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Meteoric Water Flushing and Microbial Alteration of Klamono and Linda Oils, Salawati Basin, Eastern Indonesia : Geochemical Constraints, Origin, and Regional Implications

Awang H. Satyana [1)]
Mohamad Wahyudin [2)]

ABSTRACT

Klamono and Linda Fields provide good examples of oil alteration due to meteoric water flushing and biodegradation. The oils show characteristics of biodegraded oil : low gravity, high sulfur content, high viscosity, low pour point, low saturated hydrocarbon content, removal of the majority of n-paraffins and isoprenoids, and increased δ^{13}carbon isotope ratio of saturates. Based on the molecular geochemistry (GC/GC-MS) data, the oils are moderately biodegraded (level 3 to 4 at Hunt, 1996's scale).

Regional evaluation answers the question on the origin of the biodegradation. The Miocene Kais carbonates forming the reservoir of the Klamono Field was outcropped to the east at the Ayamaru Platform. Meteoric water has entered this area, flowed downdip westwards to the Klamono Field, and altered the oils through microbial alteration. The shallow depth of the Klamono reservoir enhanced the biodegradation.

The Linda Field is in different mechanism of biodegradation. The field is located frontal to a major surface normal fault called the Cendrawasih Fault. A splay of the Cendrawasih Fault faulted the Linda Field. The faults are considered to have acted as conduits for meteoric water to reach faulted Kais reservoir of the Linda Field and altered the oil through microbial alteration. Other oils located along the Cendrawasih Fault are biodegraded and thus support this consideration.

Based on the above two mechanisms, the regional distribution of biodegraded and non-biodegraded oils within the Salawati Basin can be expected. The methods of this study c[1]an be applied elsewhere.

[1] JOB Pertamina-Santa Fe Salawati, *currently at Pertamina-BPPKA*
[2] Pertamina-EP Irian Maluku Exploration Team

INTRODUCTION

Although many of the characteristics of petroleum in reservoir are inherited from the source rock and alteration along the secondary migration pathway, under certain circumstances further compositional changes may occur after accumulation in the reservoir. These effects have important consequences for the producibility and the economic worth of the petroleum and must be considered in the evaluation of a prospect (Hunt, 1996).

Venture in a mature basin like the Salawati Basin, which has been explored since the early 1900s and produced since 1949, needs more deliberate efforts. Currently, economic requirements also make more limitations to exploration. It is in this economic context a problem of oil biodegradation is uplifted since it may cause an economic downgrade of prospect or field. The Salawati Basin provides the good examples of biodegraded oils and therefore can be referred for significances of future exploration.

The geochemistry of the Salawati oils including the biodegraded oils have been numerously published (Phoa and Samuel, 1986; Robinson, 1987; Livsey *et al*., 1992, Peters *et al*., 1999, Satyana *et al*., 2000). However, there has no published study that specifies the problem of oil biodegradation in the Salawati Basin. This paper summarizes our study of the geochemistry and geology (origin and regional implication) of the Salawati's biodegraded oils. The Klamono (Pertamina) and Linda (Pertamina, currently is operated by PT Intermega) oils are used as references. General points and method presented in this paper can also be applied elsewhere.

WATER WASHING AND BIODEGRADATION

Effect to Downgrade

Water washing and biodegradation are two of the mechanisms causing petroleum in reservoir to change its physical and chemical characteristics. The scale of biodegradation can be very severe as undergone by two of the world's largest oil fields – the Athabasca tar sands (1000 billion barrels oil or BBO) and the Orinoco tar belt (700 – 1000 BBO), two of which contain greater reserves than the whole of the Middle East (Fleet and Clayton, 1991). However, as a result of the biodegradation, the economic worth of these supergiant fields is greatly reduced.

The effects of biodegradation on oil are summarized in *Table 1*. None of these changes is desirable in that they all tend to either reduce the economic worth of the petroleum or to make its production more difficult. The high sulfur and metal contents cause problems during refining due to poisoning of catalysts; the most valuable part of the accumulation is lost – namely the lighter, simpler molecules, particularly the normal and branched paraffins (Waples, 1985). It is important therefore to understand where and why biodegradation occurs, and what its effects are on oil composition.

DECREASE IN	INCREASE IN
• wet gas ($C_2 – C_6$) • gasoline – kerosene range ($C_6 – C_{15}$) • API gravity • all n (normal) – paraffins • saturate fraction • wax content • pour point • gas oil ratio (GOR) • ^{13}C (carbon) isotope ratio of aromatics and asphaltenes fractions	• asphaltic compounds • sulfur content • nitrogen content • vanadium content • nickel content • residue fraction • oil viscosity • ^{13}C (carbon) isotope ratio of whole oils and saturates fractions *compiled from Waples (1985) and Hunt (1996)*

Table 1 Characteristics of biodegraded petroleum

Where to Occur

Four criteria must be met if biodegradation of an oil accumulation is to occur (Waples, 1985; Fleet and Clayton, 1991; Hunt, 1996) : (1) supply of fresh, nutrient rich, oxygenated water, (2) low reservoir temperature (≤ 88°C or ≤ 190°F), (3) presence of bacteria, and (4) oil-water / bacteria contact.

The relationship between water washing and biodegradation is not well understood due to biodegradation commonly obscures the effects of water washing (Waples, 1985; Fleet and Clayton, 1991). The effects of water washing are rather difficult to determine because they do not affect the oil fractions that are most frequently studied. Furthermore, in most cases the effects are quite small because of the low solubilities of all hydrocarbons in water. Water washing and biodegradation often occur together, with the more dramatic effects in biodegradation. Water washing may operate without biodegradation.

Mechanism

The general mechanism of attack is through an oxidation of hydrocarbons to result in alcohols, ketones, and acids. The order of oxidation depends on a variety of factors, but in general, small molecules up to C_{20} are consumed before large ones. Within the same molecular-weight range, the order is usually *n*-paraffins first, followed by branched isoparaffins, naphthenes, aromatics, and polycyclic aromatics. Single-ring naphthenes and aromatics are attacked before isoprenoids, steranes, and triterpanes (Waples, 1985; Hunt, 1996). Jobson *et al.*(1972) showed the order of biodegradation by treating Saskatchewan crude oil samples with bacteria cultures at 30°C and observed considerable degradation during twenty-one days of incubation (*Figure 1*). The gas chromatograms show the disappearance of n-paraffin peaks, first in the $C_{16} – C_{25}$ range and later in the entire range.

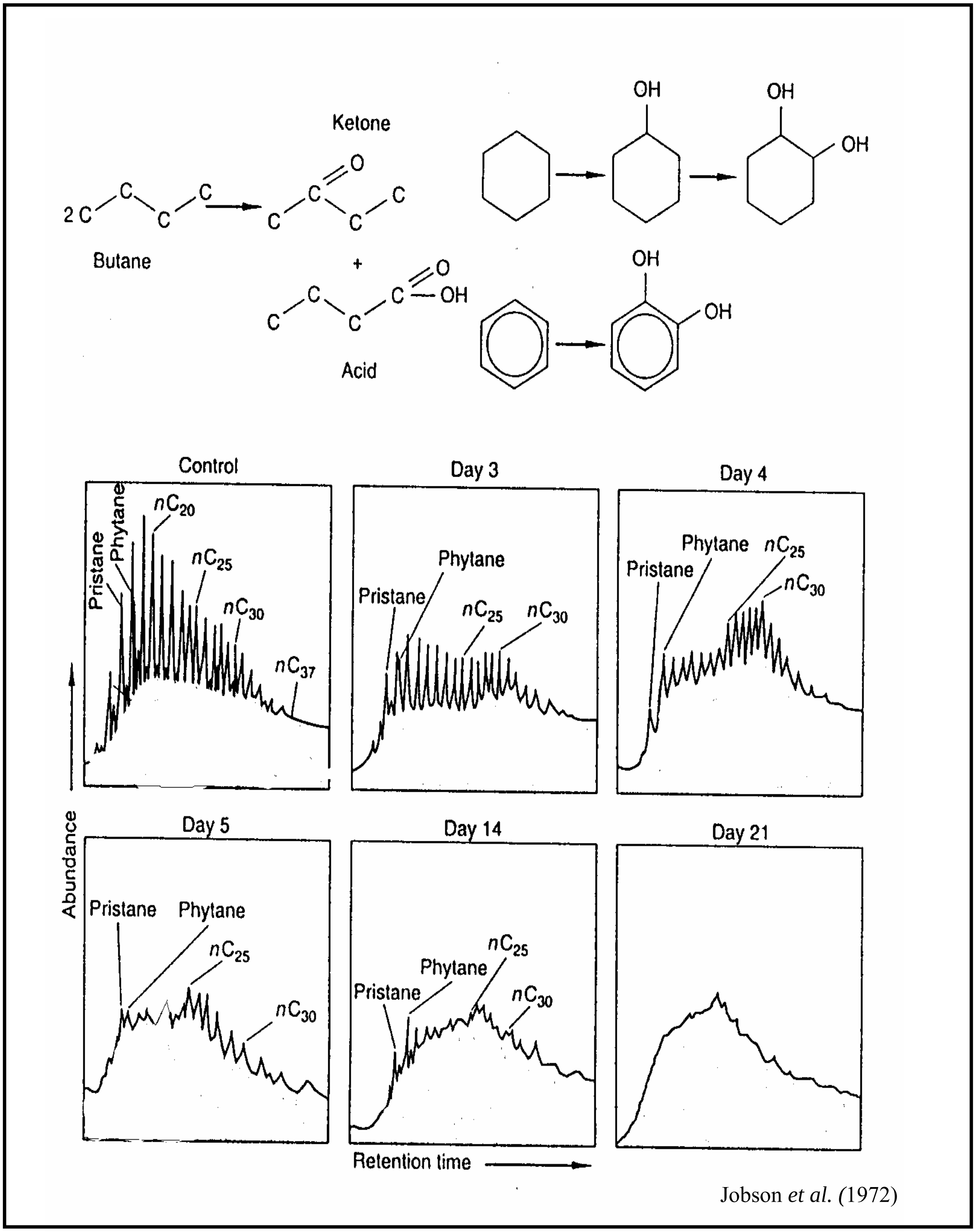

Figure 1 Biodegradation is oxidation of hydrocarbons to result in ketones, acids, and alcohols. Treatment of bacteria culture on Saskatchewan oil cause sequential disappearance of *n*-paraffins in 21 days of incubation.

Rank or Degree

Biodegradation can vary in intensity from very light to extremely heavy. Hunt (1996) compiled degradation ranks from Alexander *et al.* (1983), Volkman *et al.* (1984), Connan (1984), and Peters and Moldowan (1993) (*Table 2*). Biodegradation levels from 1 to 10 are described as minor to extreme. The levels or rankings in biodegradation are quasi-sequential in that a higher-ranked compound class can be attacked before a lower-ranked class is completely destroyed. Also, variations in the different microbes causing degradation can change the rankings of some of the compounds listed.

RANK	COMPOSITIONAL CHANGES	EXTENT
1	n-alkanes C_1-C_{15} depleted	minor
2	over 90 % C_1-C_{35} n-alkanes gone	light
3	iso-alkanes attacked, alkyl-cyclohexanes and alkyl-benzenes removed	moderate
4	isoprenoid alkanes and methyl-naphthalenes removed	moderate
5	C_{14}-C_{16} bicyclic alkanes removed	moderate
6	25-norhopanes may be formed, steranes attacked	heavy
7	steranes gone, diasteranes unaffected	heavy
8	hopanes attacked	very heavy
9	hopanes gone, diasteranes attacked; oleanane, tricyclic terpanes, and aromatic steroids survive	severe
10	diasteranes and tricyclic terpanes destroyed, aromatic steroids attacked, vanadyl porphyrins survive	extreme

(Hunt, 1996)

Table 2 Degree of biodegradation

SALAWATI BASIN REGIONAL SETTING

The Salawati Basin is an east - west trending asymmetric foreland basin located on the northern margin of the Indo-Australian Plate (*Figure 2*). The basin is presently bounded to the north and west by the deformed zone of the left-lateral Sorong Fault. The basin is terminated to the south and east by uplifted Miocene carbonates of the Misool - Onin Geanticline and the Ayamaru Platform, respectively. The Salawati Basin records the stratigraphic and tectonic history from Paleozoic time to Recent.

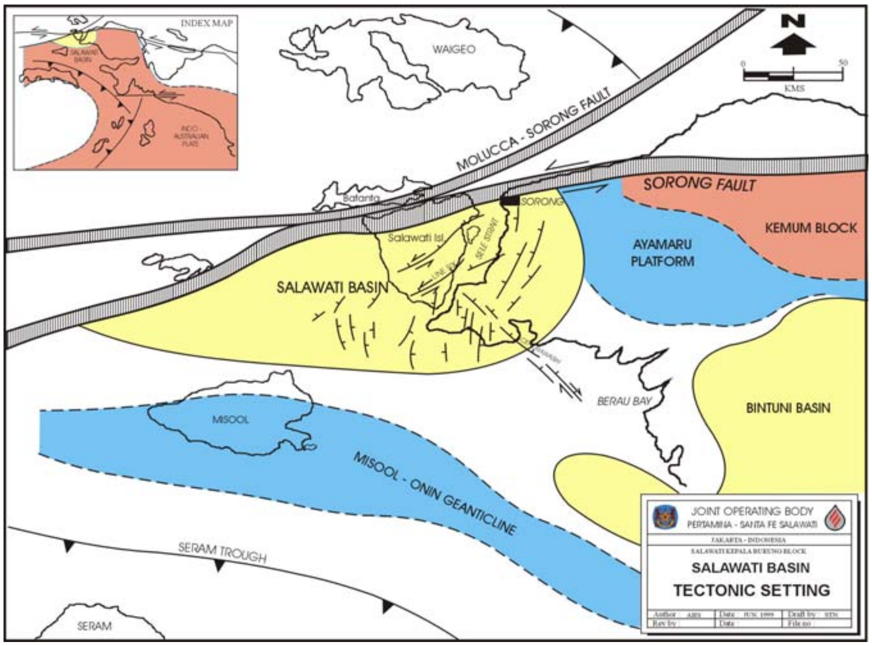

Figure 2 Tectonic setting of Klamono and Linda Fields

Stratigraphic Framework

The oldest stratigraphic sequence of the Salawati Basin is the continental basement rocks of the Siluro-Devonian Kemum metamorphics and Carbon-Permian Aifam continental margin sediments (*Figure 3*). Overlying the basement are Mesozoic sediments (Tipuma and Kembelangan groups), which developed only in the southern part of the basin due to the Late Cretaceous - Paleocene northern erosion or a Mesozoic northern non-deposition.

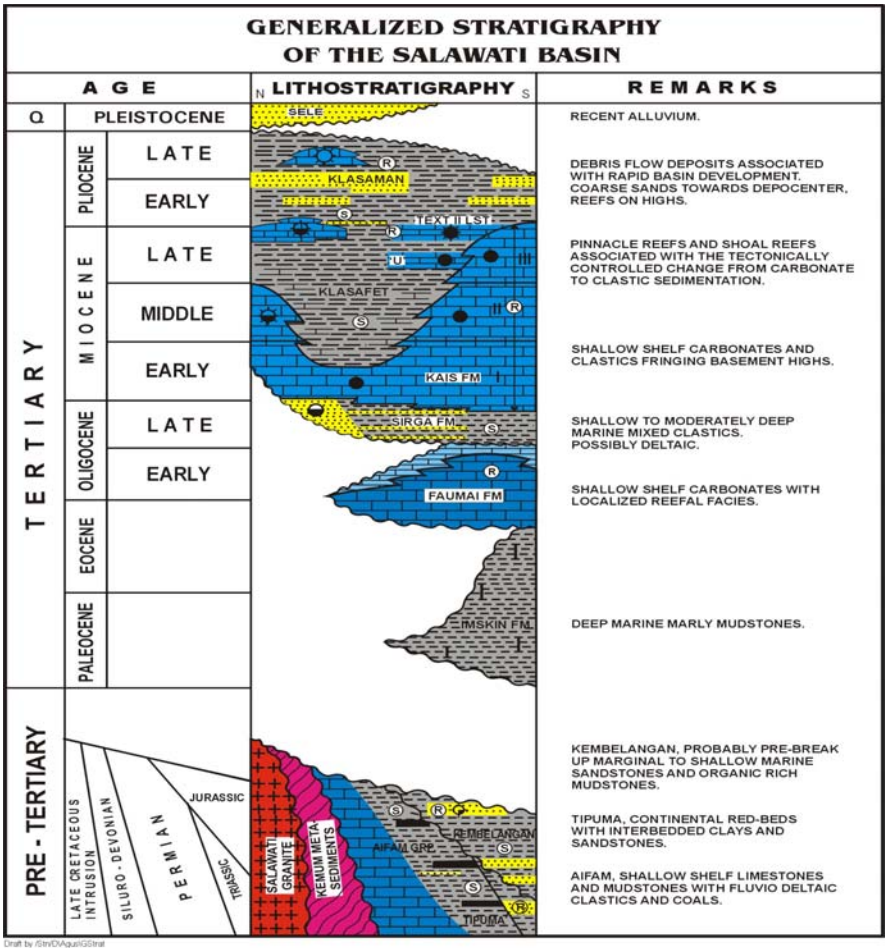

Figure 3 Stratigraphy of Salawati Basin

Tertiary sediments of the Salawati Basin began with the late Eocene to early Oligocene transgressive carbonates of the Faumai Formation. Overlying the Faumai carbonates, is the late Oligocene shallow marine clastics of the Sirga Formation. Thick carbonates of the Miocene Kais Formation cover the Sirga clastics.

Kais carbonates developed in various environments from lagoonal, bank, to deeper water facies, resulting in various types of carbonate sediments including low-energy organic-rich carbonate muds, moderate-high energy reefal carbonates, and fine crystalline carbonates. Kais carbonates are the producing reservoir of all Salawati's fields. Contemporaneously with the Kais carbonate deposition, was the deposition of the Miocene lagoonal Klasafet fine calcareous clastics (marls). The thick Pliocene Klasaman clastics ended the Tertiary stratigraphic sequences. Molassic deposits of the Sele conglomerates were deposited in Pleistocene time as eroded sediments from the deformed zone of the Sorong Fault.

Structural Framework

The main structural grain of the Salawati Basin is the Sorong Fault, which bounds the basin to the north. This is a major left - lateral fault that has been active in the basin since the Late

Pliocene. Present structural style of the basin is dominated by NNE - SSW normal faults formed as conjugate of the Sorong Fault. The Sorong Fault has also developed en echelon folds and synthetic left-lateral faults with normal slip (such as the “Line Six” Fault) in the Salawati Island. The movement of the Sorong Fault has also reactivated older normal faults, starting as rifts in the Late Paleozoic - Mesozoic time such as the Cendrawasih Fault, to become antithetic right-lateral faults with normal slip. Regionally, the Sorong Tectonism was responsible for the reversal of the basin’s polarity causing a number of geologic episodes such as the subsidence of the northern depocenter and the uplifting of the Misool – Onin Geanticline and the Ayamaru Carbonate Platform.

Petroleum System

Existing oils in the Salawati Basin were sourced by the Miocene Klasafet and Kais carbonaceous shales and carbonates. The sources have been mature since the mid-Pliocene. The generated oils have been migrated through several focused migration fairways of Kais/Klasafet carrier beds forming structural noses and enhanced by faults trending parallel with the noses (Satyana *et al*., 2000). The proven reservoir is the Miocene Kais carbonates forming as reefal build ups sealed with the Klasafet shales.

BIODEGRADATION OF THE KLAMONO OILS

Klamono Field

The Klamono Field is the easternmost field in the Salawati Basin. It is located not far from the Ayamaru Platform where the Kais carbonates were exposed. The Ayamaru Platform terminates the Salawati Basin to the east. The Klamono field was discovered in 1936 by the NNGPM Nederlandsch Nieuw Guinea Petroleum Maatschappij - Dutch New Guinea Oil Company) and has been operated by Pertamina since 1971.

The discovery well of Klamono-1 was drilled on a surface anticline near numerous oil seeps. The Klamono Field is a shallow Early-Late Miocene Kais reefal build up with the overlying Klasafet sediments forming a drape observed as an anticline at the surface. The Kais reservoirs in the field have high porosities and permeabilities of average 23 % and 400 mD, respectively. The field has been producing oil since 1949.

Geochemistry of the Biodegraded Oil

The Klamono oils have been biodegraded. The Klamono-1 well discovered black liquid oil with API gravity below 20°, this may indicate that the oil has been altered by water washing or bacterial activity. The oils of the field have been analyzed for the bulk properties, biomarkers, and carbon isotope; the analytical results confirm the biodegradation of the Klamono oils.

Table 3 shows the bulk properties and isotope characteristics of the Klamono oils. The oil is heavy (17° API), moderate sulfur content (1.0 %), low pour point (-12° C), very low GOR (gas to oil ratio) of 3.3, high viscosity (26 centi poise), low saturate content (31.7 %), high asphalt content (6.1 %), low saturate to aromatic ratio (0.74), and increased 13-carbon isotope ratio of saturate fraction (-20.24 ‰). *Figure 4* shows the GC (gas chromatograph) scan of the Klamono oil. It shows the removal of the majority of n-paraffins and isoprenoid alkanes of pristane and phytane. These characteristics show that the Klamono oil is biodegraded.

oil sample	API gravity (°)	sulfur content (%)	pour point (°C)	oil viscosity (cp)	gas oil ratio (GOR)	wax content (%)	saturate fraction (%)	asphalt fraction (%)	saturate aromatic ratio	^{13}C saturate	remarks
Klamono	17	1.0	-12	26	3.3	5.8	31.7	6.1	0.74	-20.24	biodegraded
Linda	19	1.3	-18	20	tstm	0.0	54.0	9.0	2.25	-20.16	biodegraded
Walio	34	0.7	-6	2	86	3.2	58.9	3.3	2.24	-22.04	non-biodegraded

Table 3 Characteristics of Klamono and Linda oils showing oil biodegradation as referred to the non-biodegraded Walio oil. Some anomalies could be resulted from influences of source facies and degree of maturity, interpretation of these data should be combined with the GC and GC/MS data.

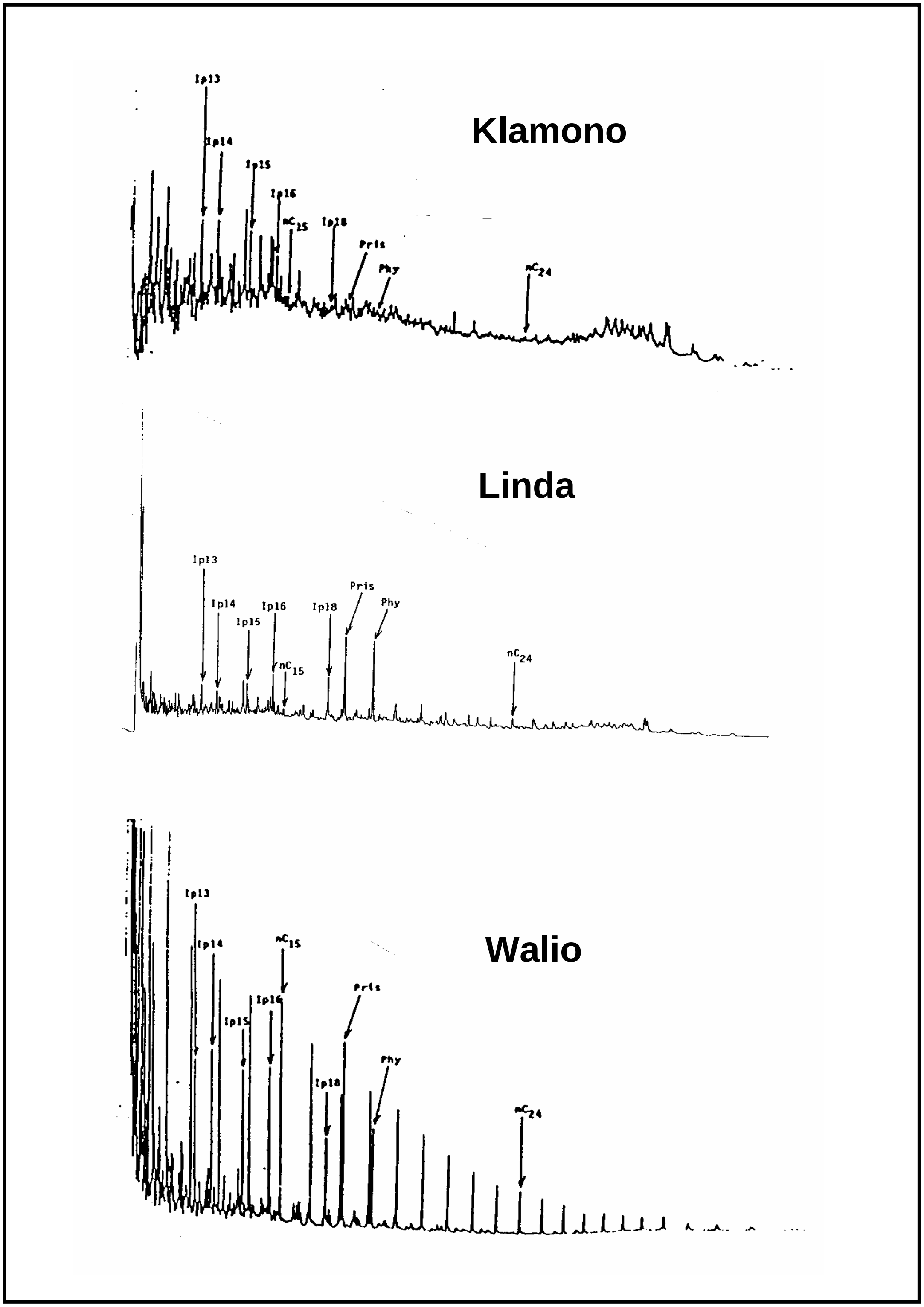

Figure 4 C10+ saturated GC scan of Klamono and Linda oils (biodegraded) and Walio oil (non-biodegraded)

Sulfur content and API gravity of oil is controlled by factors of source environment, maturation, migration, and biodegradation. The non-biodegraded Salawati oils contain 45 to 60 % saturated hydrocarbons. Pour point of oil usually reflects wax content of oil. Biodegraded oil has low pour point due to a lack of higher molecular weight (C_{22} – C_{34}) n-paraffins in oil. Carbon isotope value of saturate fraction may slightly less negative (increased) due to effect of biodegradation.

Meteoric waters penetrating into a basin and contact with an oil field preferentially dissolves the most soluble hydrocarbons, such as methane, ethane, benzene, and toluene. Microbes in the water consume the hydrocarbon molecules such as paraffins, naphthenes, and aromatics (Waples, 1985; Hunt, 1996) producing heavy oil with low API gravity, low saturate (alkane) content, high asphalt content and removing the majority of n-paraffins and isoprenoids.

Figure 5 shows the GCMS (gas chromatograph mass spectrometry) data of the Klamono oil compared to other oil in the Salawati Basin which is known to be non-biodegraded (Walio oil). Both fragmentograms (GCMS curves) of the terpane (fragment ion m/z 191) and the sterane (fragment ion m/z 217) of the Klamono oil show perfect resemblance to those of the Walio oil. The Klamono oil triterpane and sterane distributions have been totally unaffected by the biodegradation. This indicates that the biodegradation of the Klamono oil has not reached a degree at which biomarkers of steranes and terpanes are attacked.

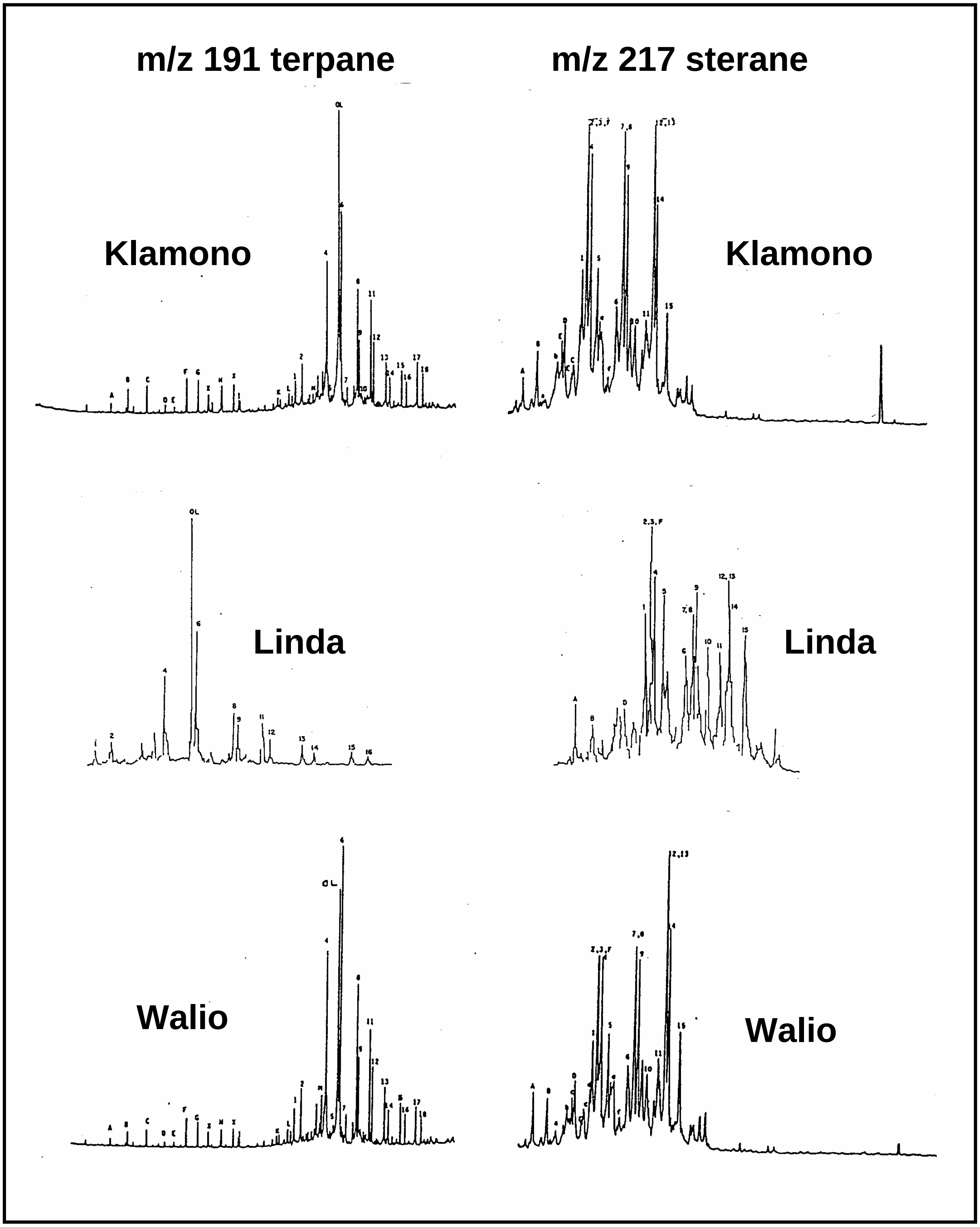

Figure 5 GC/MS scan m/z 191 (terpane) and m/z 217 (sterane) of Klamono, Linda, and Walio oils showing similar distribution indicating no attack of biodegradation on terpane and sterane of Klamono and Linda oils.

Degree of Biodegradation

Based on the removal of the majority of n-alkanes (paraffins) and some of isoprenoids, and the preserves (not attacked) of biomarkers at steranes and triterpanes distributions (hopane, oleanane, tricyclic terpane, diasterane, etc), then the degree of biodegradation of the Klamono oils is *moderate* or at rank 3 to 4 at Hunt's (1996) biodegradation scale (1 = minor, 10 = extreme).

BIODEGRADATION OF THE LINDA OILS

Linda Field

The Linda Field is located 4 kilometers to the northeast of the giant Walio Oil Field and frontal to the major surface Cendrawasih Fault. The Linda Field was discovered in 1977 by Pertamina through its discovery well of Linda A-2. The field is now operated by PT Intermega.

The Linda Field is a small patch reef of the Late Miocene Kais carbonates with its eastern half is down thrown some 100 meters by a normal fault splay of the Cendrawasih Fault. The upblock western half becomes the Linda Field, whereas the downblock eastern half is below the oil water contact at 1002 meters subsea. The Kais reservoir in the field has average porosity of 15 % and permeability of 24 mD.

Geochemistry of the Biodegraded Oil

The Linda A-2 discovery well found the black liquid oil with API gravity of 20° and sulfur content of 1.30 %. This may indicate a water washing or biodegradation. The oils of the Linda Field have been analyzed for the bulk properties, biomarkers, and carbon isotope; the results confirm the biodegradation of the Linda oils.

Table 3 shows the bulk properties and isotope characteristics of the Linda oils. The oil is heavy (19° API), moderate sulfur content (1.3 %), low pour point (-18° C), very low GOR (too small to measure), high viscosity (20 centi poise), high asphalt content (9.0 %), and increased 13-carbon isotope ratio of saturate fraction (-20.16 ‰). High saturate fraction (54 %) is questionable.

Figure 4 shows the GC (gas chromatograph) scan of the Linda oil. It shows the removal of the majority of n-paraffins and isoprenoid alkanes. These characteristics show that the Linda oil has been biodegraded to some extent. The pristane to phytane ratio of 1.20 indicates a marine affinity of source rock. The high pristane/nC_{17} of 7.86 and phytane/nC_{18} of 5.08 is due to biodegradation.

Figure 5 shows the GCMS (gas chromatograph mass spectrometry) data of the Linda oil compared to other oil in the Salawati Basin which is known to be non-biodegraded (Walio oil). Both fragmentograms (GCMS curves) of the terpane (fragment ion m/z 191) and the sterane (fragment ion m/z 217) of the Linda oil show perfect resemblance to those of the Walio oil. The Linda oil triterpane and sterane distributions have been totally unaffected by the biodegradation.

This indicates that the biodegradation of the Linda oil has not reached a degree at which biomarkers of steranes and terpanes are attacked.

Degree of the Biodegradation

Based on the removal of the majority of n-alkanes (paraffins) and some of isoprenoids, then the degree of biodegradation of the Linda oils is *moderate* or at rank 3 to 4 at Hunt's (1996) biodegradation scale.

ORIGIN OF THE BIODEGRADATION

Supportive Conditions

Geologic setting of the Klamono and Linda Fields supports the conditions within which the oil alteration through water washing and biodegradation can take place.

The fields are located close to the area of supply of fresh, nutrient rich, oxygenated water. The Kais reservoir of the Klamono Field is exposed to the east of the field in the Ayamaru Platform area. This area is the recharge area of meteoric water. The Linda Field is located frontal to a major surface normal fault of the Cendrawasih Fault. The surface fault is considered as the recharge area of meteoric water.

The Kais reservoirs in the two fields are shallow and their temperatures are low to cause the biodegradation to occur. The productive interval of the Kais carbonates in the Klamono Field range in depth from 100 to 350 meters with reservoir temperature of around 55°C. The productive Kais reservoirs of the Linda Field range in depth from 960 to 1040 meters and the reservoir temperature is around 69°C. The deepest degraded oils associated with meteoric waters have been found as deep as 3048 meters (10,000 feet) in the Bolivar coastal fields of Venezuela (Bockmuelen *et al*., 1983). Temperature of 88°C or 190°F is the maximum temperature of known biodegraded reservoir oil (Connan, 1984).

The continuing supply of fresh oxygenated water and low reservoir temperature would have favored the presence of bacteria and oil-water / bacteria contact within the Klamono and Linda Fields. This can be confirmed by analyzing the presence of bacteria within the Klamono and Linda oils. The organism *Pseudomonas methanica*, which grows at the expense of methane, ethane, propane, and butane (Hunt, 1996) may be discovered.

The water salinity of the Klamono and Linda Fields are also supportive for the biodegradation to occur. The water salinity of the fields are low (760-1400 mg/l) compared to the regional trend (5800 mg/l). Biodegraded oils are generally associated with meteoric waters low in dissolved solids. This was demonstrated by Bailey *et al.* (1973) for oils in the Williston Basin, Saskatchewan. The waters there caused various levels of biodegradation, depending on the extent of water invasion. In the area of saline brines in the southeast, the oils are about 36° API gravity. Moving north the waters become increasingly fresh, and the oil changes from 35 to 31, 27, 20, and less than 15° API gravity.

Water Washing in the Klamono Field

It has been clear that the meteoric water invasion of the Klamono Field comes from the Ayamaru Platform to the east (*Figure 6*). The Kais reservoir of the Klamono Field is exposed in this area. Meteoric water carrying fresh, nutrient rich, oxygenated water has entered the exposed Kais and flowed downdip to the equivalent Kais in the Klamono Field. The porous Kais carbonates have enhanced the water invasion. The meteoric water contained a wide variety of bacteria. The oil-water/bacteria contact was formed in the field and the bacteria have consumed the oil as a source of energy in their metabolism. By this way, the Klamono oil was degraded.

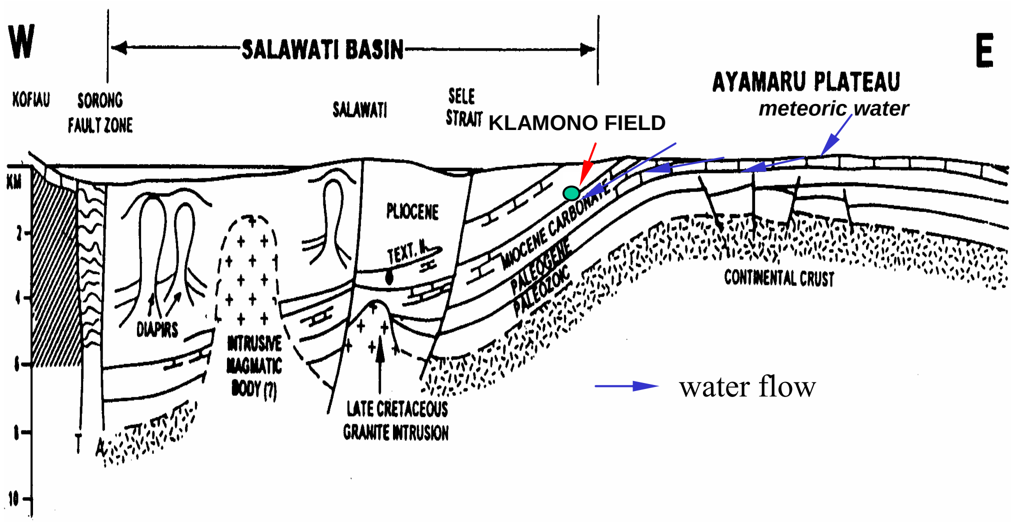

Figure 6 Mechanism of meteoric water flushing and biodegradation in the Klamono Field.

Water Washing in the Linda Field

The Linda Field is located frontal to the major surface normal fault of the Cendrawasih Fault. A north – south trending splay of the fault had faulted the Linda Field (*Figure 7*). The eastern half of the field is down thrown some 100 meters by the normal fault. The upblock western half becomes the Linda Field, whereas the downblock eastern half is below the oil water contact. The fault, which is up to the surface in association with the Cendrawasih Fault, is considered to have become a conduit for meteoric water to contact the Kais reservoir in the faulted Linda Field. As in the Klamono Field, this meteoric water has contained a wide variety of bacteria that eventually have degraded the Linda oils.

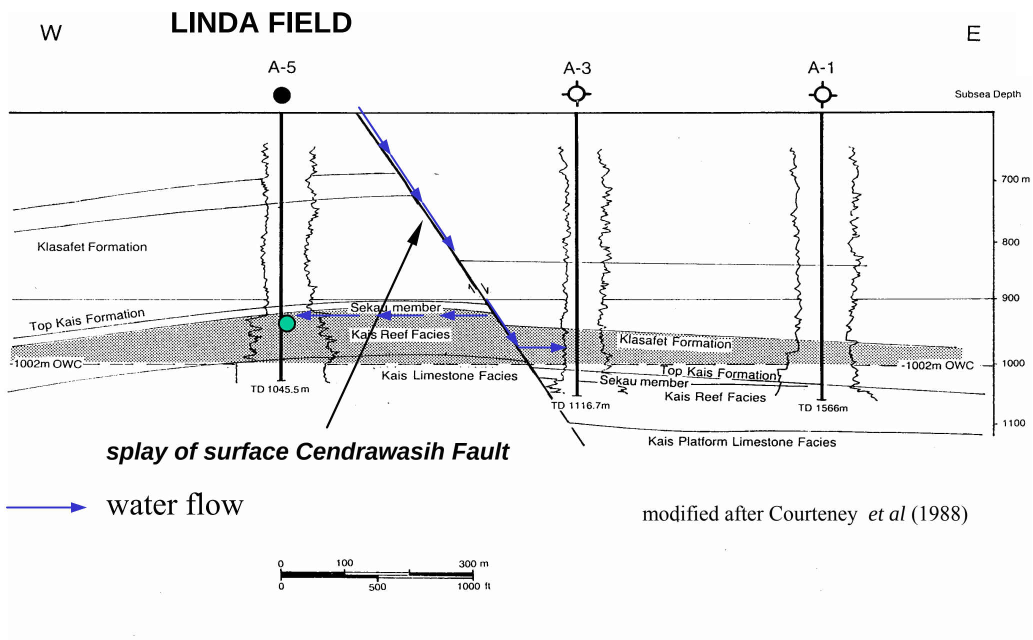

Figure 7 Mechanism of meteoric water flushing and biodegradation in the Linda Field.

REGIONAL IMPLICATIONS

Figure 8 shows the possible area in the Salawati Basin where the biodegradation may occur. This map was based on the geochemical properties of the Salawati oils (API gravity, sulfur content, GC scan), surface geological map, depth map of Kais reservoir, and regional Kais water salinity map. The mechanisms of water washing in the Klamono and Linda Fields were used as the models. Based on the Klamono biodegradation model, exposed reservoir in updip area of field may have a potential to cause biodegradation in field located downdip close to the reservoir exposure. Based on the Linda model, field located frontal to major surface fault may have a potential to be biodegraded. Key constraint in these models that should be checked is reservoir temperature. As long as the reservoir temperature is more than 88° then biodegradation will not occur although field is located close to area of meteoric water supply. However, oil degradation by water washing may still occur since the water washing is independent of temperature.

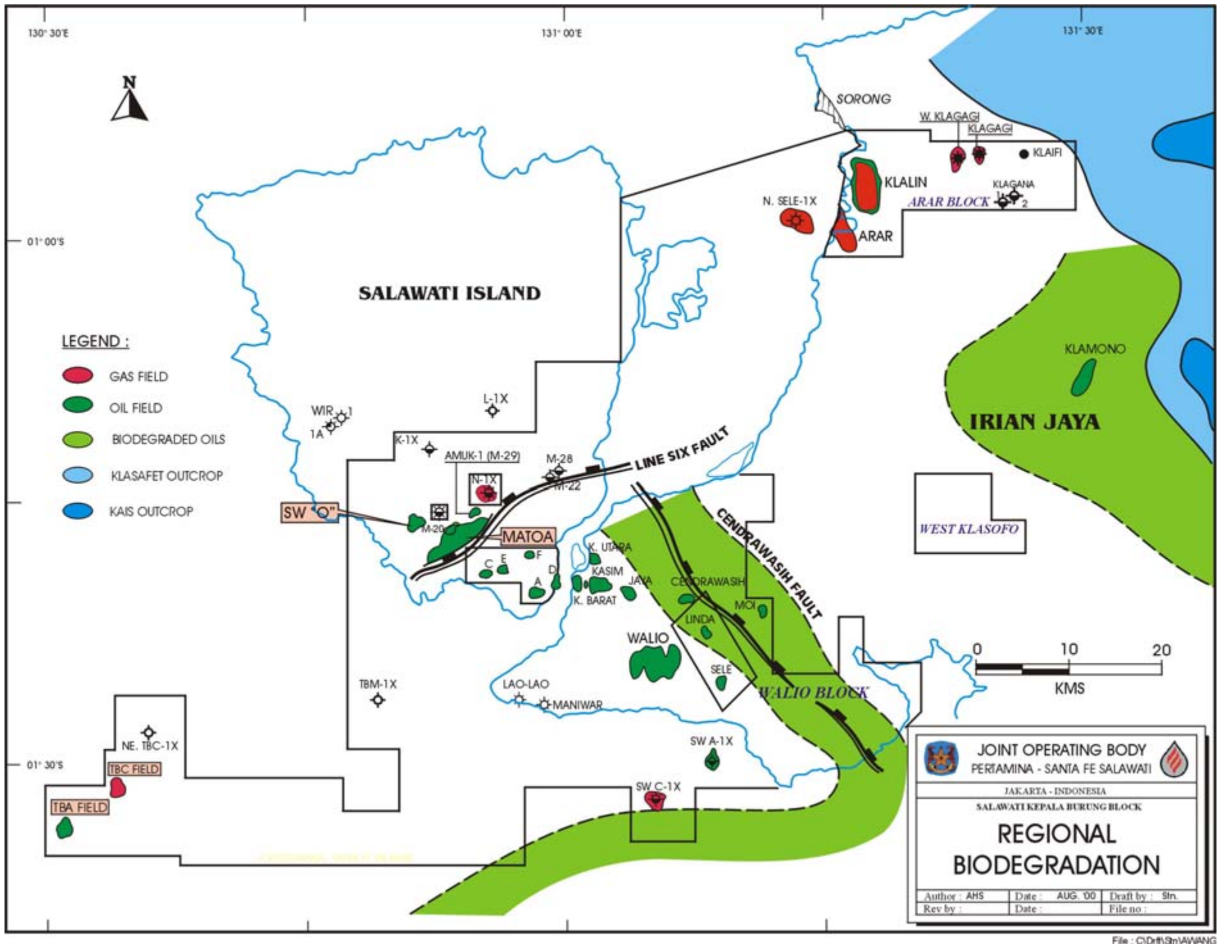

Figure 8 Area with regional biodegradation of the Salawati Basin

The expected biodegradation area based on the Klamono model is around the Klamono Field extents to the north, west, south and east. The Kais reservoirs in this area are estimated to have temperature less than 88°C and to have connection with the exposed Kais in the Ayamaru Platform. This potential area of biodegradation is proved by heavily biodegraded oil of Klamumuk (NNGPM, 1952) and slightly biodegraded oil of Klamogun (NNGPM, 1953). Klamogun, Klamono, and Klamumuk trend west – east with Kais reservoir is increasingly shallower from Klamogun to Klamumuk and the reservoir temperature decreases. Consequently, the effect of biodegradation increases to the east from the Klamogun to the Klamumuk area. Degree of biodegradation increases as reservoir temperature decreases (Connan, 1984).

The expected biodegradation area based on the Klamono model is also indicated in the offshore area of South Walio. Oil from South Walio C-1X (Phillips, 1978) indicates some biodegradation (21°API gravity). This is considered due to the shallow Kais reservoir (680 meters deep). The meteoric water invasion may come from the Kais carbonate exposure to the south of the Salawati Basin at the Kais carbonate islands on the belt of the Misool-Onin Geanticline. Uplifted Kais of this geanticline is equivalent to the uplifted Kais in the Ayamaru Platform

The expected biodegradation area based on the Linda model is concentrated along the Cendrawasih Fault trending northwest – southeast to some extent from the master fault. The possibility of the biodegradation in this area is proved by the biodegraded oils located north to south and close to the Cendrawasih Fault namely Parkit oil (14.1°API gravity), Moi oil (15.5°API, 1.96 % S), and Kasuari oil (17°API, 2.27 % S)

The Matoa Field (JOB Pertamina-Santa Fe) in the Salawati Island is located frontal to the normal fault of the "Line Six" Fault. This is a major normal fault like the Cendrawasih Fault which is also up to the surface. However, the Matoa oils have not been biodegraded (33°API gravity, sulfur 0.17 %) and this because of high Kais reservoir temperature (97°C) of the Matoa Field at the depth of 2950 meters.

Undrilled prospects may have advantage on these regional implications. It can be used to expect biodegradation or non-biodegradation in the area of prospect, then economic value of expected oil can be known.

CONCLUSIONS

- Klamono and Linda oils, Salawati Basin, have been moderately biodegraded (level 3 to 4 at Hunt (1996)'s scale of biodegradation).
- Klamono oil alteration took place when meteoric water entering the equivalent outcropped Kais reservoir flowed downdip into the field and altered the reservoir oil through water flushing and biodegradation.
- Linda oil alteration took place when meteoric water entering the surface Cendrawasih Fault flowed downdip through a splay of the fault into the field and altered the reservoir oil through water flushing and biodegradation.
- Fields or oils of the Salawati Basin with shallow reservoirs and located frontal to the outcropped Kais reservoir at the Ayamaru Platform or along the major surface faults such as the Cendrawasih Fault have potential to be biodegraded.

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