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THE NEOGENE DEFORMATION, UNCONFORMITY SURFACES AND UPLIFT FEATURES IN DELTA TECTONICS, TARAKAN SUB BASIN

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ABSTRACT

The Tarakan Sub basin is located in North East Kalimantan, several kilometers to the north from the famous Kutai Delta. As one of prolific basin in North Kalimantan, Tarakan Sub Basin is very attractive yet less explored. To the north, The Tarakan Sub basin is bounded by The Samporna Faults and to the south it is bounded by Mangkalihat Faults. Those regional faults are interpreted as sinistral strike slip that creates high morphological features known as Samporna High and Mangkalihat High. The unique setting of both boundaries give speculative ideas of what happen in the area.

The Tarakan Delta is different in some aspects to the famous Kutai. The structural and stratigraphy of the basin gave signatures to the model of Tarakan delta tectonics. Regional sedimentology knowledge helps to answer various possibilities of sedimentation process and hence, their influence to growth fault mechanism. Structural geology analysis hold an fundamental key to the basin deformations and so sedimentation process.

Some data of wells and 2D/3D seismic lines are used to observes the unconformity surfaces. Most of unconformity surfaces in Tarakan sub basin are angular unconformity, the one which created by an uplifting process. The occurrence of unconformity surfaces suggest that the area uplifted some periods in geologic time and can also pointed structural reactivation or tectonic rejuvenation. Structural reactivation in Tarakan sub-basin is one of main contributor to control depositional from fluvial to delta system, a geological marks to the migration process, and also be a rude way to lost hydrocarbon accumulation.

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INTRODUCTION

Nunukan PSC is operated by Pertamina Hulu Energi Nunukan Company (PHENC), located in the eastern part of the Tarakan sub basin. This basin is located near the national border of Indonesia and Malaysia and about 450 kilometers to the north of the famous Kutai delta. To the north, the Tarakan sub basin is bounded by the Sampoerna High and to the south it is bounded by the Mangkalihat High. The Neogene fluvio deltaic sediment in the Tarakan sub basin is thinning to the north to the Sampoerna high and to the south to the Mangkalihat high. The thickest sediment is in Bunyu, Tarakan and in Ahus structure. The sub basin is gently deepening to the east started from Kucing high in the west to an open marine of the Sulawesi sea in the east. The Kucing high is the hinterland and source provenance of the fluvio deltaic sediment deposited eastwardly since the Middle Miocene to recent. (Figure 1).

Kutai vs Tarakan

Most people tend to use Kutai delta as an straight analogue and reference while discuss deltaic depositional systems in Tarakan. Are they perfectly same? Here are several conditions to describe what different in both delta. The Kutai delta is single sourced by the Great Mahakam river which had been depositing a stacked deltaic sedimentary package in one focus area to the Makasar Strait since the Early Miocene. The deltaic depositional setting is confined by the Makasar Strait which in such a way protecting the sediment materials not to dispersed to an open sea. By any chances, there is no major tectonic events disturbed the sedimentation process in the Kutai delta other than sea level changes and tidal influences. As a result, Kutai delta has developed very thick sedimentary packages to be dumped to the Makasar strait (Sudarmono and Maulin, 2017).

The Tarakan sub basin delta system, on the other hand, is sourced by several feeding rivers like in modern setting i.e Sesayap, Sesanip, Latih and other smaller rivers. The mouth of the rivers faces an open marine setting of the Sulawesi Sea which makes the delta sediment is subject to a high dilution by waves and tidal sediment dispersing to an open sea. Consequently the delta of the Tarakan sub basin is not well perfectly developed with thickness varies across the sub-basin. Additionally, uplifting by some tectonic events and erosion have also contributed to make the deltaic deposition can not focused in single area. The setting of the present day Bunyu and Tarakan islands is probably a good analog to the ancient condition in this area. Bunyu and Tarakan island indicate unique feature which some geologists used to interpret them, together with Ahus Structure as a three arches trending NW-SE. On a topography map, the Bunyu and Tarakan islands are positioned right in the mouth of Sesayap River which is split into two rivers, as if Bunyu and Tarakan islands are sand bars deposited by the two river mouths. In fact, they act as barriers to split the river's current in to two main flows (Figure 2). Before reaching Bunyu and Tarakan islands the Sesayap river already splits into two rivers, which may be due to the same condition like in Bunyu and Tarakan islands, i.e there is a structural high blocking the Sesayap river at the more upstream location (Sudarmono and Maulin, 2017).

This condition is clearly recognized on today topography map (Google Earth). Several ancient rivers, which might act as feeder to the delta blocked by Tarakan island or Bunyu Island. The tectonic uplifting of sometimes in Pleistocene created natural barrier to main rivers as good as develop lagoonal environment to the landward.

DELTA TECTONICS

The Neogene delta of Tarakan sub-basin was developed in Middle Miocene (Morley, 2017). It was 6 Million years late than Kutai Delta. The famous Kutai was developed at Early Miocene (23 Ma) in the setting of Tertiary Sundaland. Meanwhile, Tarakan delta began to form at least in Middle Miocene (17 Ma). Both were started with the Oligocene uplifting of what in the present day is called as Kucing High, which then became a sediment provenance of the deltaic package not only to the eastside at the Tarakan sub-basin but also to the west to the Baram and Balingian Delta. It is believed that Kutai was the earliest Delta of Borneo by Early Miocene, followed by Tarakan and Barito Delta (Middle Miocene), anti clockwise to Sandakan, Baram, and Balingian (Late of Middle Miocene). Prior to this delta ages, The Oligocene Eastern Sundaland assumed in Marine environment and likely filled by carbonates and fine grain sediment of marine shale which might tend to hold plastis behavior.

During Middle to Late Miocene, Tidung and Tarakan sub basins were likely to be one basin with delta sedimentary package of Meliat, Tabul and Santul Formations. Those were deposited towards relatively east-northeast. Based on the available data, no major tectonic event is identified during the deposition of Meliat, Tabul and Santul.

Some interesting insight are coming from the seismic interpretation, particularly from Meliat, Tabul and Santul formation. Geoscientists interprets faults as north-south normal listric fault set trending from west in the landward to the east of basinward. The background concept of this interpretation is classic delta tectonics: Listric "growth" faults to toe thrust faults by utilizing detachment surface of Oligocene Plastis lithology. Those normal faults in the proximal area are growth as sediments fills to space created by downward displacement (Figure 3).

They extend parallel to proximal area that have high sediment supply.Their fault plane dips mostly toward the basin and has long term continuous displacement. A growth fault usually is a concave upward fault plane that has high updip angle and flattened at its base into zone of detachment or décollement. This angle is continuously changing from nearly vertical in the updip area to nearly horizontal in the downdip area, typical of listric fault.

Sedimentary layers have different geometry and thickness across the fault. The footwall, landward of the fault plane, has undisturbed sedimentary strata that dip gently toward the basin while the hanging wall, on the basin side of the fault plane, has folded and faulted sedimentary strata that dip landward close to the fault and basinward away from it. These layers perch on a plastis surface or overpressured shale bed that easily flows away from higher pressure into lower pressure zones.

The detachment surface actually will tranfers "loading" stress by high sediment rates of delta and with gravitational mechanism, those stress will creeped up along detachment to create Thrust faults system in the distal area. The Toe thrust will not occurred by compressional stress by tectonics but much more by gravity respectively.

Some structural element in delta tectonics ussually associated with gravity driven force like growth fault as manifesto to tension and toe thrust fault and folds to represent contractional bending. In Tarakan, We found other elements : release faults and diapirism. Shale diapirism are identified near toe thrust zone as compressive stress move uncompacted lithology upward, or sometimes pierce younger sediments. Release faults are found in a major normal fault: Badik Fault. This fault is clearly recognized for having a significant vertical displacement, around 900 - 1500 meters and held some perpendicular normal faults in its hanging wall block. These nearly perpendicular faults are recognized as release faults. A release fault forms as a result of varying throws along the strike of a listric normal fault (Figure 3). As a result of differential vertical displacement, the hanging wall bends and as the normal faults terminate laterally, some kind of cross faults and/or fractures are geometrically necessary to accommodate the increase of length along strike in the hanging wall block (Destro, 1995).

TECTONO-INFLUENCED DELTA TECTONICS

Tectonic and sedimentary process are twin factor to form unique delta systems of Tarakan sub basin. The Late Neogene stratigraphic cycles coincidently is deformed by several tectonic cycles. The most prominent tectonic events are compressive tectonics which occurred twice: firstly during Late Miocene and secondly during Pleistocene. In this paper, the discussion of the sea level change and influence of wave or tidal is very limited to a certain level and assumed to be minor factors just to minimize complexity. In the Tarakan sub basin, a tectonic event will uplift an area to create new local source sediment for the surrounding area whilst the river systems change in direction avoiding the uplifted area. A formation which was uplifted during a tectonic event will be a part of source provenance of sediment for the respective younger Formation. Two sandstones separately located in a distance may lithologically appear similar but they are actualy have different age, one sandstone is belong to the uplifted older Formation and the other one belong to the new Formation deposited along the flank of the uplited Formation. Hence erosional product of the older Formation partly will contribute to deposition of the younger Formation. Figure 2 illustrates a structural high resulted by a compressional deformation will act as a buffer to the deposition afterwards and the structural high will be a new source sediment provenance as well for the younger sediment. The position of an uplifted structure appears to move sequentially eastward so that the position of the younger formation will be shifted eastward relatively to the older formation, and so the following tectonic event will uplift both formations and other younger formation will be deposited further to the east.

Pliocene to Pleistocene Tectonics also gave major deformation to Tarakan Delta. Hypothetically said that Tarakan basin was formed by microplate boundary of Mangkalihat Terrain to Luconia. This suture or microplate boundary is basically a tectonic weak zones. The young tectonic event will reactivate those weak zone to creates strike slip fault system during Late Pliocene to present. To the northern area of Tarakan, Samporna fault zone is recognized as sinistral wrench fault. It separates the volcanics of the Semporna Peninsula of Malaysia from the Neogene sediments on Sebatik Island. The Maratua Fault zone occurs as a complex transpressional zone. It forms the boundary between the Tarakan and Muara Sub basins (Lentini and Darman, 1996).

The Pleistocene wrench fault system then form some major arches due to its compressional stress during inversion. The Delta tectonics then reactivated at this stage to create inversion and in some areas: Uplifted arches Island. Bunyu and Tarakan Island is clearly recognized as uplifted arch by seismic image.

The other uplifted structure is Ahus Arch, located in the northern area that probably was island before marine incursion. The structural inversion is estimated as 1000 – 1500 m to created high areas broad southeast plunging trend which tend to formed by NE-SW transpression. This “juvenile” orientation structures are product of reactivation of the NS listric normal faults of delta tectonics.

The flower structures are also identified in several areas between two normal faults as a product of wrenching during Pleistocene. This features are special since We do not see involvement of basement (due to thick sediments). Seismic data in particular structure shows the flower is embarking to detachment surface, not to basement, and might be influenced by lateral stress while reactivation of listric normal fault occured. Leak of Test (LoT) data then clarify that horizontal stress are dominant in deeper interval of this Structure although vertical stress keep be major stress to the upper layers (Figure 4).

Tarakan Sub basin Delta System

The Meliat delta formation predominantly may only reached Bunyu and Tarakan island and this was probably already in the late stage, meaning that majority environment was pro delta to delta front. The prograding delta of Tabul formation on the other hand, as a cycle of regressive system tract continuing the Meliat Formation, when the delta reached Bunyu island probably it was predominantly still as lower delta plain to delta front facies. Otherwise, delta front facies Santul Formation although already distal, was deposited further east up to the Badik area in the Nunukan Psc.

A major tectonic event in the end of Late Miocene during the end of Santul Fm, uplifted some part of the area to the east of Kucing High where Middle to Late Miocene delta (Meliat, Tabul and Santul Formations) was already deposited. The tectonic event is identified on seismic data offshore in the Nunukan PSC as an angular unconformity in the border of Santul to Tarakan Fm. and in the onshore area. The angular unconformity is marked by an erosion surface of uplifted structures. As erosion took place in the uplifted area, then it became a sediment provenance to surrounding, growth fault, presumably to the east area as regionally the slope started from Kucing High is dipping to the east. The existing river systems from the Kucing High may still be a source provenance but probably their direction already splitted due to barrier by the presence of the uplifted area. Hence a new formation, which is called Tarakan Formation, will be unconformably deposited to the east of the uplifted area and will have a mix sediment composition sourced from the Kucing High and the reworked of the uplifted area. On the seismic data, the Tarakan Fm. onlaps to the uplifted Late Miocene structure. In the far eastern part of the Tarakan sub basin, most of sandstone found to be fine to very fine grain as it was a reworked material from the existing formation. As most of the Simenggaris area was uplifted due to the Late Miocene tectonic event, the Tarakan Fm was probably not deposited in the Simenggaris area which only have the Meliat, Tabul and eroded Santul Formations. Finally the second major tectonic event occurred during Pleistocene where the western part of the Tarakan sub basin (the uplifted structure during the Late Miocene tectonic event) was more uplifted and the eastern part where Nunukan block is located and the Tarakan Fm is dominantly deposited was “pop up” to form the present day Bunyu, Tarakan and Ahus structural features. Before the Pleistocene tectonic event, some pulse of tectonics probably already occured which is indicated by onlapping sedimentary package over a structural high below the Pleistocene unconformity, especially identified on offshore seismic data. The erosion of the Tarakan Fm. in the Bunyu and Tarakan structural highs is then deposited as the Bunyu Fm. Hence, the Neogene deltaic deposition in the Tarakan and Tidung sub basins are product of sequential orogeny starting in the Late Oligocene up to the Present day. By that combination of continuous eastwardly fluvio-deltaic depositional and some pulse of tectonic events causing that every Formation was deposited in a limited certain area and laterally each area has different facies of the Formation. For example, in onshore Simenggaris area only the Meliat and Tabul Fm. are present as most of Santul Fm. was eroded and the Tarakan Fm. was unlikely deposited in the area. The facies of Meliat and Tabul Fm. in Simenggaris area is dominantly delta plain and in Bunyu island is lower delta plain and delta front facies. Understanding the distribution of the deltaic facies is critical for oil/gas exploration in the Tarakan sub basin. In summary, the Neogene deltaic deposition in the Tarakan sub basin was developed by sequential series of compressional uplift, erosion and deposition. In effect of the tectonic pulses during the fluvio-deltaic deposition, fluvial systems will be shifted laterally due to blocking of compressional structural highs. By uplifting in the upstream area, some part of area used to be delta would become starved of clastic deposition and be dominated by carbonate deposition like in the Ahus location during the Late Miocene tectonic event. Hence, The Tarakan Sub basin is considered to be estuarine at least since Pleistocene age when delta gradually destroyed by marine incursion of Sulawesi Sea (Figure 5 and 6) Since then, sediments were deposited trough Latih River System to create younger Latih Delta system in the southernpart of Tarakan Sub basin. The Sesayap River as main feeder still contribute to deliver huge amount of sediments in estuarine system. Those are the major differents between the Kutai delta and the Tarakan sub basin delta (Sudarmono and Maulin, 2017).

UNCONFORMITY SURFACES

Not all unconformities surfaces can be well recognized in seismic data since most of data in the area are still 2D. But in some areas, and specifically in area where 3D is available, those surfaces are clear. We can observe some, while the others still need reconditioned. Another tool use to understand and give strong justification of any geological process in same way is biostratigraphy data. Some evidence of hiatus or missing sedimentary package by thickness or lateral distribution are also be valuable input to be analysed. Regionally, We can observe a bunch of erosional surfaces in a big anticline of Bunyu Trend, known as Bunyu Arch. Somehow those eroded areas will became a perfect accomodation for delta sedimentation (Figure 6). This paper will describe 2 (two) significant structural driven unconformities in Nunukan area and will be analysed as a guide to petroleum accumulation accordingly. Both of those unconformities are correlated to the Late Miocene to Pleistocene uplift and underlined by the transition of Santul – Tarakan Fm.

Unconformity I (U-I)

As one of Petroleum trend in Tarakan sub basin, The Bunyu Trend or "B" trend is the most known and reliable to understand since supported by lot of exploration data. Exploration activities commenced at the Dutch occupation but it was more progressive at the early 1970-ies on the offshore area. The "B" trend is very attractive yet still need explored, with some new concepts.

Located in the middle of Bunyu Trend, Unconformity I (U-I) is considered as a part of structural reactivation during Late Miocene to Early Pliocene. In the early of Late Miocene, a series of NS normal faults were generated. This series of fault seems to be a parallel synthetic of a major, curving normal fault in relatively western part of study area. With high angle dip in the upper part and curving down to more gentle, this fault considered as listric but to the east some of other faults are tilted as a result of rotational movement of hanging wall. The assumption of that tilting on rotational hanging wall came with the fact that there are some "mini basins" or low areas at the hanging wall with dip of around 10-15 degree. The crestal part of this tilting then eroded, create erosional surface. This near footwall low area then filled by younger sediments with a mechanism known as growth faulting (Figure 7-a).

The end of growth fault is indicated by lateral depositional at around Early Pliocene. This sediment package is laid horizontally to cover older dipping layers. Lateral movement came to reactivated the synthetic normal fault in around Pliocene and lift it up slightly to create eastward gentle slope. The uplifting process then ceased at the end of Tarakan Formation, showed by Erosional surface in upper area of U-I (Figure 7-b).

Horizon flatten on particular area shows that Hydrocarbon appeared on horizontal strata. Two gas zones were tested from flat layers signify migration happeneed before trap development, a stratigraphic trap. Some source rock data had been evaluated in that well, come up with Ro gap and TR upsurge at the same inteval which is strong indication of uplifting process during Late Miocene to Pliocene (Figure 8). The bioevent from one of exploration well in this area show the absence of calcareous nannoplankton with siginificant montane palynomorph, whereas the geochemical data does not show VR value anomaly. This bioevent is one of the evidence of uplifting within the study area since pointing to the hinter environment plantation . Uncorformity surface at this location is much disguised with the complexity of faults. Faults are so intensive and sometimes hide the continuity of key layers due to footwall degradation.

Unconformity II (U-II)

Unconformity II is located at the other petroleum fairway/trend, The Ahus Tredn or "A" trend. This fairway is less explored compared to two others with only 3 exploration wells and 2D seismic data. Seismic can show clear image of this unconformity surface. It is described as angular unconformity where a package of sediments laid some dipping older sequences. A huge fold created by compressional stress approximately during Pliocene to Pleistocene, a period after deposition of Tarakan Fm. This fold then eroded massively marked by significant erosional surface. Sediment were transported to its vicinity and deposited in the low areas. This younger sediments then known as Bunyu Fm. The truncational surfaces consist of Upper Meliat, Tabul, Santul to Tarakan Formation. A thick Meliat package truncated and then deposited as Tabul to Santul. It seems that the erosional process is continued at every formation. The younger sediment formation sourced from the older, and the transportation considered as a short system (Figure 9).

CONCLUSION

For some reasons, the occurrence of these unconformity surfaces can be act as a guide to petroleum accumulation in this area. It is one of a key, guidance to the other clues.

Most of unconformity surfaces in Tarakan sub basin are angular unconformity, the one which created by an uplifting process. The uplift need compressional stress in order to lift the sediments up, lift it higher, then exposed as island or arches. The compressional stress also creates anticlines or sometimes can activate normal fault to move upward, inversion. This moment seems to be match with the migration of hydrocarbon in Tarakan Sub basin. There are two hypothetical hydrocarbon kitchens in this area: Kantil Trough and Local depocenter below Bunyu Island, Tarakan Island or Ahus Island. The migration scenario from Kantil Trough is more lateral, using amalgamated sandstone of deltaic system to the northern and eastern area. On the other hand, Hydrocarbon was remigrated either in lateral trough carrier beds or vertically using fault planes during the inversion (compressive event). It is assumed that the real hydrocarbon accumulation is zone between Top of Overpressure and Hard Overpressure Zone, named as “Golden zone (Nadeau, 2011). Hydrocarbon found on above Overpressure zone (marked as normal pressure interval) hypothetically are thief zone by overpressure and fault reactivation. Both Mechanism seems to be a high chance scenario for explorationist in the area to go more deeper in order to gain “the real deal”: transition between Top Overpressure to Hard Overpressure zone (Figure 10). This thesis is still need sharpened by advance basin modelling but a well had been drilled in a closure at “B” trends with positive result, Parang-1.

The occurrence of unconformity surfaces at least mark that the area uplifted some periods in geologic time. Explorationists just need to be careful with the trap, especially in the intensive faulted closures. The opportunity to get hydrocarbons in this area is sometime lesser due to leaking problem. In other way, coincidentally those leaking zone gave bright clues in the early exploration stage at onshoreTarakan to found Bunyu, Sembakung, and Tarakan Oil Fields. Finally Basin modelling, trap analysis and facies mapping using a good 3D seismic data are a must in order to derisking any prospect with unconformity surfaces approach.

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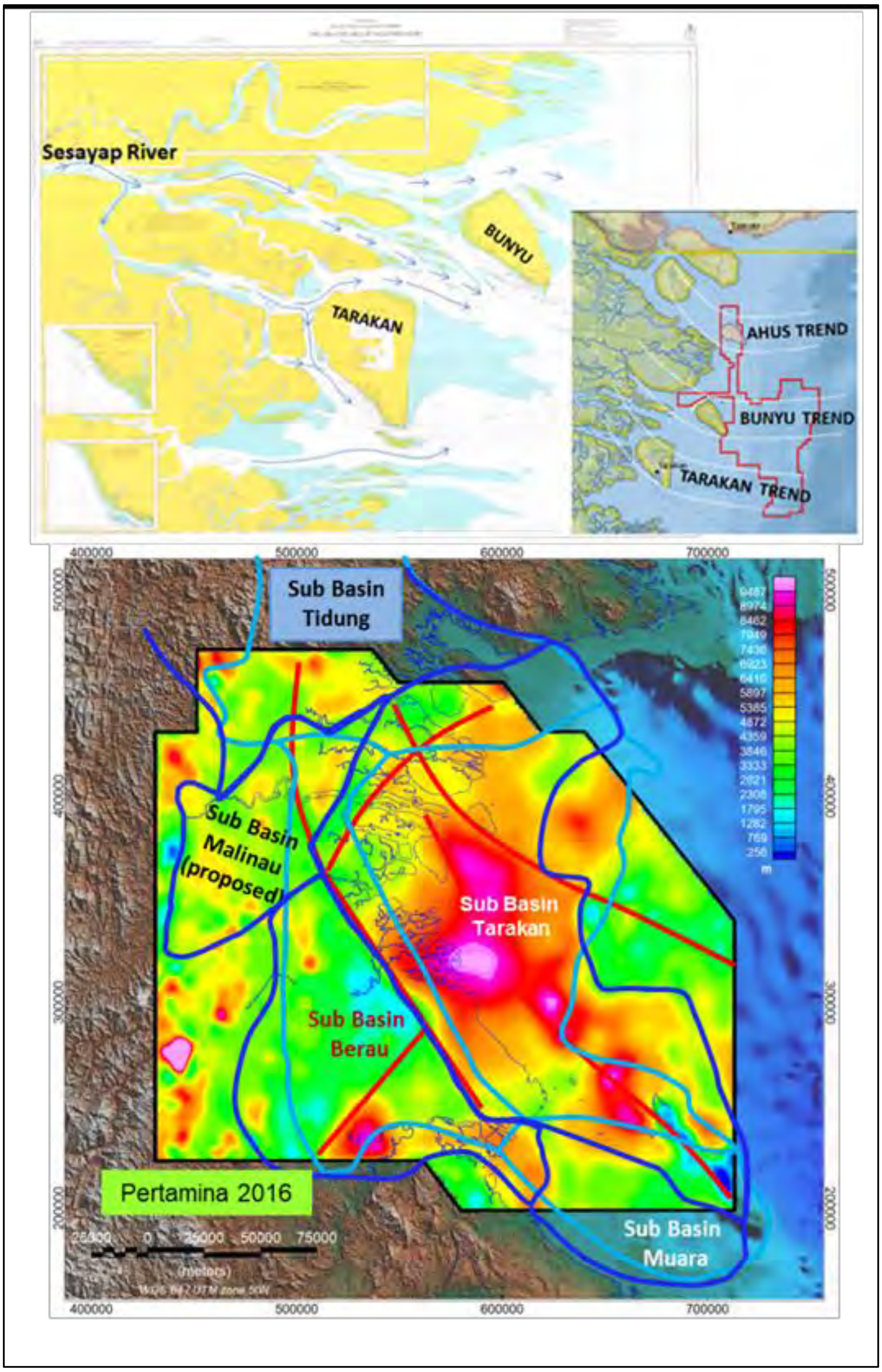

Figure 1 - PHE Nunukan location and Tarakan sub basin Regional Map. Sub basin outline from gravity map indicates other potential sub basin area, Malinau sub basin (from Pertamina regional study of Tarakan Basin).

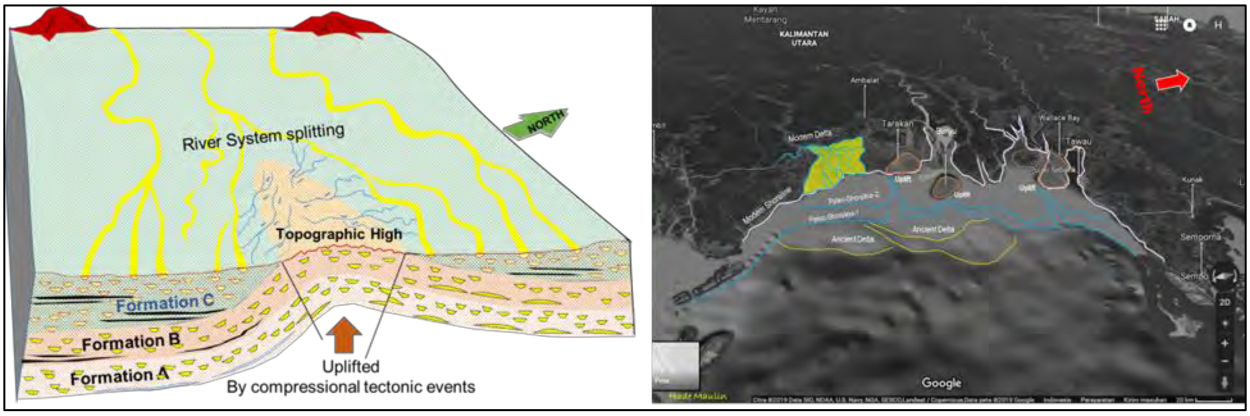

Figure 2 - Splitting river system as a direct impact of structural uplifting area.

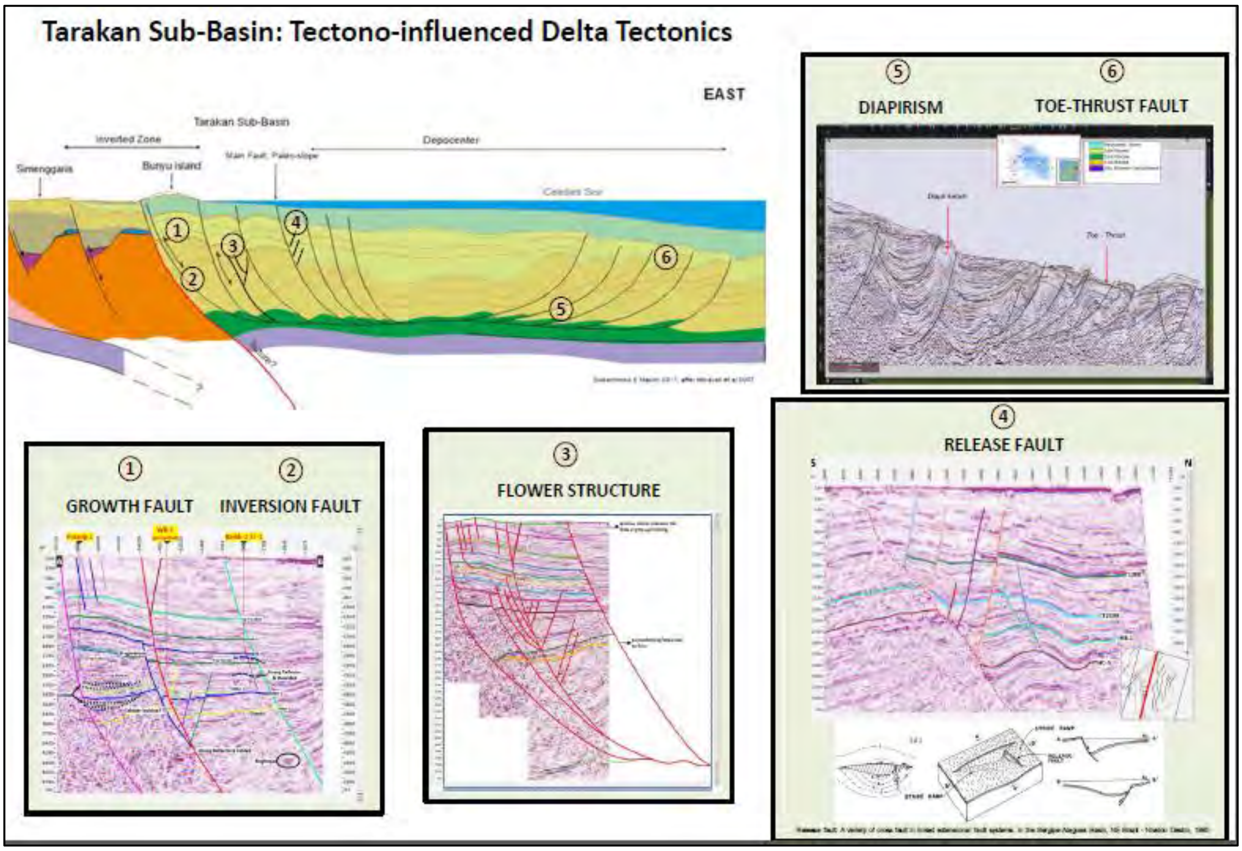

Figure 3 - Tarakan Sub basin as Miocene to Pleistocene Tectono-influenced Delta Tectonic element: Growth fault, Inversion, Flower structure, Release fault, Diapirism and Toe Thrust fault.

Kanah-Teratai-Bunyu
- Normal faulting at shallower section, in hydrostatic pressure
- Strike slip faulting at deeper section, in overpressure zone

Serban: Normal faulting
Badik: normal faulting
Parang&Vanda
- Normal faulting at shallower section, in hydrostatic pressure
- Strike slip faulting at deeper section, in overpressure zone

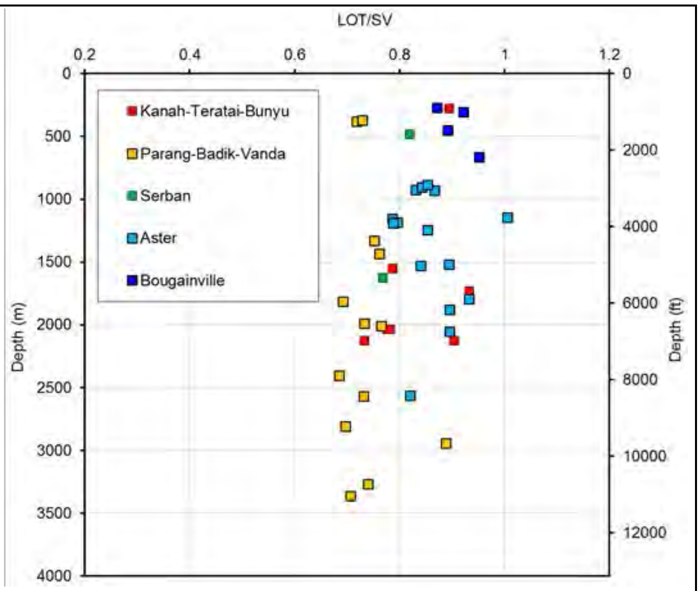

Figure 4 - Composite Leak of Test (LoT) versus vertical stress (Sv) plot. Source: Pore Pressure PHENC.

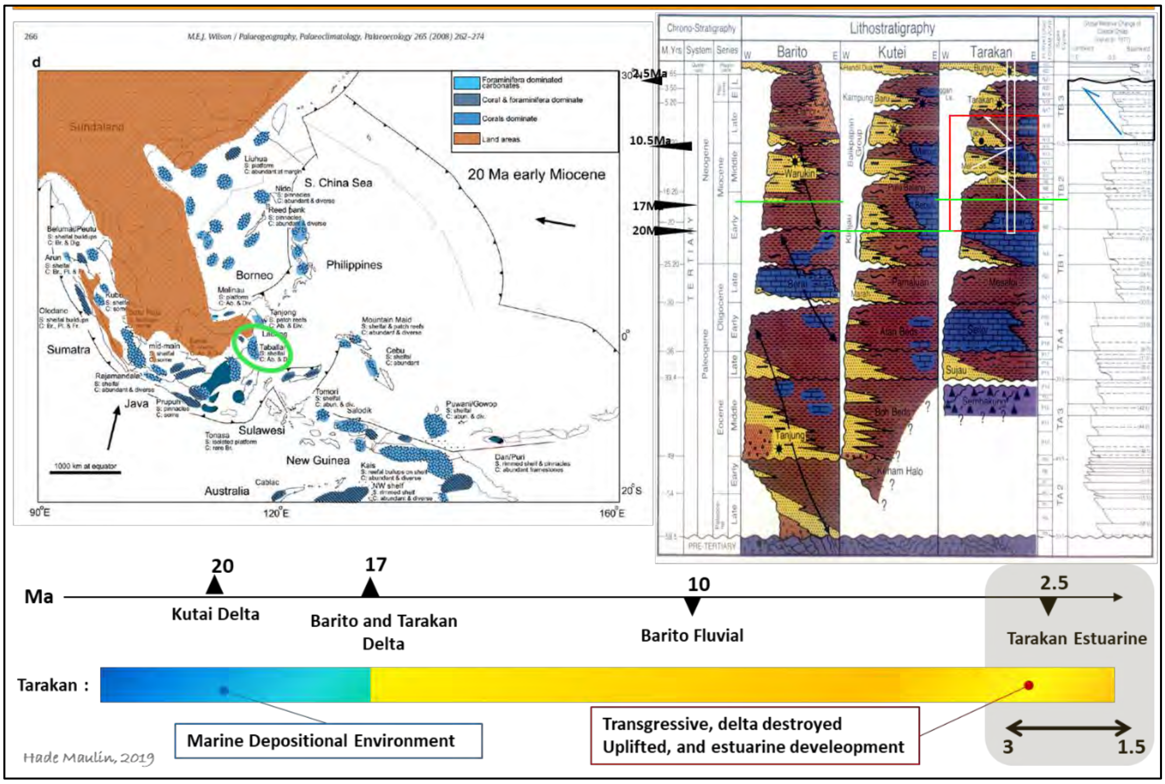

Figure 5 - Tarakan sub basin Miocene - Pleistocene Tectonic calendar to show environmental turnover from marine, delta to estuarine.

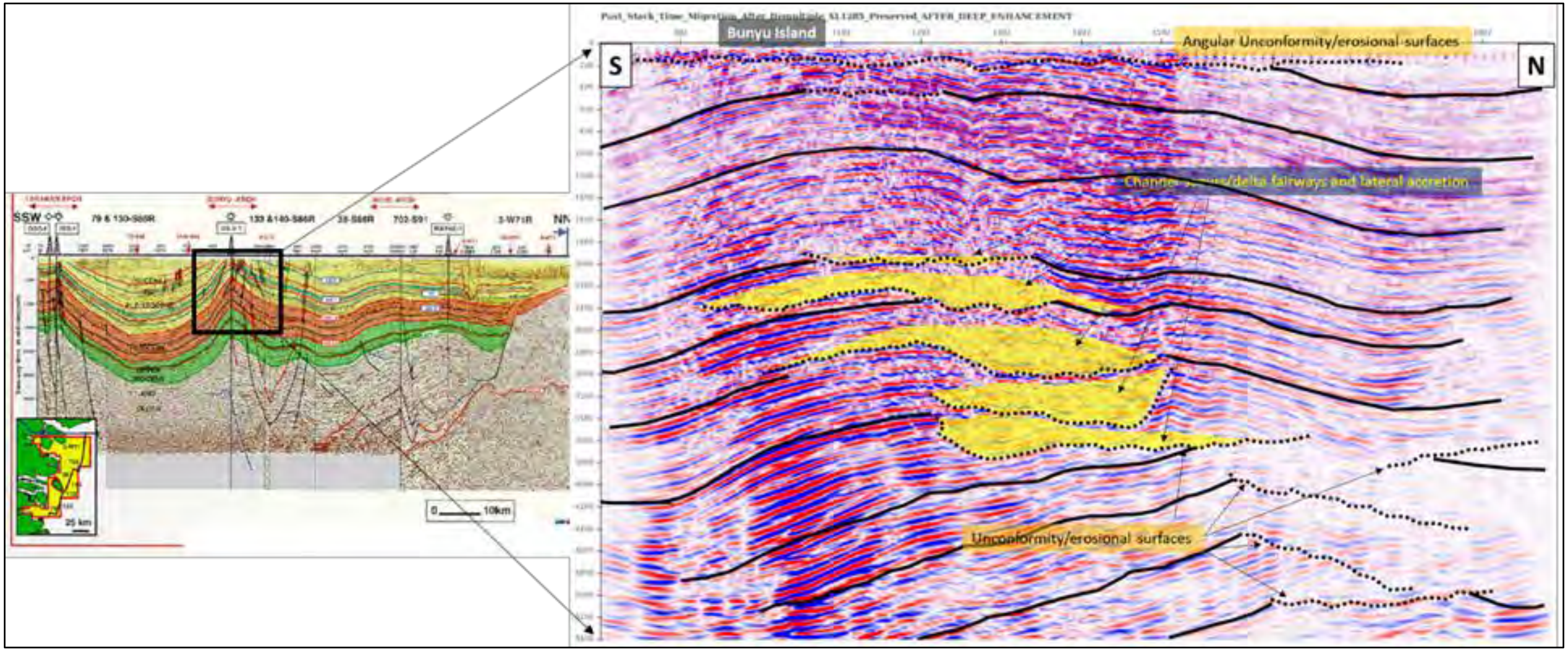

Figure 6 - Eroded Bunyu Arch as accomodation areas for the upcoming delta sedimentation.

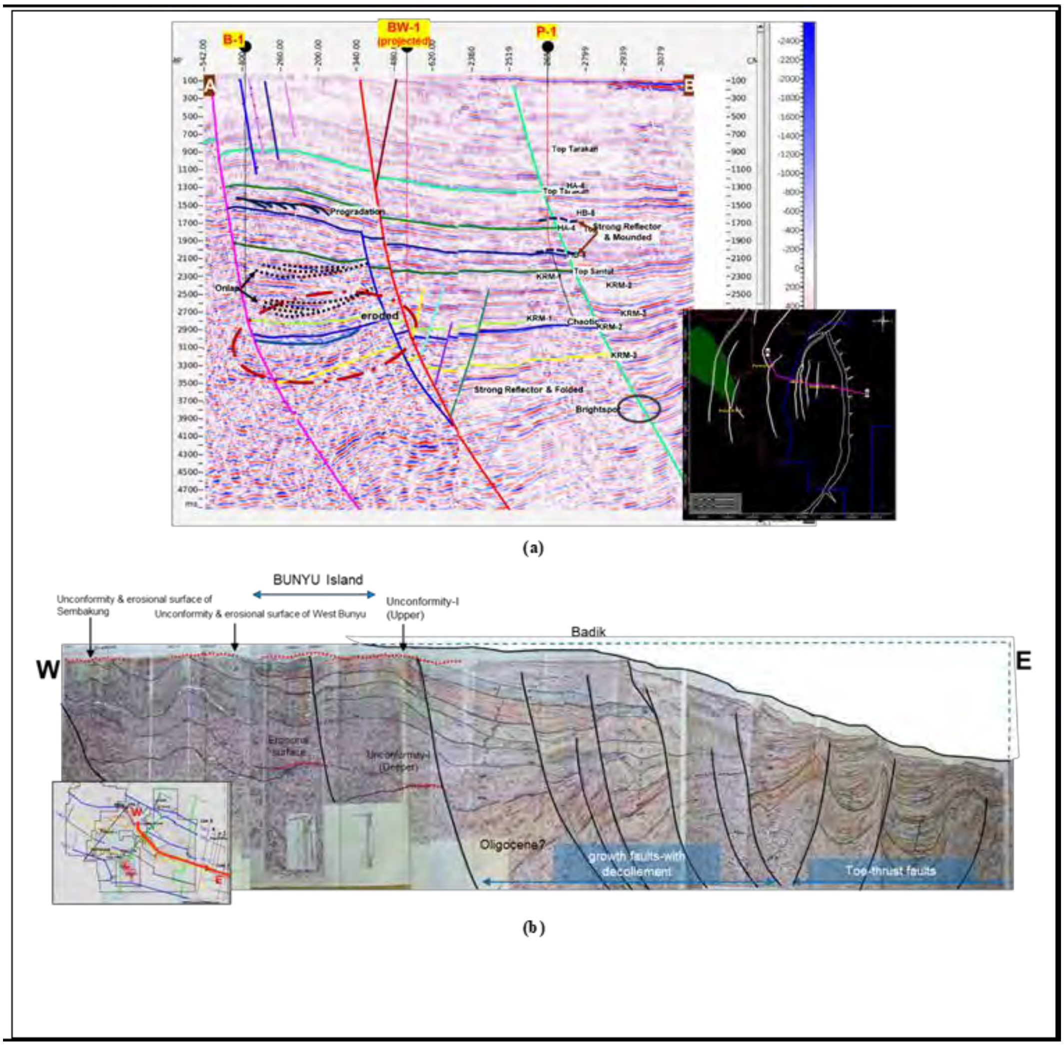

Figure 7 - Unconformity I located in Bunyu area, shows erosional and angular unconformity surface created by reactivated listric normal fault. (a) Erosional surface at Deeper zone (b) uplifted island and truncated surfaces of Bunyu.

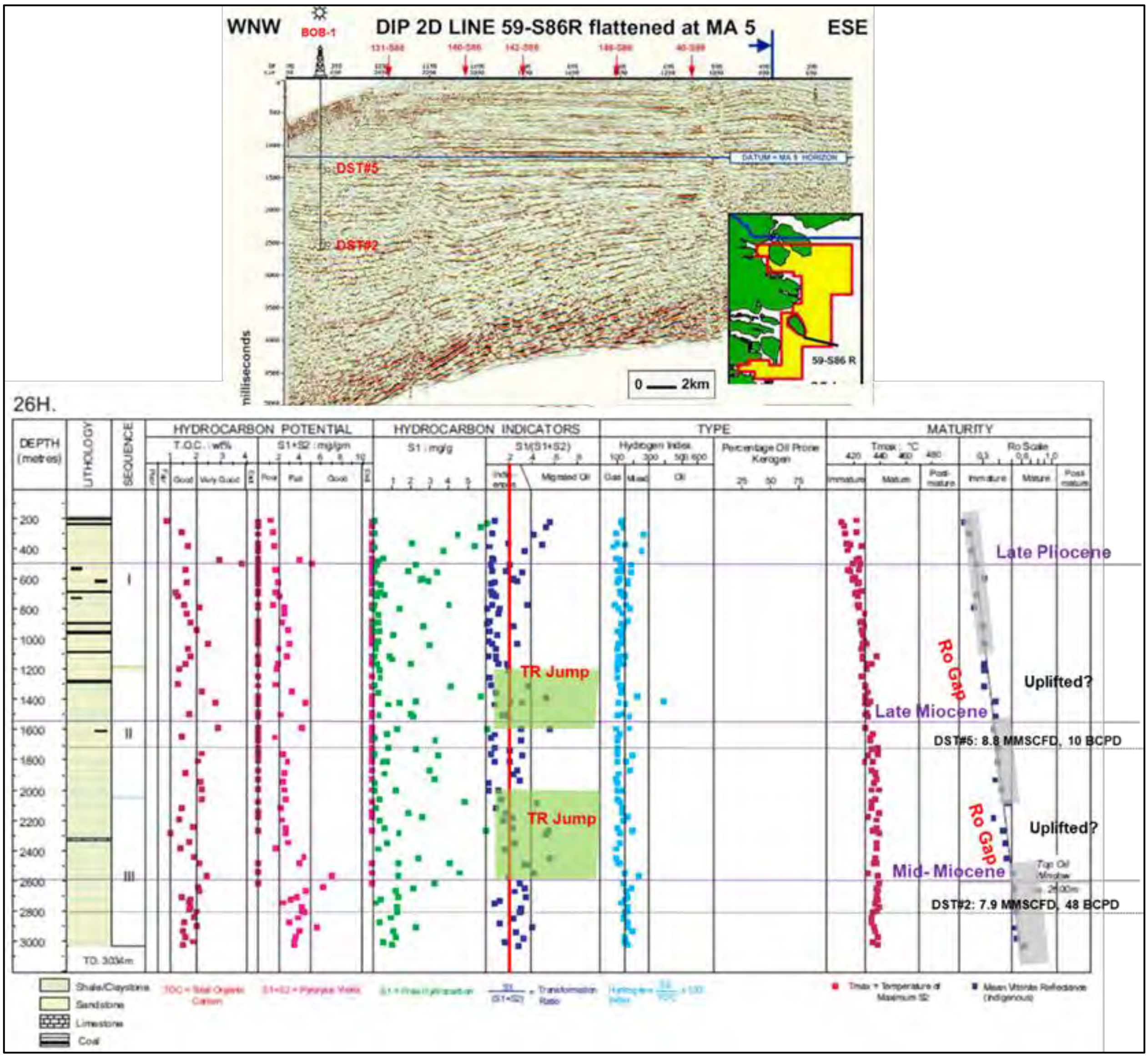

Figure 8 - Stratigraphic trap: hydrocarbon accumulation before structure development in Bunyu flank. Seismic seiction flatenned show that gas accumulated before structural development (from Sebawang I PSC report of Total, 2000).

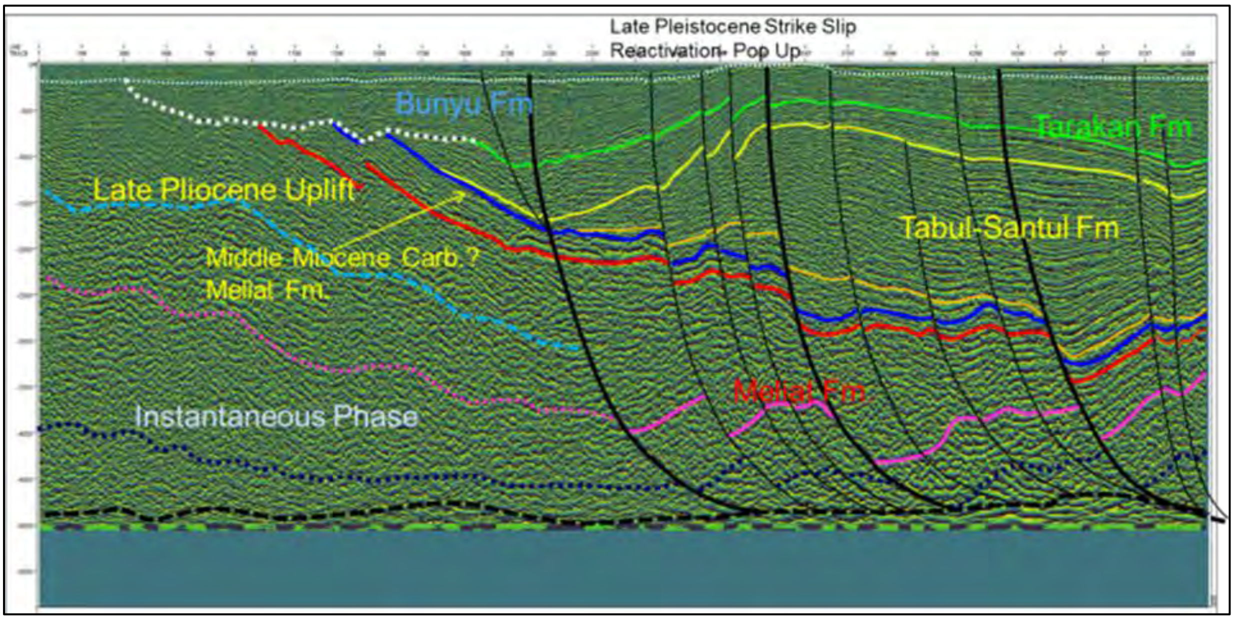

Figure 9 - Unconformity II surface with significant erosional/truncated surface indicates intensive compressional stress during Pliocene to Pleistocene.

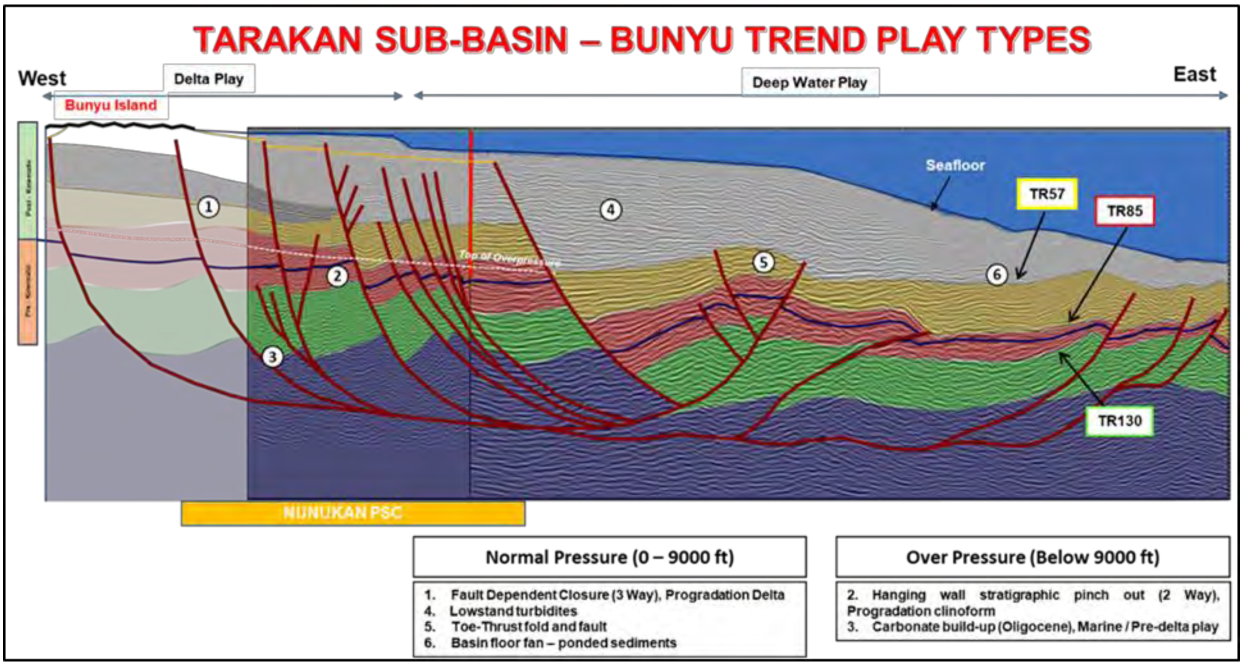

Figure 10 - Tarakan Sub basin Bunyu Trend Play Types, classified by subsurface pressure zone.