Seismic Expression of Geological Features in Seram Sea: Seram Trough, Misool-Onin Ridge and Sedimentary Basin

Herman Darman & Paul Reemst
Shell International E & P, The Haque, Netherlands

Introduction

The Seram Sea (Figure 1) is located between Seram Island and the Bird's Head of Papua, Eastern Indonesia. This sea extends to the east towards Bintuni Bay. Some part of the sea, between Seram and Misool are deeper than 2000 m. The Seram Island is mountainous with altitudes reaching 3000 m above sea level at the center of the island.

Several seismic surveys have been conducted to understand the geology of this region. The first seismic sections were published by Hamilton in 1979. These seismic sections were acquired by Western Geophysical for Phillips Petroleum. In 2000, Schlumberger published some seismic lines acquired in 1997 with an improved resolution improvement (Blunden, 2000). More higher quality seismic lines were acquired as part of non-exclusive and multi-client projects in the late 1990's which provide a better geological understanding of the region and lead to several petroleum exploration opportunities.

This article discusses the seismic expression of several geological features in the Seram Sea vicinity based on published seismic sections. The offshore seismic sections cover part of the imbricated complex in the north of Seram Island, the Seram Trough, the Misool-Onin High and the sedimentary basins the east of the Misool-Onin Ridge, such as the Tamaloi-Malagot Basin, the Semai-Berau Basin and the Bintuni Basin (Figure 1).

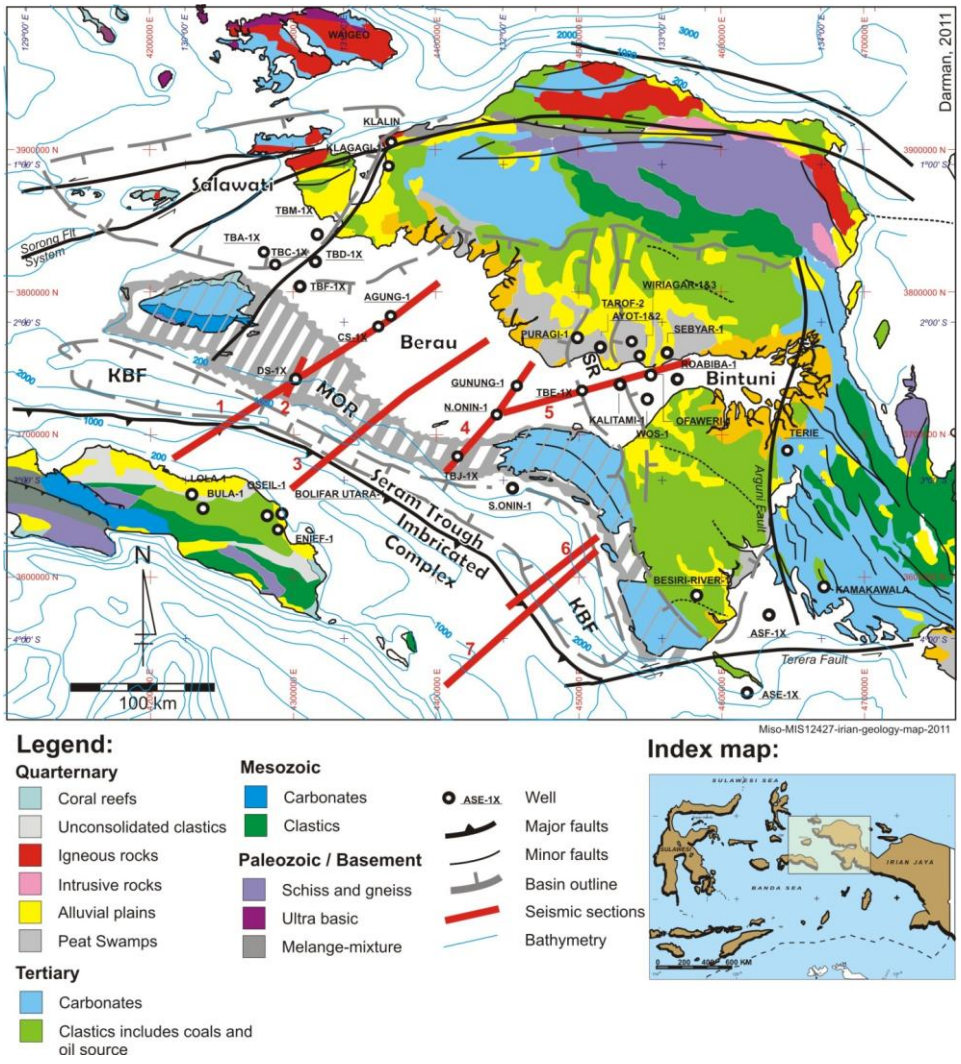


Figure 1. Regional Geological map of Seram Sea and vicinity, showing the structural elements in this area, outcrops and major faults. Seismic sections discussed in this article is shown in red. Main wells are also displayed as reference. SR = Sekak Ridge; MOR = Misool-Onin Ridge; KBF = Kepala Burung Foreland Basin.

Misool-Onin Ridge

The Missol-Onin Ridge is a structural high located in the Seram Sea between the island of Seram and the Bird's Head of Papua. This feature is exposed above the sea as the Misool Island in the northwest and the Onin Peninsula in the southeast. This high is truncated by the large Sula-Sorong Fault System in the north and the Terera Fault in the south. Both faults are interpreted as sinistral lateral faults (Figure 1). At present the southern flank of this high forms a steep sea bottom relief towards the Seram Trough but the northern flank has been covered by younger sediments and does not show a significant bathymetric expression.

Several wells have been drilled on the Misool-Onin Ridge. Daram Selatan-1 penetrated the northern part of the Misool-Onin High and TBJ-1X was drilled in the south. Daram Selatan-1 tested a section of more than 1000 m of Triassic age dominated by limestones section (Wongsosantiko & Mertosono, 1996) and TBJ-1X encountered an interval of almost 200 m of Permian clastic and carbonate interval (Fraser et al, 1993).

Seismic section 1 (Figure 2) located in the western part of the Seram Sea extends from the SW to the NE, and shows the Seram Imbricated Complex, the Seram Trough, the Kepala Burung Foredeep, the Misool Onin Ridge and the Berau Basin. The western part of the Misool-Onin Ridge has been penetrated by the Daram Selatan-1 well. Figure 3 shows a seismic section acquired for Amoseas and processed by Texaco in 1991 (Wongsosantiko and Mertosono, 1996). The structure and stratigraphy is very complex in this area and the seismic is very difficult to interpret as a result of relatively poor data quality. The two sections in figure 3 show the seismic interpretation prior to drilling of well Daram-Selatan-1 and the geological interpretation based on well data such as lithologies and stratigraphic data. The Top Triassic marker was interpreted significantly shallower and the structures are more complex than those in previous interpretations.

The northern part of the Misool-Onin Ridge has been uplifted as indicated by the missing Paleocene-Miocene stratigraphic section . Pliocene-Pleistocene interval covered the whole area. The eastern uplift is also indicated in Section 3 (Figure 4) at the center part of the ridge. Section 1 and 4 (Figure 5) clearly show an unconformity that cuts through the Paleocene – Miocene interval. Section 3 (Figure 4; Blunden, 2000), however, does not show any indication of erosion.

Based on stratigraphic reconstruction of Section 1 and 4 we identify at least two major uplift events in the Misool-Onin High area. The first one is a post Triassic age and is followed by a second event of post Cretaceous to Pleistocene time. Both uplift events mainly took place in the northern part of the ridge (Figure 2 and 4).

Imbricate Complex at North of Seram Island

The Imbricated Complex north of Seram Island and south of Misool-Onin Ridge is characterized by a highly complex fault system that generates poorly image seismic section. Some of

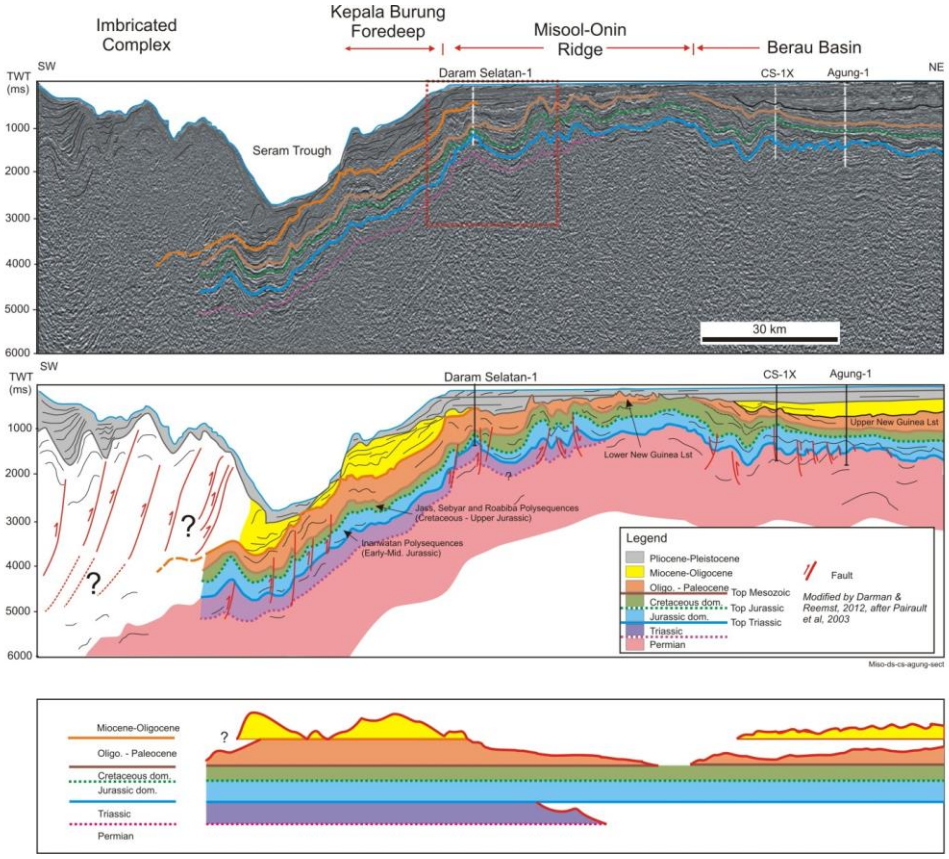


Figure 2. Section 1 across Seram Sea showing the seismic expression of the imbricated comples, Seram Trough, Kepala Burung Foredeep Basin, Misool-Onin Ridge and Bintuni Basin. CS-1X and Agung-1 well control occur in the north of the section. This section is modified after Pairault et al, 2003.

the trust faults have been interpreted by Pairault et al. (2003) in Section 1, 3, 6 and 7 (Figure 2, 4 and 7). Steeply dipping thrust faults can be seen on Section 6 and 7. The fault system generated a rough sea bottom and as a result mini basins developed between fault blocks that accommodate Pleistocene-Pliocene sediments (Figure 2)

Blunden (2000) published a detail seismic section of the imbricated complex (Figure 4). Unfortunately the quality of the seismic is poor. Figure 8 shows a higher quality seismic published by Searcher. The reflectors which cross the structures and almost parallel to the sea bottom indicate potential hydrate layers in this area.

Seram Trough

The northwest part of the Seram Trough is relatively narrow compared to the southeast. The deepest part of this trough can reach >2000 m water depth. Recent sediment supply is mainly accommodated the southeastern part of the trough, indicated by flat sea bottom as shown in Figure 7 and 8. Bright amplitude in the northern part of section 6 (Figure 8) is interpreted as a slope failure deposit from the Kepala Burung Foreland in the north.

Differences in thickness of recent sediments deposited in the Seram Trough show that the locus of depocentres changed through time (Figure 8). In some areas in the south sediments are thicker than the north. This suggests active tectonism and rapid deposition in the area.

Kepala Burung Foreland

A foreland basin developed between the Seram Trough and the Misool-Onin Ridge. Generally this tectonic unit covers an area with water depths of about 200 to 2000 meters. Section 1 (Figure 2) shows a structural high in west part of the foreland (Figure 2). Further east, Section 3 shows a simple dipping foreland. Section 6 (Figure 7.A) shows 3 anticlinal features which developed locally. Just south of this

section the anticlines disappear and the largest anticline is faulted (Figure7.B).

The structural map in Figure 1 also shows that Section 3 is located in the narrowest foreland area. The foreland developed well in the south of Onin Peninsula.

Berau Basin

The Berau Basin is located north of the Misool-Onin Ridge. Section 1, 3, 4 and 5 dissect this basin. All these sections show a significant unconformity as a result of a major uplift in the south towards the Misool-Onin Ridge and the north. Another major unconformity is shown in Section 1, below the Oligocene-Paleocene unit. This unconformity mainly occurs in the south, close to the Misool-Onin Ridge.

Wells Agung-1 and CS-1X along Section 1 penetrated Tertiary to Permian sedimentary formations deposited in the northern part of the Berau Basin. In the south of the basin, wells North Onin-1 and Gunung-1 encountered a mainly Cenozoic unit but Gunung-1 also went through Permian clastics and carbonates section at the bottom of the hole (Fraser et al, 1993).

Sekak Ridge

The Sekak Ridge is a large anticlinal feature which separates the Berau Basin from the Bintuni Basin. Section 5 (Figure6) shows a seismic profile of this ridge. The ridge has several minor highs, that are penetrated by well TBE-1X and Kalitami-1X. Fraser et al. (1993) called the minor highs Inanwatan and Puragi ridge. Both wells penetrated a Jurassic interval at their deepest levels.TBE-1X found some sandstones with coal fragments and reddish color shale indicating low terrestrial influence (Fraser et al, 1993). Kalitami-1 encountered more sands of a similar depositional setting in a Jurassic interval. The Cretaceous interval of both wells are very shally, deposited in an open marine environment.

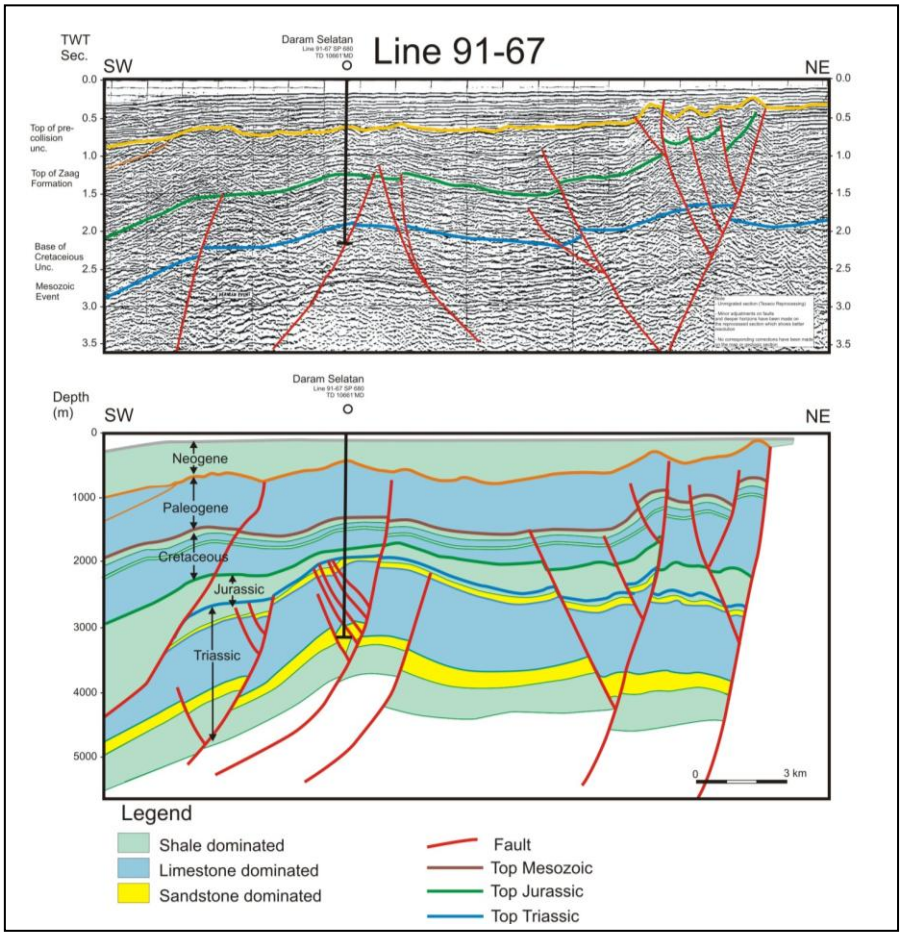


Figure 3. A detail seismic section across Daram Selatan-1 well acquired by Amoseas. Two interpretations are displayed: A) prior to the drilling result and B) after the drilling result. Note the changes of stratigraphic and structures interpretation (after Wongsosantiko & Mertosono, 1996).

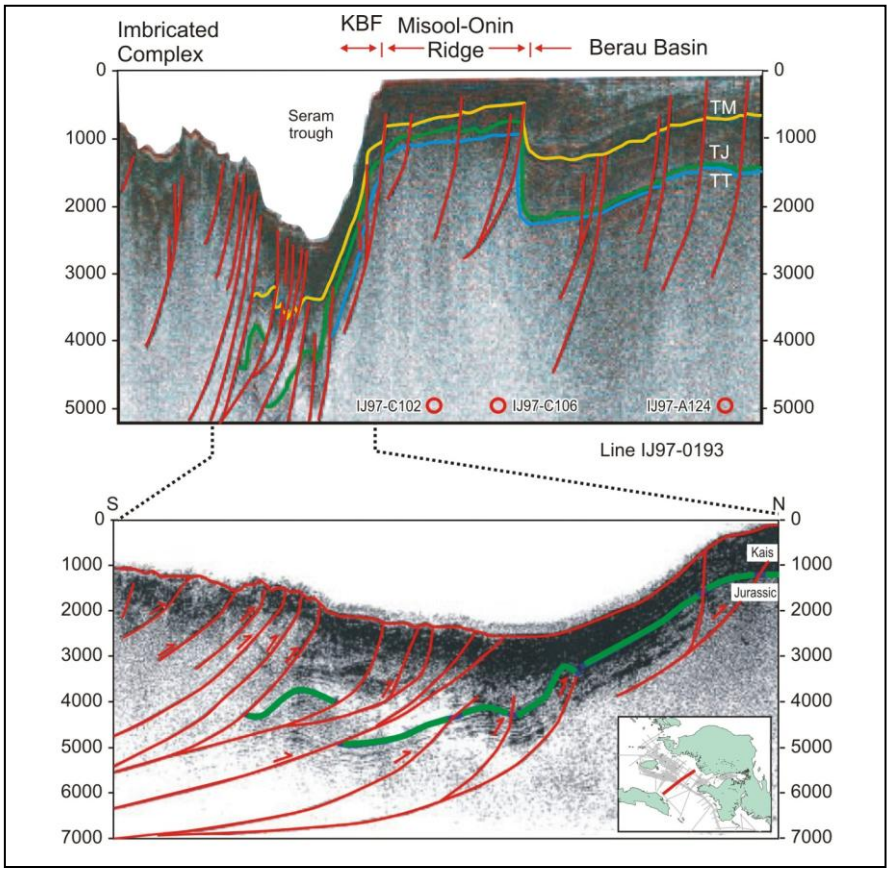


Figure 4. Seismic section at the center of Misool-Onin Ridge acquired by Schlumberger Geco-Prakla in cooperation with the government of Indonesia in 1997 (after Blunden, 2000)

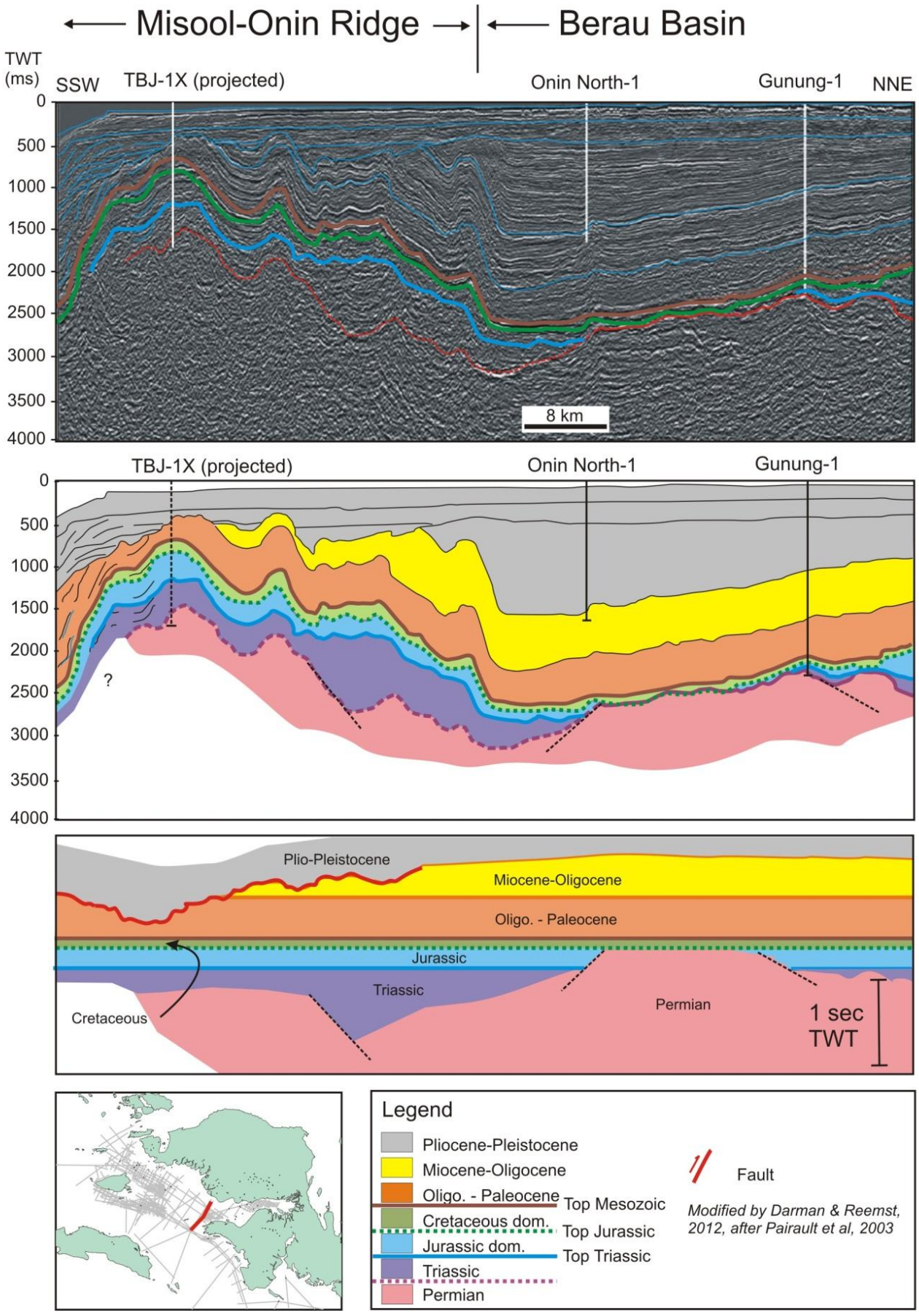


Figure 5. Section 4, modified after Pairault et al. (2003). The stratigraphic reconstruction shows a Permian paleo high and a tectonic uplift in the Misool-Onin High which caused the erosion of Tertiary section shown as unconformity in the south of the section.

The northern onshore extension of the Sekak Ridge was penetrated by wells Puragi-1, Tarof-2 and Ayot-1&2. Tarof-2 and Ayot-2 wells also encountered Permian clastics. The Mesozoic interval of Tarof-2 well is dominated by shale, but Ayot-2 well found some limestone. All wells reported the presence of a thick Miocene Kais limestone formation at shallower level.

Bintuni Basin

The sedimentary basin east of the Sekak Ridge is called the Bintuni Basin. This basin contains significant petroleum accumulation as discovered in the Vorwata, Wiriagar, Roabiba and Ofaweri fields. Towards the east, the Bintuni Basin is bounded by the north-south trending Arguni Fault.

Section 5 (Figure 6) shows a seismic section across the western part of the Bintuni Basin. Several structures developed during the Mesozoic but do not continue into the Cenozoic part of the section.

Kepala Burung Foredeep Basin

A foredeep basin developed between the Misool-Onin High and the Seram Trough. This structural unit is shown in Section 1, 3, 6 and 7. Section 1 (Figure 2) in the north of this unit indicates a Miocene-Oligocene remnant but it is not calibrated by any well. Section 3 (Figure 4) shows a relatively steeply dipping Mesozoic interval towards the Seram Trough. Several structures developed in the southern part of this foredeep basin as shown in Section 6 and 7 (Figure 7). Limestone build ups are potentially developed in the Upper Jurassic interval and generated discontinuous strong seismic reflectors. Tertiary deposits in this area have thin and continuous reflectors typical for distal marine deposits that are usually dominated by fine grained clastics (Figure 8). Hydrate layers can also be recognized from the detailed seismic section and indicated low (< 0°C) temperature, which is typical for deep water deposits.

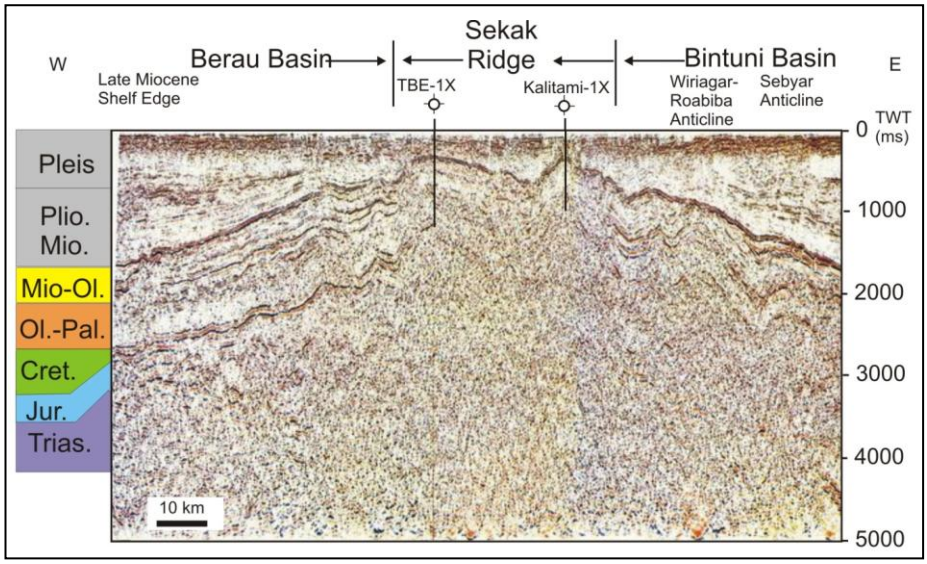


Figure 6. Section 5 across Berau Basin, Sekak Ridge and Bintuni Basin. TBE-1X is located on Inanwatan Ridge and Kalitami-1X on Puragi Ridge. These ridges are part of larger Sekak Ridge.

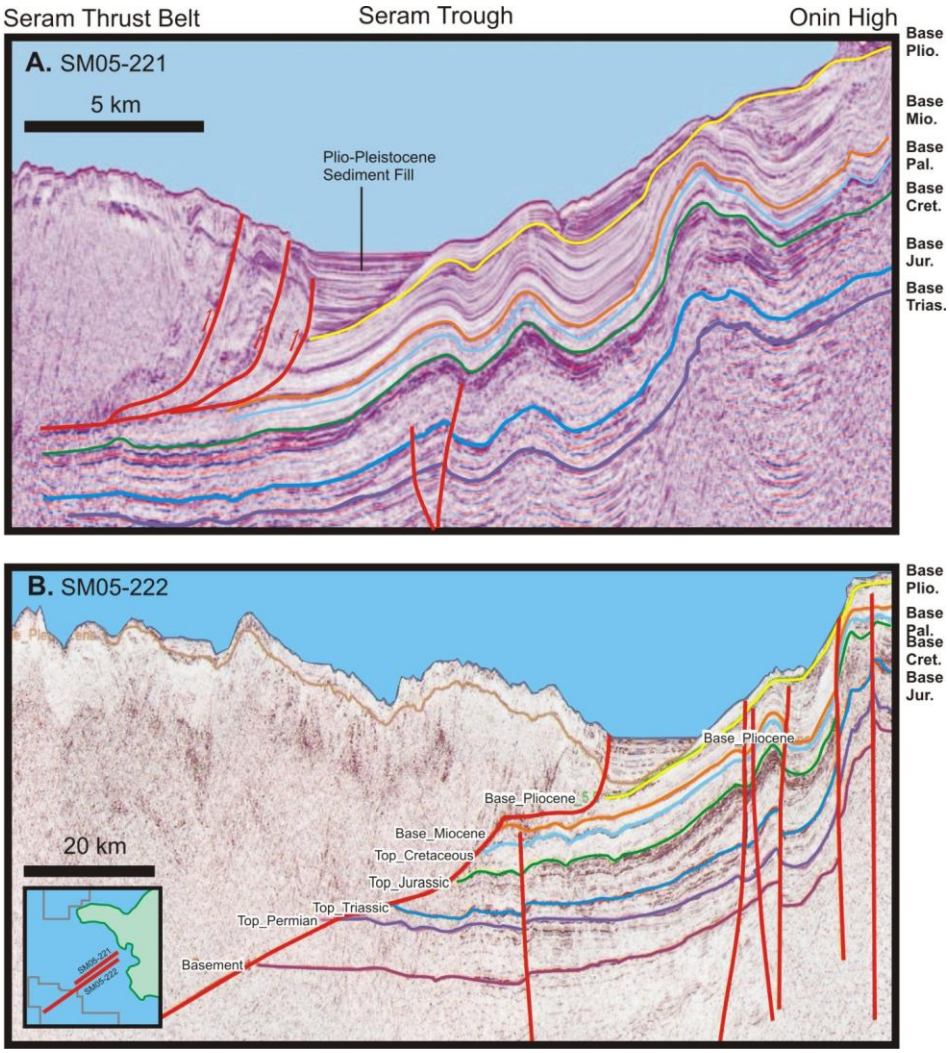


Figure 7. Two seismic sections acquired by Fugro in the south of Misool-Onin Ridge, covering Kepala Burung Foldbelt system, Seram Trough and the imbricated complex in sourth. Both sections are SW-NE trends. A) SM05-221 section shows 3 large anticlines in the complex. B) SM05-222 covers a larger area of imbricated complex.

Well South Onin-1 drilled in this basin and reported Upper Cretaceous limestones at bottom hole with minor shale interbeds (Fraser et al, 1993). Slightly shallower the well encountered >500 m thick Paleogene limestone. Although there are some gas shows,

the well is unfortunately considered as a dry well.

Seram Trough

A deep flat sea bottom characterizes the southern part of the Seram Trough (Figure 7) indicating a recent sediment fill. In the north, Section 1 (Figure 2) and Section 3 (Figure 4) show a narrow trough with limited recent sediment fill. A strong amplitude anomaly in the north of Section 6 (Figure 8) is an indication of slope failure debris flow deposits came from the north slope of the Kepala Burung Foredeep basin. This section also shows a shift of depocentres as some sediment packages are thicker in the south and some are in the north.

Imbricate Complex at South of Study Area

The Imbricate Complex in the south of the study area is generally seismically poorly imaged due to intensive faulting as shown in Figure 2, 4, 7 and 8. The thrust faults are dipping to the south and some of them are seen on the seismic sections, especially at the front end of this structural unit. Figure 4 and 8 show the detail of the faults.
Small depositional centers developed between fault blocks in the southern part, capturing recent sediments supplied from Seram Island (Figure 2). At the sea bottom the active faults generate a rough bathymetry as seen in Figure 4a and Figure 7. Tighter anticlinal features occur as drag folds as a result of the faulting. This implies that the faults are currently still active.
A potential hydrate layer occurs in this area (Figure 8) as can be interpreted from a reflector parallel to the sea bottom imaged in the south of the section. Several petroleum discoveries were made onshore Seram Island, with the Manusela Jurassic oolithic limestone unit as primary target (see K. Hill article in this volume).

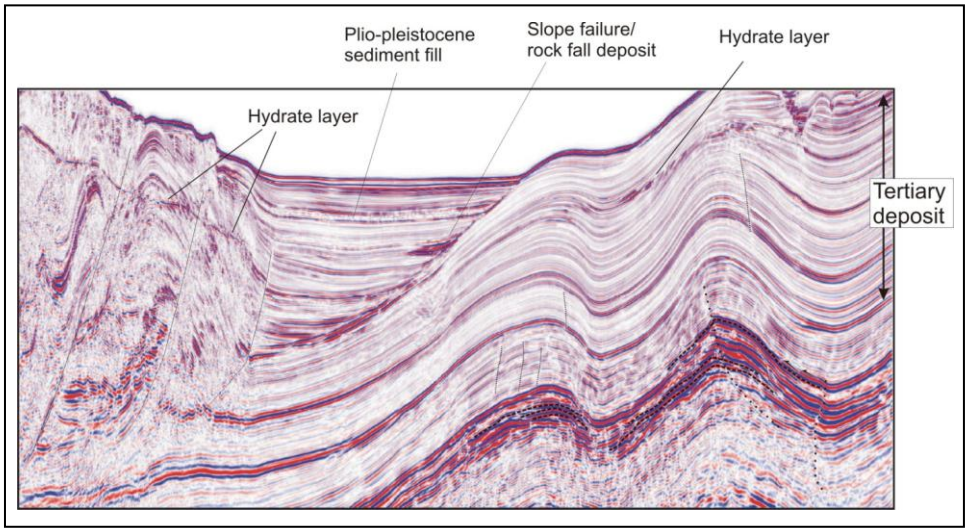


Figure 8. A detailed section of Figure 7B showing the potential hydrate layer on the left of the section and the two major anticlines on the right. Potentially some limestone developed in the north of the area as shown on this figure.

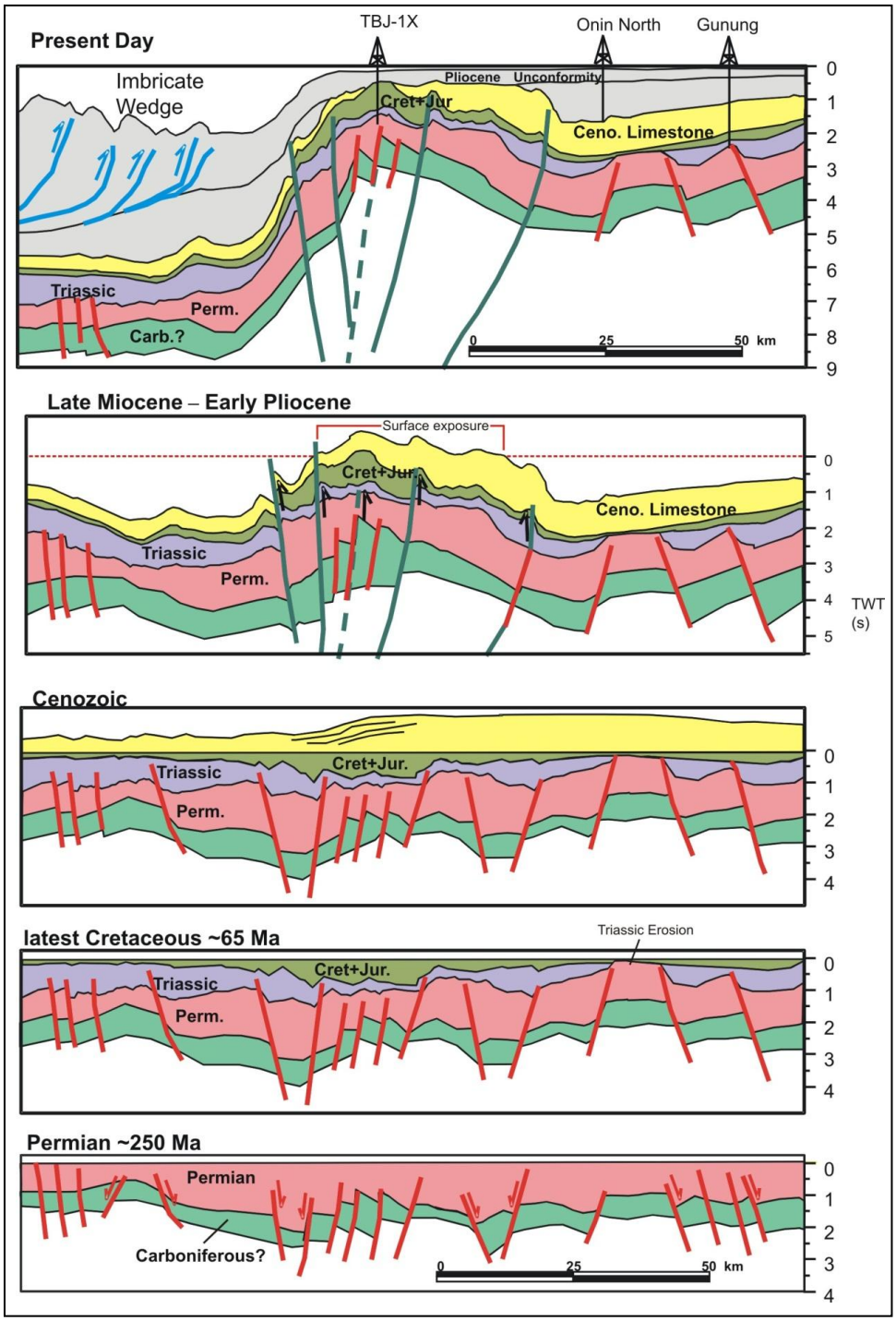


Figure 9. Structural and depositional reconstruction of Misool-Onin Ridge. Faults are red for normal faults, green for inverted faults and blue for reverse faults. See Figure 5 for location of this section.

Conclusion

The seismic sections reveal a complex tectono-stratigraphic history of the Seram Sea. Based on the interpretation of several key seismic lines, we propose the following sequence of events:

- Rift related faulting took place over an extensive area during the Permian, followed by partial uplift in the Triassic.
- During the Cenozoic, Paleogene and Miocene limestones developed extensively during this period of time.
- An inversion phase in Late Miocene – Early Pliocene indicated by transpression and folding, and reactivation of older extensional faults. Erosional process developed at the Misool-Onin Ridge during this stage.
- Emplacement of the Imbricate Wedge during Pliocene to Quaternary times.

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