Tectonics, Structures, Petroleum Systems:
Cases from Indonesia

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Some Basic Terms

- **Tectonics/geotectonics**: a branch of geology dealing with the broad architecture of the outer part of the Earth, that is, the regional assembling of structural or deformation features, a study of their mutual relations, origin, and historical evolution.

*Bates & Jackson (1987)*
Some Basic Terms

- **Structures**: the general arrangement or relative positions of the rock masses of a region or area, consequent upon such deformational processes as faulting, folding, and igneous intrusion.

* Bates & Jackson (1987)
Some Basic Terms

- **Petroleum System**: a natural system that encompasses a pod of active source rock and all related oil and gas and which includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist. The essential elements include: a petroleum source rock, reservoir rock, seal rock, and overburden rock. The processes are trap formation, the generation-migration-accumulation of petroleum, and preservation of accumulation.

(Magoon and Dow, 1994)
Contents

- Regional Tectonics of Indonesia
- Introducing Petroleum System
- Tectonics and Indonesian Basin Formation
- Petroleum from Rifted and Inverted Sundaland Basins
- Petroleum from Areas with Gravity Tectonics
- Petroleum from Collisional Terranes
- Petroleum from Australian Passive Margins
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Physiography of Indonesia: Tectonic Responses
Physiographic relief of Indonesia: Tectonic Response
Indonesia: A Geological Beauty and Tectonic Complexity

- van Bemmelen (1949): “The East Indian (Indonesia) Archipelago is the most intricate part of the earth’s surface...The East Indies are an important touchstone for conceptions on the fundamental problems of geological evolution of our planet...”
- Hamilton (1979): “Indonesia represents an ideal level of complexity for analysis within the framework of available concepts of plate tectonics.”
- Hutchison (1989): “a complex and fascinating region”
- Hall and Blundell (1996): “SE Asia is probably the finest natural geological laboratory in the world...”
- Sukamto (2000): “...Indonesian region...has proved to be very attractive to the earth scientists...Many earth scientists have attempted to explain the various unique geological phenomena by theories, hypotheses and models.”
The major tectonic plates are delineated by the major tectonic features of the globe: (1) the oceanic ridge, (2) deep-sea trenches, and (3) young mountain belts. Plate boundaries are outlined by earthquake belts and volcanic activity. Most plates (such as the North American, African, and Australian) contain both continental and oceanic crust. The Pacific, Cocos, and Nazca plates contain predominantly oceanic crust.

Hamblin & Christiansen (2009)
Present Tectonic Setting of Indonesia

Hall (2012)
Plate tectonic sections across Western Indonesia

Katili (1981)
Indonesia: Collision of Terranes
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Plan map showing the geographic extent of the fictitious Deer-Boar petroleum system at the critical moment (250 Ma). ThermaIly immature source rock is outside the oil window. The pod of active source rock lies within the oil and gas windows. (Present-day source rock maps and hydrocarbon shows are shown on Figures 5.12 and 5.13, Peters and Cassa, Chapter 5, this volume.)

Magoon and Dow (1994)
GEOGRAPHIC EXTENT OF PETROLEUM SYSTEM

STRATIGRAPHIC EXTENT OF PETROLEUM SYSTEM

POD OF ACTIVE SOURCE ROCK

Petroleum accumulation (A)
Fold-and-thrust belt: arrows indicate direction of relative motion
Location used for burial history chart

Essential elements of petroleum system

Overburden rock
Seal rock
Reservoir rock
Source rock
Underburden rock
Basement rock
Top oil window
Top gas window

Sedimentary basin fill

Magoon and Dow (1994)
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Basin classification

Basins are classified according to either their position within a plate, or according to their structural /tectonic origin.

Morley (2006)
Basins on an active margin

Morley (2006)
mod. from Pertamina and Beicip (1982, 1985)
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Stratigraphy of Sundaland Basins

- Middle to late Eocene timing for initial basin rifting and associated fluvio-lacustrine fill, including the main source rocks.

- Transgression from the middle Oligocene through to the middle Miocene with fluvial reservoirs being succeeded by the main deltaic and carbonate reservoirs in the late Oligocene to early Miocene, and regional seals being deposited in the middle Miocene at maximum transgression.

- Late Miocene through Pliocene compressional structuring events and increased heat flow associated with the collision of the Australian craton and collision of the Luzon arc with the Asian plate.

- Although there are gross geological similarities between the Western Indonesia basins, there are also significant geological differences. These are primarily controlled by basin position on the Sundaland promontory in relation to present-day and Cenozoic subduction of the Indo-Pacific plate northwards beneath Sundaland.
Comparative Stratigraphy between western and eastern margins of Sundaland.

Generalized stratigraphy of the western and eastern margin of Sundaland. Note the change from continental to marine setting of the two areas highlighted by colour change from green to blue.

Sudarmono et al. (1997)
Paleogene depocenters, generalized structure and oil field distribution for the Central Sumatra Basin

Praptono et al. (1991)
Figure 40: Morphological division, tectonic lineaments and hydrocarbon occurrences in the Natuna Sea area (after Fainstein and Meyer, 1998 and Phillips et al., 1997).

Netherwood (2000)
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Gravity Tectonics

Gravity/ vertical tectonics hypotheses attribute folding and thrusting to gravity sliding from the tops and flanks of vertically rising fault blocks, structural arches, mantle diapirs, and like phenomena (Meyerhoff and Hull, 1996). Consequently, the term gravity tectonics commonly is used in place of vertical tectonics (de Jong and Scholten, 1973)

Gliding tectonics is also variant to gravity tectonics. Gliding tectonics is mechanism whereby large masses of rocks move down a slope under gravitational force, producing folding and faulting of varying extent and complexity (Allaby and Allaby, 1999)
Deformation by Gravity Sliding-Gliding Tectonics

A Formation of Detachment

B Gravity sliding

C End of gravity sliding, early loading & downbuilding

mod. after Pew (1983)
Parallel Belts of Samarinda Anticlinorium, Kutei Basin

van de Weerd and Armin (1992)
Diagrammatic cross-sectional reconstructions of the Early Middle Miocene to Recent (not to scale).

Ott (1987)
Gravity Sliding/ Tectonics continued into North Makassar Basin, Makassar Strait in the formation of toe thrusts

*mod. after Guritno et al. (2003)*
Section across Tarakan and Kutei Basins
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Collision occurs across a converging plate margin when two masses that are too light to sink meet at a subduction zone. The boundary between the two masses is called a suture zone.

Press and Siever (1998)
Location of Neogene Collision Zones in Indonesia
Collision in Eastern Sulawesi
Drifting and collision history of Banggai-Sula micro-continent
Cross section across Banggai collision

Pertamina BPPKA (1996)
Collision in Papua

Hall (2007)
Fields at the Central Ranges of Papua and PNG

Schroder et al. (2000)
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Neogene tectonic history

Northwest - North Shelf of Australia

Keep et al. (2006)
Sedimentary basins in Southern Banda Arc – Arafura Shelf – NW Australian Shelf

Pertamina and Corelab (1998)
Stratigraphy of NW Shelf of Australia

Pertamina BPPKA (1996)
Hydrocarbon occurrences of northwest shelf of Australia
Seismic section crossing NW Shelf of Australia to Banda Arc

Barber et al. (2003)
Conclusion

- Tectonics controlled basin formation and its petroleum system, including structure that may hold an accumulation of oil or gas. There are four groups of tectonics resulting in proven petroleum systems in Indonesian basins:

1. petroleum from rifted and inverted Sundaland basins,
2. petroleum from areas with gravity tectonics,
3. petroleum from collision of terranes, and
4. petroleum from Australian passive margins
Thank you for your attention.

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