The Tiaka-Tiara Fault Bend Fold Structures and its Implication to Control Hydrocarbon Entrapment within Fracture Carbonate Reservoir in the Eastern Arm of Sulawesi, Indonesia*

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Abstract

The Tiaka-Tiara fault bend fold structures is located in a tectonically complex area of the Banggai Basin at the eastern arm of Sulawesi, formed by a collision between the Banggai Sula microcontinent and East Sulawesi ophiolite belt. The Banggai Sula micro continent has been interpreted as a fragment of the major Australia-New Guinea Continental plate, which drifted westerly directed by South Sula-Sorong Fault from the east. The objective of the study is to have a better understanding of the structural geology and fractured reservoir characterization as the impact of fault bend fold structure development. The contractional deformation style has been observed from seismic and structural interpretation and reconstruction. Regional tectonic evolution in the eastern Sulawesi was initiated by drifting of Banggai Sula microcontinent westward through the South Sula-Sorong Fault which then collided with the eastern arm of Sulawesi during Late Miocene to Pliocene. This resulted in a foreland thrust fold belt structures of Tiaka-Tiara. This complex tectonics system of the Banggai Basin has resulted in a major SW-NE orientation with a series of SSE-NNW oblique minor fault bend fold structural trend, which indicates the potential of fractured carbonate reservoirs. The methods used in this study included 2D seismic interpretation, well correlation, structure map generation, and palinspathic reconstruction using balancing cross-section technique. The Minahaki and Tomori Miocene fractured carbonate reservoirs are the main objectives in the Tiaka Fault bend fold structure in Banggai Basin. Significant hydrocarbon production from both fractured carbonate reservoirs has proved the importance of the fault bend fold structure. The high fracture density is located along the hinge of the Tiaka-Tiara structural closure, which is strongly controlled by fault bend fold geometry. We concluded that fault bend fold structure in the study area is a structural trap characterized by a NE-SW low-angle detachment in basement and involved sequence of Miocene carbonate. Compressional deformation during Neogene time is the main control of hydrocarbon entrapment and accumulation in fracture carbonate reservoir of fault bend fold structure. Syndrift deposition during Paleogene contributed to control hydrocarbon generation from source rock of marine carbonaceous shale within Lower Miocene Tomori Formation.

Introduction

The Tiaka-Tiara Fault bend Fold structure is located in the offshore Toili area of the Senoro-Toili Block. This block is situated near the eastern arm of Central Sulawesi and falls within the Tertiary Banggai Basin (Figure 1). The Senoro-Toili Block is located geologically along the tectonically complex eastern arm of Sulawesi. The block includes part of a collision complex formed during the Miocene, resulting from the collision of the Banggai-Sula micro-continental plate with a Tertiary non-volcanic arc. The Banggai-Sula micro continent has been interpreted as a fragment of the major Australia- New Guinea Continental plate before its westward displacement towards Sulawesi. This interaction formed what is now Central Sulawesi. The Tiaka-Tiara fault bend fold structure lies within one of the thrust sheets produced by this collision.

Tiaka-Tiara structures to the east are bounded by northeast – southwest trending Batus thrust front and ophiolite emplacement respectively to the west (Figure 2). The main reservoir is platform carbonate of Minahaki and Tomori Formations, which have been identified ranging from Lower to Upper Miocene ages and are underlying the Sulawesi Group Molasse of Pliocene-Pleistocene ages. The bottom part Minahaki Formation is conformable with the Matindok and then the Tomori formations in the lower part.

Carbonate sequences of Tomori and Minahaki Formations are typical carbonate reservoirs of syndrift sedimentary sequences deposited prior to development of the fault bend fold structures as the main producing zones of hydrocarbons. These are proved by spectacular discoveries of hydrocarbon fields in the Senoro-Toili Block, Central Sulawesi such as Tiaka field as shown on Figure 2, which is proposed in this paper. Encouragement of the hydrocarbon discoveries of the carbonate Minahaki and Tomori reservoirs of both carbonate sequences is interesting mainly related with controlling factor reservoir quality improvement associated with trapping system within fault bend fold structures. This paper discusses the implication of fault bend fold structures and relationships to the hydrocarbon entrapment of the fractured carbonate reservoirs in this area especially for Tomori and Minahaki formation.

Methodology

Our approach to the study has been using a combination of both published and unpublished data encompassing well correlation, petrophysical analysis, 2D seismic interpretation, structure map generation, and palinspathic reconstruction using balancing cross-section technique.

Geology Setting and General Stratigraphy

The Senoro-Toili Block is located along the tectonically complex eastern arm of Sulawesi. The block includes part of a collision complex formed during the Miocene, resulting from the collision of the Banggai-Sula micro-continental plate with a Tertiary non-volcanic arc. This interaction formed what is now Central Sulawesi. The Tiaka-Tiara Fault Bend Fold structures lies within one of the thrust sheets produced by this collision process. The collision of the Banggai-Sula micro-continent with East Sulawesi ophiolites was responsible for the formation of the pro-foreland basin of the Banggai Basin, its foredeep and fold bend fold-thrust belt, suture/axial belt of East Sulawesi Ophiolites, internal metamorphic zone of Central Sulawesi, and the retro-foreland basin of the basins in Western Sulawesi (Satyana et al, 2008).

The relationship between collision and petroleum in Eastern arm of Sulawesi has been discussed by Satyana (2006). Gas and oilfields have been discovered in the Banggai Basin, including the Minahaki, Matindok, Senoro, Donggi, Sukamaju, and Maleo Raja gas fields; and the Tiaka oil field. The play types recognized in the Banggai collision are: (1) carbonate reefal build ups, (2) thrust-sheet anticlines of Fault bend Fold structures, (3) wrench related anticlines, and thrusted anticlines of basement related faults (Hasanusi et al., 2004). The Miocene carbonate reefal build up play type is the largest stratigraphic play as proved by discoveries in the Minahaki, Senoro, Donggi, Sukamaju, and Maleo Raja gas fields. The trap is related to pre-collision tectonics where reefal buildups grew at the front of the Banggai-Sula micro-continent during its drifting.

The fault bend fold structures or thrust-sheet anticline play type involves structural closures at the leading edges of a series of imbricated collisional thrust sheet of the Miocene platform carbonates. The trap is related to collision and post-collision tectonics. Tiaka oil field proves this play type (Figure 3). The wrench fault anticline play type involves thrusted anticlines where traps have been formed as en echelon folds along strike-slip faults formed during Pliocene post-collision escape tectonics. Matindok discovery and southern Senoro field prove this play type. The play of thrusted anticlines related to basement faults is observed in the Taliabu shelf, Sula islands. Mesozoic sediments were deposited as a synrift sequence in grabens of the Banggai-Sula micro-continent. When collision of the microcontinent took place in the Late Miocene, the rift grabens were overprinted by compressional tectonics resulting in thrusted anticlines of fault bend fold structures. Some thermogenic gas and oil seepages occur in the areas along thrust front of tectonic window as shown on Figure 4.

The stratigraphy of eastern Sulawesi is related to two distinct depositional time periods, the first representing a continental margin rift/drift sequence prior to the collision, and the second representing a foreland basin flysh-molasse sedimentary sequence, deposited in front of an easterly-migrating thrust front after collision had occurred. A generalized stratigraphic diagram of the Tomori-Banggai Basin is presented in Figure 5. Platform carbonate sequences of Minahaki and Tomori Formation have been identified ranging from Middle to upper Miocene ages, which are underlying by post collision sedimentary sequences of Molasse Sulawesi Group of Pliocene-Pleistocene ages and among of those was separated by hiatus unconformity. The bottom part of the formations is conformable with the Matindok and then Tomori formations in the lower part. All together of Carbonate Mentawa member, Minahaki, Matindok and Tomori formations were namely Salodik group. The basement rocks of the Banggai-Sula micro-continent are primarily schists and granites of Permo-Triassic ages.

Implication of Fault Bend Fold Structures to control Hydrocarbon Entrapment in Fracture Carbonate Reservoir

The compressional system that formed fault bend fold structures in this study area affects the petroleum system and hydrocarbon entrapment in the fracture carbonate reservoir in the Tiaka Field and adjacent area. The subthrust section of synclinal fault bend fold structures becomes the kitchen area for shale within Tomori source rock and the anticlinal fault bend fold structures provide accommodation zones of a good trapping system to control hydrocarbons accumulation as seen on Figure 6. Geometry of the subthrust syndrift sedimentary sequences and possibly Mesozoic graben that formed in the Tomori area has a significant length of exceeding 50 km and a depth of up to 4000 meters, which are deep enough to generate significant hydrocarbon (Figure 7).

Conclusions

1. Fault bend fold structures in the study area are structural traps characterized by NE-SW low angle detachments in basement and involved sequence of Miocene carbonate.
2. Compressional deformation during Neogene time is the main control of hydrocarbon entrapment and accumulation in fracture carbonate reservoir of fault bend fold structure.
3. Syn-drift deposition during Paleogene contributed to control hydrocarbon generation from source rock of marine carbonaceous shale within Lower Miocene Tomori Formation.

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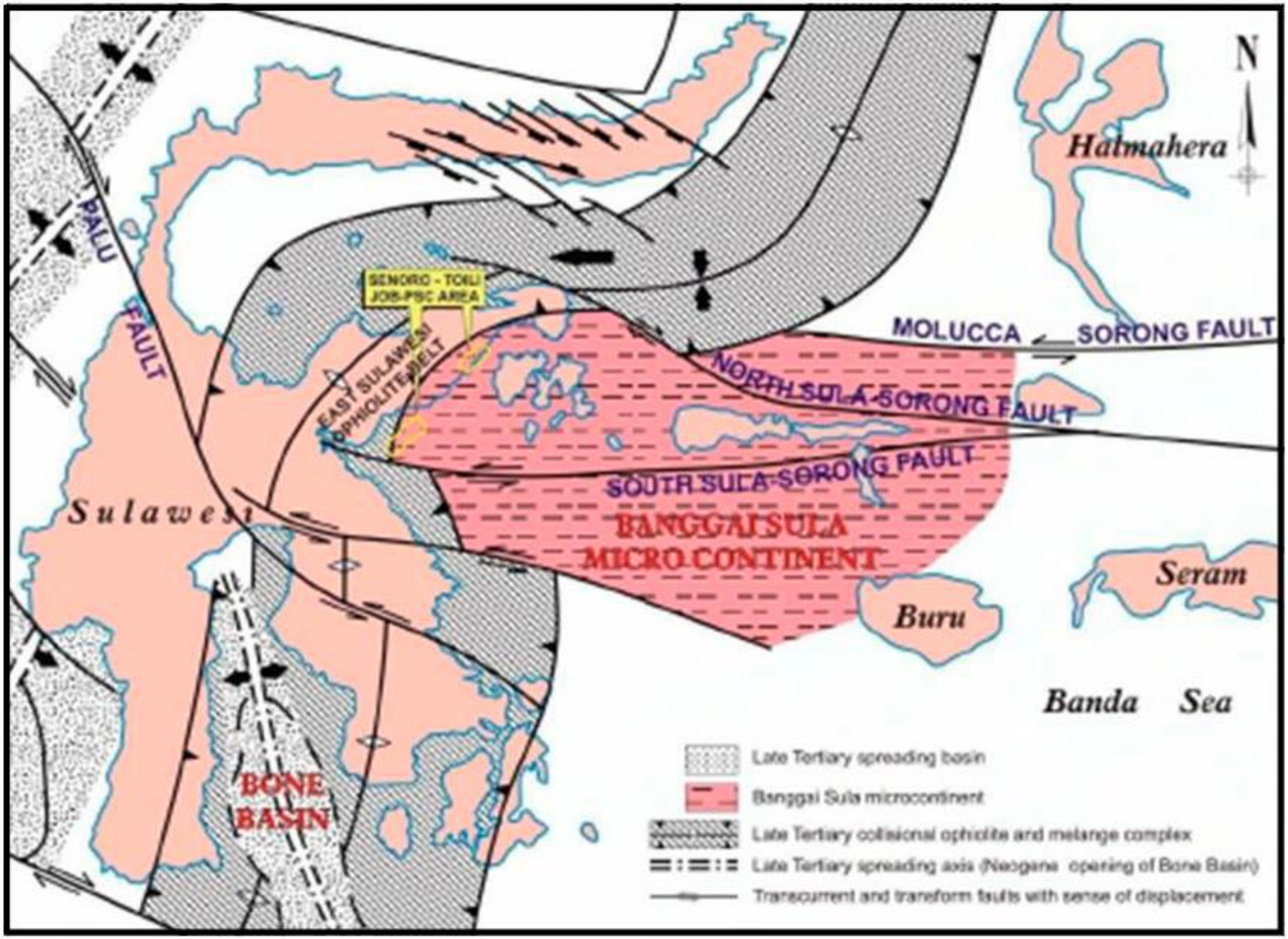

Figure 1. Location map of Senoro-Toili Block, Eastern Arm of Cenrtal Sulawesi, Indonesia.

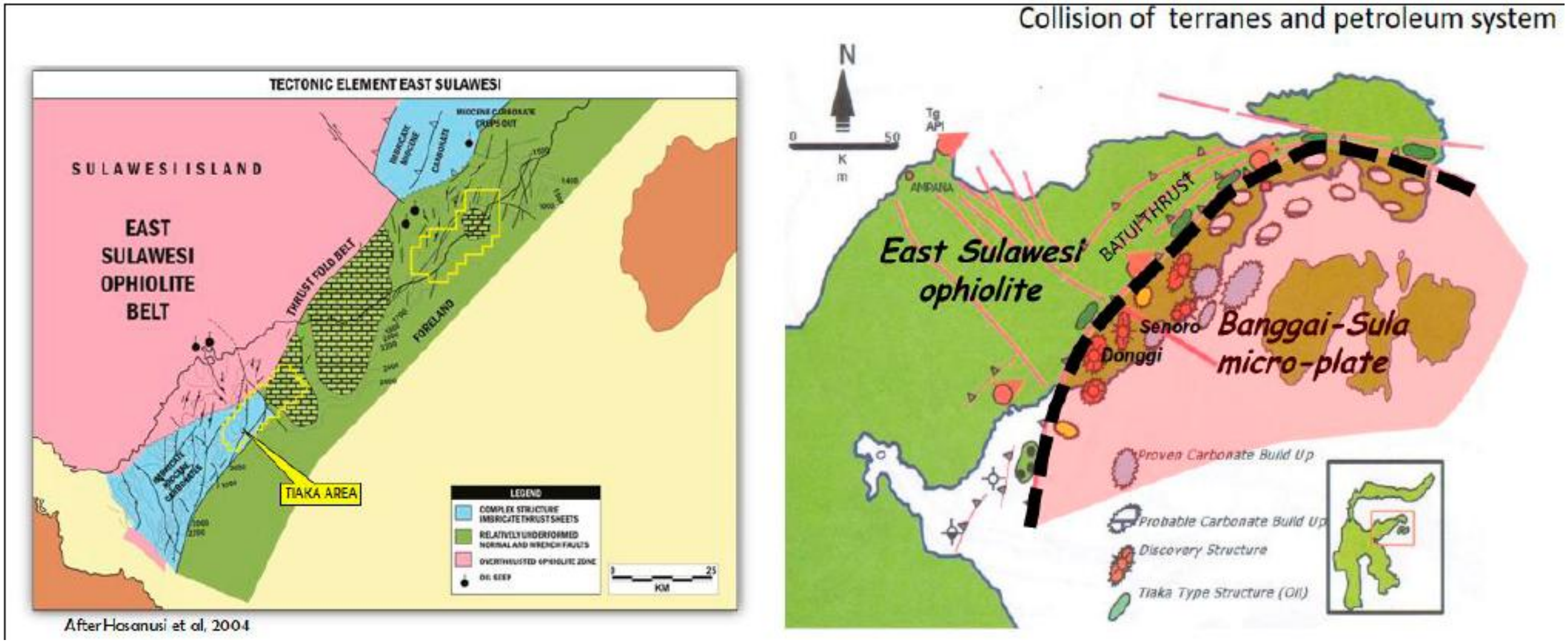

Figure 2. Tiaka-Tiara Fault Bend Fold Structures geological setting.

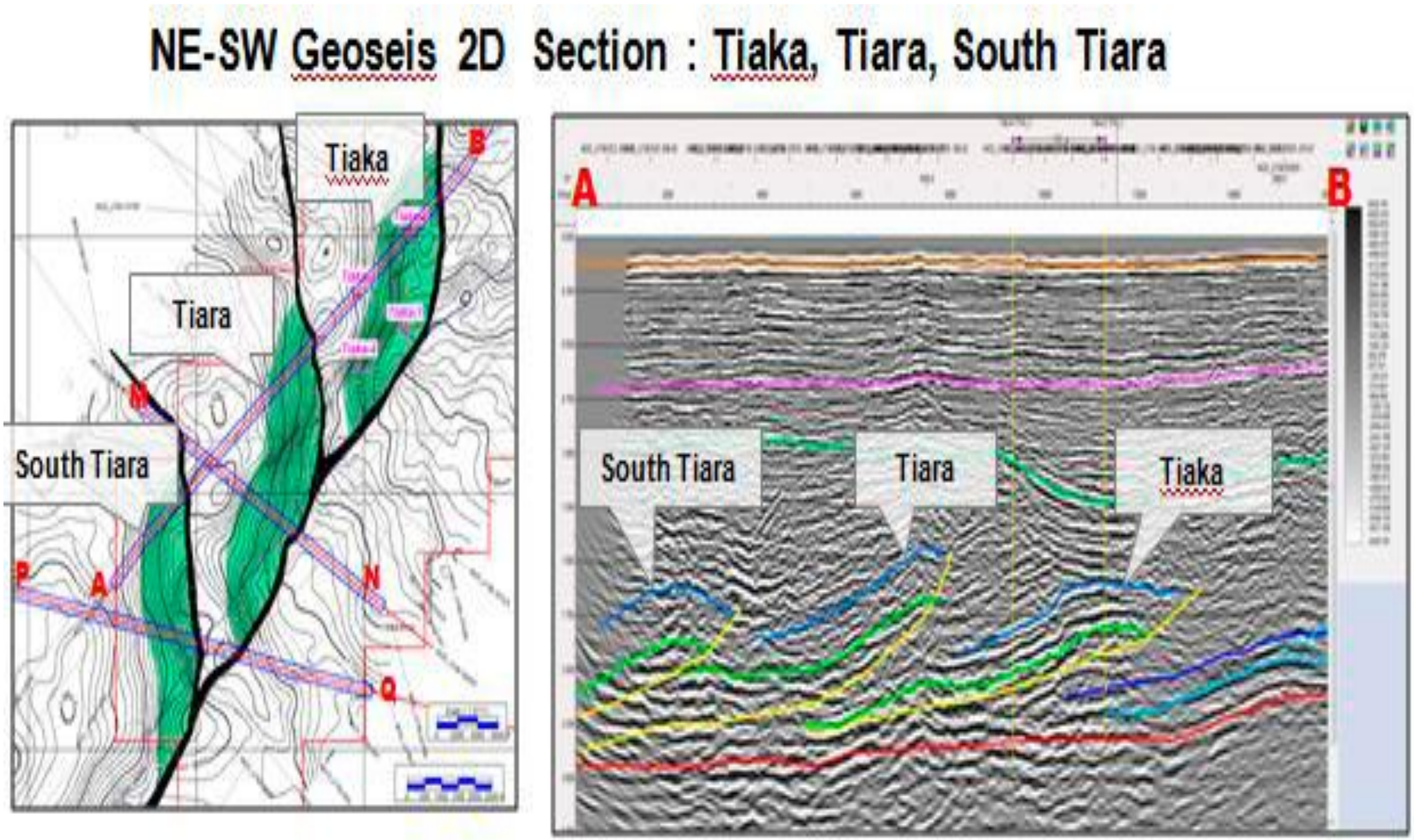

Figure 3. NE-SW GeoSeis 2D across Tiaka-Tiara Fault Bend Fold Structures.

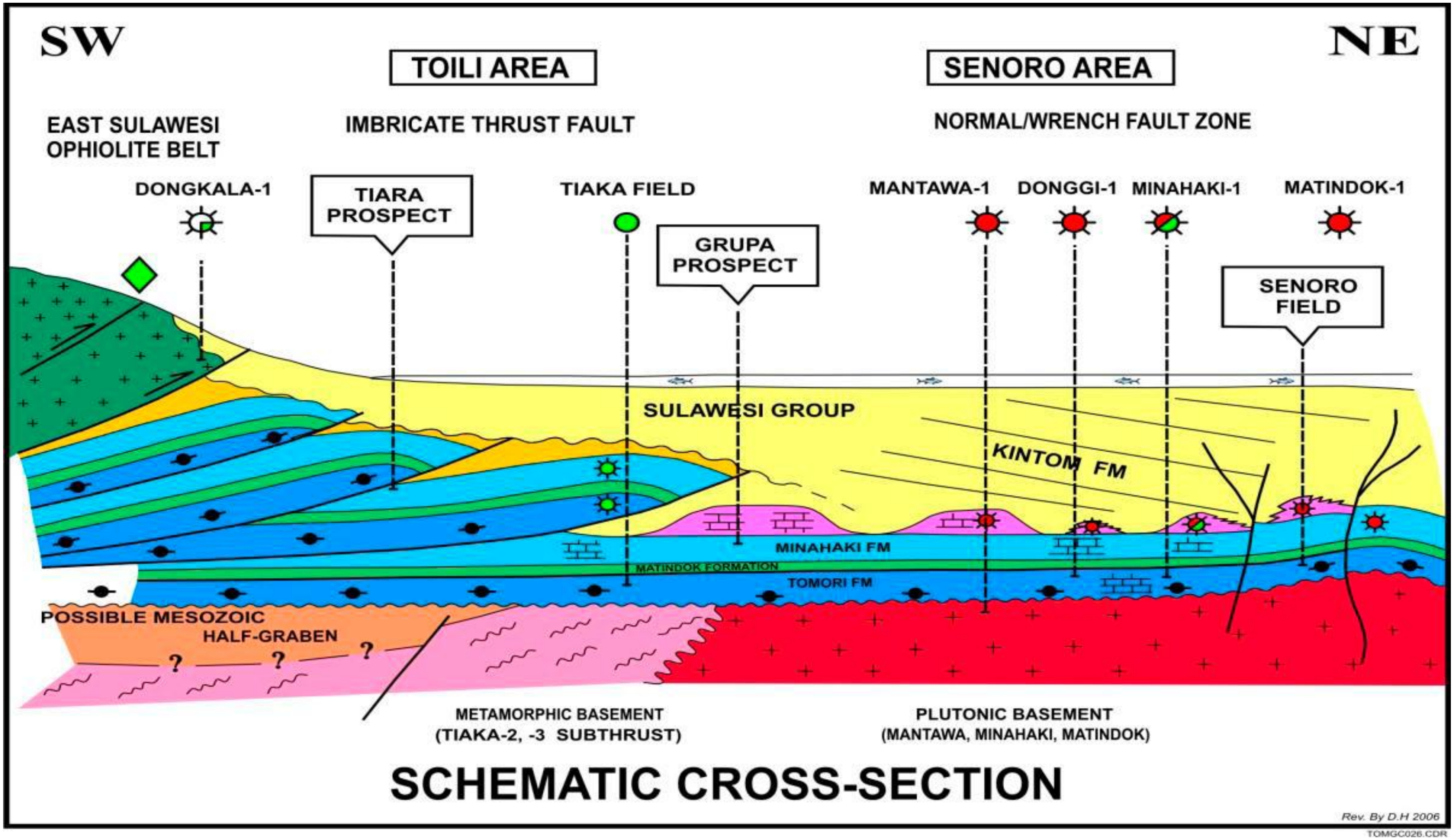

Figure 4. SW-NE Geological Cross-Section show Mesozoic Rift- Half-Graben overprinted by Post Tectonic Collision result : Fault Bend Fold Structures.

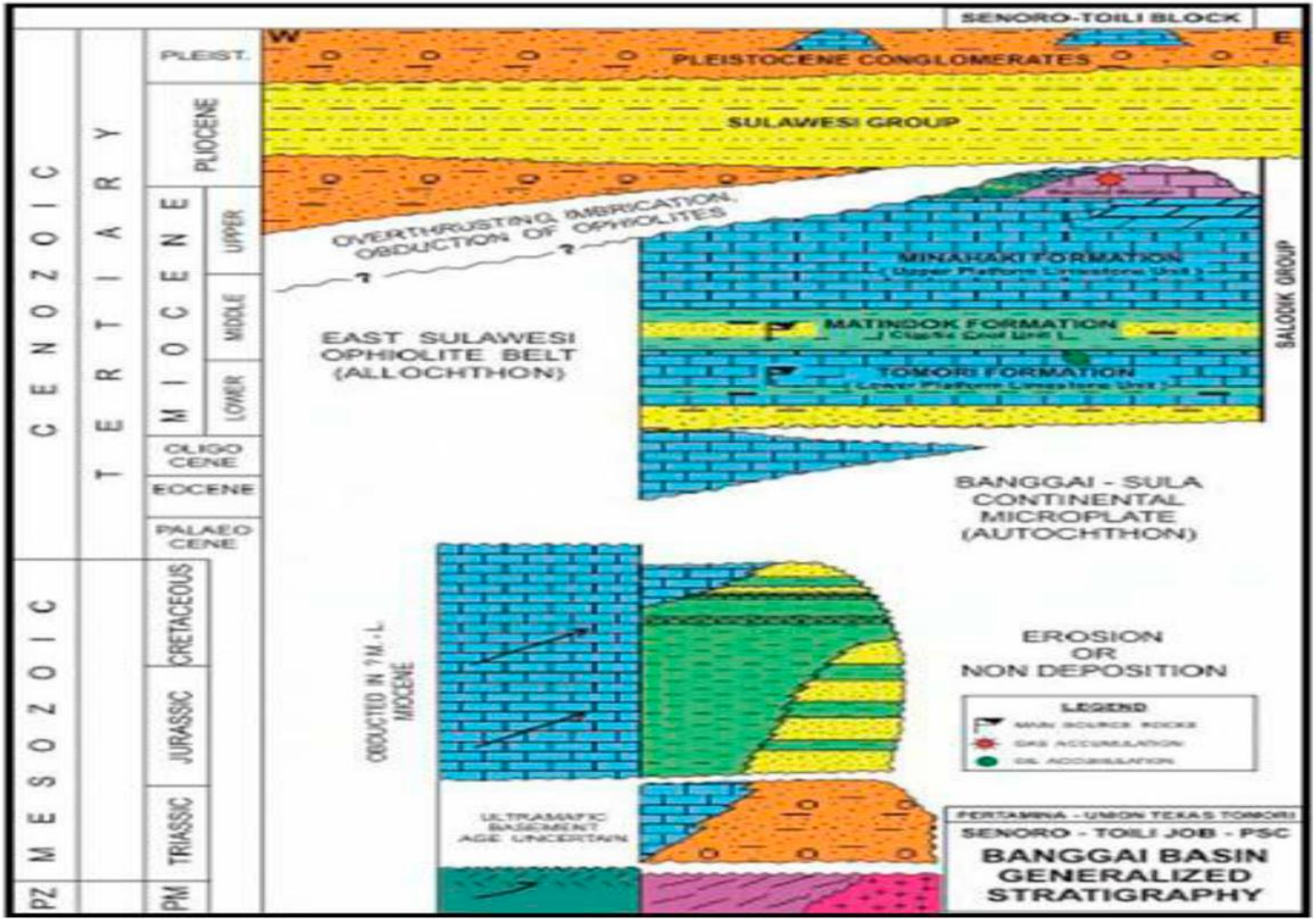

Figure 5. General Stratigraphy of the Banggai-Sula basin, East Arm of Central Sulawesi.

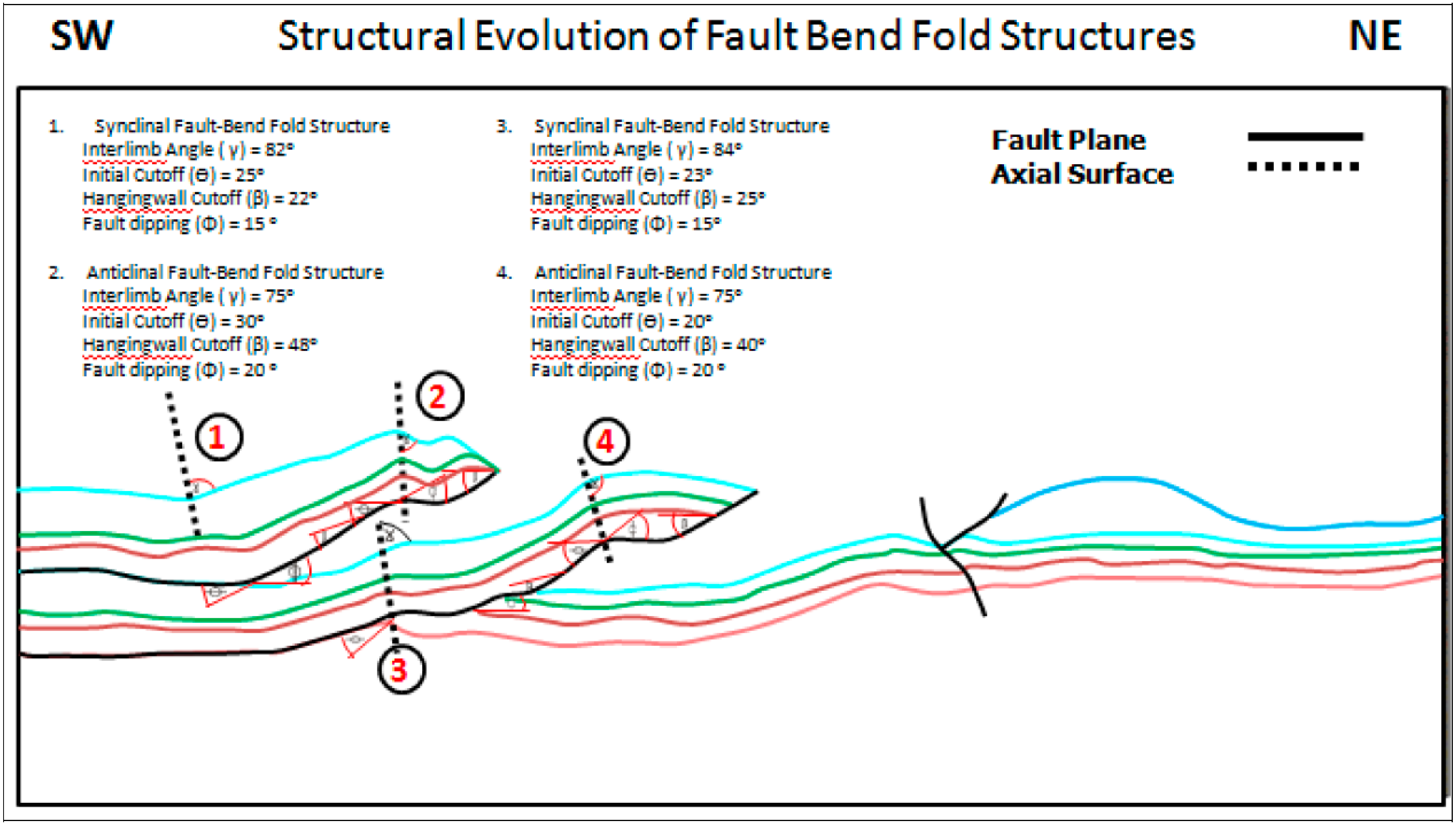

Figure 6. Structural Evolution of Fault Bend Fold Structure.

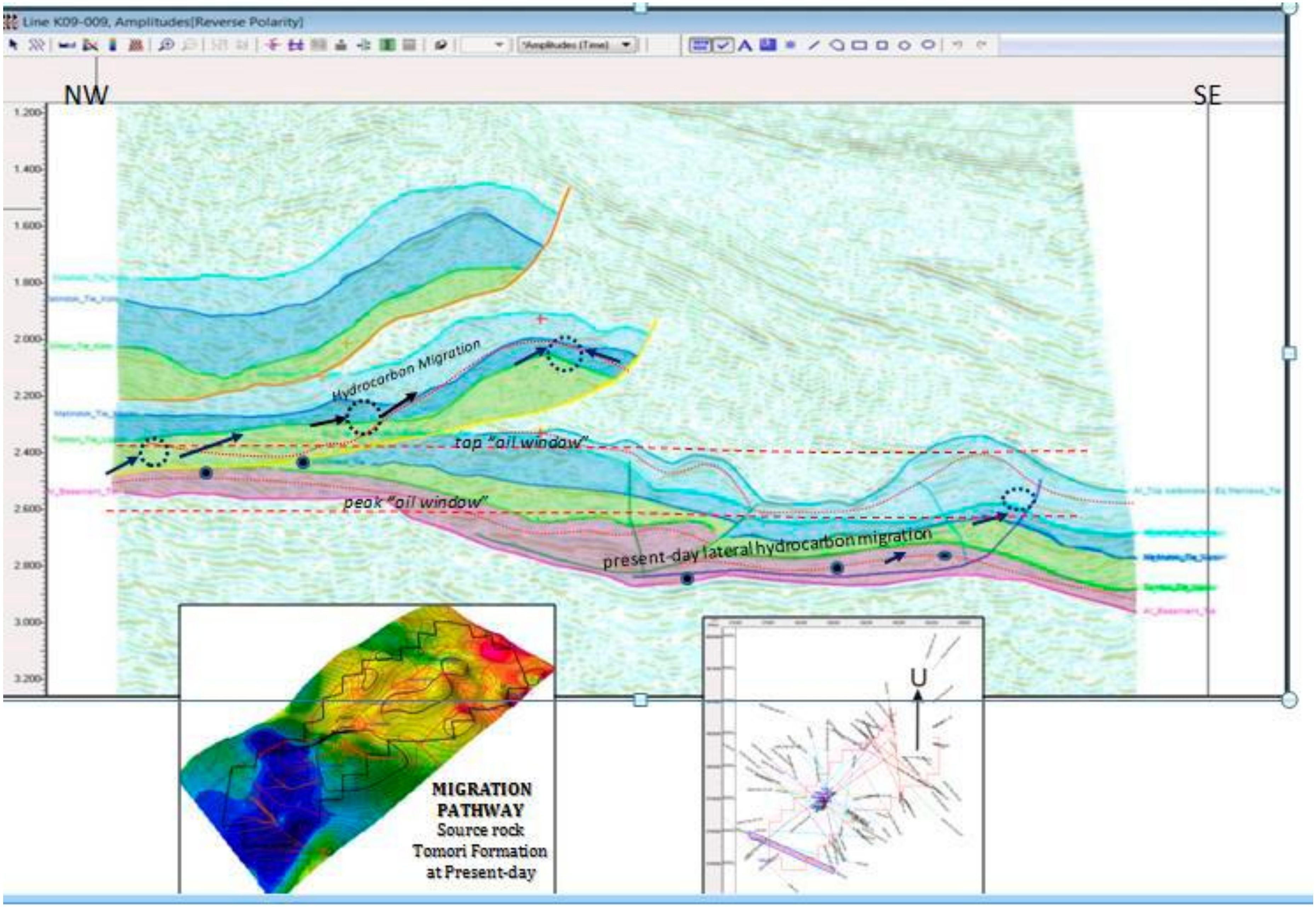

Figure 7. Hydrocarbon migration into the Trapping System "Fault Bend Fold Structure".