thrusting, inverted anticlines composed by turbidites, and reefal carbonates on horst blocks may become exploration targets in these areas. Some potential is present but we have to consider the tectonic uniqueness of Central Java to explore this region.

INTRODUCTION

The northern and southern coastlines of Central Java narrow inward forming an indentation or re-entrant compared to the coastlines of West Java and East Java. This indentation may relate to tectonic or structural origin as considered by Situmorang et al. (1976). However, there has no detailed work for this phenomenon until the publication of Satyana and Purwaningsih (2002) which proposed the origin and geologic implications of the indentation of Central Java's coastline. Two major strike-slip faults, called the Muria-Kebumen Fault and the Pamanukan-Cilacap Fault, which are opposite in slip and trend to each other, are considered to have indented Central Java's coastline and caused many geologic changes in Central Java. This paper elaborates the author's previous publications (Satyana and Purwaningsih, 2002; Satyana, 2005; Satyana, 2006)

The indentation of Central Java's coastline is argued to relate to the uplift and exposure of the pre-Tertiary to earliest Tertiary-aged mélange and basement rock complex of Luk Ulo-Karangsambung and the disappearance of Java's Southern Mountains in southern Central Java. This paper also argues that Central Java has occupied a significant position in the tectonic framework of Western Indonesia during the Latest Cretaceous to the Paleogene.

* BPMIGAS

This new tectonic insight into Central Java gives reasoning why basins in Central Java are different from their counterparts in western and eastern Java and presents where to look for possible petroleum possibilities in this area. Central Java has seen a lack of petroleum exploration making it a “terra incognita” in petroleum exploration. Based on previous exploration results, some potential is present but people should consider the tectonic uniqueness of Central Java to explore this region.

REGIONAL TECTONICS AND THE STRUCTURE OF JAVA ISLAND

Java Island occupies an active margin of plate interaction between the Eurasia continental plate and the Indian oceanic plate, which have converged since the Cretaceous (Figure 1). Therefore, the basement of Java Island is composed of both Eurasian continental crust (northern West Java and Central Java) and intermediate accreted terrain (southern West Java, southern Central Java and up to East Java). The presence of some micro-continents is also possible in Java, such as in the Jampang and Bayat areas. The main tectonic elements resulted from the convergence include subduction trenches, magmatic-volcanic arcs, accretionary prisms, and back-arc and fore-arc basins. Sedimentary and volcaniclastic rocks intruded by some magmatic intrusions cover the basement rocks. Central Java occupies a transition between predominantly continental basement in West Java and predominantly intermediate basement in East Java.

There are some published studies on the structural patterns of Java Island based on surface geology, gravity, magnetic, aerial photos, satellite imagery, and seismic. Pulunggono and Martodjojo (1994) grouped the structural trends of Java Island into three groups, including: (1) Meratus Trend (southwest-northeast), (2) Sunda Trend (north-south), and (3) Java Trend (west-east). Based on gravity data interpretation (Untung, 1974; 1977; Untung and Wiriosudarmo, 1975; Untung and Hasegawa, 1975; Untung and Sato, 1978), there is another trend in addition to the previously three trends, namely (4) Sumatra Trend (northwest-southeast). The existence of the structures with Sumatra Trend is also supported by seismic data (Pramono et al., 1990; Gresko et al., 1995; Ryacudu and Bachtiar, 2000).

The structures with Sumatra Trend mainly exist in the West Java area and disappear to the east of the Central Java area. In contrast the structures of the Meratus Trend dominate the structural grains of northern East Java (Satyana and Darwis, 2001) and reduce or disappear to the west of Central Java. It looks as though Central Java again occupies a structural transition area between the Meratus and Sumatra Trends. The formation dates of these structures are: Late Cretaceous (Meratus Trend), Late Cretaceous-Paleocene (Sumatra Trend), Eocene-Late Oligocene (Sunda Trend), and since Early Miocene in the case of the Java Trend. The structural grains of Meratus, Sumatra, and Sunda Trends are generally comprised of normal and strike-slip faults, whereas folds and thrust-reverse faults constitute the Java Trend.

Situmorang et al (1976) have an opinion that all structural grains on Java can be related to north-south compression due to Indian oceanic crust subduction. The mechanisms of structure formation are through wrench tectonism and follow the concept of wrench deformation of Moody and Hill (1956). The four structural trends of Java represent the order I to order III of wrench tectonism. This paper discusses the concept that the north-south compression mainly resulted in west-east structural trend (Java Trend).

PETROLEUM EXPLORATION OF CENTRAL JAVA: “TERRA INCOGNITA”

The petroleum potential of Central Java is not yet fully understood, by contrast with its counterparts in the West Java and East Java basins which have been known to be very prolific since the late 1800s. Central Java has seen a lack of exploration for several reasons, making it a “terra incognita” (unknown land) in petroleum exploration (Figure 2).

Petroleum exploration activities in Central Java were started in the late 1800s following the discovery of oil seepages. In North Central Java, the seepages occur in Karangkobar, Bawang and Subah, Klantung and Sodjomerto, Kaliwaru, and east and west of Mt. Ungaran. Exploratory wells were drilled by the Dutch oil company in the late 1800s near Klantung and Sodjomerto. They discovered the Cipluk field in 1889 to the southwest of Semarang. The field was produced from 1903-1912 using 12 wells with a cumulative production of 400 tons (van Bemmelen, 1949). Cumulative production of Cipluk Field was 107,000 barrels before 1933. Production came from Banyak sandstones (possibly upper Cibulakan or Ngrayong sand equivalent). There were no significant further exploratory activities after the abandonment of the Cipluk field.

However, nowadays local people still recover oil from Cipluk wells using traditional ways.

In South Central Java, oil seepages were found in Banyumas area (Cipari, Gunung Wetan, Prapagan, Majenang, and Bumiayu). Exploratory wells (Cipari, Gunung Wetan) were drilled by the Dutch company in the 1930s but failed to discover hydrocarbons. After Dutch time ended in Indonesia, no significant exploration activities were carried out in Central Java. Pertamina, which succeeded the Dutch company, actively explored, developed, and produced oil and gas fields to the west (West Java Basin) and east (East Java Basin) of Central Java but Central Java itself remained unexplored. In the early 1970s following the opening of the PSC (production sharing contract) system in the late 1960s, southern offshore Central Java was explored by Java Shell. They drilled two wells (Alveolina-1 and Borelis-1) to the southwest offshore of Yogyakarta, but the wells failed to discover hydrocarbons. Arco operated north offshore Central Java in the Java Sea and drilled some wells chasing West Java Basin plays One of the wells, Mawar-1 tested 8.0 MMCFG/D from Baturaja carbonates. The discovery was determined as non-economic and abandoned. Pertamina in the 1980s drilled three wells, NCJ A-1, NCJ B-1, and NCJ C-1 in the Kendal area. The wells tested gas from Parigi 4.3 and 5.4 MMCFG/D, respectively with 49 % CO_2 in NCJ A-1 and B-1. NCJ C-1 well was dry. After almost 20 years without exploration drilling, Pertamina drilled Jubang-1 well in 2002 but the well was dry.

In southern Central Java, (Banyumas area) Pertamina also drilled two wells (Karang Nangka-1 and Karang Gedang-1) but failed to discover hydrocarbons. From the 1980s to 2000, no significant work was carried out by Pertamina in these areas. Recently, Pertamina tried to work over Cipluk and Klantung in northern Central Java by drilling new wells, but the results were not positive. Lundin has explored Banyumas area since 2001. Lundin drilled its first well in 2005-2006, Jati-1, failing to encounter the objective due to many mechanical problems, but the well tested a small amount of gas and condensate.

Compared to works carried out by various operators in West Java and East Java Basins, Central Java has witnessed a much lower level of exploration activity, causing this area to be not yet fully understood, making it essentially a "terra incognita". Potential is there and proved, as shown by numerous seepages, field, and limited well results, but these are very difficult to elaborate and locate.

Central Java has two potential basins, i.e. South Central Java Basin and North Central Java Basin. Since the early 20th century, oil and gas seeps have been reported from the two basins providing evidence for an active petroleum system in the region. However, up to the present time, the origin of the Central Java oils has been enigmatic, as well as its geology and tectonics (Subroto et al, 2006). This paper will provide some ideas about the geology and tectonics of Central Java and their implications to petroleum exploration.

THE UNIQUENESS OF CENTRAL JAVA

Central Java, due to its geologic and tectonic position, has some geologic-tectonic phenomena, which are unique compared to both West Java and East Java. The unique features of Central Java include : (1) its position on the transition of basement rocks from continental to accreted crusts, (2) its position on the transition of structural trends from Sumatran to Meratus Trends, (3) the place where the exposure of the oldest basement rock complex of Java Island occurs in the Luk Ulo area, (4) the place where Java's Southern Mountains disappear in southern Central Java in direct contrast to those existing in southern West Java and southern East Java, (5) the place where the Quaternary volcanic arc lineament shifts northward compared with those in the western and eastern Java which are located more to the south, and (6) the place where the coastlines of Java Island indent inward compared with those of West Java and East Java. All of these unique features can be explained and related to the pair of major strike-slip faults - the Muria-Kebumen and Pamanukan-Cilacap Faults which flank Central Java and deformed it during the Late Cretaceous-Paleogene.

INDENTATION OF COASTLINES OF CENTRAL JAVA

The coastlines of Central Java, both the southern coastline and more obviously the northern one indent significantly inward compared with those of West Java and East Java (Figure 3). The northern indentation occurs on the coastline between Cirebon and Semarang, while the southern indentation takes place between the bay of Pananjung Pangandaran and Parangtritis, near Yogyakarta.

The northern coast of Java Island is made up of alluvial plains of river and beach deposits. To the west of Cirebon and to the east of Semarang, these Recent sediments constitute a wide strip of coastal plain, but they tighten to a narrow strip along the northern Central Java coast. The wide strip of coastal plain to the west of Cirebon is caused by deltaic progradation of the Cimanuk Delta. To the east of Semarang, the wide strip relates to the coastal progradation from Kudus to Mount Muria. It appears that the indentation of the coastline of northern Central Java is caused by surface processes due to sediment starvation or the embayment process of the Java Sea to the area between Cirebon and Semarang. This paper will give another mechanism.

In southern Central Java, the physiographic zone of the Java's Southern Mountains disappears right along the indentation of coastline between Pangandaran and Parangtritis (Figure 1). At the place where the Southern Mountains disappear, there is a depression area with protruding domes and ridges (van Bemmelen, 1949). The disappearance of the Southern Mountains in this area (Nusa Kambangan to the Opak River in Parangtritis) has resulted from its subsidence below sea level (van Bemmelen, 1949). The southern coastline of Java is composed of volcaniclastic and carbonate rocks.

EXPOSURE OF THE BASEMENT ROCKS

The Luk Ulo-Karangsambung area, to the north of Kebumen in southern Central Java is famous for its exposure of the basement rocks complex representing "the fossil" of the Late Cretaceous subduction in Western Indonesia. The area has been studied since Junghuhn's time in the 1850s until the present day.

The Luk Ulo area is composed of a variety of rocks with complex geological structures (Asikin, 1974; Harsolumakso, 2000). The oldest rock unit is the mélange complex of Luk Ulo. This tectonic-stratigraphic unit consists of variable rock fragments enclosed in a groundmass of scaly clay and sheared black shales. The rock complex is of Late-Cretaceous-Paleocene age. The rock fragments include both allochthonous and autochthonous fragments. The allochthonous fragments consist of : blue-green schists, chert and red limestones, serpentinite, amphibolite, gabbro, peridotite, dacite, basalt, and pillow lavas. Autochthonous fragments consist largely of turbiditic greywacke. These allochthonous and autochthonous rock fragments are considered to be a mélange complex comprised of a tectonic mixture of oceanic and continental rocks (Asikin, 1974).

Overlying the mélange complex, are Karangsambung Formation (polymict conglomerate and scaly clay, considered to be Middle Eocene-Late Eocene age olistostrome deposits), Totogan Formation (polymict breccias, considered to be an Early Oligocene olistostrome), Waturanda Formation (breccias and turbiditic volcaniclastic deposits of Oligo-Miocene age), and Penosogan Formation (sandstone and turbiditic, calcareous and volcanic claystone of Middle Miocene age). Ages are based on unpublished data of Lundin Banyumas B.V., 2002.

Structural deformation of the Luk Ulo area took place in tectonic episodes of Late Cretaceous-Paleocene and Tertiary orogenesis. The structural grains consist of folds, joints, and faults trending in two main directions of almost southwest-northeast (Meratus Trend) for pre-Tertiary structures and west-east (Java Trend) for folds (Kusumayudha and Murwanto, 1994).

The tectonic origin of the Luk Ulo mélange complex has been argued to be either a true mélange or alternatively an olistostrome complex. The examination of these two mechanisms of origin involves both petrologic and structural aspects. Kusumayudha and Murwanto (1994) discussed the origin of Luk Ulo mélange complex based on measurement of directions of sheared joints formed both on fragments and matrix of the mélange complex. They concluded that both true mélange and an olistostrome complex exist in this area. The Luk Ulo mélange complex is a mélange complex formed by tectonization. Parts of the mélange complex shattered, collapsed, and slid down through a delaptional process forming olistostrome deposits deposited both totally overlying the mélange complex and in between the mélange depression areas. Presently, both the mélange and the olistostrome complex are observed to be in association.

Tertiary orogenesis occurred several times in southern Central Java, mainly in middle Eocene (45 Ma), middle Oligocene (30 Ma), middle part of early Miocene (20 Ma), and Mio-Pliocene (5 Ma). The dates of the periods of orogenesis are based on unpublished Lundin Banyumas B.V. data. The orogeneses uplifted the area and were associated with volcanic activity. These orogenesis periods eventually exposed all basement rocks in the Luk

Ulo area but the area has been significantly uplifted since the late Miocene.

MAJOR STRIKE-SLIP FAULTS FLANKING CENTRAL JAVA

Two major faults or structural lineaments flank the indentation of coastlines of Central Java (Figures 3, 4, 7, 8). These two structural elements are considered to be major strike-slip faults (wrench faults) which along their traces also develop both normal and reverse slips. The two faults are called the Muria-Kebumen Sinistral Fault and the Pamanukan-Cilacap Dextral Fault. These faults are opposite (complementary) in slips and trends, widely separated in northern Central Java (on the northern indentation) and closer and eventually crossing in southern Central Java (on the southern indentation). The existence of these major faults is firstly based on interpretation of gravity data (Figures 3 and 4) (Untung, 1974; 1977; Untung and Wiriosudarmo, 1975; Untung and Hasegawa, 1975; Untung and Sato, 1978). Lineaments on Landsat and radar imageries (Chotin et al., 1984 in Pulunggono and Martodjojo, 1994 and Geology of UGM, 1994), and surface faults seen on geologic mapping (Kastowo, 1975; Martodjojo, 1994) and seismic data (Pramono et al., 1990; Sujanto et al., 1994; Gresko et al., 1995; Ryacudu and Bachtiar, 2000) confirm the existence of fault traces which regionally compose the Pamanukan-Cilacap and Muria-Kebumen Faults.

Gravity Bouguer anomaly data in West Java shows a northwest-southeast anomaly trend (Sumatra Trend), whereas there are many areas in Central and East Java showing the southwest-northeast Bouguer anomaly trends associated with the Meratus Trend. (Figures 3 and 4) (Untung and Wiriosudarmo, 1975). Bouguer anomalies of Central Java decrease from + 100 mgal in the southern indentation to –5 mgal in the northern indentation over an area between Jatibarang and Semarang. This area of differential Bouguer anomaly is bordered to the east by a major fault trending southwest to northeast from the foot of Mount Muria, through the Luk Ulo-Karangsambung area, to an area west of Kebumen. This major fault is called the Muria-Kebumen Fault and interpreted as a left lateral strike-slip fault. To the west the Bouguer anomaly is bordered by a major fault trending northwest-southeast from east of Jakarta to the Cilacap area, called the Pamanukan-Cilacap Fault and interpreted to be a right lateral strike-slip fault.

The Muria-Kebumen Sinistral Fault lineation may continue northeastwards crossing the Java Sea (Untung, 1974; Asikin, 1974; Situmorang et al., 1976) into the Meratus Mountains in Southeast Kalimantan (Figure 5) (Sikumbang, 1986). The origin of the fault is considered to relate closely to oblique subduction of the Indian oceanic plate beneath the southern and southeastern part of Sundaland (the southeastern promontory of Eurasia continental plate) in Late Cretaceous-earliest Tertiary times. This major fault constitutes the southeastern margin of the Paleozoic Sunda Shield (Sundaland) (Fraser and Ichram, 2000).

The Pamanukan-Cilacap Dextral Fault lineation may continue northwestward crossing the Java Sea through the North Seribu Fault (normal fault) separating the Sunda and Asri basins to the north of the Seribu Islands (Figure 5)(Pramono et al. 1990; Gresko et al., 1995) into the South Sumatra area and merging there with the major Lematang Fault (reverse fault - Pulunggono et al., 1992). In West Java onshore, the Gantar-Randegan Ridge (Ryacudu and Bachtiar, 2000), northern margin of the major Baribis Fault (reverse fault) (Martodjojo, 1994), and Kroya Fault (Untung and Sato, 1978) represent the fault traces associated with the Pamanukan-Cilacap Dextral Fault lineation. Dextral strike-slip faults trending northwest-southeast in the Majenang area (Kastowo, 1975) are splays of the Pamanukan-Cilacap Fault. Untung (1977) merged the Lematang Fault in South Sumatra and Kroya Fault in Cilacap area and called them as the Lematang-Kroya Dextral Fault trending northwest-southeast. The Lematang-Kroya Fault was significant when Sumatra and Java separated through rifting in the Sunda Strait (Untung, 1977).

The Muria-Kebumen Sinistral Fault and Cilacap-Pamanukan Dextral Fault are perfectly opposite in trend and slip to each other. North-south compression due to plate convergence during the Paleogene had moved the crustal masses bounded by the two faults. The crustal mass to the east of the Muria-Kebumen Fault moved northward, whereas the crustal mass west of the fault moved southward (Figure 6). The crustal mass east of the Pamanukan-Cilacap Fault moved southward, whereas the crustal mass west of the fault moved northward. Because the Muria-Kebumen and Pamanukan Cilacap Faults are separated in northern Central Java and approaching each other moving southwards and eventually crossing in the Cilacap area, the two faults make a triangle zone with a base across northern Central Java between Cirebon and Semarang and an apex in the Cilacap area. The sides of the triangle are the Muria-Kebumen and Pamanukan-Cilacap Faults, respectively. Within the triangle, the crustal mass moved southward. Towards the apex of the triangle, the deformation of the moved crustal mass becomes more conspicuous as the area for structural compensation becomes narrower. Right around the apex area, the deformation in the form of uplift is at a maximum and the area is tectonically locked. The maximum gravity anomaly in Central Java of +110 mgal has been measured in this area and may relate to the maximum uplift which occurred in the apex area. The origin of the Bumiayu-Luk Ulo High may also relate to this apex area. By contrast, towards the base of the triangle at northern Central Java, the crustal mass actually subsided. The minimum gravity anomaly of -5 mgal in northern Central Java may relate to this subsided basement.

STRUCTURAL ANALYSIS OF THE STRIKE-SLIP FAULTS

The origin of these major strike-slip faults and other main faults in Java Island has been analyzed using the concept of the strain ellipsoid for wrench tectonism of Wilcox et al. (1973), Harding (1974), and Christie-Blick and Biddle (1985). The direction of the principal stress is north-south (around N 350^{o} E – Kusumayudha and Murwanto, 1994) similar to the direction of the Indian crust subduction from the Late Cretaceous to the present. Situmorang et al. (1976) analyzed these structures using the concept of Moody and Hill (1956) (Figure 7), concluding that the Muria-Kebumen Fault is the primary-first order strike-slip fault and that the Pamanukan-Cilacap Fault is the complementary-first order strike-slip fault.

A similar conclusion is obtained if we analyze the structures using a strain ellipsoid (Figure 8). The Muria-Kebumen Fault is the main sinistral strike-slip fault (master fault or “Y” shear), whereas the Pamanukan-Cilacap Fault is a dextral strike-slip fault (antithetic or conjugate Riedel R’ shear). The compressional component of the strain ellipsoid trends north-south parallel with the compression due to Indian oceanic plate subduction beneath Java. The compressional stress not only moved the blocks laterally across the faults, but also resulted in folds and reverse faults/thrusts trending west-east (Java Trend). The extensional component of the strain ellipsoid directs west-east resulting in extensional rifting/fractures trend north-south (Sunda Trend). The north-south rifted structures in the offshore West Java area may confirm this extensional fracture orientation.

Therefore, based on structural analyses using Moody and Hill (1956), Wilcox et al. (1973), Harding (1974) and Christie-Blick and Biddle (1985), the presence of major strike-slip faults flanking Central Java (here called the Muria-Kebumen Sinistral Fault and the Pamanukan-Cilacap Dextral Fault) is reasonable.

GEOLOGIC IMPLICATIONS

The existence of the Muria-Kebumen and Pamanukan-Cilacap Faults, perfectly opposed in trends and slips to each other, crossing Java Island in the middle and flanking Central Java, separated in northern Central Java and crossing each other in southern Central Java has many geologic implications for Central Java (Figure 9). The faults are responsible for the uniqueness of Central Java discussed earlier.

Transition of Basement

The Muria-Kebumen Fault accommodated the transition of basement from granitic continental crust in West Java to metasediment-accreted crust in East Java (Satyana and Darwis, 2001). As has been discussed, the fault was formed by the oblique subduction of the Indian oceanic plate beneath the southeastern margin of Sundaland. Below the Muria-Kebumen Fault, there is crustal amalgamation between continental plate to the west towards West Java and accreted crust to the east of the fault.

Uplift of Bumiayu-Luk Ulo Area and Exposure of Basement Rocks

Towards southern Central Java, the basement is uplifted (Figures 6, 9). Maximum uplift, as has been discussed earlier, occurred at the apex of a triangle zone through a compressive tectonic-locked area. Untung and Sato (1978) estimated the amount of uplift as 2000 meters based on gravity data. The uplift was completed in Early Miocene time. The Luk Ulo-Karangsambung area, at the eastern part of the Bumiayu-Luk Ulo High, was eroded and the basement rock complex of the Late Cretaceous mélange was exposed.

Subsidence and Indentation of Northern Central Java

The Muria-Kebumen and Pamanukan-Cilacap Faults had subsided northern Central Java as a response to the uplift of southern Central Java (Figures 6, 9). The subsidence took place as isostatic compensation to the uplift. A decreasing Bouguer anomaly northward, from +110 mgal at southern Central Java to –5 mgal at northern Central Java, shows a subsided basement northward.

The uplift of southern Central Java in the Middle-Late Miocene was volumetrically compensated by a sudden increase of subsidence of the floor of the North Serayu Basin (van Bemmelen, 1949; Satyana and Armandita, 2004). The subsidence took place since Early Miocene until Pliocene times. This sudden increase of orogenic relief has not only caused the gravitational sliding movements from south to north, but has also caused that portion of the northern flank of the basin to slide down toward the deepest part. The Brebes Flexure, Tegal Diapir, and Semarang Flexure show this subsidence. In the Mio-Pliocene, again strong basin subsidence began, which volumetrically compensated the strong Mio-Pliocene uplift of the South Serayu Range at the southern part of Central Java.

The Mio-Pliocene succession of strata, filling the trough of the North Serayu Zone, began with volcanic deposits, alternated with conglomerates, and ended with the soft clay marls and tuffaceous sandstones of the Kalibiuk Beds. The volcanic series are called the Kumbang Breccias in the western part of the basin, the Bodas Series in the middle, and the Banyak Breccias in the eastern part. The volcanic breccias of the Lower Bodas Series contain polymict conglomerates with boulders derived from the raised Luk Ulo areas in the south.

The subsidence of northern Central Java had caused major structural indentation. The sea inundated this area farther to the south due to the subsidence, causing the coastline indentation of northern Central Java.

Subsidence of Java's Southern Mountains and Southern Coastline Indentation

Just to the south of the tectonic-locked area where maximum uplift is obtained, surrounding the apex of the triangle, is an isostatic compensating low area (Figure 9). Isostatic contrast occurs just to the south of the Bumiayu-Luk Ulo, namely the Citanduy-Kroya-Kebumen Low (Sujanto et al., 1994) which extends into the offshore area south of Central Java. This low area represents an isostatic compensation or a release tension to a tectonic-locked area. By this process, the crustal mass at the outer sides of the triangle downwarps or subsides. Java's Southern Mountains disappear in this area between Citanduy and Kebumen due to subsidence southward below the present sea level. This subsidence has caused the sea to transgress northward resulting in a coastline indentation. In the area where the Southern Mountains should exist, is the Central Depression of South Serayu (van Bemmelen, 1949). In the offshore region, the depression area is manifested as the Western Deep and Eastern Deep (Bollinger and de Ruiter, 1975). The two basins are separated by the Karangbolong High, which is located at the triangular apex.

Northward Shifting of the Volcanic Arc Lineament

The quaternary volcanic arc on Java Island forms a lineament parallel with the long axis of the island trending WNW - ESE (100°). However, the lineament breaks slightly in Central Java in the area of the coastline indentation. In this area, the volcanoes shift northward making a separated arc to the volcanic lineament. The diversion starts to the northeast of Ajibarang with Mount Slamet at the foot of arching. Mount Rogojembangan and Mount Dieng are positioned at the crest of the arc and from this point the trend tracks southeastward to the other foot of the arc through the volcanoes of Sundoro, Sumbing, Merbabu, and ends with Merapi.

The northward shifting of the volcanic arc in this area is considered to relate to the position of the basement which is uplifted southward in this area. The uplifted basement may have blocked the magmatic volcanic vents. Blocking in the southern area may divert the volcanic venting to the north where the basement collapsed due to subsidence and volcanoes subsequently developed in this area. Since the uplift and subsidence of the basement were caused by the strike-slip indentation deformation, then this northward shifting of volcanic lineament in this area was also related to the strike-slip indentation deformation.

The termination of the Mio-Pliocene volcanic arc of Java in Banjarnegara area (Prihatmoko et al., 2002) may also relate to this strike-slip indentation deformation. The Banjarnegara area is just to the west of the major trace of the Muria-Kebumen Fault. The Mio-Pliocene arc appears again in Jember area, a minor structural indentation in East Java.

PETROLEUM IMPLICATIONS

The tectonics of Central Java are unique relative to West and East Java and this is considered to affect its petroleum geology as revealed in the stratigraphic comparison (Figure 10). Backarc and forearc basins which are typically developed in Sumatra and Java are modified in Central Java due its tectonic uniqueness. Maximum uplift undergone by southern Central Java due to the presence of two opposite major strike-slip faults strongly modified the backarc and forearc basins of Central Java. This maximum uplift was compensated isostatically by the subsidence of two areas to the north and south of the uplifted area: the northern area (North Serayu) and the southern area (South Serayu / Banyumas)

Opportunities in the North Serayu (North Central Java) Basin

The uplift of the southern Central Java in the Middle-Late Miocene was volumetrically compensated by a sudden increase of subsidence of the floor of the North Serayu Basin (van Bemmelen, 1949). The detailed history of sedimentation and tectonics of the North Serayu Basin was discussed in Satyana and Armandita (2004).The sudden increase of orogenic relief not only caused gravitational sliding movements from south to north, but caused also portions of the northern flank of the basin to slide down under gravity toward the deepest part. In the Mio-Pliocene, a basal limestone of the Bodas Series was deposited transgressively and unconformably upon the older Miocene series. Then again strong basin subsidence began, which volumetrically compensated the strong Mio-Pliocene uplift of the South Serayu Range at the southern part of Central Java. Structures related to gravity tectonics – such as toe thrusting – developed verging to the north.

Eocene to Late Miocene rock beds of Worowari, Lutut, and Sigugur nonmarine to shallow marine formations, and Merawu and Lower Penyatan turbidites (Figure 11) were deformed as toe thrust anticlines and fault-propagation folds. This mechanism of deformation is similar to proved hydrocarbon traps in the Lower Kutei-North Makassar Basin where uplift of the updip area of the Kutei Basin during the Late Miocene to Recent formed traps in the Lower Kutei-North Makassar area with some sediments ponded in the synclinal area formed between the thrusted anticlines (Figure 12). All elements and processes of the petroleum system could be formed in this system. Hydrocarbon sources can be provided by the nonmarine-shallow marine Worowari shales and marly clays of the Merawu Beds. Based on an integration of the data of crude oils and the geochemical model, the most probable source rock of the North Central Java Basin is the source rocks which are age-equivalent to the East Java Ngimbang Formation (Subroto et al., 2006), therefore Eocene Worowari shales has potential to be the source rock in this area. Most of the organic matter contained in the sediments indicate a Type III kerogen, primarily vitrinite and some of them oxidised amorphous materials. Reservoirs could be formed by the quartzitic sandstones and tuffaceous sandstones of the Lutut and Merawu Beds, and reef limestones of the Sigugur Beds. Potential seals are intraformational shales within the Merawu and Penyatan Beds. Maturation of the source rocks could be attained as the basin subsided and burial sediments of post Late-Miocene were deposited. Generated hydrocarbons could enter the traps of the toe thrust anticlines formed in the Lutut and Merawu Beds or reefs of the Sigugur Beds via faults of the toe thrust system. A number of seepages in the surface indicate the presence of a viable petroleum system in the region.

The thrust front play is essentially untested. There are no wells drilled in the thrust front after the Cipluk wells drilled in late 1800s. In 1889, “the Dutch” discovered Cipluk field within the most northern side of the thrust front. Cipluk should be considered a healthy show at shallow levels offering encouragement that the petroleum system is active and could have significant upside. The large number of seeps in the area and the possibility of similar structural traps that have been tested in East Java make the area interesting.

Opportunities in the South Serayu (South Central Java) Basin

The South Serayu Basin (also often called the Banyumas Basin) was formed as a forearc basin. The northern part of the basin subsided, compensating for the uplift of the Serayu Range. Volcanoclastic turbidites were deposited into the basin creating the appearance of diapiric structures. Offshore south Central Java, two basins developed just to the west and east of the apex of the uplifted triangle zone ; these are called the Western and Eastern Deeps, respectively.

Oil and gas seepages occur in the South Serayu Basin (Figure 2) showing that a petroleum system is active in this area. Recent study by Subroto et al. (2006) provided the newest petroleum evaluation of this basin. Two main source rock intervals have been identified: middle-late Eocene type III/II kerogen equivalent to the Nanggulan Fm and the early-middle Miocene type II/III kerogen equivalent to the Pemali Fm. The mature kitchen area is located in the southern offshore area. Various hydrocarbon plays in this area include middle Miocene Kalipucang reefs in the offshore area growing at the late Oligocene basement high which subsided to compensate for the uplift of the Serayu Range, seals are provided by Lower Pemali shales and marls, traps are Oligo-Miocene Gabon volcaniclastic (Plio-Pleistocene inverted anticlines), and the middle Miocene Rambatan lowstand play (Plio-Pleistocene inverted anticlines)

Several oil samples were analyzed for their biomarkers. It was revealed that the oils could be classified into three families: the first was sourced by terrestrial facies, the second is from a more marine environment, and the third indicates a lacustrine environment. The isotope data support this classification. Characteristics of the oils were then used to infer the identity of source rock(s) in the region. Based on an integration of the data of crude oils and the geochemical model, the most probable source rock of the South Central Java Basin is the Pemali Formation.

A recent well drilled by Lundin in the Banyumas Block, namely Jati-1 (2005-2006) failed to discover commercial hydrocarbons from the Oligocene/Eocene section. The well encountered many mechanical problems of overpressure, complex tectonics not imaged on seismic, and a very thick Miocene clastic section, with the result that the well did not reach the main reservoir objective. However, Jati-1 tested some amounts of gas and condensate from the Miocene sands, proving movable hydrocarbons in this basin. It means that the well does not condemn other Eocene prospects.

CONCLUSIONS

1. There are two major strike-slip faults, opposite in slips and trends; the Muria-Kebumen Fault (sinistral, trends SW-NE, Meratus Trend) and the Pamanukan-Cilacap Fault (dextral, trends NW-SE, Sumatran Trend), crossing Central Java, separated in the northern area and meeting in the southern area; the presence of the faults and related structures are reasonable based on strain-ellipsoid analysis.

2. The two faults are considered to cause significant geologic changes in Central Java related to isostatic compensation. The faults caused: uplift of the Serayu Range and exposure of the pre-Tertiary Luk Ulo mélange complex, subsidence of the northern part of Central Java and indentation of the northern coastline, subsidence of the Southern Mountains of Java in southern Central Java and indentation of southern coastline, and northward shifting of the Quaternary volcanic arc in Central Java.

3. From a petroleum point of view, Central Java has been explored in a very limited fashion compared to its counterparts in the West and East Java Basins. Accordingly, the proper petroleum potential of Central Java is unknown, making the region a “terra incognita” (unknown land). The presence of numerous oil and gas seepages in Central Java and positive results of existing exploration show that Central Java has at least one active petroleum system.

4. The presence of two opposite regional strike-slip faults crossing each other in southern Central Java has configured the petroleum geology of Central Java. Southern Central Java was uplifted (the Serayu Range), the uplift was compensated isostatically by the subsidence of two areas to the north and south of the uplifted area: the northern area (North Serayu) and the southern area (South Serayu / Banyumas). The subsided area became the basins within which petroleum system elements and processes are operating as manifested by numerous oil and gas seepages within the basins.

5. Potential play types developing within the basins are: (1) North Serayu area, consisting of Neogene subsidence-related toe thrusting and Paleogene Sigugur reefs on the subsided horst blocks, (2) South Serayu areas, consisting of Paleogene Kalipucang reefs on the Old-Andesite (Gabon) horst blocks and inverted anticlines of Paleogene-Neogene turbidites.

ACKNOWLEDGMENTS

New considerations on the tectonics of Central Java were started in 2001 and I discussed the issue with many geologists who once worked in this region. Special thanks must go to: Carolus Prasetyadi (UPN), Benyamin Sapiie (ITB), R. P. Koesoemadinata (formerly at ITB), Mohammad Untung (formerly at GRDC), Margaretha Purwaningsih (COPI), Peter Lunt (formerly with Lundin), and Bambang Yosaatmadja (Lundin). I acknowledge Pudji Astono (Pertamina) for updated information of Pertamina activities in Central Java. I thank the IPA Technical Committee for this opportunity to contribute for publication. Jeremy

Dyer (PT Opac Barata) edited the text of the paper and suggested some improvements. BPMIGAS is acknowledged for support and sponsorship to publish the study.

REFERENCES CITED

Bolliger, W. and de Ruiter, P. A. C., 1975, Geology of the South Central Java offshore area, Proceedings Indonesian Petroleum Association (IPA) 4th Annual Convention, p. 67-82.

Christie-Blick, N. and Biddle, K. T., 1985, Deformation and basin formation along strike-slip faults in Biddle, K. T. and Christie-Blick, N., ed., Strike-slip Deformation, Basin Formation, and Sedimentation, Special Publication of Society of Economic Paleontologists and Mineralogists (SEPM), 37, p. 1-34.

Cowan, D. R., Tompkins, L.A., and Tyler, T., 2000, Understanding basement controls on basin development : constraints from gravity and magnetic data, Proceedings Indonesian Petroleum Association (IPA), 27th Annual Convention, p. 633 – 639.

Fraser, T. H. and Ichram, L. O., 2000, Significance of the Celebes Sea spreading centre to the Paleogene petroleum systems of the SE Sunda margin, Central Indonesia, Proceedings Indonesian Petroleum Association (IPA), 27th Annual Convention, p. 431 – 442.

Geology of UGM, 1994, Geologi Daerah Pegunungan Selatan: Suatu Kontribusi, Pertemuan Ilmiah Ulang Tahun ke-10 Stasiun Lapangan Geologi "Prof. R. Soeroso Notohadiprawiro" Bayat, Klaten 3-4 Februari 1994.

Gresko, M., Suria, C. and Sinclair, S., 1995, Basin evolution of the Ardjuna rift system and its implications for hydrocarbon exploration, offshore NW Java, Indonesia, Proceedings Indonesian Petroleum Association (IPA), 24th Annual Convention, p. 147 – 161.

Harding, T. P., 1974, Petroleum traps associated with wrench faults, American Association of Petroleum Geologists (AAPG) Bulletin, vol. 58, no. 7, p. 1290-1304.

Kastowo, 1975, Peta Lembar Majenang, Jawa, Skala 1 : 100.000, Geological Survey, Bandung.

Kusumayudha, S. B. and Murwanto, H., 1994, Penentuan tektonogenesis komplek bancuh Karangsambung berdasarkan analisis kekar gerus, Kumpulan Makalah Seminar Geologi dan Geotektonik Pulau Jawa sejak Akhir Mesozoik hingga Kuarter, Geology Department University of Gadjah Mada, Yogyakarta, p. 101 – 120.

Martodjojo, S., 1994, Data stratigrafi, pola tektonik dan perkembangan cekungan pada jalur anjakan-lipatan di P. Jawa, Kumpulan Makalah Seminar Geologi dan Geotektonik Pulau Jawa sejak Akhir Mesozoik hingga Kuarter, Geology Department University of Gadjah Mada, Yogyakarta, p. 15 – 26.

Moody, J. D. and Hill, M. J., 1956, Wrench fault tectonics, Geological Society of America (GSA) Bulletin, vol. 67, p. 1207 – 1246.

Pramono, H., Wu, C. H. C., and Noble, R. A., 1990, A new oil kitchen and petroleum bearing subbasin in the offshore NW Java area, Proceedings Indonesian Petroleum Association (IPA), 19th Annual Convention, p. 253 – 278.

Prihatmoko, S., Digdowirogo, S., and Kusumanto, D., 2002, Potensi cebakan mineral di Propinsi Jawa Tengah dan Daerah Istimewa Yogyakarta, Sumberdaya Geologi Daerah Istimewa Yogyakarta dan Jawa Tengah, IAGI Pengda DIY-Jateng, p. 87-105.

Pulunggono, A. and Martodjojo, S., 1994, Perubahan tektonik Paleogen-Neogen merupakan peristiwa tektonik penting di Jawa, Kumpulan Makalah Seminar Geologi dan Geotektonik Pulau Jawa sejak Akhir Mesozoik hingga Kuarter, Geology Department University of Gadjah Mada, Yogyakarta, p. 1 – 14.

Pulunggono, A., Haryo S. A. and Kosuma, C. G., 1992, Pre-Tertiary and Tertiary fault systems as a framework of the South Sumatra Basin : a study of SAR – maps, Proceedings Indonesian Petroleum Association (IPA), 21st Annual Convention, p. 339 – 360.

Ryacudu, R. and Bachtiar, A., 2000, The status of the OO-Brebes fault system and its implication to hydrocarbon exploration in the eastern part of NW Java Basin, Proceedings Indonesian Petroleum Association (IPA), 27th Annual Convention, p. 223 – 234.

Santoso, H., Bermawi, A., and Murhantoro, E., 1990, Combined interpretation of gravity with seismic and well data using stripping technique, Proceedings Indonesian Petroleum Association (IPA), 19th Annual Convention, p. 131 – 146.

Satyana, A. H., and Darwis, A., 2001, Recent significant discoveries within Oligo – Miocene carbonates of the East Java Basin : integrating the petroleum geology, Proceedings 30th Annual Convention Indonesian Association of Geologists & 10th Geosea Regional Congress on Geology, Mineral and Energy Resources, p. 42 – 46.

Satyana, A. H. and Armandita, C., 2004, Deepwater plays of Java, Indonesia : regional evaluation on opportunities and risks, in Noble, R. A., Argenton, A., and Caughey, C.A., eds., Proceedings of an International Geoscience Conference on Deepwater and Frontier Exploration in Asia and Australasia, Indonesian Petroleum Association (IPA), Jakarta, p. 293-320.

Satyana, A. H. and Purwaningsih, M. E. M., 2002, Lekukan struktur Jawa Tengah : suatu segmentasi sesar mendatar, Sumberdaya Geologi Daerah Istimewa Yogyakarta dan Jawa Tengah, IAGI Pengda DIY-Jateng, p. 55-66.

Satyana, A H., 2005, Structural Indentation of Central Java : a Regional Wrench Segmentation, Proceedings Joint Convention Surabaya 2005- the 30th HAGI, the 34th IAGI, and the 14th PERHAPI Annual Conference and Exhibition, Surabaya.

Satyana, A. H., 2006, New insight on tectonics of Central Java, Indonesia and its petroleum implications, Abstract Volume, American Association Petroleum Geologists (AAPG), International Conference and Exhibition, Perth, November 5-8, 2006.

Sikumbang, N., 1986, Geology and Tectonics of the Pre-tertiary Rocks in the Meratus Mountains, S.E. Kalimantan, Indonesia, Ph.D. dissertation, University of London, London, unpublished.

Situmorang, B., Siswoyo, Thajib, E., and Paltrinieri, F., 1976, Wrench fault tectonics and aspects of hydrocarbon accumulation in Java, Proceedings Indonesian Petroleum Association (IPA), 5th Annual Convention, p. 53 – 66.

Subroto, E. A., Wahono, H. E., Hermanto, E., Noeradi, D., and Zaim, Y., 2006, Re-evaluation of the petroleum potential in Central Java province, Indonesia: innovative approach using geochemical inversion and modeling, Abstract Volume, American Association of Petroleum Geologists (AAPG) International Conference and Exhibition, Perth, 5-8 November 2006.

Sujanto, F. X., Siwindono, T., Sahudi, K., and Purnomo, E., 1994, Pandangan baru tektonik Neogen daerah sekitar Java axial ridge Banyumas-Kebumen, Kumpulan Makalah Seminar Geologi dan Geotektonik Pulau Jawa sejak Akhir Mesozoik hingga Kuarter, Geology Department University of Gadjah Mada, Yogyakarta, p. 27 – 52.

Untung, M. (ed.), 1974, Peta Anomali Bouguer Jawa dan Madura Skala 1 : 1.000.000, Geological Survey, Bandung.

Untung, M. and Hasegawa, H., 1975, Penyusunan dan pengolahan data beserta penafsiran peta gaya-berat Indonesia, Geologi Indonesia, vol. 2, no. 3, p. 11-17.

Untung, M. and Sato, Y., 1978, Gravity and Geological Studies in Jawa, Indonesia, Geological Survey, Bandung and Geological Survey of Japan, Tokyo.

Untung, M. and Wiriosudarmo, G., 1975, Pola struktur Jawa dan Madura sebagai hasil penafsiran pendahuluan data gayaberat, Geologi Indonesia, vol. 2, no. 1, p. 15 – 24.

Untung, M., 1977, Sebuah Rekonstruksi Paleogeografi Pulau Jawa, Proceedings Pertemuan Ilmiah Tahunan IAGI (Ikatan Ahli Geologi Indonesia), VI Bandung 5-7 December 1977.

van Bemmelen, R. W., 1949, The Geology of Indonesia vol. IA : General Geology of Indonesia and Adjacent Archipelagoes, (second edition 1970 – reprint), Martinus Nijhoff, The Hague.

Wilcox, R .E., Harding, T. P., and Seely, D. R., 1973, Basic wrench tectonics, American Association of Petroleum Geologists (AAPG) Bulletin, vol. 57, no. 1, p. 74 – 96.

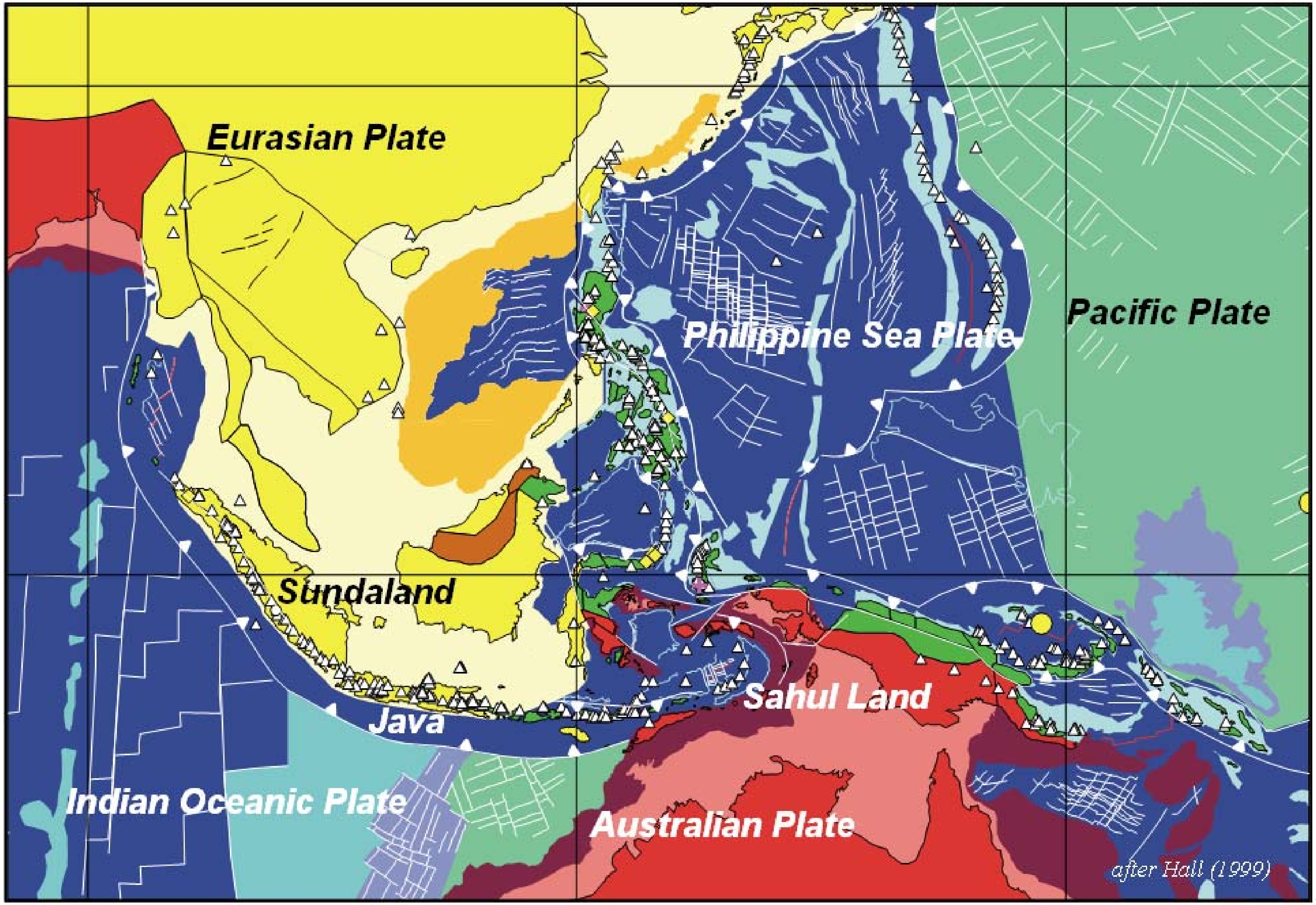

Figure 1 - Present tectonic setting of Indonesia. Java Island occupies an active margin of plates interaction between the Eurasia continental plate and the Indian oceanic plate, which have converged since the Cretaceous. The main tectonic elements resulting from the convergence include : subduction trenches, accretionary prisms, fore-arc basins, magmatic-volcanic arcs, and back-arc basins.

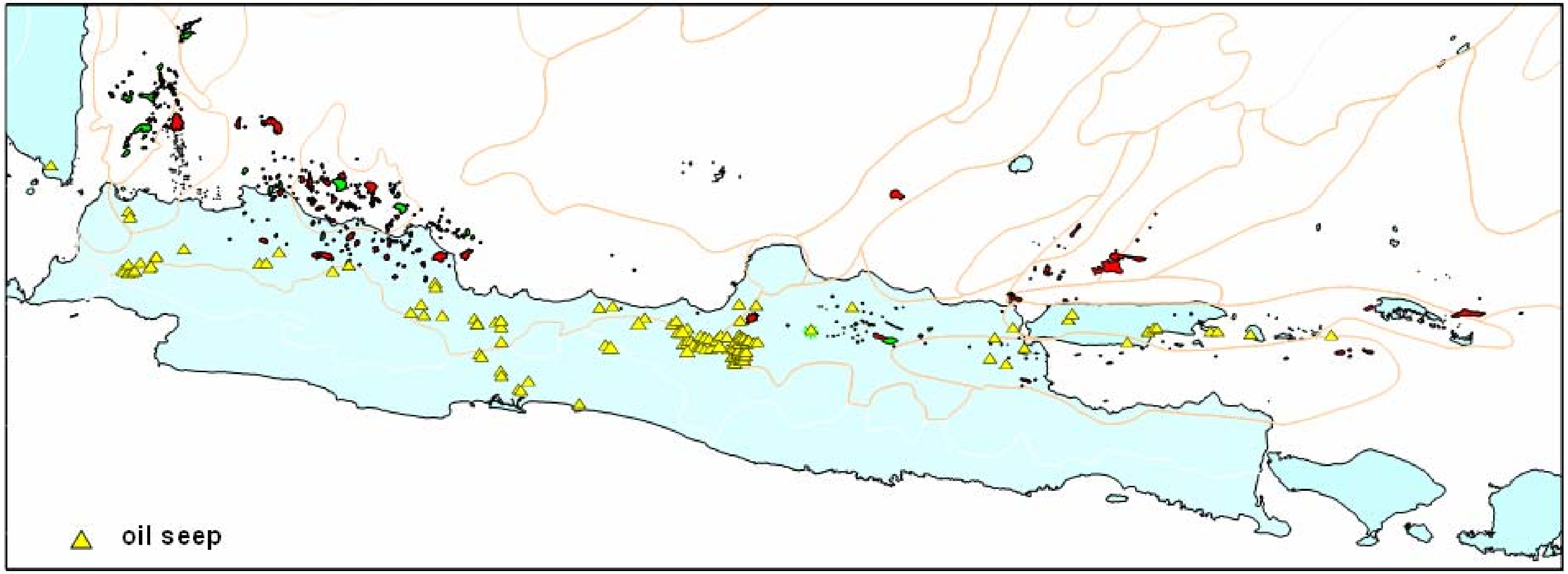

Figure 2 - Oil and gas fields and oil seeps of Java. West Java and East Java Basins are prolific basins for hydrocarbon accumulation. Central Java has been explored in a very limited fashion, therefore the petroleum geology of the area is not yet fully understood making Central Java a "terra incognita" or unknown land. The presence of numerous seeps in Central Java may demonstrate the presence of an active petroleum system there.

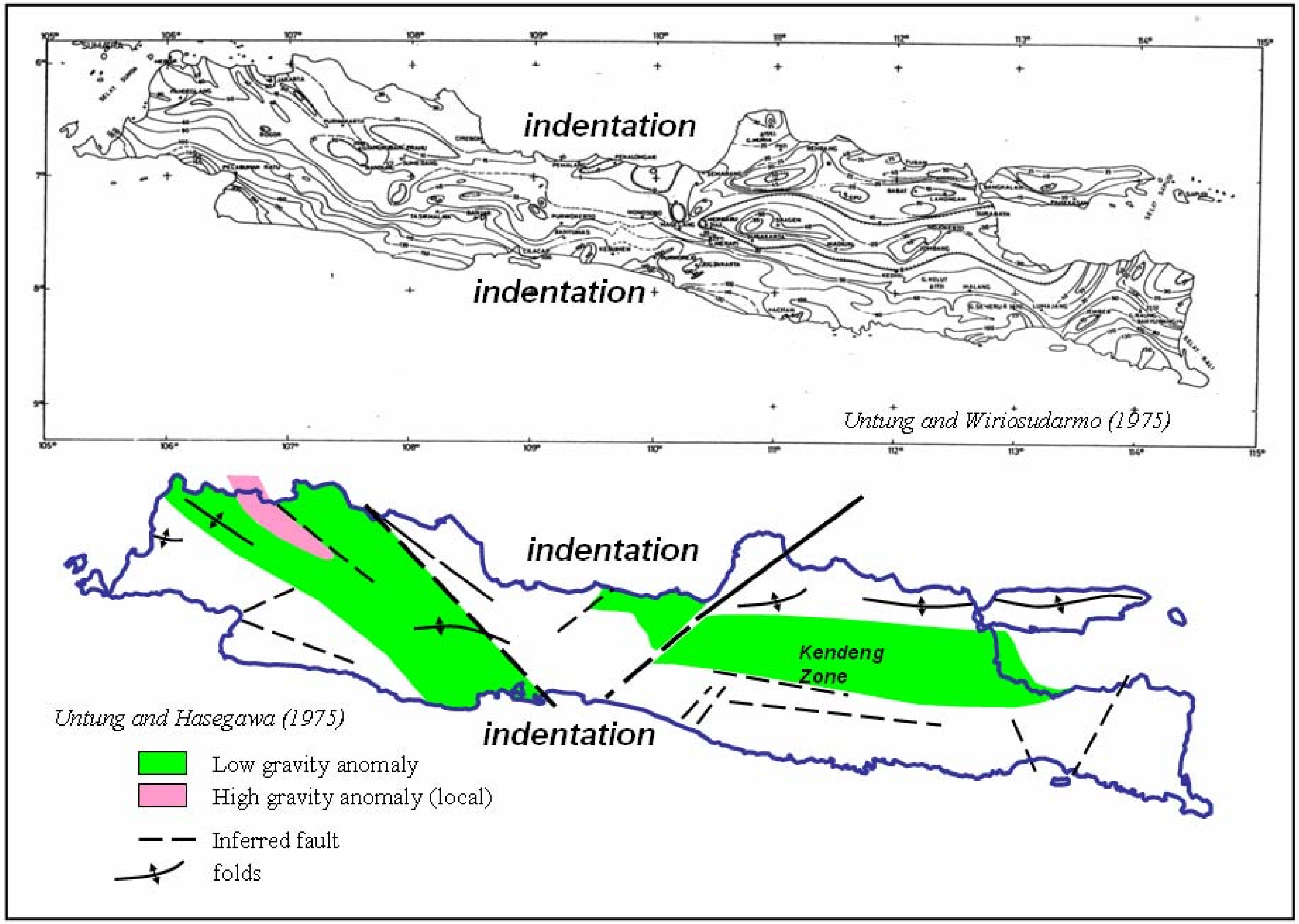

Figure 4 - Regional Bouguer anomaly map of Java and interpretation of main structures. Note that Central Java becomes the meeting point of the Sumatra Trend and the Meratus Trend. Two major strike slip faults border the re-entrant Central Java.

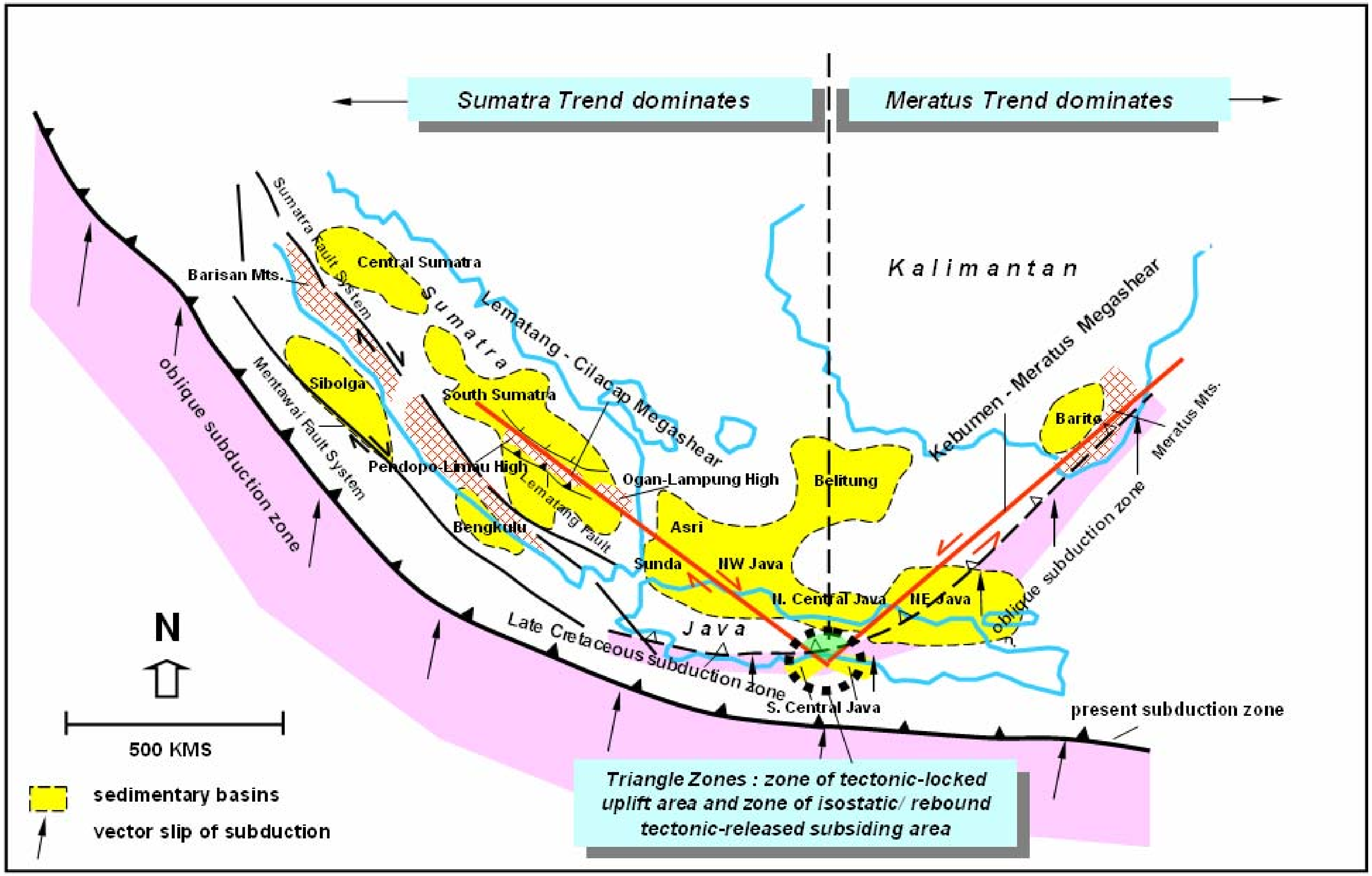

Figure 5 - Regionally, two major strike-slip faults flanking Central Java may continue to the Meratus and Lematang Fault, respectively. In this position, Central Java is tectonically important because position the center of structural trend between Sumatra and Meratus trends.

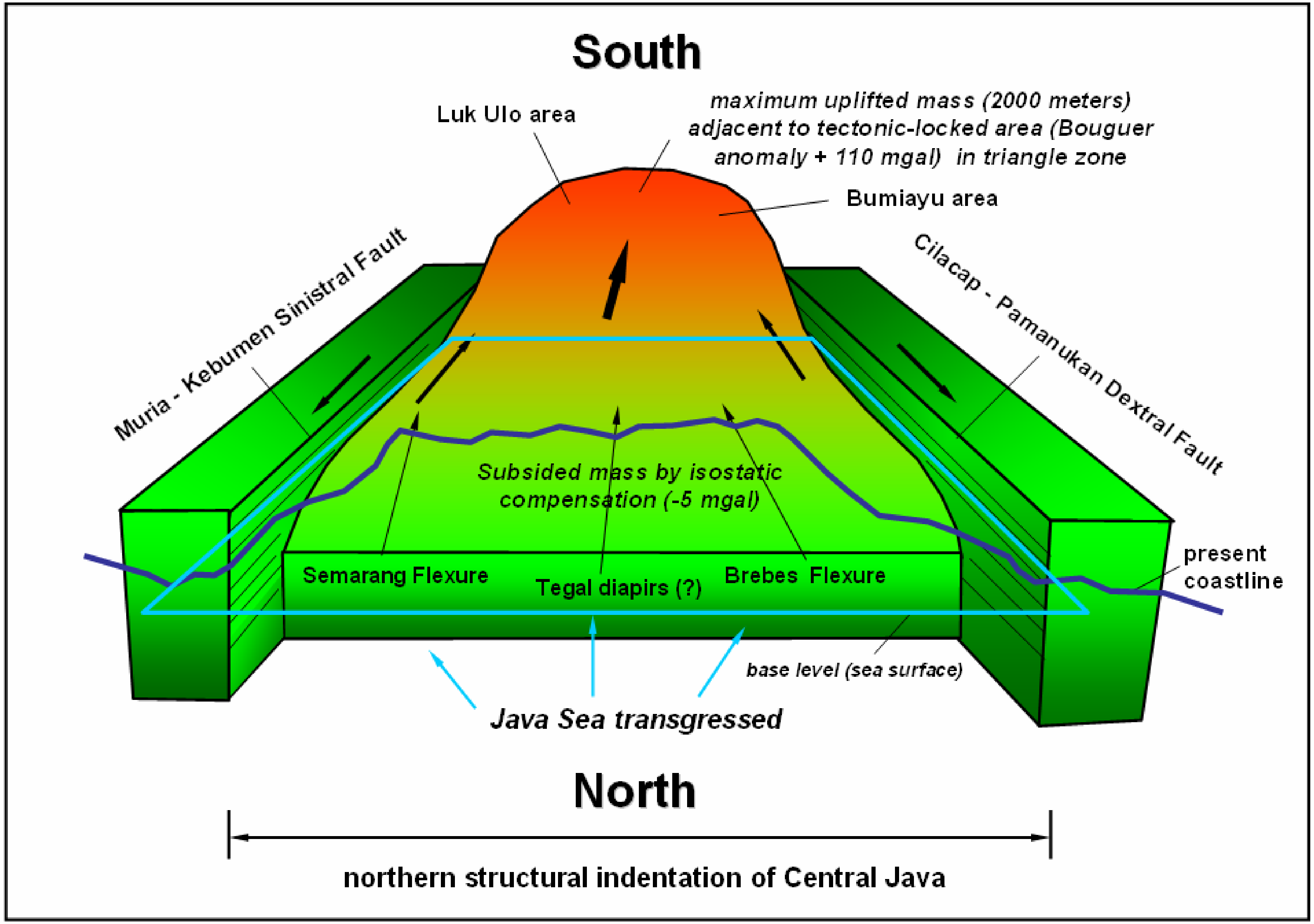

Figure 6 - Schematic block diagram showing process of uplift of southern central Java due to structural indentation. The crustal mass to the east of the Muria-Kebumen Fault moved northward, whereas the crustal mass west of the fault moved southward. The crustal mass east of the Pamanukan-Cilacap Fault moved southward, whereas the crustal mass west of the fault moved northward.

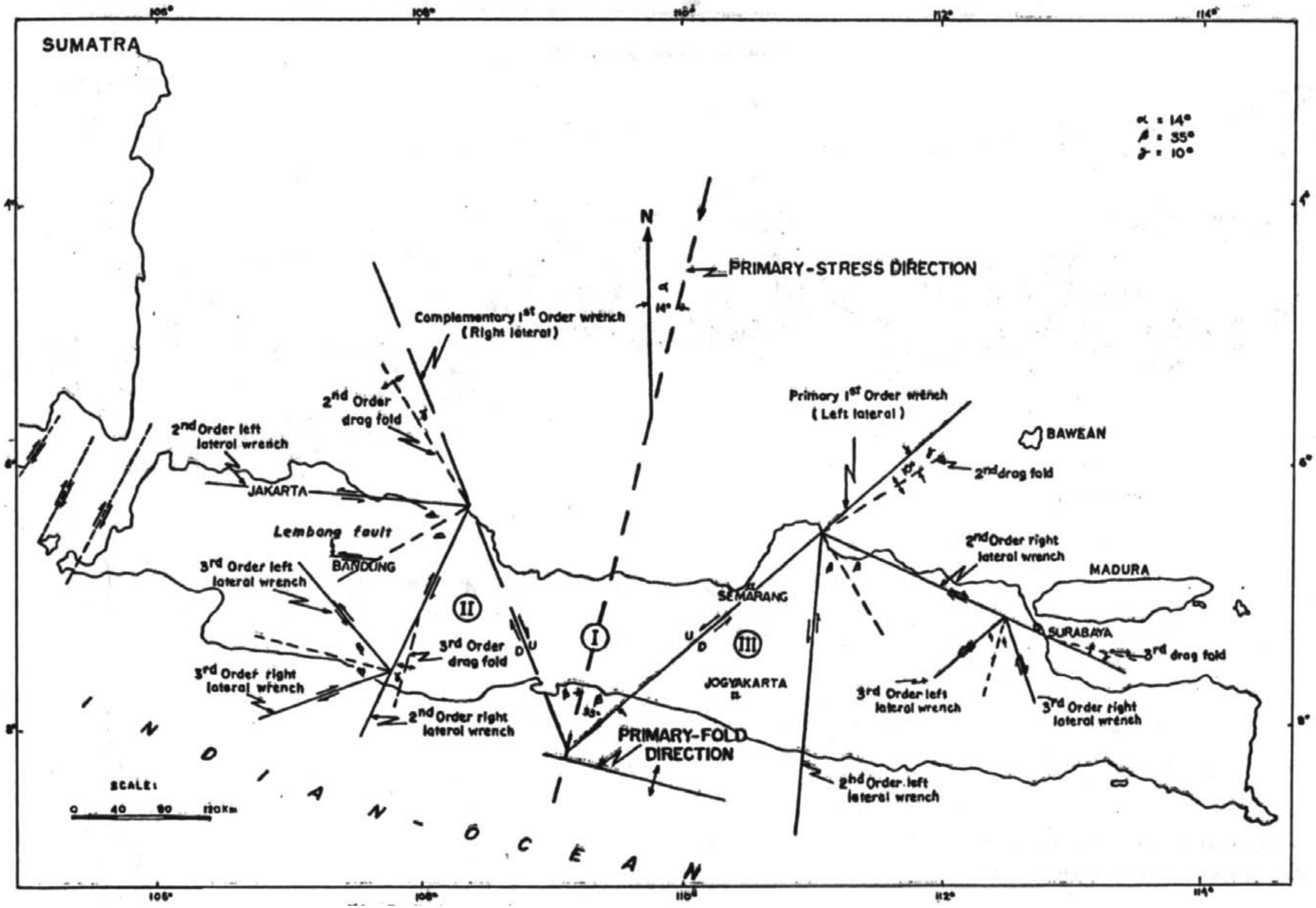

Figure 7 - Wrenching system of Java based on Moody and Hill (1956)'s concept. Note the possibility of the presence of two major strike-slip faults flanking Central Java which are opposite to each other in slip and trend.

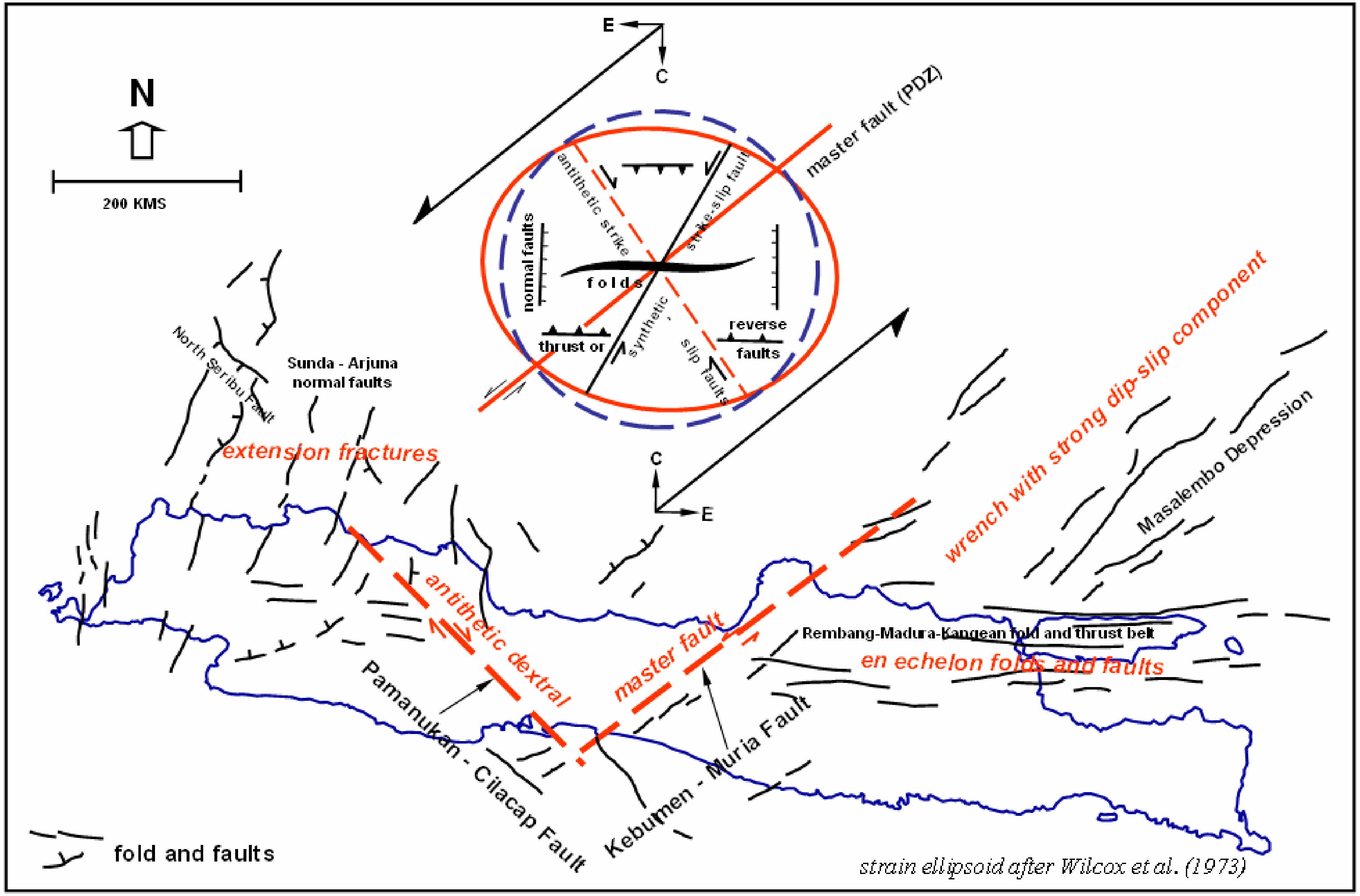

Figure 8 - Structural analysis of Java using strain ellipsoid kinematics. The Muria-Kebumen Fault is the main sinistral strike-slip fault (*master fault* or "Y" *shear*), whereas the Pamanukan-Cilacap Fault is a dextral strike-slip fault (*antithetic* or *conjugate* Riedel R' *shear*). The compressional component of the strain ellipsoid trends north-south parallel with the compression due to Indian oceanic plate subduction beneath Java. The compressional stress resulted in folds and reverse faults/thrusts trending west-east (Java Trend). The extensional component of the strain ellipsoid resulted in extensional rifting/fractures which trend north-south (Sunda Trend), most noticeably offshore and onshore NW Java.

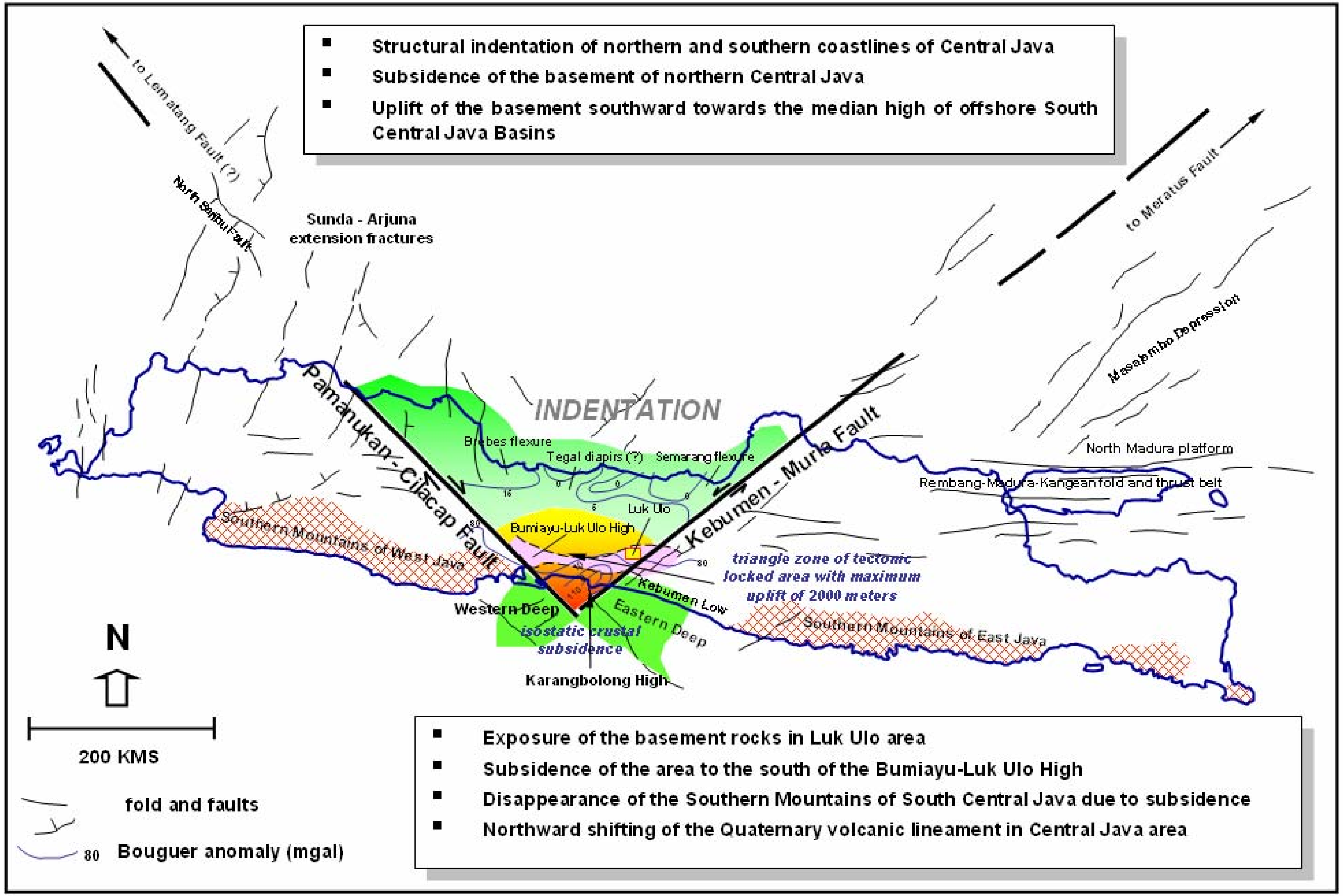

Figure 9 - Presence of opposed Pamanukan-Cilacap and Muria-Kebumen Faults resulted in many geologic implications in Central Java. The main cause was the uplift of southern Central Java. Later implications were due to isostatic compensation of this uplift.

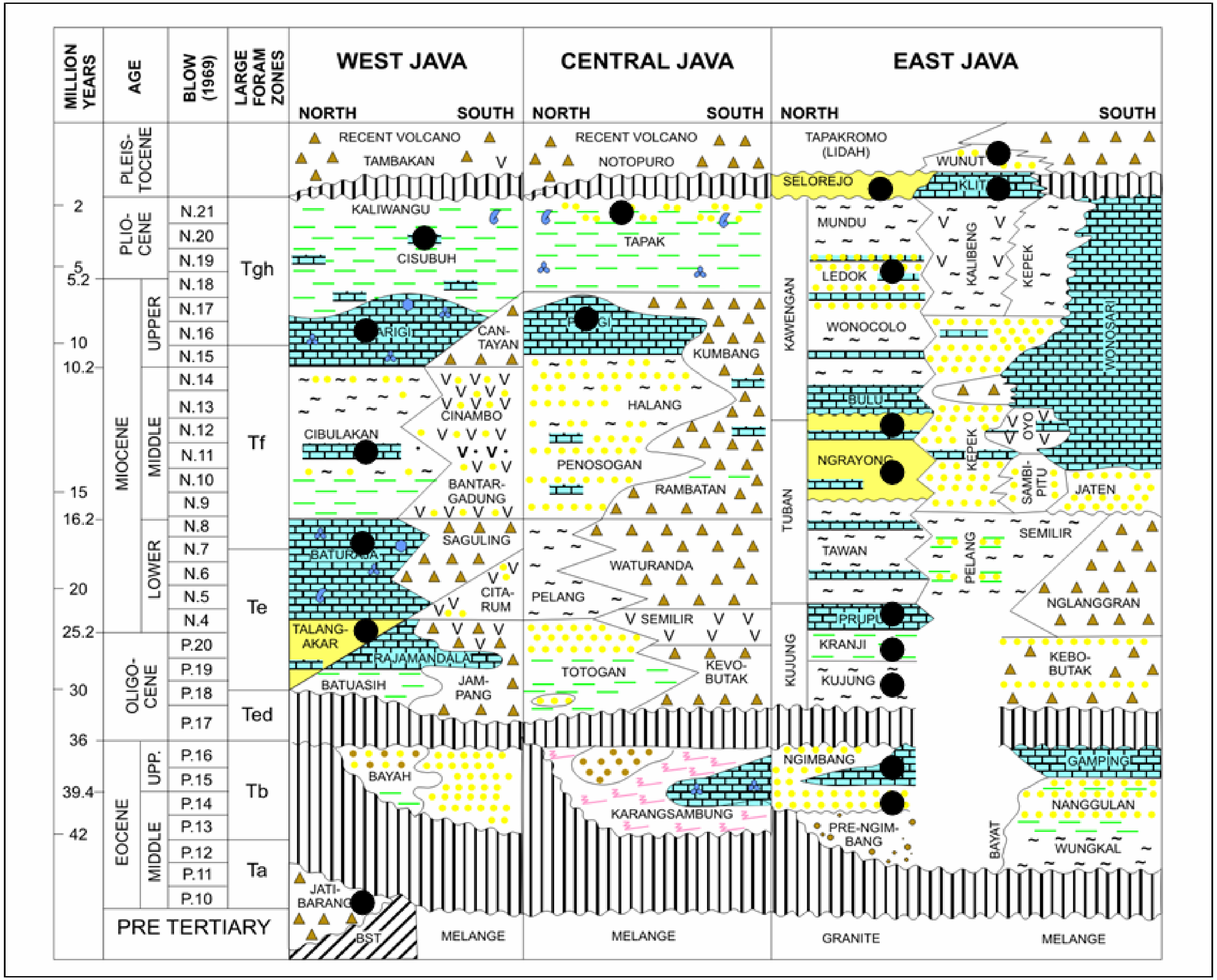

Figure 10 - Comparative stratigraphy of West, Central, and East Java Basins and the occurrence of hydrocarbon accumulations.

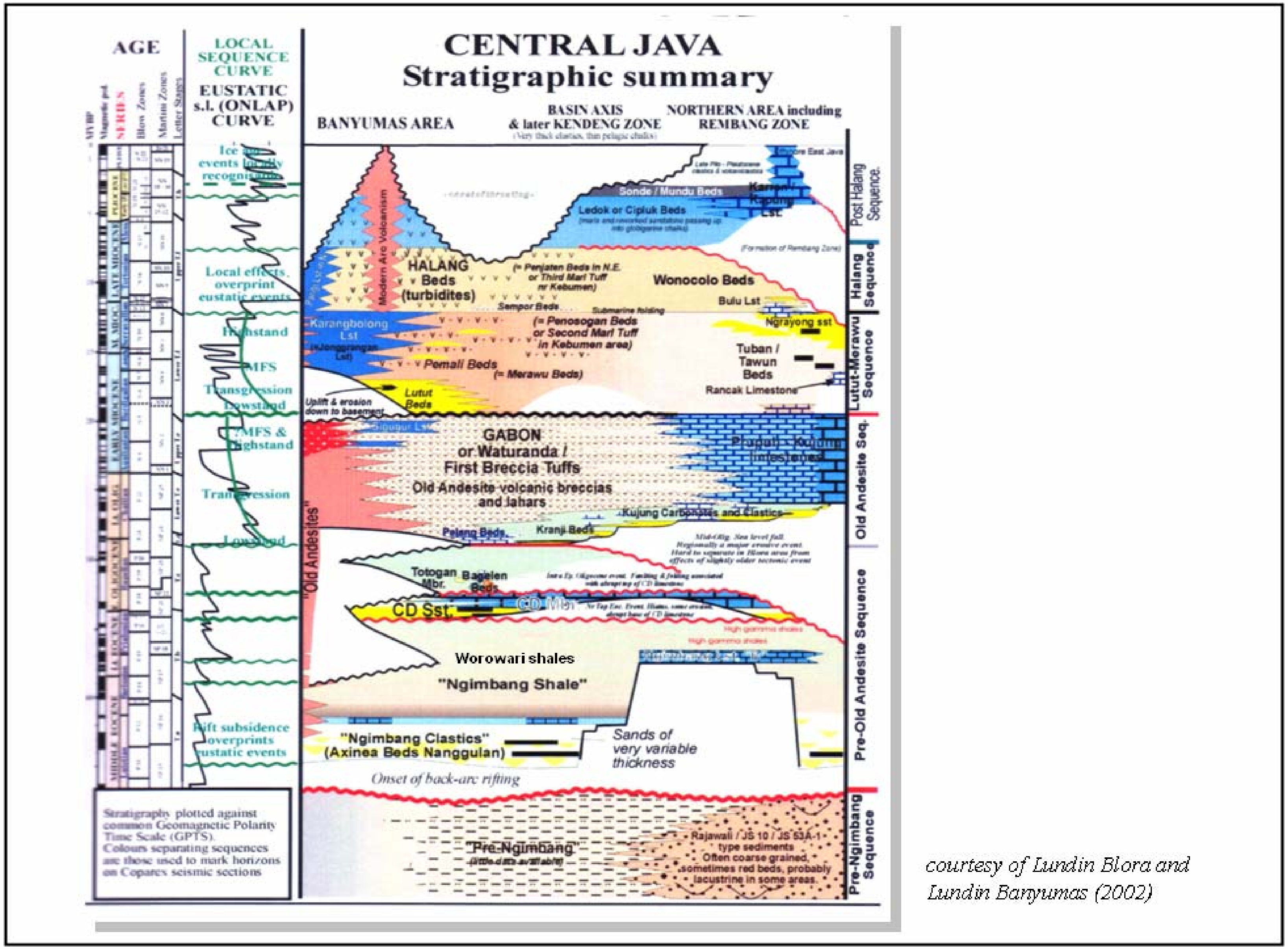

Figure 11 – Stratigraphy of Central Java for Banyumas area (South Serayu), basin axis, and northern area (North Serayu). Worowari shales (middle Eocene to lower Oligocene) are potential source rocks. Early Miocene Sigugur limestones, Lutut Beds, and volcanoclastic deposits from Early Miocene to Pliocene are expected targets. Uplift of the southern Central Java area was completed in Early Miocene.

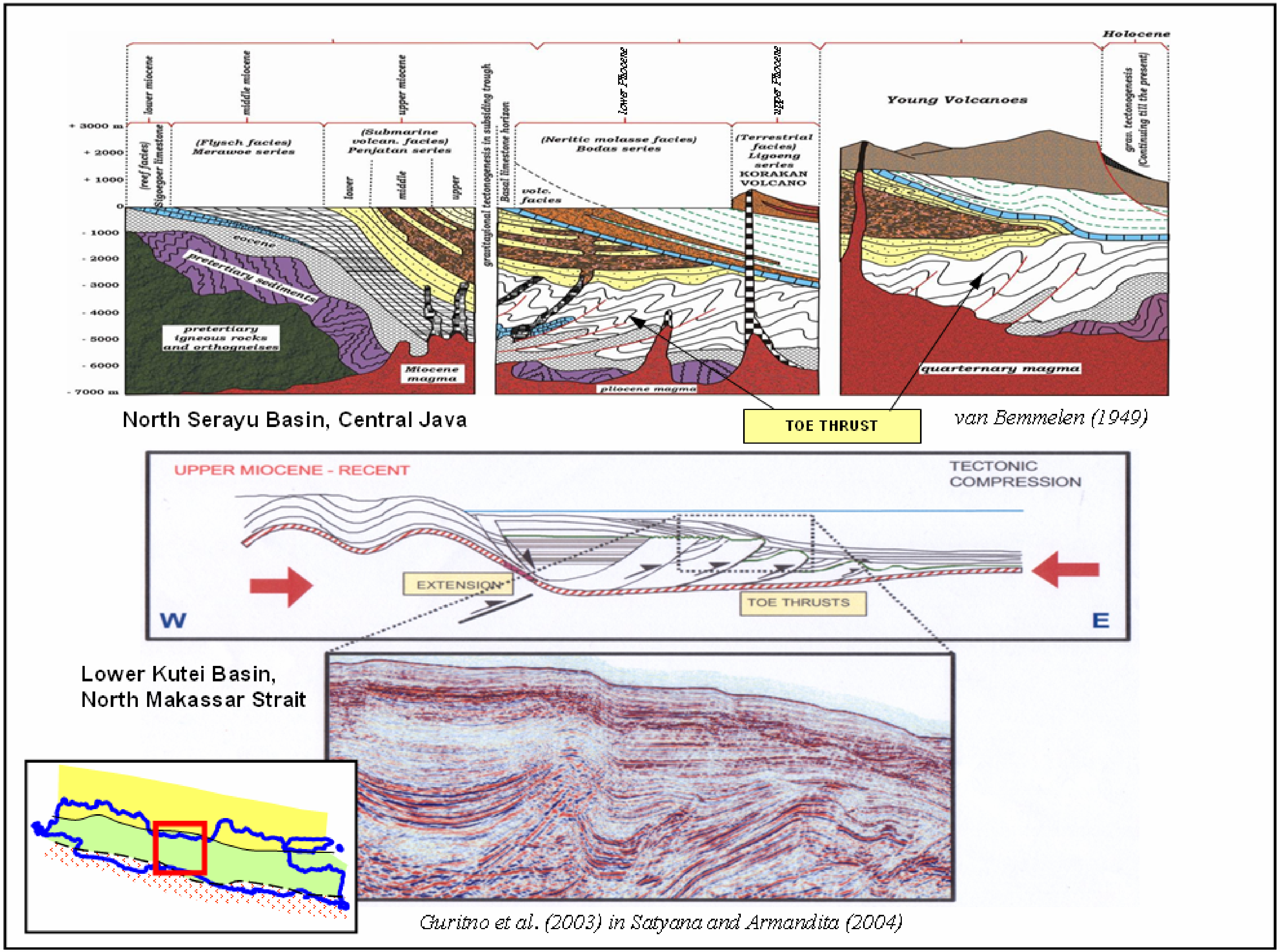

Figure 12 - The play type analog between North Serayu and Kutei-Makassar Strait. The uplift of the South Serayu Range caused subsidence in the North Serayu Basin. Gravity tectonics resulted in toe thrusting which may play as traps.