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DEEPWATER PLAYS OF JAVA, INDONESIA: REGIONAL EVALUATION ON OPPORTUNITIES AND RISKS

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ABSTRACT

Deepwater sedimentation occurred in Java during Miocene and Pliocene time in trough/basinal areas called the Bogor-North Serayu-Kendeng Zone located in the middle of the island. These depressions were formed by isostatic subsidence compensating for the uplifted volcanic arcs located just to the south. In Plio-Pleistocene time, the trough/basins were themselves significantly uplifted and deformed, and they currently form an anticlinorium of fold and thrust belts.

Field geology and examination of seismic and well data in the Bogor-North Serayu-Kendeng Zone show that deepwater plays are viable in Java. Re-deposited reservoir-quality sediments sourced from the NW Java Basin occur in the Bogor Trough/Basin. A number of oil seeps and oil fields occur in the North Serayu Trough/Basin in reservoirs of turbiditic volcaniclastic sandstones. A toe-thrust system, similar to proven productive traps in the deepwater Lower Kutei Basin, developed in the North Serayu Trough/Basin as the response to northward subsidence. A number of oil fields in the East Java area have reservoirs of Ngrayong sands, considered as deepwater deposits in the slope of the Rembang Zone. A number of gas and oil fields in Pliocene-Pleistocene volcaniclastic turbidites of the eastern Kendeng Zone also show the prospectivity of deepwater plays in Java.

Risks for deepwater plays in Java are related to the tectonic-volcanic setting of the island. Limited provenance for re-deposited reservoirs and sources, limited space of accommodation due to northward migration of thrust fronts, and complex deformation add risk to the petroleum system. Abundant volcanic materials also place some difficulties on operations and reduce the resolution of seismic data.

However, opportunities for deepwater plays in Java are worth considering. The presence of existing oil and gas fields in the Bogor-North Serayu-Kendeng Zone shows the prospectivity of this play. Its potential is promising and should not be overlooked any longer.

INTRODUCTION

Deepwater exploration (bathymetry of more than 200 m in either geologic or operational definitions, or sedimentation which is consistently below storm wave base – Walker, 1978) is an increasingly important component in the search for hydrocarbons in SE Asia and Australasia. Discoveries of oil and gas fields of this play type in the Makassar Strait, the South China Sea, and the Northwest Shelf of Australia in the last ten years show the prospectivity of this play in the region. In Indonesia, there is potential as large as 5 BBO in the unexplored deep-water areas (Sujanto, 2001).

In the Java area, Indonesia, deepwater sedimentation has taken place since the Miocene in an accommodation space with length of 1000 km and present width of around 60 km from Rangkasbitung area in the onshore western Java to the Madura Strait south of Kangean Islands in the east. Van Bemmelen (1949) called this area the Bogor-North Serayu-Kendeng Anticlinorium and defined it as one of the seven physiographic zones composing Java Island. Deepwater sedimentation took place in this zone during the Miocene and Pliocene, and the sedimentary packages were intensively deformed mainly during the Plio-Pleistocene tectonic episode to form the present anticlinorium.

The presence of a deepwater area along the axis of central Java Island may provide opportunities for hydrocarbon exploration. From analogues in worldwide success of deepwater plays, the deepwater area of Java may also have reservoirs and

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sources derived from the erosional products of shelfal basins located updip. In this case, the prolific Northwest Java Basin to the west and the Northeast Java Basin to the east, which have produced hydrocarbons since the late 1800s, are good sediment sources for the deepwater areas to the south. Volcaniclastic sediments sourced from the southern volcanic arc also develop reservoirs in the Bogor-North Serayu-Kendeng Zone. A number of oil seeps and oil and gas fields in the Bogor-North Serayu-Kendeng Zone are believed to be sourced and contained in deepwater deposits and show the prospectivity of the deepwater play in Java.

This paper discusses the regional aspects of deepwater sedimentation on Java Island and surrounding offshore areas. Opportunities for deepwater plays, examples of existing fields, and the petroleum system are outlined. Risks which may affect opportunities for a deepwater play are also addressed.

TECTONIC AND SEDIMENTARY SETTING

Java Island, located at the southern end of the Sundaland craton, 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 continental fragment since Late Cretaceous time. Therefore, the island is made up of a complex of plutonic-volcanic arcs, accretionary prisms, subduction zones, and related sedimentary rocks.

Three basic geologic provinces can be outlined in Java, all trending east-west parallel with the long axis of the island: (1) uplifted nonmarine to shallow marine sediments in the north, comprising the prolific Northwest Java and Northeast Java Basins, (2) uplifted volcanic and carbonate sediments in the south, and (3) subsided volcaniclastic sediments in the center. Deepwater sedimentation is related with the last of these, a geologic province that has been significantly uplifted since the Plio-Pleistocene.

The zone of deepwater sedimentation is the present manifestation of the Bogor-North Serayu-Kendeng Anticlinorium physiographic zones of van Bemmelen (1949; Figure 1). This zone encompasses a length of 1000 km and width of 60 km, from the Rangkasbitung area in the western part of West Java to the offshore areas to the east of the Madura Strait. The width of the zone once extended farther south, across the physiographic zone of Java's Central Depression to the Southern Mountains. Later tectonic episodes have uplifted, deformed, and reduced the dimension of the zone from south to north to eventually become the anticlinorium, or fold and thrust belt. However, deepwater sedimentation is still taking place in the eastern end of this zone, in offshore areas to the south of the Kangean Islands and to the north of Bali Island. In this paper, the terminologies of "Trough", "Basin", and "Zone" to designate the area of Bogor-North Serayu-Kendeng are exchangeable and have no specific definition.

The Bogor-North Serayu-Kendeng deepwater zone is situated as a back-arc basin relative to the Oligo-Miocene volcanic arc that developed in the southern part of the island (Figures 2, 3). This position has remained the same until now, still located behind the Quaternary volcanic arc. However, many northern slopes of the volcanoes within this arc overlap the Bogor-North Serayu-Kendeng Zone. The chain of Slamet-Prau-Sundoro-Sumbing volcanoes is actually located within the North Serayu sector in Central Java, forming the North Serayu Mountains.

The Bogor-North Serayu-Kendeng Zone has developed as a response to isostatic compensation for the uplift of the southern volcanic arc. Burial loading by volcanic-clastic debris eroded from the southern volcanic arc also subsided the zone. The zone also subsided due to the thrust loads formed in the Miocene to Pleistocene, where the thrust fronts migrated northward during the periods.

The Bogor-North Serayu-Kendeng Zone once consisted of deepwater basinal areas receiving sediments from the northern and southern uplifted areas. The northern provenance consisted of nonmarine to shallow marine provinces comprising the prolific Northwest Java and Northeast Java hydrocarbon basins. The southern provenance was mostly volcanic terrain, with some siliciclastic and carbonate deposits. The two provenances supplied sediments for the Bogor-North Serayu-Kendeng basinal areas, which were mostly deposited as turbiditic sediments.

OPPORTUNITIES FOR DEEPWATER PLAYS

Lessons from the Proven Deepwater Plays of the Lower Kutei – North Makassar Basins

Success of deepwater plays in Indonesia was firstly shown by exploration efforts of Unocal and partners in the Lower Kutei – North Makassar Basin. A number of fields have been discovered since the late 1990s, including: Merah Besar, West Seno, Gendalo, Gandang, Gula, Gada, Ranggas, and Gehem. A discussion of the petroleum system of that region is outlined below, as recently synthesized by Guritno et al. (2003).

Excellent quality quartzose sandstones for reservoirs in the Miocene to recent section have been supplied in abundance by the uplift of Central Kalimantan, delivered through the huge Mahakam Delta. Deepwater reservoirs are slope to basin floor turbidites. Despite the sands being thin to very thin bedded, the reservoir quality is generally excellent. The source is terrestrial derived material transported from the delta into the deepwater by turbidity currents. Detailed geochemical sampling in cores confirms that the source material is exclusively in association with the sands and siltstones and not in the shale. The organic fragments are scattered chaotically within the sands or organised into parallel lamina, mechanically controlled by the density of the turbidity current. Excellent seals are generated by both intra formational mudstones and hemipelagic mudstones. Individual sandstone units encased by intra formational mudstones frequently exhibit their own independent pressure regime. Traps are provided by anticlines associated with gravity driven extension-toe-thrust systems. In addition to the closures developed across these anticlines, stratigraphic traps are also generated by the pinchout of sand-prone channels or fans onto the crest of these anticlines. Migration is another key factor affecting the distribution of oil relative to gas. The most likely migration route from the mature kitchen in the Middle Miocene section to the immature Late Miocene and Pliocene reservoir sections is via vertical faults.

Opportunities for Java's Deepwater Plays

There are significant lessons to be learned from successful deep-water exploration program of the Kutei Basin. The most significant lesson is that the presence of abundant sands on the Kutei shelf clearly pointed to the high probability of significant deep-water sands in the basin (Dunham and McKee, 2001).

In Java, The Bogor-North Serayu-Kendeng Zone is located just to south of major hydrocarbon production in the Northwest Java and Northeast Java Basins (Figures 2, 3). Prolific Miocene sands of NW Java Basin (Talang Akar, Cibulakan, Cisubuh) and NE Java Basin (Tawun and Ngrayong) can be analogous to the Miocene and Pliocene deltaic sands of the Kutei shelf, providing sediments for deeper basins. Therefore, significant sand accumulations of the northern Java shelf could be re-transported southward during lowstands by turbidity currents through submarine channels deeply incised into the slope of the Bogor-North Serayu-Kendeng-South Madura basinal areas. The transported sands were probably deposited in ponded basins formed within the slope areas or accumulated as submarine fans on the basin floor. Like the Kutei or North Makassar Basin, hydrocarbon sources may also provided by terrestrial debris from the Java shelf. The seals are hemipelagic shales of the deep basins. Traps may be provided like the Kutei Basin by anticlines associated with gravity-driven toe-thrust systems and stratigraphic traps of sand pinchouts or shale outs related to deepwater sedimentation. Hydrocarbon migration is through deep-seated faults.

Unlike the Lower Kutei/North Makassar Basin, volcanic material is abundant in Java. This has provided a different petroleum system where volcaniclastic deposits may also serve as reservoirs.

Deepwater Plays of West Java: Bogor – Sumedang Field Study

The Bogor Trough/Basin is dominated by volcaniclastic turbidites (Martodjojo, 1994). Figure 4 shows stratigraphic relationships of the Bogor Basin with the Northwest Java Basin and the Southern Mountains. Sediments were mostly sourced by southern volcanic provenances. However, field geologic study in the Sumedang area (Raharjo et al., 2002; Satyana et al., 2002; Satyana, 2003) located in the Bogor Trough/Basin, 45 km to the east of Bandung, reveals that the northern provenance of the prolific Northwest Java Basin may source the sediments in the Bogor Basin. In this area, the Miocene to Pliocene turbiditic sands of Cinambo, Subang, and Bantarujeg Formations are interpreted to be sourced from the Jatibarang Sub-basin and deposited as submarine fans (Figure 5). Cibulakan and Parigi Formations deposited in the Ciputat, Pasir Putih, and Jatibarang Sub-Basins of the Northwest Java Basin could source these sands. Lowstand conditions occurred several times in these sub-basins, providing opportunities for sand erosion. The presence of the Baribis normal fault in the slope area could accommodate the sediments transported from the northern shelf area into the Bogor Basin. The Baribis Fault was later inverted in Pliocene time (Raharjo et al., 2002).

Figure 6 shows the history of filling of the Bogor Trough/Basin, with volcaniclastic sediments from the southern provenances forming prograding submarine fans. This process was complicated by migration of thrust fronts during the Miocene and Pliocene. The areal extent of the Bogor basin was controlled by this thrust migration.

The Cinambo Formation (N14-15, Middle-Late Miocene) consists of interbedded sandstones and shales, locally intercalated with calcareous breccias of limestone and claystone debris. The formation is strongly deformed. It is interpreted as deepwater deposits of the submarine slope or shelf break slope based on lithofacies and biofacies analyses. Provenance study including physical properties of limestone and claystone rock components, flutecast paleocurrent direction, and other current-indicating sedimentary structures such as current lamination indicate that the Cinambo turbidites are derived from the Northwest Java Basin. The paleocurrent directions were structurally restored to original horizontal deposition. The sediments were transported in northeast-southwest direction and sourced from the northwest. The main Cibulakan of the Jatibarang Sub-Basin, comprising the present Indramayu and Majalengka areas, is considered to source the Cinambo sediments. During the N13-N15, the Jatibarang Sub-Basin was in a non-marine fluvial environment during a lowstand stage based on the eustatic curve. The main Cibulakan sedimentary rocks were eroded and the debris was transported into the Bogor Trough/Basin. There were no turbidite deposits derived from the south during this period, or they were limited only to the southern area such as around Bandung.

Differing from the Cinambo Formation, the Late Miocene (N16-N17) Halang Formation is a turbiditic deposit sourced from the southern provenance. The breccias of the formation are dominated by andesitic fragments considered to derive from the Southern Mountains. These prograded to the north, coeval with northward migration of the thrust front of the Saguling Fault. Migration of this thrust front caused a marine transgression in the Northwest Java Basin, and Parigi carbonates were deposited during the period. Basinal pelagic sediments were deposited in the Bogor Basin.

During N18 (base Pliocene), the Cirata thrust uplift took place in West Java (Figure 6). This shoaled the depocenter of the Bogor Basin. Post-lifting extension then caused a sea level lowstand in the NW Java Basin. The Parigi carbonates were eroded and the sediments were deposited as slope turbidites in the Bogor Basin, known as the Subang Formation in western Sumedang and the Bantarujeg turbidites in the Majalengka area. Characteristics of the Subang Formation are similar to the Cinambo Formation, typified by the dominance of limestone and claystone debris.

During N19 (Early Pliocene), the Cirata uplift was stronger and eventually the Bogor Basin and the Northwest Java Basin formed one shelfal area. The shallow marine Cisubuh sediments were deposited in the Northwest Java Basin and the N20-aged (Early Pliocene) Kaliwangu lagoonal to shallow marine sediments were deposited in the eastern Bogor Basin. During the N21 period (Late Pliocene), the thrust uplift migrated northward and lastly inverted the Baribis normal fault at the border of the Northwest Java and the Bogor Basins to become a back-arc thrust. The Bogor Basin was higher than the Northwest Java Basin and sediments were transported to the north from the mountainous Bogor Zone, such as the Pleistocene Citalang Formation.

The Baribis reverse fault, the northernmost fault of the northward migrating thrust fronts of West Java (Figure 6; Martodjojo, 1994), has occupied the margin between the NW Java and the Bogor Basins since the Paleogene. The fault trends WNW-ESE from around Purwakarta through Majalengka to the southwest of Ciremai Volcano. The fault can actually be traced further to the west into the Banten Block in the Serang area, forming the northern border of the Bogor Basin.

Seismic sections, structural reconstruction, and stratigraphic histories from the NW Java to the Bogor Basins lead to the conclusion that the Baribis Fault is inverted. It was a normal fault until the Late Pliocene, occupying the slope area connecting the Northwest Java Basin to the Bogor Basin. When the northward migration of the West Java regional thrust faults reached its northernmost position, the normal Baribis Fault was reactivated to become an inverted reverse fault with a northerly vergence. Seismic data show that the Talang Akar Formation crossing the fault still shows normal slip, but shallower horizons from the Baturaja into the Cisubuh show reverse slips. This indicates that the Baribis Fault is an inverted normal fault. The normal fault accommodated the transport of sediments from the Northwest Java Basin into the Bogor Basin. Presently, the Baribis reverse fault forms the western sector of the Java back arc thrust, which regionally is considered to continue eastwards through Central Java-East Java to the Flores Sea.

All proven productive turbidite plays in the world have the following processes in common: erosion and transportation of reservoir and hydrocarbon source sediments from the updip productive areas, deposition in slope or basin floor areas in the adjacent deep-water setting, and later formation of structural or stratigraphic traps. These conditions occur in the Bogor Basin, where the prolific source and reservoir-quality sediments were eroded from the productive Pasir Putih and Jatibarang Sub-Basins in the Northwest Java Basin, transported, and deposited on the slope and maybe the floor of the Bogor Basin.

The Pasir Putih (Pasir Bungur and Kepuh) and Jatibarang Sub-Basins are included in the prolific Northwest Java Basin. Onshore and offshore sub-basins of Northwest Java contain at least ten active petroleum systems which have given rise to more than 150 separate oil and gas fields. The expected ultimate reserves of the region exceeds 4 BBOE, which represents about 14 BBOE in-place (Noble et al., 1997).

In the Jatibarang Sub-Basin, deltaic Talang Akar sediments provide the major source. The Jatibarang volcanics are an important reservoir in this area. Many shallower units are also charged and have good reservoir properties. The Pasir Putih Sub-Basin, including the Pasir Bungur and Kepuh, is part of a broad low lying area. The Talang Akar Formation is well developed, and adequate thicknesses of coal are present. These coals serve as the primary source for hydrocarbons. Besides the usual clastic reservoir units in the Talang Akar and Upper Cibulakan, a Mid-Main Carbonate is well developed along the Rengasdengklok ridge and is an important reservoir in this area.

The Ciputat and Cipunegara are other sub-basins of Northwest Java located to the north of the Bogor Basin. In the Ciputat Sub-Basin, the Talang Akar Formation thins considerably and is largely made up of Main limestones. Some coaly and shaly facies are present. In the Cipunegara Sub-Basin, the Talang Akar source rocks are the most important, and multiple reservoir horizons are charged from this source.

The presence of productive shelfal sub-basins to the north is important for the hydrocarbon potential of the Bogor Trough/Basin. During lowstands, these sub-basins could provide detritus for hydrocarbon reservoirs and sources deposited on the slope and floor areas of the Bogor Trough/Basin. Lowstands occurred several times in the Ciputat and Jatibarang Sub-Basins. Cinambo, Subang, and Bantarujeg turbiditic sands provide material for the reservoirs and/or source rocks. Re-deposited rock sequences older than the Cinambo Formation are possible in the Bogor Basin, since lowstand sea level occurred several times in the Paleogene of the Northwest Java Basin. Very deep marine quartzitic sand turbidites of older Tertiary age are considered to occur within the Bogor Trough/Basin. They now crop out at the southern margin of the basin (Lunt, personal communication, 2004). These re-deposited rocks may form additional elements of the petroleum system of the deepwater play in the Bogor Basin.

Deepwater Plays of Central Java: North Serayu Trough/Basin

The North Serayu Trough/Basin is located in the northern part of Central Java and was later uplifted to become the North Serayu Range. It extends eastward into the Randublatung Zone and the Kendeng Ridge, and its westward extension unites with the Bogor anticlinorium belt (van Bemmelen, 1949). The Geology of the North Serayu Range shows a history of basin subsidence with deepwater sedimentation that ended with uplift, something like the Bogor Basin.

The Eocene Worowari siliciclastic beds are the oldest sedimentary rocks in this area. These were covered transgressively by Early Miocene coarse conglomerates and quartzitic sandstones of the Lutut Beds and reef limestones called Sigugur Beds. Significant subsidence of the North Serayu Basin started thereafter. Thick succession of turbiditic deposits of Early to Middle Miocene marly clays, quartz sandstones and tuff-sandstones indicate the subsidence. This flysch-like series consists of the Merawu and Penyatan Beds in central and eastern areas and the Pemali Beds in the western section of the North Serayu Basin (Figure 7). Re-examination of fossil content of the Pemali Beds in the type-locality 30 km SE of Cirebon shows that the Pemali Beds are not Early Miocene or basal Middle Miocene, but an Early Pliocene deep marine facies. A rapid regression is implied prior to the Pleistocene deposition of shallow or non-marine vertebrate bearing beds (Lunt and Burgon, 2003; Lunt – personal communication, 2004).

The Merawu and Penyatan Beds can be correlated with similar deposits in East Java, where they are called Kerek Beds in the Kendeng Zone and Rembang Beds in the Rembang Zone. In the Bogor Basin, the Merawu Beds are correlative with the Citarum and Jatiluhur (Saguling) turbidites. Overlying the Merawu Beds are Late Miocene volcanic-clastic turbidites of the Halang Beds (Figure 7).

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 Trough/Basin (van Bemmelen, 1949; Figure 8). This sudden increase of orogenic relief not only caused gravitational sliding movements from south to north, but it also caused portions of the northern flank to slide down toward the deepest part of the basin. In the Mio-Pliocene, a basal limestone of the Bodas Series was deposited transgressively and unconformably upon the older Miocene series. Then strong basin subsidence began, which volumetrically compensated the strong Mio-Pliocene uplift of the South Serayu Range in the southern part of Central Java.

The Mio-Pliocene succession of strata filling the trough of the North Serayu Zone began with volcanic deposits alternating with conglomerates, and it ended with the soft clay marls and tuffaceous sandstones of the Kalibiuk Beds. The volcanic series are called as the Kumbang Breccias in the western part of the basin, the Bodas Series in the middle, and Banyak Breccias in the eastern part, which are conformably succeeded by the tuff-sandstones and marls of the Early Pliocene Cipluk Beds. The volcanic breccias of the Lower Bodas Series contain polymictic conglomerates with boulders derived from the raised Lukulo areas in the south. The volcanic breccias proper are the products of submarine volcanoes in the subsiding North Serayu Basin.

In the Pliocene, deepwater sedimentation was still taking place in the North Serayu Trough/Basin. Facies analysis in the Brebes-Tegal-Pemalang districts, northern Central Java (Sunardi et al., 2001) revealed the presence of turbidites in these areas equivalent to the Pliocene Cisubuh Formation in the shelfal area to the north. Some features in measured sections could be attributed to the depositional and erosional elements of turbidites. Approaches through mapping, facies correlation, and profile comparison indicate depositional systems responding to the break between shelfal and basinal sedimentation.

After early-Miocene volcanic activity, reefal carbonates accumulated such as the reef limestones on top of the Tapak Beds to the west and the Kapung limestone to the east. The depositional succession in the North Serayu Basin strongly indicates uplift starting in Plio-Pleistocent, because these deposits only occur along the margins of the North Serayu Range. They consist of the Damar Series, Ligung Series, and the Kaliglagah-Mengger-Gintung Series. This period of uplift was contemporaneous with the period of inversion in the Bogor Basin.

Van Bemmelen (1949) reported a number of oil seepages and one oil field located in the North Serayu Zone. The seepages occur in the areas of Karangkobar, Bawang and Subah, Klantung and Sodjomerto, Kaliwaru, West of Mt. Ungaran (many seepages), and East of Mt. Ungaran. Exploratory drillings carried out by Dutch oil companies since early 1900s near the seepages met no success. However, drilling in Klantung and Sodjomerto was successful and the Cipluk Field was discovered. During the 35 years of production, the average yearly production was a few hundreds of tons. Cipluk Field, now is abandoned, is formed by a faulted anticline of Late Miocene Banyak volcaniclastic sandstones. The oils are considered to be sourced from shales of the underlying Merawu Beds or Eocene aged shales of Worowari (equivalent to Ngimbang shales in the East Java Basin), which charged the trap using faults as conduits. Interbedded marls of the Cipluk Beds provide the vertical/lateral sealing. One of the westernmost Pemali beds crops out in Madja, west of Ciremai volcano in the Cirebon area, and was reported to have active oil seeps which are less biodegraded (Lunt and Burgon, 2003; Lunt, personal communication, 2004). The first well drilled for oil in Indonesia was at the Madja seeps in 1872.

Gravitational sliding movements from south to north in the North Serayu Trough/Basin occurred in response to the uplift of the South Serayu Range during the Middle to Late Miocene and resulted in the formation of structures (Figure 8). The Eocene to Late Miocene Worowari, Lutut, and Sigugur nonmarine to shallow marine beds and the Merawu and Lower Penyatan turbidites were deformed as toe thrust anticlines and fault-propagation folds.

This mechanism is similar to proven hydrocarbon traps in the Lower Kutei-North Makassar Basin, where uplift of the updip area in the Kutei Basin during the Late Miocene to Recent has formed traps in the Lower Kutei-North Makassar area with some sediments being ponded in the synclinal area formed between the thrusted anticlines. All elements and processes of the petroleum system could be formed with this system in North Central Java. Hydrocarbon sources can be provided by the nonmarine-shallow marine Worowari shales and marly clays of the Merawu Beds. Reservoirs are quartzitic sandstones and tuffaceous sandstones of the Lutut and Merawu Beds, plus reef limestones of the Sigugur Beds. Seals are intraformational shales within the Merawu and Penyatan Beds. Maturation of the source rocks could be attained as the basin subsided and buried by sediments of the post Late-Miocene. 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 the faults of the toe thrust system. A number of seepages in the surface indicate the presence of a viable petroleum system in the region.

Deepwater Plays of East Java: South Rembang – Kendeng – South Madura Trough/Basinal Area

The shelf-edge has been identified for the Paleogene and lower Neogene in northern East Java. It presently trends west–east from around Rembang in the west through Tuban to north Madura Island. The depressions from this line southward to the border of the Oligo-Miocene volcanic arc (the East Java Southern Mountains) were areas where deepwater sedimentation took place. These areas now include the physiographic zones of the Rembang-Madura Hills, the Randublatung Zone, and the Kendeng Ridge that continues into the Madura Strait (van Bemmelen, 1949).

Like in the Bogor Zone, sediments deposited into the South Rembang-Kendeng-South Madura basinal area came from erosional products of sedimentary successions comprising the Northeast Java Basin to the north and uplifted volcanic arcs to the south. The deposition has taken place since the Early Miocene. Subsidence of the Kendeng Basin occurred several times as volcanic arcs to the south of the basin were uplifted. In Pleistocene time, both the South Rembang and Kendeng were uplifted and intensively deformed. Most of the southward thrusting occurred in the Rembang Zone, in contrast to the northward thrusting in the Kendeng Zone. The opposite direction of thrusting has formed a triangle zone which subsided due to thrust loading. This triangular zone is the Randublatung Zone, located between the Rembang and Kendeng Zones.

Important for petroleum geology is the deposition of deepwater facies of (1) the Middle Miocene Ngrayong sands (from South Rembang to the Madura Strait) and (2) the Middle-Late Miocene Kerek volcaniclastics (from the Kendeng to the Madura Strait).

Ngrayong Sandstones of the Rembang Zone to the Madura Strait

The Ngrayong sandstone has no formally defined type section but is generally recognised as the sequence of quartz sand rich beds in the lower part of the Wonocolo Formation (Lunt, 1991). The rocks crop out in the Rembang Hills area from Cepu in Central-East Java to Madura Island. The Ngrayong includes interbedded quartzose sandstones, mudstones and thin limestones, and the overlying sandy, bioclastic limestones (the Platten or Bulu limestones). The age of Ngrayong ranges from N9-N12 (early Middle Miocene to mid-Middle Miocene (Ardhana, 1993). The precise depositional setting for the Ngrayong sandstone in the Rembang Hill area is problematic and has been under debate for a number of years (Lunt et al., 1996; Burgon et al., 2002). Sedimentologically, the sands appear to represent a shallow marine tidal sand bar complex, with some channelling and locally bioturbated shoreface deposits. However, thin interbedded limestones within the sands, the Platten limestone capping the sands, and the presence of multiple deeper-setting rare foraminifera of the genus *Cyclammina* (usually a bathyal marker) and *Cycloclypeus* show the possibility of deepwater facies for the Ngrayong. Lunt (1991) argued that all characteristics showing shoreface to shallow marine facies for Ngrayong in Cepu area can also occur in a deepwater facies. A more detailed paleo-environmental analysis is needed to resolve this problem.

Based on extensive studies of field geology, seismic, and well data in the Cepu to Madura area, Ardhana (1993) proposed three depositional units (Unit I to III) within the Ngrayong sediments, each having a different areal extent and sedimentary facies as a consequence of differing depositional environments and sedimentary processes (Figures 9, 10). Unit I comprises cross-bedded sandstones interbedded with mudstones and thin limestones deposited on shelf to upper slope area in the north and northwest. Unit II comprises Unit I equivalent sediments including sandy turbidites and hemipelagic muds which accumulated in the deeper basin to the south. Unit III includes the overlying sandy bioclastic Platten/Bulu limestone, deposited in the north, and the equivalent sandy turbidite (mostly channelized), hemipelagic muds and contourites developed in the south.

Pre-Tertiary basement architecture controlled the paleogeography of Kujung carbonates in the Oligo-Miocene and greatly influenced the depositional pattern within the younger Ngrayong. Coarser clastics of the Unit II sandy turbidites appear to be restricted to paleo-lows; paleo-highs were bypassed by currents carrying coarser sediments and were consequently dominated by hemipelagic sediments. Five sandy turbidite bodies of this unit have been identified representing deepwater, slope to basinal sediments of the lower regressive part of the Ngrayong (Ardhana, 1993; Figure 10): the Nglobo Fan, the Kawengan Fan, and the Candi Turbidite Body in the Cepu area; the Bungoh-Grigis Fan to the north of Surabaya; and the Gondang-Ngasin Turbidite Body to the southwest of Madura Island. These fans/turbidite bodies were deposited south and southwestward from the approximate boundary of the upper and the lower slope at the Ngrayong level.

The **Nglobo Fan** complex overlies the Kening Trough. The thickest recorded section is penetrated by Nglobo Utara-1 well and comprises 750 meters of interbedded quartzose sandstones and mudstones with a reported 50% sand content. The inner fan facies is well shown, containing bathyal indicative faunal assemblages and sedimentary structures associated with turbidite facies.

The **Kawengan Fan** or Debris Apron is situated in the eastern part of the Kening Trough, overlying a relatively small restricted embayment. A Bathyal index fauna of *Cyclammina cancellata* is present. Seismically, the transverse section of the fan shows convex-up, bi-directional thinning and downlapping characteristics.

The **Candi turbidite body** is situated at the northeast trending Pati Trough. Paleontological data suggest that Ngrayong sands of the Candi body were deposited in outer neritic to upper bathyal environments. Other deepwater deposits of the Ngrayong include the sandy turbidite facies and contourite facies of the Upper Ngrayong Unit III.

The **Bungoh-Grigis Fan** is located at the northern portion of the Ngimbang Basin or the southern portion of the Central Deep. The Ngrayong part of this fan comprises interbedded quartzose sandstones and mudstones with thin limestone intercalations. Faunal assemblages are indicative of fully bathyal conditions.

The **Gondang-Ngasin** turbidite body is interpreted to occur in the Madura Strait north of the BD Ridge. Paleontological data in all the wells that penetrated this fan indicate a bathyal depositional environment.

These sandy turbidite bodies posses a great variation of reservoir characteristics corresponding to different facies. Good to excellent reservoir qualities can be expected in the proximal facies including the inner-fan channel–slope gully system and in the middle-fan channels where the sandstones are usually thicker and cleaner. In the distal facies, sandstones are generally thinner, siltier, and mud-rich with a decrease in reservoir quality. In the Kawengan Field, reported porosities range between 17-20% with permeabilities between 270-350 mD.

In the South Madura Sub-Basin, recently acquired seismic data show good reflectors at the Ngrayong equivalent level, which may relate to direct hydrocarbon indicators (DHIs; John Bates, personal communication, 2004). Ngrayong deposition in this area is considered to be storm generated shelf turbidites and deepwater fans in slope to bathyal environments (Figure 11). The Camplong-1 well drilled on Madura Island by Shell in the 1980's penetrated feeder channel facies in the Ngrayong. Southward into the Madura Strait, Ngrayong sands were deposited as deepwater fans in the slope area. The Ngrayong sandstones in this fan are considered to be composed of quartzose sands and channelised sand bodies associated with hemipelagic muds and contourites of Unit II and III.

In excess of 150 MMBO have been produced from the sandstones of both middle to outer-fan or distal turbidite facies of Unit II and the channelized turbidites of Unit III (Ardhana, 1993). Turbidite sandstones of Unit II, which were deposited as submarine fans, form the primary target in East Java. These sandstones have good reservoir potential and are productive. They overlie paleo-low areas, most of which were tectonically inverted at the end of Miocene time or later. This combination of good reservoirs in potentially large structures remains the best Ngrayong play in the East Java Basin. Effective stratigraphic pinch-outs should form an exploration play updip of an inner-fan filled submarine canyon at the walls or channel margins. Hemipelagic muds will make an excellent seal, and Ngimbang shales deposited within low areas provide a mature kitchen. Faults will play roles as conduits for hydrocarbon migration.

Volcaniclastic Turbidites of the Kendeng Zone

Deepwater sedimentation in East Java also includes the Miocene Kerek volcaniclastics in the Kendeng Trough/Basin. The Kendeng Basin is now a west-east trending fold and thrust belt (anticlinorium) extending around 250 km in length and 20 km in width from Ungaran volcano in the west to the Brantas River in the east, where it plunges beneath the alluvial plain bounding the Madura Strait (de Genevraye and Samuel, 1972). The western part of the Kendeng Zone is characterized by a high content of volcanic material and structural complications. In the central part, pyroclastic materials decrease northward but the structures are still complex. In the eastern part, volcanic materials are reduced and the structural trends shift northward.

Figure 12 shows the evolution of the Kendeng Zone and its relationship to the Rembang and the Randublatung Zones. The Miocene-aged Kerek Formation represents deepwater sedimentation in the Kendeng Zone. As a whole, the Kerek Formation consists of a massive argillaceous and calcareous sequence where volcaniclastic material is very abundant. Various names have been given to members of this formation due to facies changes.

In the westernmost part of the Kendeng Zone, De Genevraye and Samuel (1972) used similar names to those of the North Serayu Zone. In this area, the Kerek Formation has been divided into two members: the Middle Miocene Merawu Member in the lower part and the Late Miocene Penyatan Member in the upper part. The Merawu Member is a volcaniclastic sequence. The lower interval of the Merawu consists of conglomerates and micro-conglomerates with pebbles of quartz, andesitic tuffs and *Lepidocyclina*-bearing limestones. These coarse volcanic detrital layers are overlain by shaly-sandy-calcareous alternations of turbidite-like deposits. The Penyatan Member is essentially clastic and tuffaceous; .numerous thick beds of very coarse tuff sandstones are interbedded with dark layers of clays and marls, including turbidite-like sequences, and calcareous layers are seldom seen.

In the Central and Eastern Kendeng Zone, the Kerek Formation is made up chiefly of a rather monotonous series of clays, argillaceous marls, and marls alternating with calcareous and non-calcareous tuffaceous sandstones responsible for the turbiditic-like aspect of the sequence. In the Central Kendeng Zone, a three member division was made by de Genevraye and Samuel (1972). The Banyuurip Member is an alternation of argillaceous marls, marls and clays with calcareous and non-calcareous tuffaceous sandstones. The Sentul Member which also consists of an alternation of argillaceous volcanic detrital layers, but tuffaceous beds are more frequent in the upper part of the member and can reach thickness of 20 m each. The Kerek Limestone Member is the upper member of the Kerek Formation, conformably overlying the Sentul Member and consists of an alternation of tuffaceous limestones and tuffaceous and argillaceous layers.

The Kerek formation was formed in outer neritic to bathyal depositional environments when the Kendeng Zone was subsiding during the mid-Early Miocene to Middle Miocene and a large volume of volcanic materials were deposited into the subsiding basin (Figure 12). The total thickness of the Kerek Formation is estimated to be more than 1000 meters. The subsidence of the Kendeng Zone is related to isostatic compensation due to uplift of the volcanic belt along the axial ridge of Java. Frequent sedimentary structures related to subsidence are observed at several levels in the Kerek Formation, such as flow rolls, synsedimentary microfolds, and micro growth faulting.

Kerek volcaniclastic sediments deposited in the Kendeng Zone have not been explored for hydrocarbons. Outcrops in the west Kendeng indicate this sandy volcaniclastic sequence has better quality and more quartz-rich sands than the overlying Banyak volcaniclastic beds. Minor oil in the Klantung-Cipluk Field in the most western end of the Kendeng Zone is considered to have come from the Banyak volcaniclastic beds.

The discoveries of Wunut gas field (Huffco Brantas, 1994), Carat gas field (Lapindo Brantas, 2001), and Tanggulangin gas and oil field (Lapindo Brantas, 2001), all located 30 km south of Surabaya, show the productivity of turbiditic volcaniclastic deposits in the Kendeng Zone as gas and oil reservoirs (Figure 13). Reservoirs are in the Pleistocene Pucangan Formation. Basal Wunut sands were deposited as a turbiditic sequence, shoaling upsection to deltaic facies (Kusumastuti et al., 2000), whereas the Carat and Tanggulangin sands were all deposited as turbiditic sediments (Agung Darmoyo, personal communication, 2004). The volcaniclastic sands in the Wunut field can be classified as lithic arkose or feldspathic litharenites. The rock matrix consists predominantly of plagioclase feldspar and volcanic rock fragments with secondary amounts of altered grains and heavy minerals. The clay content is variable and is dominated by smectite. The average porosities of the individual sands range from 25 to 35%, and the average permeabilities range from 25 to 195 mD. The pore systems are mainly intergranular and have been enhanced by secondary pores resulting from mineral dissolution (Kusumastuti et al., 2000).

The Kerek volcaniclastic sands will not as good as the Pucangan sands in reservoir quality due to the being more deeply buried and compacted. Willumsen and Schiller (1994) estimated total porosity of greater than 30% at shallow depths, decreasing to approximately 20% at 7500 feet, with permeability averaging 100 mD at shallow depths and decreasing to 20 mD at 5000 feet. Secondary porosity created by mineral dissolution, however, can be enhanced at greater depths.

The long abandoned Kuti and Metatu Fields (discovered in the late 1890s) located in the Randublatung Zone near Surabaya also produced oils from volcaniclastic sands. The Kuti Field produced 0.75 MMBO from Pleistocene tuffaceous sandstone whilst Metatu produced 0.3 MMBO from the same Pleistocene volcaniclastics (Willumsen and Schiller, 1994).

These examples show that volcaniclastic sandstones can be good hydrocarbon producers. They suggest that the negative aspects of volcaniclastic reservoirs may have been overemphasized in the past. The Kendeng Zone with its abundant volcaniclastic deposits of all ages may contain considerable overlooked potential within these horizons. Hydrocarbon source beds may be provided by marls deposited contemporaneously with the volcaniclastic sands in a configuration allowing direct migration of generated hydrocarbons from source to reservoir. A biogenic gas source, related to rapid sedimentation, could be encountered in the shallow horizons of the Kendeng Zone. Subsidence of the Kendeng Zone and deep burial of the source beds would have put the source rocks into the hydrocarbon generation windows. The presence of faults which accommodated the subsidence of the basin could act as vertical hydrocarbon conduits from the deep source to the shallow reservoir. The discovery of oils in significant amounts in the Oyong Field in the Madura Strait (Santos Sampang, 2000) and in the Tanggulangin-3 well (Lapindo Brantas, 2004) shows that the Eocene Ngimbang shales deposited in the Kendeng Trough have entered the oil window and oils were migrated through vertical faults charging the Pliocene and Pleistocene reservoirs. Rocks comprising fine-grained material are abundant within the subsided Kendeng Zone and will provide a good resilient seal. Entrapment could occur in stratigraphic traps for turbidites, sub-thrust structural traps below the north-verging Kendeng thrusts, and structural and stratigraphic traps related to subsidence (like toe-thrust systems) and uplift (like sub-thrust systems of the triangle zone) within the Kendeng Zone. The occurrences of gas and oil fields in the volcaniclastic deposits of the Kendeng Zone suggest that the petroleum possibilities of this zone cannot be overlooked.

RISKS OF DEEPWATER PLAYS IN JAVA

The difference in tectonic setting between the Kutei/North Makassar Basin, which developed in a passive plate margin, and Java, which developed in an active plate margin, causes the differences in hydrocarbon prospectivity for deepwater plays. There are four aspects which may significantly increase risk in applying the proven deepwater Kutei/North Makassar plays to Java: (1) limited provenance, (2) limited space of accommodation for sediments, (3) complex deformation within the deepwater areas, and (4) thick volcanic cover.

Limited Provenance for Siliciclastic Deposits

Limits on provenance for siliciclastic deposits are related to the tectonic position of the Java shelfal area, which was not a centre of uplift, and that the Paleogene sediments of the shelfal area were not exposed significantly at the lowstands. The compression of Java by plate interaction offshore to the south did not uplift the NW Java and NE Java Basin shelfal area, but instead uplifted and deformed the volcanic arcs in the axial ridge of Java. This became the source of volcaniclastic deposits into the Bogor-North Serayu-Kendeng deepwater trough. Therefore, due to minimum uplift of the shelfal area of NW Java and NE Java, continental associated erosional products which may be rich in quartz were not significant in the Bogor-North Serayu-Kendeng trough. This condition is much different from uplifts of the Kuching High and the Central Ranges of Kalimantan, which became the long-lasting provenances for the Kutei/North Makassar Basin and other basins in surrounding areas. These uplifts started in the late Oligocene/Early Miocene. Evaluation of current sediment yields of SE Asia showed that Kalimantan is a region of high productivity with total sediment yields of $582x10^6$ ton/year compared to Java with $322x10^6$ ton/year (Milliman et al., 1999). The present high yields appear similar to rates of sediment production estimated over much longer periods in the Cenozoic (Suggate and Hall, 2003). Direction of sediment transport in Kalimantan has remained the same, from centre of Kalimantan to all its surrounding basins. However, in Java, current sediment transport direction is from south to north in the Northwest and Northeast Java Basins. This changed from the direction during the Neogene, when transport of sediments was from north to south.

Limited Space of Accommodation

Limited space of accommodation for deposition of sediments is caused by compressive tectonics undergone by Java's central deep-water basinal area. Since the Early Tertiary, Java Island has been a site for frontal compression due to subduction of the Indian oceanic plate to the south. The extent of the deep basinal area in the middle of the island had been reduced from time to time by a northward advancing volcanic front. The basin was eventually uplifted, terminating deepwater sedimentation. This condition is much different from the passive margin of the Makassar Strait. The Kutei and North Makassar basins have subsided continuously, mainly because deposition of a very thick sedimentary section increased accommodation space. The thickness of the sedimentary rocks in the Lower Kutei Basin is estimated to be 15,000 meters, making the Kutei Basin the deepest sedimentary basin in Indonesia.

Complicated Deformation

Complex deformation of Java presents problems for exploration. In contrast, the Lower Kutei/North Makassar Basins have not been deformed significantly by tectonic compression. Most of the structures within deepwater sediments of the Lower Kutei/North Makassar Basins are related to basin subsidence and turbiditic syn-depositional structures, such as toe-thrusts.

Deepwater sediments in the Bogor-North Serayu-Kendeng areas were strongly deformed and uplifted to become the Bogor-North Serayu-Kendeng Anticlinorium. The structural grains are dominated by thrust and reverse faults trending almost east-west, thrusting the blocks northwards and northeastwards. Northward migration of the thrust fronts from Early Miocene to Pleistocene time was outlined by Martodjojo (1994) in the Bogor Trough and West Java.

The Kendeng Zone was significantly uplifted during the late Pliocene, and resulting structures are tightly folded and commonly faulted (de Genevraye and Samuel, 1972). The intensity of folding and faulting appears to decrease from west to east. Structures are rather small, but they are numerous and distributed all along the anticlinorium. These are very elongated, trending west-east. The structures mostly verge northward with steeper northern flanks. They often broke and, as a consequence, northward thrusting parallel to the structural axis is common. Such faults usually do not extend very far in depth (thin-skinned faults). Faults located farther to the south approaching the uplifted axial ridge commonly reach a great depth and may deform the Kerek Formation. A folding mechanism appears to include gravity sliding of the sedimentary cover on the basement. In addition to longitudinal reverse and thrust faults distributed along the anticlinorium, transverse wrench faults also occur. The major wrench faults are roughly perpendicular to the anticlinorium axes, transversely cutting across the Kendeng Zone over a long distance, and they are often arranged in a staggered network. These are considered to be deep-seated faults originating from the basement. In the Pleistocene, the whole Kendeng Zone was uplifted.

Effects of Volcanism

Volcanic arcs have characterized Java since the Early Tertiary (Smyth et al., 2003), and three significant volcanic periods are recognised: Oligo-Miocene, Mio-Pliocene, and the Quaternary. The volcanic belts of these periods overlap each other along Java and are located close to or within the deep-water basinal areas. As a result, significant amounts of volcanic sediments were deposited in the deep-water basinal areas of Bogor-North Serayu-Kendeng. The Quaternary volcanoes of Java are located just to the south of the Bogor Zone in West Java, Kendeng Zone in East Java, and within the North Serayu Zone in Central Java.

Significant volcanic cover at the surface complicates operational activities like seismic surveys and drilling. Seismic quality is also reduced by the presence of volcanic cover at surface and/or sub-surface. No volcanic cover occurs in the Lower Kutei/North Makassar Basin. This allows seismic imaging of the subsurface data to be of excellent quality.

Summary of Risks

The presence of these negative aspects for deepwater plays in Java which are not present in the proven Lower Kutei/North Makassar Basin affects some elements and processes of the petroleum system. Limited uplifted areas in the Northwest Java and Northeast Java basins reduces sediment provenance, which in turn diminishes the redeposition of reservoir and source quality sediments in the Bogor-North Serayu-Kendeng Basins. Limited space of accommodation due to northward migrating thrust fronts reduces the volume of the deepwater depositional system. Complex deformation then complicates and may degrade already formed structural and stratigraphic traps, breaking closures and breaching seals. Seismic imaging of the subsurface data may be difficult due to thick surface and subsurface volcanic cover, which will complicate mapping and evaluation.

CONCLUSIONS

Deepwater sedimentation occurred in Java during Miocene to Pliocene time in trough/basinal areas called the Bogor-North Serayu-Kendeng Zone located along the axis in the middle of Java. The basins were formed by subsidence to isostatically compensate for uplifted volcanic arcs located just to the south. Turbiditic flysch deposits occur in the sediments of these basins. Sedimentary debris from the Northwest Java and Northeast Java basins was re-deposited into the deepwater basins. Volcanic materials sourced from the southern volcanic arcs also accumulated as significant deepwater deposits. In the Plio-Pleistocene, the deepwater basins were uplifted significantly and deformed to become the current zone of an anticlinorium or fold and thrust belt.

Field geology and examination of seismic and well data in the Bogor-North Serayu-Kendeng Zone show that deepwater plays which are proven to be productive in the Lower Kutei/North Makassar Basin may also be present in Java. Re-deposited reservoir-quality sediments sourced from the Northwest Java Basin are observed in the Sumedang area, Bogor Basin. A number of oils seeps and one oil field (Cipluk) occur in the North Serayu Basin, reservoired by turbiditic volcaniclastic and calcareous sandstones of Merawu, Banyak, and Pemali Beds. Toe-thrust systems like those proven to be structural traps in the Lower Kutei Basin are developed in the North Serayu Basin in its response to subsidence to the north. A number of oil fields in the Cepu area (such as: Nglobo, Kawengan complex, Ledok, Semanggi, Gondang) are considered to have reservoirs of Ngrayong sands that were deposited as turbiditic sediments in the slope area of the Rembang Zone. A number of gas and oil fields also occur in Pliocene-Pleistocene volcaniclastic turbidites in the Kendeng Zone (like: Wunut, Carat, Tanggulangin, Kutei, Metatu), showing that the volcaniclastic sandstones are not poor reservoirs. Petroleum system analysis shows that possibilities for deepwater plays in the Bogor-North Serayu-Kendeng Zone are worth considering.

Risks for the deepwater plays of Java are related to the tectonic-volcanic setting of the island:

(1) Limited uplifted areas in the Northwest Java and Northeast Java basins restricts the provenance for reservoir and source quality sediments deposited into the Bogor-North Serayu-Kendeng Zone.

(2) Limited space of accommodation due to northward migration of thrust fronts reduces the volume of the deepwater depositional system.

(3) The complex structures of Java complicate structural and stratigraphic traps formed in the deepwater system.

(4) Abundant volcanic materials deposited into the basins hinder seismic imaging of the subsurface data which accordingly complicates evaluation.

However, opportunities for a deepwater play in Java are worth being considered. The presence of existing oil and gas fields in the Bogor-North Serayu-Kendeng areas shows the prospectivity of this play in Java. Its potential is promising and should not be overlooked.

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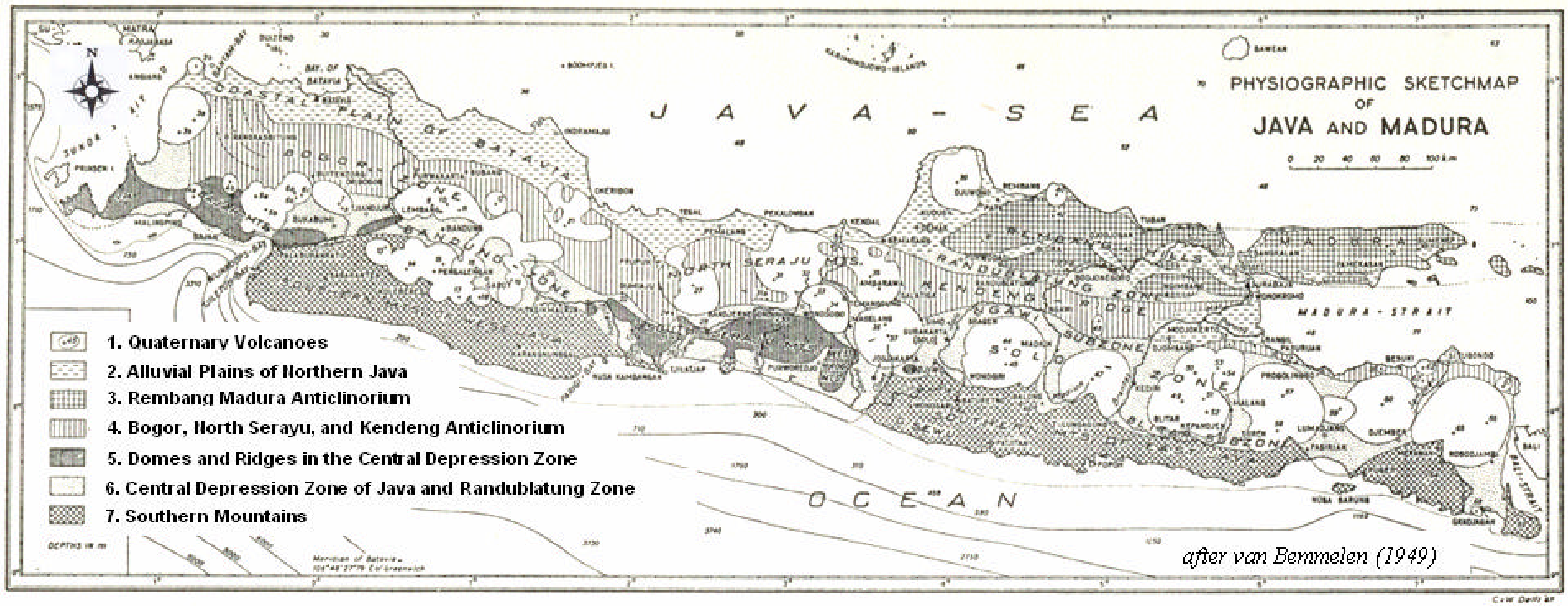


Figure 1 - Physiographic zones of Java and Madura. The zones display the geologic histories during the Tertiary and the Quaternary. The zone of the Bogor-North Serayu-Kendeng Anticlinorium was a deepwater basinal/trough area during the Miocene and Pliocene. The area was intensively uplifted and deformed in the Pleistocene to become the present zone of the anticlinorium (fold and thrust belt).

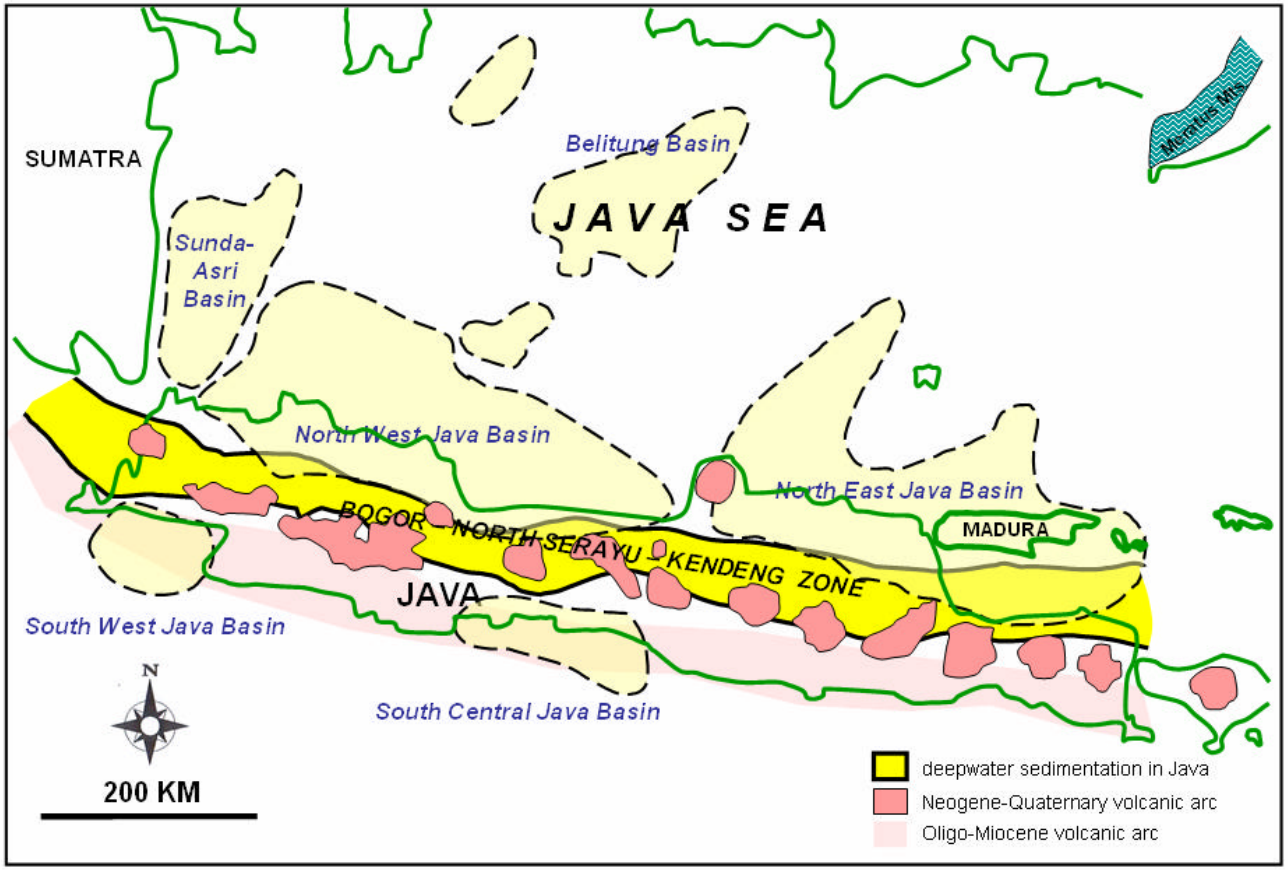


Figure 2 - The Bogor-North Serayu-Kendeng deepwater area was located in between the uplifted prolific hydrocarbon basins of NW Java and NE Java Basins to the north, and the uplifted volcanic arcs of the Oligo-Miocene and the Neogene-Quaternary to the south. The two uplifted areas sourced the sediments for the Bogor-North Serayu-Kendeng deepwater basins/trough.

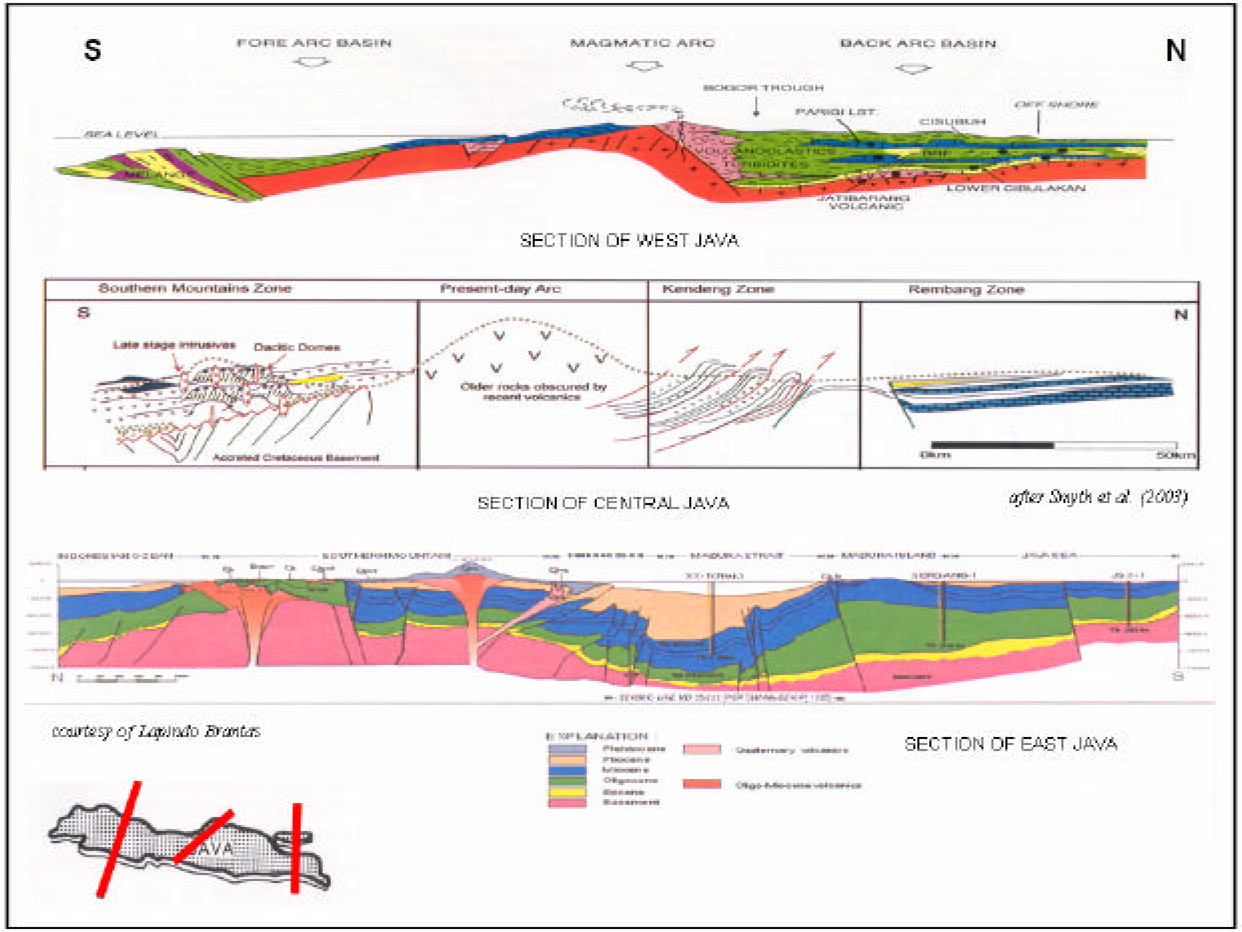


Figure 3 - Sections across Java for western, central, and eastern parts showing the configuration of three basic elements including northern shelf/platform, deepwater area of Bogor-Kendeng-Madura Strait in the middle, which was intensively thrusted in the Kendeng Zone, and uplifted volcanic arc and its southern slope in the south.

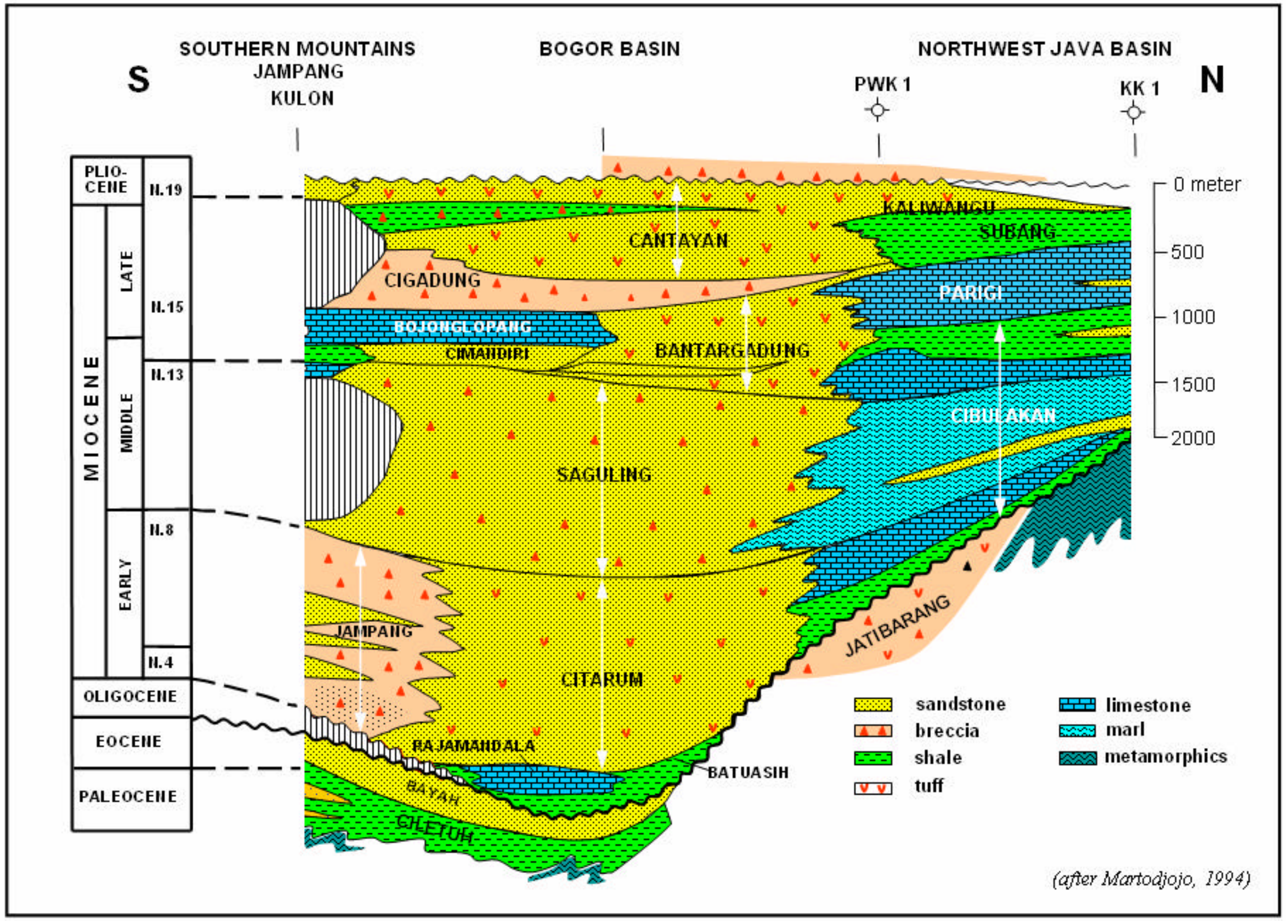


Figure 4 - Section across West Java showing stratigraphic comparison of the Southern Mountains, Bogor Trough/Basin, and Northwest Java Basin. Deepwater sedimentation took place in the Bogor Basin. The Bogor Basin is mainly composed of volcaniclastic sediments. The Southern Mountains were significantly more uplifted than the NW Java Basin, making the Bogor Basin more volcaniclastic than siliciclastic.

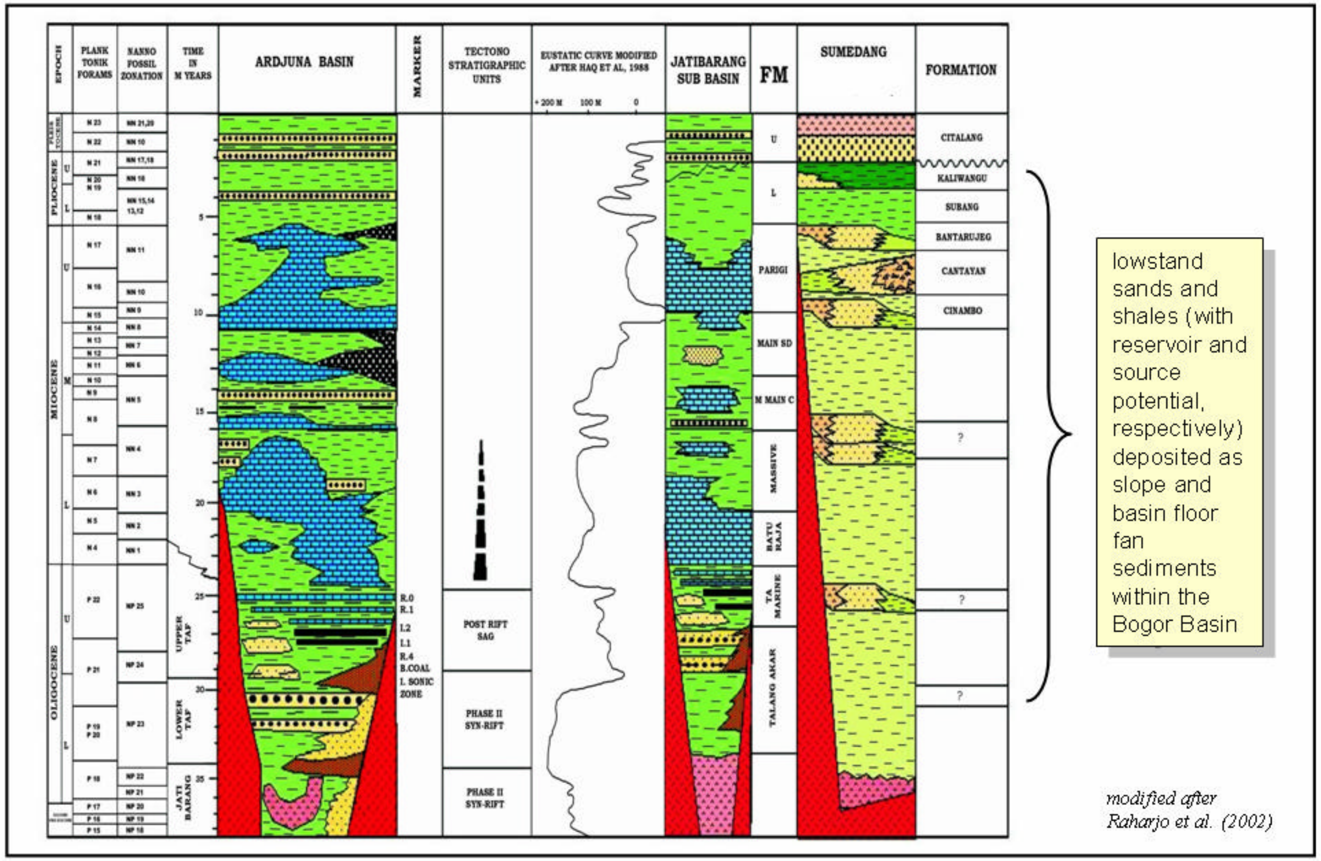


Figure 5 - Stratigraphic column of the Sumedang area in the Bogor Trough/Basin and the comparison with the Arjuna and Jatibarang sub-basins. Coarse clastics in the Sumedang area are considered to originate from erosional products of the Jatibarang Sub-basin during lowstand sea levels as can be seen on the eustatic curve. Significant erosional periods occurred in the mid-Oligocene, early to middle Miocene, and middle to late Miocene. The Cinambo, Cantayan, and Bantarujeg sands in the Sumedang area are considered to originate from erosion of Cibulakan and Parigi Formations. Older and deeper sands produced from erosion of Baturaja and Talangakar maybe present at depth.

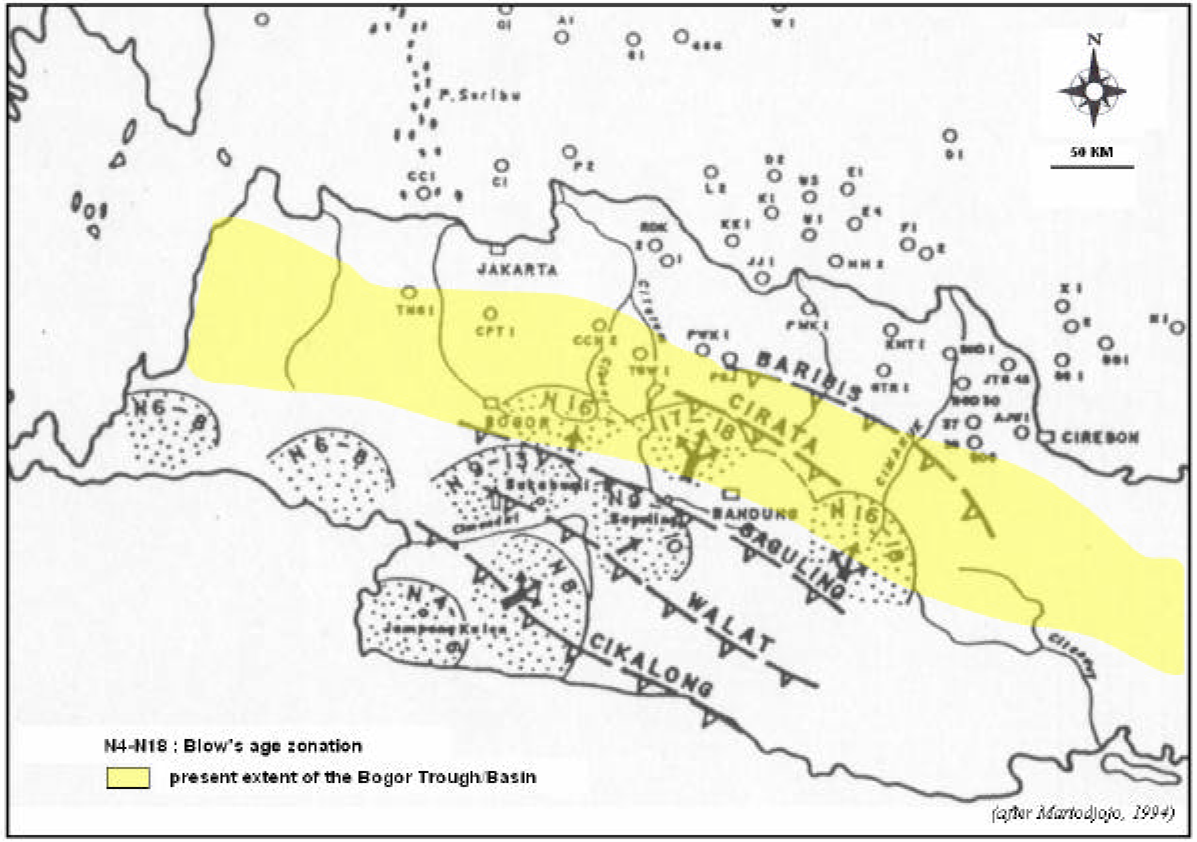
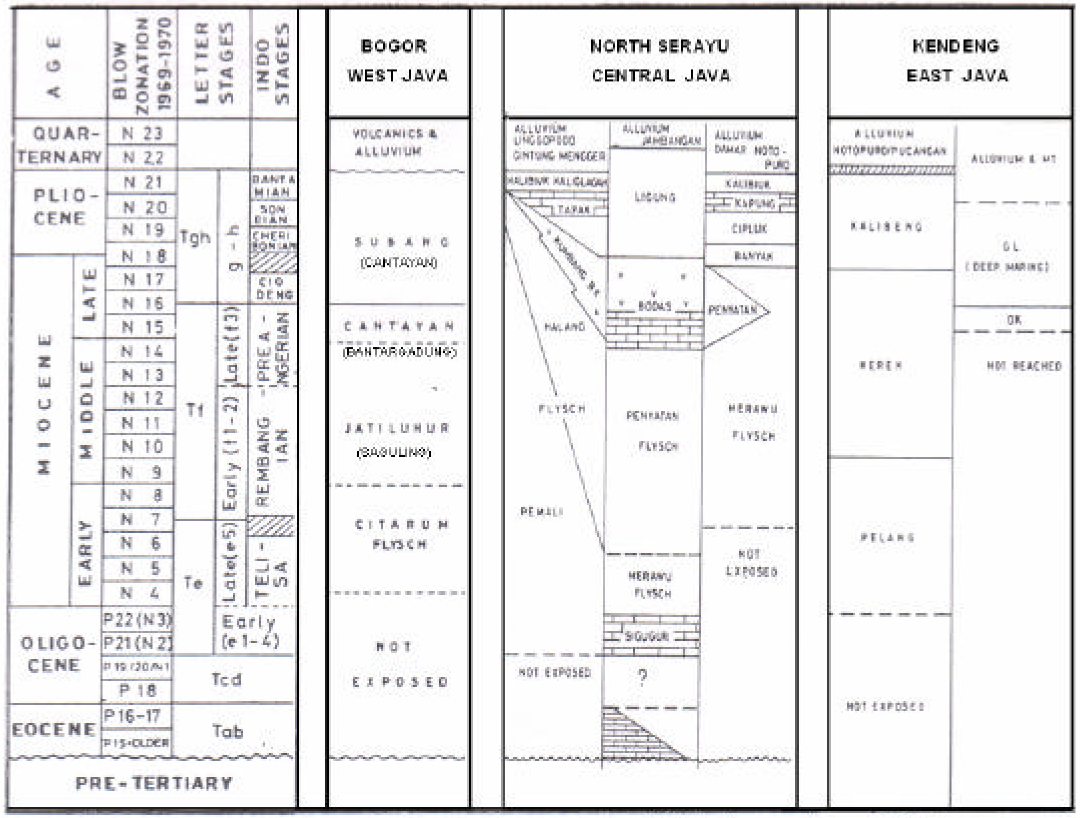


Figure 6 - Migration of thrust fronts and prograding turbiditic volcaniclastic submarine fans in West Java. The extent of the Bogor Trough/Basin was initially broader to the south before it was uplifted and deformed from time to time by northward migrating thrust fronts. The Baribis Fault is an inverted normal fault currently partly bordering the NW Java Basin and the Bogor Basins.



modified after Sujanto and Sumantri (1977), formation names in parentheses in Bogor West Java are after Martodjojo (1994)

Figure 7 - Comparison of the stratigraphic succession of the Bogor-North Serayu-Kendeng Trough/Basins. Deepwater sedimentation took place during the Miocene and mostly until the Pliocene. The sediments show turbiditic characteristics and are mainly volcaniclastic and calcareous in nature.

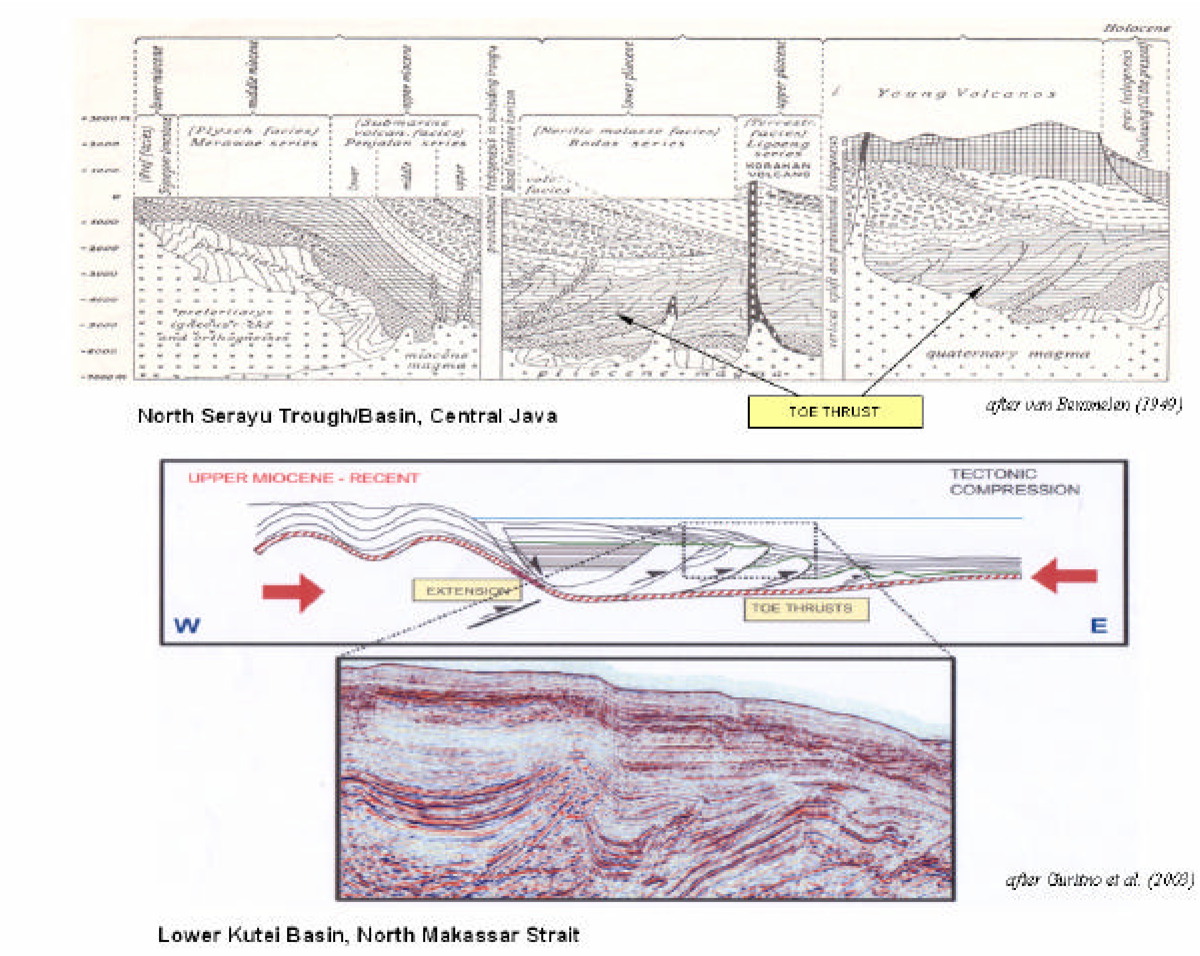


Figure 8 - Schematic section across North Serayu Trough/Basin, northern Central Java showing the evolution of subsidence from Miocene to Holocene. Middle Miocene Merawu turbiditic volcaniclastics and older formations were deformed as toe-thrust systems related to subsidence. This kind of structure can play as hydrocarbon trap like those of the Lower Kutei and North Makassar Basins illustrated below.

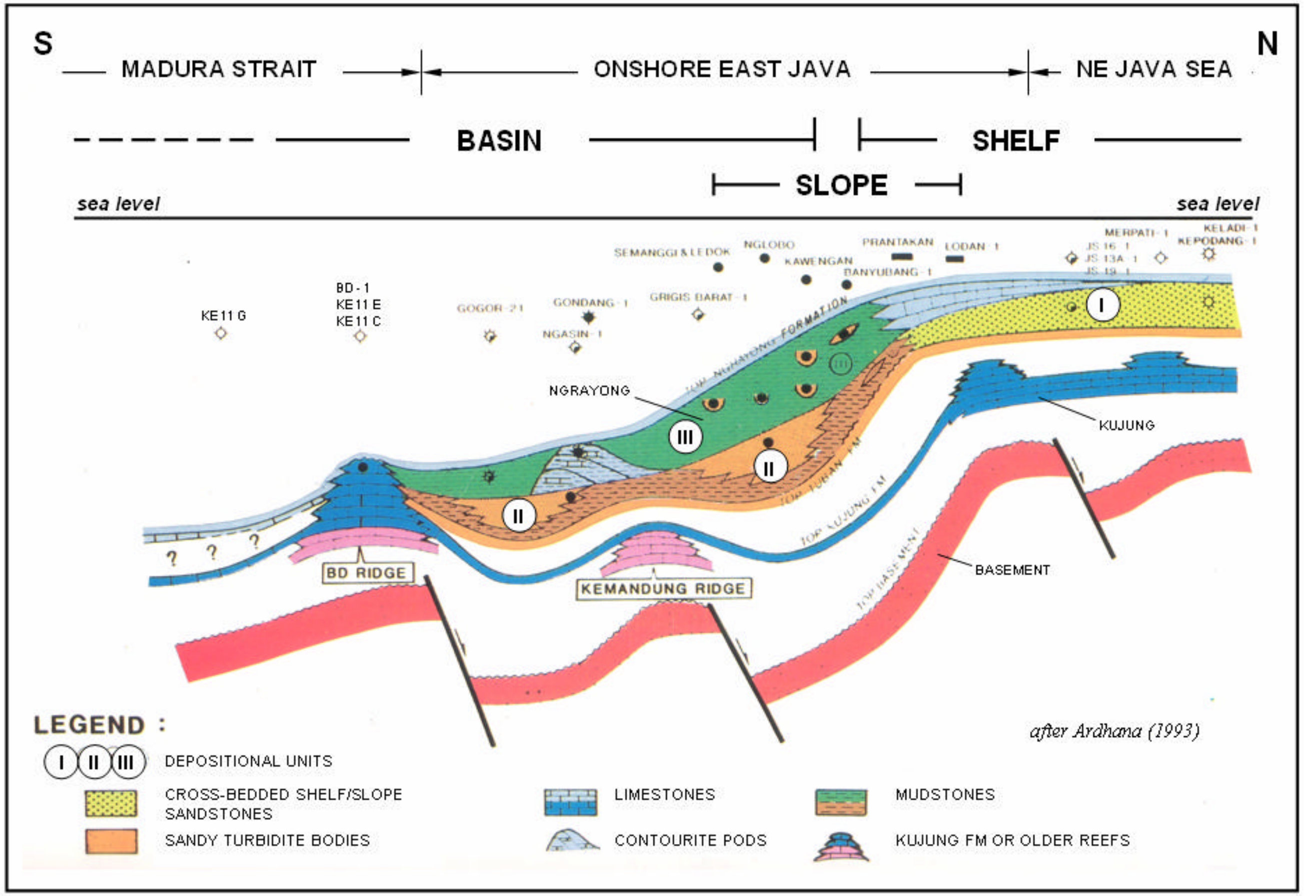


Figure 9 - Schematic section showing depositional environments of the Ngrayong sediments from shelf through slope to basin areas. Three depositional units are indicated. Unit I is shallow beach to marine deposits, Unit II and III are turbiditic deposits of deepwater sedimentation. Underlying Oligo-Miocene Kujung carbonates and Pre-Tertiary Basement is also indicated.

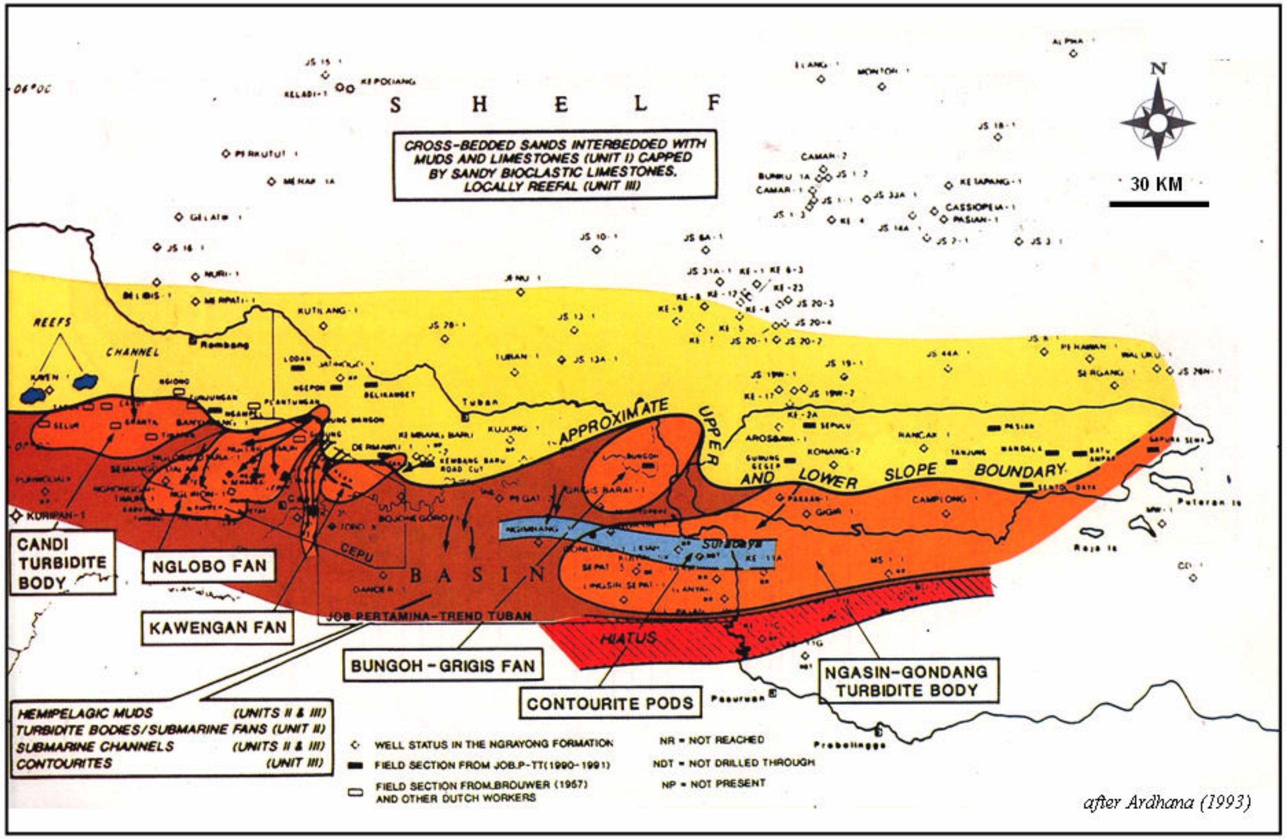


Figure 10 - Paleogeography of the Middle Miocene Ngrayong deposition in the East Java Basin showing various depositional facies including shelf to upper slope in the north and submarine turbiditic fans and contourite pods in the south. A number of turbidite bodies and submarine fans are identified, deposited on slope and basin floor with hemipelagic muds.

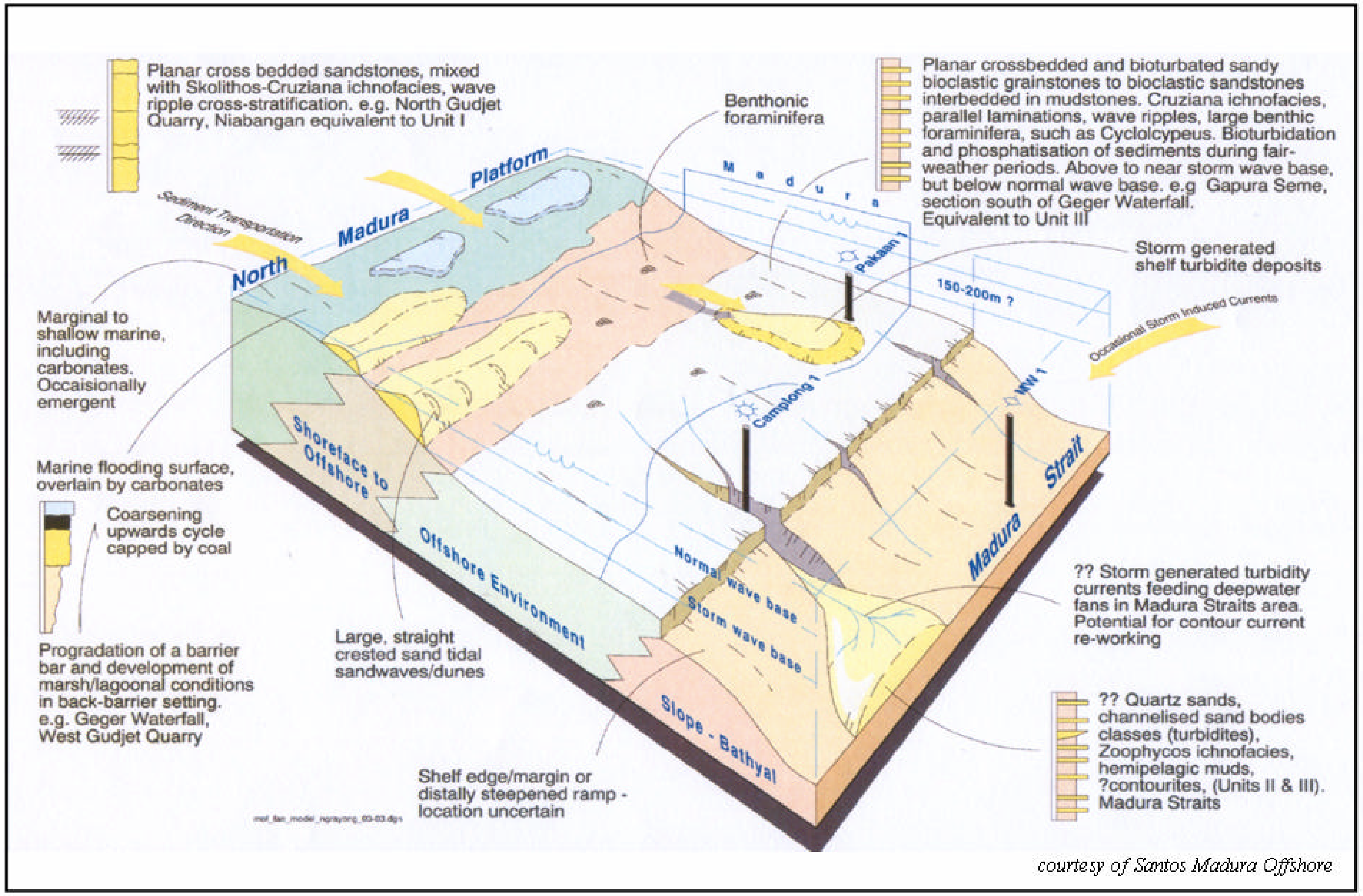


Figure 11 - Deposition model of the Middle Miocene Ngrayong sediments from the North Madura Platform to the Madura Strait including depositional environments/facies from nearshore to bathyal. Wells Camplong-1 and Pakaan-1 are now located on the uplifted Madura Island. Sedimentologic succession of each facies is indicated.

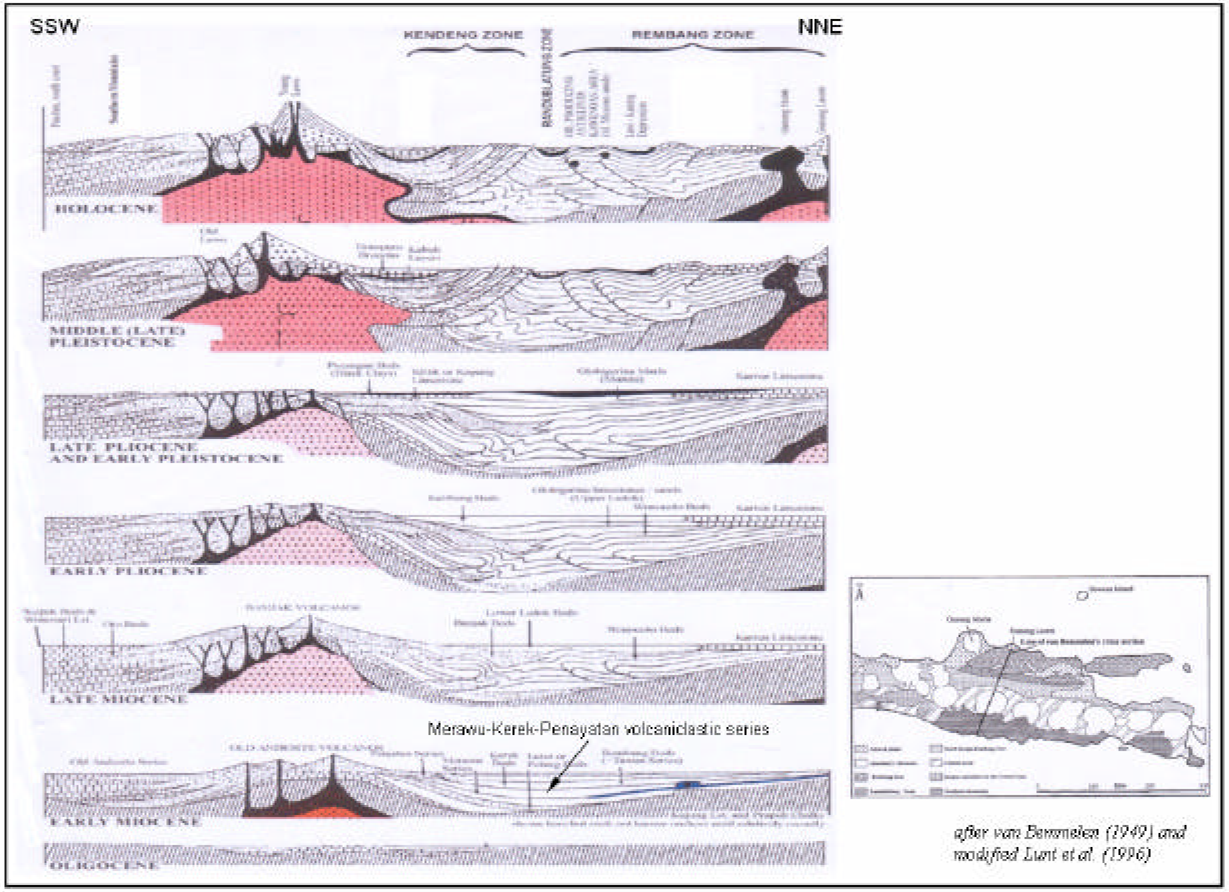


Figure 12 - Schematic sections across the Kendeng, Randublatung, and Rembang Zones, East Java showing the evolution of the zones. Deepwater sedimentation within the zones took place during the Miocene and Pliocene. The sediments were sourced from uplifted areas in the north and south. In the Pleistocene the zones were uplifted and deformed. Opposite thrust vergency between the Kendeng and the Rembang Zones could form a triangle zone within the Randublatung Zone.

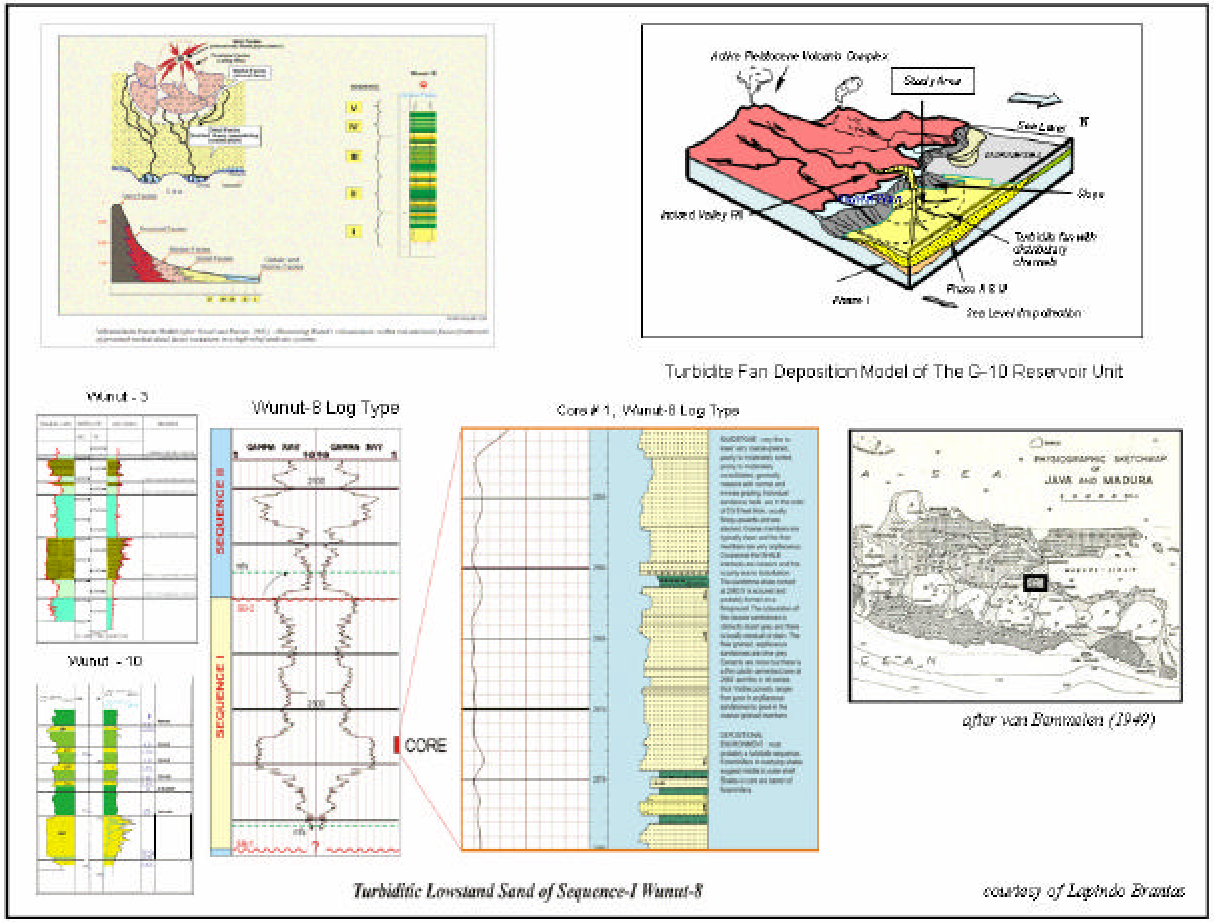


Figure 13 - Composite figures showing the sedimentology and reservoir characteristics of the Wunut gas field, 30 kms south of Surabaya, reservoired by turbidite volcaniclastic sandstones in its lower part. The field proves the prospectivity of the turbiditic volcaniclastic sandstones in the Kendeng Zone.