Sedimentary Basins of Indonesia: Outline and Thickness Variation Understanding

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INTRODUCTION

Offshore petroleum exploration in Indonesia began in late 1960's and thereafter a significant number of seismic data sets were acquired. Based on these data, several basin outline maps were generated such as those published by Hamilton (1974), BEICIP FRANLAP (1992), and Sujanto (1997). Based on these data sets, 60 sedimentary basins were officially recognized by the Government of Indonesia (Sunarjanto et al., 2007 included in 2008 publication). The outlines of the basins were used as a reference by government officials and the petroleum industry. Recently, the Geological Agency published a map which shows 128 sedimentary basin outlines in Indonesia. Unfortunately, these maps were not accompanied with supporting subsurface data.

The understanding of those sedimentary basins is very important for petroleum exploration, as they are basically the places to find hydrocarbons. Petroleum potential within a basin is related to its sediment accumulation and tectonic history. Critical petroleum system elements such as source rocks, reservoir and seal mainly comprise sedimentary rocks. The order of deposition, quantity of sediments and basin history will control the effectiveness and quantity of hydrocarbon generation in a particular basin.

This article will go through the history of various basin outline maps and aim to provide additional information, such as basement depth, to give further detail on the basins in Indonesia. There are some detailed maps which show the distribution of oil and gas fields, which are obviously related to sediment thickness.

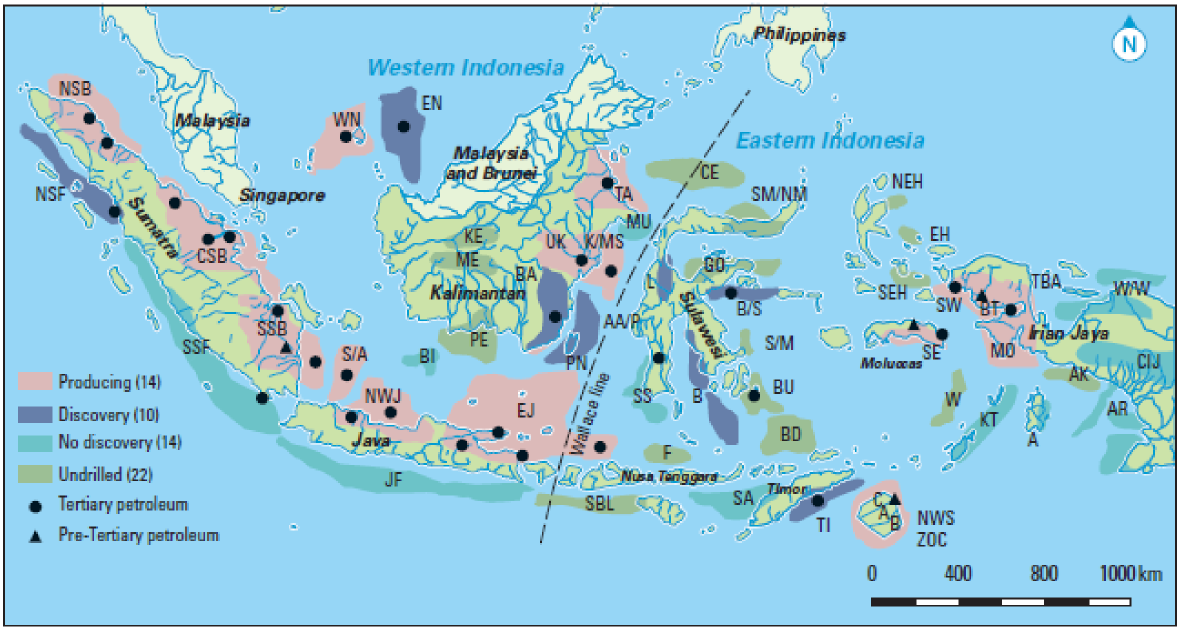
BASIN STATUS AND DISTRIBUTION

Several basin outline maps have been published and the authors have classified the status of the basins into: basin with production, basin with hydrocarbon discovery, basin with exploration wells but no discovery and undrilled basins (e.g. Sujanto, 1997 and Netherwood, 2000). The latter add a statistical comparison of basin distribution between the west and east of Indonesia (Figure 1). Several authors came with the same classification but different number of basins. The numbers of producing basins have increased as more exploration successes brought the hydrocarbon on stream. The numbers of undrilled basins are also increased within Indonesia territory. BPMIGAS/LAPI-ITB (2008, in Satyana, 2011), almost double the number of undrilled basins compared to Sunarjanto et al. (2008), which was published only a year before. The number of total sedimentary basins according to the Geological Agency (2009) also increased by 50% compared to the BPMIGAS/LAPI-ITB version (Figure 2).

The significant changes on the number of basins like the total and undrilled basins probably require a detailed look. The basins' definition and boundary are key support to these numbers. The data and reason for classification behind the number of basins were incomplete in these publications.

Sunarjanto et al. (2008) applied GIS (Geographic Information System) in the study and referred to sedimentary thickness map, gravity anomaly and age analysis in defining the basin outlines (Figure 3). The known comprehensive sediment thickness map available at that time was a map which was published by Hardy et al. (1997) [Figure 4] as a result of collaboration between Pertamina and Unocal. At the time, probably Pertamina had the most comprehensive subsurface data in Indonesia. Although the map was rough, it provided good understanding of the depth of each key basins in Indonesia.

The Geological Agency generated a map with the largest number of basins in 2010 (Figure 5). This map defined 128 basins and included shallow and young basins which are most likely non-prolific for hydrocarbons. BPMIGAS and LAPI-ITB generated a map with the second largest number of basins (86 basins, Figure 6), where Pre-Tertiary (Mesozoic and older) basins were separated from the Tertiary (Cenozoic) basins. Based on the outlines, this map includes young sedimentary basins and splits the outline of previously defined basins. The sediment thickness map, like Hardy et al. (1997), should be updated and used as a basis of the basin definition.



Western Indonesia

NSB - North Sumatra
CSB - Central Sumatra
SSB - South Sumatra
NSF - North Sumatra fore arc
SSF - South Sumatra fore arc/Bengkulu
S/A - Sunda/Asri
NWJ - Northwest Java
JF - Java fore arc
EJ - East Java/Java Sea
BI - Billitong
PE - Pembuang
BA - Barito
PN - Pater Noster platform
AA/P - Asem-Asem/Pasir
UK - Upper Kutei
K/MS - Kutei/Makassar Straits
MU - Muara
TA - Tarakan
CE - Celebes
KE - Ketungau
ME - Melawai
WN - West Natuna
EN - East Natuna

Eastern Indonesia

SM/NM - South/North Minahasa
GO - Gorontalo
B/S - Banggai–Sula
S/M - Salabangka–Manui
BU - Buton
BD - Banda
B - Bone
F - Flores
SS - Spermonde/Selayar
L - Lariang
SBL - South Bali–Lombok
SA - Savu
TI - Timor
NWSZOC - Northwest Shelf zone of cooperation
W - Weber
SE - Seram
NEH - Northeast Halmahera
EH - East Halmahera
SEH - Southeast Halmahera
SW - Salawati
BT - Bintuni
MO - Misool-Onin
TBA - Teluk Berau–Ajumaru
KT - Kai Tanimbar
A - Aru
AK - Akmeugah
AR - Arafura
CIJ - Central Irian Jaya
W/W - Waipoga/Waropen

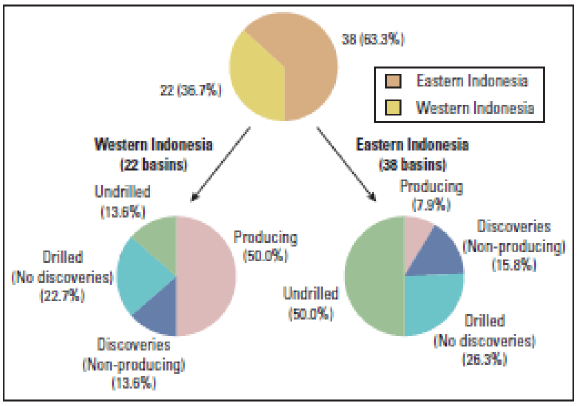


Figure 1: *Indonesian basin classification and their exploration status after Sujanto, 1997; Sumantri and Sjahbuddin, 1994 (Netherwood, 2000).*

Year	Author / Institute	Producing Basin	With discovery	Without discovery	Undrilled basin	Total basins
1997	Sujanto	14	10	14	22	60
2000	Netherwood, R. / Schlumberger	14	10	14	22	60
2007	Avicenia et al. / BPMIGAS	15	9	14	22	60
2007	Sunarjanto et al. / LEMIGAS	16	8	15	24	63
2008	BPMIGAS / LAPI-ITB	17	11	16	42	86
2009	Geological Agency	----unclassified ----				128

Figure 2: *Number of Indonesian sedimentary basins and their classification according to several authors.*

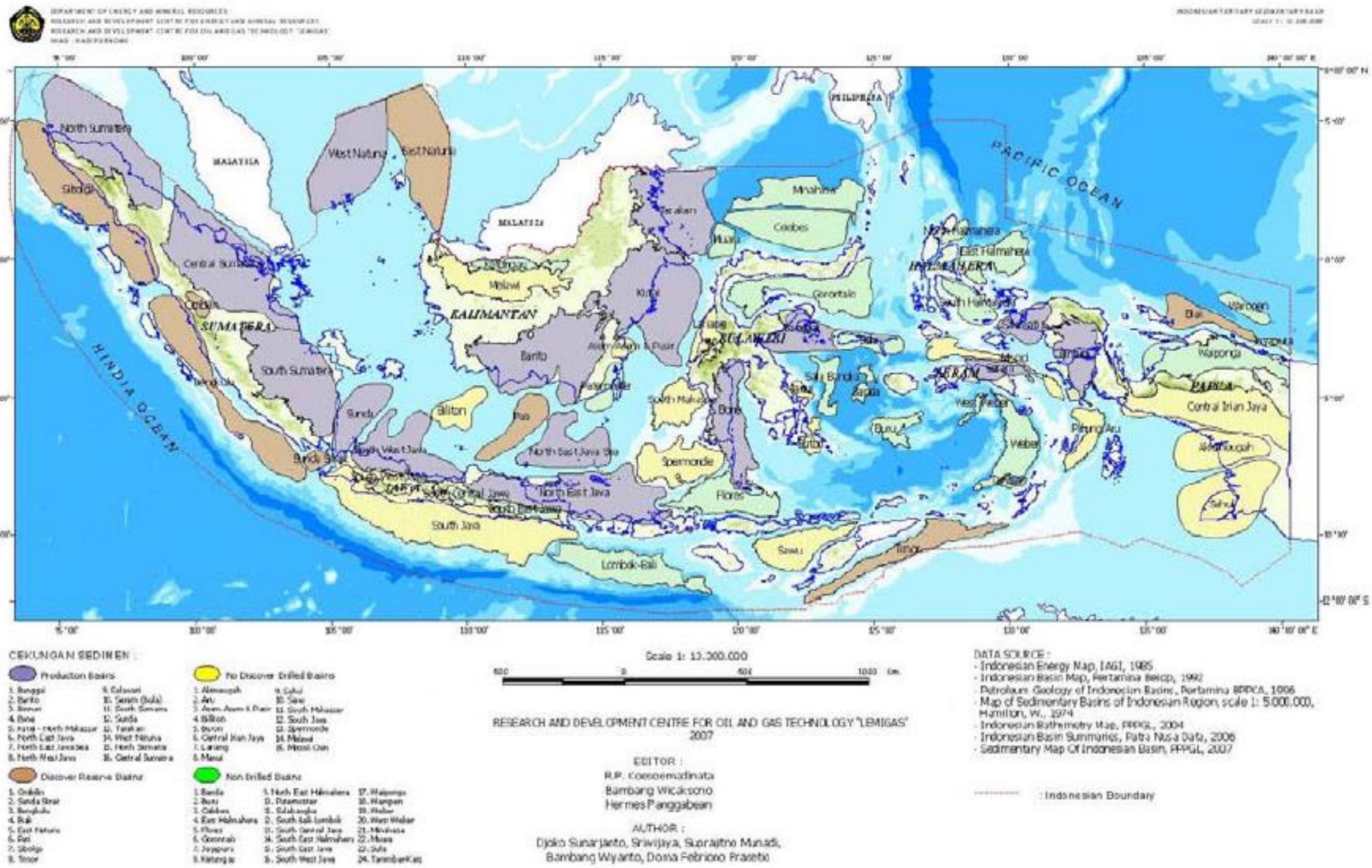


Figure 3: *Indonesian sedimentary basin outlines published by Sunarjanto et al., from LEMIGAS, in 2007, published in 2008, with total of 63 basins.*

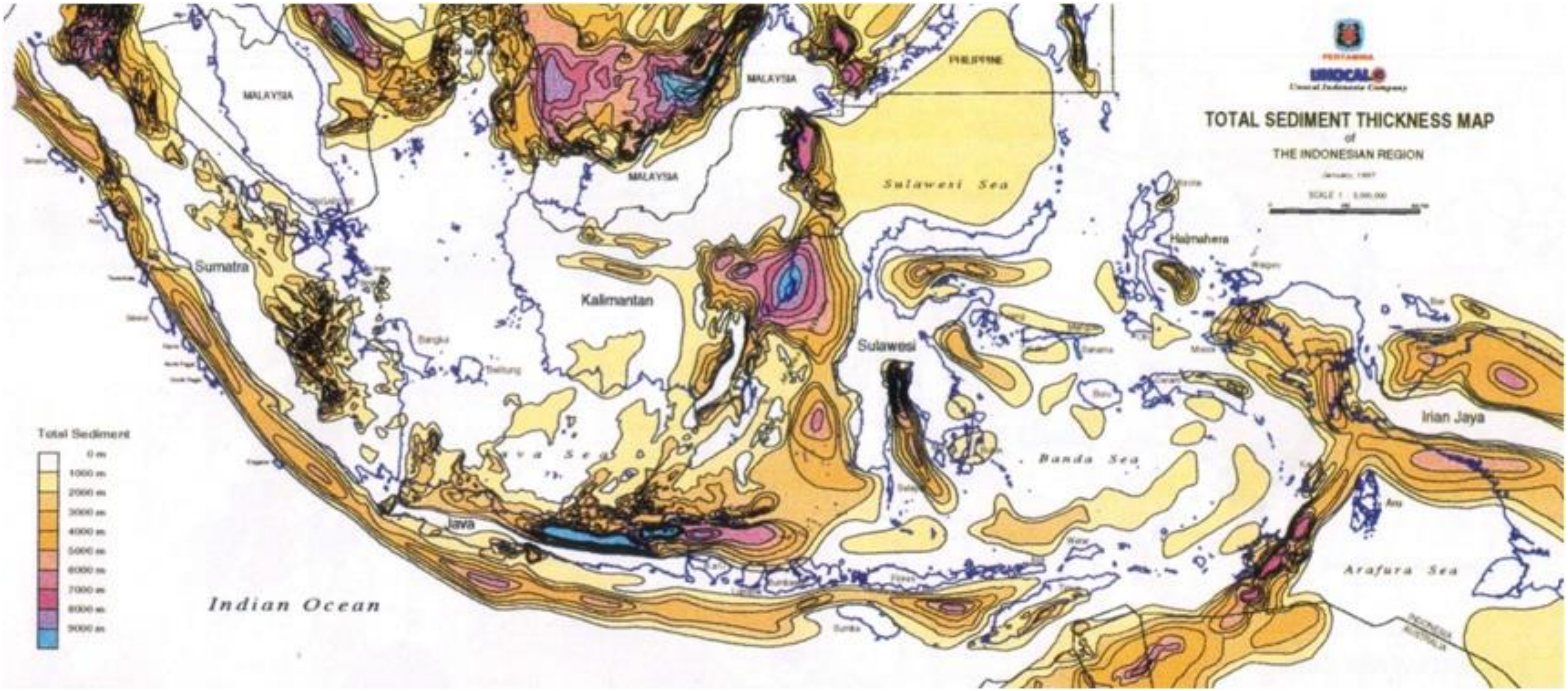


Figure 4: *Total sediment thickness map of Indonesia by Hardy et al. (1997).*

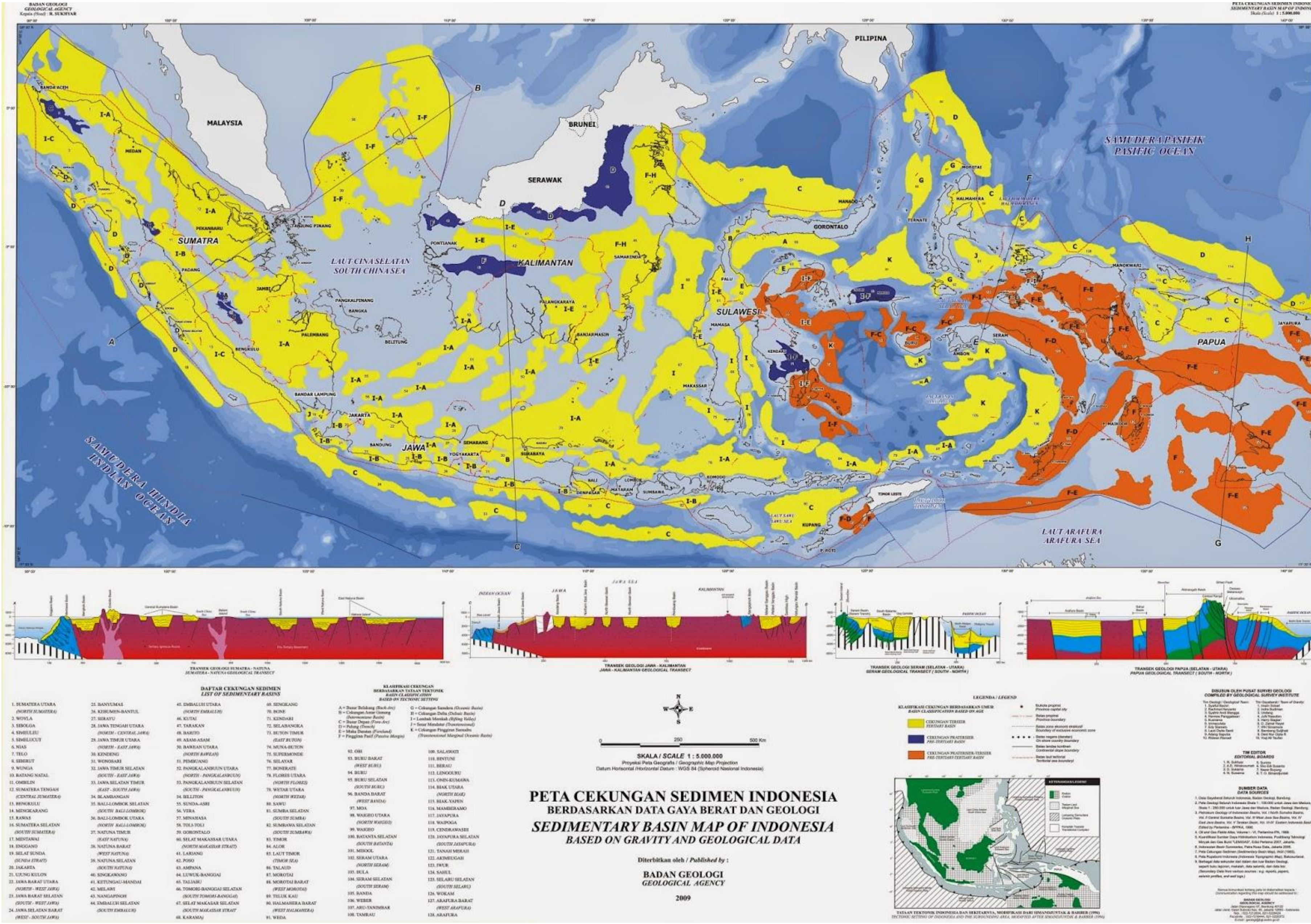


Figure 5: *Indonesian basin outlines according to the Geological Agency (2009). There are 128 sedimentary basins identified including Tertiary, pre-Tertiary and a combination of Tertiary and pre-Tertiary basins.*

Figure 6: *Indonesian basin outlines published by BPMIGAS and LAPI-ITB (2008), showing the distribution of 86 sedimentary basins in Indonesia.*

INDIVIDUAL BASIN WORK

Continuous acquisition of subsurface data in various basins provides better understanding of how deep and how thick sediment fill of the basins are. The lateral distribution of the sediments is also better defined. The best basin definitions are usually provided by operating companies in the corresponding basins. Some companies are also using gravity data as seismic data may not define the deeper part of the basins. The operators do detailed work using the available data, as they aimed to understand the basins in great detail for exploration. Several examples of sediment thickness or depth to basement maps are discussed in the following sections.

The North Sumatra Basin is the westernmost producing basin in Indonesia. The basin's depth to basement map (Figure 7) shows basements high in the southeast and the deeper part of the basin is located in the north, in the areas called Jawa Deep and Lhok Sukon Deep (after Anderson, 1993). Both depocenters are deeper than 5 seconds TWT (two way time), which could be up to 8 kilometers thick of sediments below the sea bottom. The north –south horst and graben trends are typical for this basin. The largest field is Arun Gas field, located on the Arun High which separates those two deeps or depocenters. The horst and graben in the eastern part of the basin are well defined on the seismic data. The majority of onshore oil fields are located in the southeast of the area, resulted from early exploration in Indonesia back in 1800s era. The first commercial oil discovery well, Telaga Tunggal-1, was drilled in this area.

In the Central Sumatra Basin, the depth to basement contours and faults show NW-SE and N-S trend (Figure 8). The N-S trend is considered the older structural element and it continues northwards to the Malaysian Peninsula. A large depocenter is located in the northwest of Duri, Minas and Kotabatak fields, and the sediments here are thicker than 2000 meters. Sediment thickness in the basin is thinning northward. The NW-SE trend of Barisan Mountain and/or Great Sumatra Fault system bounded the southern part of the basin. Figure 8 is a modified version after Heidrick & Aulia (1993) and Barber and Crow (2005). Oil and gas field outlines were added to the map to show their relative position to the basement deep and their orientation related to the fault trends.

Figure 9 shows the depth to basement map of the South Sumatra Basin with Central Palembang Basin right at the center of the basin (after Barber & Crow, 2005; and Ginger & Yielding, 2005). The depocenters are deeper than 4 seconds TWT or up to 6 to 7 kilometers thick of sediments below the surface. The larger fields are located around the depocenter. A number of fields were also discovered around the Muara Enim Deep. Barisan Mountains in the south is dominated by Quaternary volcanic deposits. The sediment thickness is much less towards the north of Malacca Strait.

The depocenter of the North West Java Basin is located in the south (Noble et al., 1997; Figure 10), which is thicker than 3 seconds TWT below the surface or approximately around 4 kilometers thick of sediments. In general, hydrocarbons in the basin migrate northward from the depocenter in the south. The basin is getting shallower towards Sunda Platform in the north. Isolated depocenters are identified in the northwest of the Northwest Java Basin, namely Sunda and Asri Basins. These basins are separated from the NW Java Basin by the Seribu Platform. A mix of oil and gas are found in this basin, but gas is more dominant.

Similar to the Northwest Java Basin, the East Java Basin has the depocenter located in the south (Nawawi et al., 1996 and Kenyon, 1977), which is deeper than 2 second TWT, approximately more than 3 km thick. The W–E structural trend in the south (Figure 11) are dominated by an inverted wrench fault zone, which is exposed well in the Madura Island. This structural trend extends westwards to onshore Java Island and eastwards to the Kangean Island. Towards the north there are troughs and arches which have SW-NE trend, following the paleo-subduction zone.

SEDIMENT THICKNESS MAPS UPDATE

Basinal sediment thickness or depth to basement maps are available for most of the producing basins, especially in the basin center area. To the basin margin where less hydrocarbon is expected, there will be less seismic and well data to create such maps. In the basin margin and also inter-basinal areas, outcrop and gravity data are useful for joining the depth to basement maps. Outcropping basement give a good control for such maps.

Integration of several depth to basement maps from different basins in Southeast Asia is shown in Figure 12. Apart from using existing published maps, there are others unpublished information which are integrated into this map. On top of that, well tops, gravity anomaly and outcrop data were also used to control the distribution of the contours.

The outcropping basements are colored in dark green. The outline of these outcrops indicated the 0 contour line of the sediment thickness map. The Malay Basin in Malaysia is the deepest basin in the region, followed by the Kutei Basin in East Kalimantan. Northwest Borneo Basin is the largest basin in the region. Thick sediment accumulation are identified in the southern part of the Celebes Sea, but they are relatively young (e.g. Pliocene – Pleistocene dominated sediments). Unfortunately, this area has almost no well control, and these contours are purely based on gravity map interpretation.

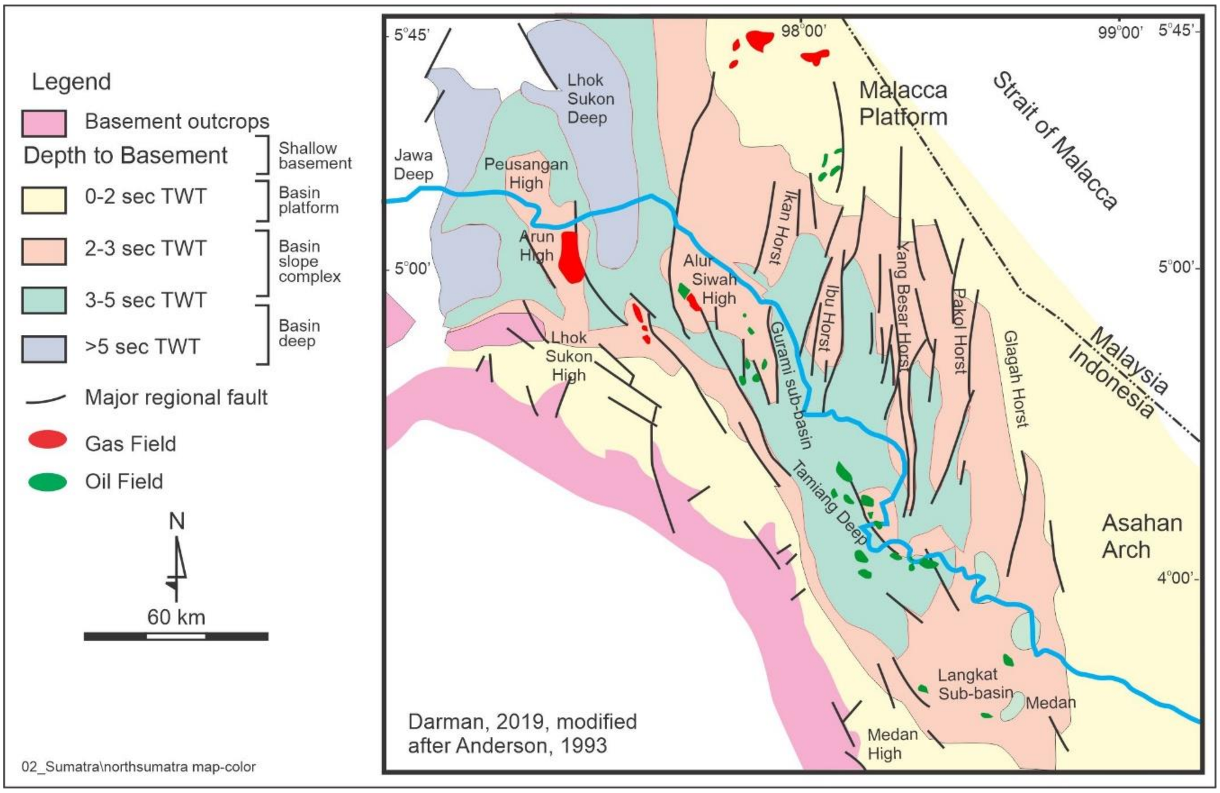


Figure 7: *Depth to basement map of North Sumatra Basin shows the isochrone contours in Two-Way-Time. The map shows the position of oil and gas fields relative to the depocenters.*

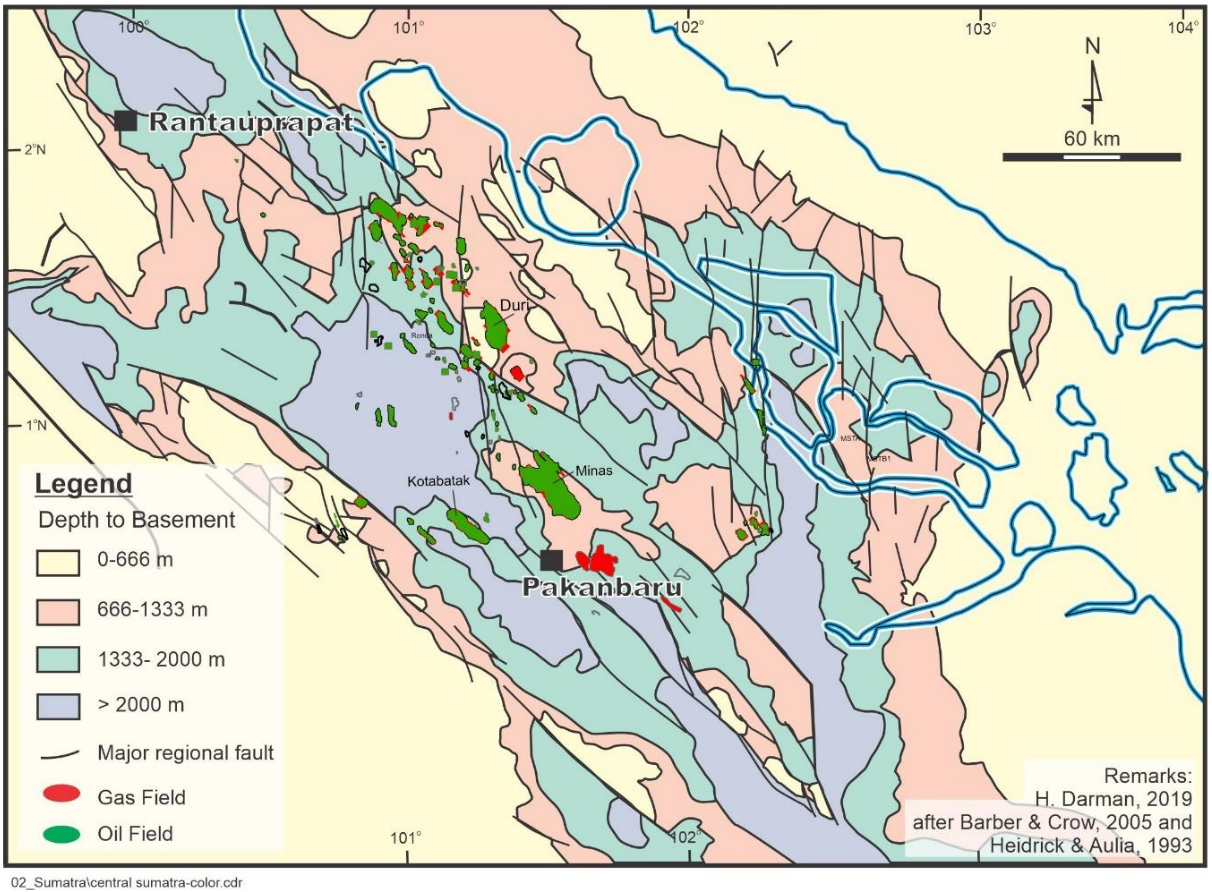


Figure 8: *Depth to basement map of Central Sumatra Basin shows the isochore contours in meters. The map shows the position of oil and gas fields relative to the depocenters.*

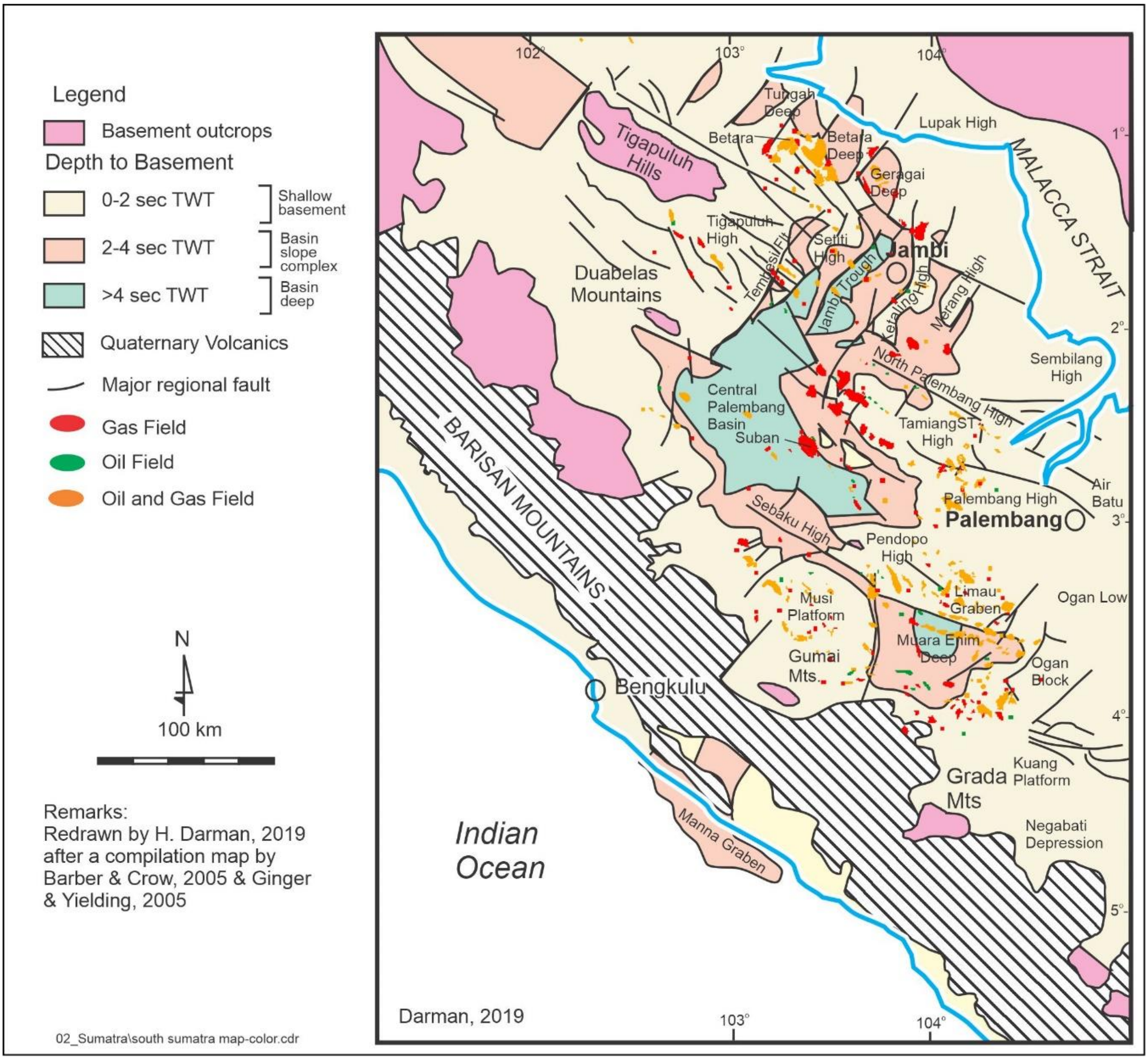


Figure 9: *Depth to basement map of South Sumatra Basin shows the isochrone contours in Two-Way-Time. The map shows the position of oil and gas fields relative to the depocenters.*

Apart from the Salawati Basin in the Bird Head of Papua, the sediment thickness contours in Eastern Indonesia basins generally have poor well control. The basement outcrop data from Buru, Seram, Timor, Halmahera and Papua provide a degree of confident on the understanding of basinal extend.

DISCUSSION

The sediment thickness map generated by Indogeo Social Enterprise (Figure 12) map is available in GIS version and will be revisited after a certain period of time or when new data are available. In the GIS, the map can be easily overlain by concession outlines and the companies that have better data can easily correct the map. More detailed gravity modelling may also help to improve the sediment thickness map.

Apart from potential map refinement by using new data, the map is also expected to be a tool to facilitate discussions between different operators in the same basins or for general discussion related to geosciences. The contours in this map will give additional data on top of the gravity data which is available online, such as those from Scripps Institution of Oceanography, University of California San Diego, USA (topex.ucsd.edu). As geoscientists, overlying maps onto the sediment thickness map would be a key to quickly determine which basins are potentially prolific for hydrocarbons, but perhaps little exploration activities were done so far therefore further study is necessary.

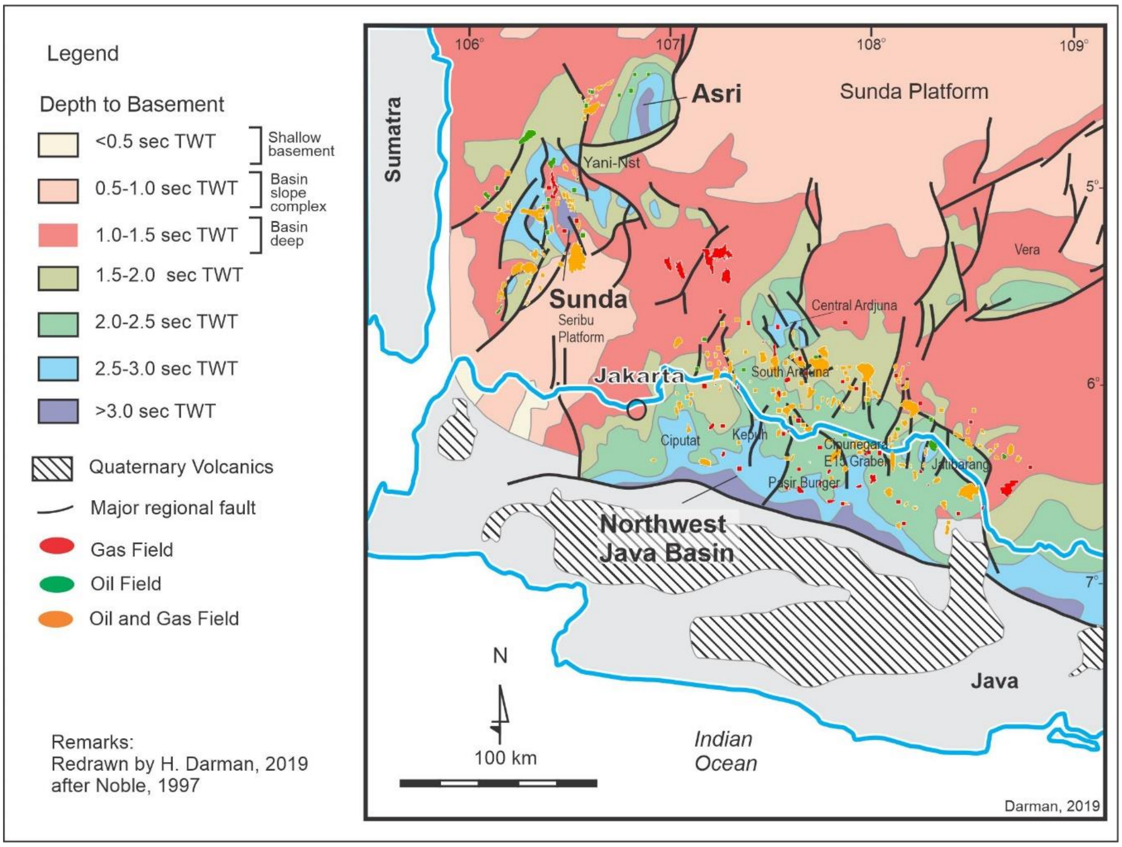


Figure 10: *Depth to basement map of Northwest Java Basin shows the isochrone contours in Two-Way-Time. The map shows the position of oil and gas fields relative to the depocenters.*

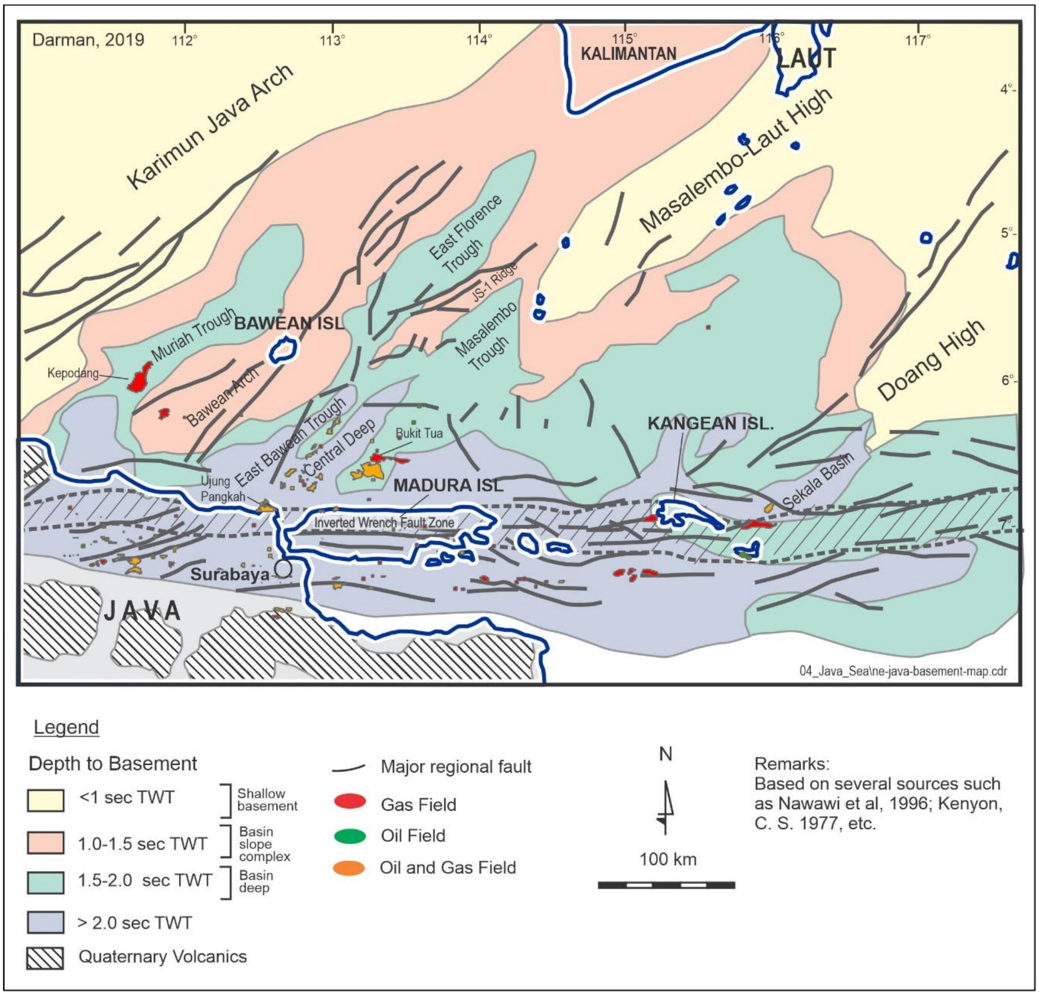


Figure 11: *Depth to basement map of East Java Basin shows the isochrone contours in Two-Way-Time. The map shows the position of oil and gas fields relative to the depocenters.*

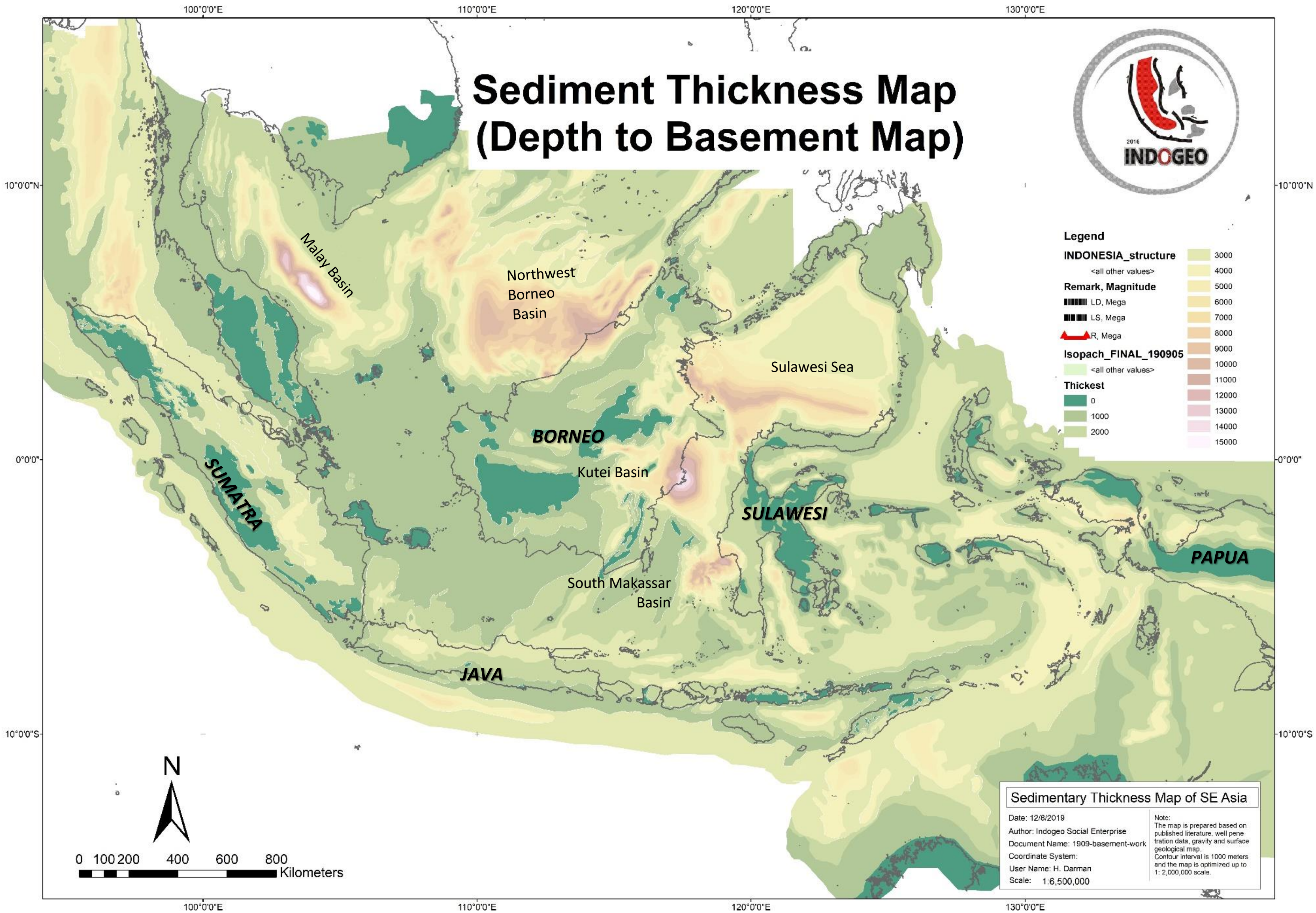


Figure 12: *Sediment thickness map of Indonesian and some SE Asian basins*

The following list shows the benefits of using integrated sediment thickness map, when the map is overlain with other data, such as:

1. Fields, discoveries and wells with shows, also hydrocarbon seeps, which are able to highlight proven petroleum system and indication of richness potential to add reserves in each basin. Integrating them with Estimated Ultimate Recoverable oil and gas data will help to validate yet to find hydrocarbon resources. Outside nearby area will be potential for step-out lower risk exploration.
2. Exploration wells and seismic lines, which will show indication of exploration maturity and highlight lightly explored area with significant remaining resources potential.
3. Basin outlines, geothermal gradient, heat flow and source rock type maps, which can indicate thick sediment with best regional source rock potential.
4. Tectonic, regional structure and basement type maps, which will highlight potential fracture basement play to connect to source rock potential.

Most geoscientists have finally realized that optimizing available published data can conduct quicker basin evaluation, therefore, the method is appropriate to select focus areas for further studies.

CONCLUSION

A newer version of Sediment Thickness Map is available publicly. It is not only a product of stitching existing published map but also using gravity, well data and controlled by basement outcrops. This map is expected to help both geoscientist and non-geoscientists to understand basin outline maps which are generated by previous authors. The sediment thickness map shows thickness variety across the sedimentary basins in Southeast Asia, especially in Indonesia.

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