Late Neogene Seismic Structures of The South Batanta Basin, West Papua

Struktur Seismik Neogen Akhir Cekungan Batanta Selatan, Papua Barat

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ABSTRACT: Study on multi-channel seismic records from South Batanta Basin, West Papua acquired during RV Geomarin III cruise in 2013 were aimed to invent and map geological aspects and for geo-tectonic and geological history studies.
Seismic data indicate that sediment sequences which can be observed from our seismic system in the study area are characterized by pre-extension sediments (Lower Early Miocene-Upper Early Pliocene), syn-extension sediments (Lower Middle Pliocene-Upper Late Pliocene), post-extension sediments (Early Pleistocene), and syn-inversion sediments (Late Pleistocene-Recent) typical of the West Papua tectonic system. In the study area, sediment sequences are possibly characterized by clastical sedimentary cover such as slumps, debrites and turbidites.

Key words: South Batanta Basin, seismic sequence, tectonic, faults, clastical sediments.

ABSTRAK: *Studi rekaman seismik multi kanal dari Cekungan Batanta Selatan, Papua Barat yang diperoleh selama pelayaran KR Geomarin III pada tahun 2013 bertujuan untuk menginventarisir dan memetakan aspek-aspek geologi serta untuk studi geo-tektonik dan sejarah geologi.*
Data seismik menunjukkan bahwa urutan sedimen yang dapat diamati dari sistem seismik di daerah studi ditandai oleh sedimen pra-ekstensi (Miosen Awal Bagian Bawah-Pliosen Awal Bagian Atas), sedimen syn-ekstensi (Pliosen Tengah Bagian Bawah-Pliosen Akhir Bagian Atas), sedimen post-ekstensi (Plestosen Awal), dan sedimen syn-inversi (Pleistosen Akhir-Resen) tipikal sistem tektonik Papua Barat. Di daerah studi, urutan sedimen dicirikan oleh sedimen penutup klastika kemungkinan berupa slump, debrit dan turbidit.

Kata kunci: *Cekungan Batanta Selatan, sekuen seismik, tektonik, sesar, sedimen klastika.*

INTRODUCTION

At the moment, Indonesia has officially become a net oil importer country since the level of fuel consumption began to exceed production levels. These national issues and the slow increase in oil and gas lifting and production for the last decade are supposed to motivate the extensive petroleum exploration activities in the country. To promote offshore petroleum exploration activities particularly in the frontier areas such as in Eastern Indonesia deep waters is the discovery of new oil reserve trough detailed petroleum geology study using current geosciences concepts and on the basis of data obtained from more sophisticated technology.

Marine geological and geophysical surveys in the South Batanta Basin and surrounding area, West Papua have been conducted in the framework of systematic marine geological mapping initiated by Marine Geological Institute of Indonesia in 2013. The aims of this survey are to invent and map geological and geophysical aspects related to the geological recourses and to study geo-tectonic and geological history of the areas.

South Batanta Basin (GAI, 2009), geographically lies within the Bird's Head waters,West Papua directly adjacent to Weda Basin to the north characterizing the Tertiary Transtensional Basin, and Misool-Onin-Kumawa-Anticlinorium (MOKA) High to the south characterizing the pre-Tertiary-Tertiary Passive Margin Basin and Foreland. South Batanta Basin so far is not recognized as one of the 37 sedimentary basins in Eastern Indonesia released by the Directorate General of Oil and Gas (2003). However, based on gravity models (GAI, 2009), the basin is recognized as the result of transtensional mechanism at the south Sula-Sorong Fault Zone characterizing a rifting valley of a Passive Margin Basin.

The study area lies within the region at the latitude 1 00'00" - 4 00'00" S and longitude 128 00'00" - 134 00'00" E. South Batanta Basin (Figure 1) has a water depth of 200 meters in the northeast and reaches slightly below 1500 meters to the southwest and merged with the Seram Trough. The basin is bounded by a group of Raja Ampat Islands in the northeastern and Misool Islands to the southeastern which have a water depth of 20-65 meters and Seram Trough to the south. The northeastern flank of the South Batanta Basin is bordered by the Transtensional Sorong Fault that extends along the northern part of Papua New Guinea, swing southwestern along Bird's Head in West Papua and into the southern coast of Banggai-Sula islands in the west. In contrast, the southern flank of South Batanta Basin is merged with the northwestern edge of Misool-Onin-Kumawa-Anticlinorium (MOKA) Ridge system.

REGIONAL TECTONICS

Henage (1993), noted the occurrence of four major tectonic events formed a complex structures in West Papua, those are: 1). Early Jurassic rifting along the northern edge of the Australian plate; 2) Early Jurassic rifting along the northwestern Australian shelf; 3) Neogene Collision Phase of the Pacific plate and the Australian plate with the subduction zone that extends from the New Guinea Trench until the West Papua Fold and Lengguru Fold Thrust Belt (LFTB); and 4) Neogene Collision Phase of the Banda Arc with the Australian plate formed Misool-Onin-Kumawa-Anticlinorium (MOKA). Therefore, it seem to be normal when the major structural patterns in the Bird's Head region (Figure 2) generally indicated by the E-W to SW-SE lineaments trending of the Misool-Onin-Kumawa-Anticlinorium (MOKA) in Misool-Onin waters, and N-S lineament of the *Lengguru Thrust-Fold Belt.*

Tectonic events as mentioned by Henage (1993) form the main structures around Bird's Head and can be divided into: Sorong Fault Zone (SFZ) as the main structural elements, and Kemum High, Ayamaru Plateau in the north, Ransiki Fault and Lengguru Fold-Thrust Belt (LFTB) in the east; Misool-Onin-Kumawa Anticlinorium (MOKA) and Seram Thrust Fold Belt (SFTB) in the south; Berau Basin in the southwest, and Salawati Basin in the northwest. Ransiki Fault and SFZ bounded by the Bird's Head basement known as Kemum High which is composed of Paleozoic metamorphic sediments (Silurian-Devonian) covered by sediments of Aifam Group (Carboniferous-Permian) in the south. Meanwhile, Ayamaru platform unconformably underlie the Kais Formation (Miocene) as a source of Paleozoic to Resen sedimentary rocks. Structure configuration of Kemum High, LFTB and MOKA High are limited by Bintuni Basin. This basin is separated from Salawati Basin by Ayamaru platform. SFZ also limit Salawati Basin in the north and by MOKA in the southwest.

Tectonic development of the Papua region since mid-Tertiary (Hamilton, 1979; Hall, 1997 and Cloos et al, 2005) characterize the plate convergence of the northern edge of the Australian Continent with the Pacific Oceanic Plate in the north, and the Banda Sea Oceanic Plate in the northwestern part. Study on regional tectonics of the Western Papua area and Seram waters (Fraser and Samuel, 1993; Pairault et al, 2003;

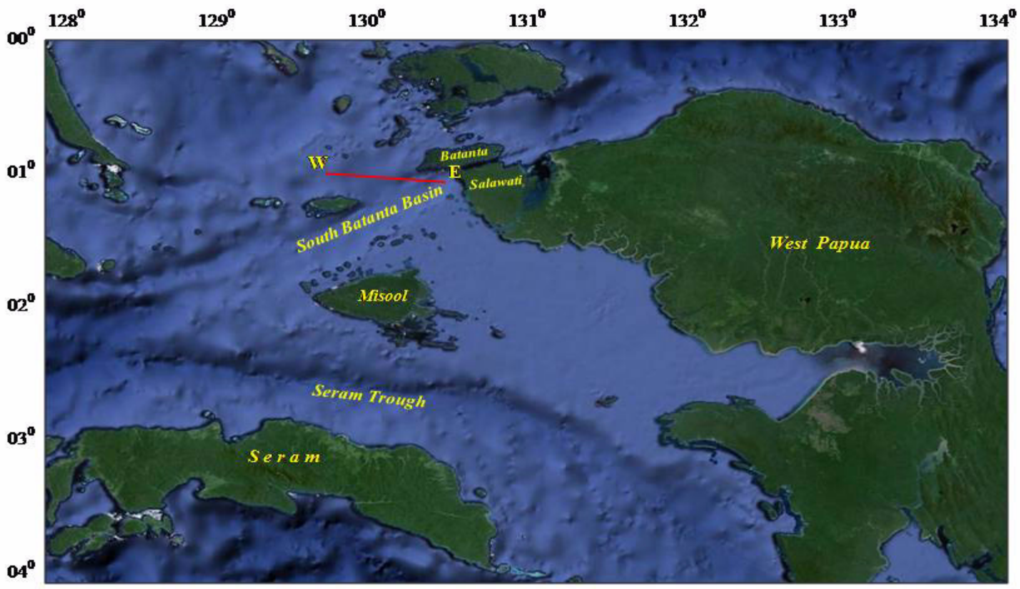

Figure 1. Location map of the study area. Red line indicates seismic profiles produced in Figure 3. (Map source : Google Earth, imagery date 14/03/2013)

Sapiie and Cloos, 2004; Syafron et al, 2008; Bailly et al, 2009; Sapin et al, 2009; Teas et al, 2009; Riadini et al, 2010; Riandini et al, 2012; Darman and Reemst, 2012; Naibaho et al, 2013) gave a highlight of tectonic development of the areas considerably detailed.

Sapiie and Cloos (2004) stated that the relative southwestward motion of the Pacific Plate and the northeastward motion of the Australia Plate resulted in a strike-slip convergence movement across Papua to form the thrust fault and wrench fault. These authors also mentioned that the NW-SE and E-W trending of paleo faults are reactivated as a sinistral wrench fault and thrust faults in the Neogene convergence. Furthermore, Sapiie and Cloos (2004) indicated that the N-S paleo faults, such as *Lengguru Fold Belt* acts as the westward movement accommodation zone for north blocks of Papua resulted the intensively increase of *Lengguru Thrust and Folds Zones*. However, Syafron et al (2008) stated that the relative E-W to NE-SW structural lineament possibly caused by the active movement of *Sorong Fault Zone* (SFZ), whereas the NNE-SSW to the N-S around Vorwata and Deep Wiriagar area caused by Late Permian graben structures.

However, the main structures formed the Bird's Head and Misool block is controlled by the configuration of the main structure SFZ and Ransiki Fault. Oligocene deformation phase has changed the development of the NW-SE lineament of Central Bird's Head (Vogelkop) monocline. Pigram and Panggabean (1984), indicated that Oligocene tectonic phase in Misool Island also shows the sedimentary rocks of Late Oligocene-Early Miocene unconformably bounded by the older sediments of the Eocene-Oligocene.

Early movement of SFZ suggests occur in Middle Oligocene and Pliocene with the main phase of movement occur in the Middle Miocene-Pliocene (Charlton, 1996). According to Pairault et al (2003) deformation in the upper Tertiary period also affected the formation of structure in the Seram Trough. Seram is a foredeep trough area as a result of the formation of fold-thrust belt system which is also known as the *Seram Thrust Fold Belt* (SFTB) during the Early Pliocene. All of the structure elements mentioned above explain several hypotheses of the relative movement of the Bird's Head, both clockwise rotation of Late Tertiary (Robinson and Ratman, 1978; Hamilton, 1979) or composite micro-continent with a separate drift history (Pigram and Pangabean, 1984).

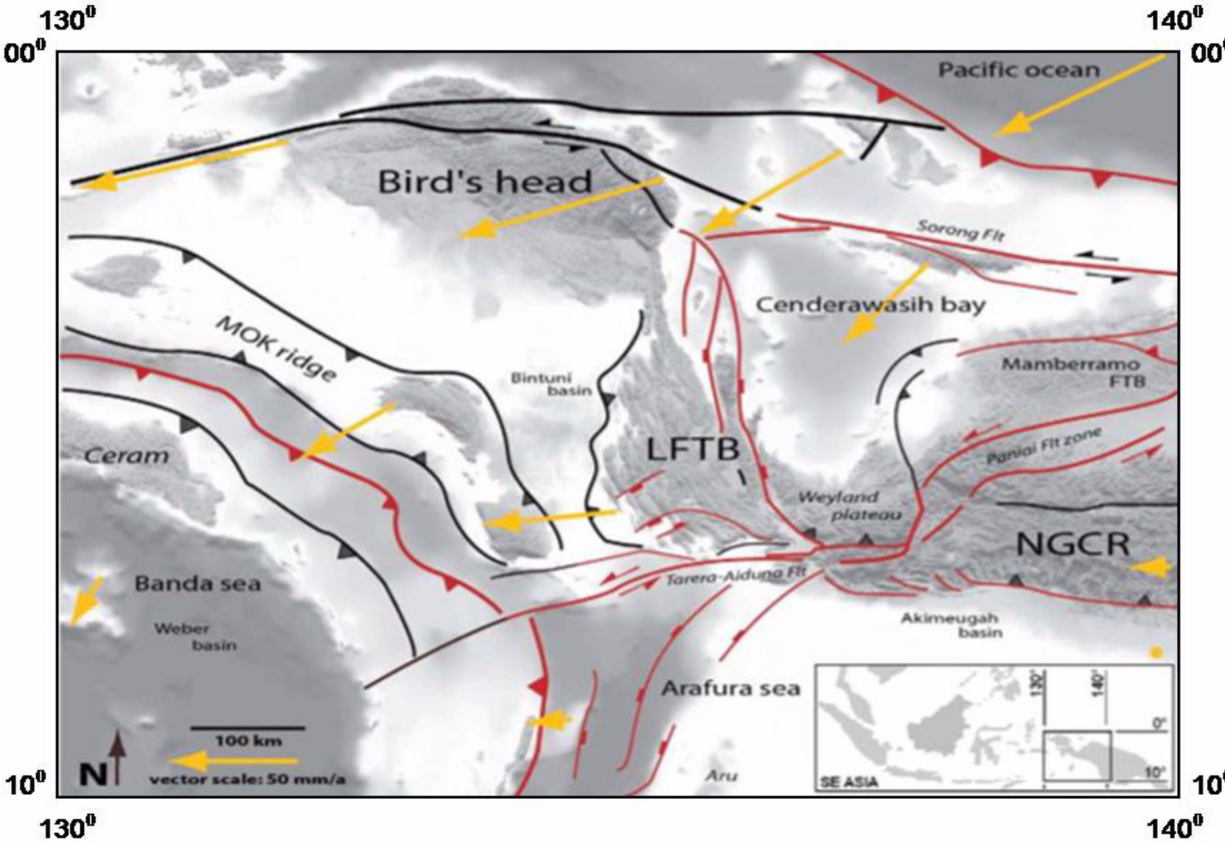

Figure 2. Regional Tectonic Elements of the Study Area (After Bailly et al, 2009)

METHOD AND TECHNIQUES

Continuous marine multi-channel seismic reflection data acquisition was carried out with a 500-600 meters or 5 active sections (ALS) long *Sercel Seal Steamer* where the spacing between each channel was 12.5 m. The whole length of streamer was divided into 60 channels with individual length of 150 meters; therefore, each active section consisted of 12 active channels. Along the streamer, 3 Ion Digibird 5010 was towed 150 m behind the vessel which were assembled in the front, in the middle and at the end of the streamer to maintained the depth of streamer at 5-7 m below sea level. Six units of Field Digitizer Unit (FDU) were mounted in the streamer to convert analog signals into digital that received by a hydrophone. Therefore, the signal transmitted to the recording system has been in digital form. During the survey, the seismic data was obtained by using 2 parallel of 2 *G Guns* II air guns in an array system of totally 630 cu inch as energy source with a firing rate of 12.5 seconds, and of ship movement at a speed of 4 knots. Recording parameter was as follows: Low Cut Filter of 3 Hz; High Cut Filter of 400 Hz; Sampling Rate of 2 milliseconds; and Record Length of 6 seconds.

Seismic data processing was performed by using ProMax 2D software 2003.3.3 version. The following steps were applied to optimised the seismic data quality : *Geometry,Amplitude Correction*, *F-K Analisis/ Frequency Filter,Common Mid Point/CDP, Velocity Analysis*, *NMO Correction*, *Muting*, *Deconvolution*, *Stacking* and *Migration.* The stratigraphy framework has been subdivided into several seismic intervals (depositional sequences) on the basis of sequence boundary and facies analysis (Vail et al, 1977). The database for this study is complemented by the on-and offshore geological data, which have been collected and published recently.

The navigation in the surveyed area was carried out by means of a *Differential Global Positioning System (DGPS) C-NAV* and GeoNav navigation system with an accuracy of the vessel position up to 0.1 m, and by means of a Gyro Compass *Simrad GC-80.* The bathymetry and Sub-Bottom Profiling (SBP) was measured by means of Chirp Sub-bottom Profiler Bathy 2010 using 12 tranducers with a frequency of 3.5 kHz .

RESULTS AND DISCUSION

Seismic Stratigraphy

Seismic penetration in South Batanta Basin that can be reached by our multi-channel seismic system is 2-3.5 seconds TWT. Preliminary interpretation results on sequence stratigraphy analyses indicate the complexity of the basin. Therefore, polysequences analyses was applied in seismic horizons grouping. This analyses is based on tectonic events and reflection configuration difference (particularly Neogene-Quaternary sediments).

Following polysequence model of Sapin et al (2009), the interpretation of seismic records obtained from South Batanta Basin (Figure 3) generally can be divided into four sedimentary rock sequences. The lowest sequence (1) is of *Pre-extension Sediments (Lower Early Miocene-Upper Late Miocene)* composed of Klasafet Fm. and *Upper New Guinea Fm. (Oligocene-Miocene).* The second sequence (2) is of *Syn-extension Sediments* of *Upper Late Miocene-Early Pliocene* composed of clastical sediments that were deposited during the formation of *Berau, Salawati* and *South Batanta Basin* (GA, 2009), and seem to has been undergone of normal faulting (*extension*) as indirect result of *left-lateral Sorong Fault Zone (SFZ)* movement to the west. The third sequence (3) is of *Post-extension Sediments* of *Late Pliocene-Early Pleistocene,* which are also composed of clastical sediments that has been undergone of *extension* formed normal faults as the result of SFZ movement. The fourth sequence (4) is of *Syn-inversion Sediments* of *Late Pleistocene-Recent,* composed of clastical sediments and seems to have been inversed from the extensional phase to the shortening phase.

Seismic Sequence 1 (Pre-extension sediment sequence)

Seismic sequence 1 is interpreted as the acoustic basement and act as the basin floor for the seismic sequence 2, 3 and 4. In the center of the basin, the sequence boundary is erotional truncation and is covered in the eastern flank of the basin by the downlapping reflectors of sequence 2. The seismic facies is characterized by continuous, even bedded, low amplitude and low frequency reflectors. On the basis of its depositional setting and reflection configuration (Vail et al, 1977), the lithofacies is interpreted as clastical sequence.

Pre-extension sediment sequence that can also be called Pre-extension basin of Lower Early Miocene-Upper Early Pliocene can be found in the South Batanta Basin (Figure 3) and in MOKA High. Base on the reflector pattern, the Pre-extension sediment sequence can be distinguished and balanced correlated with *Upper New Guinea* limestones of *Oligocene-Miocene* and its upper part which consist of clastical sediments of Pliocene-*Miocene* Klasafet Fm. *Upper New Guinea Limestone* Group are found in all seismic lines, and characterized by internal reflector pattern of low-moderate amplitude, low continuity with transparent (*free reflector*) at it lower part.

Klasafet Fm. unconformaby deposited on the top of *Upper New Guinea Limestone.* The upper part of this formation characterized by wavy morphology where some part of it has been truncated characterized by internal reflector of moderate-very strong amplitudes, undulated and discontinuous; at the lower part it is characterized by the internal reflector of weak-moderate chaotic to transparent. At the upper part, this rock complex has been eroded and deformed. On the basis of reflector pattern, this formation suggested as the clastical sediments deposited within neritic environment with the thickness reached >500 ms TWT at the eastern part of Misool Islands. Seismic record indicate that this sequence (*Pre-extension Sediments*) has been deformed in the form of thrusting (*blind thrust*) during the formation of the basin (*extensional phase*) as the result of *left-lateral strike slip* movement to the west and the rotation of *Sorong Fault Zone* (SFZ) in *Lower Middle Pliocene*.

Seismic Sequence 2 (Syn-extension sequence)

This sequence is characterized by semi-transparent nearly chaotic and moderate amplitude at the base-of-slope of the basin, and stratified, divergence with parallel reflectors toward the center part of the basin. This difference presumably reflects differentiation of sedimentary facies of the basin fill. This sequence has been slightly deformed, especially along the eastern and western margins of the basin, and laps onto sequence 1 in the center of the basin and in the eastern flank of the basin. In the center of the basins, the sequence has a maximum thickness of 2000-2500 ms TWT and is faulted. Toward the flanks of the basins, it rapidly thins to a few hundred meters, and extends westward across acoustic basement high as a parallel bedded depositional unit. The seismic facies is composed of relatively steep east-dipping reflectors, which downlap seismic sequence 1 and have an interval velocity of 2000 m/s. The upper boundary is erosive and characterized by a high amplitude reflector toward the flanks of the basin but conformably toward the center of the basin. The depositional setting and seismic facies are typical for active slope mass-flow progradation of basin fill complex (Vail et al, 1977). The same reflector is also recognized in the entire Tomini basin (Kusnida and Subarsyah, 2008). This reflection character and configuration suggests an alternation of slump deposits at the slope of the basin and debrite or turbidite and thin bedded pelagic sediments toward the center of the basin. In South Batanta Basin, this seismic sequence possibly of *Syn-extension Sediments* in the form of clastical sediments of Lower *Middle Pliocene-Upper Late Pliocene* as indicated in Salawati Basin (Sapin et al, 2009).

The alternating of low-moderate amplitudes, cotinuous and some are undulated reflectors indicate that *Syn-extension Sediments* deposited during *transgression phase* (Vail et al, 1977). In South Batanta Basin (Figure 3), the thickness of this *Syn-extension Sediments* sequence reached >700 ms TWT in the north of and thicken toward the center of the basin in the west up to >1600 ms TWT. Seismic record indicate that this sequence were deposited during the formation of the basin and faulted by *normal fault* during *extensional phase*, possibly as the results of *left-lateral strike slip* movement to the west and the rotation of *Sorong Fault Zone* (SFZ) in *Lower Middle Pliocene*.

Seismic Sequence 3 (Post-extension sequence)

This sequence extends into the entire basin, and gradually thins to a few reflectors above the flanks of the basin with thickness of less than 300 ms in the western and about 500 ms in the eastern flanks of the basin. The sequence pinches out against the top of the basement high especially in the western flank of the basin. Seismic sequence 3 in South Batanta Basin characterized by the alternating of semi-transparent to weakly reflective beds of a fairly good continuity. At the western base of slope (Figure 3), minor updoming structures arise the sequence and seem due to pull out and pull down of velocity anomalies. Toward the center of the basin, seismic sequence 3 is >800 ms TWT thick and consists of a band of continuous alternated by a semi-transparent, low amplitude and low frequency reflectors. The geometry and seismic facies of this sequence indicate an active lower slope progradation nearly similar to seismic sequence 2 underneath. Both the weak reflectivity and the low seismic coherence of the seismic facies unit indicate slump or debrite deposits. The high and strong amplitude reflections of the upper sequence 3 suggest an alternation of turbidites and pelagic sediments.

Post-extension Sediments seismic sequence 3 in South Batanta Basin seem to be balanced with those found in Salawati Basin and Berau Basin of *Early Pleistocene* (Sapin et al, 2009) with the thickness reached up >1600 ms. The boundary between this sequence with the sequence underneath (*Syn-extension Sediments*) is unconformity as indicated by *onlap* contact at the both flanks of the basin and conformable toward the center of the basin.

Seismic record shows that this rock sequence was deposited during *regression phase* after the formation of the basin or towards the end of *extensional phase*. Deformation such as normal fault within this sequence occurred during *Early Pleistocene* as the result of *left-lateral strike slip* movement of the *Sorong Fault Zone* (SFZ) to the west. This SFZ movement suggests reactivated the *blind thrust* and affected the occurrence of Pleistocene terraces along the north coast of Misool Islands.

Seismic Sequence 4 (Syn-inversion Sediments)

Seismic Sequence 4 is a the youngest sediment deposit and suggest of *Late Pleistocene-Recent* represent *Syn-inversion Sediments* and well develop in South Batanta Basin. The lower boundary of this sequence is *onlap* onto *Post-extension Sediments* (sequence 3) underneath at the both flanks of the basin but conformable toward the center of the basin.

Sequence 4 particularly in the easternmost flank of the basin suggest is dominated by the clastical rocks composed of shallow marine deposits (*neritic*) at both upper slopes of basin flank. It is indicated by the alternating reflectors of low-moderate amplitudes and show the external form of prograded. This sequence is also found as *basin fill sediment* toward the center of the basin, composed of *trench debrite/turbidite* mixed with *slump deposits* at the lower slope of the basin, with the thickness reached < 200 ms TWT in the center of the basin. Seismic record shows that this rocks were deposited during *regression phase* after tectonic inversion from *extensional phase* into *shortening phase*.

Reflection configuration of seismic sequence 4 can be considered as the continuation of seismic sequence 3. However, the alternating of amplitude within seismic sequence 4 is not as good as amplitude alternating within seismic sequence 3. It is because seismic sequence 4 deposited coincided with geological deformation process in the form of extension reversal (inverse) where the direction of the force is opposite to the direction of the force of the extension that causes the folding effect of the younger depocenter in the eastern area. Meanwhile, in the western part of the basin, the effect of inversion process can be seen from the formed of small faults pattern. The fault pattern indicates the presence of normal faults that formed as the impact of the inverse process . Configuration reflection of seismic sequence 4 are wavy and its external form is sheet particularly on positive flower structure.

Structures

Our seismic reflection profiles indicate that the South Batanta Basin exhibits a prominent tectonic features of a series of buried faulted acoustic basement which reached its depth of 1000 in the western flank up to 3500 ms in the center of the basin and 1500 ms in the eastern flank of the basin (Figure 4). The eastern part of the basin has been uplifted, which in turn is partially faulted by strike slip fault indicated by positive flower structure possibly exhibit the *Sorong Fault Zone* that developed since Pliocene. Seismic profiles also indicate that the acoustic basement blocks in the center of the basin seem to be thrusted westward indicated by blind thrust (?).

The eastward prograded-lying, faulted sediments fill in the center of the basins and lack of the faults toward seismic sequence 4 suggests that these normal faults have not been active prior to the inversion since *Late Pleistocene*. The nearly NE-SW trending and NW-SE widening of the basin dimension and a uplift of the nearly southeastern tip of the South Batanta Basin can also be explained probably related with an SE-NW pull-apart basin formation. Based on the seismic profile interpretation, four general tectonic phases can be portraying in South Batanta Basin:

a. Strike slip faults and thrusting were active during the earliest phase of tectonism and formed pre extensional basin and filled continuously by *Lower Early Miocene-Upper Late Miocene* sediment deposits such as Klasafet Fm.
b. Thrust structural style recognized in the South Batanta Basin indicates *Syn-extension* tectonic related to the movement of left lateral Sorong Fault Zone, where the extension movement has modified the previously extensional tectonic environment within the basin. It was involving basement differential faulting of the basin and sediment deposition within *Berau, Salawati* and *South Batanta Basin* in *Upper Late Miocene-Early Pliocene.*
c. Continuous movement of Sorong Fault Zone resulted in normal faults within the basin followed by deposition of clastical sediments of *Late Pliocene-Early Pleistocene.*
d. Relatively NW-SE widening and differential subsidence of the basin clastical sediment deposition since *Late Pleistocene-Recent* indicates a E-W increase in the total amount of shortening.

CONCLUSION

Tectonically, the study area is an active region and expressed by *Sorong Fault Zone* (SFZ) in the form of *positive flower structure*, *blind thrust*, *normal fault* in *extensional* phase. The movement of Sorong Fault Zone during Middle Oligocene and Pliocene with the main phase occurred during Middle Miocene-Pliocene, (Charlton, 1996), indirectly has formed sedimentary basin in the western part of West Papua such as *Salawati Basin*, *Berau Basin*, *South Batanta Basin*, *Misool Basin*, and Bula Basin in the northern part of Seram Island (GAI,2009). Tertiary period deformation also affected the development of *Misool-Onin-Kumawa-Anticlinorium* (MOKA) and the formation of *Seram Trough* in Early Pliocene (Pairault etal., 2003) and *Seram Fold Thrust Belt* (SFTB).

Oblique lifting of Misool in Oligocene initiated the formation of MOKA (*proto-MOKA*), while the main phase of movement during Middle Miocene-Pliocene has resulted the morphology of MOKA relatively E-W extends as the present. In contrast, the

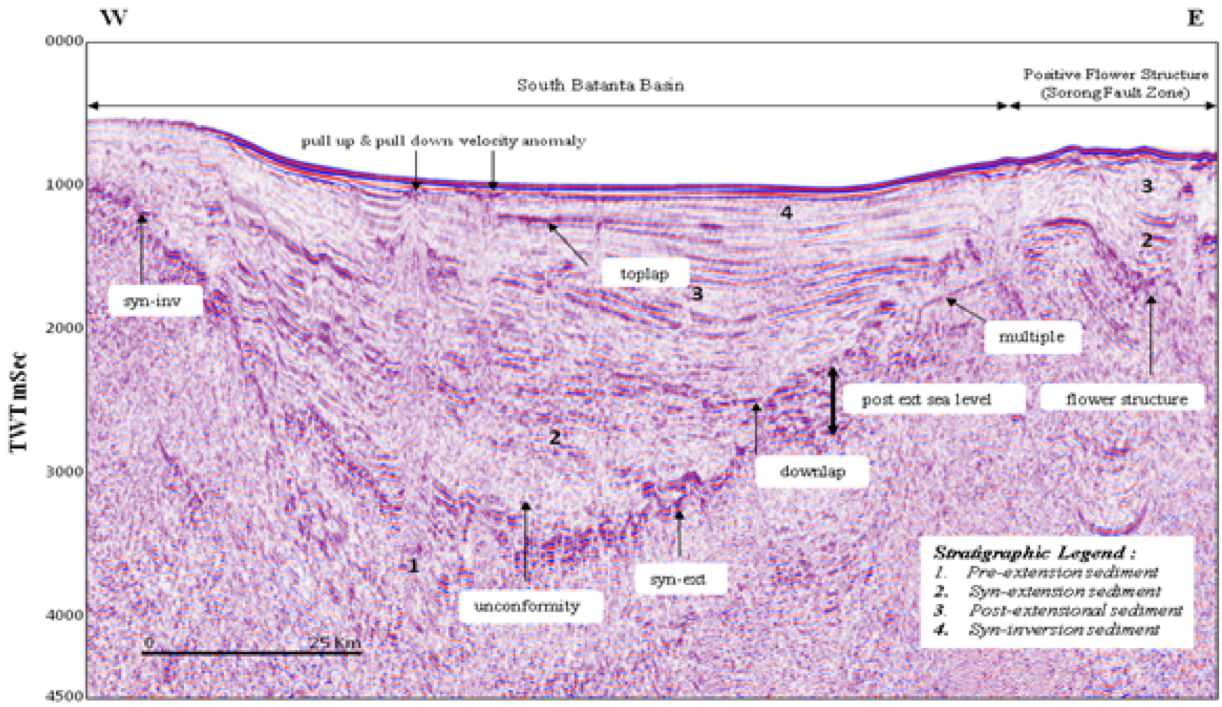

Figure 3. Seismic Stratigraphy of line PMSL#42 (Location see Figure 1)

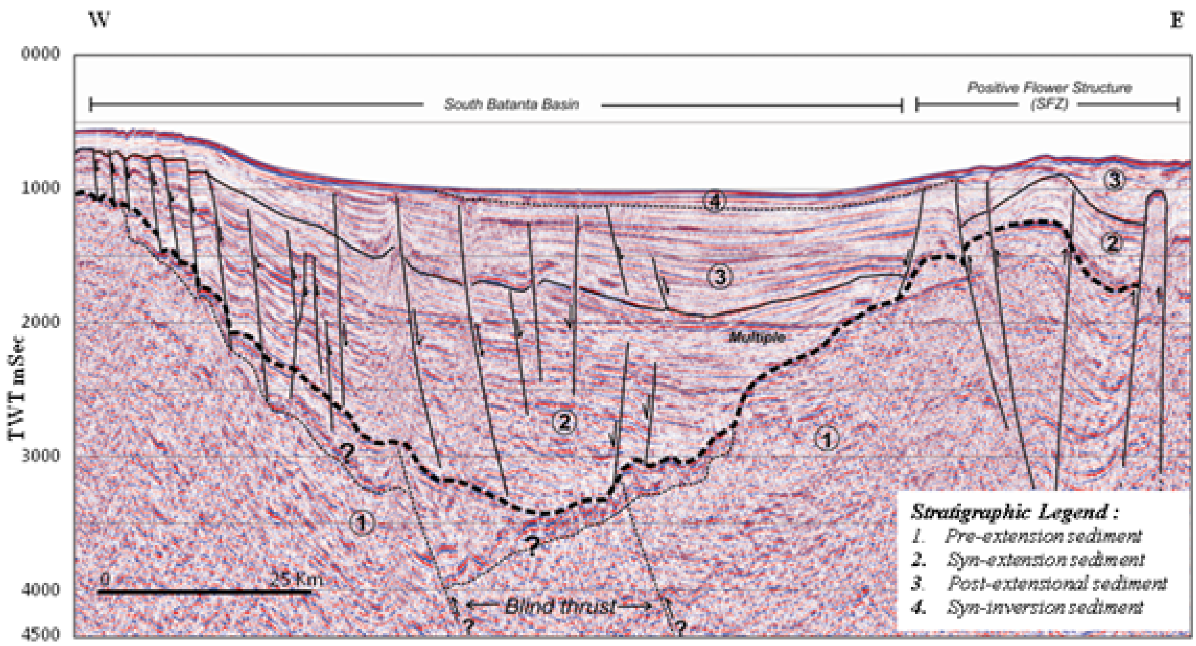

Figure 4. Fault structures of line PMSL#42 (Location see Figure 1)

northwest shortening Sorong Fault Zone suggest as the response of combination movement at Bird's Head and westward movement of *left-lateral-strike-slip Tarera-Aiduna Fault system* in the form of *Seram Fold Thrust Belt* (SFTB). Morphologically, the Seram Trough is a foredeep as the result of loading increase of *fold-thrust belt* in north Seram Island. This is shown in seismic record by increasing of SFTB in Late Miocene-Pleistocene correlated with the movement of MOKA High to the south (*Seram Trough*) with slightly gentle slope and *thin-skinned* expression underneath which is associated with gentle *thrust-sheets* within *Syn-extension Sediments* and *Post-extension Sediments* sequence.

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