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INTRA-ARC TRANS-TENSION DUPLEX OF MAJALENGKA TO BANYUMAS AREA : PROLIFIC PETROLEUM SEEPS AND OPPORTUNITIES IN WEST-CENTRAL JAVA BORDER

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ABSTRACT

Intra-arc region of Java from Majalengka to Banyumas area straddles the West-Central Java border. The area has been the least-explored area in Java. This contrasts with the facts that numerous petroleum seeps and the first exploration well of Indonesia (Maja-1 well, drilled in 1871, oil discovery) are located in this area. In this study, analyses and synthesis of a series of data comprising gravity, surface geological maps, field study, seismic, and wells lead to a new look of petroleum geology of the area.

Major NW-SE trending dextral fault called the Pamanukan-Cilacap Fault Zone crossed this area possibly since the early Neogene or could be slightly older. Around the Majalengka-Kuningan-Majenang areas, the fault zone formed duplex system causing pull-apart opening of trough or trans-tension duplex. The opening controlled the occurrences of pre-Late Miocene back-arc volcanism sourcing the Late Miocene-aged turbiditic Halang volcanoclastic deposits. The Majalengka-Banyumas trough was then inverted in the Mio-Pliocene forming a structural high. Pemali sediments were deposited afterward in low areas flanking the structural high.

Trough and trans-tension duplex of the Majalengka-Banyumas area and their inversion had controlled petroleum system of this intra-arc region. High heatflow and geothermal gradient due to pull-apart opening and volcanism, thrust loading within inverted Halang deposits and thick Pemali burial sediments had matured the Paleogene and/or Neogene source rocks existing in this area. Petroleum was generated and migrated updip to Majalengka-Banyumas structural high and trapped in various structures. Numerous oil and gas seeps reveal that petroleum system is working in this area. Reservoir quality, trap integration and poor structure imaging due to volcanic cover may risk exploration. However, based on its active petroleum system, the area merits further exploration endeavor.

INTRODUCTION

Systematic geological surface maps across the border of West to Central Java from Majalengka to Banyumas areas show a peculiar distribution of the Late Miocene volcaniclastic Halang Formation. Generally, this formation is distributed forming a lithological belt trending northwest-southeast. This is interesting since this pattern is parallel with the regional strike-slip fault called the Pamanukan-Cilacap dextral fault (Satyana and Purwaningsih, 2002; Satyana 2005, 2006, 2007). More interestingly in petroleum point of view, numerous oil seeps occur along this area. The overlapping position among the lithology, fault, and oil seeps triggers our curiosity whether they have related to each other, how, and the advantages for petroleum exploration in this area.

Recent work of detailed facies mapping and paleocurrent analyses of the Late Miocene Halang Formation to the south of Kuningan area (western part of the belt) (Mukti *et al.*, 2008) showed that the volcanoclastic Halang Formation downsloped to the southeast, and interpreted to be sourced from pre-Late Miocene volcanic provenance called the proto-Ciremai to the northwest.

This paper presents a regional synthesis on the petroleum geology of the intra-arc area at the border of West to Central Java from Majalengka to Banyumas area based on published and unpublished studies and data as well as recent detailed field study. We will present firstly the regional setting of the area, further discussions on stratigraphy and tectonics of the area, followed by tectonostratigraphic analysis, and will be ended

Back to Menu

with petroleum implications. The intra-arc areas of Java from Majalengka to Banyumas area has been lack of exploration activities despite of numerous oil seep occurrences. This paper will contribute a new look on petroleum geology of the area.

REGIONAL SETTING

Java Island, located at the southern part of the Sundaland, was formed by rock assemblages associated with an active margin of plate convergence. The island has recorded plate convergence between the Indian oceanic crust and the Sundaland continent since Jurassic/Late Cretaceous time. Therefore, the island is made up of complex of plutonic-volcanic arcs, accretionary prisms, subduction zones, and related sedimentary rocks.

Three basic geologic provinces trending east-west parallel with the long axis of the island can be outlined in Java : (1) uplifted nonmarine to shallow marine sediments in the north composing the prolific Northwest Java and Northeast Java basins, (2) uplifted volcanic and carbonate sediments in the south, and (3) once subsided presently uplifted volcaniclastic sediments in the middle. The paper discussed a part of the last province. The presence of these three provinces can be revealed on physiographic map of Java (Bemmelen, 1949) (Figure 1).

Regionally, the discussed area (Majalengka-Banyumas) is included into the border of Bogor-North Serayu Anticlinorium. The anticlinorium was a deep-water trough into which volcaniclastic sediments were deposited. The trough was compressed and uplifted in the Plio-Pleistocene forming a zone of anticlinorium. It is obvious on the physiographic map, that here the Bogor Trough/Anticlinorium bends its trend from west-east in main West Java area to become NW-SE trending parallel with area of study. Eastern part of the discussed area belongs to western part of the North Serayu Trough/Anticlinorium. Two Quaternary volcano complexes exist on the northwestern and southeastern ends of discussed area namely Ciremai and Slamet volcanoes, respectively. Our study revealed that the area has been sites for volcaniclastic deposits not only in Quaternary, but also during the Neogene.

The Bogor-North Serayu Trough in the area of study shares a same place with the major dextral fault called the Pamanukan-Cilacap Fault (Satyana and Purwaningsih, 2002; Satyana, 2005; 2006; 2007) (Figure 2). The fault formed in the early Neogene. In several places, the fault zone formed multiple arrays of faults in duplex position and caused pull-apart opening. The opening of trough and its pull-apart rifting was considered to associate with this trans-tension duplex.

The rifting of the Bogor-North Serayu border by trans-tension duplex mechanism had located back-arc volcanism (relative to the Oligo-Miocene volcanic arc in southern Java – Old Andesite) in this area. The volcanism is considered as the provenance for the Late Miocene Halang volcaniclastics deposited along the area of discussion from Majalengka to Banyumas (Figures 3, 4).

The area was compressed and uplifted in the Mio-Pliocene forming a structural high of Majalengka-Banyumas area. Isostatically, low areas were formed flanking the structural high. The low areas were locus for Pemali sediments. Numerous petroleum seeps are located within the area. The interplay among the trans-tension duplex in part of Pamanukan-Cilacap Fault Zone, the location of back-arc volcanism within the tension area, the compression and uplift of the area to presently become structural high, and numerous petroleum seeps located in this area are interesting to examine.

RESULTS AND DISCUSSION

In this study, we try to re-analyze and re-interpret the tectono-stratigraphic setting of the region from Majalengka to Banyumas by gathering regional data on gravity, surface geological maps, seismic, well, terrain morphology using digital elevation modeling (DEM), sedimentology and stratigraphy, tectonics, geochemistry, and petroleum system. This re-interpretation leads to a new look of petroleum geology of the region from Majalengka to Banyumas.

Stratigraphy of Majalengka-Banyumas Area

The area from Majalengka in northeastern part of West Java province to Banyumas area in southwestern part of Central Java province builds the border of the two provinces. Geologically, the area forms the northwest-southeast trending belt and is positioned within the intra-arc setting. Systematic geological mapping at 1 : 100,000 scale conducted by Geological Research and Development Centre (Geologic Map of Arjawinangun Quadrangle by Djuri, 1995, Banyumas Quadrangle by Asikin *et al.*, 1992, and Majenang Quadrangle, by Kastowo and Suwarna, 1996) show that the area has been in intra-arc setting since the Late Miocene. This interpretation is based on the presence of Late Miocene volcaniclastic deposits called collectively as the Halang Formation (Hetzel, 1935; Asikin *et al.,* 1992; Kastowo and Suwarna, 1996) (Figures 4 and 5).

As discussed above, the area across the border of the Miocene and Pliocene Bogor and North Serayu Troughs. Deepwater volcaniclastic sediments were deposited into the troughs, including sediments of the Halang Formation in areas of Majalengka, Kuningan, Majenang and Banyumas (all represent the eastern margin of the Bogor Trough), as well as sediments called the Pemali Formation in areas around Bumiayu to the west and northwest of Slamet volcano (western margin of the North Serayu Trough).

The oldest sediments that crop out in the area is the Early - Middle Miocene Pemali Formation (Hetzel, 1935; ter Haar, 1935; Bemmelen, 1949; Kastowo and Suwarna, 1996). The work by Lunt *et al*. (2008) based on surface samples at the type locality of Pemali Formation and well samples (Karang Gedang-1 well in Banyumas area) and tied into seismic lines and geological surface maps, however, concluded that the Pemali Formation is actually Late Miocene-Pliocene (N16-N18) in age (Figure 5).

In the area around Kuningan, the Pemali Formation (e.g. ter Haar, 1935) is characterized dominantly by mudstones alternating with thin-bedded calcareous sandstones, tuffaceous lithic sandstones, and minor quartzitic sandstones. These mudstones are largely different with the Pemali Formation described in its type locality which mostly as deep marine mudstones (Lunt *et al*., 2008). In this paper, the term pre-Halang sediments refer to sediments previously called the Pemali Formation by ter Haar (1935). The pre-Halang sediments are older and shallower than those of the proper Pemali Formation in its type locality. The proper Pemali Formation (Lunt *et al.*, 2008) is younger than the Halang Formation (post-Halang). The pre-Halang Formation around the Majalengka area could be age-equivalent to parts of the Cinambo or Cisaar Formations (Martodjojo, 1984; Djuhaeni and Martodjojo, 1989).

During the pre-Halang deposition (pre-Late Miocene), the Bogor Trough formed an accommodation space into which reworked materials from the Northwest Java Basin were re-deposited (Raharjo *et al.*, 2002). These re-deposited sediments may become deep-water sources and reservoirs of the Bogor Trough (Satyana and Armandita, 2004). The Bogor and North Serayu Troughs could not be continuous troughs during the Miocene. Based on the sedimentary facies of the coeval sediments within the two troughs, it looked that at the certain periods within the Miocene, the two troughs did not form continuing avenues for sediments.

In Banyumas area, the Early to Middle Miocene stratigraphy is characterized by pre-Halang sediments deposited unconformably above the Late Oligocene volcaniclastics of Gabon/Old Andesites. The sediments were grouped into the Pemali and Rambatan Formation by Muchsin *et al*. (2002) and consist of interbedded marls, calcareous shales and sandstones. The sediments are turbiditic deposited in the environment until the upper bathyal. The sandstones are volcanic litharenites mostly composed of andesitic volcanic fragments. Early Miocene volcanic activity occurred during the period in this area (Muchsin *et al*., 2002). Paleocurrent measurements indicate that the sediments were mainly derived from the southern uplifted area of Gabon volcanic high. Marine sedimentation proceeded into the Late Miocene, during which upper bathyal sediments and limestones of the Halang Formation were deposited in this area. In Banyumas area, volcanic nature of the Halang sediments is less compared to that of its counterpart in Majalengka area. It can be understood that volcanic nature of Majalengka area was due its proximal position to proto-Ciremai volcanic complex in the trans-tension duplex area.

Tectonics of Majalengka-Banyumas Area

The Majalengka-Banyumas area was a site of a major fault called the dextral Pamanukan-Cilacap Fault Zone (Satyana and Purwaningsih, 2002; Satyana 2005, 2006, 2007). This was a major fault extending from Pamanukan area (northern West Java) to Cilacap area (southern Central Java). Citanduy Fault (Simandjuntak, 1979) and Kroya Fault (Untung and Hasegawa, 1978) are parts of this major fault. The discussions on the origin of the Pamanukan-Cilacap Fault, its relationship to the other major fault in Java called the sinistral Muria-Kebumen Fault (Figure 2), and the implications of these two major faults for geology and petroleum geology of Central Java can be found in Satyana and Purwaningsih (2002) and Satyana (2005, 2006, 2007).

Based on the gravity and systematic surface geological maps along the Majalengka-Banyumas areas (Untung and Sato, 1978; Djuri, 1975 ; Asikin *et al*., 1992 ; Kastowo and Suwarna, 1996), the Pamanukan-Cilacap Fault could be actually not a single fault zone. Like many other major strike-slip faults, the fault zone consists of complicated array of multiple large faults, duplexing and stepping to each other to form a dog-leg in plane view array of faults. The bending or dog-leg of faults in strike-slip fault will result in opening (transtension) and closing (transpression) of crustal mass depending on the slip of the master fault and orientation of the bending.

As for the Pamanukan-Cilacap Fault, a major bending or dog leg fault array occur in area between Kuningan and Majenang (Figures 3, 4). This dog-leg disturbs the northwest-southeast trending Pamanukan-Cilacap Fault bent into north-south trending fault. Fault zone from Kuningan area northwestward to Pamanukan and fault zone from Majenang area southeastward to Cilacap are actually two major faults composing the major Pamanukan-Cilacap Fault. The two major faults duplexed (overlapped) in Kuningan-Majenang area forming a north-south trending dog leg. Due to the slips of the two major faults were dextral, they opened the crustal mass in overlapping/duplexing area and therefore, we name the mechanism as trans-tension duplex.

It is interpreted that the fault zone, mainly in the area of transtension duplex opening, gave rise to the occurrences of some submarine and subaerial volcanoes. These volcanoes have erupted pyro- and epi-clastics which became the sources of Halang Formation and its slightly older and younger sediments deposited along the Majalengka-Banyumas area. Detailed facies mapping of the Halang Formation to the south of Kuningan (Mukti *et al*., 2008) found that here the volcanoclastic sediments of the Halang Formation were deposited downsloped to the southeast indicating the presence of pre-Late Miocene volcanic provenance northwestward called here as the proto-Ciremai.

Presently, the area of Majalengka-Banyumas forms a structural high. The origin of high area may be volcanic uplift because the area has been a site for volcanic belts since pre-Late Miocene time. The area was also possibly uplifted by major compressional fronts of reverse faults and/or thrusts of West Java migrating or prograding from southwest to northeast since the Early Miocene to Plei-Pleistocene time (Martodjojo, 1984). All of these faults are parallel with the Majalengka-Banyumas area. The uplift of the area was coeval with the deformation of Cirata, and Baribis Faults in the Late Miocene to Plio-Pleistocene time. Noeradi (2006) considered that the uplift of the area (called in his paper as the Majalengka-Bumiayu Foldbelt) related to transpression zone developed in the Late Neogene due to couple of major sinistral strike-slip faults of SW-NE trending Cimandiri Fault in West Java and the “N 70^o E” Fault in Central Java. We doubt the mechanism proposed by Noeradi (2006) since there has no evidence that the “N 70^o E” was active during the Neogene. Both Cimandiri and “N 70^o E” Faults should be active in Neogene to compress the Majalengka-Bumiayu Belt.

Tectono-Stratigraphic Analyses

Extensive paleocurrent measurements in the lower part of Halang Formation in Kuningan area (Mukti *et al*., 2008) showed the sediments were derived mainly from the provenance to the north-northwest (Figure 4). This interpretation is largely different with the previous interpretation studies (Martodjojo, 1984; Martodjojo, 1994; Clements and Hall, 2007) interpreting the sediments were derived from southern area. The differences in the interpretation of the paleo-transport of this deep-marine Late Miocene series would contribute significantly to the paleogeographic setting.

The materials of the Halang Formation turbidites are dominated by lithic wackes and locally include carbonate fragments. These indicate that there was body of volcanic and carbonates in the area to the north-northwest of Kuningan or possibly near the present location of Ciremai volcano. In this study, the volcanic area is called the proto-Ciremai volcanic complex. Previous authors (e.g. Martodjojo, 1984 ; Clements and Hall, 2007) interpreted that the Late Miocene volcanic arc was in the south. Based on the reconstruction of the regional gravity data, in the area near to Ciremai volcano it can be observed the presence of fault splays forming duplex configuration. Dextral duplex configuration in this area gave rise to trans-tension opening or pull-apart rifting. The occurrence of proto-Ciremai volcanic complex is considered to relate to rifting volcanism. Major Late Miocene volcanic arc was at the southern Java during the period (Martodjojo, 1984; Clements and Hall, 2007). Therefore, the proto-Ciremai complex was an isolated back-arc volcanism along the trans-tension duplex area.

Back to Menu

The development of pull-apart zone by trans-tension duplex occurred in several places along the Pamanukan-Cilacap Fault Zone. Kastowo and Suwarna (1992) reported that the splays developed in the Majenang area; we interpret that the splays might form tanstensional zone that controlled the deposition of the Pliocene Kumbang volcaniclastic deposits. These observation leads to the interpretation that the Pamanukan-Cilacap Fault Zone had controlled the deposition of back-arc and intra-arc volcanism. The fault zone is also considerd to have controlled the distribution of Late Miocene deep-marine sediments deposited restrictively along the fault zone. The fault zone was a narrow trough with some trans-tension duplex in places and had controlled the occurrences of rifting volcanism and played a role as a space of accommodation for volcaniclastic and deep-marine sediments transported from the nearby highs.

The Majalengka-Banyumas trough underwent inversion due to uplift and compression during the Mio-Pliocene, changing the trans-tensional zone into the trans-pressional zone. This is considered largely due to development of prograding thrust fault-belt system in West Java (Martodjojo, 1994; Raharjo *et al*., 2002) (Figures 6, 7). The generation of the intra-arc volcanics and the inversion of the Majalengka-Banyumas area initiated the northwest-southeast structural high that became the barrier between the Bogor and North Serayu Troughs. Isostatically, depression areas developed flanking the structural high such as Citanduy and Bobotsari Low areas. Into these depression areas, sediments of the Pemali Formation (Lunt *et al.*, 2008) were deposited, restrictive in the northeast and southwest flank of the Halang Formation. Lunt *et al* (2008) estimated approximately 8000 ft or 2,500 m of Pemali clastics were deposited rapidly in less than four million years. Figure 8 displays seismic section and well data of Karang Gedang-1 (KRG-1) in Banyumas area show that the Pemali Formation overlies Halang Formation in the North Serayu, Bobotsari and Citanduy low areas flanking the Majalengka-Banyumas area. The structural barrier of Majalengka-Banyumas had caused the sedimentation of the Pemali sediments in the western part of the North Serayu Trough to be east-southeastward and in the eastern part of Bogor Trough to be south-southwestward.

Implications to Petroleum

Numerous oil and gas seeps occur along the study area forming a belt of seeps which is parallel to the study area from Majalengka to Banyumas (Figures 4, 9). This is intriguing and whether there is relationship between geology and petroleum in this area. We examined each element and process of petroleum system in Majalengka-Banyumas area to reveal the opportunities and risks of its petroleum potential.

The area has been lack of attention for petroleum activities despite of the occurrences of many oil and gas seeps. The first well in Indonesia was actually drilled in Majalengka area (Maja-1 or Cibodas Tangat-1 well) (Figure 9) drilled in 1871/1872 by a Dutchman - general store manager named Jan Reerink on the western slope of Ciremai volcano. Total depth of well was 125 feet only. The well discovered non-economic oil. As many as 19 wells drilled by Jan afterward, the funding was partly backed by the NHM (Nederlandsche Handel Maatschappij, precursor of the Royal Dutch Shell). However, the discoveries were sub-commercial and abandoned due to Jan's private capital was exhausted and he called it quits. The local inhabitants presently still collect some oils from the wells.

Numerous oil seeps in Banyumas area have been targeted by wells drilled by Dutch companies and the later operators (Pertamina and Coparex/Lundin). The wells so far failed to find commercial hydrocarbons. Most of the wells underwent mechanical troubles related to overpressuring generated by deepwater Halang and pre-Halang (called as Penosogan) volcaniclastics. The last well drilled in the area was Jati-1 well (Lundin, 2005) (Figure 9). The well underwent many mechanical troubles, it did not get the objective, but the well reached the deepest horizon never reached by previous wells. Jati-1 well found small amount of oil and gas from sandstone intercalations within the Middle-Miocene Penosogan volcaniclastics. No well was drilled in Majenang area. Numerous oil and gas seeps occur in this area.

Usman *et al*. (2005) analyzed the biomarkers of Maja-1 oil and Early Miocene (N4) sample from outcrop of Cikaramas, Majalengka area. Maja oil show steranes % ββ C_{27}=22, C_{28}=29, C_{29}=49; pristane/nC_{17} = 0.83, pristane/phytane = 3.92; these indicate terrestrial sources. Plotting of C_{29}/C_{30} hopane versus diasterane/sterane reveal the source is siliciclastic; plotting of sterane/hopane versus diasterane/sterane pinpoint the source as clay-rich source. Early Miocene Cikaramas rock sample has TOC 1.21 %; steranes %ββ C_{27}=21, C_{28}=25, C_{29}=54; pristane/nC_{17} = 2.08, pristane/phytane = 6.93. The sample shows a real terrestrial source facies. It looks that geochemically, the Maja oil is correlatable with the Early Miocene (N-4) Cikaramas source sample. Sterane m/z 217 and triterpane m/z 191 distributions for the oil and rock samples show a fair correlation.

Neogene rocks as source for oil seeps in Majalengka-Banyumas area is also shown by geochemical analyses of oil seep and rock samples of Rambatan and Halang Formations in Banyumas area (Subroto *et al*., 2008). Based on biomarker distribution using triterpane m/z 191, the oil seep of LW-05 A shows good correlation with triterpane distribution of rock samples of Rambatan and Halang Formations. Muchsin *et al*. (2002) analyzed the Early Miocene Kalipucang and pre-Halang bituminous shales. The shales show TOC of 0.7-15 %, T max 400-440 ºC (early mature-mature).

Noeradi *et al*. (2006) analyzed Halang and Pemali outcrop samples in areas of Majenang and Bumiayu and found that generally the TOC (total organic carbon) of samples are below 0.5 % and hydrogen index (HI) below 200 showing poor potential. Noeradi *et al*. (2006) considered that numerous seeps in the area were sourced by Paleogene sources instead of Neogene sources. Noeradi *et al*. (2006) and Subroto *et al*. (2008) expected the presences of rift grabens underlying Majalengka-Banyumas area into which Paleogene sources deposited and were matured by tectonic loads of Neogene compression. Oligo-Miocene source samples from Kadu, south Kuningan area, show stratified carbonaceous and micaceous mudstones. Present oil analyses of Jati-1 well in Banyumas area show that the source of oil is rock equivalent with the Eocene Karang Sambung shallow marine sediments (Subroto *et al*., 2008).

Based on geochemical data, we expect that both Neogene and Paleogene rocks can be sources for petroleum in Majalengka-Banyumas area. Low TOC and HI of Neogene outcrop samples do not preclude their roles as source rocks since outcrop samples are always oxidized decreasing their TOC and HI. Maturation of sources through many mechanisms: thrust loading subsiding the sources to attain oil window (Noeradi *et al*., 2006), high gradient of geothermal due to the area is positioned within intra-arc setting (Satyana, 2006; 2007), and burial by thick Late Miocene-Pliocene Pemali beds (Lunt *et al*., 2008) (Figure 9). Top of oil window is estimated at depth of 2000 m. The charging of generated and expelled hydrocarbons are both vertically from Neogene and Paleogene sources deposited within the rifts of Majalengka-Banyumas trough, or laterally from adjacent depression areas to the east and west of Majalengka-Banyumas structural high.

Sandstone reservoirs are provided by Middle Miocene to Pliocene pre-Halang, Halang, and Pemali Formation which are as thick as 400 to 800 meters based on field section in Majalengka and Majenang/Bumiayu (Noeradi *et al*., 2006), respectively. The sandstones are interbedded with clay or shale beds playing a role as the intraformational seals. Oil seeps were discovered partly from fractures of Halang and Pemali outcrops.

Traps made of pre-Halang, Halang, and Lower Pemali reservoirs and seals are expected to be inverted horst blocks, thrust fault-dependent anticlines and shallow long wavelength anticlines independent of faults or thrusts. In Banyumas area, traps related with diapirism are possible. Middle Miocene volcaniclastic lowstand play equivalent with Rambatan Formation is also possible. Paleogene traps may relate to: erosional products from crest of fault block, truncated fault block, drape above fault block, and pinch out inverted by block faulting.

Risks of petroleum in Majalengka to Banyumas area mainly concern with reservoir quality of volcaniclastic reservoirs. Volcanic materials diagenetically change to clay minerals which can deteriorate porosity and permeability of reservoir. Episodic restructuring and pulses of volcaniclastic progradations might result in breaching and remigration of hydrocarbons from earlier trap hence complicating trap integrity. Seismic imaging is also poor due to volcanic cover at the surface, difficulting trap definition and reservoir characterization.

CONCLUSIONS

1. Majalengka-Banyumas is an intra-arc area of West-Central Java border sitting on NW-SE trending major Pamanukan-Cilacap dextral fault zone. Along the fault zone, some arrays of faults developed overlapping duplex system resulting in trans-tension opening when the faults moved dextrally. Pull-apart rifting resulted from trans-tension duplex system had been a locus for back-arc volcanism such as proto-Ciremai complex. The volcanic complex sourced Late Miocene Halang volcaniclastic sediments deposited within the Majalengka-Banyumas fault-related through. Surface geological maps and gravity data show that

distribution of Halang Formation was controlled by the Pamanukan-Cilacap fault zone.

2. Volcaniclastic complex of the Majalengka-Banyumas trough were compressed and uplifted in the end of Miocene by compressional fronts migrating or prograding northeastward from the southwest corner of West Java since the Early Miocene. The structural high of Majalengka-Banyumas provided a barrier between the eastern part of the Bogor Trough and the western part of the North Serayu Trough. Isostatically, depression areas flanking the structural high were formed, into which thick (2500 m) Mio-Pliocene Pemali sediments were deposited.

3. In petroleum point of view, high geothermal gradient due to intra-arc setting of Majalengka-Banyumas area, high heat flow due to pull-apart rifting, thick burial sediments of Pemali, and thrust loading of structural high, matured the Neogene and Paleogene sources deposited within the Majalengka-Banyumas rifts or nearby depression areas to attain hydrocarbon windows. Hydrocarbons were generated, expelled, and migrated to various traps within the Majalengka-Banyumas structural high. Numerous oil and gas seeps distributed parallel with the structural high prove a working petroleum system in this area.

4. Reservoir quality, trap integrity and poor subsurface imaging due to volcanic cover may risk petroleum exploration in this area. However, numerous petroleum seeps and previously oil-discovered wells show that in the Majalengka-Banyumas areas elements and processes of petroleum system are working therefore, it merits further exploration endeavor.

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Back to Menu

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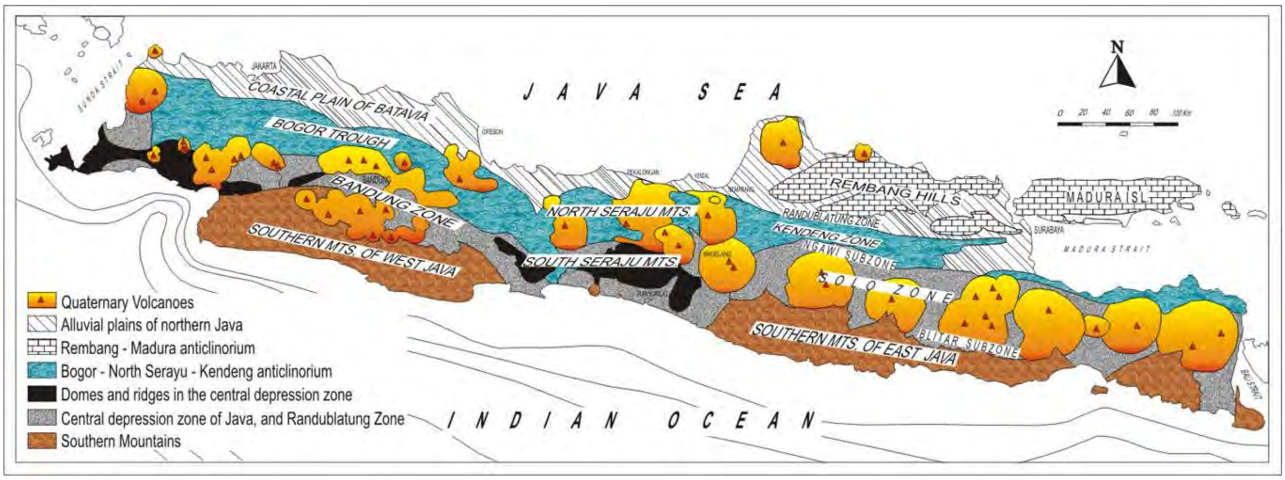

Figure 1 - Physiographic map of Java and Madura Islands (Bemmelen, 1949). The box marks the study area, it is located at the border of West to Central Java. Geologically, it occupies the Bogor to North Serayu Troughs presently uplifted to become anticlinorium. The area is in intra-arc setting with Quaternary volcanoes of Mt. Ciremai to the northwest and Mt. Slamet to the southeast.

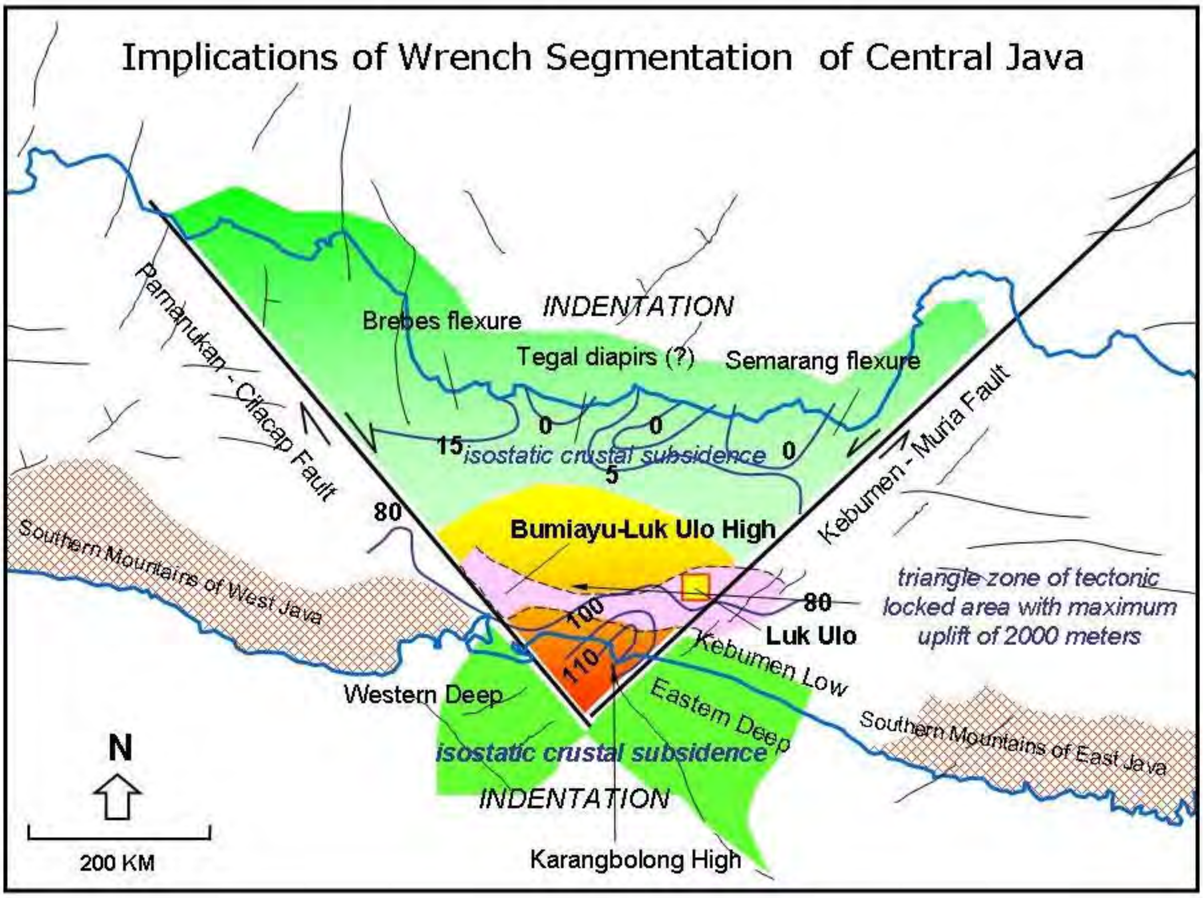

Figure 2 - Two major strike-slip faults flanking Central Java, the Muria-Kebumen sinistral fault zone and Pamanukan-Cilacap dextral fault zone, are expected (Satyana, 2005, 2006, 2007). The latter fault has significant implications on the geology of Majalengka-Banyumas area, such as affecting the distribution of Late Miocene Halang volcaniclastics and termal history of the area which is important for petroleum generation.

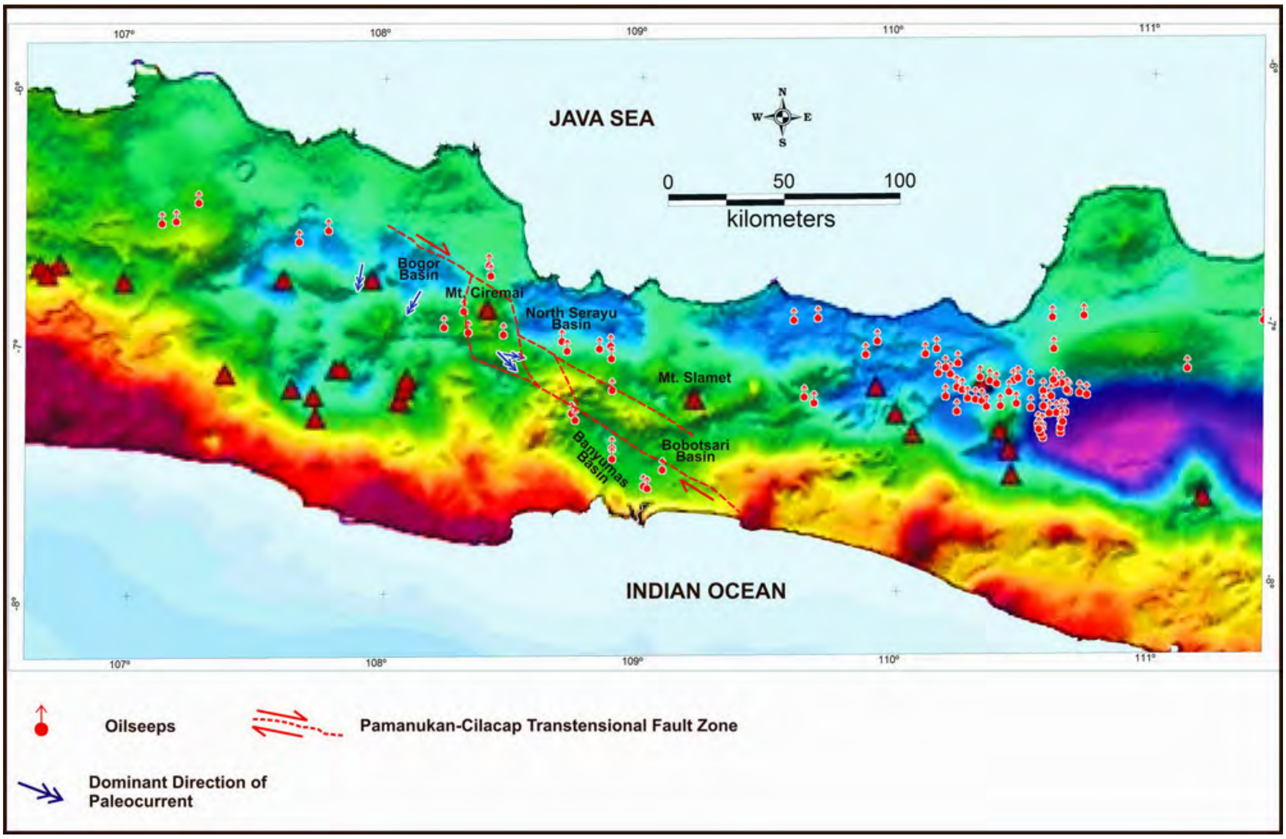

Figure 3 - Regional gravity map showing Bouguer anomay (mGal color scales decrease from red, yellow, green, to blue). Distributions of Quaternary volcanoes and oil seeps are indicated. Based on detailed gravity data, the Pamanukan-Cilacap fault zone forms fault splays overlapping to each other in area around Mt. Ciremai to the north of Banyumas Basin. The overlapping fault splays configure duplex system resulting in pull-apart opening by trans-tension deformation. Paleocurrents of sediments deposited within the area basically followed downslope progradation

Back to Menu

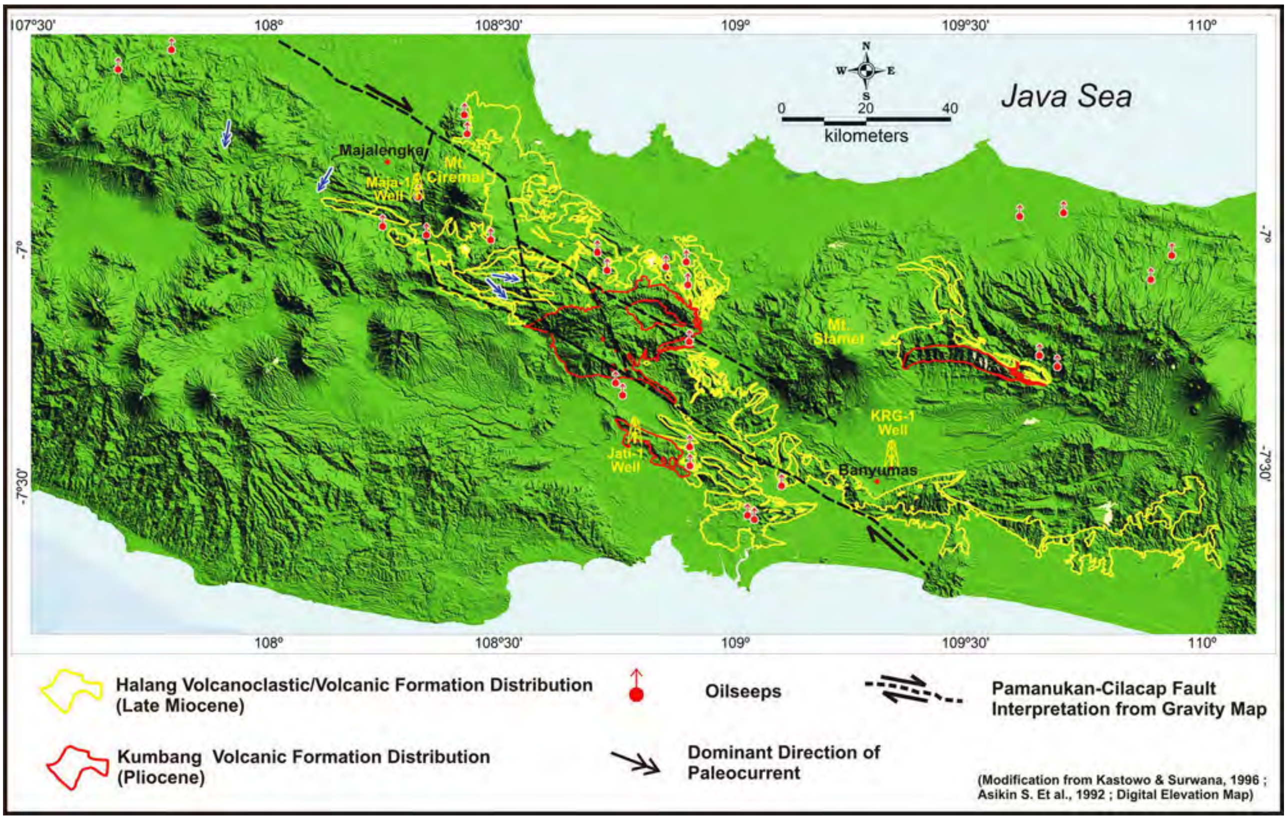

Figure 4 - DEM (digital elevation model) map of West-Central Java border showing trend of distributions of Late Miocene Halang and Pliocene Kumbang Formations. The distributions follow the trend of Pamanukan-Cilacap Fault Zone showing the trans-tension duplex in the middle of the fault zone. The pull-apart opening by trans-tension duplex is considered providing centers of volcanic provenances related to back-arc volcanism for both Halang and Kumbang sediments. Paleocurrents of sediments deposited within the area are marked. Oil seeps are distributed parallel with the lithological and structural trends indicating that the trends geologically are related to each other. White line indicates seismic section displayed in Figure 8.

Back to Menu

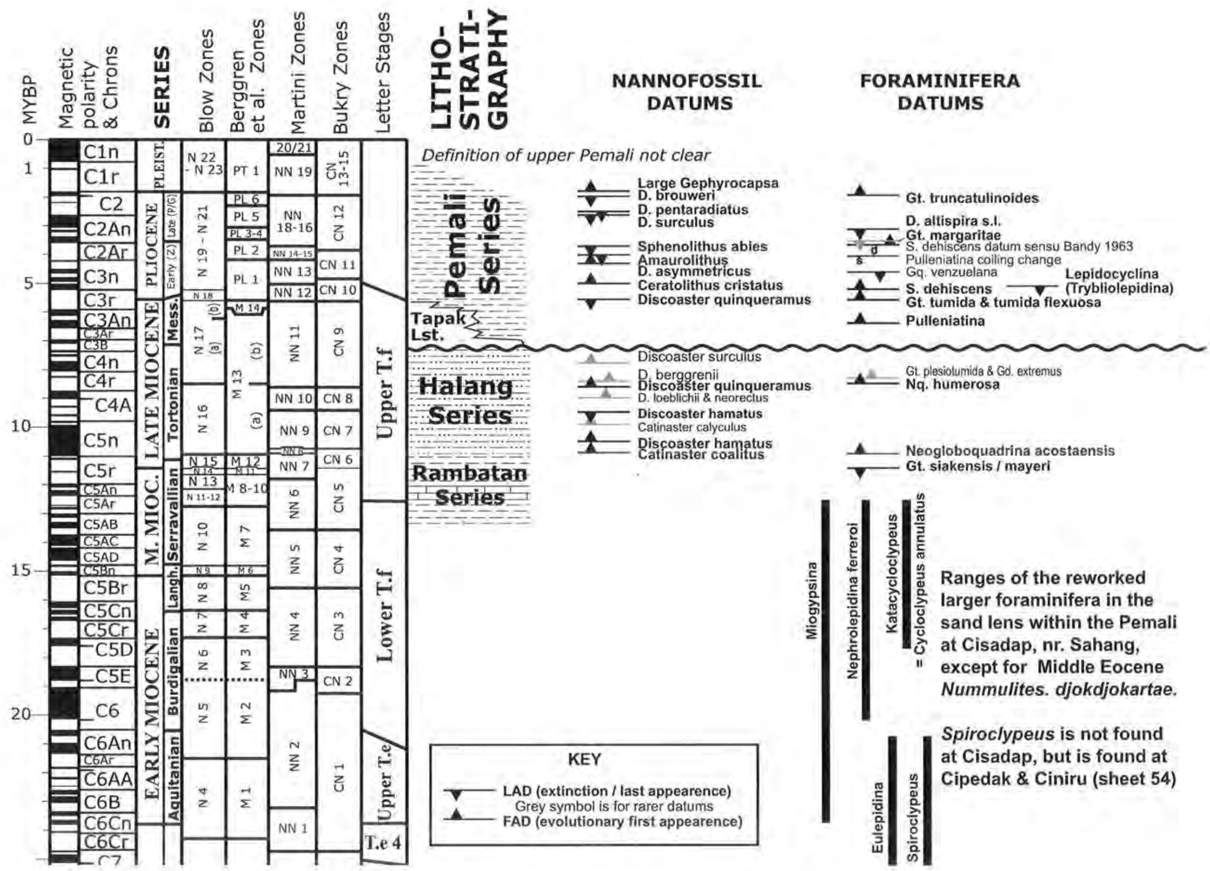

Figure 5 - Stratigraphic column and zonation of the study area (based on outcrops) (Lunt *et al*., 2008). Two formations are dominant in the area : the Halang Formation (Late Miocene) and the Pemali Formation (upper Late Miocene-Pliocene). Previous authors put the Pemali Formation to be older than the Halang Formation. Recent study by Lunt *et al.* (2008) revised the age of the Pemali Formation to be younger than the Halang Formation based on insitu fossils. Previous age designation was based on reworked fossils.

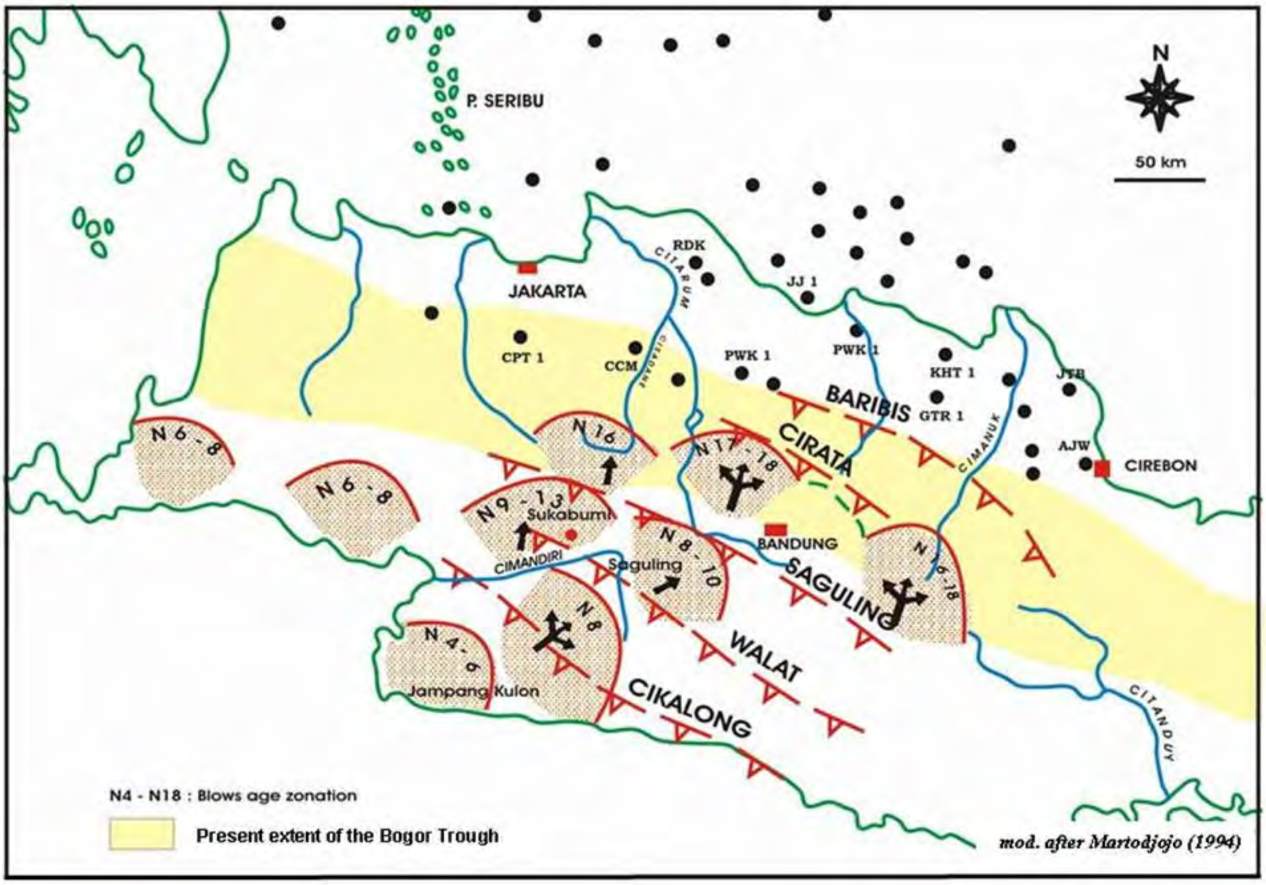

Figure 6 - Progradation of major reverse and thrust faults in West Java (Martodjojo, 1994). The faults prograded northeastward started from Ciletuh area in the Early Miocene. Each fault zone uplifted area in its upblock to become provenance for sediments of submarine fan deposited in the following period. Progradation of fault affected the study area (in box) started in the upper Late Miocene, and it was contemporaneous with the deformation of Cirata and Baribis Faults.

Back to Menu

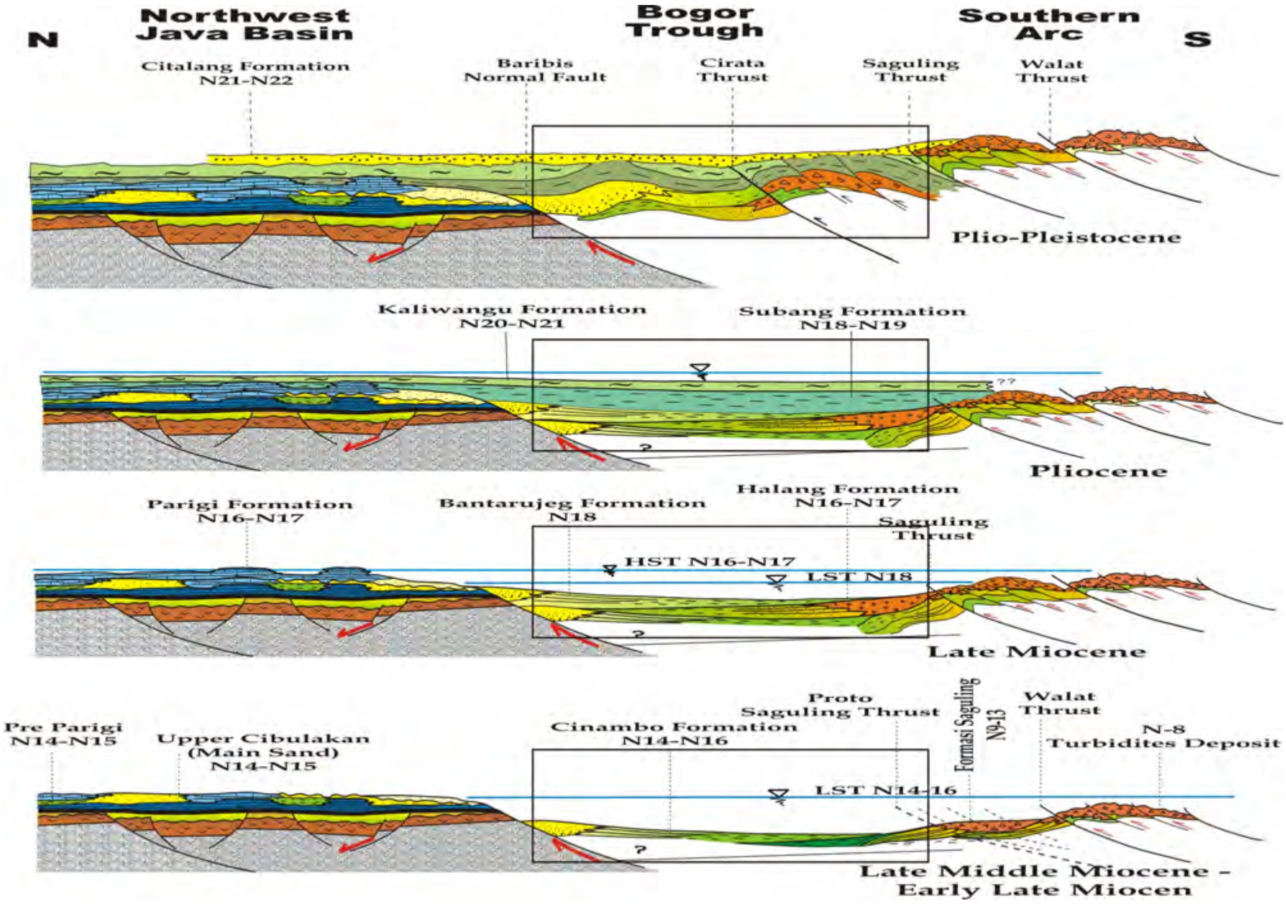

Figure 7 - A series of sections showing sedimentation history of the Bogor Trough and its association with the progradation of reverse and thrust faults in West Java (Raharjo *et al*., 2002). Note that the Bogor Trough received sediments both from the Northwest Java Basin and the Southern Arc. The box represents northwestern part of the study area. Significant inversion in the study area took place in the Plio-Pleistocene.

Back to Menu

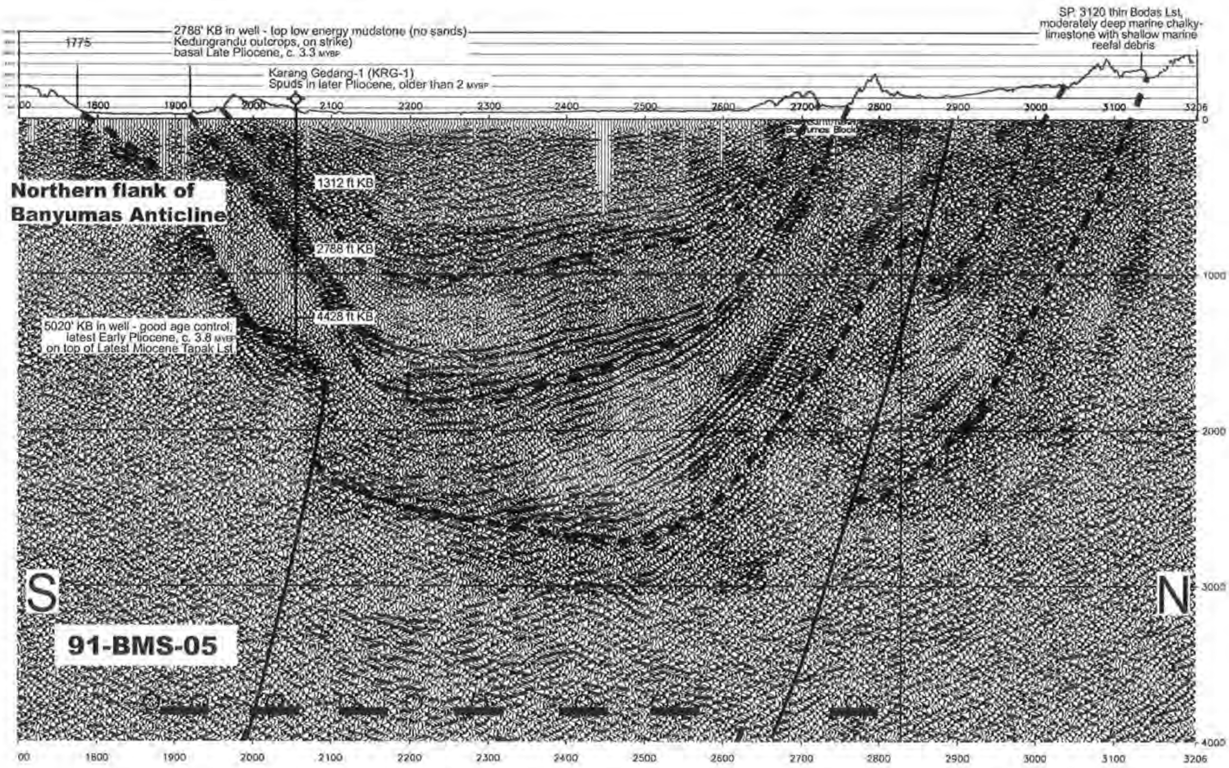

Figure 8 - Seismic section crossing the South Serayu Mountains, the Bobotsari Low, and the Banyumas Anticline (location of seismic line see Figure 4) (Lunt *et al*., 2008). Karang Gedang-1 well (dry) was drilled at the northern flank of the Banyumas Anticline or at the southern part of the Bobotsari Low. Thick Pemali sediments were deposited in the Bobotsari Low. The large reverse faults, uplift and angular truncation of the Pemali Beds and the folding of the reflectors, demonstrates that since initiation of the Banyumas Anticline there has been continual compressional shrinking of this sub-basin while it was being rapidly filled.

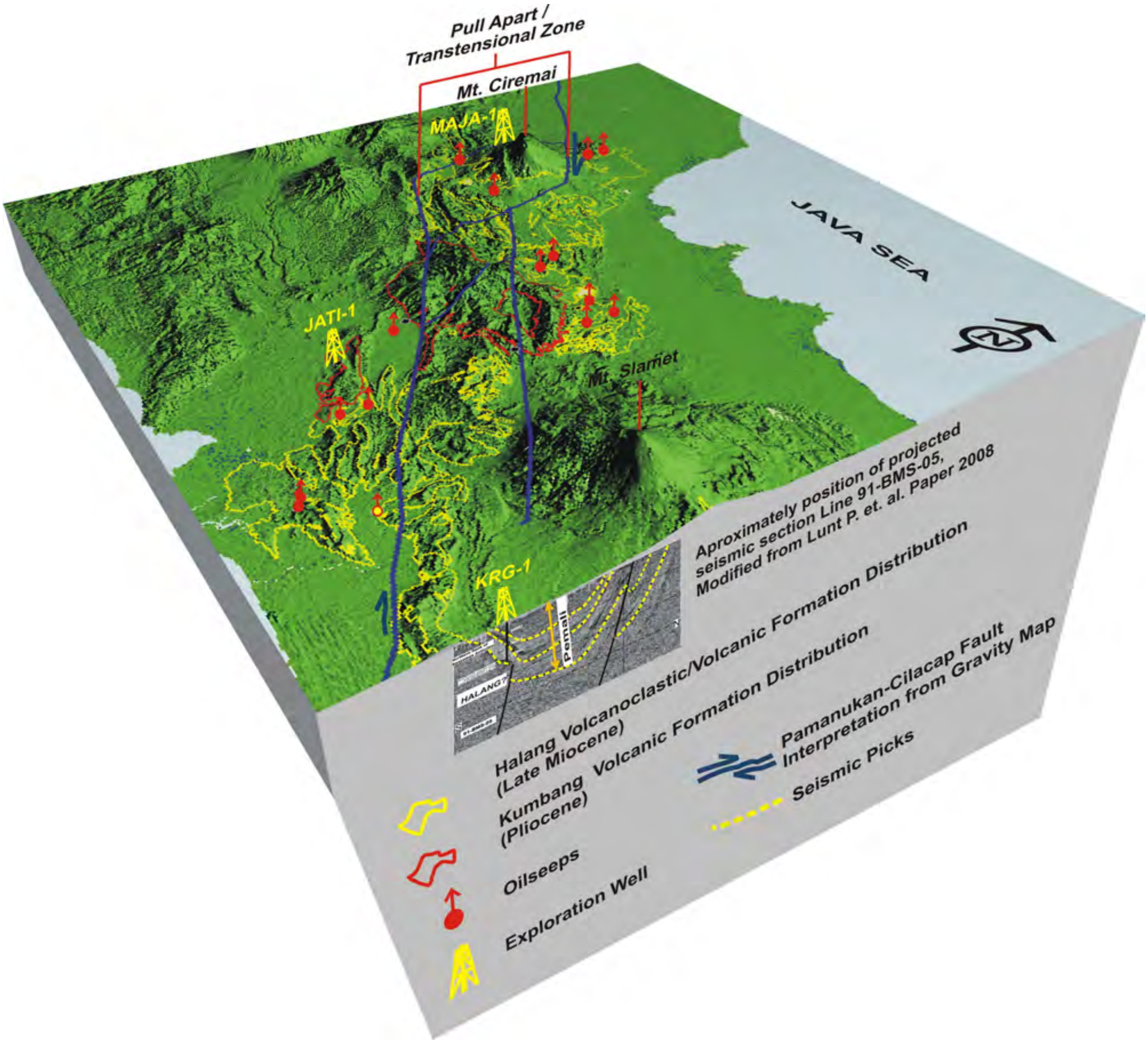

Figure 9 - Schematic block diagram showing parallel trends of Pamanukan-Cilacap Fault Zone, lithological distribution of the Halang and Kumbang Formations, and oil seeps. Northwestern end of the area is called Majalengka where Maja-1 well is located. Southeastern end of the area is called Banyumas where KRG-1 (Karang Gedang-1) well is located. The elements composing the trends were actually related to each other. The Pamanukan-Cilacap Fault Zone with its trans-tension duplex-pull apart system provided trough and rifted areas at which Miocene-Quaternary back-arc volcanism has taken place. These volcanoes have become provenances for Halang and Kumbang volcaniclastics deposited along the Majalengka-Banyumas trough. Started in the upper Late Miocene, the trough was inverted to become structural high. The high became the provenance for thick Pemali sediments deposited in low areas flanking the Majalengka-Banyumas High as one seismic section shows (see Figure 8 for more clearly seismic section). High heatflow and geothermal gradient due to rifting volcanism, thick Pemali burial sediments, and thrust loading within inversion zone; have matured Paleogene and/or Neogene source rocks deposited underlying and around Majalengka-Banyumas area. Generated petroleum might have migrated to the Majalengka-Banyumas structural high. Petroleum might have charged available traps and partly up to the surface and become oil seeps.