Lithofacies interpretation and depositional model of Talangakar Lacustrine Deposits: A Study in the Ardjuna Field, Eastern Sunda Basin

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ABSTRACT

The Ardjuna Field in the Northwest Corner (NWC) block is located on the eastern side of Sunda Basin and is adjacent to the Seribu Fault. Producing reservoirs in the Ardjuna Field are mainly of the Talangakar (TAF) fluvio-deltaic sandstones, however all wells within the four production platforms of the field had been shut in November 2006. Hence it is necessary to re-evaluate remaining potential and to seek new reservoirs within the field in order to reactivate oil and gas production from the structure.

The main focus of our study is to evaluate the remaining potential of TAF fluvio-deltaic producing zones and identify new potential in the TAF lacustrine deposits. We used a total of 8 exploration wells, 17 development wells, and a 3D seismic dataset during our evaluation. Out of the 25 wells, only two wells have penetrated the lacustrine deposits interval, i.e. W-1 and S-5 wells. The S-5 well proved flowing HC of up to 1,043 MMCFGPD and 332 BOPD from DST.

The lower TAF lacustrine deposit is characterized by the occurrence of typical freshwater pollens, displaying a serrated and coarsening upward log pattern, thin succession, and absence of sediment structures. Seismic interpretation and Acoustic Impedance (AI) analysis indicate that low AI value (< 7200 gr/cc*ft/s) correlate with high porosity, interpreted as sandstone. The AI-guided seismic attribute reveals a relatively regular lobate shape resembling a fan measuring 1.7 km by 2.5 km. Furthermore, low AI values are more prevalent and widely distributed, particularly on top of the closure.

Keywords: *Talangakar Formation, lacustrine, synrift fan, Ardjuna Field, Sunda Basin*

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INTRODUCTION

The Ardjuna structure is located in the Sunda Basin, adjacent to the Seribu Fault. This structure is currently producing oil fields within the Northwest Corner (NWC) Block (Figure 1). The first exploration well in the Ardjuna structure was S-1 well, which was drilled in 1982 and produced 6,500 BOPD with 0% water cut during DST. Previous volumetric calculation indicates that the Ardjuna structure contains approx. 43.7 BSCF and 49.9 MMBO of hydrocarbons in place. The field produced oil from the Talangakar fluvio-deltaic reservoirs through two platforms, namely Ardjuna-A and Ardjuna-C. The Ardjuna-A platform has 13 development wells, with peak production reaching a rate of 9,056 BOPD and 16.7 MMCFD in 1986. The Ardjuna-C platform has 8 development wells, with the peak production rate of 2,856 BOPD and 5.4 MMCFD. When HC production was shut down in November 2006, a total of 30.1 BSCF of gas and 7.9 MMBO of oil were produced cumulatively. Therefore, the recovery factor (RF) for gas and oil were 68.9 % and 15.9%, respectively.

This study was conducted to summarize the remaining potential from existing production zones, and to evaluate the upside potential of the Talangakar lacustrine deposit. Further studies on the economic and development strategies are necessary to determine the appropriate approach for redeveloping a mature structure with significant upside potential.

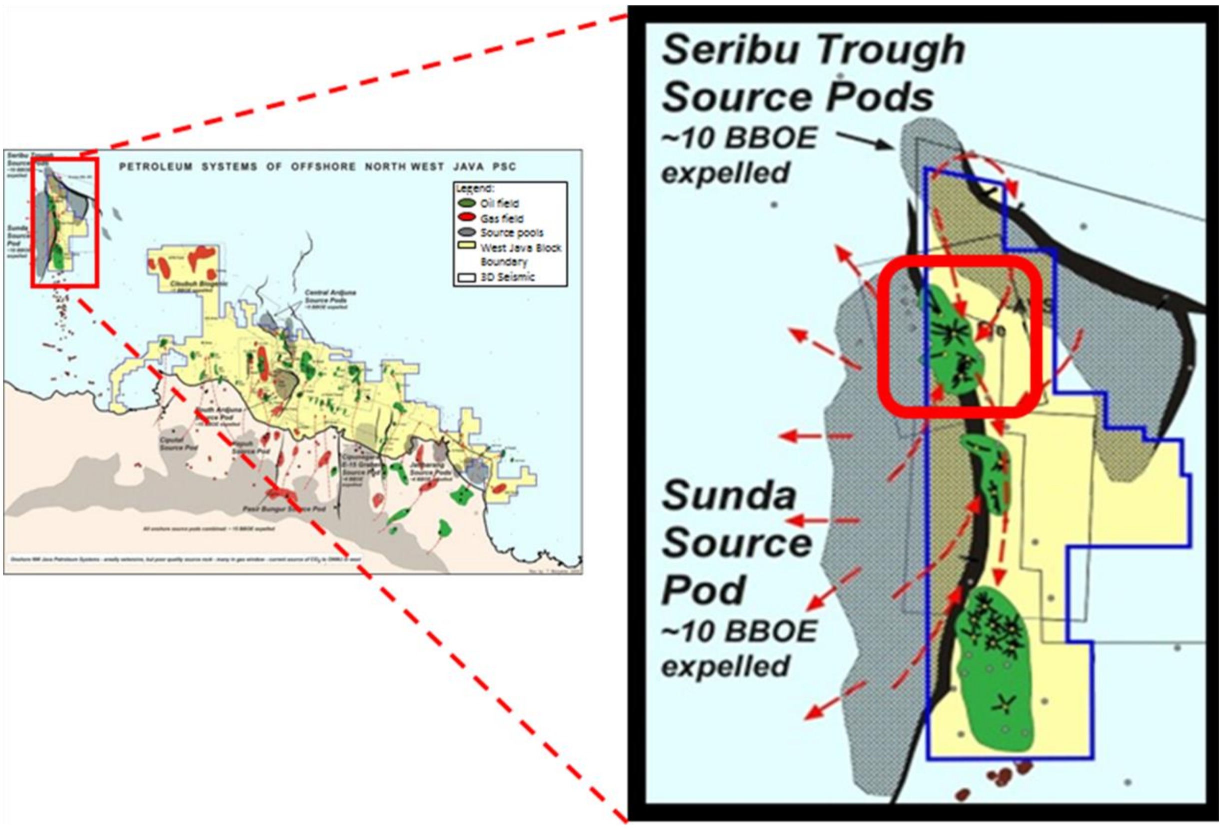

Figure 1: *Location of Ardjuna structure within the Northwest Corner Block, eastern Sunda. Basin*

DATA AND METHODOLOGY

In total, 8 exploration wells, 17 development wells and 3D seismic data were utilized in this study. However, only 2 wells were utilized to evaluate lacustrine potential since these were the only wells that penetrated the lacustrine interval.

This study was conducted to re-evaluate the presence and distribution of hydrocarbon in the Talangakar lacustrine interval by integrating biostratigraphy, core sedimentology, mudlogging & wireline log data, 3D seismic data and DST result. Seismic attribute was analyzed to understand facies boundary trend and porosity distribution i.e., acoustic impedance. Afterward, 3D static model was built to acquire more robust volumetric calculation with uncertainty analysis.

GEOLOGICAL SETTING

Tectonic and Basin Evolution

The Northwest Corner (NWC) block is located in the Offshore Northwest Java Basin (ONWJ) working area, specifically within the Sunda Basin, adjacent to the Seribu fault. The Sunda Basins reservoirs are mainly from the syn-rift deposits which are currently positioned in a back arc setting, but the rift system did not form as a back-arc basin (Ralanarko, 2020). The history of the Asri and Sunda Basin (as a part of Sundaland) can be subdivided into the several stages of tectonic megasequences as described below (Longley, 1997):

- Stage I (50 – 43.5 Ma) – Corresponds to a period of early continental collision which led to the formation of many of the older synrift grabens. The India – Eurasia collision caused a slow-down in the oceanic spreading rates in the Indian Ocean reducing the convergence velocity along the Sunda Arc subduction system and resulting in a phase of extension in the adjacent fore-arc and back-arc areas. Daly et al. (1987) pointed out that the velocity decrease would cause the subduction slab to sink, with consequent decoupling of the slab and creation of an extensional environment in the arc region.
- Stage II (43.5 – 32 Ma) – Major plate reorganizations took place, resulted in the formation and active subsidence of the younger rifts. This extension resulted in the opening up of numerous half-grabens whose geometry and orientation were influenced by basement heterogeneity. Hall (1995) mentioned that South Sumatra has been rotated by approximately 15 degrees clockwise since the Miocene resulting in a present-day graben orientation.
- Stage III (32 – 21 Ma) – Contemporaneous with sea floor spreading of the South China Sea, was a period during which rift ceased, local inversion took place, and a major marine transgression marked the beginning of postrift development.
- Stage IV (21 – 0 Ma) – Characterized by a maximum transgression followed by several collision phases that led to inversions, uplift and the development of regressive deltaic sequences. This is equivalent to the early and late postrift stages.

Stratigraphy

The stratigraphy of Sunda Basin (Figure 2) can be subdivided into several formations from younger to older as described below (Eksindo Pratama, 1996):

- Cisubuh Formation

  Cisubuh Formation is dated as Early Pliocene to Late Miocene age. The presence of a diverse palynoflora consisting of marine, mangrove, and peatswamp suggest deposition in an outer littoral to inner sublittoral environment, close to mangrove vegetation and near to fluvial sediment provenance.

- Parigi Formation

  Parigi Formation is dated as Early Pliocene to Late Miocene. The benthonic fauna consist mainly of shallow water similar to Cisubuh formation.

- Main-Massive Formation

  The Main-Massive sequence is dated as Early to Middle Miocene in age and consist of outer neritic, locally bathyal mudstone with sand overlain by complex of sandstone and mudstone deposited in neritic environment. The upper part of Main-Massive sequence is mostly dated as Early Miocene in age and relatively deposited in middle neritic as calcareous mudstone.

- Baturaja Formation

  The Baturaja (BRF) limestone is dated as Early Miocene in age and deposited in open marine neritic origin, with a distinct relatively deepwater (middle to outer neritic) facies in upper part.

- Talangakar Formation

  Talangakar Formation (TAF) was deposited during Early Miocene to Late Oligocene and it can be subdivided into 3 sequences as below (Figure 2):

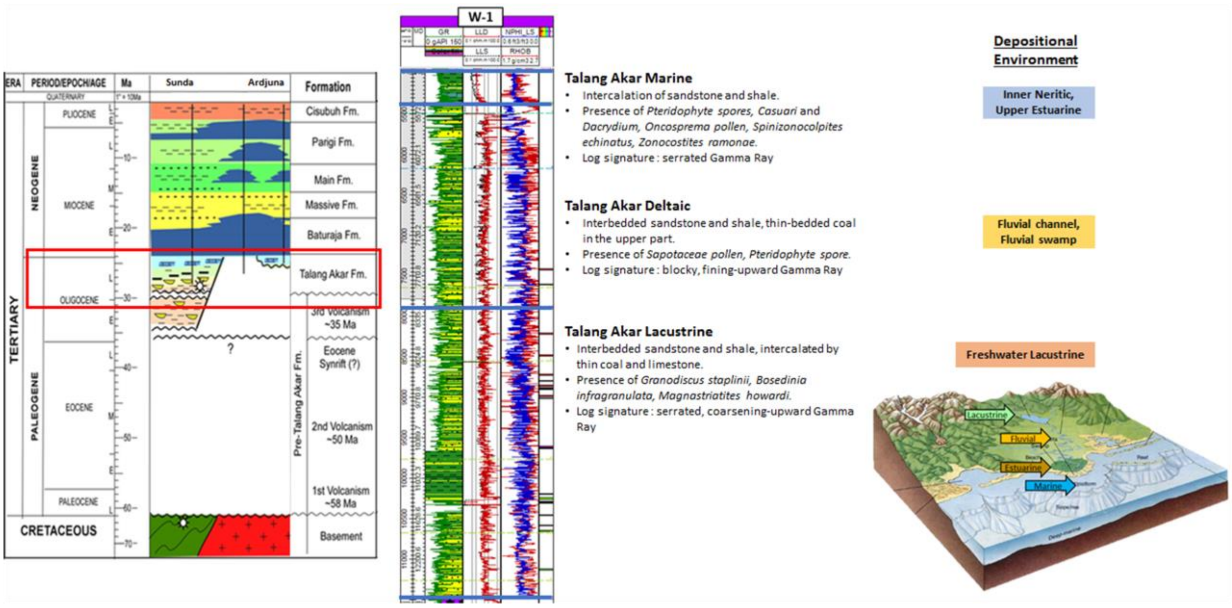

Figure 2: *Stratigraphic column of the Sunda Basin (modified after Aveliansyah et al., 2016)*

1. Talangakar marine consists of calcareous shale intercalation with limestone streak and locally carbonaceous shale or coal. This interval is the transition between fluvio-deltaic sediment to marine. Unfortunately, lack of sand deposits and no hydrocarbon was detected in this interval.

2. Talangakar fluvio-deltaic to estuarine is characterized by interbedded of sandstone and shale with coal deposit that were deposited in fluvio-deltaic to upper estuarine. This interval is the main production layer.

3. Talangakar lacustrine consists of interbedded sandstone and shale, predominantly shale with intercalation of coal and limestone. This interval is the focus interval in this study.

RESULT AND DISCUSSION

Talangakar Lacustrine in the Ardjuna structure

The lacustrine section of TAF was identified from biostratigraphy, log characteristics, core interpretation and seismic attribute analysis. The following section describes the characteristic of Talangakar lacustrine interval within the Ardjuna structure:

- *Biostratigraphy Approach*

Detailed biostratigraphic analyses such as micropaleontology, nannofossils, and palynology were performed from cutting samples of the W-1 and S-5 wells to determine the age and depositional environment (Eksindo Pratama, 1996). *Bosedinia infragranulata* type ‘C’ is abundant in the interval of 8850’ – 10710’ and this is a similar event as seen in the West Natuna Sea, within the basal part of Barat Formation (Eksindo Pratama, 1996). This event is dated by graphic correlation at about 24.5 Ma which equivalent to Early Miocene. *Granodiscus staplinii* and *Bosedinia laevigita* are observed at 10740’ to 12812’, which is usually found within and below Keras Formation in the West Natuna Sea (Eksindo Pratama, 1996). This datum is dated by graphic correlation at about 27 Ma which is equivalent to Late Oligocene. The presence of *Bosedinia* spp., *Magnastriatites howardi*, *Pediastrum* spp., *Granodiscus staplinii,* and *Bosedinia infragranulata* at interval 7860’ – 12812’ suggests this interval was deposited in lacustrine with fluvial swamp influence. Meanwhile, fluvio-deltaic deposition of the upper Talangakar is characterized by the occurrences of *Sapotaceae* pollen, *Pteridophytes* spores, *Zonocostites ramonae, Spinizonocolpites enchinatus*, and *Florschuetzia* spp.

- *Core Interpretation*

The full 28-foot conventional core from the lacustrine section of TAF, retrieved at the W-1 well includes various lithofacies such as shale, sandstone, and coal (Figure 3). The sandstone lithofacies is light grey, well-sorted, very fine-grained with ripples indicating syn-sedimentary deformation. This is followed by lacustrine shale lithofacies, characterized by dark greenish, grey mudstone with minor silty lamination sand lenses occurring in several places.

- *Wireline Log Characteristics*

In the 8150’ – 12745’ interval in W-1 well and 8200’ – 9767’ interval in S-5 well, a pattern of serrated, coarsening upward

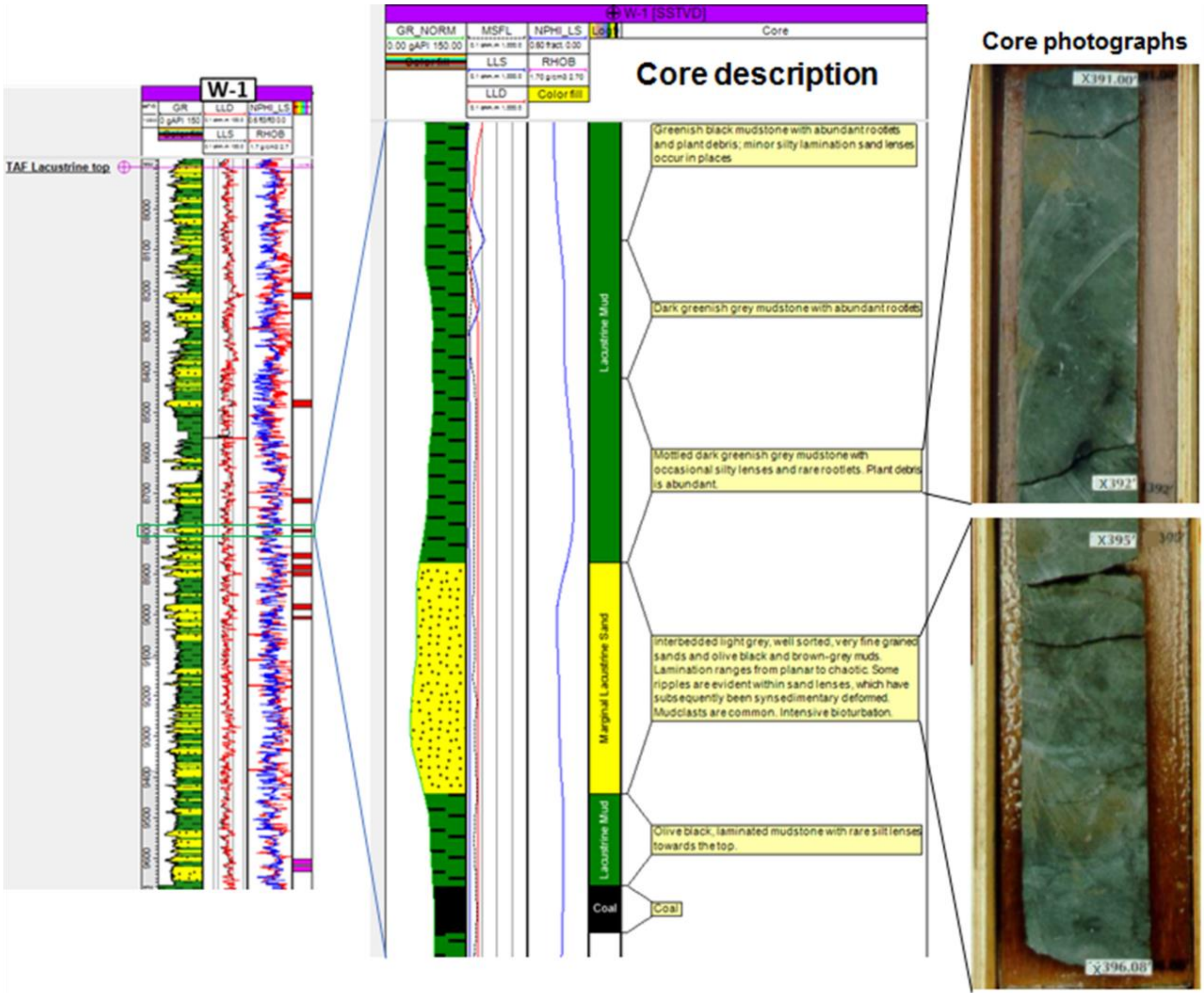

Figure 3: *Core description on lacustrine sandstones and shales at W-1 well.*

and frequent thin sands (3 – 20 ft) suggested lacustrine deposits. The serrated log pattern, indicative of laminated muds and thin, very fine-grained sandstones implies a deposition in a low-energy system. In contrast, the fluvio-deltaic interval shows a blocky to fining upward log signature with relatively thick (5 – 40 ft) of coarser sand bedding (Figure 4), indicating relatively higher energy of deposition. Comparatively, the TAF lacustrine section, with up to 863 ft of total thickness and 24% sand to gross ratio, predominantly contains more shales than the TAF fluvio-deltaic section that has 30% sand to gross ratio despite its total thickness of 755 ft. This smaller sand to gross ratio within the lacustrine section is as expected because in general there is less sand in a deep lake compared to it is in the fluvio-deltaic setting.

- *Seismic Attribute Analysis*

The 3D seismic data revealed a three-way dip fault structural trap resembling a fan bounded by a major N-S trending fault (Figure 5A). Prior to delineating the lateral distribution of sand bodies, a crossplot of p-impedance versus porosity in W-1 well indicated a noticeable separation between sand and shale lithologies ($R^2 > 0.7$ and

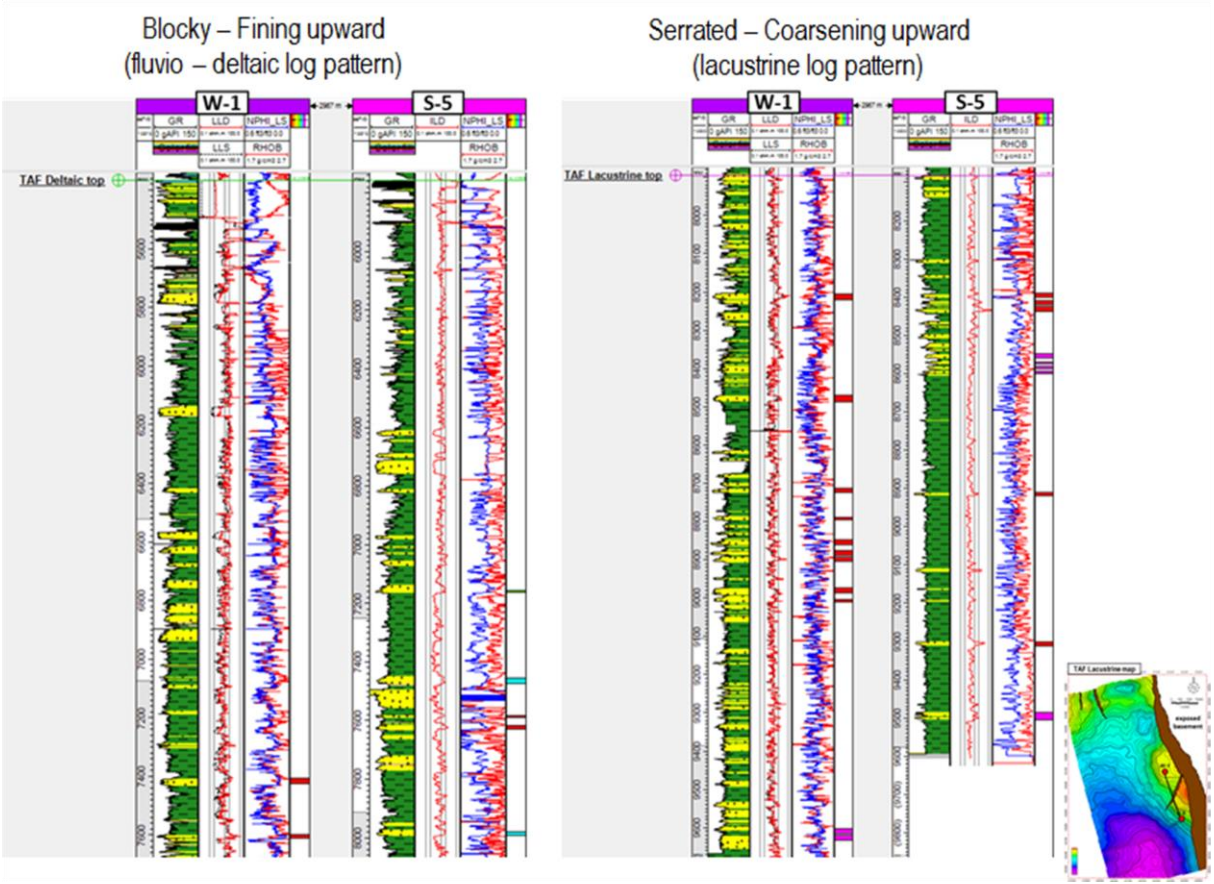

Figure 4: *Well correlation of W-1 and S-5 wells comparing the deltaic and lacustrine sections of the TAF.*

sand value < 7200 gr/cc*ft/s). Consequently, acoustic impedance (AI) inversion displayed the lateral distribution of sand and porosity. Slicing the AI volume unveiled sand (yellow to bright red colors) and shale (dark blue to black colors) distribution emphasizing the fan-like geometry in close proximity to the major fault (Figure 5B).

Depositional Model

Through various approaches, it is demonstrated that the lithology of the targeted interval in the W-1 and S-5 wells is predominantly mudstone with intercalations of siltstone and fine sandstone. The occurrence of bio-event (*Magnastriatites howardi, Pediastrum* spp., *Granodiscus staplinii*, and *Bosedinia infragranulata),* a serrated log signature with relatively thin sand, and a fan geometry revealed by seismic interpretation and AI inversion indicate that the deposits are of shallow subaqueous fan of lacustrine system (Figure 6). The final product, incorporating the depositional model cartoon and the AI-guided seismic attribute of sandstone, is then modeled in the 3-dimentional facies model to facilitate volumetric calculations.

A modern-day analog for the lacustrine section of TAF in the Ardjuna Field probably exists in Lake Singkarak, West Sumatra. At the lake, the Malalo alluvial fan delta exhibits an irregular, lobate shape with dimensions of 2.1 km by 2.3 km (Figure 7).

Likewise, the lacustrine section of TAF in the Sunda Basin is approximately 2.5 km wide and 1.7 km long displaying a relatively regular lobate shape. According to Sihombing et al. (2016), the Malalo alluvial fan delta comprises five distinct facies associations: upper, middle, lower, subaqueous fans and lacustrine shale. This study suggests that the lower and subaqueous fans are favorable reservoir locations characterized predominately by medium to coarse-grained sandstone with moderate to well-sorted fabric, indicating good porosity and permeability. However, TAF lacustrine in the study area, characterized by olive-black, well-sorted, very fine-grained sandstone may also be deposited in subaqueous locations showing similarities to the sandstone interval of Malalo Fan in Lake Singkarak.

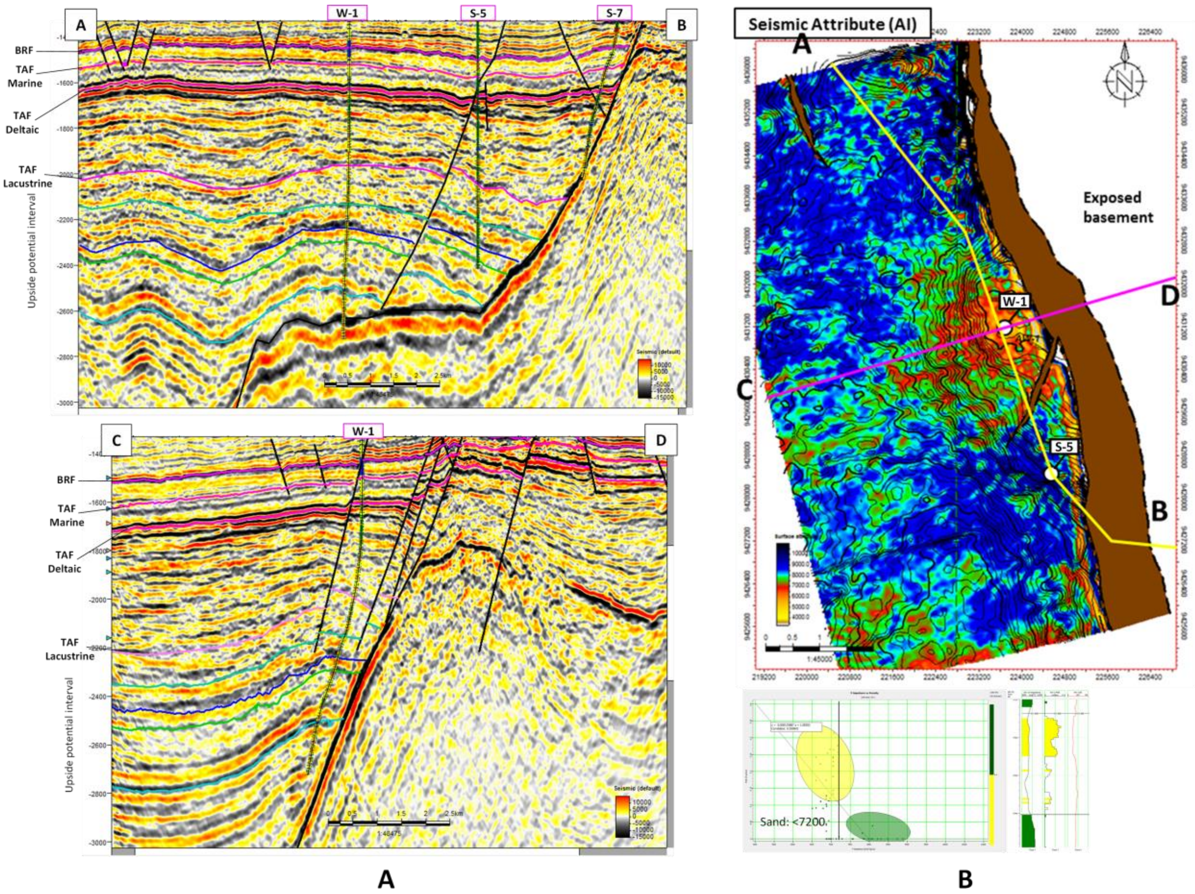

Figure 5: *(A) Seismic section of Lacustrine Deposits. (B) The fan-like geometry of slicing AI.*

DST tests further confirm the potential of the lacustrine petroleum system. Tight, thin sand packages serve as reservoirs, while shale/mudstone facies act as both source rock and seal rock. Hydrocarbon, predominantly oil, are present in almost all sand-packages penetrated by W-1 and S-5 wells in the lacustrine interval.

CONCLUSIONS

The Talangakar Formation (TAF) exhibits three distinct depositional environments, from older to younger: TAF Lacustrine, TAF Fluvio-Deltaic, and TAF Marine. The TAF Lacustrine section in the study area was

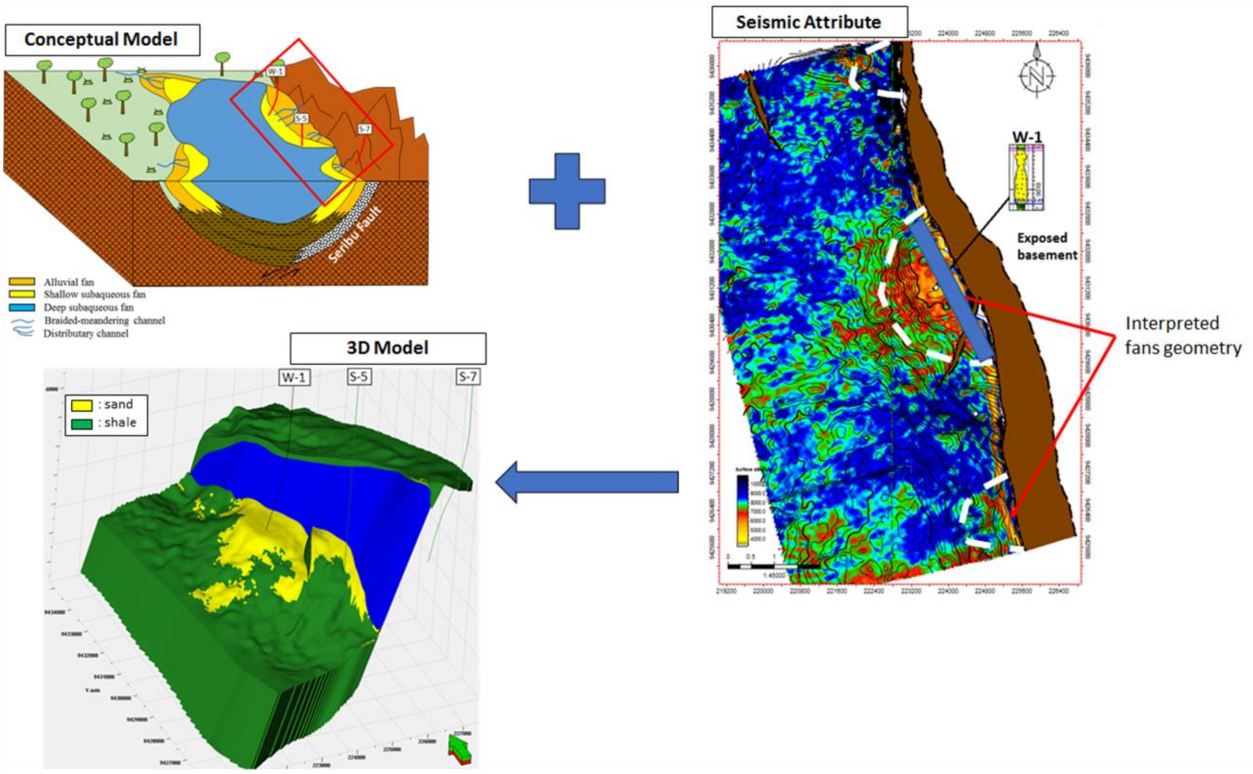

Figure 6: *3D facies model based on conceptual geological model and seismic attribute.*

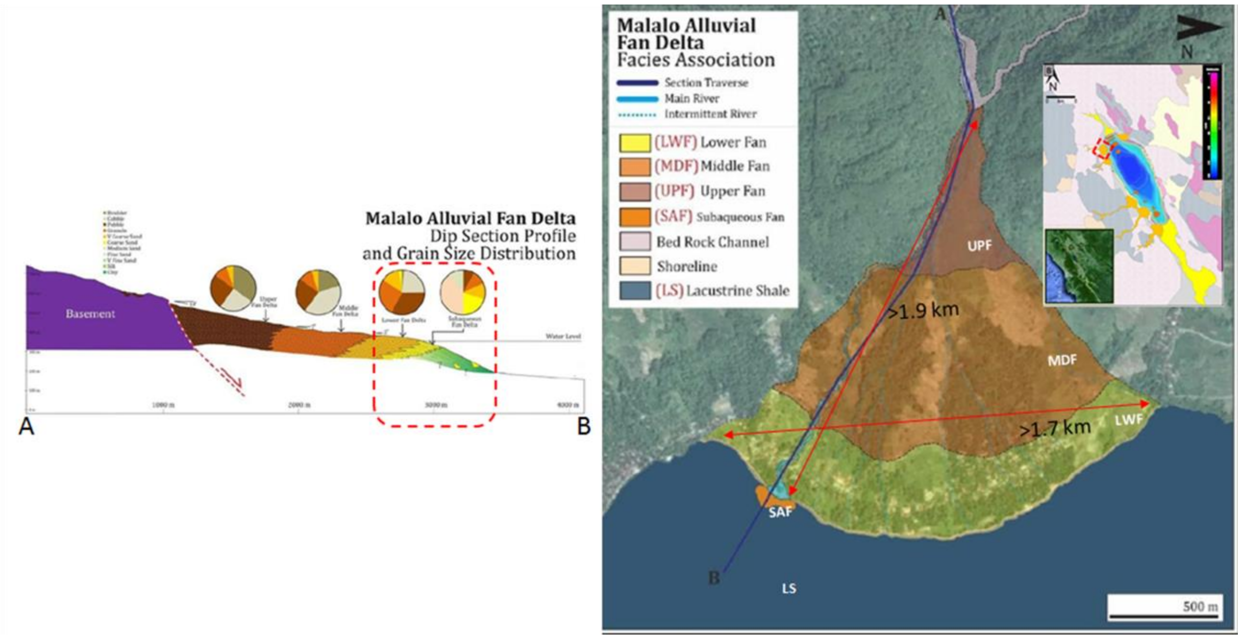

Figure 7: *Modern-day lacustrine deposits in Malalo Alluvial Fan Delta, Lake Singkarak (Sihombing et al., 2016).*

deposited in a freshwater lake with several alluvial fans along a major N-S trending fault. Analyzed data indicate that lacustrine sandstone tends to be thin and composed predominantly of shale facies compared to its fluvio-deltaic sandstone counterparts. Despite this, the thinly bedded sandstones of the lacustrine section are favorable for hydrocarbon accumulation, as evidenced by Drill Stem Test (DST) results in this interval. Seismic interpretation reveals that the study area resembles a relatively regular lobate shape of a fan delta with dimensions of 1.7 km by 2.5 km, similar to the modern analogue in Lake Singkarak. Additionally, low Acoustic Impedance (AI) values, indicative of sandstone, are more frequently and widely distributed, primarily occurring on top of the closure.

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