THIN-SKINNED TECTONICS AND FAULT-PROPAGATION FOLDS : NEW INSIGHTS TO THE TECTONIC ORIGIN OF BARITO FOLDS, SOUTH KALIMANTAN *)

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ABSTRACT

Barito Basin, South Kalimantan is located in between Sunda Shield to the west and Meratus Range to the east. The area is foreland- backarc region typified by foredeep at the frontal zone of Meratus and platform approaching the shield. The structural style of the Barito Foredeep is characterized by parallel trends of folds and thrusts that repeat in closely spaced, wavelike bands constituting the belt. The folds are bounded by high angle, westerly -hanging thrust faults. These structures become increasingly imbricate towards the Meratus Range. Conjugate pair of strike-slip faults cut older structures. The platform is marked by weak tectonic patterns, some of which with gentle folds.

The study tried to apply concepts of thin-skinned (detached) tectonics and fault-propagation folds in search of the tectonic origin of Barito folds. Seismic sections were examined to define the structural characteristics of the basin. Retrodeformable sections were tested to solve the problems of structural history.

The study showed that the Barito Basin had been tectonized into different structural styles of unreal basement-involved tectonics with fault-related folds in the foredeep and indistinct thin- skinned tectonics in the platform with discontinuous decollement, ramps and obscure fault-propagation folds. The hydrocarbon so far is known to be trapped in the fault-related folds and paleohighs

of the northeastern end of Barito Foredeep. The possibility of decollement folds to trap hydrocarbon still needs to be examined by newer-and better-quality seismic sections of the platform area.

1. INTRODUCTION

This paper describes the structural configuration of Barito Basin, South Kalimantan. The study tried to apply concepts of detached (thin-skinned) tectonics and fault-propagation folds in search of the tectonic origin of Barito folds. The classic view asserts that all Barito faults involve basement and that fold formation has nothing to do with faults (nonfault-related folds).

In this paper, firstly we discuss the characteristics of thin-skinned tectonics and fault-propagation folds in general terms. Following this part we examine the tectonic origin of Barito foldsin which the detached faults, fault-propagation folds and basement-involved tectonics are discussed. Finally, implications to the hydrocarbon exploration significance are considered.

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2. TECTONICS OF FOLD AND THRUST BELTS

2.1 Thin-Skinned Tectonics

The Appalachian Mountains, which extend along the eastern side of North America, are clas-

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sic ground for structural geology, for here many of the major concepts of the science were developed. The Pine Mountain thrust sheet in the Valley and Ridge Province of Southern Appalachian is the classic model for thin-skinned deformation (Harris and Milici, 1977; Suppe, 1985). Rich (1934) *see* Harris and Milici (1977), utilizing the Pine Mountain thrust as an example, suggested that deformation was confined to the sedimentary cover, which was stripped off crystalline basement above a detached fault and was independently-deformed. This particular style of deformation, because it has been confined to the sedimentary sequence above the basement complex, has been termed "thin-skinned tectonics" (Rodgers, 1949). A 32-km -long seismic profile from part of the Valley and Ridge of Tennessee (Fig.1A) clearly establishes the thin-skinned style of deformation. Decollement (floor thrust) segments of thrust faults are confined to stratigraphic horizons that appear to be inherently weak either because of low rock strength, high fluid pressure, or both (Suppe, 1985).

The thin-skinned tectonics may be related with basement-involved tectonics (thick-skinned tectonics). Compressive settings can mix detached thrusts and folds with basement thrusts. Detached thrust systems in the outer fringe of orogenic belts can ultimately root downdip as basement thrust toward the core region of orogenic belts (Harding and Lowell, 1979).

2.2 Fault-Propagation Folds

Fault-propagation folds are fault-related folds that form as part of the process of fault propagation. The growth of a fault- propagation fold associated with the stepping up of a thrust fault was outlined schematically by Suppe (1985) (Fig.1B). As the propagating fault tip begins to diverge from the bedding-plane of decollement and step up through the section, two kink bands, A-A' and B-B', immediately form. Axial surface B is pinned to the footwall cutoff and beds roll through it. Axial surface A' terminates at the fault tip and beds roll through it as fault propagates. Axial surface AB', formed by the merging of A and B', moves with the velocity of the thrust sheet and is the only axial surface fixed in the material.

The important evidence for fault-propagation folds is the faults die out in the cores of folds. This upsection dying-out of fault eventually transfer its slip to a fold at its tip, or by distributing it among several splays (Mitra, 1986) (Fig.1C).

3. TECTONIC ORIGIN OF BARITO FOLDS

3.1 Barito Basin : Tectonic and Stratigraphic Frameworks

The Barito Basin is located along the southeastern edge of the stable continental Sunda Shield. The Meratus Range defines the basin in the east. To the north it is distinguished from the Kutei Basin by the Barito-Kutei Cross High. Soutwards it extends into the Java Sea. Within its internal framework the Barito Basin contains the present-day NE to SW trending Barito Foredeep, flanked to the west by the Barito Platform or Shelf. The Buntok Subbasin, situated to the NW of the foredeep is probably an offset extension of the foredeep (Fig.2A).

The geologic history of the basin during Tertiary was started by rifting of the basement in Paleo-Eocene. The condition prevailed up to Oligo-Miocene during which localized and regional subsidence, lithospheric stretching, interrupted by uplifting, impressed the basin. Graben-fill comprises Tanjung and shallow platform and marl of Berai formations were established. By mid-Miocene, the prevailing structural style changed to more compressional nature. Regional uplift, appeared in middle Miocene and Plio-Pleistocene established the sediments of Warukin and Dahor formations and gave rise to the present structural configuration (Figs.2B,5A).

The rifting or block faulting of the Barito basement is a unique structural history and crucial to the present study. The rifting produced a set of horsts and grabens that were decisive for the following structures. The consequence of early rifting followed by compression and uplifting, has reactivated the old fault blocks rather than developed entirely new structures.

3.2 Barito Thin-Skinned Tectonics

The thin-skinned tectonics in the Barito Basin may be observed in the area beyond the Barito Foredeep (Barito Platform). Seismic sections reveal that the most areas in the Barito Platform are weakly tectonized (Figs.3B,C).

The possibility of the existence of thin-skinned tectonics in the basin is apparent in some

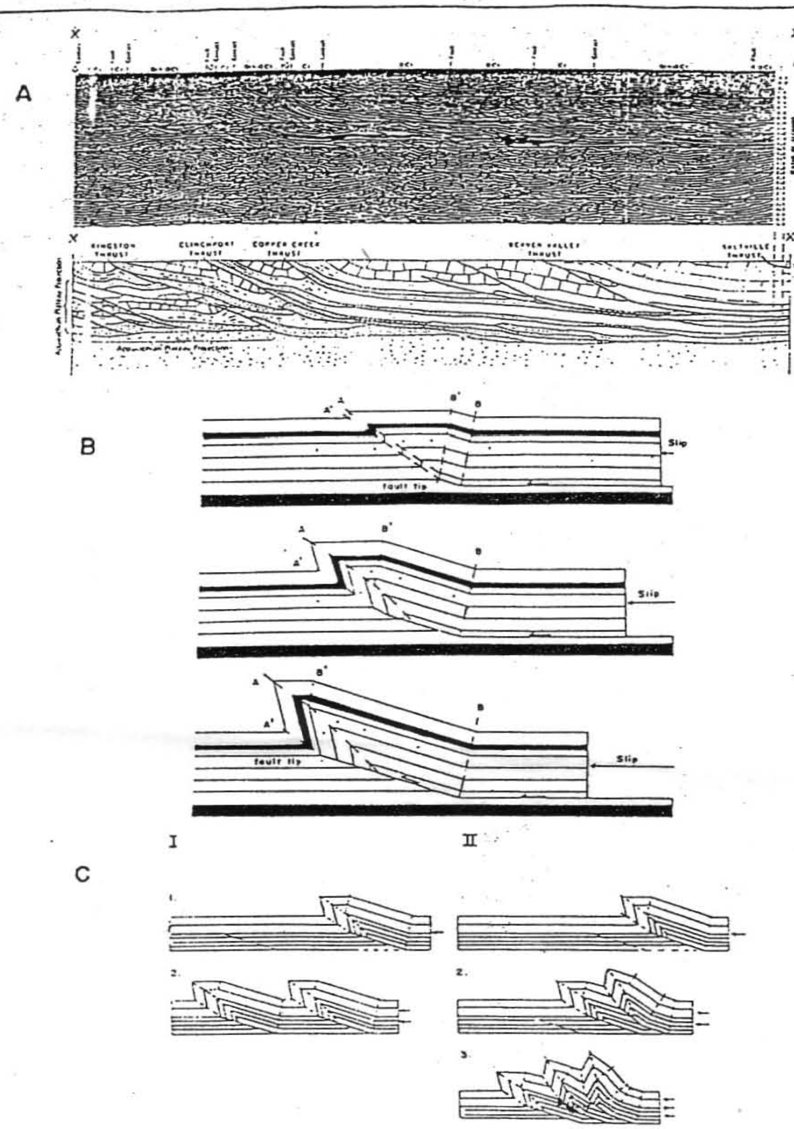
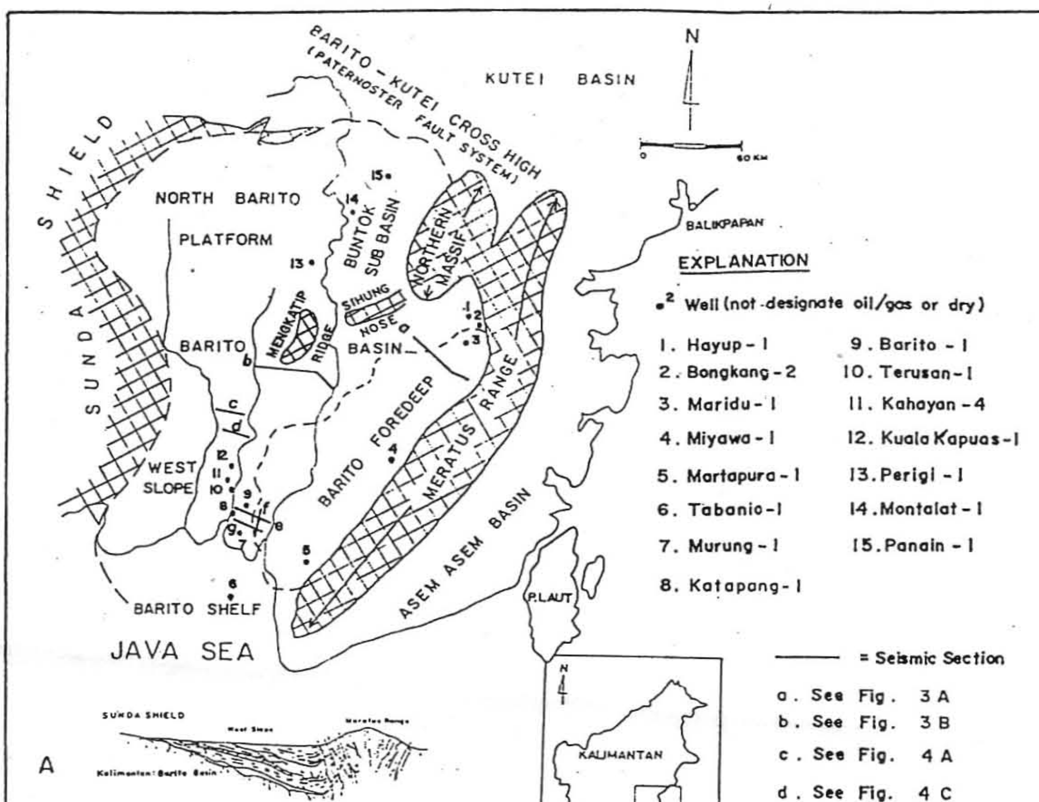


Fig.1 -A. Seismic profile and interpretative structure section showing major reflectors dipping steeply to X' and decreasing their dips gradually to where they merge with the decollement just above the basement (from Harris and Milici, 1977). B. Schematic progressive development of a fault-propagation fold at the tip of a thrust fault (from Suppe, 1985). C. Formation of imbricate thrust systems from thrust faults propagation for large (I) and small (II) initial spacings of faults (from Mitra, 1986).



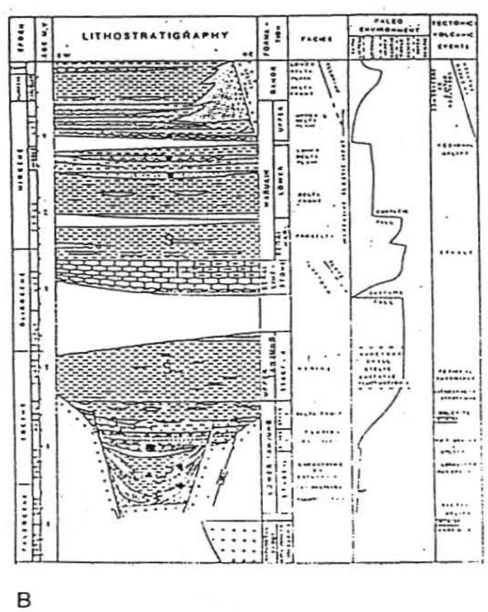


Fig.2 - A. Tectonic setting of Barito Basin. Locations of well and seismic section discussed in the text are shown (modified after PERTAMINA and INOCO, 1985, completed with well and seismic section locations). B. sedimentary, Stratigraphic, and tectonic summary of Barito Basin (from Bow Valley, 1992)

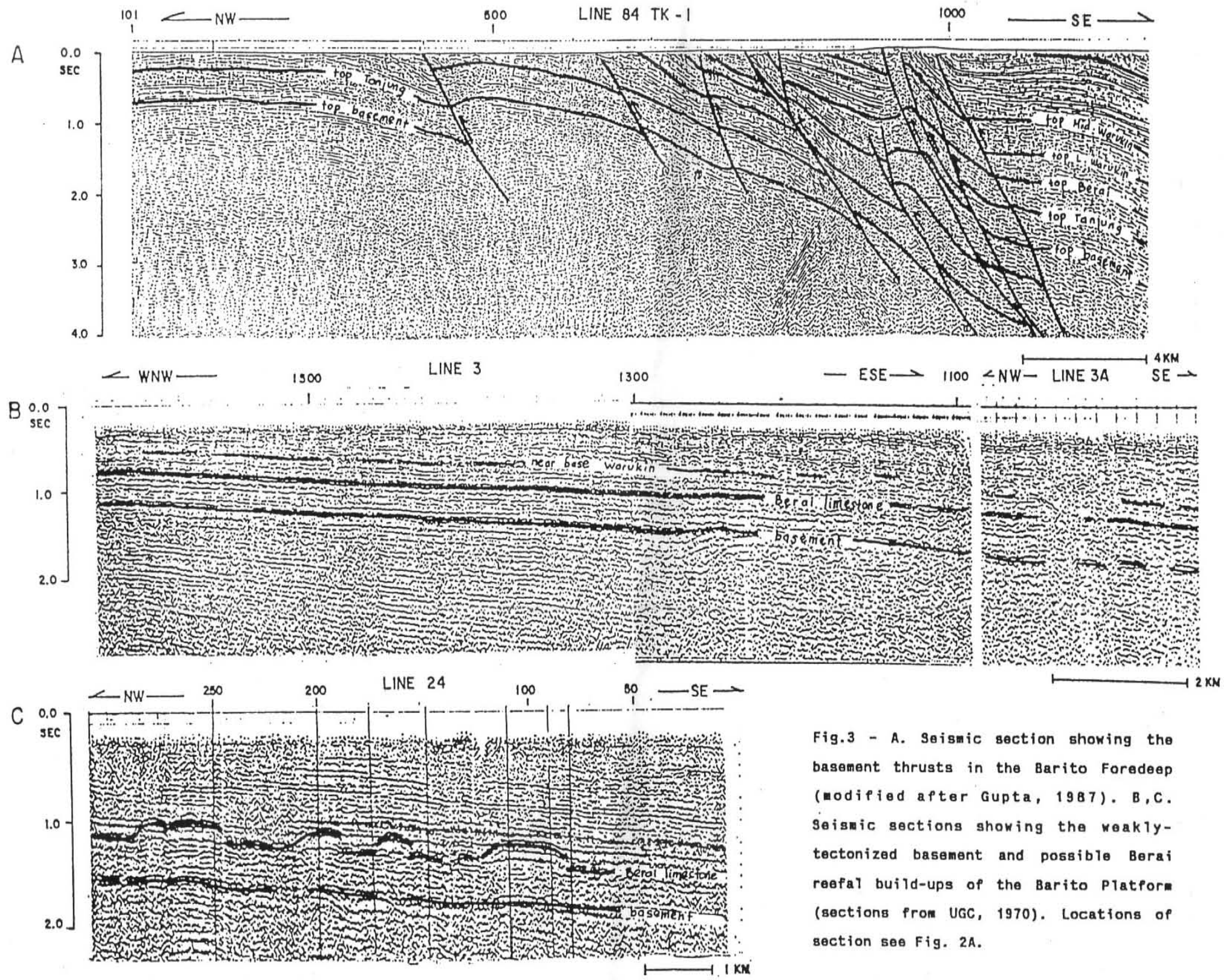


Fig.3 - A. Seismic section showing the basement thrusts in the Barito Foredeep (modified after Gupta, 1987). B,C. Seismic sections showing the weakly-tectonized basement and possible Berai reefal build-ups of the Barito Platform (sections from UGC, 1970). Locations of section see Fig. 2A.

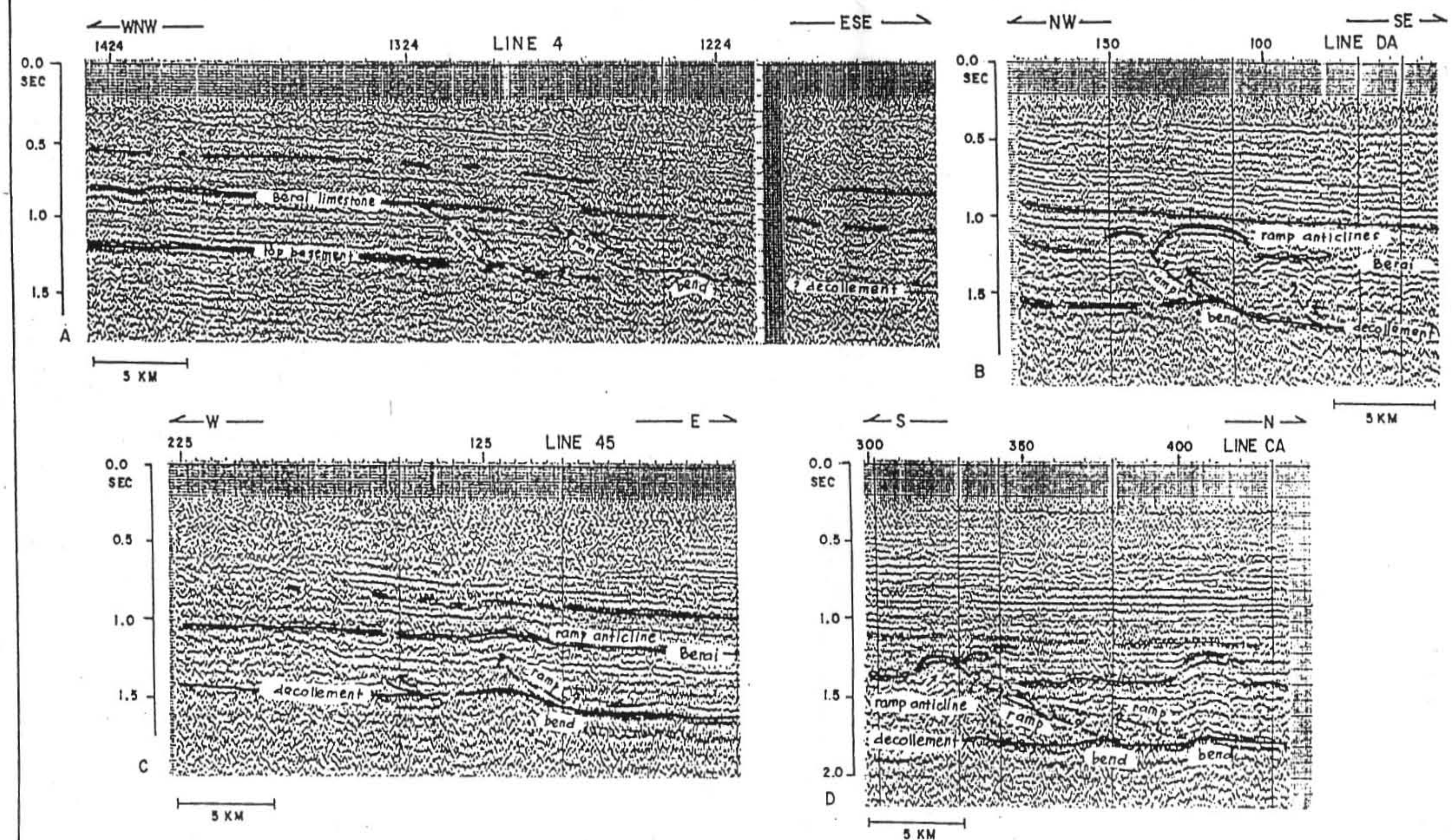


Fig.4- Seismic sections showing the possibility of the existence of decollement, ramps, and fault -propagation folds (ramp anticlines) in the Barito Platform. Note the bends at the decollement which possibly create the ramps. The patterns of thin-skinned tectonics are indistinct may be caused by their far distance from positive structure-forming orogeny of Meratus Range (sections from UGC, 1970). Locations of section see Fig. 2A.

seismic sections gained for Conoco by UGC (1970) in Southwest Barito (Fig.4). The sections show the presence of ramps that possibly root downdip and join the decollement just above the top of basement. These ramps are possibly triggered by bends at the basement. Several ramps are repeated subsequently one in front of another. This shows the sequential evolution of progresive detachment from inner to outer zone (from ESE to WNW directions). The ramps over the decollement appear to have deformed beds above their tips. Some Berai reefal build-ups are possibly connected with these ramps. However, not all ramps are followed by deformations of overlying beds. We assume that the coherently strong competency of rocks either of Tanjung or Berai formations makes ramps that are not always accompanied by deformations.

The basement itself is apparently not disturbed by faults. It is still dubious as to the constant continuation of decollement along the basement. The discontinuity of decollement is supposed to be caused by the varied basement composition of the region. Nine wells that penetrated the basement in this region showed that the basement is composed of metaquartzite (Murung-1, Katapang-1), phyllite (Barito-1), granitic gneiss (Terusan-1), phyllitic quartzite (Kahayan-4), quartzitic schist (Kuala Kapuas- 1), granodiorite (Perigi-1), granite (Montalat-1) and sand-shale (Panain-1). This different competency of rocks makes the decollements discontinuous.

3.3 Barito Fault-Propagation Folds

It was Bow-Valley (1992) who was the first to say that, structurally, the Tanjung Raya Area, at the northern end of the Barito Basin, was typified by a series of asymmetric fault- propagation folds. In this paper we tried to examine the existence of such folds in Tanjung Raya Area and to extend our examination to other parts of the basin. Having returned to the basic concepts of fault-propagation folding, we were dubious about the existence of such folds in Tanjung Raya Area. We did not find any decollements from which propagated faults were originated. The faults thrusted both the basement and sedimentary covers (Fig.3A). We did not find any ramps that step up or bifurcate as splays from floor thrusts. In addition to that, faults appear to have thrusted all sedimentary sequences of the basin, so there are no dying-outs of fault which should mark the fault propagation folds. Nevertheless, in the western region beyond the foredeep area, we found the appearances of fault- propagation folds that rightly juxtaposed with the possible ramps (Fig.4). Right to the west of Barito Foredeep border we found some dying- outs of fault which could be the indications of fault-propagation folds (Fig.5A). Unfortunately, there are no significant overlying ramp anticlines associated with the fault propagation.

One fact about Barito folds, about which we are sure to be right, is that all Barito folds are fault-related folds. It means that the folds are formed by vertical force couple applied by slip along the underlying nonplanar faults. This origin of folds is connected with the contrast structural history of the basin from Paleogene to Neogene. The folds were formed by inversion tectonic force that propagated along newly- formed thrust faults started in mid-Miocene and continued to Plio-Pleistocene to grow the amplitude of folds (Figs.5A,B).

3.4 Barito Basement-Involved Tectonics

The basement-involved tectonics of the Barito Basin is restricted around the Barito Foredeep and Buntok Subbasin. The structural configuration is clearly expressed in the Tanjung Raya Area (Figs.3A,5A,B). We assumed that the involvement of the basement in thrusting was caused by strong competency of composed rocks. Some wells that penetrated the basement in the foredeep (Hayup-1, Bongkang-2, Maridu-1, Miyawa-1, Martapura-1, Tabanio-1) reveal that the basement consists of limestone, granodiorite, basalt, altered porphyry, quartzite, and granite. These competent rocks when tectonized, make fault crosscut the rocks diagonally (the rocks are involved) (see Harris and Milici, 1977; Suppe, 1985).

The restoration of tectonic stages reveals that the basement involvement in thrusting of Barito Foredeep is not a real basement-involved tectonics. It means that the basement is not thrusted at once by single tectonic force. Basement thrusting of the Barito Foredeep was caused by inversion tectonics. It was started by rifting of the basement in Paleogene and inverted by compressional force in Neogene as basement thrusts (Fig.5A). Figure 5B discerns tectonic origin of Barito basement thrusts more clearly. It shows that Paleogene rifts trending parallel to tectonic

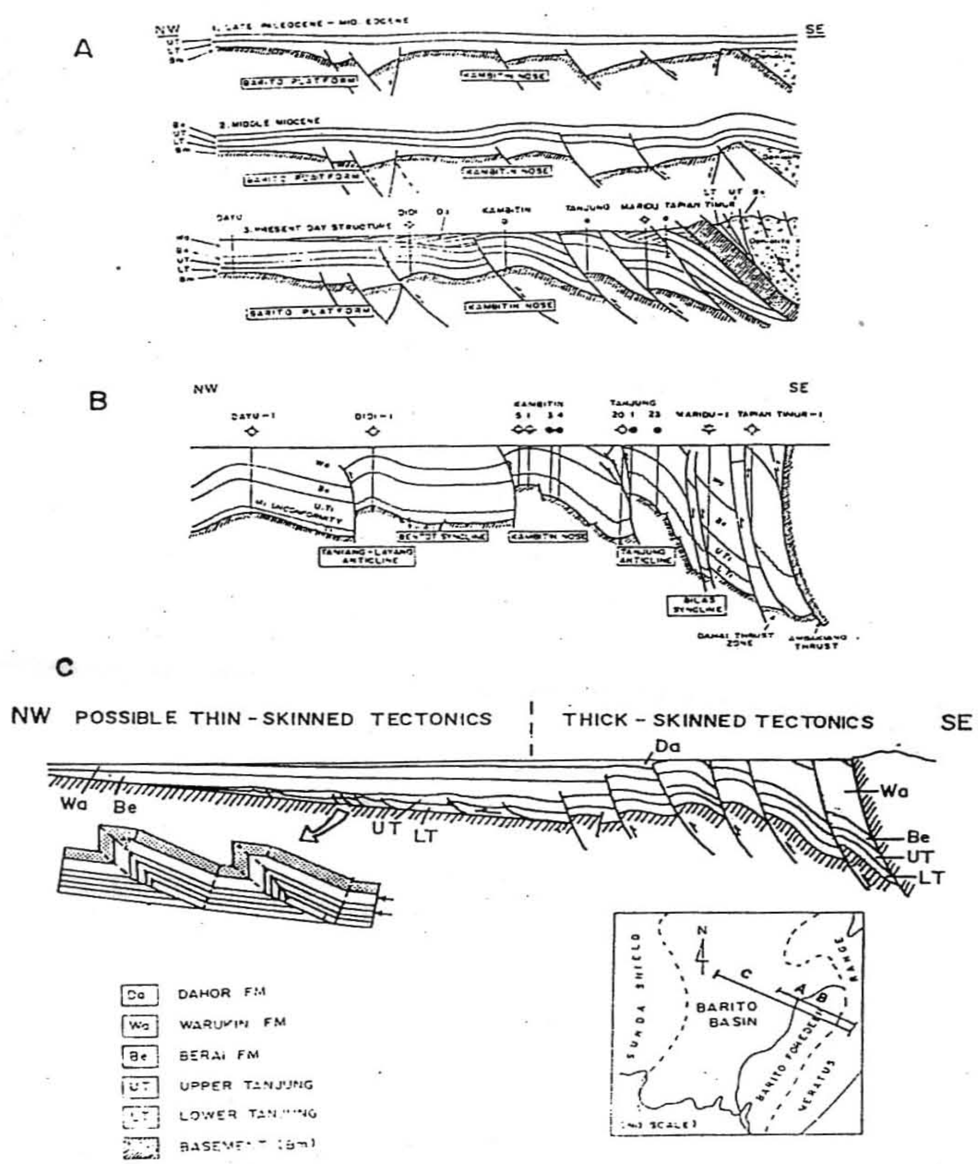


Fig.5 - A. Restoration of the tectonic stages of Barito Foredeep showing opposite structural styles during Tertiary (modified after Bow Valley, 1997). B. Present day structural configuration of the foredeep showing reactivated and nonreactivated rift systems (from PERTAMINA and Trend Energy, 1988). C. Structural section traverses the basin showing possible thin-skinned and thick-skinned tectonics.

transport (to W-NW) were inverted as basement thrusts, whereas the opposite trending rifts remained as rifts for the following stages.

4. HYDROCARBON EXPLORATION SIGNIFICANCE

Most petroleum in thrust-fold belts has been trapped in asymmetric, hanging-wall folds and lead edges of thrust sheets. Effective closures are commonly located at a relatively outer zone or external folds of a belt which are considered to be detached. Closures at these positions have been only sligthly to moderately disrupted by faulting, allowing reservoir continuity and migration pathways to remain essentialy intact (Harding and Lowell, 1979). Ramp anticlines or fault propagation folds constitute the simplest structural traps. Overlapping ramp anticlines or imbricate thrust systems constitute the best hydrocarbon traps because of multiple stacking of the reservoir unit and enhanced fracturing resulting from increased curvature in the overlapping sheets (Mitra, 1986).

The Barito Basin has evidently to be major hydrocarbon producer. Up to July 1993 the basin has produced 124 MMBO and 155 BCFG. Today the producing fields in the basin still produce 3118 BOPD and 3302 MSCFGPD (July 1993 status). The fields are concentrated in Tanjung Raya Area. The hydrocarbon is trapped in fault-related folds. Some hydrocarbon entrapment is connected with paleohighs. So far there is no known other productive area in the basin. If the decollement folds really came into existence in the area of Barito Platform we can still hope to find structural traps with probably better quality and quantity than that in Tanjung Raya area. The continuous decollement that root downdip to the kitchen area in the foredeep can play a role as migration pathway. The hydrocarbon will be trapped either in simple fault- propagation folds or overlapping ramp anticlines. However, the available seismic sections for the western area (taken in 1968) so far do not account for significant traps. We may need the newer- and better- quality seismic sections to asses the hydrocarbon potential beyond the existing productive areas.

5. CONCLUSIONS

In general terms, the structure of fold and thrust belts in the foreland-backarc tectonic setting is fundamentally dominated by thrust faults at depth that dip towards the interior of the mountain belt and run along bedding planes over much of their length. The deformed structure is detached from its substrate along a bedding plane zone of slip called a decollement. The individual thrusts called ramps or splays typically step-up from decollement upward and outward towards the margin of the mountain belt. Because of tectonic transport along the step-ups, fault- related folds are formed over the ramps as fault-propagation folds.

The Barito structural style is typified by unreal basement- involved tectonics around the foredeep in which the folds are originated as fault-related folds. Beyond the foredeep approaching the Sunda Shield the basement is devoid tectonized, otherwise the thin-skinned tectonics may have taken place. Discontinuous decollements, ramps and fault-propagation folds are indicated in some seismic sections of the area even if without obvious characteristics (Fig.5C).

The hydrocarbon entrapment of the Barito Basin is known to be trapped in fault-related folds of Tanjung Raya Area. So far, there is no other producing area in the basin. The newer and better -quality seismic sections of the Barito Platform are strictly needed to asses the existence and capability of decollement folds as hydrocarbon closures.

6. REFERENCES CITED

1. Bow Valley (Asia) Ltd., 1992, *Tanjung Raya Area East Kalimantan, technical evaluation,* Bow Valley (Asia) Ltd., Jakarta, (unpubl).
2. Gupta, A., 1987, *Seismic interpretation and petroleum potential of Tanjung Raya Area, South Kalimantan, Indonesia,* Eksplorasi PERTAMINA DAK, Balikpapan, (unpubl).
3. Harding, T.P. and Lowell, J.D., 1979, Structural styles, heir plate-tectonic habitats, and hydrocarbon traps in petroleum provinces : *The AAPG Bull.,* v.63, no.7, pp. 1016-1058.

4. Harris, L.D. and Milici, R.C., 1977, Characteristics of thin-skinned style of deformation in the Southern Appalachians and potential hydrocarbon traps : *USGS Professional Paper 1018.*

5. Mitra, S., 1986, Duplex structures and imbricate thrust systems : geometry, structural position, and hydrocarbon potential : *The AAPG Bull.*, v.70, no.9, pp. 1087-1112.

6. PERTAMINA-INOCO, 1985, *Geological assessment of target area IVa, IVb, IVc, IVd, Kalimantan, Indonesia,* IndonesiaNippon OilCooperation Co., Ltd., Jakarta, (unpubl).

7. ---------- and Trend Energy Kalimantan Ltd., 1988, *The hydrocarbon potential of the lower Tanjung Formation, Barito Basin, SE Kalimantan, Indonesia,* PERTAMINA-Trend Energy Kalimantan Ltd., Jakarta, (unpubl.)

8. Rodgers, J., 1949, Evolution of thought on structure of Middleand Southern Appalachian : *The AAPG Bull.,* v.33, no.10, pp. 1643-1654.

9. Suppe, J., 1985, *Principles of structural geology,* Prentice-Hall, Inc., Englewood Cliffs.

10. United Geophysical Co. (UGC), 1970, *Final report of the South Barito Basin geophysical survey for CONOCO of Indonesia, United Geophysical Corporation, Jakarta, (unpubl.).*