PS An Overview of Geochemical Exploration of Hydrocarbons in Papuan Basin, Papua New Guinea*

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Abstract

Papua New Guinea has five sedimentary basins of which only one (Papuan basin) is a producing basin. Exploration efforts in the larger Papuan basin has been in progress for decades. The larger Papuan basin is characterized by varied geology, age, tectonics and depositional environments. Hydrocarbon shows, oil and gas discoveries in commercial, sub-commercial and non-commercial quantities have been made. Petroleum production is limited to the highlands of Papuan fold belt at present. Exploration for hydrocarbon in Papuan basin is challenging due to structural complexity, poor-fair quality seismic and limited dataset. The purpose of this study is to evaluate source rock and hydrocarbon geochemical data available to improve our understanding of burial history, maturity, timing of hydrocarbon generation and migration. This will help constrain opportunities to develop new petroleum charge models for geological features across the Papuan basin and to lower exploration risk. The present-day oil accumulations in the Papuan fold belt fields such as Kutubu (Iagifu, Hedinia) and Gobe are thought to be derived from clay-rich, Jurassic marine source rocks containing mixed algal–terrigeneous organic matter that were deposited in oxic environments possibly along shelf slopes. The co-reservoired natural gases suggest a substantial gas input from the basinal facies further to the north/northwest, reflecting relatively more marine-influence, high maturity, and cracking-genesis attributes. The basinal facies of Jurassic source rocks may have only contributed highly mature gas-condensate to the current deposits (Hides, Juha, P'nyang), however, implying a loss of the earlier-generated black oils. Published data for geochemical characteristics of recovered oils, oil extracts, fluid inclusion oils, condensates, and oil/gas seeps suggest two major families of hydrocarbons occurring in both the western and eastern Papuan basin regions. Hydrocarbons in the western region (Papuan foreland) were likely sourced from Late Triassic and Late Jurassic clay-rich marine source rocks containing terrigeneous higher plant derived organic matter (OM) deposited in a sub-oxic to oxic environments. Five oil families and two charge events have been modelled based on the geochemical data. Hydrocarbons distributed in the eastern region were generated from Cretaceous or younger marine carbonate source rocks deposited in an anoxic to sub-oxic conditions. Biomarker characteristics of solid bitumen extracts from Late Cretaceous Pale and Subu sandstones indicate two separate oil charges. One (family A) is from a strongly terrestrially influenced marine source rock that may well be Jurassic in age whereas the other (family B) originated from a marine source rock with a calcareous component, with a high proportion of prokaryotic OM and a low proportion of terrestrial higher plant inputs. The Mesozoic rift basin of Gulf of Papua (GoP) contain more gas than oil because the Middle-Upper

Jurassic or Lower Cretaceous marine source rocks have mixed gas-oil potential. The quality of source rocks is fair to good, typically averaging 150−300 mg HC/g rock HI and 1−2% TOC, with good average thickness of 2−3km. The Jurassic source rocks in the GoP have generated petroleum in two discrete pulses, the first at the end of the Cretaceous and the second at the end of Cenozoic where the end-Cretaceous pulse was volumetrically more important. Mesozoic hydrocarbons draining into Tertiary reef traps were limited because reefs were not present however, the gas-condensates accumulation in Tertiary reefal carbonates were derived from the depleted Jurassic source rocks during the Late Cenozoic generation and migration. Numerous studies on hydrocarbon characteristics from the larger Papuan basin indicate that the hydrocarbons are not homogeneous and display variabilities. The variabilities are likely to be a function of lateral and vertical changes in both organic facies and source rock maturity.

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An Overview of Geochemical Exploration of Hydrocarbons in Papuan Basin, Papua New Guinea

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PNG's Oil and Gas Industry: Maturing Through Exploration, Development, and Production

Introduction

Petroleum exploration has a long history in Papua New Guinea (PNG), with the first well, Upoia-1, drilled in 1912 (Rickwood, 1990). Exploration efforts in the larger Papuan basin has been in progress for decades and focused on prospects of Mesozoic and Tertiary age. The larger Papuan basin is characterized by varied geology, age, tectonics and depositional environments. Typical reservoir rocks are Late Jurassic−Early Cretaceous shoreface to estuarine sandstones and Miocene carbonates. These reservoirs are charged virtually by Mid-Late Jurassic organic rich marine type II and III shales (i.e. Magobu Coal, Barikewa, Maril and Imburu Formations).

Geochemical data of oil, gas and source rocks suggest hydrocarbons in the larger Papuan basin have a variety of origins. Oil accumulations in fields such as Kutubu, Moran and Gobe are thought to be mainly derived from clay-rich, Jurassic marine source rocks containing terrestrially-derived organic matter that were deposited under oxic conditions. Organic geochemistry of hydrocarbons from Papuan foreland suggest three different generative source rocks which are (1) Late Cretaceous marine source rocks deposited in a reducing conditions, (2) an algal-dominated lacustrine source rocks, and (3) carbonate-rich source rocks deposited in a sub-oxic conditions. Hydrocarbons in the Eastern Papuan basin (EPB) were generated from sources of Jurassic age enriched in clay and terrestrial organic matter deposited in a reducing conditions discovered in the Gulf of Papua (GoP) are believed to be generated from deltaic-marine mudstones rich in the remains of land-plants and Miocene marine shales.

The purpose of this study is to evaluate source rocks and hydrocarbon geochemical data available to improve our understanding of burial history, maturity, timing of petroleum generation and migration. This will help constrain opportunities to develop new petroleum charge models for geological features across the Papuan basin and to lower exploration risk.

Map of Papuan Basin

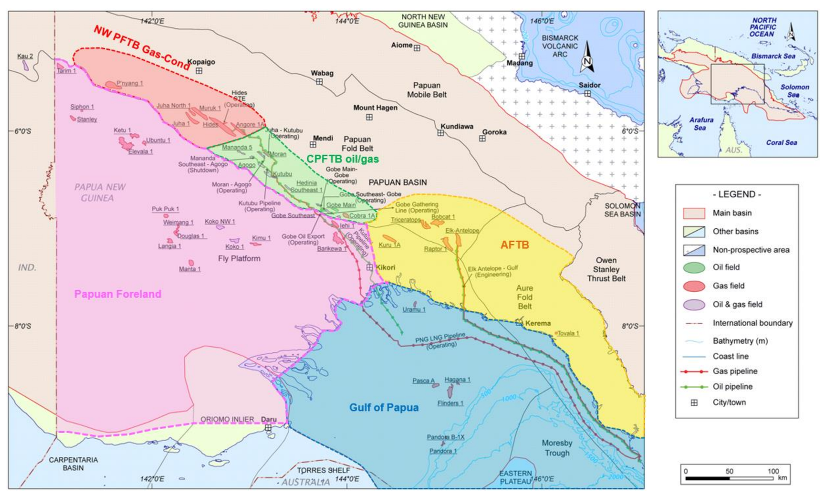

Fig.1. Map showing the larger Papuan basin, oil and gas fields, wells and pipelines. *Abbrev*: FTB, fold thrust belt; P, Papuan; A, Aure; NW, North West; C, Central

Papuan Basin Stratigraphy

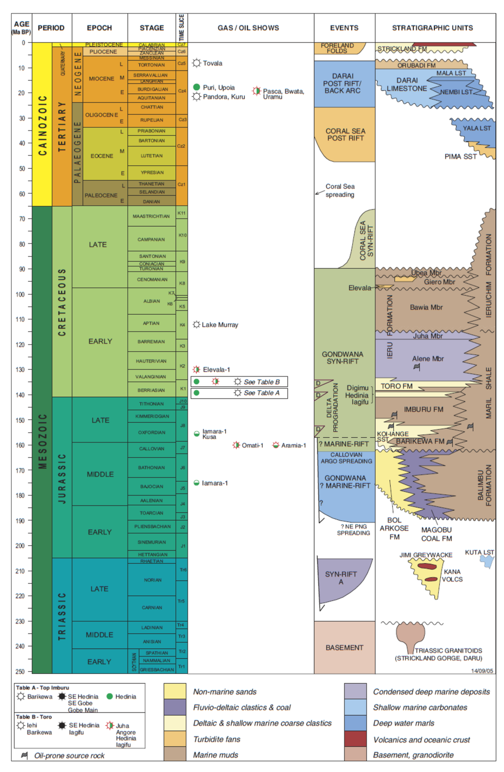

Fig. 2. Papuan Basin stratigraphy (after Home *et al.*, 1990)

Papuan Basin Petroleum Systems

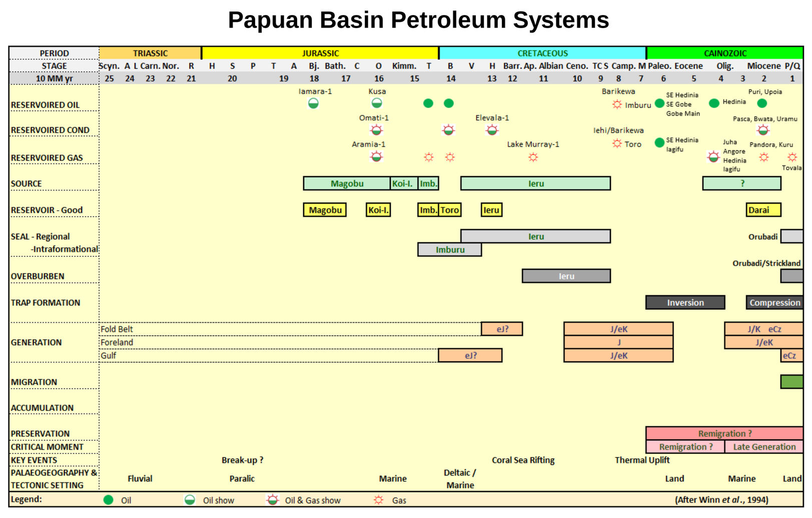

Fig. 3. Petroleum systems and events chart, Papuan Basin.

Oil and Gas Generation−Migration Concept

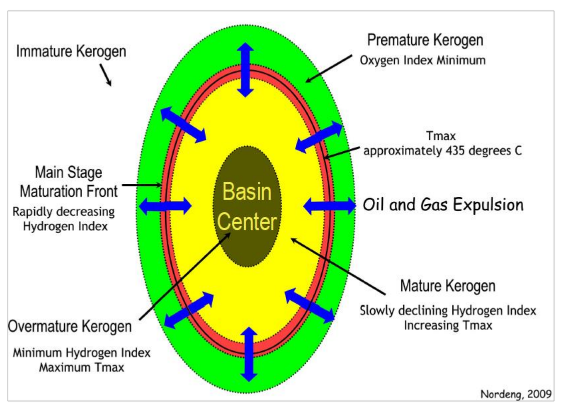

Fig. 4. Oil and gas formation−migration model.

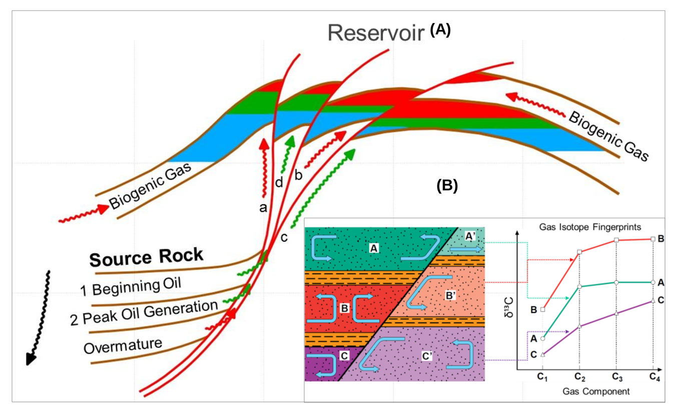

Fig. 5. (A) Episodic expulsion of natural gases during different stages of subsidence and maturity of source rock results in compositionally different gases in reservoirs. (B) Gas isotope fingerprinting is the principal tool that allows to recognize isotopically different gases in reservoirs.

Genetic Characterization of Natural Gas & Oil

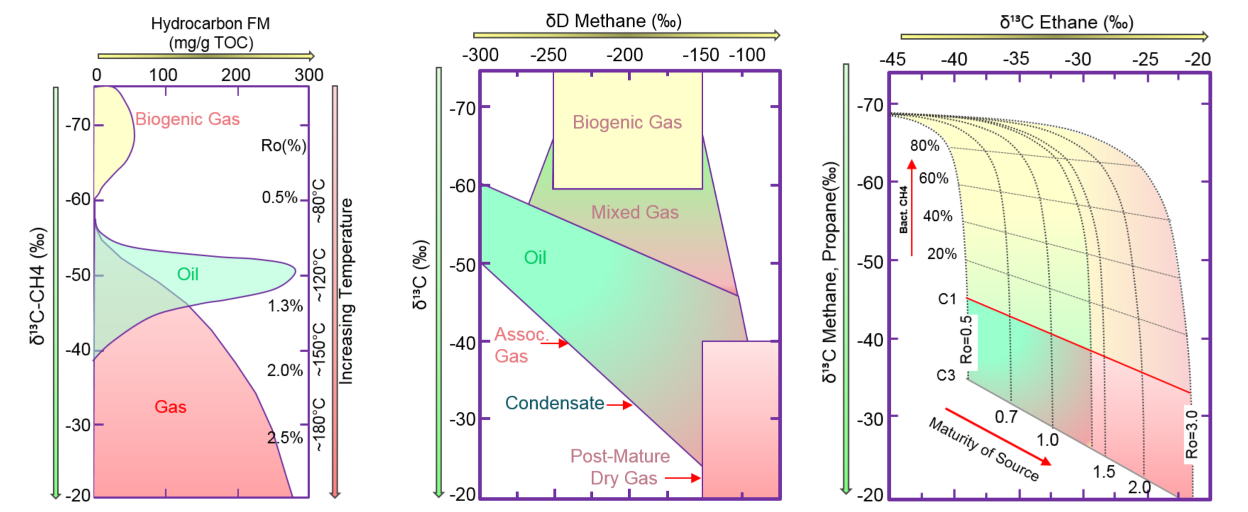

Fig. 6. Maturation and mixing are the two most important processes that control compositional and isotopic variations in natural gases. Maturation and mixing can be recognized through specific trends in diagrams for the genetic characterization of natural gases. Maturation generally results in all diagrams in trends towards more positive isotope values and lower C2+ values.

Papuan Basin Structures

Papuan Fold-Thrust Belt

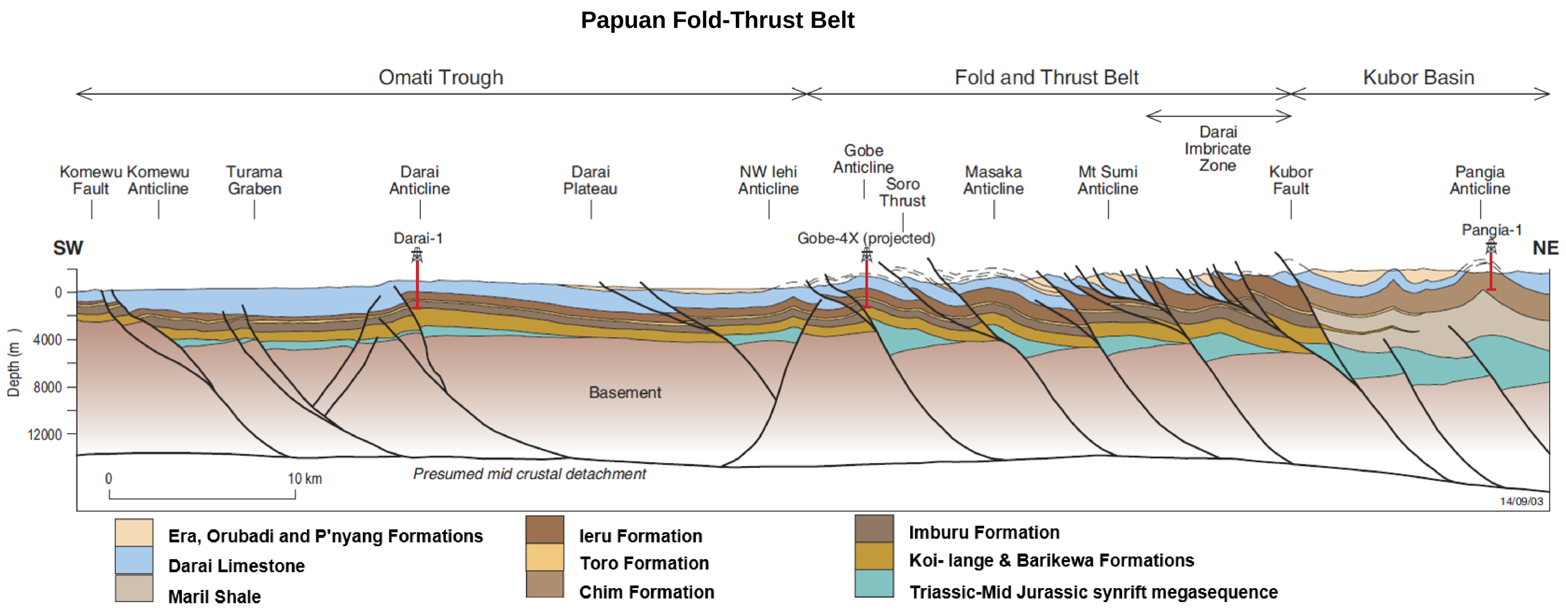

Fig. 7. Regional cross-section of the Papuan Fold & Thrust Belt (after Buchanan & Warburton, 1996).

Aure Fold-Thrust Belt

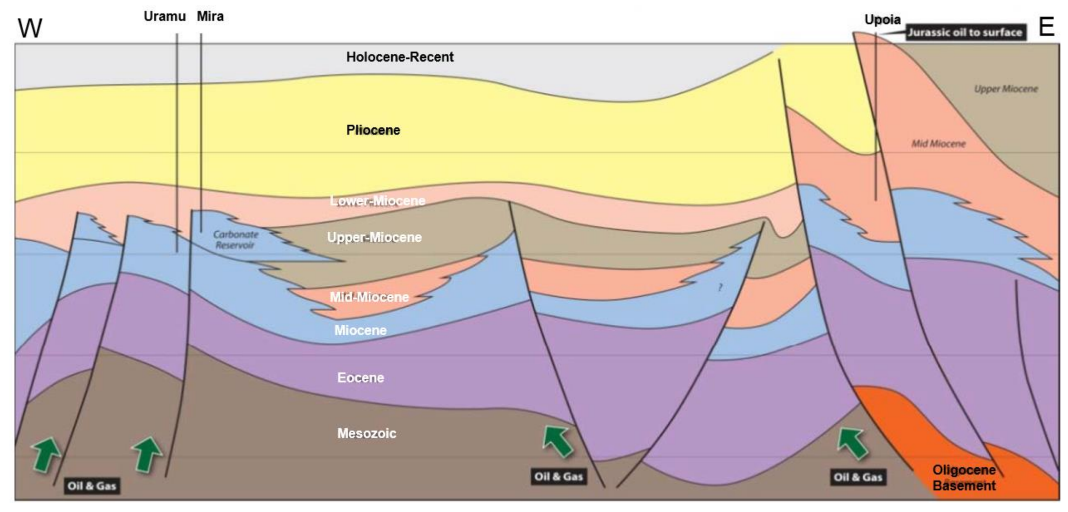

Fig. 9. Cross-section profile interpretation of shallow-water offshore to onshore of Eastern Papuan basin showing distribution of lithologies, structures, traps, reservoirs, sources and seals.

Papuan Foreland

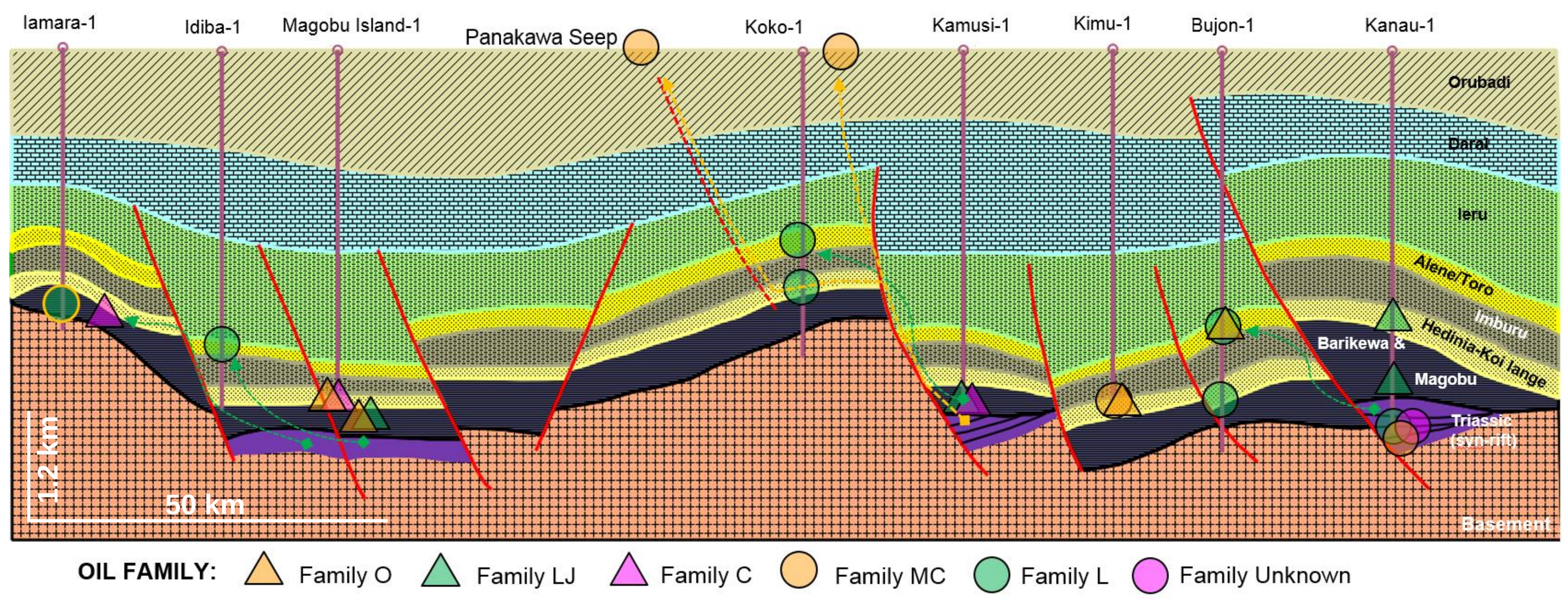

Fig. 8. Cross-section shows the distribution of low maturity oils. These oils are interpreted to be derived in-situ from source rocks in the near vicinity. The progenitor source rocks for these oils have been insufficiently buried to reach peak expulsion. There is a slight increase in maturity in a SE direction along the axis of the Omati Trough. Oil at Omati-1 recovered by DST indicate that Family LJ sources have reached peak expulsion in this area likely due to deeper burial, identified as Late Jurassic source by Waples & Wulff (1996). Modified after Wood, 2010.

Gulf of Papua

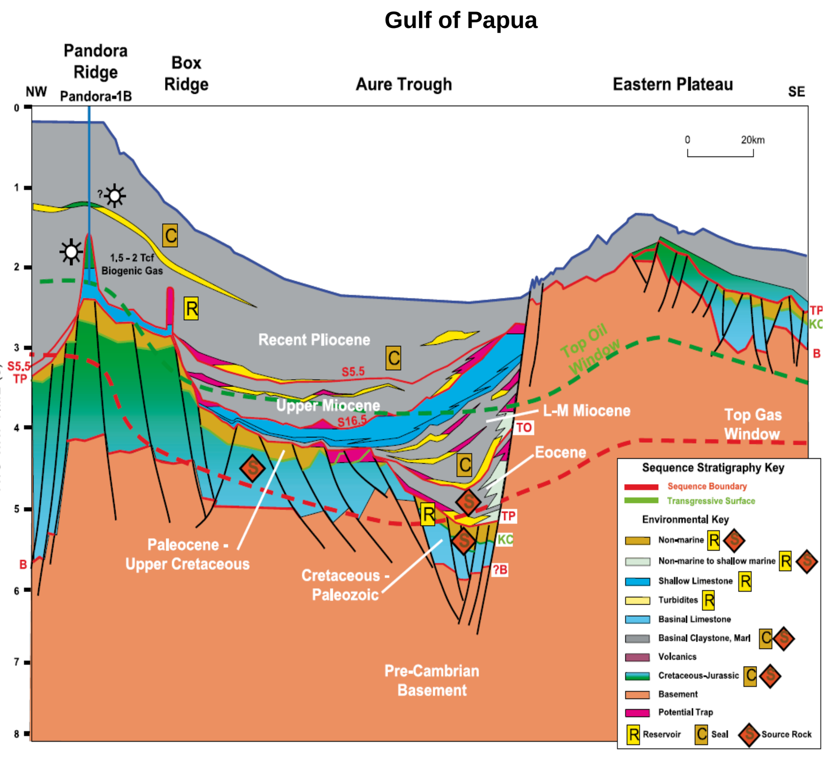

Fig. 10. Cross-section profile interpretation of deep-water GoP showing distribution of lithologies and environments, structures, traps, reservoirs, sources and seals and oil window (after Jablonski *et al*., 2006).

Petroleum Potential of Source Rocks

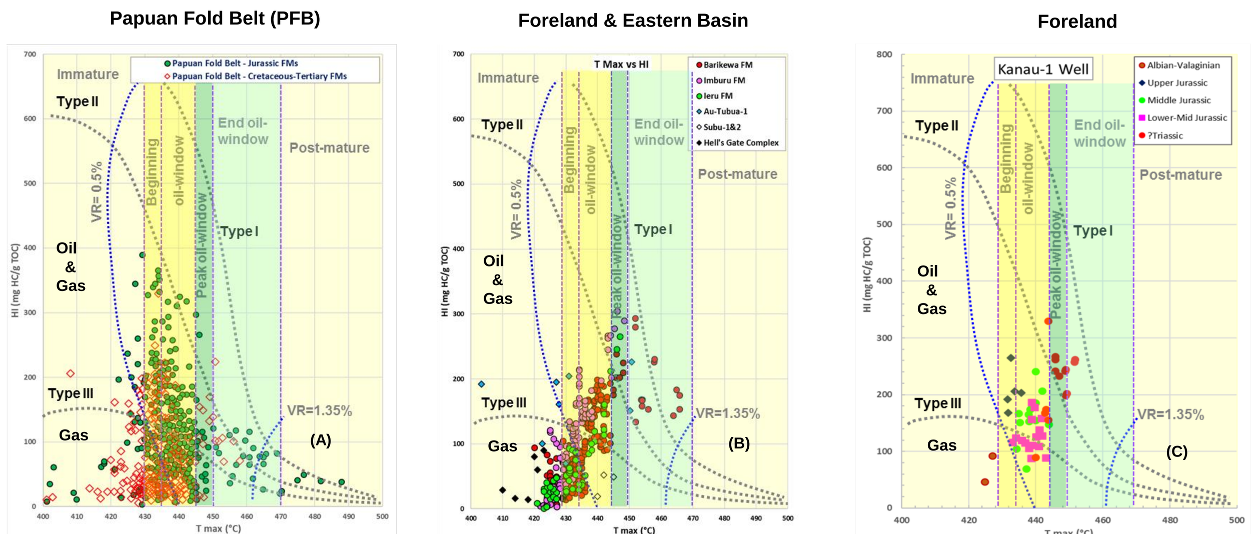

Fig. 11. Rock-Eval Tmax (°C) vs Hydrogen Index (mg S2/g TOC) plots indicate petroleum potential and thermal maturity for source rocks (TOC >1wt%) from the PFB (A), Foreland and EPB (B & C). Jurassic and Cretaceous−Tertiary source rocks from the PFB have in general potential for both oil and gas, and thermal maturities generally corresponding to the upper−middle part of the oil window. Maturity for Jurassic source rock samples ranges from early- to post-mature. Jurassic–Cretaceous and Cainozoic source rocks from the foreland and EPB have potential for oil and gas although some fall within the immature category. (C) Rock-Eval Tmax (°C) vs Hydrogen Index (mg S2/g TOC) for potential source intervals from Kanau-1 well in the foreland. Data from Winn *et al*., 1994; Wood, 2010; Carman, 1990; Volk *et al*., 2005.

Foreland & Eastern Basin

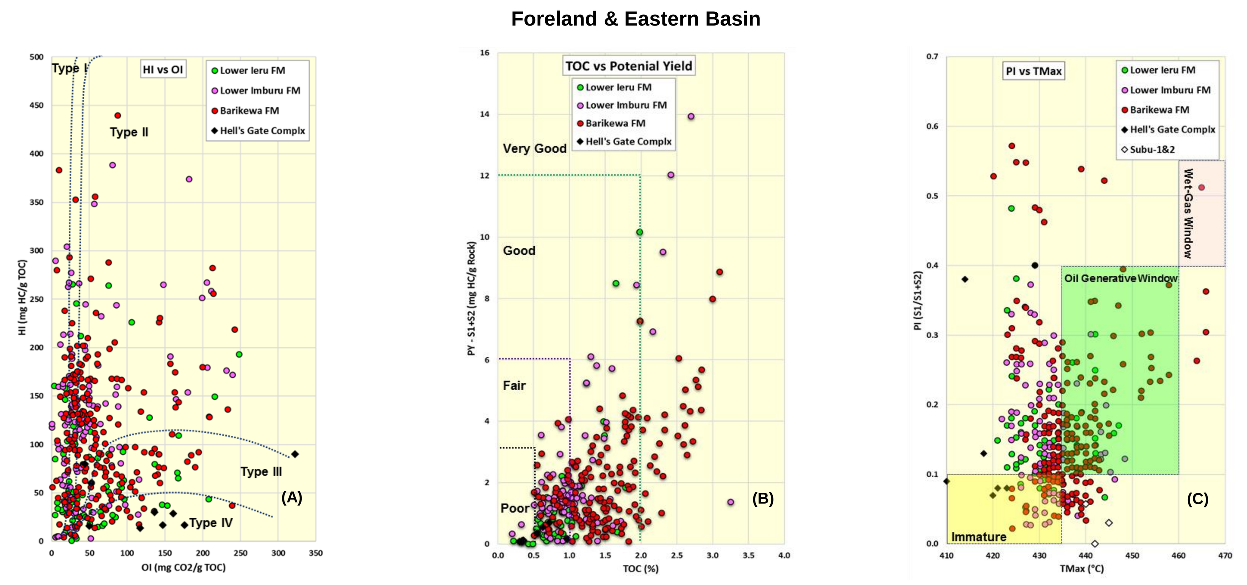

Fig. 12. (A) Van Krevelen diagram of HI vs OI indicates the Jurassic–Cretaceous source rocks of the Papuan foreland contain mostly Type I/II organic matter although Type III/IV are also present. Cenozoic source rock (Hell's Gate Complex) from EPB contains Type III/IV organic matter. (B) Values for TOC (wt% of total organic carbon in source rock) and S2 (source rock petroleum potential, mg petroleum per g TOC) indicate the richness and quality of source rock candidates. Only samples with TOC >1wt% are regarded as source rock candidates. Most samples from Jurassic–Cretaceous have fair to good potential. Late Jurassic source rocks (Barikewa & Imburu FMs) have good to very good petroleum potential. Note that increased maturity of a source rock sample decreases the petroleum potential. (C) The PI vs TMax indicates the Jurassic source rock (Barikewa FM) lies within the oil generative window. Data from Winn *et al*., 1994; Wood, 2010; Carman, 1990.

Thermal Maturity

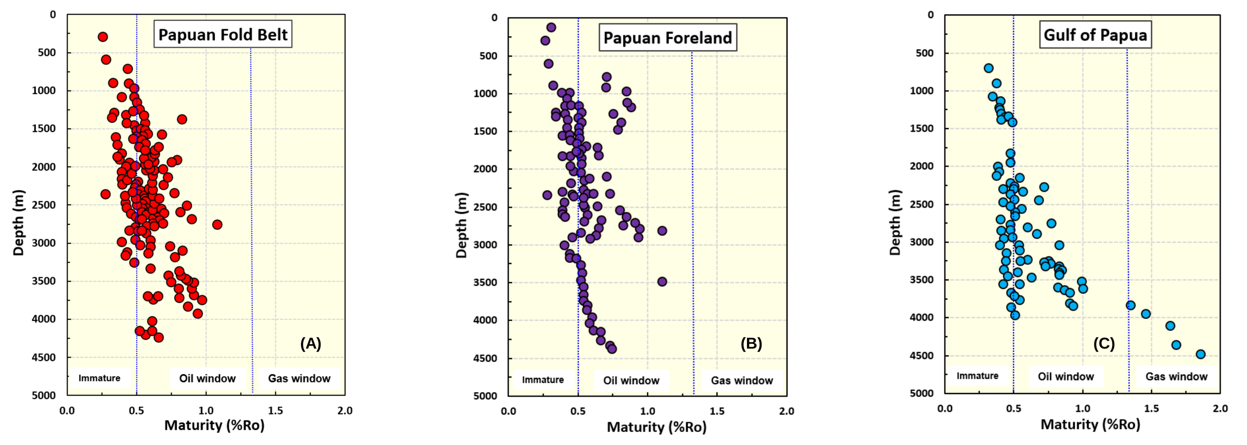

Fig. 13. A vitrinite reflectivity versus depth plot showing thermal maturity of source rock samples from various wells drilled in the (A) PFB area, (B) foreland and (C) the GoP. The majority of samples are in the oil generating zone (the oil window) whereas significant samples fall in the immature zone. Few deeper samples in the GoP are in gas window. Data from Winn *et. al*., (1994).

Organic Facies

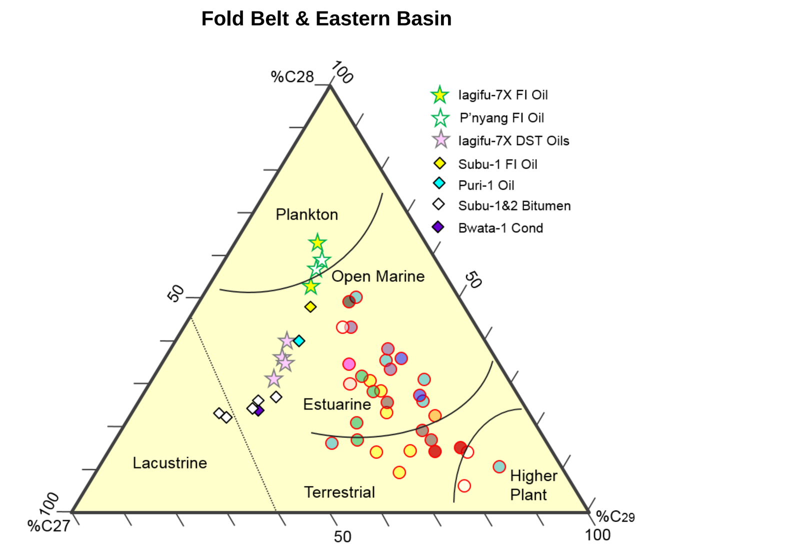

Fig. 14. Ternary diagram showing relationship between the C_{27}, C_{28} and C_{29} regular steranes in oils and source rock extracts. The regular steranes indicates the organic facies of a source rock. Mid-Late Jurassic and Cretaceous source rocks have both marine and terrestrial origins. Hydrocarbons in PFB are predominantly sourced from marine environment whereas in the EPB have mixed source of marine and lacustrine environments. Closed circles same as in Fig. 15. Data sources as in Fig. 16.

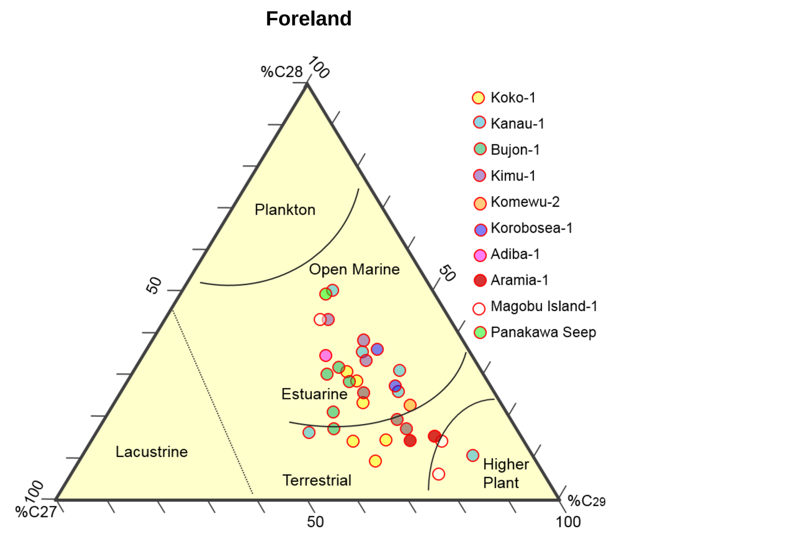

Fig. 15. Ternary diagram showing relationship between the C_{27}, C_{28} and C_{29} regular steranes in oils and source rock extracts. The regular steranes indicates the organic facies of a source rock. Late Jurassic and Cretaceous source rocks have both marine and terrestrial origins, while few sourced from higher plant/coal terrestrial environments. Data from Wood, 2010.

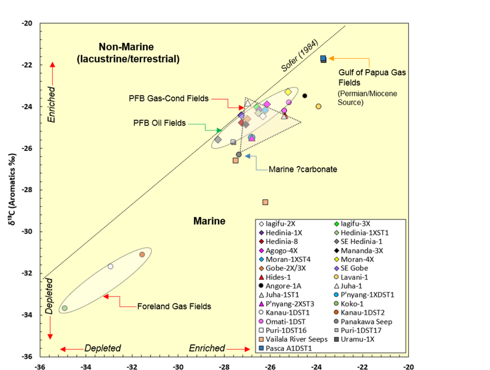

Fig. 16. Carbon isotopic composition of the saturated versus aromatic hydrocarbon fractions for oil and condensate families in the larger Papuan basin. Moran-4X is more enriched in δ13C whereas SE Hedinia-1 shows a relative depletion in δ13C. Uramu-1A condensate is the most δ13C-enriched suggesting such enriched isotopic values occur from Permian deltaic-marine mudstones rich in the remains of land-plants (Edwards *et al*., 1997) and Miocene marine shales. Papuan foreland (Koko & Kanau) oils appear much depleted and suggest a different petroleum system, possibly a Triassic source. Data from Waples & Wulff, 1996; Edwards & Zumberge, 2005, Wood, 2010.

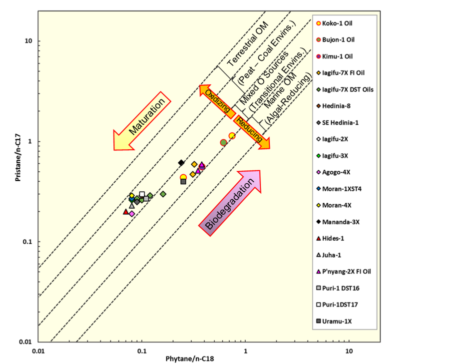

Fig. 17. A cross plot of isoprenoid *n*-alkane ratios describing the maturity and source rock facies of the petroleum samples from Papuan basin. Hydrocarbons in the Papuan basin were derived from mixed organic sources of both marine and terrestrial environments. Data sources as in Fig. 16.

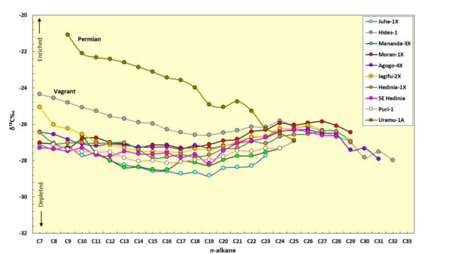

Fig. 18. Carbon isotopic composition for C7+ *n*-alkanes of selected oils and condensates from the Papuan Basin (data from Edwards & Zumberge, 2005).

Genetic Characterization of Hydrocarbons

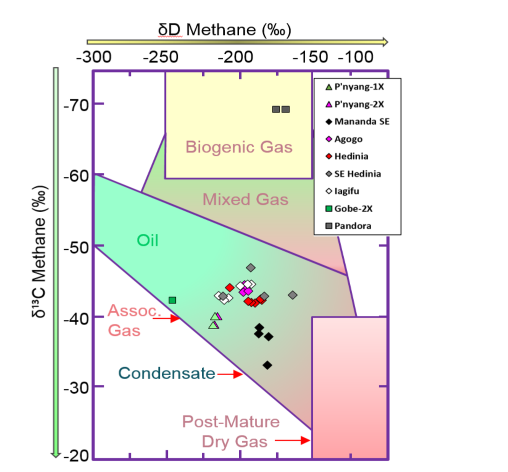

Fig. 19. Hydrocarbons from various fields across the larger Papuan basin are characterized by two distinct isotopic compositions. Oil and gases in the PFB have thermogenic origin whereas the Pandora gas in the GoP has biogenic origin. The data suggest there is no mixed gases and post-mature dry gases. Data from Waples & Wulff, 1996; Edwards & Zumberge, 2005.

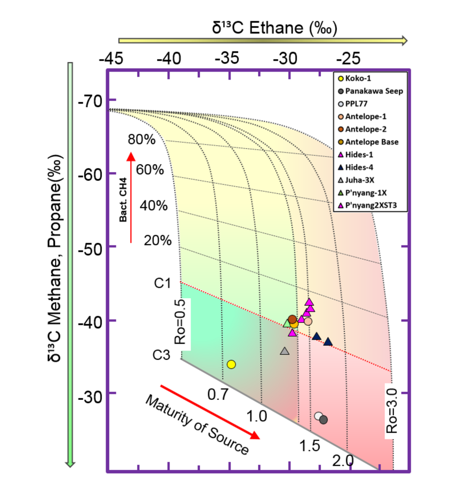

Fig. 20. Thermal maturity of hydrocarbons from various fields across the larger Papuan basin. Most PFB and EPB oil and gases have thermogenic origin and lie on or close to the end-member line, $\delta^{13}C_1$ −42.9‰. The foreland oil and gases show an increasing propane component with increasing maturity of source. Data from Wood, 2010; Waples & Wulff, 1996; Edwards & Zumberge, 2005.

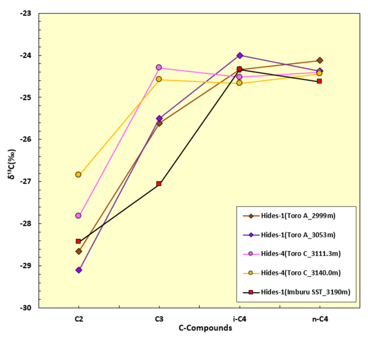

Fig. 21. Isotopic fingerprints of gases show systematic differences in the C_2-C_4 gases which are predominantly of thermogenic origin. These differences are attributed to different thermogenic gas migration episodes during which gases of different maturities migrated into different reservoirs of the Hides structure.

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Concluding Summary

» **Jurassic and Cretaceous–Tertiary source rocks from the PFB have in general potential for both oil and gas, and thermal maturities correspond to the upper–middle part of the oil window. The source rocks from both the foreland and EPB have potential for oil and gas whereas few show immaturity.**

» **Type II/III organic matters are dominant in the Jurassic and Cretaceous–Tertiary source rocks in the larger Papuan basin with minor Type I in the older source rocks.**

» **The Jurassic−Cretaceous source rocks (Barikewa & Imburu) generally have good to very good petroleum potential.**

» **Vitrinite reflectivity (Ro%) suggest thermal maturity of source rocks in PFB, foreland and GoP are in the oil generating window. The deeper source rocks from GoP appear to be gas prone.**

» **The relationship between the C_{27}, C_{28} and C_{29} regular steranes in oils and source rock extracts indicate that Jurassic-Cretaceous source rocks in both PFB and foreland have both marine and terrestrial origin of organic facies. The EPB have mixed source of marine and lacustrine environments.**

» **C-isotope values suggest a relative C-enrichment for the PFB hydrocarbons. The foreland (Koko & Kanau) oils appear much depleted and suggest a different petroleum system, possibly a Triassic source.**

» **Uramu-1A condensate is the most δ13C-enriched suggesting such enriched isotopic values occur from Permian deltaic-marine mudstones rich in the remains of land-plants and/or Miocene marine shales since Permian strata not present in the GoP.**

» **Hydrocarbons from various fields across the larger Papuan basin are characterized by two distinct isotopic compositions suggesting hydrocarbons of PFB have thermogenic origin whereas the Pandora gas (GoP) has a biogenic origin. The foreland oil and gases show an increasing propane (C_3H_8) component with increasing maturity of source whereas the PFB and EPB oil and gases lie on or proximal to the end-member line, $\delta^{13}C_1$ −42.9‰.**

» **The overall C-isotope data from individual fields within the larger Papuan basin suggest there is no significant mixing of oil, gases and post-mature dry gases.**

» **Isotopic fingerprints of thermogenic origin gases, C_2–C_4, from Hides field show systematic differences suggesting the differences are attributed to different migration episodes during which gases of different maturities migrated into different reservoir horizons of the Hides structure.**