IPA94 - 1.1 - 027

PROCEEDINGS INDONESIAN PETROLEUM ASSOCIATION
Twenty Third Annual Convention, October 1994

TECTONIC REVERSAL IN EAST BARITO BASIN, SOUTH KALIMANTAN : CONSIDERATION OF THE TYPES OF INVERSION STRUCTURES AND PETROLEUM SYSTEM SIGNIFICANCE

Awang Harun Satyana*
Parada D. Silitonga**

ABSTRACT

The Barito basin, South Kalimantan, is located between Sundaland to the west and the Meratus Range to the east. Tectonic reversal characterizes Tertiary structural history of the eastern part of the basin. In Paleogene time, extensional deformation prevailed through a period of rifting and subsidence giving rise to a series of NW to SE trending horsts and grabens. In the Neogene, compressional deformation aligned broadly WNW to ESE has reactivated and inverted Paleogene structures producing wrench faults, folds, and reverse faults within the basin.

The East Barito inversion structures are examined in detail to define the types of the structures based on Mitra's (1993) classification of inversion structures. The study concluded that the East Barito inversion structures fall under the type formed by simple fault-propagation folding along a planar fault. The structures originated through a number of mechanisms: (1) compressional movement along the restraining bends of wrench faults, (2) en echelon structures adjacent to wrench faults, and (3) direct inversion of NE-SW aligned Paleogene normal faults.

The structural-stratigraphic evolution of East Barito inversion structures has provided ideal conditions for the accumulation of hydrocarbons. Growth sedimentation into an extensional basin resulted in early to middle Eocene synrift Lower Tanjung source rocks and reservoir sandstones. Postrift shales of late Eocene to early Oligocene Upper Tanjung provide an effective seal. Structural inversion which commenced in mid-early Miocene and greatly affected the basin from late Miocene to Pliocene has subsided Lower Tanjung source rocks to the depth wherein hydrocarbons could be generated and expelled. Migrated hydrocarbons were entrapped in anticlinal traps formed during the inversion. Plio-Pleistocene inversion might either create new structural traps or destroy previous hydrocarbon accumulations. In the latter case, hydrocarbons would remigrate and be trapped in the newly-formed inversion structures. Tanjung Raya fields represent such ideal hydrocarbon-trapping conditions. Remaining hydrocarbon potential should be considered before and after the advent of basin inversion.

INTRODUCTION

Inversion structures are structures formed by the compressional reactivation of pre-existing extensional structures. They are widespread structural phenomena and recently have been described from a number of basins. From a petroleum exploration viewpoint, they play an important part since they may either create the favorable conditions for structural trapping or destroy previous hydrocarbon accumulations.

Tectonic reversal characterizes the structural history of the East Barito basin during Tertiary time (Figure 1). In the Paleogene, an extensional deformation period of rifting gave rise to a series of NW- to SE- trending horsts and grabens. In the Neogene, compressional deformation, aligned broadly WNW to ESE, has reactivated and inverted pre-existing structures producing wrench faults, folds, and reverse faults.

In this paper, we examine East Barito inversion structures to determine their types based on Mitra's

* Pertamina
** Presently with Total Indonesie

(1993) classification. Seismic and retrodeformable sections are used to define the structural characteristics and inversion history. Consideration of the significance of the structures to the petroleum system is also addressed in the paper.

INVERSION STRUCTURES OVERVIEW

Structural inversion occurs when basin-controlling extensional faults reverse their movements during compressional tectonics, and, to varying degrees, basins are turned inside out to become positive features (Figure 2). The whole process of reversing the style of deformation of a basin is called tectonic inversion, tectonic reversal, structural inversion, or simply inversion (Williams, Powell, and Cooper, 1989 *in* Jones, 1992). The result of inversion is that contractions occur to all pre-existing extensions. It is also possible that faults may retain net extension at depth and show net contraction associated with anticline growth in their upper portions.

Types of Inversion Structures

Mitra (1993) classified inversion structures according to the kinematic relationship between folds and faults during extension and compression. The simplest structures are characterized by reversal of slip on planar faults without any accompanying folding. More complex structures will result if faulting is accompanied by folding. Two main types of structure are recognized : (1) fault-propagation folds associated with planar faults, and (2) fault-bend folds associated with listric faults.

a. Fault-Propagation Folding on Planar Faults

Extensional fault-propagation folding is characterized by the upward termination of a master normal fault into a drape fold. The fault may propagate through this fold with increasing extension. Synextensional growth units typically thicken from the footwall to the hanging wall. Compressional deformation results in the inversion of these features into compressional fault-propagation folds (a simple fault-propagation fold type - Figure 3 A). The characteristic feature of these structures is the constant basinward thickness of synextensional units from a reactivated fault. The effect is magnified in structures where the master fault breaks through a fold during extensional deformation, and subsequently during compressional deformation (a fold with fault breakthrough type - Figure 3 B).

b. Fault-Bend Folding on Listric Faults

Many normal faults have a listric geometry and flatten into a detachment at depth. Extension along such faults creates a hanging-wall rollover fold through fault-bend folding, with increasing thickness of the hanging-wall synextensional units into the fault. Inversion of the structure results in a compressional fault-bend fold, which preserves the thickness variation (a simple fault-bend folding type - Figure 3 C). In addition to the rollover structures, an extensional fault-propagation fold may form above the fault during the early stages of fault propagation. During compression, a small component of compressional fault-propagation folding may also occur at the fault tip (fault-bend with fault-propagation folding type - Figure 3 D). In this case, synextensional units exhibit a tighter fold geometry and decreasing thickness away from the fault.

REGIONAL FRAMEWORK

Tectonic and Structural Setting

The Barito Basin is located along the southeastern edge of the stable continental Sundaland. The area is foreland-backarc region typified by foredeep at the frontal zone of the Meratus Range and platform approaching the Sundaland. The Meratus Range defines the basin in the east. To the north it is distinguished from the Kutei Basin by the Adang Flexure. Southward it extends into the Java Sea (Figures 1 and 6).

In the foredeep the structural style is typified by basement-involved tectonics in which the folds are originated as fault-related folds. The style is characterized by parallel trends of folds and faults that repeat in closely-spaced wavelike bands constituting the belt. The folds are bounded by high-angle westerly-hanging reverse faults. The structures increasingly imbricate toward the Meratus Range (Figures 14 E and 15 A).

Beyond the foredeep approaching Sundaland, the basement is devoid of tectonic influence ; otherwise the thin-skinned tectonics indicated by discontinuous decollements, ramps, and fault-propagation folds may have taken place (Satyana and Silitonga, 1993).

The structural history of the East Barito Basin is marked by a great contrast in style between the Paleogene and Neogene. Rifting of the basement started structuring the basin in Paleo-Eocene time. The condition prevailed up to Oligo-Miocene time during which localized and regional subsidence and lithospheric stretching impressed the basin. By mid Miocene time, the prevailing structural style changed to a more contracting nature. Regional uplift and compressional faults appeared in middle Miocene time up to Plio-Pleistocene time, inverting and reactivating old extensional faults, resulting in the positive features typifying the area today (Figure 4).

Tectono-Stratigraphy

The stratigraphic successions of the area may be divided into four megasequences including prerift, synrift, postrift, and syninversion sequences (Figures 4 and 5).

a. Prerift Sequence

The prerift sequence of East Barito is presently represented by the basement complex which underlies the basin. Being located along the margin of continental Sundaland, the basement is composed of a variety of amalgamated terrains : continental basement in the west and accreted zones of Mesozoic and early Paleogene rocks in the east.

The distribution of the rock types in the subsurface is not clear. It is notable, however, that at least in the East Barito (especially in PERTAMINA-Bow Valley's Tanjung Raya area), the basement is evidently Meratus type rather than acidic-crystalline Barito Platform type. This has led to speculation about the nature of the contact between the two types, and it is suggested that this is faulted (Gaffney-Cline, 1971).

b. Synrift Sequence

The collisions between continental India, the Eurasian margin and the western Pacific region at about 50 Ma (early middle Eocene) had initiated the Barito Basin through rifting in convergent wrenching or back-arc extension (Daly, Hooper, and Smith, 1987; Kusuma and Darin, 1989; Daly et al., 1991; van de Weerd and Armin, 1992). During this period the basin was receiving rift sediments.

The synrift sequence of the basin comprises late Paleocene to middle Eocene sediments of the Lower Tanjung Formation. The sediments are grouped into Stage 1 deposits by PERTAMINA and Trend Energy (1988). The sediments represent localized rift-infill deposited on the irregular surface formed by Paleogene rifting.

The sediments consist of sandstone, silts, shale and conglomerate, with coal as a minor constituent. The base of this sequence is composed of conglomerate and redbeds deposited as piedmont fan sediments. The upper units of the sequence consist of alluvial to lacustrinal facies. The sediments represent the main rifting phase, developing due to syndepositional faulting (Figure 5).

c. Postrift Sequence

Regional subsidence after the rifting prevailed in the basin from middle Eocene time up to mid-early Miocene, during which the sediments of upper Lower Tanjung, Upper Tanjung and Berai were deposited. These sediments are transgressive in nature.

A distinct change in sedimentary character occurs at the boundary of synrift and postrift sequences. In the lower section, sedimentation is localized with well-defined thickness and facies changes indicating rift-infill; while in the upper sequence the sediments are more regionally correlatable, indicating the reduced influence of the irregular horst and graben terrain.

The lower part of the sequence consists of middle to earliest Oligocene upper Lower Tanjung and Upper Tanjung; the sediments are grouped into Stage 2 to Stage 4 by PERTAMINA and Trend Energy (1988) showing sag-infill and marine incursion characteristics. They are represented by deltaic sands, silts, muds, and coals; and neritic mudstone of Upper Tanjung (Figure 5).

Basin subsidence continued throughout the Oligocene and by mid-Miocene time had resulted in sediments constituting the upper part of the sequence. The calcareous sediments of the Berai Formation fed the basin at that time. The lower part of the formation, below the massive limestone, consists of a condensed paralic and inner neritic sequence of shales and marls. This passes up into thick massive late Oligocene limestone, which is succeeded by early Miocene shales, marls, and thin limestones (Figure 4).

d. Syninversion Sequence

In mid-Miocene time the South China Sea continental fragments collided with North Kalimantan in which the Kuching High was uplifted. At the same time, the collision to the east of Sulawesi had ended the Makassar Strait rifting and uplifted the proto-Meratus Range. Both tectonic events started inversion in the Barito basin. The basin inversion was more strongly expressed when the NW Australian passive margin collided with the Sunda Trench and Banda Forearc at early Pliocene in which the inversion was accommodated by strike-slip fault systems through Sulawesi (Daly, Hooper, and Smith, 1987; Letouzey, Werner, and Marty, 1990; Daly et al., 1991). The uplifted Kuching High provided the sediments feeding the lowerstream basins, whereas the uplifted proto-Meratus Range separated the Barito Basin from open sea to the east causing the characteristics of sediments to change from transgressive to regressive cycles.

The syninversion sequence of the Barito basin consists of Warukin and Dahor formations (Figure 4). The upper early to late Miocene Warukin sediments were deposited into a rapidly subsiding basin as the result of the continental uplift in the west and the Meratus uplift in the east. The sediments that resulted are up to several thousands of meters thick in the central part of the basin. The Warukin Formation consists of shallow and marginal marine clastics of sands, shales, silts, and coals. The last intense tectonism in Plio-Pleistocene time, which reactivated the Meratus Range against the rigid Barito Platform, resulted in the shedding of clastic sediments and tectonic molasse of the Plio-Pleistocene Dahor Formation westward, off the mountain front, into the Barito Basin.

EAST BARITO INVERSION STRUCTURES

Background of Interpretation

There are many studies of seismic interpretation of the Barito basin available (e.g.: Geoservices, 1983; 1984; PILONA and PERTAMINA, 1986). However, for this study, the sections that can be used immediately are the sections which were provided and interpreted by PERTAMINA and Trend Energy (1988). Other workers did not pick the horizon of top of stage-1 (top of synrift Lower Tanjung sediments) which is crucial to our study. This is reasonable because the division of the Tanjung Formation into four stages was defined by PERTAMINA and Trend Energy (1988).

Type and Characteristics of Inversion Structures

Having examined seismic sections in detail, we conclude that most of the East Barito inversion structures fall under the type formed by *simple fault-propagation folding along a planar fault*. Several representative sections obtained from PERTAMINA and Trend Energy (1988) are displayed in this paper.

Figures 7 and 8 show seismic reflection profiles across structures associated with NW to SE aligned horst and grabens in the foredeep of East Barito. The interval between top of stage-1 and basement shows synrift sediments of the Tanjung Formation. Detailed variations in the thickness of sediments are clearly observed in it. The sediments are always thicker in the downthrown block of the fault. The sequences overlying the synrift unit up to the surface are distributed in constant thickness, which reveal that the rifting did not control the deposition of the sequences.

Figures 9 to 13 exhibit inversion structures in East Barito. The interval between the top of stage 1 and basement shows little variation in thickness across the reactivated faults. Synrift sediments in Figure 11 indicate normal separation across the fault, but show reverse separation across the adjacent fault. The separation becomes wider eastward. These conditions explain that the force which formed inversion structures originated from the east. The front limbs of the inverted synrift unit in the vicinity of the faults did not experience deformation resulting in steep dip. Sequences younger than stage 1 (upper Tanjung, Berai, and Warukin) exhibit some upwarping indicating the effects of compressional folding. Most faults broke through along the synclinal axial plane with increasing slip. Compressional fault-propagation folding which deformed Warukin sediments is still indicated in Figure 10.

Gradual change in the thickness of the synextensional/synrift units from the footwall to the hanging wall, in addition to constant thickness basinward and low-angle dips of front limbs of inverted folds, suggests that the structures are inversion structures formed by simple fault-propagation folding along a planar fault.

We do not interpret the structures as the type of inversion structures formed by fault breakthrough on planar faults because the difference in thickness of synrift sediments across the reactivated faults is not dramatic. In addition to that, the frontlimbs of the inverted folds have no steep dips. Also, the structures are not included in the type of inversion structures formed by fault-bend folding along a listric fault since the thickness of synrift sediments is constant basinward.

Evolution of Inversion Structures

Based on comparisons with the experimental and kinematic models detailed by Mitra (1993), most high-angle reverse faults of East Barito are interpreted to have initially developed as extensional faults in early Eocene time. The master faults which rifted the basement terminated in gentle extensional fault-propagation folds of stage 1 synrift sediments. With increasing rifting, eventually the faults propagated as minor faults through the synrift sediments (Figure 14 A). Regional subsidence might have propagated the faults from early Oligocene up to the early Miocene through postrift sediments (Figure 14 B). Compressional deformation, which initially influenced the basin in mid-early Miocene time, has resulted in compressional fault-propagation folding of synrift sediments and younger units, and a reduction of normal slip of the rifted basement and faulted sediments (Figure 14 C). Multiple compressional periods in the Neogene which peaked in the Plio-Pleistocene have resulted in dramatic inversion structures in East Barito. With the increasing slip, major faults have broken through along the synclinal axial plane of the inverted folds (Figures 14 D and 14 E).

Tectonic Origin of Inversion Structures

Oblique subduction along the Meratus Range in Late Cretaceous time (Sikumbang, undated ca. 1986) had resulted in regional tensile stresses oriented NE to SW in the southeastern edge of Sundaland which commenced formation of the Barito basin. The resulted rifted horst and graben structures show this general alignment (Figure 15 A). By mid-Miocene time uplift of the proto-Meratus Range started because of collisions to the east of Sulawesi. The collision and uplifting had propagated compressional force to close and invert the rifted and subsided Barito basin. Afterwards, the compressional deformation applied to Sundaland by the interplay of the Indo-Australian and Pacific plates greatly inverted the Barito basin.

Neogene regional compression stresses aligned approximately in WNW to ESE direction began to squeeze the area of SE Kalimantan (Figure 15 A). This compression firstly reactivated NW-SE aligned Paleogene normal faults as Neogene left-lateral wrench faults. It was this lateral motion which allowed displacement and uplift towards the northwest as the paleo-horsts and -grabens became reactivated, and which in turn led to folding and reverse faulting. The traces of the wrench faults are curvilinear or sinuous in map view, causing their principal displacement zone to have restraining and releasing bends along their lengths (Christie-Blick and Biddle, 1985) (Figure 15 C). These restraining bends caused compressional (transpressive) movement to give rise to folds and reverse faults. Folds and reverse faults in East Barito which are arcuate at their southern end and which are aligned in a NW to SE direction, such as to the SW of Kambitin and south of Tanjung fields, developed in this way. Where the reverse faults are distinctly arcuate southward, they can be traced into a single old normal fault, such as to the south of Kambitin-Bagok and Tanjung fields (Figure 15 A).

Elsewhere, the folds and reverse faults which are aligned in a NE-SW direction and subperpendicular to Paleogene structural elements, developed as en echelon structures adjacent to wrench faults (Figure 15 B), such as to the west of Kambitin, Tanjung, and to the east of Maridu (Figure 15 A).

In addition, folds and reverse faults developing to the west of Bongkang and Hayup and to the southeast of Berimbun have had nothing to do with the principal displacement zone of East Barito wrench faults (Figure 15 A). The structures were formed directly as the grabens were inverted. The paleograbens at both places, aligned in NE to SW direction, consequently allowed inversion as compressional deformation propagated west-northwestward.

Thus, the East Barito inversion structures originated from reactivation and inversion of Paleogene structural elements in a number of mechanisms.

PETROLEUM SYSTEM SIGNIFICANCE

In the Tanjung Raya area hydrocarbons have been generated from Lower Tanjung and Lower Warukin source rocks (Tanjung, Kambitin, Warukin, and Tapian Timur fields). The hydrocarbons have been trapped primarily in structural closures consisting of Lower Tanjung and Upper Warukin sands. In this paper we discuss only the petroleum system of the Tanjung Formation, since we want to see the significance of graben-fill deposits to the generation of hydrocarbons and their role in the hydrocarbon trapping mechanism through structural inversion.

Graben-Fill Hydrocarbon Potential

a. Source Rock Potential

The stage-1 sediments were deposited in the Paleogene grabens as alluvial channels and fans prograding into lacustrine environments (Figure 5). Numerous thin coals are presumably deposited along the lake margins. Deep lacustrine environments may have developed in the axes of grabens. Such environments would provide an anoxic environment for the accumulation of rich algal organic matter. Algal lacustrine source beds are known to have prolific oil source potential. Analysis conducted on stage-1 samples collected from outcrop at locations which are interpreted as representing lacustrine environments resulted in TOC values ranging from 9.94 to 73 % (PERTAMINA and Trend Energy, 1988).

Carbonaceous clays/ shales and thick coal beds (more than 10 meters thick) are found in the stage-2 sediments (Figure 5). Carbonaceous clays and coals of this interval have TOC values over 2 % and 51 - 73 % respectively. Most hydrocarbons in Tanjung Raya fields are considered to be generated from this interval. Clays/ shales of stage-3 and stage-4 are lean in organic matter.

The kerogen types of Lower Tanjung source rocks are dominated by vitrinite (type III, 40-60 %), amorphinite and exinite (types I and II, 10-30 %) and inertinite (type IV, 10-30 %). The hydrogen index (HI) varies from 40 to 300 mg/g TOC. Such data indicate that oil and gas may be generated from Lower Tanjung source rocks (Rotinsulu, Sardjono, and Heriyanto, 1993).

b. Maturation

Maturity analysis of Lower Tanjung source rock well samples has resulted in the maturity pattern of the area. The pattern reveals immature to early mature Lower Tanjung in the northwestern part, mature in the central part trending in a NE-SW direction, and over mature in the southeastern part of the area in the deepest part of the basin. Note that this pattern is obtained using the present depth of the formation.

c. Reservoir Potential

Primary reservoirs of the graben-fill facies of East Barito consist of restricted synrift sands of stage 1 and widespread, postrift sag-fill sands of stages 2 and 3 (Figure 5).

Synrift sands of stage 1 (called A- and B- sands or Z.1015 and Z.950 sands) were deposited in alluvial fan (distributary channel) and lacustrine delta front environments. These sands were distributed restrictively in grabens. The net thickness of these sands is 30 to 50 meters in the central part of the graben. Generally, the reservoir character is strongly controlled by local provenance.

Sands of stage 2 (C- and D- sands or Z.860 and Z.825 sands) represent alluvial fan (deltaic) sands. The C/Z.860 sands are stacked, deposited in alluvial plain channels, and found extensively throughout the Tanjung Raya area. Generally, reservoir properties of these sands are better than those of other sands in the Lower Tanjung Formation, reflecting a higher degree of sorting and mineralogical maturity. The net thickness of these sands is 25 to 30 meters, with average porosities and permeabilities of 20 % and 156 mD respectively. Unlike the C/Z.860 sands, the D/Z.825 sands are thin and discontinuous (lenses). The sands are 3 to 5 meters thick, fine- to coarse-grained, and slightly argillaceous.

Stage 3 reservoirs consist of E-sands (Z.710 sands) and Z.670 sands. E sands were deposited as beach/ barrier bar in a regressive shoreline environment. The maximum net thickness of E-sands is 30 meters. Z.670 sands were deposited overlying the Z.710 sands far off shore in a prodelta area. The sands are 2 to 3 meters thick, very fine- to fine-grained.

d.. Sealing Rock

The postrifting phase of regional transgression/ subsidence after the deposition of sag-fill sediments has resulted in shallow marine mudstone of the stage 4 Upper Tanjung Formation (Figure 4). These marine mudstones provide a very effective regional seal to the Lower Tanjung reservoirs. They consist of up to 800 meters of dominantly neritic shales and silty shales.

e. Hydrocarbon Trapping Mechanism

The inversion history of the basin by the Meratus Uplift began as early as middle early Miocene, during which the initial deposition of Warukin Formation occurred. The inversion resulted in the asymmetric Barito Basin. The basin dipped gently to the northwest toward the Barito Platform and dipped steeply to the southeast into the Meratus Uplift. Consequently, the central part of the basin subsided rapidly. This condition caused Lower Tanjung source rocks deposited in the basin center to attain such depth that the rocks started generating hydrocarbons.

Burial history/TTI modeling of the basin depocentre inferred that the onset of oil generation and expulsion began some 20 Ma (middle early Miocene). The significant expulsion occurred some 15 Ma (early middle Miocene - Figure 14 C).

The uplift of the proto-Meratus resulted in compressional tectonism in the basin. Lower Tanjung graben-fill sequences were actively inverted and asymmetric anticlines were being propagated along the reverse faults. Expelled hydrocarbons generated from the depocentre would fill these structural traps at the same time. Structures such as Tanjung field were thus favorably positioned for the entrapment of early migrating hydrocarbons.

The uplifting of the Meratus was continuous during the late Miocene, through Pliocene and peaked in Plio-Pleistocene time. All the subsided Lower Tanjung source rocks in the depocentre had already matured by late Miocene. The proto-inverted structural traps formed in the early Miocene were continuously inverted as basin compression developed, resulting in strongly positive features. Hydrocarbons filled these traps through the faults and along permeable sands.

It is considered that in early Pliocene time the Lower Tanjung source rocks in this area had exhausted their liquid hydrocarbon generating capabilities. Gas was generated and expelled, filling the existing traps (Figure 14 D).

Plio-Pleistocene tectonism caused the whole of the Barito Basin to be strongly inverted. This tectonic event could have formed new inversion traps as well as destroying existing traps. Entrapped hydrocarbons probably remigrated to newly-formed structures as old traps were tilted or breached by Plio-Pleistocene inversion. Lower Tanjung source rocks had ceased to generate oil and gas in the depocentre since the section was by now firmly within the dry gas window (Figure 14 E).

The foregoing discussion depicted how critical are the factors of hydrocarbon generation and migration timing relative to the timing of extensional and compressional deformation and the preservation of a structural trap during inversion.

CONCLUSIONS

The study undertaken has drawn conclusions presented below in the order in which the subjects appeared in the foregoing text.

1. Inversion structures are formed by the compressional reactivation of pre-existing normal faults.

2. Tertiary tectono-stratigraphy of the East Barito basin, in terms of tectonic history and associated sedimentary patterns, can be divided into prerift, synrift, postrift, and syninversion sequences.

3. East Barito inversion structures fall under the type of inversion structures formed by simple fault-propagation folding along a planar fault. The structures originated from reactivation and inversion of Paleogene extensional structures through mechanisms of : (1) compressional movement along the restraining bends of the wrench faults, (2) en echelon structures adjacent to the wrench faults, and (3) direct inversion from NE-SW aligned Paleogene normal faults having nothing to do with wrench faults.

4. Structural-stratigraphic evolution of East Barito inversion structures has resulted in ideal

conditions for the accumulation of hydrocarbons. Growth sedimentation into an extensional basin resulted in early to middle Eocene synrift Lower Tanjung source rocks and reservoir sandstones. Postrift shales of late Eocene to early Oligocene Upper Tanjung provide an effective seal. Structural inversion, which commenced in the mid-early Miocene and greatly affected the basin from late Miocene to Pliocene time, subsided Lower Tanjung source rocks in the depocentre to a depth such that hydrocarbons could be generated and expelled. Migrated hydrocarbons were entrapped in anticlinal traps formed during the inversion. Plio-Pleistocene inversion might have created favorable conditions for structural traps as well as destroying previous hydrocarbon accumulations. If the latter occurred, hydrocarbons would remigrate and fill the newly formed inversion structures.

ACKNOWLEDGMENTS

Grateful appreciation is extended to the Exploration Department of PERTAMINA Balikpapan and the Exploration Division of PERTAMINA Jakarta for their permission to publish the paper. The authors thank Putut Sukasno who drafted the illustrations. Great appreciation is expressed to Lanny Kristiani for critical review of the text language. The assistance of all is gratefully acknowledged.

REFERENCES

Austin, P.M., 1969. *Geological report on the Barito sub-basin, Kalimantan, Indonesia*, CONOCO, no publ. place, 107 ps, unpublished.

Bow Valley, 1992. *Tanjung Raya area East Kalimantan technical evaluation*, Bow Valley (Asia) Ltd., Jakarta, 23 ps, unpublished.

Christie-Blick, N. and Biddle, K.T., 1985. Deformation and basin formation along strike-slip faults, *in* Biddle, K.T. and Christie-Blick, N. (eds), *Strike-slip deformation, basin formation, and sedimentation - SEPM Spec. Publ.*, no. 37, pp. 1-34.

Coffield, D.Q. et al., 1993. Tectonic and stratigraphic evolution of the Kalosi PSC area and associated development of a Tertiary petroleum system, South Sulawesi, Indonesia : *Proceedings of the IPA 22nd annu. conv.*, pp. 679-706.

Daly, M.C. et al., 1991. Cenozoic plate tectonics and basin evolution in Indonesia : *Marine and Petroleum Geology*, v. 8, pp. 2-21.

Daly, M.C.; Hooper, B.G.D., and Smith, D.G., 1987. Tertiary plate tectonics and basin evolution in Indonesia : *Proceedings of the IPA 16th annu. conv.*, pp. 399-428.

Gaffney-Cline, 1971. *North Barito basin, geology and hydrocarbon prospects*, Gaffney-Cline and Assoc., no publ. place, 117 ps, unpublished.

Geoservices, 1983. *Geological and geophysical evaluation of the Tanjung Raya area, Barito basin*, PT Geoservices, Jakarta, 42 ps, unpublished.

Geoservices, 1984. *Detailed seismic interpretation of Tanjung Raya area, South Kalimantan*, PT Geoservices, Jakarta, unpublished.

Ginger, D.C. et al., 1993. Inversion history of the West Natuna basin : examples from the Cumi-cumi PSC : *Proceedings of the IPA 22nd annu. conv.*, pp. 635-658

Jones, P., 1992. *Petroleum exploration in fold and thrust belts a quantitative approach*, Geoservices course manual, Bandung, 168 ps, unpublished.

Kusuma, M.I., 1988. *Potensi hidrokarbon Formasi Tanjung Bawah, cekungan Barito, Kalimantan*, Eksplorasi UEP IV PERTAMINA DAK, Balikpapan, 20 ps, unpublished.

Kusuma, M.I. and Darin, T., The hydrocarbon potential of the Lower Tanjung Formation, Barito basin, SE Kalimantan : *Proceedings of the IPA 18th annu.* conv., pp. 107-138.

Letouzey, J., Werner, P., and Marty, A., 1990. Fault reactivation and structural inversion. Backarc and intraplate compressive deformations. Example of the eastern Sunda shelf (Indonesia) : *Tectonophysics*, 183, pp. 341-362.

Mason, A.D.M., Haebig, J.C., and McAdoo, R.L., 1993. A fresh look at the North Barito basin, Kalimantan : *Proceedings of the IPA 22nd annu.*

conv., pp. 589-606.

Mitra, S., 1993. Geometry and kinematic evolution of inversion structures, *The AAPG Bull.*, v. 77, no. 7, pp. 1159-1191.

PERTAMINA and Trend Energy, 1988. *The hydrocarbon potential of the Lower Tanjung Formation, Barito Basin, SE Kalimantan, Indonesia*, PERTAMINA-Trend Energy Kalimantan Ltd., Jakarta, 219 ps, unpublished.

PILONA and PERTAMINA, 1986. *Seismic interpretation and petroleum potential, Tanjung Raya area, South Kalimantan, Indonesia*, PT PILONA, Jakarta, unpublished.

Rotinsulu, L.F., Sardjono, S., and Heriyanto, N., 1993. The hydrocarbon generation and trapping mechanism within the northern part of Barito basin, South Kalimantan : *Proceedings of the IPA 22nd annu. conv.*, pp. 607-633.

Satyana, A.H. and Silitonga, P.D., 1993. Thin-skinned tectonics and fault-propagation folds : new insights to the tectonic origin of Barito folds, South Kalimantan: *Proceedings of the IAGI 22nd annu. conv*.pp.282-291.

Sikumbang, N., undated-ca. 1986. *The geology and tectonics of the Meratus Mountains, South Kalimantan, Indonesia*, Marine Geological Institute, Bandung, 142 ps, unpublished.

van de Weerd, A.A. and Armin, R.A., 1992. Origin and evolution of the Tertiary hydrocarbon bearing basins in Kalimantan (Borneo), Indonesia : *The AAPG Bull.*, v. 76, no. 11, pp. 1778-1803.

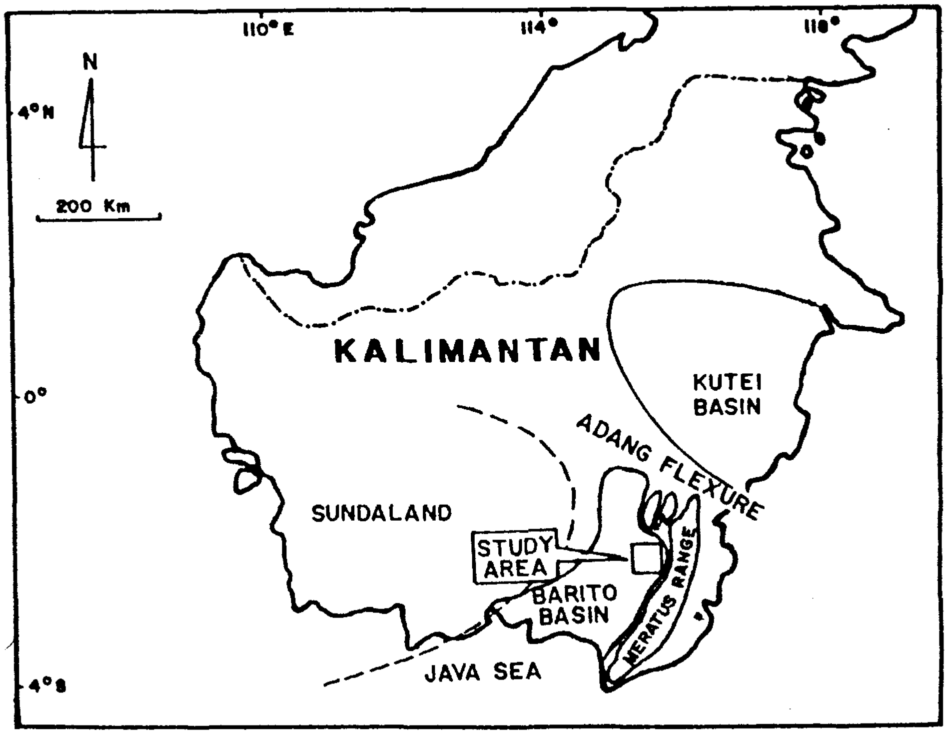


FIGURE 1 - Regional setting of Barito basin and location map.

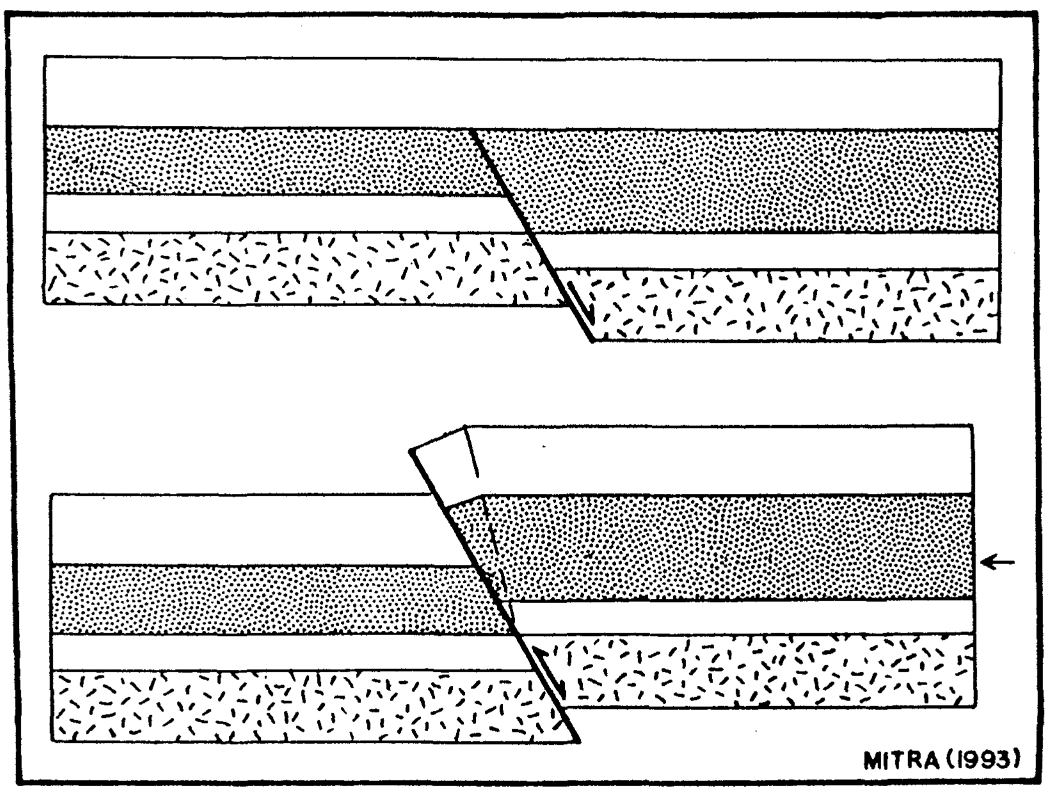


FIGURE 2 - Normal fault reactivated as reverse fault resulting in an inversion structure.

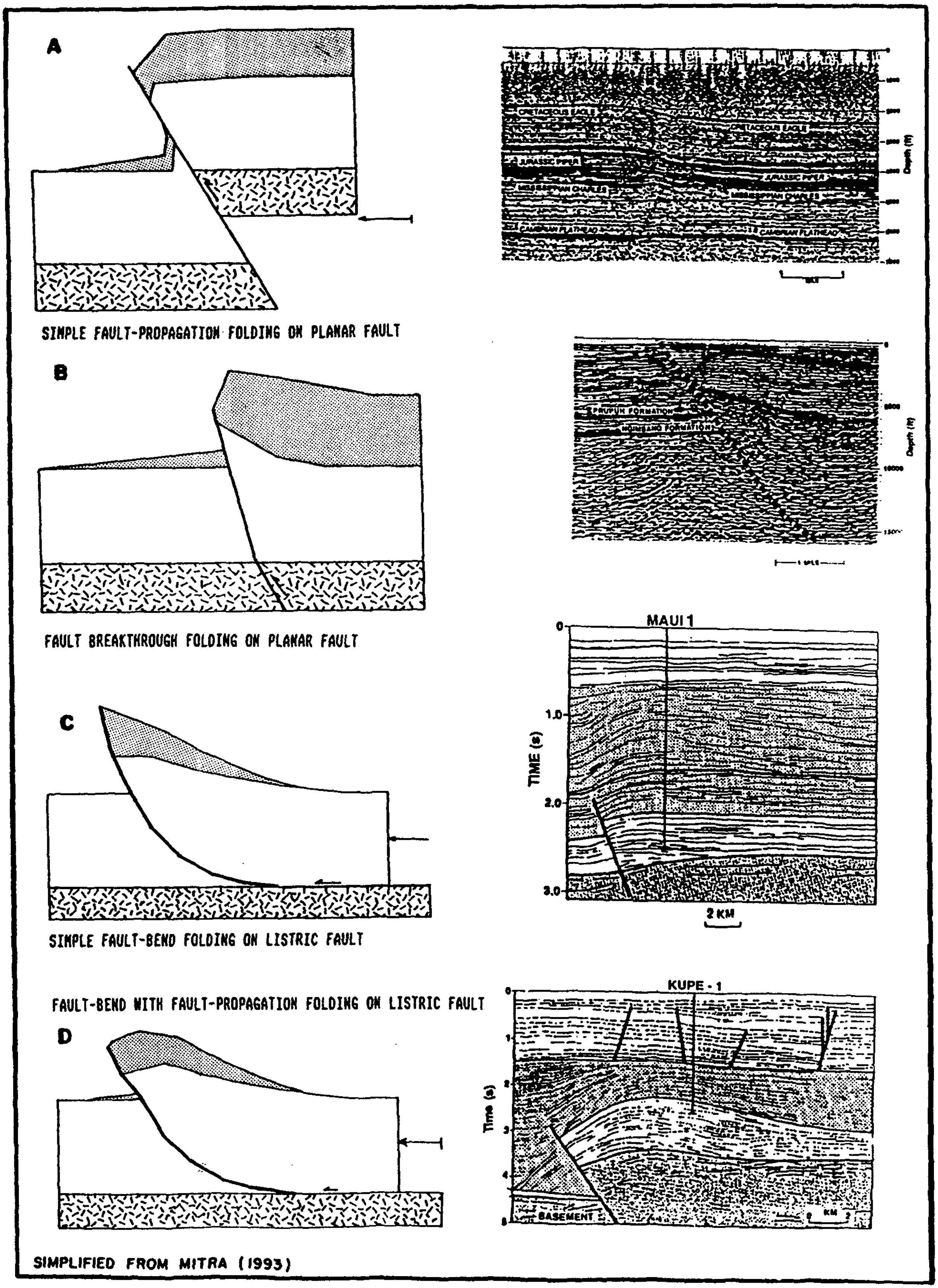


FIGURE 3 - Kinematic models and corresponding real examples from seismic sections showing types of inversion structures.

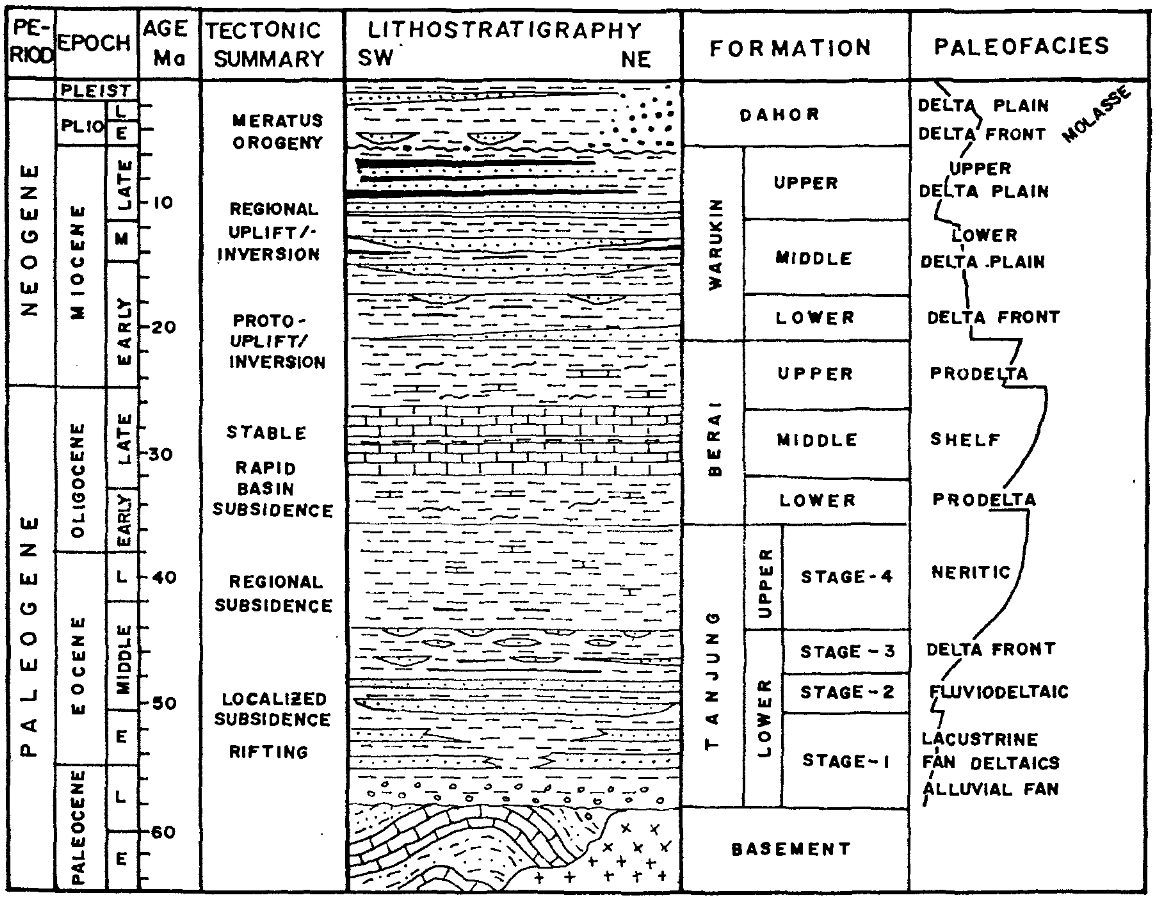
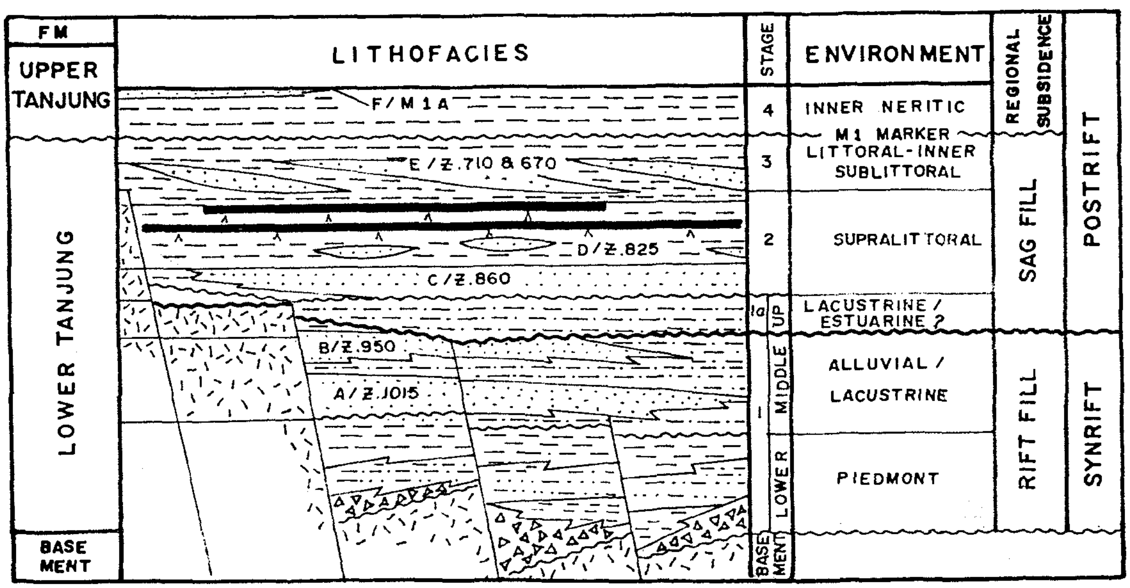


FIGURE 4 - Stratigraphic chart of the Barito basin showing major formations, their paleofacies, and coeval tectonic episodes.



(SIMPLIFIED AND MOD. FROM BOW VALLEY. 1992)

FIGURE 5 - Lower Tanjung graben-fill facies. Productive sand bodies in Tanjung field are indicated.

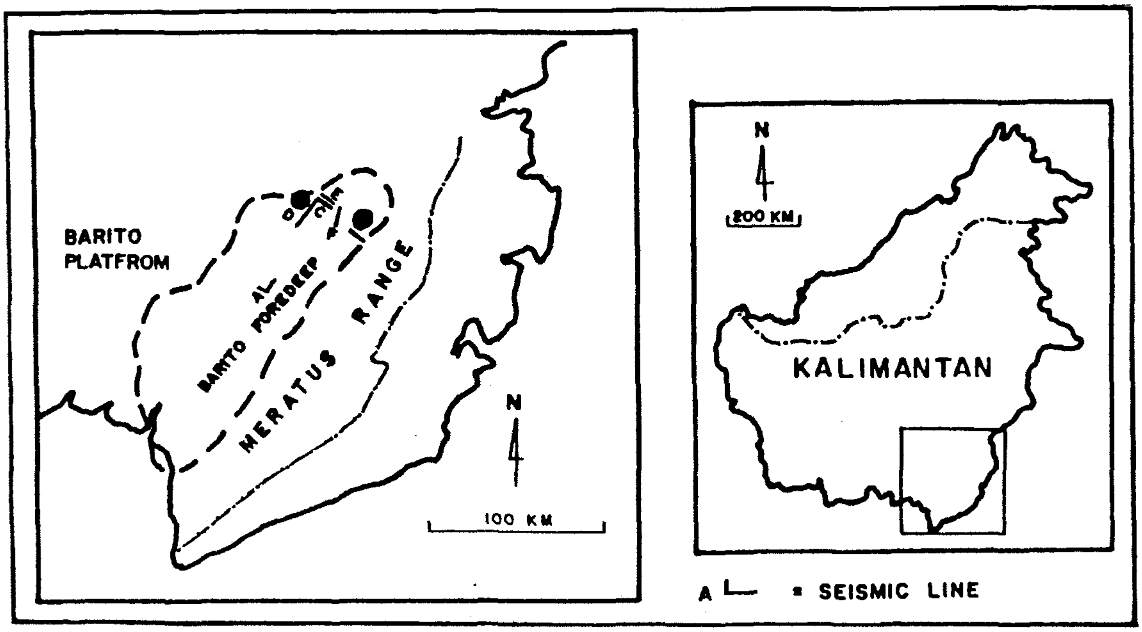


FIGURE 6 - Map showing locations of representative seismic sections displayed in this paper.

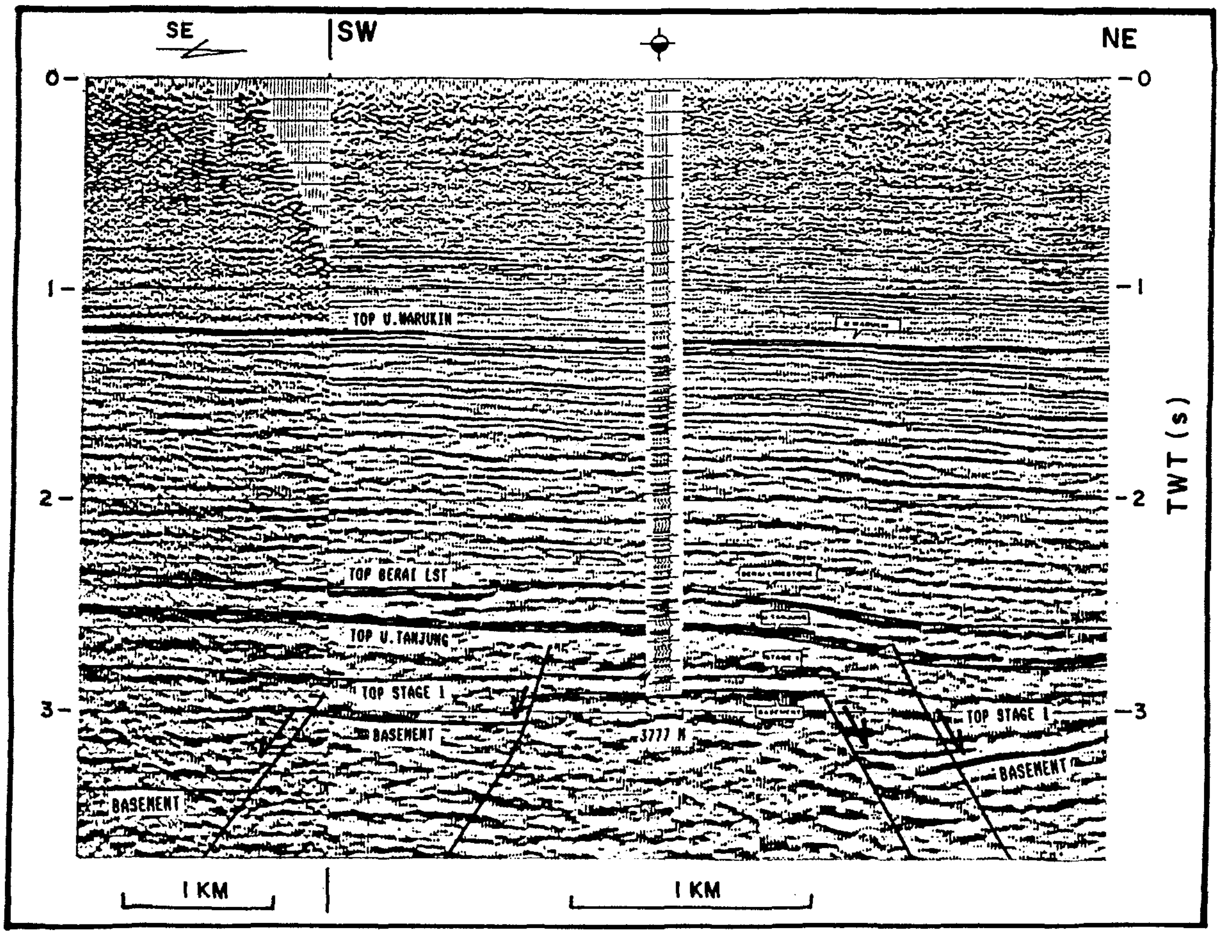


FIGURE 7 - Seismic section "A" across NW - SE trending horst and grabens in East Barito. Note the thickening of synrift sediments (basement to stage 1) across the faults.

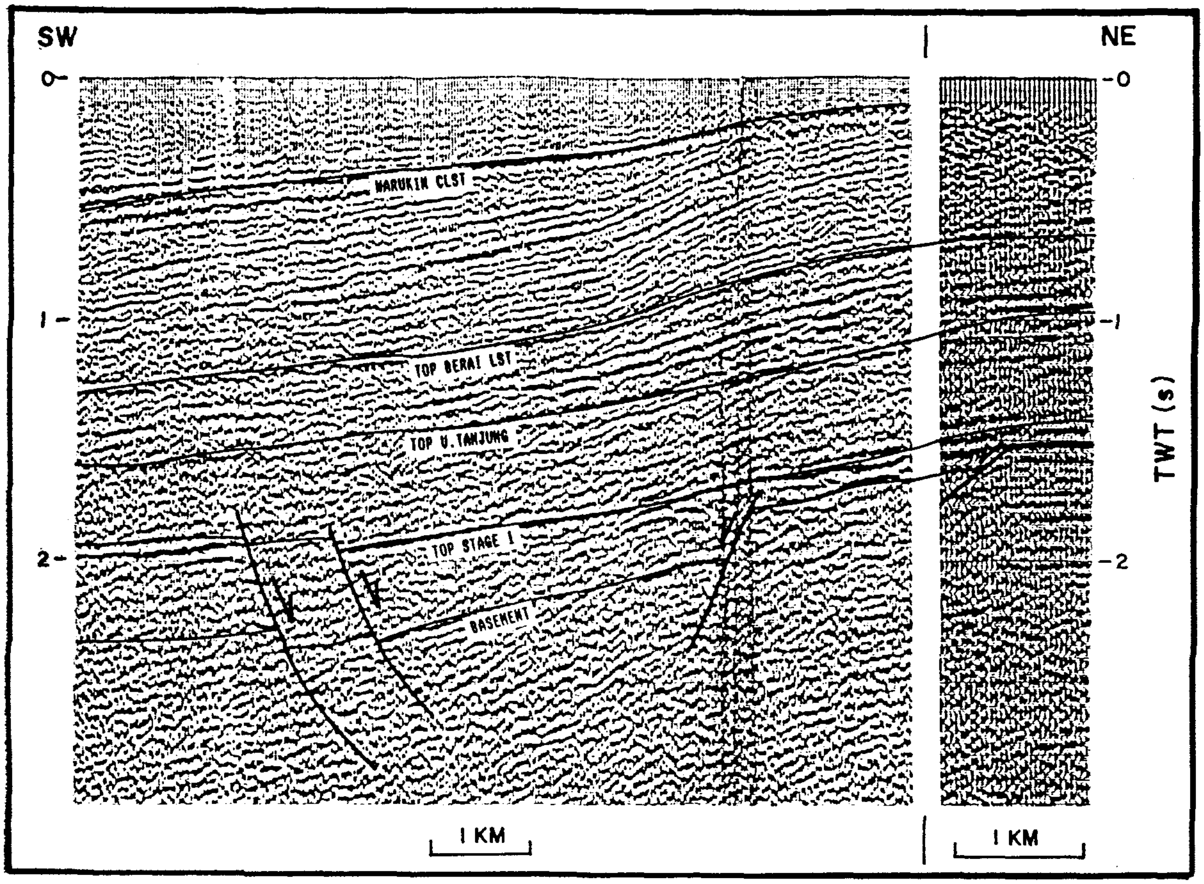


FIGURE 8 - Seismic section "B" showing NW-SE trending grabens. Synrift sediments of stage 1 thicken into the basin.

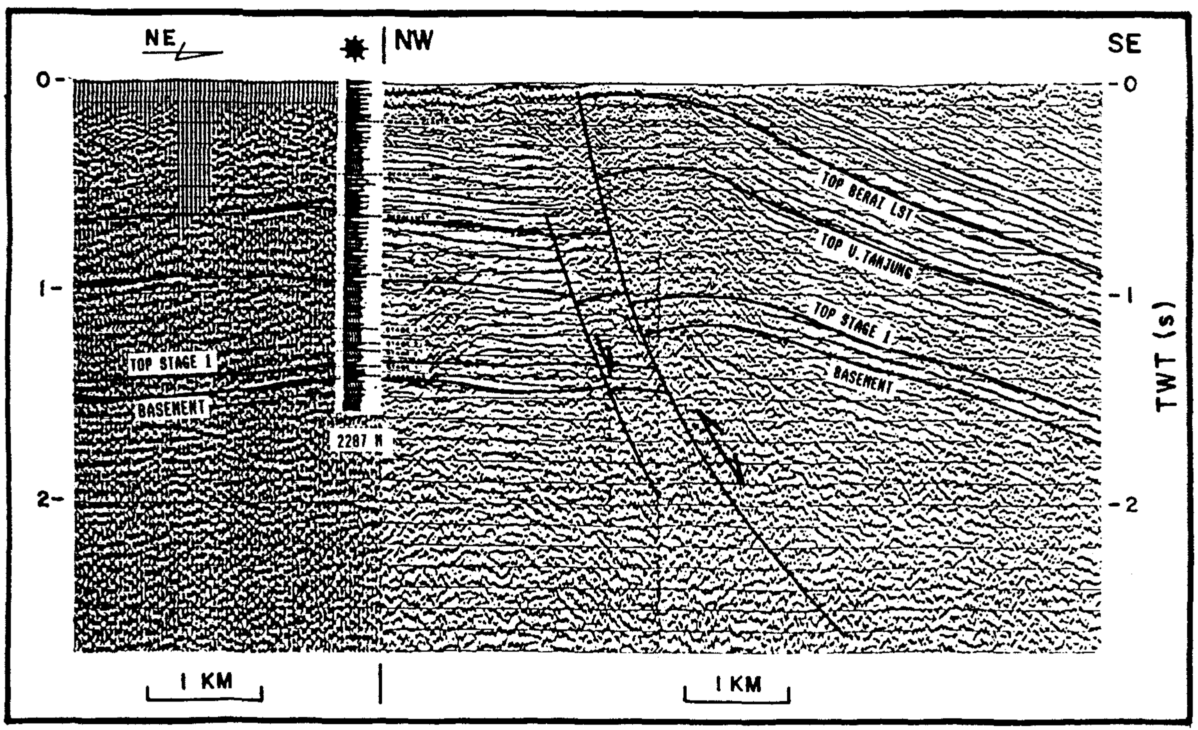


FIGURE 9 - Seismic section "C" crosses reactivated fault. Note that the adjacent fault has normal slip.

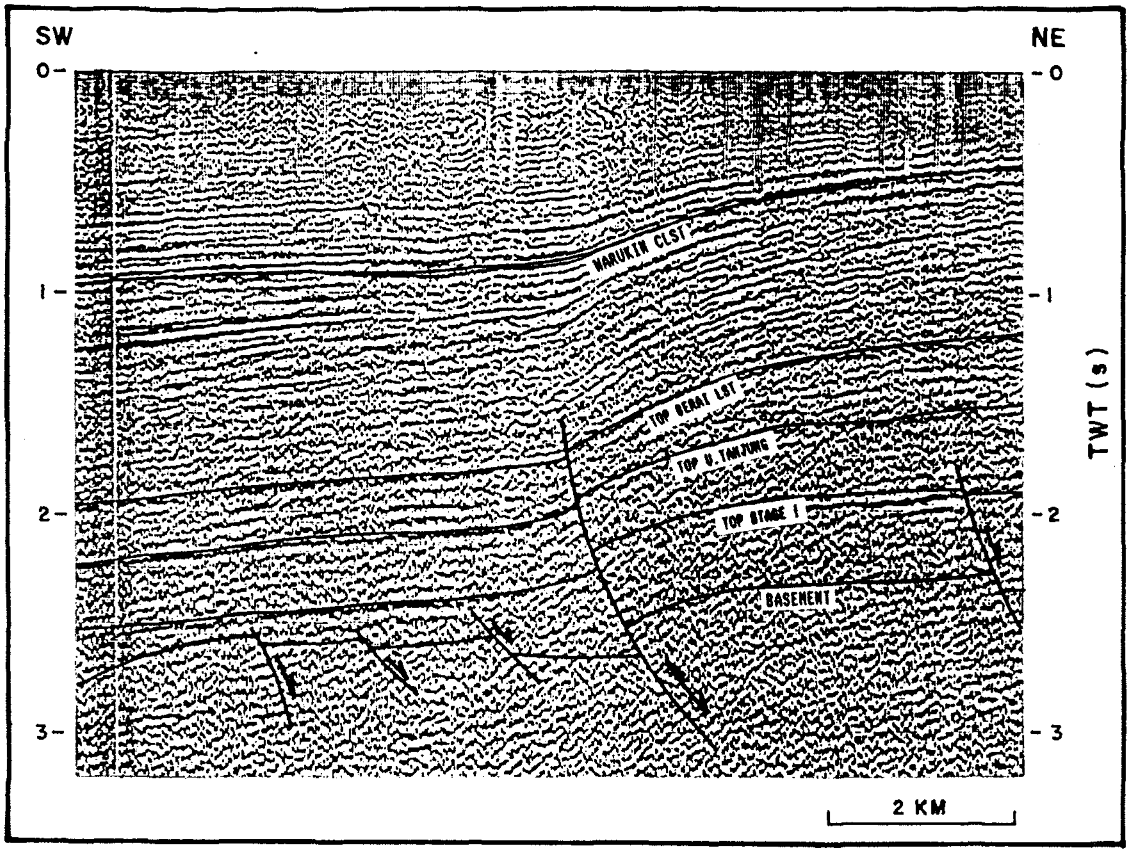


FIGURE 10 - Seismic section "D" showing reactivated faulst. Graben and thickening stage 1 synrift sediments are indicated.

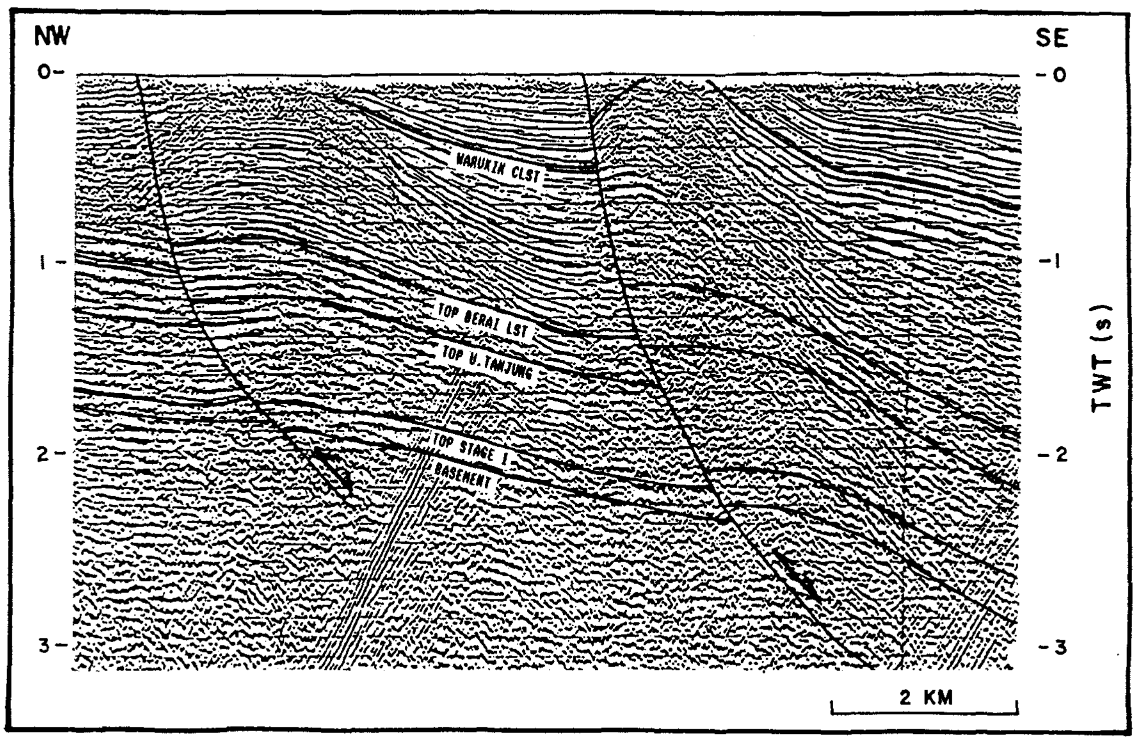


FIGURE 11 - Seismic section "E" through inversion structures in East Barito. Note the increasing reverse slip of stage 1 and basement across the Basin.

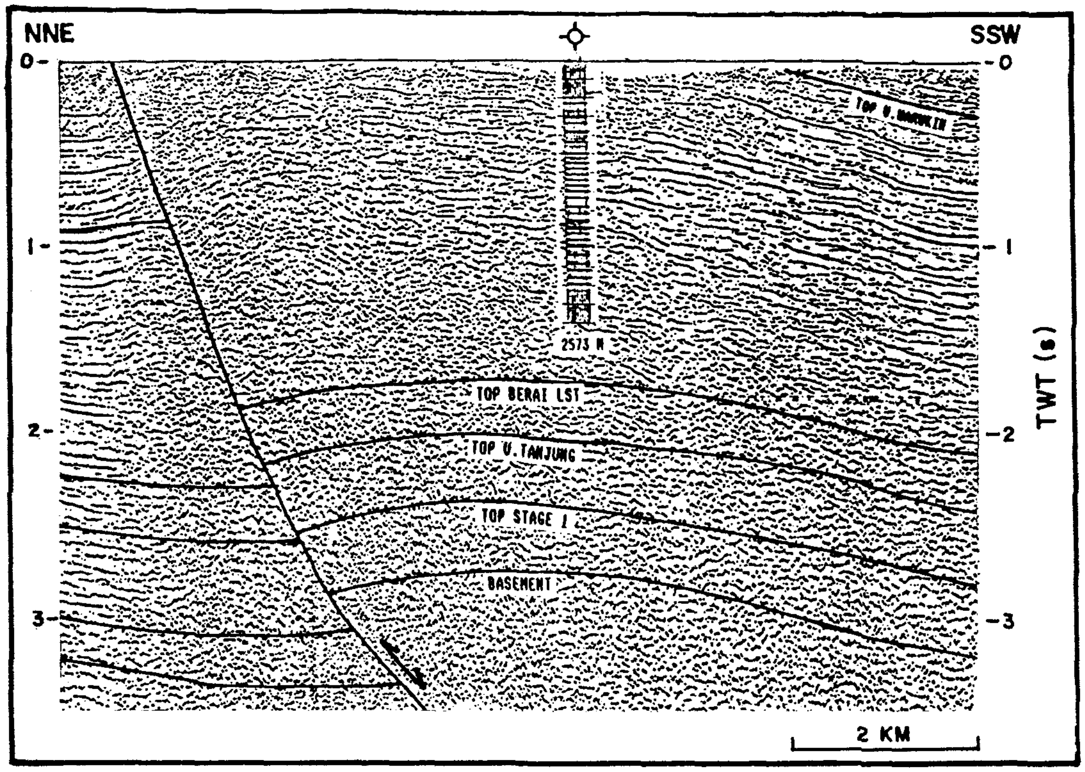


FIGURE 12 - Seismic section "F" showing variation in thickness of stage 1 synrift sediments across the reactivated fault.

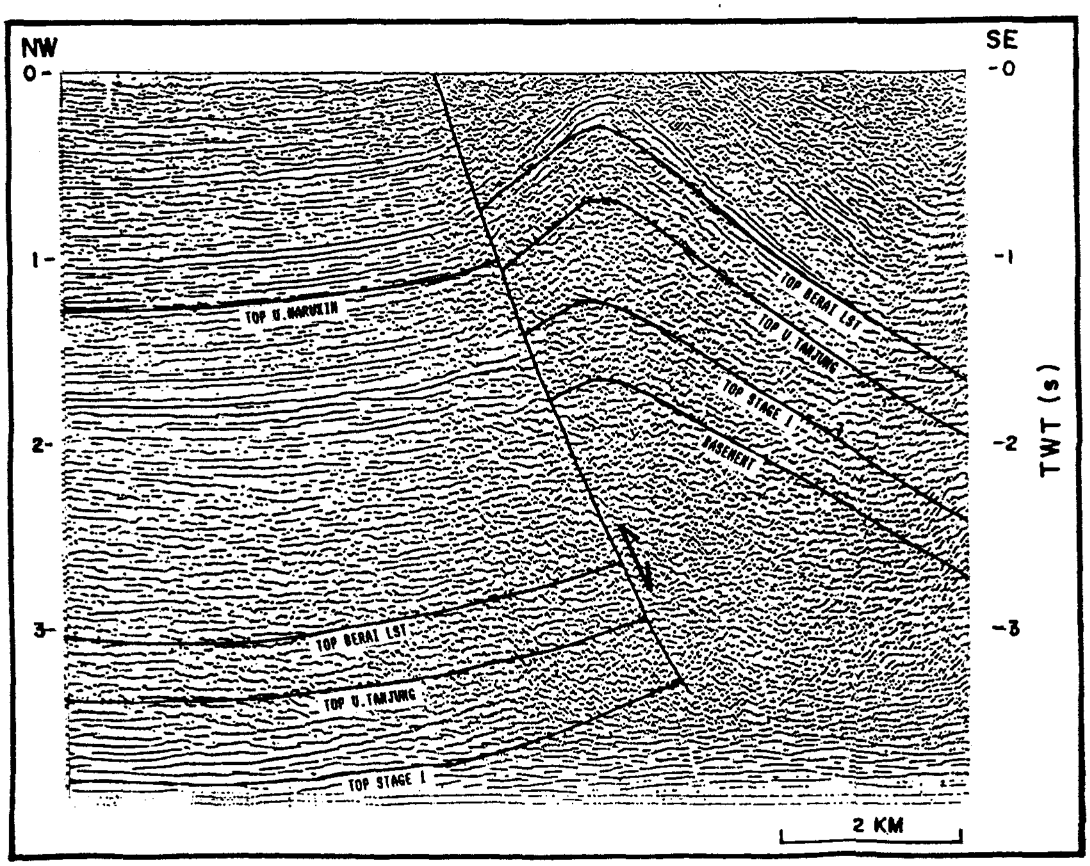


FIGURE 13 - Seismic section "G" showing wide reverse slip of stage 1 and basement across the fault. The section is located at mountain front of the Meratus Range.

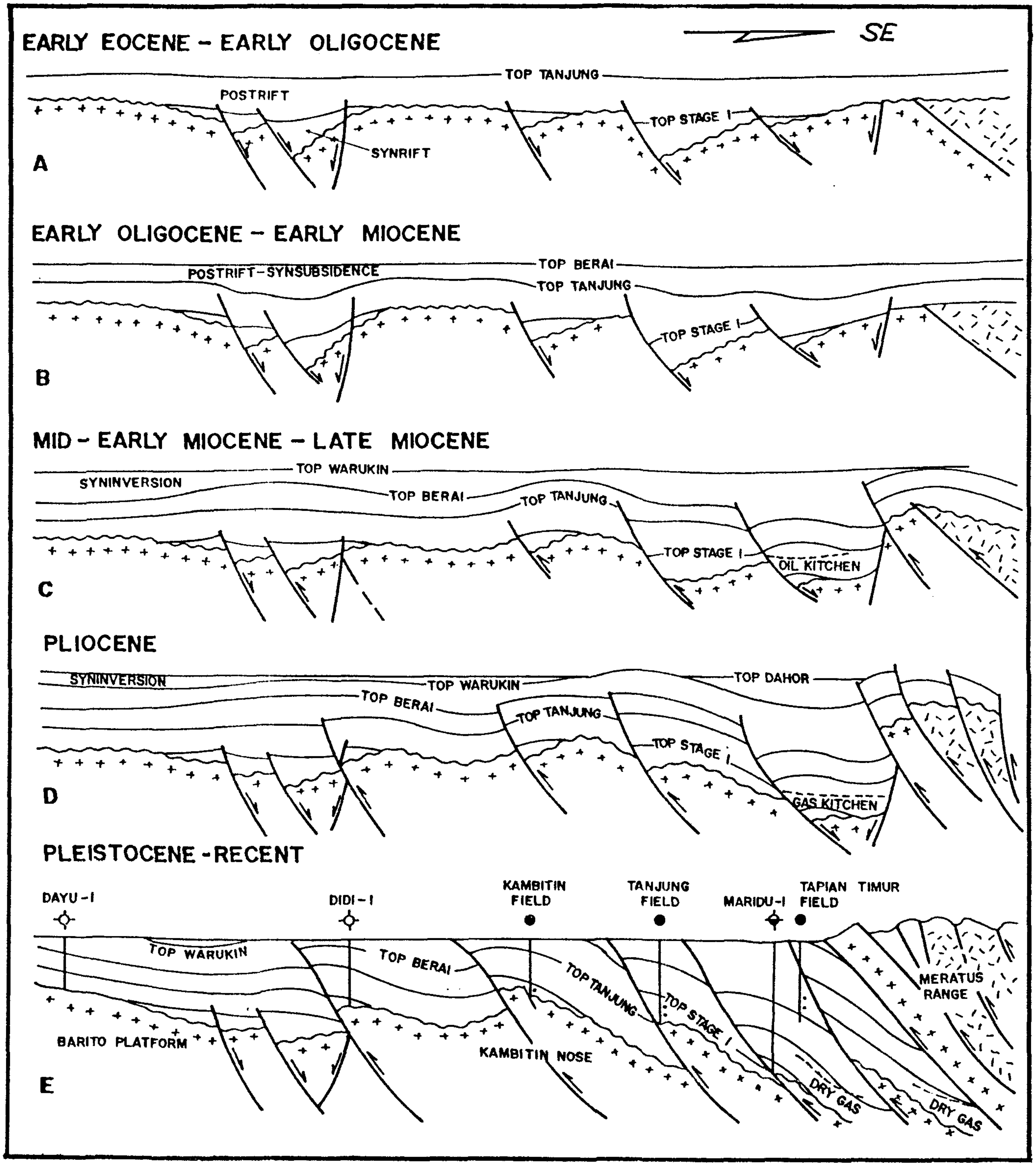


FIGURE 14 - Retrodeformable sections across East Barito basin showing the evolution of inversion structures and associated petroleum implications.

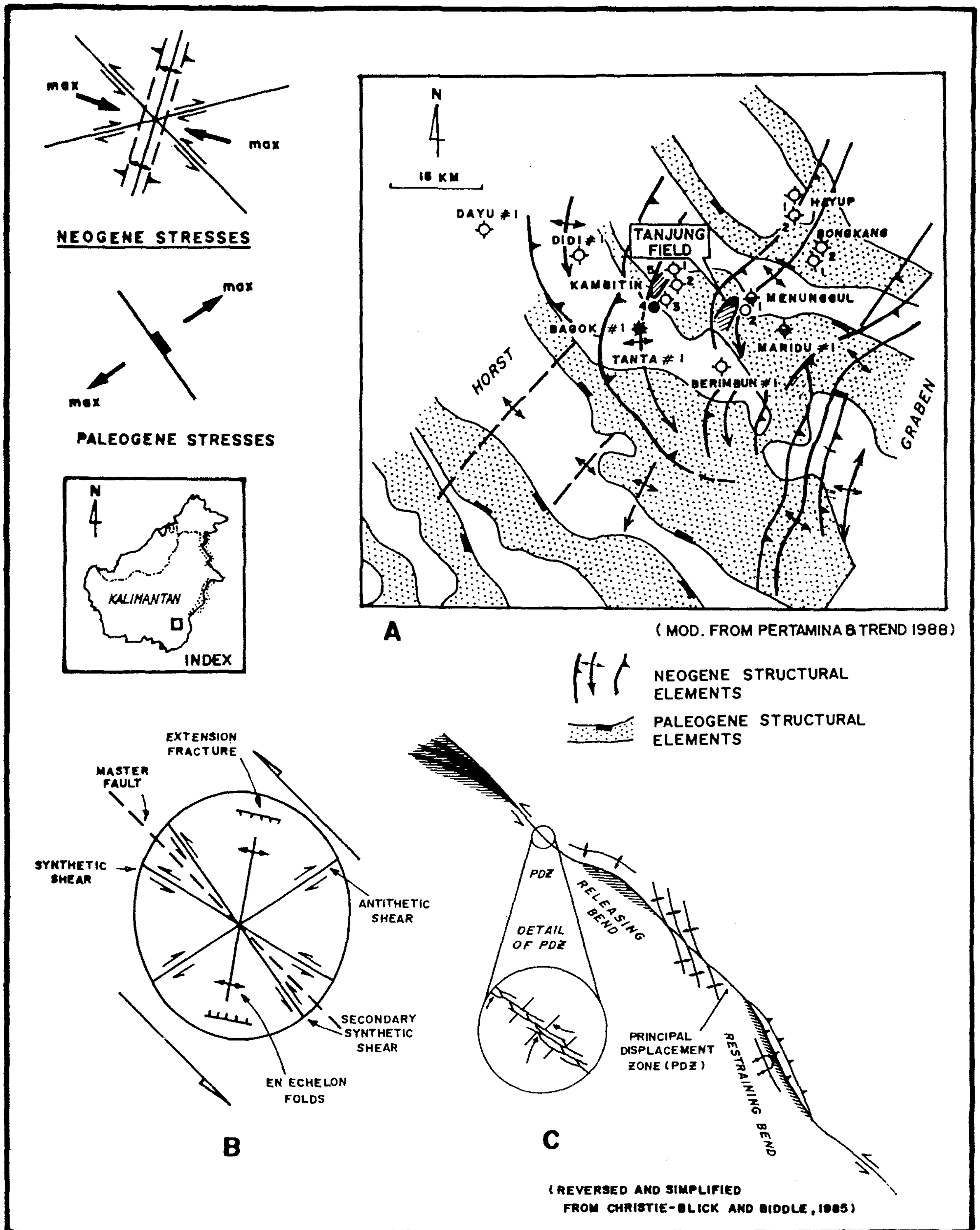


FIGURE 15 - Paleogene and Neogene structural elements of East Barito. Left-slip strain ellipse and map view-fault trace are presented to explain tectonic relationship between Paleogene and Neogene elements.