Pliocene Deep Water Channel System of Celebes Molasse as New Exploration Play In Banggai Sula Foreland Basin, Eastern Sulawesi-Indonesia

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Abstract. Banggai-Sula foreland basin in Matindok block is the product of Late Miocene to Early Pliocene collision between Banggai-Sula microcontinent and East Sulawesi Ophiolite (ESO)-magmatic arc of Sundaland. Proven petroleum system plays for Donggi, Senoro, and Matindok gas fields are Miocene build-up carbonate and platform carbonates related to wrench structures, sealed by Plio-Pleistocene Celebes Molasse consists of conglomerate, conglomeratic sandstone, shale and charged during early Pliocene related to collisional tectonic from Miocene marine clastic source rocks. Latest in interpretation of 3D & 2D seismic datasets on onshore area of Matindok block shown that there is possibility of NE to SW trending channel systems existed in Plio-Pleistocene Celebes Molasse as post collision sediments. Based on biostratigraphy interpretation, Celebes Molasse interval was deposited in marine environment, generally outer sublittoral to upper bathyal. Channel filled pattern on seismic data expression shown onlap, divergent and mound- onlap fills on 6 (six) interpreted channel bodies. Fining upward sequences is well recognized based on gamma ray log from several wells that penetrated those interpreted channel. The thicknesses of channel bodies vary from 50 m to 150 m with sand to shale ratio up to 40 % and gas composition reading from C1 to C3. Despite of there is no well testing data on these channels interval; we believed that this Pliocene deep water channel can become the new exploration play although several studies about seal effectiveness of channel bodies as stratigraphic traps, lateral and vertical migration pathways need to be carried out.

1. Introduction
Study area located in the onshore area of Matindok Block, Eastern Sulawesi, Indonesia (figure 1). Pertamina EP started exploration activities in this area from 1999, several gas fields have been discovered such as Matindok, Maleo Raja and Donggi. The main reservoir targets are Miocene build-up and platform carbonate as syn-dfriting deposits.

In 2014, Pertamina EP drilled 2 (two) wells, Matindok-7 and Penyu-1, located 20 km west of Matindok gas field, and discovered gas & condensate in Pliocene Carbonate (M-52 layers) of Celebes Molasse as post-collision deposits. Based on gas geochemistry analysis, gas sample in Matindok-7 is possible thermogenic origin and gas sample in Penyu-1 is possible biogenic origin. These discoveries were significantly important because from previous study Celebes Molasse only act as overburden sediment and regional seal. There is no detailed study about petroleum system of Celebes Molasse.
In this study, using 2D and 3D seismic datasets, we deliver the geological model of NE to SW trending Pliocene channel systems in Celebes Molasse. Hopefully, this model can trigger another possibility of finding hydrocarbon in Pliocene post collision interval.

2. Regional Tectonic Setting
Tectonically, Sulawesi island is the product of several collisions between micro-continents from Sundaland and Australian Area (figure 2a). Garrard (1988), Simandjuntak and Barber (1996), Satyana (2011), Hall (2012) and Sani (2015) describe rifting, drifting and collision stages of Banggai Sula micro-continent toward East Sulawesi (figure 2b). Matindok block is precisely located on the collision border and post collision foreland basin. Tertiary rocks in the Banggai foreland basin along the east coast of Sulawesi comprise Miocene carbonate shelf and reefal limestones as main reservoir. The overlying Pliocene Celebes Molasse sediments contain conglomerate, conglomeratic sandstones and thick shales that provide a good overburden and regional seal (figure 2c). Hasanusi et. al. (2004) explained about Mercury Injection Capillary Pressure analysis of Senoro-1 samples indicated that the Pliocene Kintom shales have excellent sealing capacity with pore throat sizes mostly less than 0.5 micron.

As early as 1985, oil was discovered in Miocene carbonate platform related to imbricate thrust in the offshore Tiaka Field In the Onshore area, subsequent discoveries have been mainly gas in Minahaki and Matindok Fields (figure 2d). Possible source rocks in the Banggai Basin include Lower Miocene carbonaceous shale and argillaceous limestone and Eocene bituminous limestone and shale (Kartaadiputra and Samuel, 1988).

Shale facies of Pliocene Celebes Molasse also have potential to be biogenic gas generation. Subroto et. al (2009) describe biogenc gas in Matindok Block. Burial history models were useful in identifying wells with shallow intervals having high sedimentation rate and present-day low temperature that are predicted to be favorable for biogenic gas generation, such as the Pliocene celebes molasse. Another result of the geochemical modelling indicates that the biogenic gas found in the Tomori block was deposited 1.7-3.5 million years ago (Plio-Pleistocene).
Figure 2. (a) Geological & Structural Map of Sulawesi - the red dot area shows the Matindok Block location (Pholbud et al, 2012), (b) Rift-Drift-Collision stages of Australian Micro-Continent, the black dot box show collision area (Hall and Sevatjanova, 2012), (c) Updated Stratigraphic Column of Matindok Block (modified after Ardana et al, 1996), (d) Petroleum System Play in Matindok Block (modified after Sani, K., 2015)

3. Data and Method
3D Seismic and mostly 2D Seismic lines from several vintages from 1973 to 2005 were used as the main data source in this study. Several well data related to wireline log, mudlog, and biostratigraphy analysis were also used to calibrate the channel system model. Published and unpublished reports about previous study of post collision deposits in other foreland basin were collected and used as model analogue.

4. Result and Discussion
Based on NW-SE 2D regional seismic key line, we interpret 6 (six) NE to SW trending channel system (figure 3). Isochron map of each channel were used to construct channel system model. Using channel fill pattern on seismic data characterization by Mitchum et al (1977), mostly all channels have onlap, divergent and mounded onlap pattern fill that related to low energy sediment in medial to distal area. We interpreted several point of erosion on the NNE area as sediment provenance that filled the deep water channel in the southwest area (figure 4).

Regional well correlation using 4 (four) well data pass through NW-SE 2D Regional seismic line in figure 3 were made, there are several result as follows (figure 5):
- **Biostratigraphy analysis shown that post-collision interval was deposited in marine environment from outer sub littoral to bathyal**
- **Fining upward sequences is detected based on gamma ray log.**
- **Gas reading of channel interval shows C1 to C3 up to 980 ppm. Gas Analysis ratio using gas dryness, wetness, balance, character and pixler plot indicate possible light dry gas.**
- **Possible Low Resistivity – Low Contrast (LRLC) pay due to thin laminated sandstone-shale sequences in channel interval.**
- **Shale Kintom Formation as top and base regional seal**

**Figure 3.** Pliocene Deep Water Channel Top and Base Interpretation in 2D NW-E Composite Seismic line

**Figure 4.** Deep Water Channel Model of Banggai Sula Foreland Basin

In order to calibrate the geometry of deep water channel based on isochron map, we used lithofacies section on each channel. Cibaj (2011) describe correlation of sand and shale ratio and pattern on each channel depositional environment such as overbank/levee, axis, off-axis, and margin. For example; lithofacies section of channel “C” (figure 6) in Minahaki-1 show channel margin to
channel off-axis pattern and KPB-1 show channel margin to overbank, this interpretation positively correlate with channel “C” isochron map.

![Figure 5](image1.png)

**Figure 5.** NW-E Regional Well Correlation of Post Collision Interval

![Figure 6](image2.png)

**Figure 6.** Lithofacies Interpretation of Channel “C”

We also run 3D seismic attributes such as RMS amplitude and spectral decomposition to determine the geometry of the channel. Due to 3D Seismic data set only covered small portion of southern study area, we only able to interpret 2 (two) channel, which are channel C and D (figure 7). Using these seismic attributes, we are able to define much better depositional environment such as oxbow lake, abandoned channel, possible splays or distributary channel.
Figure 7. Interpretation of 3D Seismic Attributes (a) RMS Amplitude Map of Channel “C”, (b) Spectral Decomposition of Channel “C”, (c) RMS Amplitude Map of Channel “D”, (d) Spectral Decomposition of Channel “D”

5. Conclusions
Based on our interpretation, NE to SW trending deep water channel existed in Celebes Molasse as Pliocene post collision interval. Existing 2D and 3D seismic data sets are able to delineate each channel geometry and depositional environment. Regional well correlation and lithofacies section positively support deep water channel model.

Despite of there is no well testing data on these channels interval yet; we believed that this Pliocene deep water channel can become the new exploration play.

Further study about biogenic generation and migration, lateral seal effectives of each channel and possibility to acquire new 3D seismic data set in northern area study is needed to give better understanding of deep water channel petroleum system play.

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