IPA03-G-021

PROCEEDINGS, INDONESIAN PETROLEUM ASSOCIATION
Twenty-Ninth Annual Convention & Exhibition, October 2003

GEOCHEMISTRY OF THE EAST JAVA BASIN: NEW OBSERVATIONS ON OIL GROUPING, GENETIC GAS TYPES AND TRENDS OF HYDROCARBON HABITATS

Awang Harun Satyana*
Margaretha E.M. Purwaningsih**

ABSTRACT

Highly significant oil and gas accumulations have been discovered recently in the East Java Basin, turning the area into the "hottest spot" for hydrocarbon exploration in Indonesia. These discoveries, fortunately, are commensurate with the fast growing fuel consumption in the East Java Province. Accordingly, hydrocarbon exploration in the basin has been aggressively enhanced.

Despite the recent significant discoveries, there are still many uncertainties concerning aspects of petroleum geochemistry in the basin. This paper summarizes a recent regional study of the geochemistry and habitat of oil and gas in the East Java Basin. It was envisioned that a better understanding of the basin's oil and gas geochemistry would aid exploration activity. During the study, geochemical data of oil, gas, and source samples comprising physical to molecular properties from around 100 wells and seeps of the onshore and offshore areas of the East Java Basin were interpreted using various geochemical crossplots and methods. The habitats of oil and gas are examined by synthesizing the results of geochemical evaluation with geologic framework of the basin.

It is shown from the oil geochemistry study that most oils were derived from sub-oxic to oxic terrestrial to marginal marine source facies (class "D"). The Paleogene Ngimbang, Lower Kujung, and Lower Tuban shales and coals are the inferred source rocks for the oils. Offshore oils have a more terrestrial signature than those of onshore. The source of offshore oils is thought to have sourced by older sources than those of onshore.

Based on gas geochemistry study, three genetic types of natural gases have been identified in the East Java Basin, they are: thermogenic, biogenic, and mixed thermo-biogenic gases. The thermogenic gases were sourced by the Paleogene sources, whereas the biogenic gases were sourced by the Miocene to Pleistocene Tawun to Lidah shales and coals. The study also evaluated the amount of CO_2 gas pollutant, identified areas with high CO_2 gas content, and investigated the origin of CO_2.

Four trends of habitats are recognized: the Ngimbang, Kujung, Ngrayong, and Tawun-Mundu Trends. It is within these trends that hydrocarbon prospectivity of the East Java Province is situated.

INTRODUCTION

The East Java Basin is one of the earliest basins in Indonesia to start being explored in the late 1800s. The basin has produced oil and gas for 114 years and been explored for 130 years. However, even today, the basin is still very attractive for exploration (Satyana and Darwis, 2001; Satyana, 2002a). Recent discoveries, fortunately, are commensurate with the region's fast growing fuel consumption (Luthfi et al., 2003). Therefore, the basin is currently the "hottest spot" for hydrocarbon exploration in Indonesia. Figure 1 shows the oil and gas fields of the basin.

As a mature basin, geochemical data of oil, gas, and rock samples, are abundant. Available published geochemistry include studies those of Russel et al. (1976) for selected crude oils and their source rocks in the East Java Sea and from Phillips et al. (1991) on the origin of hydrocarbons in the Kangean area, offshore northeast Java Sea. Recent publications on the geochemistry of the East Java Basin are from Purwanti and Bachtiar (2001) discussing the

---

* **BP Migas**
** **Anadarko Indonesia**

volumetrics of the Eocene kitchen and a paper by Satyana and Purwaningsih (2002) discussing a regional evaluation of oil and gas geochemistry of the East Java Basin both onshore and offshore, and their habitats. This paper is an update of Satyana and Purwaningsih's (2002) paper.

The study was based on abundant published and unpublished data of more than 100 wells and seeps (86 oils, 35 gases, and 57 rock samples from onshore and offshore areas). The objective of the paper is to understand regional geochemistry of oil and gas and to define their habitats.

GEOLOGIC SETTING

Located at the southeastern margin of the Sundaland Craton, the East Java Basin has had an active geodynamic history. The basin changed from an oceanic basin located to the south of a subduction zone in the Late Cretaceous, to the present day backarc basin lying to the north of the volcanic arc. Three main structural configurations can be established from north to south: the Northern Platform, the Central Deep, and the Southern Uplift (Satyana, 2002b).

The basement of the East Java Basin was segmented into a number of horsts and grabens trending roughly southwest-northeast. The segmented basement accommodated deposition of the Paleogene synrift and postrift sediments as well as carbonate development. The rocks include pre-Ngimbang non-marine siliciclastic, non-marine to marginal marine rocks of early to middle Eocene Lower Ngimbang, Late Eocene to Early Oligocene Upper Ngimbang and "CD" shales and carbonates, and late Oligocene to early Miocene Kujung siliciclastics and carbonates.

The time of peak carbonate sedimentation was during the Early Miocene when the Kujung I/Tuban/Lower OK, and Rancak Formations were deposited. Inversion affected the basin from the Middle Miocene. The Ngrayong sands/Upper OK and base Wonocolo Members were deposited in the lower early Middle Miocene. Up to Pliocene times, transgressions and regressions were associated with deposition of the Wonocolo, Mundu, Paciran, and Lidah Formations consisting of shales, sandstones, carbonates and some coals. Volcaniclastic sediment influx peaked during the Plio-Pleistocene.

Two principal structural trends of Tertiary origin can be distinguished: a Paleogene northeast-southwest extensional fault trend and an east-west sinistral wrench fault trend known as the Rembang-Madura Kangean (RMK) or Sakala Fault Zone (Manur and Barraclough, 1994; Satyana, 2002b). During the Plio-Pleistocene most of the areas became emergent and this situation continues to the present day.

OIL GEOCHEMISTRY

Database and Interpretation Methods

Geochemical data from a total of 86 oil samples (49 onshore, 37 offshore) and 57 rock samples (31 onshore, 26 offshore) have been compiled for this study. Some of the oil database can be found in Tables 1. The data have been grouped together based on the most common properties including: API gravity, sulfur content, carbon-13 isotope, pristane/phytane, oleanane/hopane, hopane/sterane, and C_{27}-C_{29} sterane contents, which allows an interpretation of source facies, maturation, and oil alteration. Interpretation of oil properties, grouping, maturation, alteration, and expected source is mainly based on geochemical cross plots. A method of "geochemical inversion" (Bissada et al., 1992) was used in the study to expect source from oil properties. Hierarchical cluster analysis resulting in dendrogram showing oil groupings was not performed in this study. Further study is suggested to include this.

Oil Occurrences

Four geological domains can be distinguished for the oil occurrences in the East Java Basin (Figure 1). The four oil domains are: the Cepu-Bojonegoro area, the Surabaya area, the Madura area, and the North Madura Sea area. The Cepu-Bojonegoro area includes the old fields discovered during the late 1800s to early 1900s producing oils from the middle to late Miocene Ngrayong sandstones forming faulted anticlines such as : Wonocolo-Kawengan, Ledok, Nglobo and Metes fields. Recently discovered fields producing oils from the Oligo-Miocene Kujung reefs like Mudi Sukowati, and Banyu Urip fields are also included in this area. The Surabaya area includes the old fields producing oils from the Ngrayong sands, such as Kuti (the first discovered oil field of the East Java Basin in 1888), Kruka, Lidah, and Sepat. The Madura area include the old fields in the same trend with those of the Cepu and Surabaya areas, like Lerpak, Tanjung, and

Kertegeneh fields. The North Madura sea area include all fields reservoired by the Kujung carbonate reefs like: Camar, Poleng, KE-23, KE-40, KE-5, Ujung Pangkah, Bukit Tua, Jenggolo, Payang, and all discovery wells containing oils in the Paleogene reservoirs from Ngimbang sands to Rancak carbonates.

Analyses of Oil Properties

Based on GC (gas chromatograph) and GC-MS (gas chromatograph-mass spectrometry) and results of geochemical cross-plots, there are slight differences in the properties of the onshore and offshore oils. Onshore oil samples show API (density of oil) 8-69º average 29º, sulfur 0.02-0.68 wt.% average 0.19 wt.% (Figure 2), average saturate and aromatic content of oil are 61 % and 29 %, respectively. Offshore oil samples show API 10-58º average 36º, sulfur 0.01-0.70 wt.% average 0.24 wt.%, average saturate and aromatic content of oil are 59 % and 23 %, respectively. The variation seen in API gravities may be due to the effects of water washing or biodegradation and degree of maturation. The unaltered East Java oils are all paraffinic waxy to moderately waxy (pour point 40-90º F), medium to medium high API (30.9 to 41.3º), low to medium sulfur crude oils (< 0.50 wt% S). Biodegradation to some degrees occurs in fields located at the Cepu and Surabaya areas.

Gas chromatograms of East Java oils show pronounced waxy alkanes of C_{20} and above, indicating derivation from land plants. Pristane/phytane ratios of the oils are roughly similar (average 4.97 for onshore oils, 5.36 for offshore oils) (Figure 2) and are interpreted as a terrestrially derived type III kerogen from a moderately oxic environment (Figure 3).

Figure 4 shows carbon isotope data plot of the saturate and aromatic fractions of the oils showing little difference between the oils. Average stable carbon isotope ratios for saturated and aromatic hydrocarbons of onshore oils are -26.91‰ and -25.65 ‰, respectively. Average stable carbon isotope ratios for saturated and aromatic hydrocarbons of offshore oils are -27.4 ‰ and -25.6 ‰, respectively. The carbon isotope data suggests all the oils are derived from the same or similar source rocks/organic facies with offshore oils more terrestrial. The carbon isotope data is in an intermediate range and consistent with generation from a mixed terrestrial/algal organic facies.

The GC data on the unaltered oils is very similar for all the oils. The wax content in the oils is variable but is generally moderately high to high (nC31/nC19 often > 0.30). Figure 5 shows the GC data of onshore and offshore oils. The oils show a cyclic hump in the C13-C15 range interpreted as showing significant angiosperm terrestrial resin input to the oils. The GC scans for the oils are fairly typical of Indonesian oils sourced from fluvio-deltaic shales and coals containing a mainly terrestrial/minor algal organic facies (Robinson, 1987).

A visual comparison of triterpane (m/z 191) and sterane (m/z 217) distributions shows close similarities between the oils. This is suggestive of them both being generated from the same or very similar source rocks. The relatively minor differences in biomarker between the oils may reflect organic facies variation in the source rocks rather than generation from a distinctly different source rock unit. The biomarker composition of oils suggest generation from a predominantly terrestrial/minor algal organic facies. All the data is consistent with deposition of the source rock in a fluvio-deltaic to near shore marine environment. The high 18a oleanane content is suggestive of angiosperm resin input. A C_{24} tetra cyclic content is indicative of significant terrestrial input. Low concentrations of tricyclic terpanes and relatively low concentrations of C27 steranes (average C_{27}/C_{29} steranes for onshore oils 1.04 for offshore oils 0.36) show only minor or moderate algal input. High hopane/sterane ratios are typical of predominantly sub-oxic to oxic terrestrial sourced oils. Figure 6 shows C_{27}-C_{28}-C_{29} ternary plot of East Java's oils. It is inferred that although there is a continuum in the source type of oil, the offshore oils are more terrestrial in origin, whereas the onshore oils are more marine.

Oil Grouping

In order to simplify the understanding of crude oil composition, it is useful to classify oils into distinct groups. The study used a classification developed by the BP Research Center (1991 - unpublished) which enables oils to be put into one of five categories: A, B, C, D, or E, depending upon their bulk properties.

Oils in classes A and B are both derived from a mixture of algal and bacterial remains which have accumulated in marine environments; the difference is in the associated lithology – either clastic (B) or non-clastic (A). Class C oils are sourced from mainly algal organic remains with some bacterial input. This type of organic matter is often found in lacustrine environments where green algae are a major contributor to the kerogen. Classes D and E represent kerogen derived mainly from higher land plants. Such organic matter is oil prone if it contains hydrogen rich components such as waxes from cuticle or resin from leaves and trunks. Class D source material differs from class E in having a higher proportion of resin and examples are found in many Indonesian source rocks.

A total of 41 onshore and 39 offshore oils were examined for their grouping using bulk and molecular properties of sulfur content, nitrogen, wax, nickel, vanadium, API degree, saturate content, and pristane/phytane supported by cross plots derived from molecular properties. The examination showed that most East Java oils fall under classification or group "D" oils meaning that kerogen derived from higher land plant in marginal marine - deltaic or paralic environments sourced the oils. Onshore and offshore oils are slightly different. Offshore oils were more terrestrial and oxic than those of onshore oils. Offshore oils are classified as "D_I" and onshore oils are classified as "D_{II}".

Source Identification

Geochemical Inversion method (Bissada et al., 1992) was used for source identification. Geochemical inversion utilizes the chemical characteristic of any encountered hydrocarbons to infer the possible character, maturity and identity of the potential source system. From these conclusions it is then possible to make specific inferences about the depositional environment, age, identity and location of the hydrocarbon source sequence.

The East Java oils are typically waxy, leading to the conclusion that they were derived from non-marine source rocks. All of the oils thus far identified contain properties associated with terrestrially derived kerogen. The results of bulk properties, gas chromatography, carbon isotope, and GC-MS biomarker analyses indicate that the oils are all very similar and probably generated from fluvio-deltaic shales and coals containing mainly terrestrial/minor algal organic facies. Possible sources for the oils are non-marine to marginal marine of shales and coals of the middle-late Eocene Ngimbang/pre-Kujung, late Oligocene Lower Kujung, and the early Miocene Tuban formations.

Separation into discrete source is difficult because more or less similar kerogen types are found throughout the source section. However, age-related biomarkers may give a clue to this problem. Oleanane/(oleanane + hopane) ratios over 0.20 in oils are diagnostic of Tertiary source rock (Peters et al., 1999). Oleanane is a biomarker derived from angiosperms (flowering plants) that originated in the Cretaceous but did not dominate the land until the Tertiary. Angiosperms increasingly predominated through the Tertiary (Peters et al., 2000). Hence, the oil derived from the Early Tertiary land plant will be lower in oleanane content than oils sourced from Miocene deposits. In this study, the ratio of oleanane to hopane has been used to distinguish the sources from the middle Eocene Ngimbang and from the early Miocene Tuban shales and coals. Oleanane/hopane of onshore oils are 0.05-3.04, averagely 0.85; for offshore oils are 0.04-0.95 and 0.26, respectively. It is suggested that the onshore oils were derived from younger source than those of offshore areas. Figure 7 shows this for the case of KE-23 (offshore) and Kawengan (onshore).

Based on geochemical oil data including bulk physical, carbon isotopic, and molecular properties, and stratigraphic setting of the East Java Basin it is considered that the Ngimbang and Lower Kujung shales and coals are the main sources of the offshore oils and the Lower Kujung and Lower Tuban shales and coals are the main sources of the onshore oils.

Source Facies

The results of source analysis on a number of wells reveal that the Paleocene-Eocene pre-Ngimbang, middle Eocene Ngimbang, Oligo-Miocene Kujung, Early Miocene Tuban, and middle Miocene Lower OK shales and coals have potential to be the sources of the East Java oils and thermogenic gases. Some of the source database can be seen in Table 2.

Results of analyses from limited data in Pagerungan show that the pre-Ngimbang has fair-excellent source rock potential with TOC 0.96-8.03 %. Non-marine shales of the Ngimbang Formation have been long recognized as proven source rocks in the East Java Basin. These organically rich shales with interbedded coaly layers are expected to be good non-marine oil source rocks containing both algal and terrestrial kerogen. TOC data of Ngimbang shales range from 1.64-5.67 % with coals ranging between 62-67 %. No coal is observed in the onshore wells. The Lower Ngimbang Formation was deposited in a variety of non-marine environments that pass upward into a more marine environment. The Lower Ngimbang Formation is more likely to generate more gas and light-end oils having dominantly kerogen type III, whereas the Upper Ngimbang Formation is more oil-prone having kerogen type II from marine sediments. The marine Upper Ngimbang Formation has much poorer source quality than the Lower Ngimbang Formation.

Based on several geochemical analyses, the Early Oligocene CD Formation has TOCs up to 12 % for shale and 57 % for coal (Rembang-1 well). The organic matter is predominantly composed of terrestrial derived humic kerogen type III. The source potential of the Kujung Formation is confined to coals and carbonaceous shales of the Kujung II and Kujung III. Although the Kujung Formation was deposited predominantly in a marine environment, the kerogen is mostly terrestrially derived and contains biomarkers from higher plants. TOC values in the Kujung Formation range from 0.14-3.93 %. Extreme TOC values occur in Rajawali-1 (5.7 %) and Bawean-1 (17 %) samples. Offshore samples generally have higher TOC values. The Kujung III source is composed of predominant terrestrial origin humic kerogen type like in Central Deep and some sapropel, alginate and cutinite kerogen types in East Bawean Trough. The Kujung II shale and coals contain moderate to good organic contents in the deeper portion of the basin/trough and poor to moderate organic carbon contents towards the highs. The Early Miocene Kujung I in its deeper facies (predominantly a limestone with shale interbeds) shows good source rock potential of up to 1.7 % TOC. The Tuban Formation shales contain relatively high levels of TOC values in basinal areas both north and south of the shelf edge. In the Central Deep, Tuban shales contain sufficient TOC to be regarded as potential source rocks. JS 33A-1 contains Tuban claystones with up to 2.25 % TOC. On the Madura Island, TOC values reach 2.45 % in Camplong-1 well. The kerogen type is a terrestrial organofacies with some marine influence. The Middle Miocene Lower OK Formation is composed of predominantly interbedded sands and shales with coal especially in highs, which have excellent organic carbon contents with TOC up to 8.07 %.

GAS GEOCHEMISTRY

Database and Interpretation Methods

There is no previous publication on the geochemistry of gas from East Java. A total of 35 gas data have been compiled for this study derived from gas seeps (13 seeps), gas fields, and gas discovery wells. Geochemical gas data consist of hydrocarbon (C_1 to C_{7+}) and non-hydrocarbon (CO_2, H_2S, N_2) gas compositions and isotope data of carbon (C_1-C_4, CO_2) and of deuterium (D). The interpretation is based on various correlation and characterization plots. Some of the gas database can be seen in Table 3.

Gas Occurrences

Generally, gas has multiple formation mechanisms. The mode of formation is reflected in a gas bulk and molecular geochemistry (Rice and Claypool, 1981; Schoell, 1983; Hunt, 1996; Katz, 2002).Three genetic types of natural gases can be distinguished in the East Java Basin: (1) thermogenic gases which are commonly associated with oil and are produced predominantly from Miocene and older reservoirs, (2) bacterial/bacteriogenic/biogenic gases which are found predominantly in the Pliocene-Pleistocene reservoirs, and (2) mixed gases of thermo-biogenic origin which are predominantly present in reservoirs of late Miocene age, but also are found in older and younger reservoirs. Figure 8 shows the gas data crossplot defining genetic types of gases for thermogenic (like Kedung Tuban and Rembang), biogenic gases (like Terang-Sirasun and Kepodang), and mixed like Oyong.

Thermogenic gas accumulations are distributed across the basin from west to east and north to south (Figure 9). The Pagerungan and West Kangean Fields constitute the easternmost accumulation around the Kangean Islands. The gases occur in the Eocene pre-Ngimbang and Ngimbang sands. BD gas is the southernmost accumulation, located to the south of Madura Island, reservoired in early Miocene Kujung I. Mudi, Sukowati, Banyu Urip, Kedung Tuban, and Rembang gases at the Cepu High accumulated in the

Oligo-Miocene Kujung carbonates. Suci gas, from the northern onshore East Java area, is reservoired within the Ngimbang carbonate. KE 5, KE 40, KE 23, Bukit Tua, Jenggolo, and Payang fields, in the East Java Sea to the north of Madura Island, form the northernmost known gas accumulation and are reservoired within the Kujung and Rancak carbonates. These thermogenic gas fields occur both as non-associated and associated gas. Condensates are generally produced from these fields in addition to gas.

Occurrences of biogenic or bacterial gas fields and discovery wells form two belts. These are : (1) the South Madura Belt consisting of Maleo, MDA, Terang-Sirasun-Batur-Kubu, and (2) Muriah-Bawean Belt consisting of Kepodang Field and recent discoveries close to the Bawean Island (Titan and Calypso). The reservoirs containing biogenic gas are in middle Miocene Tawun to early Pliocene Mundu and Paciran sands and carbonates.

Mixing between the thermogenic and biogenic gas is observed in the Surabaya-Madura Strait Belt such as in the Oyong Field, south of Madura Island, and in the Wunut Field to the south of Surabaya. The mixed gas is reservoired within a Plio-Pleistocene volcano-clastic reservoir. Mixing is also observed in the Muriah-Bawean Belt in the Kepodang Field.

Thermogenic Gas Properties

Thermogenic gas accumulation occurs as non-associated gas in Pagerungan, Kedung Tuban, and Rembang; and as associated gas in Sukowati and KE-23. The Pagerungan gas has a methane composition of 94.24 % with C_{2+} gas of 5.76 %. This composition is suggestive of thermogenic gas. No carbon isotope analysis has been done on the Pagerungan gas, but modeling (Phillips et al., 1991) suggests the gas was generated at high maturity levels consistent with a thermogenic origin. Condensates are produced. The condensate has an API of 53.6°, sulfur of 0.01 % and $\delta^{13}C$ whole oil of –25.8 ‰. The Pagerungan condensate is considered as a mixture of oil dissolved in a high maturity non-associated gas suggestive of a fluvio-deltaic source rock (coals and carbonaceous shales). Kedung Tuban non-associated gas was analyzed for its composition and carbon isotope. The methane content is 92.53 % and C_{2+} gas is 7.47 %. The carbon isotopic value of the methane is of -37.5 to –35.5 ‰ indicating a wet thermogenic origin. The Kedung Tuban condensate has an API of 41.2°, sulfur below 0.1 %, a saturate content of 95 %, pristane/phytane 5.51, $\delta^{13}C$ saturate of –25.29 ‰ and an aromatic content of –23.77 ‰. Based on these values a fluvio-deltaic source is inferred. The low API for condensate and very high saturate content indicate that the condensate is a product of fractionation, or that the retrograde condensate resulted from fractionation during migration rather than expulsion from a very mature source. The condensate was generated from maturity Ro of 0.59 % (calculated Ro from methyl phenanthrene index). The Rembang non-associated gas has a methane content of 86.35 % and C_{2+} gas values of 13.65 %. Data of $\delta^{13}C_{C1}$ ranges from –39.80 to -33.84 ‰ and δD_{C1} of –152 to -145 ‰, suggesting a wet thermogenic origin. Rembang produces condensate, which is unusual in its light hydrocarbon content. These condensates exhibit evidence of light n-alkane depletion and relative enhancement in aromatic compounds, and to a lesser extent cyclic compounds. It is inferred that these condensates result from fractionation of normal oil as a result of gas migration into the reservoir.

Associated gases in East Java Basin occur in oil fields, such as Sukowati, Mudi, Banyu Urip, KE-23, KE-40, Bukit Tua, and Jenggolo fields. Geochemical data from Sukowati are representative of these associated gas accumulations. Sukowati gas contains 72.83 % methane with C_{2+} of 27.17 %. The field produces oil with an API of 37.2°. KE-23 associated gas has 85.78 % methane, 8.41 % ethane, or C_{2+} of 14.22 %. The wet gas component is up to C_{10}. The KE-23 field produces oil with API 46.1°, a sulfur content 0.03 % and wax 1.12 %.

Thermogenic gas characteristics suggest that the sources are non-marine to marginal marine sediments of Ngimbang, Lower Kujung, and Lower Tuban shales and coals.

Biogenic Gas Properties

Kepodang and Terang-Sirasun Fields and some gas seeps in the western Cepu area contain biogenic gas which is representative of biogenic gas in the East Java Basin. In the Kepodang Field, gas in the middle Miocene Tawun Formation has a dominant methane (C_1) component (average 99.82 %), C_{2+} is average 0.18 %. Isotopic carbon-13 and deuterium of the methane ranges from -67.31 to -67.42 ‰ and -197 to -198 ‰, respectively. Based on the strong predominance of methane over the C_{2+} gases, and isotopic analysis of the methane component it is inferred that the gas is predominantly biogenic in origin. However, the gas in the lower Miocene Prupuh Formation is richer in wet gas (C_{2+} 1.46 %) and ^{13}C (-58.93 ‰) suggesting the presence of a low maturity thermogenic component. The gas reservoired in the Pliocene Paciran limestones of the Terang-Sirasun Field contains over 99.5 % methane, and has a gas gravity of 0.56. Based upon stable isotope ratios (isotopic carbon-13 and deuterium of the methane are -65.0 ‰ and - 185 ‰, respectively) it is considered that the gas has been generated exclusively by bacterial processes (Basden et al., 2000). Biogenic gas is also inferred for the Wonolelo seep in the western Cepu area. It is composed of 100 % methane with $\delta^{13}C_{C1}$ of -70.80 % and δD_{C1} of -320 ‰. Recently discovered gases in the Oyong and Maleo fields (Santos) located in the Madura Strait are also considered to be biogenic gas. The gases are reservoired in the Early Pliocene Mundu globigerinid limestones. The low gas gravity of 0.63 and its occurrence in Pliocene reservoirs may show its biogenic origin. Biogenic gases in the middle Miocene to Plio-Pleistocene reservoirs were sourced from the coeval shales and coals of the Tawun, Wonocolo, Mundu, Paciran, and Lidah Formations. The primary source beds for the Terang-Sirasun biogenic gas are claystones and other fine-grained lithologies that are interbedded within the reservoir section. TOC levels in these source beds are about 1 % and the organic matter was derived predominantly from land plants (Basden et al., 2000).

Mixed Thermo-Biogenic Gas Properties

Mixing between biogenic and thermogenic gas occurs commonly. Where mixing occurs it is usual for biogenic gas to fill the shallower reservoirs, whereas thermogenic gas will fill the deeper reservoirs. Wunut gas field (Lapindo Brantas) to the southwest of Surabaya provides an example of this. The field is composed of ten productive zones. Gases charged these zones with gas gravity becoming heavier downwards ranging from 0.55 to 0.63 g/cc, more viscous downwards from 0.0121 to 0.0148 cp, and higher BTU downwards from 966 to 1103 (Kusumastuti et al., 2000). These show that the gas is more thermogenic downward. Gas composition data from Wunut-2 shows that the methane content decreases downward from 97.43 % at depth of 1900 ft to 85.36 % at depth 2767 ft, and that associated wet gas increases from 0.56 to 13.33. Wunut-1 data show methane contents of 99.87 % at depths of 1019 ft, and 93.23 % at depth 2022 ft. Stable carbon isotope analysis was performed on Wunut-1 gas (not available to this study) and generally confirmed a thermogenic origin. Extracts from side wall cores of this well resulted in biogenic dry gas at a depth of 1018 ft and oil of API 30-35° at depth 2672 ft. Geochemical study on oil-stained samples revealed a moderately waxy and paraffinic oil from non-marine aquatic (algal/bacteria) debris with only secondary input from higher plant material. The presence of dry gas, wet gas, and oil indicate that mixing took place in the Wunut Field. Mixing of gases is also seen in the Oyong gas from the Madura Strait (Santos Sampang). Oyong gas has $\delta^{13}C_{C1}$ of -48.22 % and δD_{C1} of -128 ‰ indicative of a wet thermogenic gas. The gas has a methane content of around 95 %. Based on further isotopic study it was concluded that bacterial gas contributed to the gas and was very likely generated by carbonate reduction in marine waters.

CO_2 Pollutant

An understanding of CO_2 gas is of economic importance because of reduction in BTU (British Thermal Unit) content, individual accumulation, and the acidic nature of many of these gases, which results in a significant increase in production costs through the increased costs of tubular goods and the need for pre-processing prior to going to market (Katz, 2002).

Two areas with high CO_2 pollutant are identified in onshore and offshore areas. Onshore, high CO_2 contents are in fields reservoired in the Oligo-Miocene Kujung-Tuban carbonates of the West and East Cepu High such as Kedung Tuban : 24.86 % CO_2, Sukowati : 40.74 %, Banyu Urip : 47 %, Rembang 45-65 %, and Gabus : 78.57 %. Some gas seeps in the Surabaya area also show high CO_2 content such as Deling (38.72 %) and Sepat Kaliasin (35.59 %). In offshore areas, high CO_2 content occurs in dry wells in Rembang Bay (Kutilang-1, Nuri-1, Perkutut-1) containing 74 to 91 % vol. and in gas wells recently drilled around the Bawean Island, namely Titan-1 (BP, 2003) and Calypso-1 (BP, 2003) with CO_2 pollutant of 75 to 85 % vol.

CO_2 has various possible origins and this can be investigated by analysing the ^{13}C isotope of CO_2 (Hunt, 1996). Carbon isotope data of CO_2 from onshore gases are available. Kedung Tuban shows $\delta^{13}C_{CO2}$ of 0.52-1.62 ‰, Rembang: -5.17 to 0.03 ‰, and Gabus: -4.85 ‰. These values are thought to be related with CO_2 released by thermal destruction of carbonates which have range of $\delta^{13}C_{CO2}$ from –5 to 4 ‰. This means that the carbonate reservoirs of these fields, or carbonates at depth, have entered into the mature or over mature window. CO_2 gas was released through thermal degradation and migrated up dip into the fields. The origin of high CO_2 in offshore area is not understood since there is a paucity of isotopic data. However, based on its geologic setting, it may be related to volcanic degassing associated with the Muria, Lasem, and Bawean Neogene-Quaternary volcanoes.

TRENDS OF HYDROCARBON HABITATS

The relationship between tectonics, sedimentary regimes, peteroleum system, and occurrences of oils and gases will determine hydrocarbon habitat. The generation, migration, and accumulation of oil and gas are related to the intense Paleogene and Neogene tectonic events and to sedimentologic events in East Java. Consequently, the different physical and geochemical properties of the oil and gas are related to the diverse geodynamic histories.

Four domains of hydrocarbon habitats can be established: Ngimbang Trend, Kujung Trend, Ngrayong Trend, and Tawun-Mundu Trend (Figure 9). Hydrocarbons in the Ngimbang Trend filled the stratigraphic and structural traps associated with synrift deposits. East-west trending grabens developed in the early Paleogene including : Muriah, Pati-Tuban, JS1-West Florence, Ngimbang-Central Deep-East Florence, BD North, Porong-BD South, Pagerungan, and Southern Troughs/Grabens/Basins. Onlaps/pinchouts, paleohigh reefs, and tilted fault blocks are examples of potential traps within these trend. The identification of the Eocene Ngimbang reservoirs within the traps which are connected to basinal kitchens by migration pathways is important. Most of these traps were already present during the initial phase of hydrocarbon generation in the Oligocene. During inversion in the Rembang-Madura-Kangean zone, the heatflow was elevated and the source rocks entered into the gas window.

Hydrocarbons in the Kujung Trend are associated with the Oligo-Miocene Kujung-Tuban-Rancak reefs developing along the paleohighs adjacent to the grabens defined above. These carbonates formed both land-attached platforms like Bawean Arch and North Madura Platforms, and offshore isolated platforms like East Cepu High and BD Ridge. Satyana and Darwis (2001) and Satyana (2002a) documented recent discoveries within these carbonates. Banyu Urip, Mudi, Bukit Tua are examples of these accumulations. Ngimbang, Kujung III, and it may be that Lower Tuban source rocks deposited within the intervening grabens provide the hydrocarbons for this kind of accumulation.

Hydrocarbons in the Ngrayong Trend are related to oil accumulations in the Cepu area. These accumulations are found mainly within the middle Miocene Ngrayong/Wonocolo sandstones. East Java's first oilfields that were discovered in the late 1800s and early 1900s are from this trend. The trend is due to Mio-Pliocene compressional or inverted structures along the Rembang-Madura-Kangean (RMK) Fault Zone. The faulted anticlines or anticlines from Cepu through to Surabaya and Madura to Kangean areas form the prolific fields. Terrestrial paraffinic oils derived from overlying source rocks of the Ngimbang to Lower Tuban Formation filled the traps. Faults are important conduits for the migration of hydrocarbons in this trend.

In the Tawun-Mundu Trend, all the hydrocarbons are accumulated within the Miocene, Pliocene to Pleistocene reservoirs and are filled by biogenic gases. Some mixing with thermogenic gas or oil may occur. The main areas of these reservoirs in this trend are offshore areas to the south of Madura-Kangean Islands. Terang-Sirasun and Maleo are examples of these types of accumulation. A similar trend is also seen in the Muriah-Bawean area in the middle Miocene Tawun sands. The sources of biogenic gas are shales/coals from similar formations, while mixtures with thermogenic gas and oil came from Ngimbang-Lower Tuban source rocks.

CONCLUSIONS

- Based on oil geochemistry study, it is inferred that East Java's oils had an oxic to sub-oxic terrestrial to marginal marine source. Present offshore oils are more terrestrial in origin and were sourced from older sources; and present onshore oils are more marine and were sourced from younger sources. The oils were generated from medium maturity. The expected source rocks are middle Eocene Ngimbang Formation, late Oligocene Lower Kujung Formation, and early Miocene Lower Tuban shales/coals. On a local scale, the most likely source rock will vary depending on the geological setting.

- From gas geochemistry analysis, natural gas in East Java can be divided into three genetic types: (1) thermogenic associated and non-associated gas, (2) biogenic/bacterial gas, and (3) mixed biogenic-thermogenic gas. Thermogenic gas sources are similar to those of the oils. The biogenic gas is likely to have been sourced from the Neogene shales and coals. The amount of non-hydrocarbon gas of CO_2 gas pollutant was evaluated on a regional scale and two areas of high CO_2 gas were noted. Onshore, these occur in the Cepu area and offshore in the Rembang-Bawean area, with different modes of CO_2 origin inferred for each area.

- The habitats of East Java's oils and gases were evaluated within the framework of tectonics, sedimentary regimes, and the occurrences of oils and gases. Four trends of hydrocarbon habitats are recognized. These are Ngimbang, Kujung, Ngrayong, and Tawun-Mundu Habitats. Future potential for hydrocarbons in East Java are likely to be located within these trends.

ACKNOWLEDGMENTS

The paper mainly benefited from materials provided by, and discussions with, explorationists working in the East Java Basin. Special thanks are due to Agung Darmoyo (Lapindo Brantas), Wahyudin Suwarlan (now with Petronas Carigali), Kuntadi Nugrahanto (BP Bawean), Imron Ashari (Kodeco West Madura), Moh. Irfani (JOB PetroChina Tuban), Pudji Astono (Pertamina Upstream), Gadjah Pireno (Petronas-Rims Karapan), Imam Setiawan (now with JOB PetroChina Salawati), and John Bates (Santos). Dr. Moyra Wilson from University of Durham edited the text. The management of Exploration BP Migas is acknowledged for sponsorship of this paper.

REFERENCES

Basden, W. A., Posamentier, H., Noble, R., 2000. Structural history of the Terang and Sirasun fields and the impact upon timing of charge and reservoir performance, Kangean PSC, East Java Sea, Indonesia, Proceedings Indonesian Petroleum Association (IPA), 27th Annual Convention, p. 269-286.

Bissada, K.K., Elrod, L.W., Darnell, L.M., Szymczyk, H.M. and Trostle, J.L., 1992. Geochemical inversion – a modern approach to inferring source rock identity from characteristics of accumulated oil and gas, Proceedings Indonesian Petroleum Association (IPA), 23rd Annual Convention, p. 165-199.

Huang, W.Y., and Meinschein, W.G., 1979. Sterols as ecological indicators, Geochimia Cosmochimia Acta, 43, p. 739-745.

Hunt, J.M., 1996. Petroleum Geochemistry and Geology, second edition, W.H. Freeman and Company, New York.

Katz, B.J., 2002. Gas geochemistry – a key to understanding formation and alteration processes, Proceedings Indonesian Petroleum Association (IPA), 28th Annual Convention and Exhibition, p. 789-802.

Kusumastuti, A., Darmoyo, A.B., Suwarlan, W., Sosromihardjo, S.P.C., 2000. The Wunut Field : Pleistocene volcanoclastic sands in East Java, Proceedings Indonesian Petroleum Association (IPA), 27th Annual Convention, p. 195-216.

Luthfi, A., Biantoro, E., and Satyana, A.H., 2003. Gas Habitat of the East Java Basin, Indonesia : Meets the Future Demand, European Association of Geoscientists and Engineers (EAGE), 65th Conference and Exhibition, Stavanger, Norway, 2-5 June 2003.

Manur, H. and Barraclough, R., 1994. Structural control on hydrocarbon habitat in the Bawean area, East Java Sea, Proceedings Indonesian Petroleum Association, 23rd annu. conv., p. 129-144.

Phillips, T., Noble, R.A. and Sinartio, F.F., 1991. Origin of hydrocarbons, Kangean Block Northern Platform, Proceedings Indonesian Petroleum Association (IPA), 23rd Annual Convention, p. 637-661.

Peters, K.E., Fraser, T.H., Amris, W., Rustanto, B., and Hermanto, E., 1999. Geochemistry of crude oils from Eastern Indonesia, American Association of Petroleum Geologists (AAPG) Bulletin, v. 83, p. 1927-1942.

Purwanti, Y. and Bachtiar, A., 2001. Analyses of Eocene petroleum kitchen in East Java Basin : implication for prospect ranking - Abstract, Proceedings 30th Annual Convention Indonesian Association of Geologists & 10th Geosea Regional Congress, p. 33.

Rice, D.D. and Claypool, G.E., 1981. Generation, accumulation, and resource potential of biogenic gas, American Association of Petroleum Geologists (AAPG) Bulletin, v. 65, p. 5-25.

Robinson, K.M., 1987. An overview of source rocks and oils in Indonesia, Proceedings Indonesian Petroleum Association (IPA), 16th Annual Convention, p. 97-121.

Russel, K., Sutton, C., Myers, W.C., 1976. Organic geochemistry as an aid to oil exploration in the eastern Java Sea, Proceedings Indonesian Petroleum Association (IPA), 5th Annual Convention, p. 69-80.

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

Satyana, A.H., 2002a. Oligo-Miocene reefs: East Java's giant fields, Proceedings Giant Field and New Exploration Concepts Seminar, IAGI, Jakarta 17 October 2002.

Satyana, A.H., 2002b. Petroleum Geology of East Java Basin : A Dynamic Review – One-Day Course, Indonesian Association of Geologists (IAGI), 31st Annual Convention, 132 ps.

Satyana, A.H. and Purwaningsih, M.E.M., 2002. Geochemistry and habitats of oil and gas in the East Java Basin: regional evaluation and new observations, Proceedings Indonesian Association of Geologists (IAGI), 31st Annual Convention, p. 68-102.

Schoell, M., 1983. Genetic characterization of natural gases, American Association of Petroleum Geologists (AAPG) Bulletin, v. 67, p. 2225-2238.

TABLE 1

PROPERTIES OF SOME EAST JAVA OIL SAMPLES

EAST JAVA OIL SAMPLE-ONSHORE

well/seep	API(^{0})	S(%)	13Csat($^0/_{00}$)	13Caro($^0/_{00}$)	pr/ph	ol/hop	hop/ster	C27(%)	C28(%)	C29(%)
mudi-1	37.30	0.36	-27.13	-24.30	3.54		5.82	33.90	34.70	31.50
suci-B	39.20		-27.50	-25.30	3.94		1.30	47.10	46.20	6.70
banyuasin	13.90	0.28	-27.30	-26.40	5.00	1.88		19.00	28.00	53.00
kawengan	33.90	0.25	-27.80	-25.20	5.30	0.50	11.40	14.00	28.00	58.00
ledok	40.80	0.14	-27.70	-26.30	6.30	0.55		21.00	27.00	52.00
nglobo	40.40	0.07	-28.00	-26.30	5.60	0.60	7.15	17.00	25.00	58.00
sekarkorong	51.90	0.19	-26.80	-25.20	11.70	0.10		31.00	44.00	38.00
semanggi	26.80	0.15	-28.00	-26.30	5.90	0.62	16.30	19.00	26.00	55.00
lidah	20.20	0.05	-26.70	-25.80	5.00	0.59		21.00	29.00	50.00
gegunung	24.70	0.07	-27.80	-26.20	5.60	0.62		20.00	29.00	51.00
wonocolo	29.00	0.13	-27.80	-25.20	4.70	0.50		14.00	28.00	58.00
kuti	21.00	0.13	-27.10	-26.30	5.00	2.19		17.00	32.00	51.00
kertageneh	21.10	0.13	-27.10	-26.50	5.00	0.51		16.00	21.00	62.00
lerpak	20.20	0.10	-27.50	-26.70	5.00	0.38		16.00	25.00	59.00
arosbaya	42.00	0.13	-27.70	-26.50	3.50	0.36		23.00	26.00	51.00
carat	18.20	0.68	-25.40	-23.80						
gegunung	32.40	0.07	-27.30	-26.20	2.56					
kembangbaru-2	30.00	0.08	-27.70	-24.70	4.84					
kujung-1			-27.10	-25.30						
ngasin-1			-27.70	-27.70	3.11					
porong-1			-24.20	-24.10	3.63					
randugunting	69.20	0.03	-27.20	-26.20	6.46					
lusi-5	48.90	0.11			3.41		7.43	26.00	31.00	43.00
sepat kaliasin	14.30	0.46	-26.10	-25.20						
rembang-2	30.90	0.14	-28.19	-25.98						
kedungtuban-1	41.20	0.05	-25.29	-23.77	5.51	1.26				

TABLE 1 (CONT'D)

EAST JAVA OIL SAMPLE-OFFSHORE

well/seep	API(^{0})	S(%)	13Csat($^0/_{00}$)	13Caro($^0/_{00}$)	pr/ph	ol/hop	hop/ster	C27(%)	C28(%)	C29(%)
BD-1	27.20	0.26	-28.20	-25.30	4.43					
BD-2	43.00	0.26	-27.40	-22.50	3.10					
Camar	37.90	0.14	-27.90	-26.00	5.31			11.00	25.00	64.00
JS 19W-1	44.90	0.19	-28.70	-26.90	5.19	0.25	5.40	17.00	39.00	44.00
JS 53A-1	29.10	0.21	-28.30	-27.70	7.70	0.20	7.20	29.00	15.00	56.00
KE-2	44.70	0.18	-27.60	-27.40	5.30		5.80	24.00	32.00	44.00
KE 23-2	38.70	0.04	-27.50	-26.00	3.90					
KE 5-3	34.10	0.47	-25.50	-22.90	2.14					
KE 6-3	31.60	0.38	-27.80	-25.10	2.69	0.95	2.90	16.00	31.00	53.00
KE 7	41.00	0.21	-28.00	-26.10	3.64					
KE 9	34.20	0.32	-27.40	-25.20	3.82	0.15	5.60	22.00	37.00	41.00
sepanjang Isl	32.40	0.34	-23.60	-23.04	2.67			24.00	25.00	51.00
poleng(JS 20-4)	43.00	0.10	-28.79	-25.96	6.15	0.29		16.00	27.00	57.00
JS 20-3	46.00		-27.40	-26.20	1.76	0.15				
ujungpangkah-1	38.20		-27.80	-26.70	2.98	0.29				
sidayu-1	27.20				5.80	0.28				
L 46-1(SE Kangean)	30.00	0.68	-22.96	-22.78	4.19	0.04		23.00	29.00	48.00
JS 44-A1	57.70	0.70	-28.03	-25.06	5.15	0.28		26.00	34.00	41.00
JS 1-1	33.00	0.17	-28.38	-26.37	5.80	0.29		11.00	26.00	63.00
JS 2-1	28.60	0.34	-28.55	-26.41	6.21	0.13		16.00	26.00	59.00
JS 14A	32.20	0.20	-30.24	-27.85	9.81	0.21		11.00	27.00	62.00
JS 18-1	9.70	0.21	-27.38	-25.64		0.25		10.00	25.00	65.00
JS 19-1	37.30	0.25	-28.36	-25.85	6.65	0.12		16.00	28.00	56.00
L 46-1(SE Kangean)	30.00	0.68	-22.96	-22.78	4.19	0.04		23.00	29.00	48.00
L 46-2(SE Kangean)	28.50	0.09	-24.89	-24.64	7.72	0.09		18.00	32.00	50.00
JS 20-4 (Poleng)	33.80	0.14	-28.53	-25.87	3.95	0.31		16.00	27.00	57.00
pagerungan-1	53.60	0.01	-27.00	-25.60	13.20	0.13				
poleng A-3	44.70	0.14	-28.63	-26.17	5.28	0.29		17.00	28.00	55.00

TABLE 2

GEOCHEMICAL PROPERTIES OF SOME SOURCE SAMPLES FROM THE EAST JAVA BASIN

EAST JAVA ROCK/EXTRACT SAMPLE-ONSHORE

well/seep	sample origin	TOC($^{\%}$)	HI	13Csat($^0/_{00}$)	13Caro($^0/_{00}$)	pr/ph	ol/hop	hop/ster	C27(%)	C28(%)	C29(%)
Arosbaya-1	Cepu			-27.67	-26.92	2.61					
	Kujung			-27.42	-26.58	2.25					
	Kujung			-26.30	-25.20						
	Ngimbang	3.17	299	-26.67	-26.24						
Batakan-1	Ngimbang	5.67	133	-28.7	-27.5	0.85					
Bawean-1	Kujung	17.27	157	-27.58	-26.54						
Blimbing-1	Tuban	1.30	235	-27.6	-26.60	4.7					
Gigir-1	Cepu	5.97	426	-28.08	-26.61	2.19					
Gondang-1	Ngrayong			-26.55	-27.48	4.56					
	Tuban			-27.71	-27.38	4.84					
Grigis Barat-1	Ngrayong			-27.23	-27.3	2.78					
	Tuban			-27.46	-27.54	3.14					
Kembang Baru-1	Kujung-1			-18.64	-17.56	1.2					
Kembang Baru-2	Kujung-1			-27.53	-24.97	5.5					
Kradenan-1A	Tuban	1.37	158	-26.79	-27.29	3.8					
Kujung-1	Ngimbang			-27.1	-25.3						
Ngasin-1	Wonocolo			-27.67	-27.72	3.11					
	Ngrayong			-27.68	-27.02	4.4					
Kedung Tuban	Tuban	0.81	87	-25.54	-24.75	5.4	0.64		5	39	56
	Kujung	0.14	29	-25.68	-24.75	2.9	0.51		25	29	46
Banyubang-1	Rancak			-26.09	-25.66	1.91		5.07	32	33	35
Suci-1	Rancak			-27.25	-26.93	1.2		2.27	27	27	46
Jatirogo-1	Rancak			-26.57	-26.03	1.95		4.2	33	29	38
Ngimbang-1	Rancak			-26.77	-26.35	0.97		2.05	34	21	45
Dander-1	Prupuh	2.57	97			3.22					
	Kujung	0.95	122			3.45					
Purwodadi-1	Ngimbang	2.25				3.78			35	18	47
Kayen-1	Kujung Lst					1.68					
Rembang-1	Kujung Lst	0.78	32.8			11.47		2.88	19	30	51
	CD Shales	12.17	396	-27.33	-26.99	10.44	0.19	4.27	38	29	33
	CD Shales	56.86	343	-26.75	-26.95	9.81	0.11	3.27	28	25	47
	Eocene clastics	0.69	49			4.66		3.14	31	23	46

TABLE 2 (CONT'D)

EAST JAVA ROCK/EXTRACT SAMPLE-OFFSHORE

well/seep	sample origin	TOC(%)	HI	13Csat($^0/_{00}$)	13Caro($^0/_{00}$)	pr/ph	ol/hop	hop/ster	C27(%)	C28(%)	C29(%)
Cassiopeia-1	Kujung II			-28.99	-27.7	7.45					
JS 4-1	Cepu			-26.82	-6.8	0.54					
JS 8-1	Cepu			-27.86	-26.79	2.18					
JS 13A-1	Kujung			-27.83	-26.6	1.92					
JS 14A-1	Kujung	2.67	443	-26.28	-25.36	1.76					
JS 17-1	Kujung	0.52	286	-26.5	-26.3	1.85					
JS 20-3	Kujung	1.15	93	-26.19	-25.53	4.96					
JS 28-1	Kujung	3.93	253	-26.95	-25.53	4.96					
JS 3-1	Ngimbang	1.64	233	-28.44	-27.17						
JS 53A-1	Ngimbang	62.3	245	-27.8	-26.41	8.31					
	Ngimbang	1.93	110	-27.9	-26.71	2					
MDA-2	Mundu			-27.58	-27.21	0.94					
MS 2-1/1A	Cepu			-27.3	-26.03	2.47					
JS 3-1	Ngimbang	1.64		-28.44	-27.17	2.28					
Nuri-1	Ngrayong					2.43					
	Tuban					5.1					
	Kujung					3.73					
Poleng	Cepu			-27.67	-26.61	2.04					
	Kujung			-27.69	-27.2	1.04					
Rajawali-1	Kujung	5.7	154	-27.57	-26.82	4.93					
Sakala-1	Pre-Eosen			-27.67	-26.75	1.94					
Terang-1	Cepu	0.81	235	-27.12	-25.71	2.95					
Pagerungan	Ngimbang	67.04	448	-28.2	-26.1						
	Ngimbang	2.41	231	-29.1	-26.6						
South Sepanjang	Pre-Ngimbang	8.03	42								
	Pre-Ngimbang	0.96	24	-25	-24						

TABLE 3

COMPOSITION AND ISOTOPE PROPERTIES OF SOME EAST JAVA GASES

GAS SAMPLE	HC GAS (normalized)		SG (g/cc)	CO_2 (% MOL)	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{CO2}$ (‰)	δD (‰)	INTERPRETATION
	C_1	C_{2+}						
KELADI-1 (KEPODANG)								
DST-2	99.80	0.20		0.10	-67.31		-198	BIOGENIC GAS
DST-1A	99.60	0.40		0.16	-65.66		-209	BIOGENIC GAS
DELING	98.30	1.70		38.70				THERMOGENIC GAS (?)
SEPAT KALIASIN	98.80	1.20		35.60				THERMOGENIC GAS (?)
KE 30-1	78.92	21.08	0.76	1.07				THERMOGENIC GAS
WUNUT-1								
DEPTH 802 FT	100							BIOGENIC GAS
DEPTH 1019 FT	99.87	0.13	0.58	0.40				BIOGENIC GAS
DEPTH 2022 FT	93.38	6.62	0.60	0.34				THERMOGENIC GAS
REMBANG-1								
DST-2	91.82	8.18	1.21	65.21				THERMOGENIC GAS
DST-1A	90.75	9.25	1.22	65.16				THERMOGENIC GAS
SUKOWATI	72.83	27.07	1.11	40.70				THERMOGENIC GAS
TERANG-SIRASUN	99.50	0.50	0.56	0 - 0.11				
OYONG-1			0.63					BIOGENIC GAS (?)
PAGERUNGAN	94.24	5.76						THERMOGENIC GAS
KEDUNGTUBAN	92.53	7.47		24.86	-37.5 to -35.5	0.52 - 1.62		THERMOGENIC GAS
REMBANG-2	86.35	13.65		65	-39.80 to -33.84	-5.17 to 0.03	-152 to -145	THERMOGENIC GAS
KE-23	85.78	14.22						THERMOGENIC GAS
BANYU URIP				47				THERMOGENIC GAS
GABUS				78.57		-5 to 4		

REMARKS

HC GAS (normalized) = hydrocarbon gas

C_1= methane, C_{2+} = ethane, propane, butane, etc.

$\delta^{13}C_{C1}$ (‰) =carbon isotope relative to PDB (Pee Dee Belemnite)

δD (‰) = deuterium isotope relative to SMOW (standard mean ocean water)

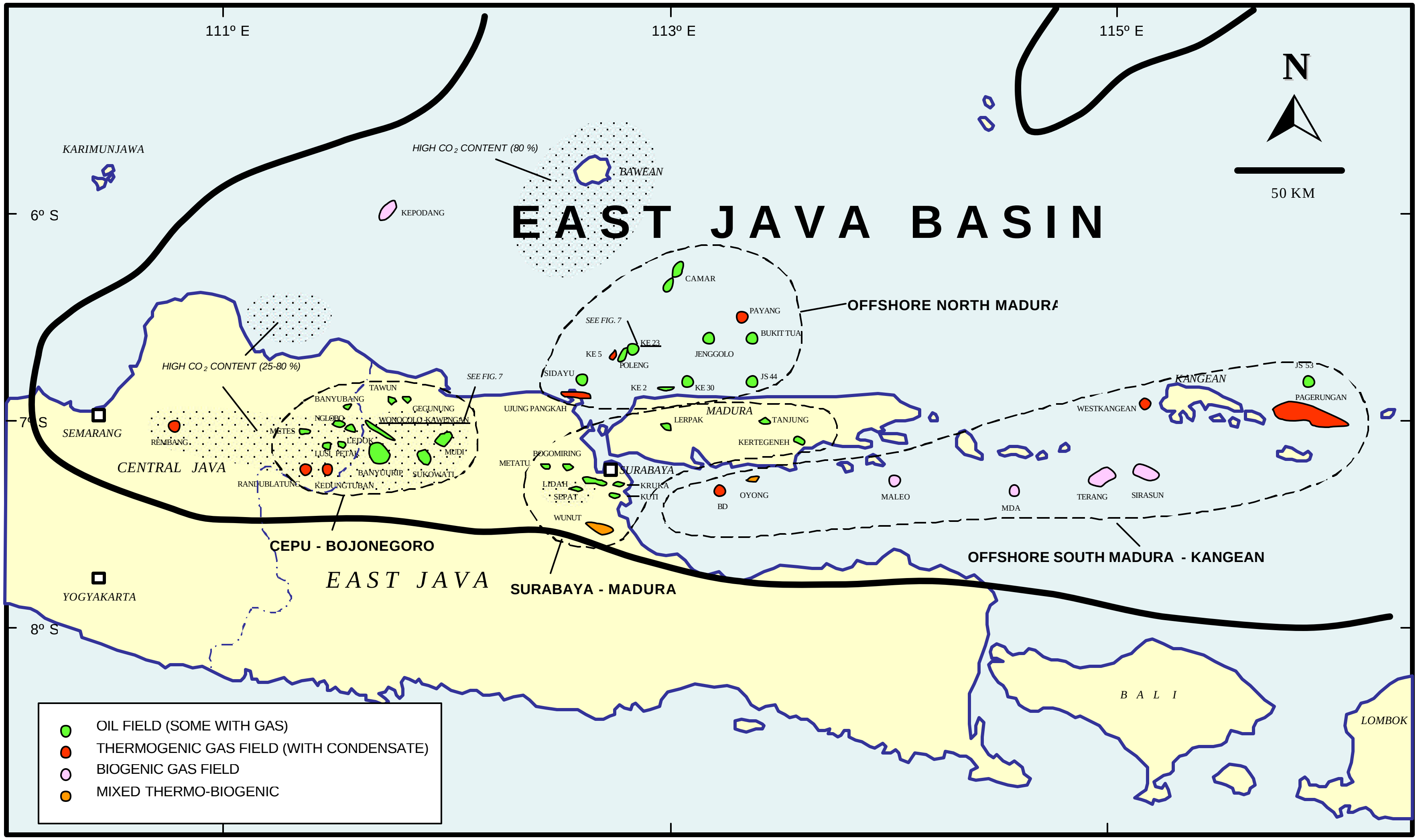
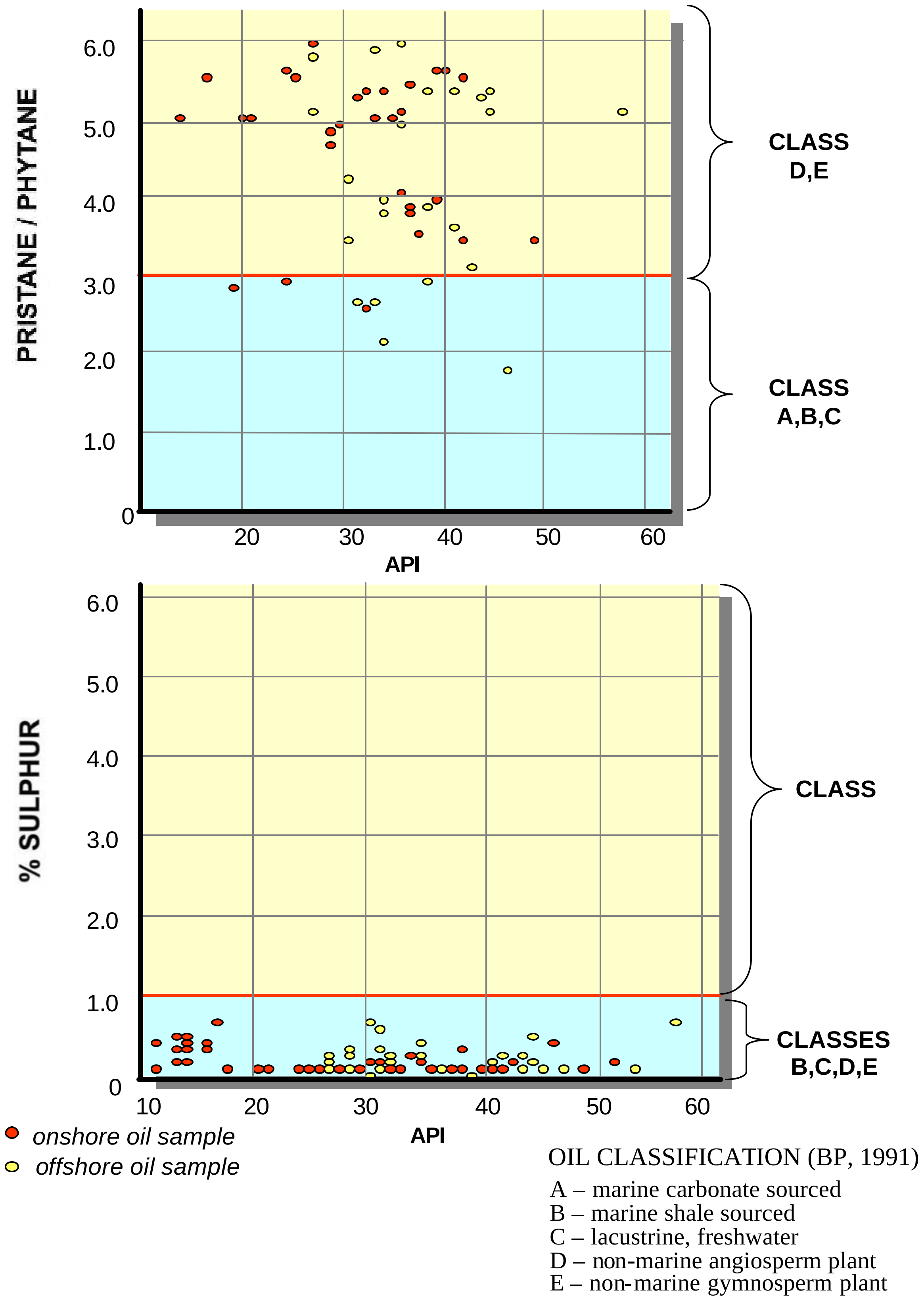


Figure 1 - Location of oil and gas fields in the East Java Basin. Four areas can be established including : Cepu-Bojonegoro, Surabaya-Madura, Offshore North Madura, and Offshore South Madura-Kangean areas. Oil fields dominate Cepu-Bojonegoro-Surabaya-Madura-Offshore North Madura areas. Gas fields dominate Offshore South Madura-Kangean area.



OIL CLASSIFICATION (BP, 1991)

A – marine carbonate sourced
B – marine shale sourced
C – lacustrine, freshwater
D – non-marine angiosperm plant
E – non-marine gymnosperm plant

Figure 2 - Cross plot of onshore and offshore oils from the East Java Basin based on physical bulk properties and pristane/phytane. Most of the oils fall under Class “D or E” indicating predominating non-marine sources typified by low sulphur content (below 1.0 %) and pristane/phytane > 3.0.

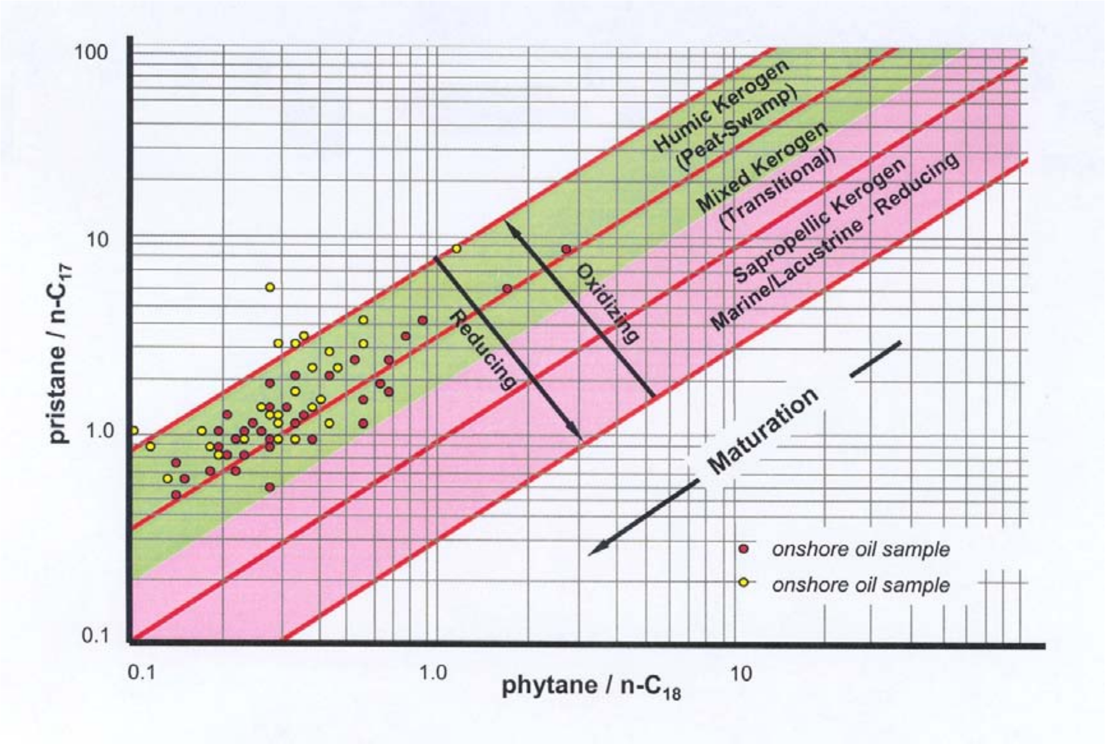


Figure 3 - Cross plot of pristane and phytane to normal alkane showing kerogen input, source facies, and reduction-oxidation conditions. Note that data distribution of onshore oils shift towards more marine characteristics and the offshore oils have more terrestrial characteristics, although there is considerable variability.

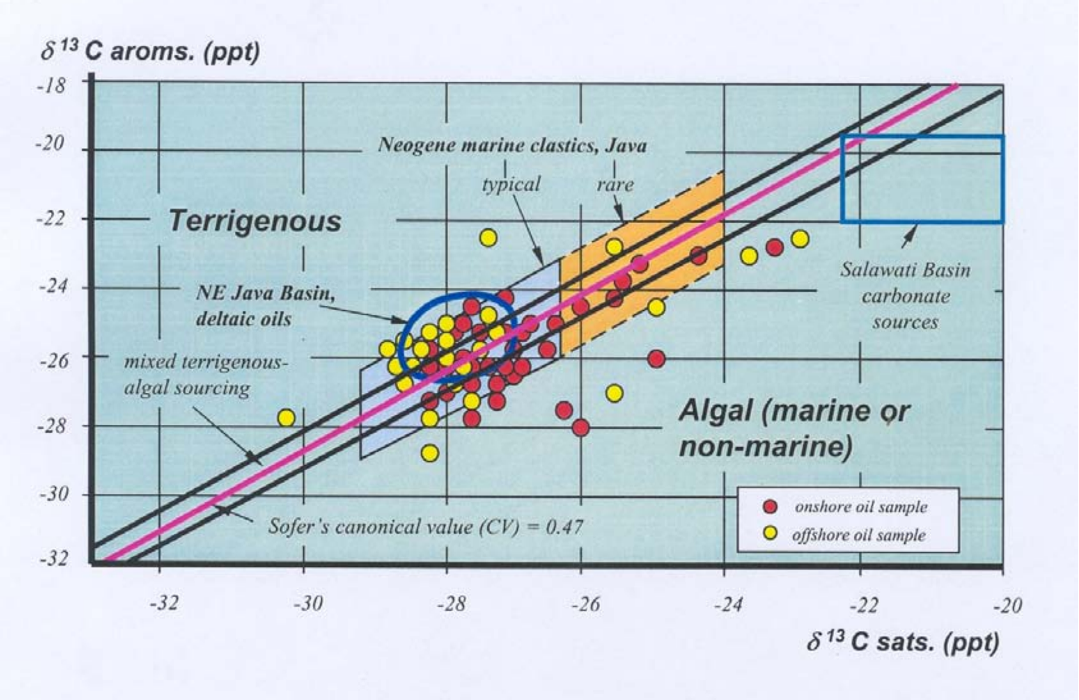
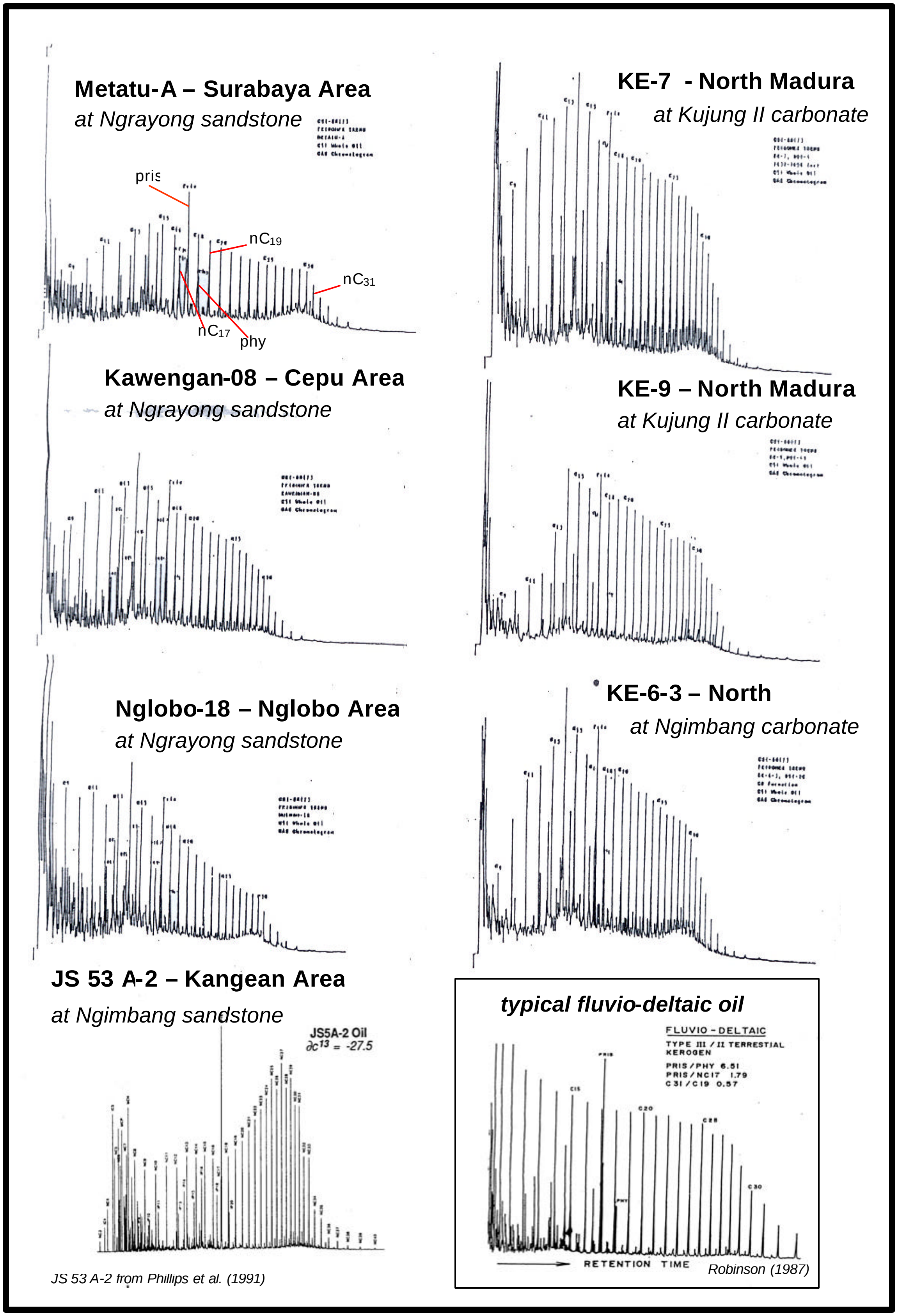


Figure 4 - Cross plot of aromatic and saturate carbon-13 isotopes showing source facies. Note that data distribution of onshore oils shift towards more marine and offshore oils shift towards more terrestrial.



Metatu-A – Surabaya Area
at Ngrayong sandstone

KE-7 - North Madura
at Kujung II carbonate

Kawengan-08 – Cepu Area
at Ngrayong sandstone

KE-9 – North Madura
at Kujung II carbonate

Nglobo-18 – Nglobo Area
at Ngrayong sandstone

KE-6-3 – North
at Ngimbang carbonate

JS 53 A-2 – Kangean Area
at Ngimbang sandstone

typical fluvio-deltaic oil

JS 53 A-2 from Phillips et al. (1991)

Robinson (1987)

Figure 5 - C_{5+} whole oil chromatogram of East Java oils from onshore and offshore showing similar patterns. Typical fluvio-deltaic chromatogram is put for reference. The East Java oils show fluvio-deltaic characteristics.

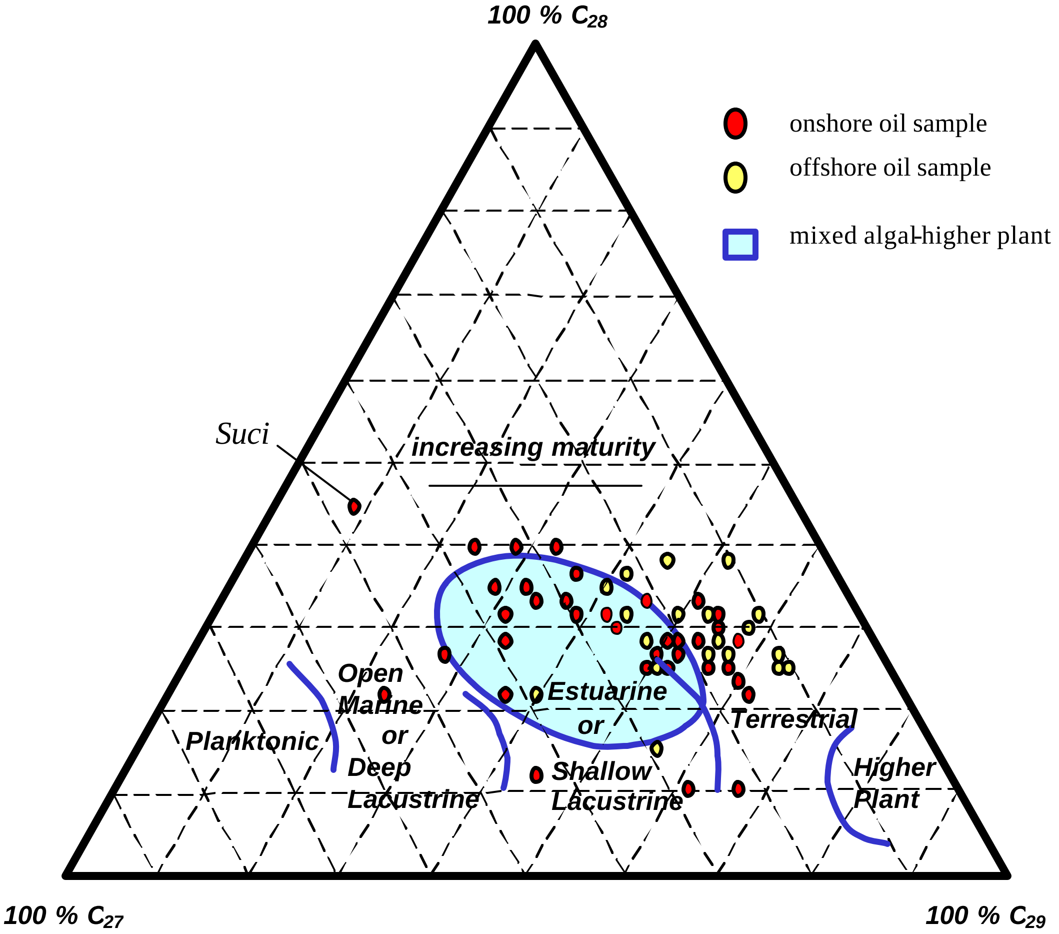


Figure 6 - Ternary diagram of m/z 217 sterane C_{27}-C_{28}-C_{29} showing depositional environments of sources generating the oils and a maturity profile. Note that data distribution of offshore oils shift more to the terrestrial and less mature and onshore oils more marine and more mature.

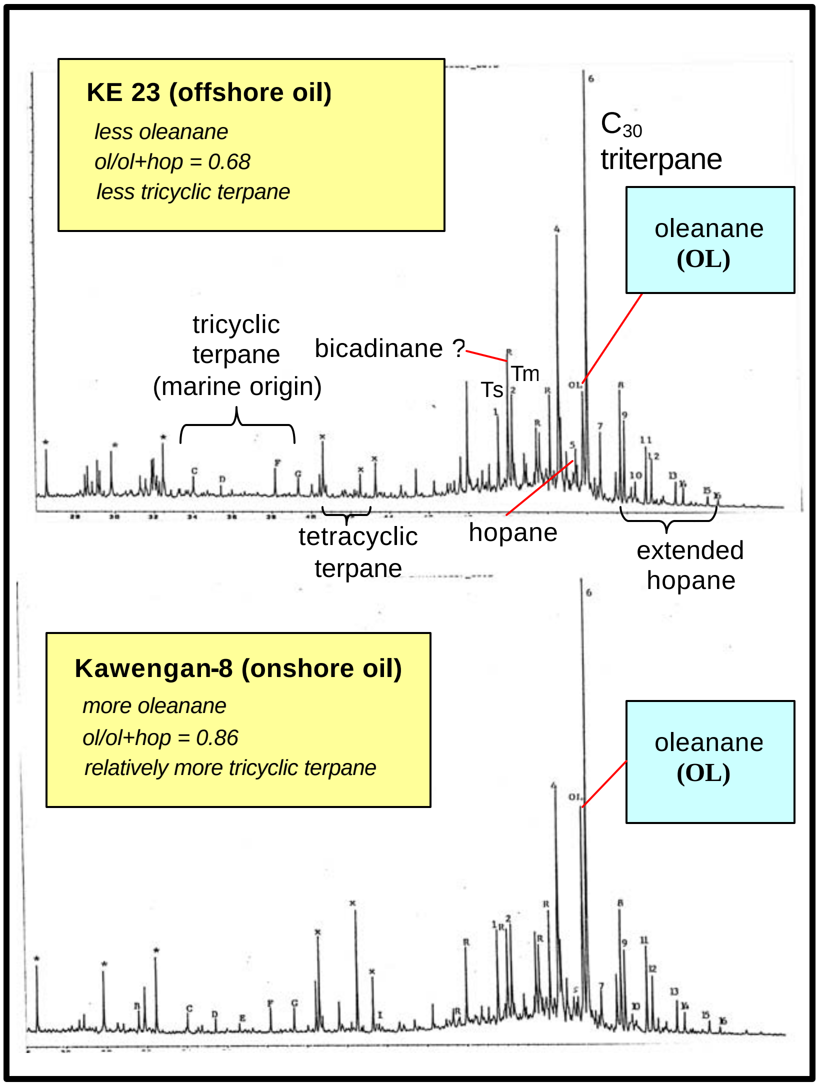


Figure 7 - Fragmentogram of m/z 191 triterpane for offshore (e.g. KE 23 in offshore North Madura Platform) and for onshore (Kawengan-8 in Cepu area) showing subtle difference in the amount of oleanane and tricyclic terpane biomarkers. Based on this and other analysis onshore oils are considered to be more marine and sourced by younger sources (oleanane increases from Eocene to Miocene).

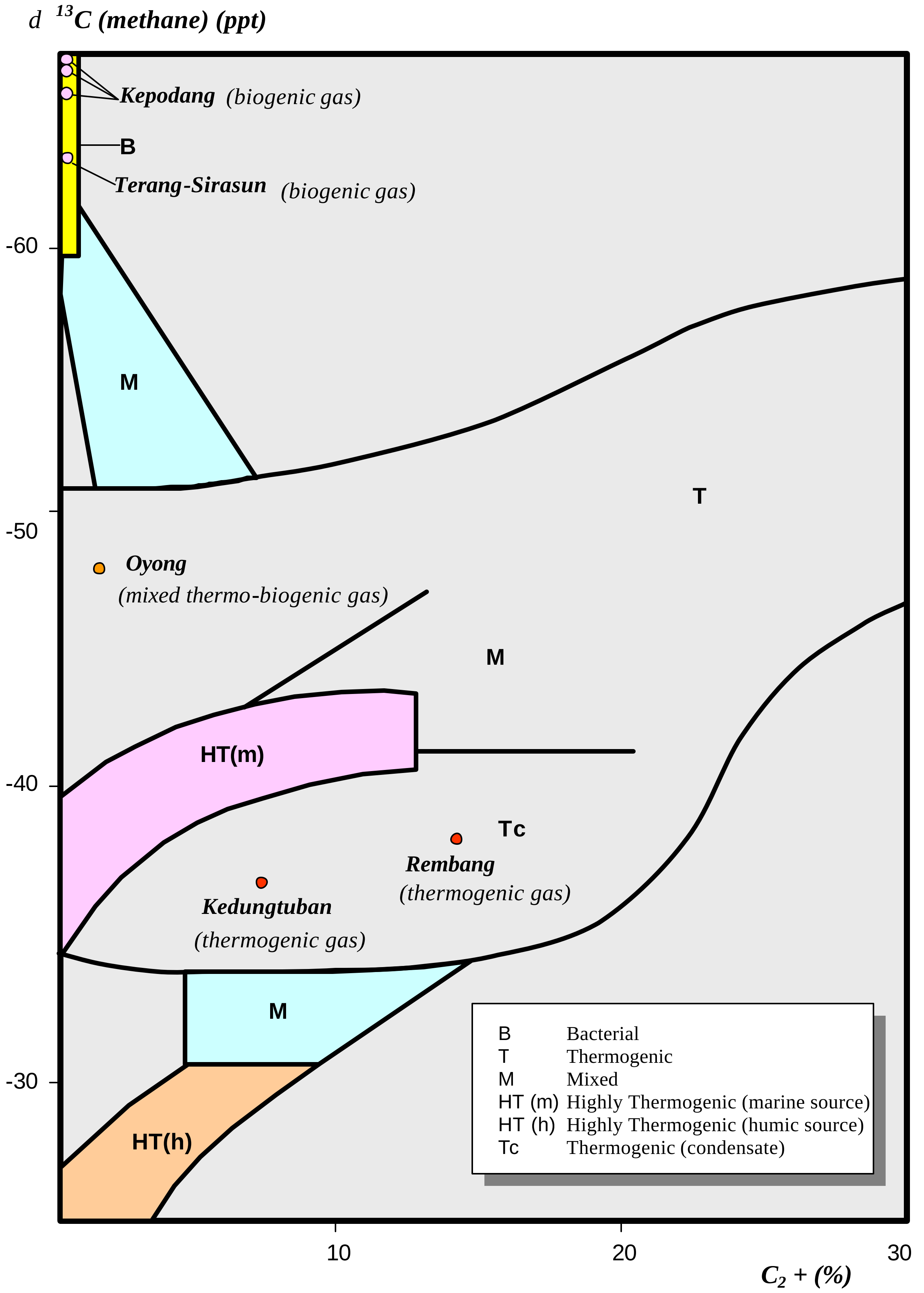


Figure 8 - Cross plot of gas composition of ethane (C2) plus and carbon-13 isotope showing genetic types of gases. Three types of gases can be recognized: thermogenic (Kedung Tuban and Rembang), biogenic (Kepodang and Terang Sirasun) and of mixed thermo-biogenic origin (Oyong).

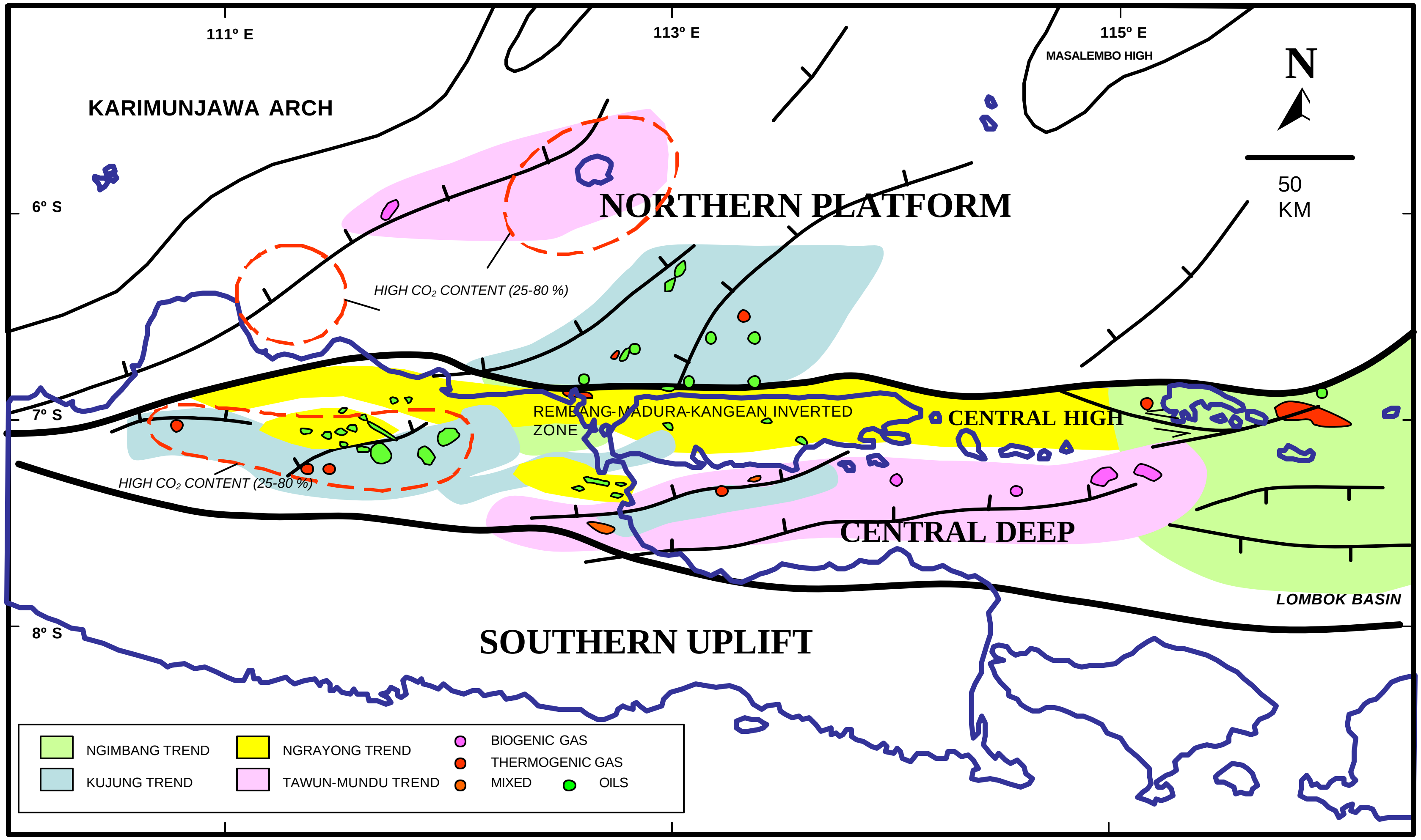


Figure 9 - Map showing trend of habitats of oil and gas in the East Java Basin. Four trends can be recognized containing oil, thermogenic and biogenic gas fields. The habitats are closely related with the geologic setting and petroleum system. Areas with high CO_2 gas content are identified.