

Structural evolution of the Pematang reservoirs, Kelabu-Jingga Gas Fields, Sumatra

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Abstract: The Kelabu-Jingga area, located in the Kiri Trough of the Central Sumatra Basin, produces gas from the Paleogene Pematang Group. The Pematang Group consists of sandstones, claystones, organic-rich shales and conglomerates deposited in fluvial and fresh-water deltaic and lacustrine environments. Deposition occurred during regional tectonism associated with a major plate reorganization in the Pacific and Indian Oceans during the Paleogene. Subsequent rifting and basin development occurred in the Kiri Trough area in Central Sumatra. Syngenetic listric faults and associated "rollover" folds formed during rifting. The Pematang Group was deposited in deep, transtensional pull-apart grabens and shallow extensional rifts. Tectonics strongly influenced the geometry and lateral continuity of the fluvial-deltaic sands.

During the Neogene, oblique convergence of the Indian Ocean plate with the Asian plate resulted in a regional dextral-wrenching event in the Central Sumatra Basin that overprinted the earlier extensional style of faulting. In the Kiri Trough, both extensional and compressional features are evident. Interpretation of a 3D seismic survey, wireline logs (including dipmeter and FMS data) and core data has delineated fault styles and depositional trends within the Pematang Group in the Kelabu-Jingga Fields. The resultant maps and cross sections reveal hydrocarbon reserves and new drilling opportunities.

INTRODUCTION

The Kelabu and Jingga Gas Fields are located approximately 200 kilometers south of Kuala Lumpur, on Caltex's Siak Lease Block in Central Sumatra (Fig. 1). The fields are in the southern portion of the Kiri Trough. The north-trending Kiri Trough covers an area of 550 square kilometers along the western margin of the Central Sumatra Basin (Fig. 2).

This study classifies and describes a complex fault system in the Kelabu-Jingga Gas Fields. Hydrocarbon-bearing formations in the Kiri trough have experienced multiple periods of tectonic deformation, ranging in age from Paleogene to Recent. Many previous authors have documented the different periods of faulting in the Central Sumatra Basin (Mertosono, 1975; Hamilton, 1979; Eubank and Makki, 1981; Heidrick and Aulia, 1993). This study incorporates the regional interpretations and builds on previous contributions using 3D seismic data and new regional structural and tectonic models. Classifying the timing and style of faulting is important in reconstructing the history of migration and trapping of hydrocarbons in the Kelabu-Jingga area. An accurate structural interpretation of these gas fields may be useful as a model in assessing the risk of other, local exploratory prospects in the Kiri Trough.

REGIONAL TECTONICS

Figure 3 shows the present configuration of structure and tectonics in Southeast Asia. The formation of the right-lateral strike-slip Sumatra Fault, also known as the "Great Sumatra Fault", is controlled by the convergence of the Indian Ocean Plate with the Asian Plate. The plate boundary is marked by a subduction zone in Indonesia. Plate convergence is at an oblique angle, and combined with the Andaman Sea rift spreading center, has resulted in a stress field conducive to the formation of a system of right-lateral strike-slip faults.

The non-marine Paleogene strata in the Central Sumatra Basin indicates a stable continental shelf until the Eocene. During Eocene time, India collided with Southeast Asia, forcing the Tibetan Plateau and China southeast and forming a system of north-south trending basins across Sumatra and Malaysia (Williams *et al.*, 1988; Moulds, 1989). The geometry of this system is poorly understood in Central Sumatra, as the original structural framework has been overprinted and/or reactivated during several succeeding tectonic episodes, most notably Plio-Pleistocene wrench-tectonics.

The Central Sumatra Basin is one of three Tertiary Basins in Sumatra (Fig. 4). All three basins are bordered on the west by the Sumatra Fault, which follows the thermally-weakened zone

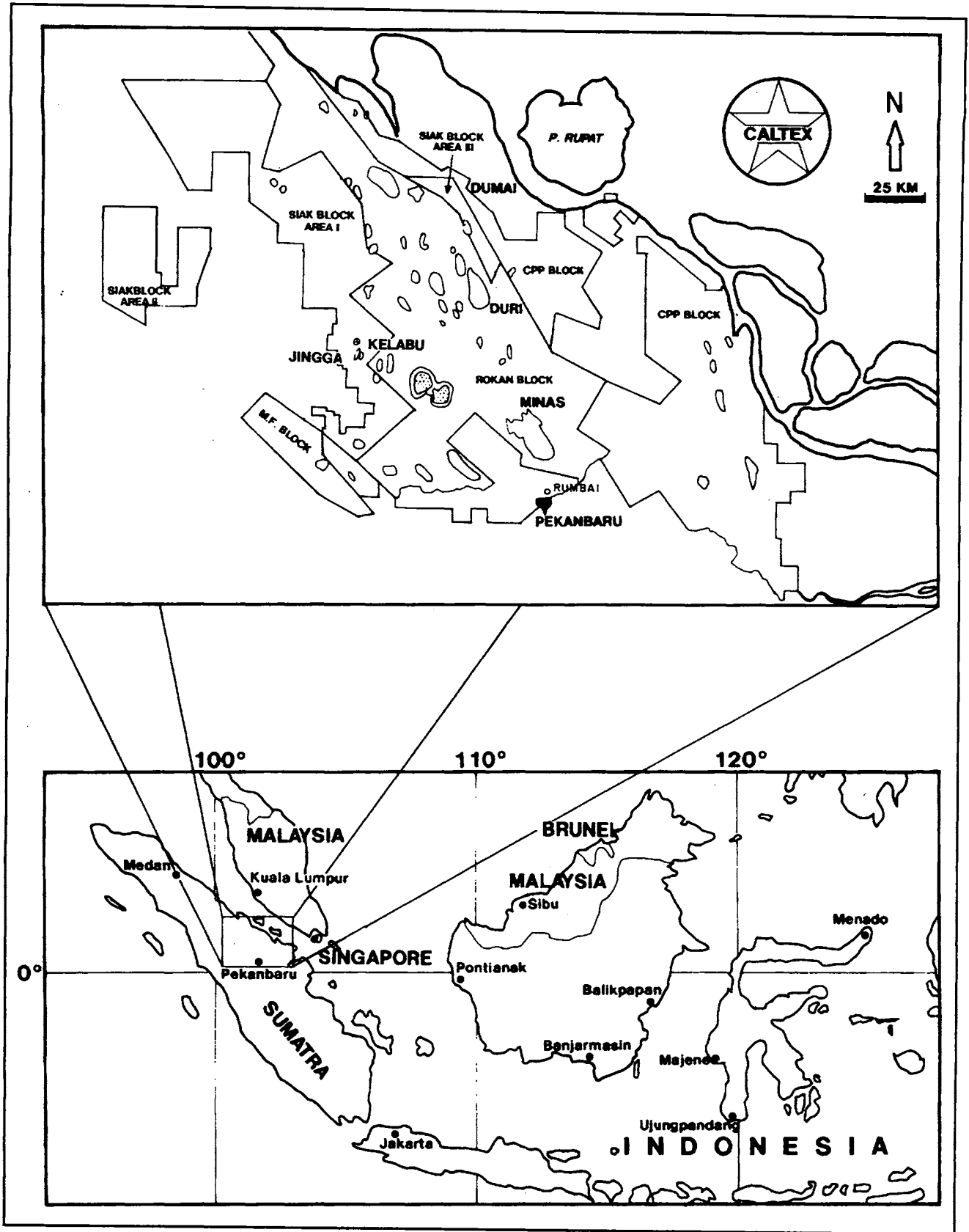


Figure 1. Location map — Kelabu-Jingga Gas Fields, Sumatra.

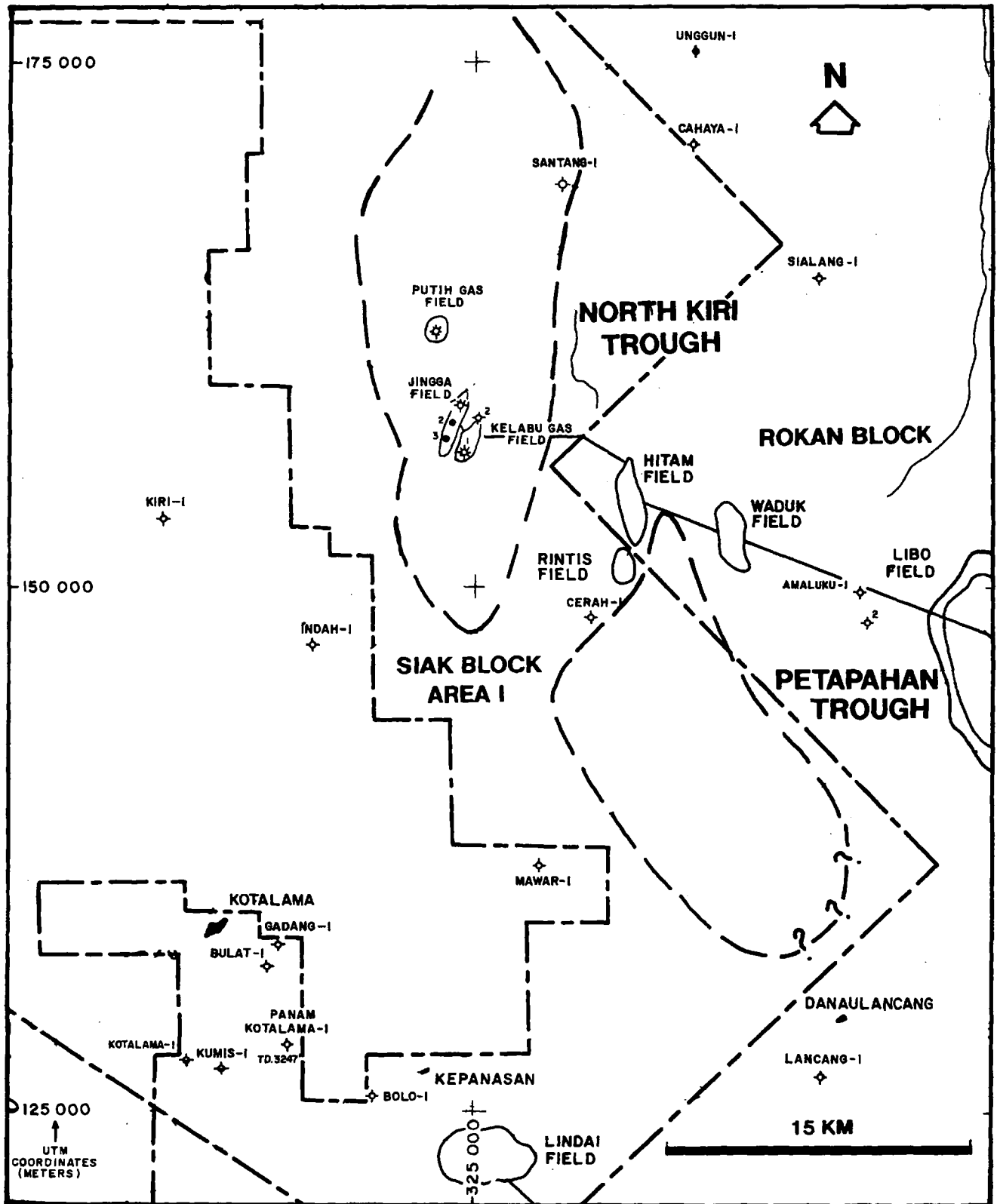


Figure 2. Location of the Kiri Trough.

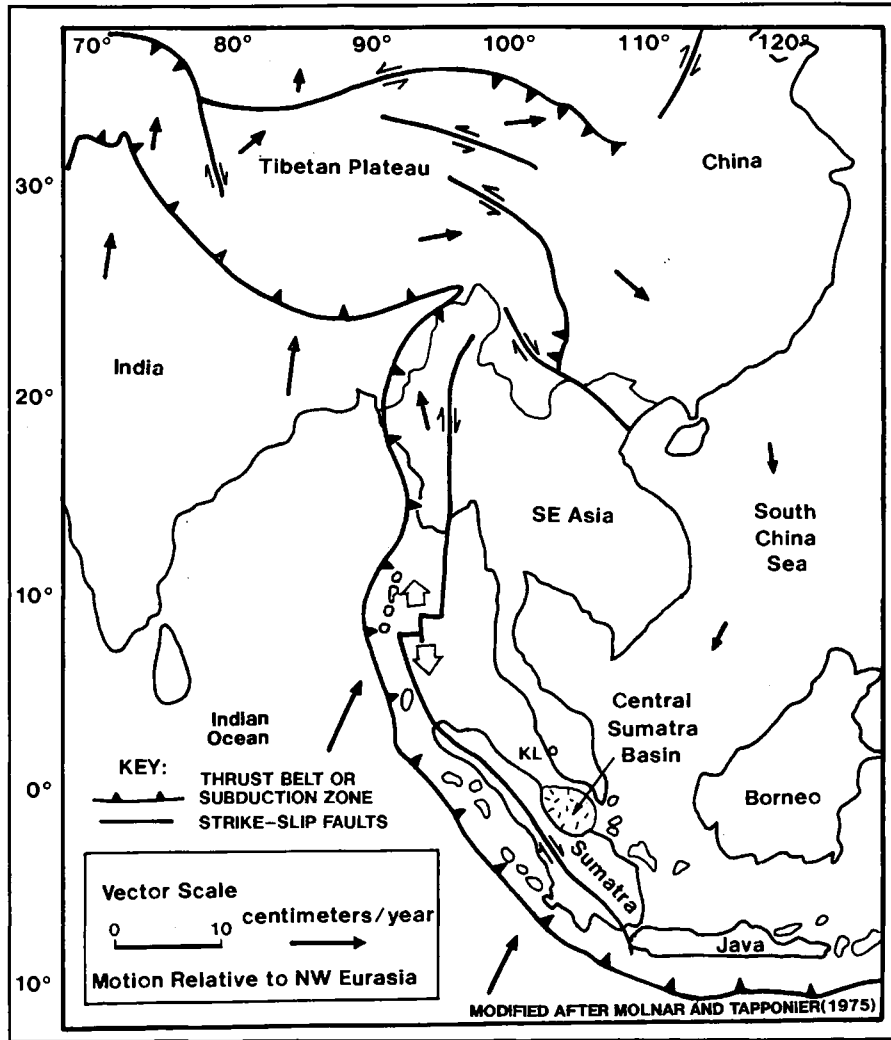


Figure 3. Tectonic map of SE Asia.

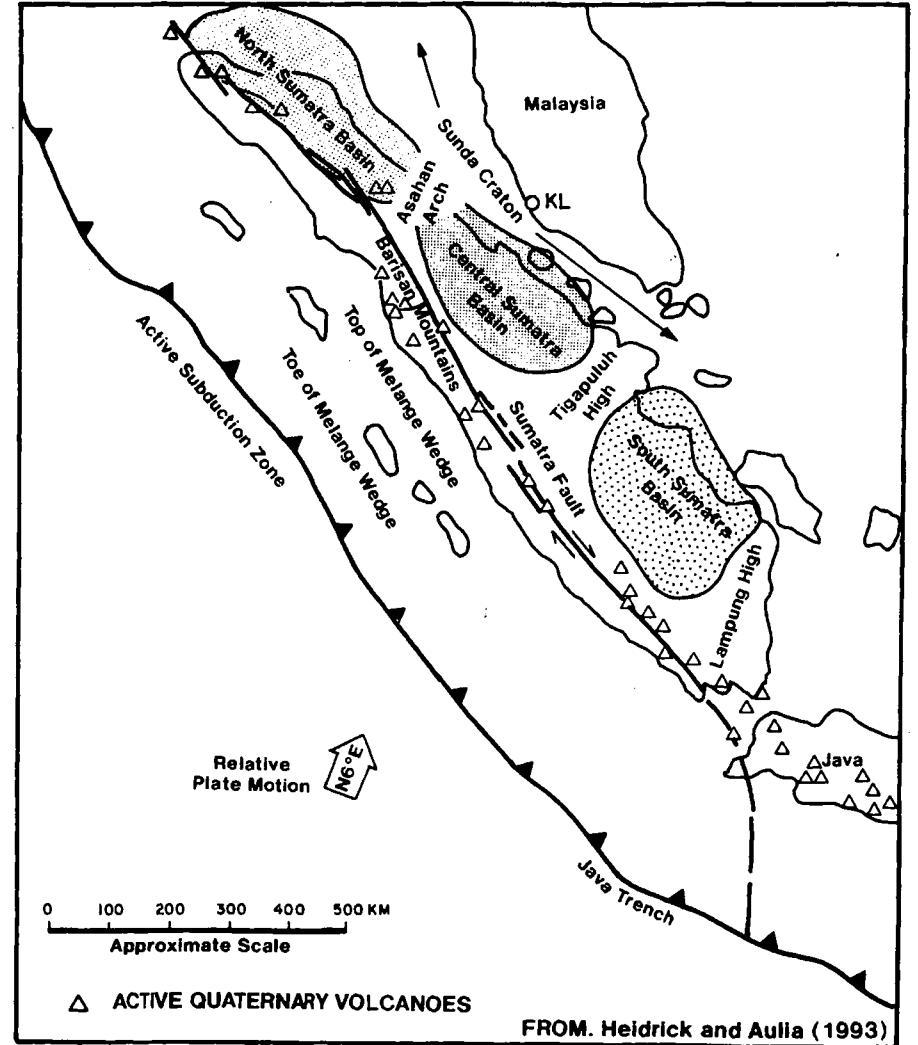


Figure 4. Regional structural-tectonic map of Tertiary basins in Sumatra.

associated with the subduction of the Indian Ocean Plate. In the Central Sumatra Basin, two major fault trends occur: a NW-SE-trending set and a N-S-trending set (Fig. 5). In general, the N-S set is older and resulted from Paleogene extensional tectonics, and the NE-SE set is younger, following the trend of the Sumatra Fault (Mertosono and Nayoan, 1974; de Coster, 1974). Many of the older, north-south faults have been reactivated by dextral wrenching (Eubank and Makki, 1981).

The Kiri Trough is located in an area which has mainly NNE trending faults, and is anomalous in that it has undergone mostly extensional deformation during the Plio-Pleistocene wrenching event in the Central Sumatra Basin. The NW-SE directed right-lateral motion superimposed on the older NNE-SSW trending faults resulted in a mainly releasing, pull-apart fault geometry. As a result, the Kiri Trough does not exhibit the large, contractional anticlines which trap hydrocarbons in the Central Sumatra Basin.

STRATIGRAPHY OF THE KIRI TROUGH

Figure 6 summarizes the stratigraphy of the Central Sumatra Basin. The lithology of the Kiri Trough is described in the right-hand column. Pre-Tertiary Basement, which was penetrated by the Santang #1 well, is composed primarily of graywacke. Basement is unconformably overlain by the Paleogene Pematang Group, which was deposited in a fluvial, fresh-water deltaic and lacustrine environment. The lower Pematang consists of dark brown shale, thinly interbedded with discontinuous lenses of fine-grained sands. The dark brown shale is believed to be the source rock in the Central Sumatra Basin. The upper Pematang Formation consists of sequences of conglomerates, fine to coarse sandstone and variegated claystone. Sediments were deposited during extensional faulting in deep, transtensional pull-apart grabens and shallow extensional rifts. Tectonics strongly influenced the geometry and lateral continuity of the fluvial-deltaic sands. The focus of this presentation will be on the Upper Pematang reservoir sands.

The Pematang is separated from the overlying Sihapas Group by a distinct regional angular unconformity (Eubank and Makki, 1981). This unconformity is identifiable on both regional seismic lines and drill cuttings. The Sihapas represents the beginning of marine transgression. Sihapas formations range from fluvial-deltaic in the lower section to increasing marine influence upwards. The Sihapas Group was deposited during a period of tectonic quiescence. The Sihapas Group contains most of the known hydrocarbon reserves of the

Central Sumatra Basin. The deeper, more geologically complex Pematang Formation make up a smaller portion of reserves, as these reservoirs contain traps which are more subtle and difficult to explore.

Increasing regional subsidence resulted in deposition of shales and mudstones of the Telisa Formation, which provides a regional seal. The Duri event during the mid-Miocene marks the beginning of a regressive phase. The Petani Formation shows a progressive shallowing upward of marine conditions.

TECTONIC SEQUENCE — KIRI TROUGH

Much work has been done at P.T. Caltex Pacific Indonesia to group the different structural styles observed in Central Sumatra into a sequence of tectonic events. The most detailed work has been on Caltex's Coastal Plains Lease by Aulia *et al.* (1986), Yarmanto and Aulia (1988) and more recently, Heidrick and Aulia (1993).

In the Kiri Trough, the tectonic sequence can be divided into three events:

1. E-W rifting during the Eo-Oligocene which resulted in extensional faulting during deposition of the continental Pematang Group, followed by inversion,
2. Thermal subsidence and deposition of the transgressive Sihapas Group during the Early Miocene,
3. Wrenching which culminated during the Plio-Pleistocene.

Classifying the timing and style of faulting is important in reconstructing the history of migration and trapping of hydrocarbons. Simply mapping the faults is not enough. It is important to understand the genesis of the structural framework to predict the areal extent of reservoir-quality rocks.

Dividing the different types of structure into separate events is a simplification of a continuous process. As Sumatra rotated clockwise through time, the stress field affecting the Central Sumatra Basin became more compressive as the angle of convergence between the Indian Ocean Plate and Asian Plate increased. Separate basins in Central Sumatra experienced tectonic events at different times.

DEVELOPMENT HISTORY OF THE KELABU-JINGGA FIELDS

Regional mapping using seismic data acquired during the 1970s identified several prospective structural closures. Well Putih #1 (Fig. 7) was

drilled on one of these closures in 1979, and encountered 19 ft of gas in an upper Pematang sand. The Kelabu #1 and Jingga #1 Wells were drilled in 1983 and 1984 respectively, discovering gas in two separate, highly-faulted and unconnected upper Pematang sands. Kelabu #1 tested gas from two lobes in the Pematang 7,750 ft Sand. The upper lobe (30 ft of perforations) flowed 3.0 MMSCFPD and 118 BOPD condensate through 5/8" choke with 400 psi FTP. The lower lobe (26 ft of perforations) flowed 4.1 MMSCFPD, without condensate, through 5/8" choke at 660 psi FTP. The Jingga #1 Well tested gas from the 8,420 ft Sand (20 ft of perforations) flowing 1.05 MMSCFPD and 3 BOPD 53.1 degree API condensate at a BHFP of 5,437 psi.

Jingga #1 also discovered 155 ft of oil pay in the Sihapas Group Menggala Formation. The Menggala tested at a rate of 2,000 BOPD from five sets of perforations.

To delineate the highly-faulted, north-south anticlinal trend mapped in the Kelabu-Jingga Fields, a 40 square-kilometer 3D seismic survey was shot during 1984. Based on the results of this survey, two wells were drilled in the Jingga Field to the Menggala oil sand, both successful oil-producers. Last year Caltex drilled Kelabu #2 below

the minimum gas penetrated in Kelabu #1, to delineate the extent of the Pematang gas reservoir. The well penetrated the objective sands on target, but was wet, because the structure is not filled to spill-point.

STRUCTURE OF THE KIRI TROUGH

Faults within the Pematang Group Brown Shale Formation show a prevailing NNE strike (Fig. 7). This trend is different from the prevailing NW-SE structural grain present in other Central Sumatra troughs. Due to the prevailing NNE strike of Paleogene faults in the Kiri Trough, right-lateral motion associated with the Plio-Pleistocene wrench tectonics resulted in an extensional fault geometry.

The Kiri trough is bordered on the west by east-dipping listric normal faults, and on the east by a structural high which limits the extent of the Brown Shale source rock. The left-stepping dog-leg character of the western border faults and the right-stepping offset along the two main dextral wrench-fault systems is caused by an interference pattern associated with a Pre-Tertiary, NW-SE trending basement arch. These fault patterns suggest an oblique, extensional geometry (Chorowicz and Sorlien, 1992).

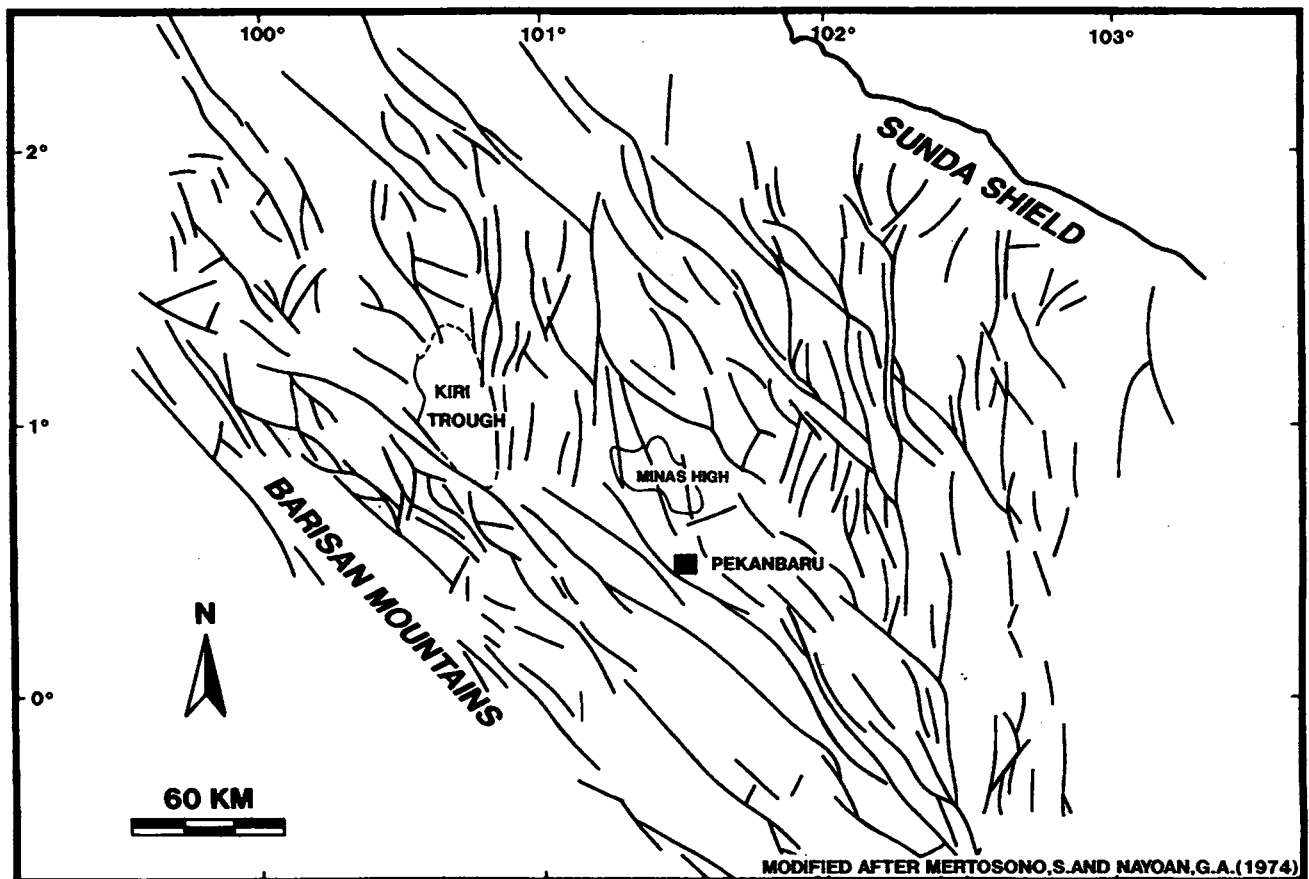
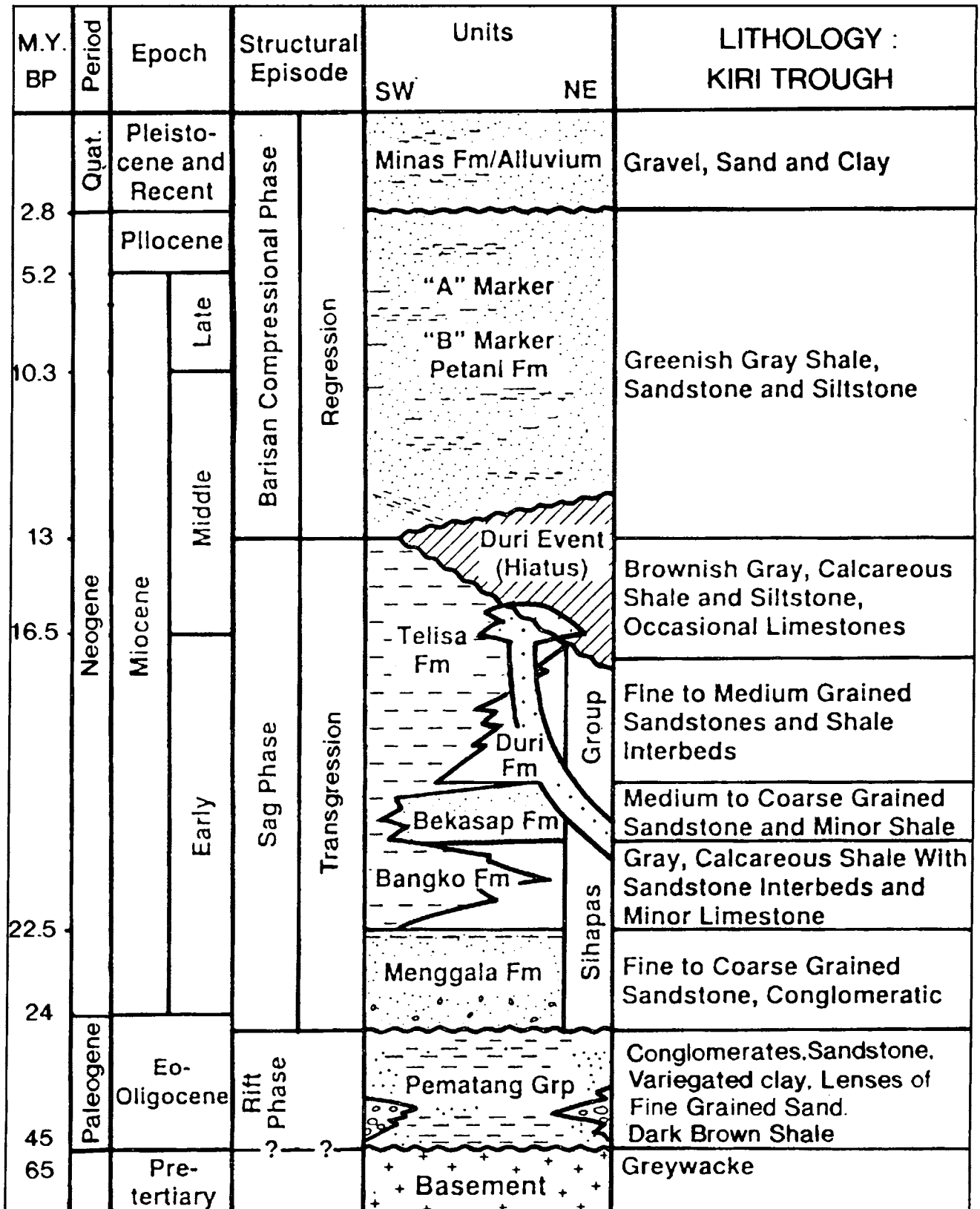


Figure 5. Structural framework of the Central Sumatra Basin.



White (1975) and Wongsosantiko (1976); Time scale from Vail and Mitchum (1979), Eubank and Makki (1981), Suryanto and Wycherley (1984), Heidrick and Aulia (1993).

Figure 6. Stratigraphy of the Central Sumatra Basin.

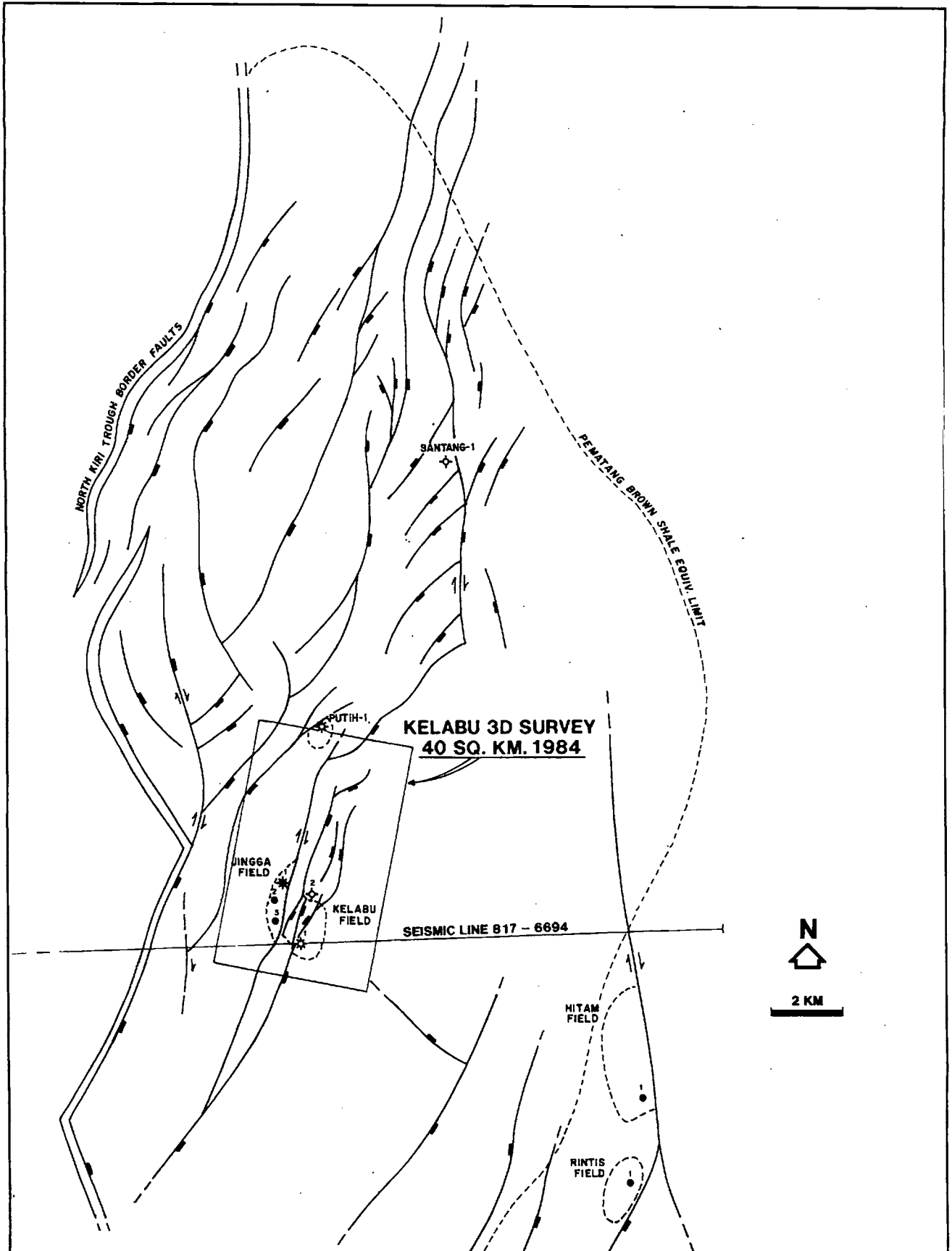


Figure 7. North Kiri Trough, faults on top of the Pematang Group Brown Shale.

Migrated seismic line 817-6694 (Fig. 8) runs from west to east across the Kiri Trough, approximately two kilometers south of Jingga Field through Kelabu #1 Well. The most prominent feature on the line is the sag basin morphology within the Menggala Formation of the Sihapas Group and the rollover towards the west into a listric normal fault within the Pematang Group. This rollover is indicative of extensional tectonics (Xiao and Suppe, 1992).

Three tectonic periods are evident on seismic line 817-6694. **Eo-Oligocene rifting** occurred during deposition of the fluvial-deltaic Pematang Formation. Rifting is indicated by the discontinuous reflectors, an angular unconformity at the top of the Pematang, and extensional faulting which soles downward into a shallow depth of detachment. The depth to detachment is relatively shallow compared to extensional basins outside of Sumatra. However, shallow detachments are common and well documented in other troughs within the Central Sumatra Basin (Heidrick and Aulia, 1993). Structural inversion occurred following rifting during deposition of the Upper Pematang Sand, forming the Kelabu-Jingga anticline.

Early Miocene sag-phase subsidence and deposition of the marine-transgressive Sihapas Group is indicated by the sag-drape of the Menggala over the Pematang-age faulted anticline. The reflectors within the Sihapas section are more continuous than reflectors in the Pematang, because Sihapas sediments were deposited during a time of relative tectonic quiescence.

The **Plio-Pleistocene wrench phase** is present on seismic line 817-6694 as two faults which cut the shallow Pliocene strata. An apparent normal fault cuts through Kelabu #1. This fault appears on this line as a simple normal fault, but 3D seismic data suggests that movement on this fault is right-lateral. Also, a flower structure on the right side of the line near the Hitam Field continues up into the younger Sihapas section. This flower structure is extensional, as it shows negative or transtensional character.

Where NW-SE dextral wrench-faulting has been superimposed onto the pre-existing NNE-SSW structural grain, the result is a predominantly transtensional fault pattern. Diagnostic structures observed along the releasing bends are pull-apart grabens, listric, *en echelon* or domino-style normal faults, negative flower structures, and associated folds. These resultant folds are short, discontinuous, and passively draped into flanking sag-troughs. An example is the Kelabu Field near Kelabu #1 (Fig. 8).

The fault trend near the Santang #1 Well location (Fig. 7) and the NNE striking faults crossing

the Kelabu-Jingga Fields form a pattern which is indicative of an extensional, releasing geometry. Figure 9 shows a map view of idealized right-lateral strike-slip fault systems. Diagram b on Figure 9 shows an extensional duplex, similar in character to the faults which splay from the main north-striking right-lateral fault adjacent to the Santang #1 Well. Also, the north portion of the right-lateral fault near Santang #1 displays a trailing extensional imbricate fan geometry.

A block diagram of the extensional duplex (Fig. 10) shows the difference between an extensional duplex/negative flower structure and a contractional duplex/positive flower structure. The block diagram reveals that extensional duplex transfer faults terminate down to a main dextral wrench fault.

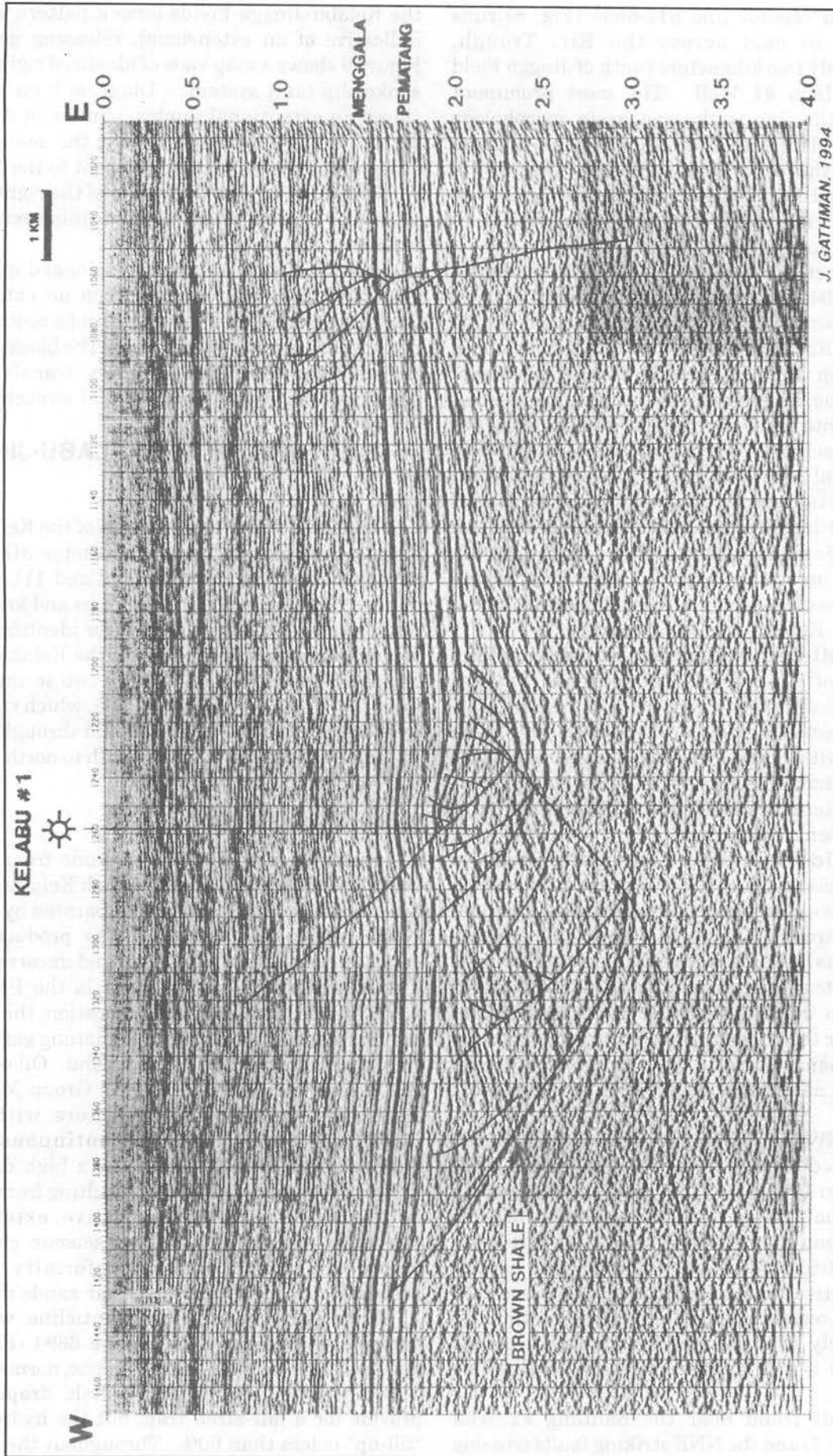
STRUCTURE OF THE KELABU-JINGGA FIELDS

To accurately map the extent of the Kelabu and Jingga Fields, a 50 square-kilometer 3D seismic survey was shot in 1984 (Figs. 7 and 11). The 3D survey, combined with wireline logs and knowledge of the regional tectonics allows for identification of a complex history of faulting in the Kelabu-Jingga Fields. Figures 12 and 13 show two seismic slices from the 3D survey: Dip Line 505, which runs from west to east close to Jingga #1 and through Kelabu #2, and Strike Line 644, from south to north through the Kelabu Field.

3D seismic dip line

Seismic Line 505 (Fig. 12) runs from west to east close to Jingga #1 and through Kelabu #2. The Jingga and Kelabu Fields are separated by a major NNE-striking fault system. The productive gas sands in each field are separate and uncorrelatable. The Kelabu Field gas reservoir is the Pematang 7,750 ft sand, although at this location, the 7,750 ft Sand is wet. The productive Pematang gas sand in the Jingga Field is the 8,420 ft sand. Oil occurs in the Jingga Field in the Sihapas Group Menggala Formation. Note that reflectors within the Pematang section are discontinuous. The discontinuous reflectors indicate a high degree of lateral depositional variation resulting from fluvial/deltaic deposition during active extensional tectonics. The discontinuous seismic character below the Pematang unconformity makes correlation of individual reservoir sands difficult.

Note that the inversion anticline which is depicted on regional seismic line 6694 (Fig. 8) is dissected by a complex array of listric, normal faults. This anticline and overlying shale drape would provide for a fair-sized trap, but the hydrocarbon "fill-up" is less than 60%. Throughout the Central



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Figure 8. Seismic line 6694, Kiri Trough, FD migration enhanced stack, acquired 1985.

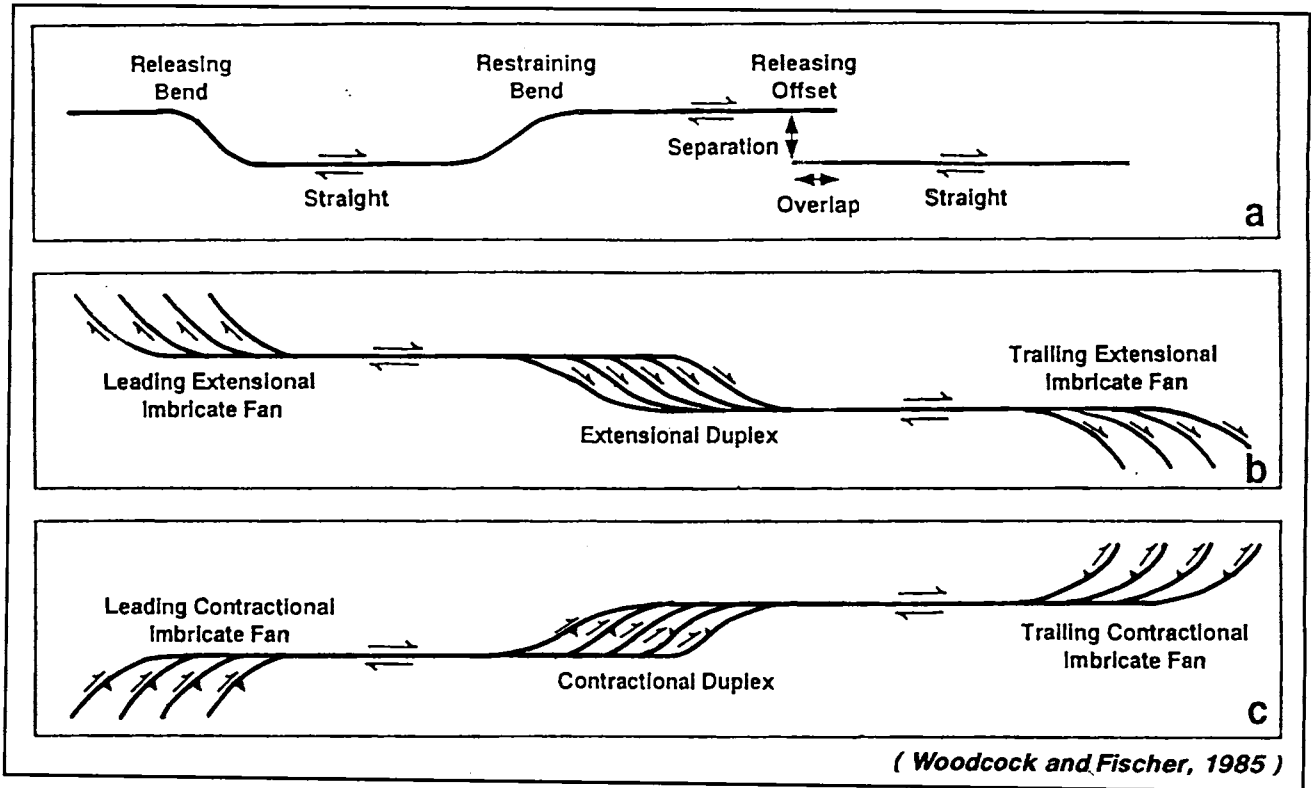


Figure 9. Map views of idealized strike-slip fault systems.

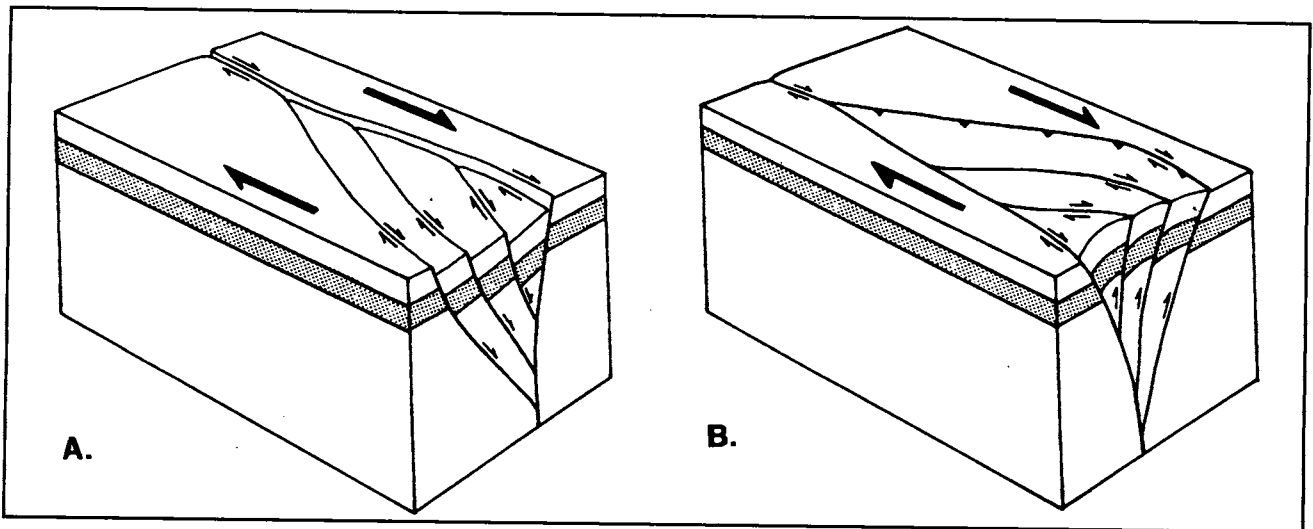


Figure 10. Block diagram of (A) an extensional duplex, negative flower structure and (B) contractional duplex, positive flower structure (Wilcox *et al.*, 1973).

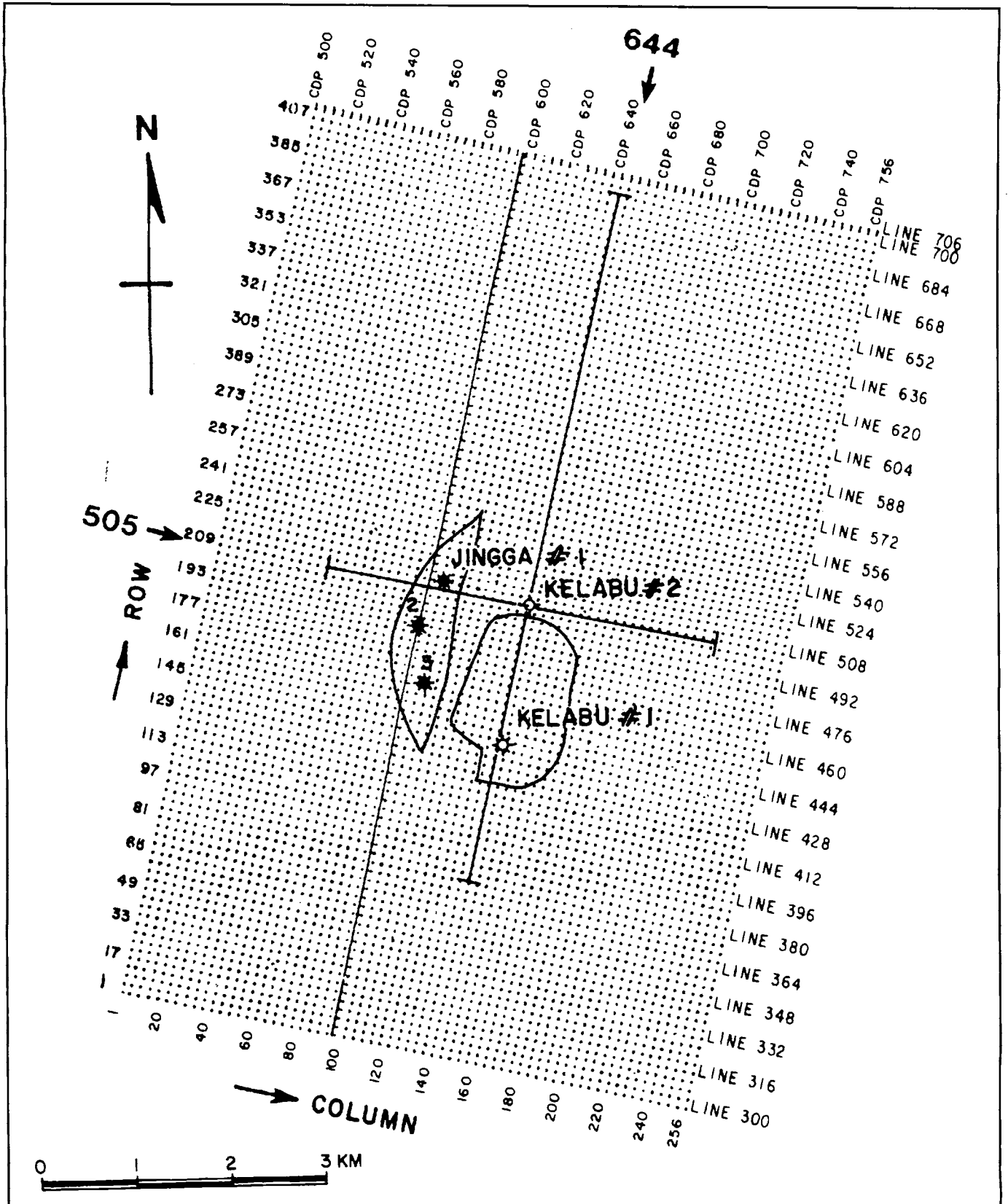


Figure 11. Index to Kelabu-Jingga 3D seismic lines and cross lines.

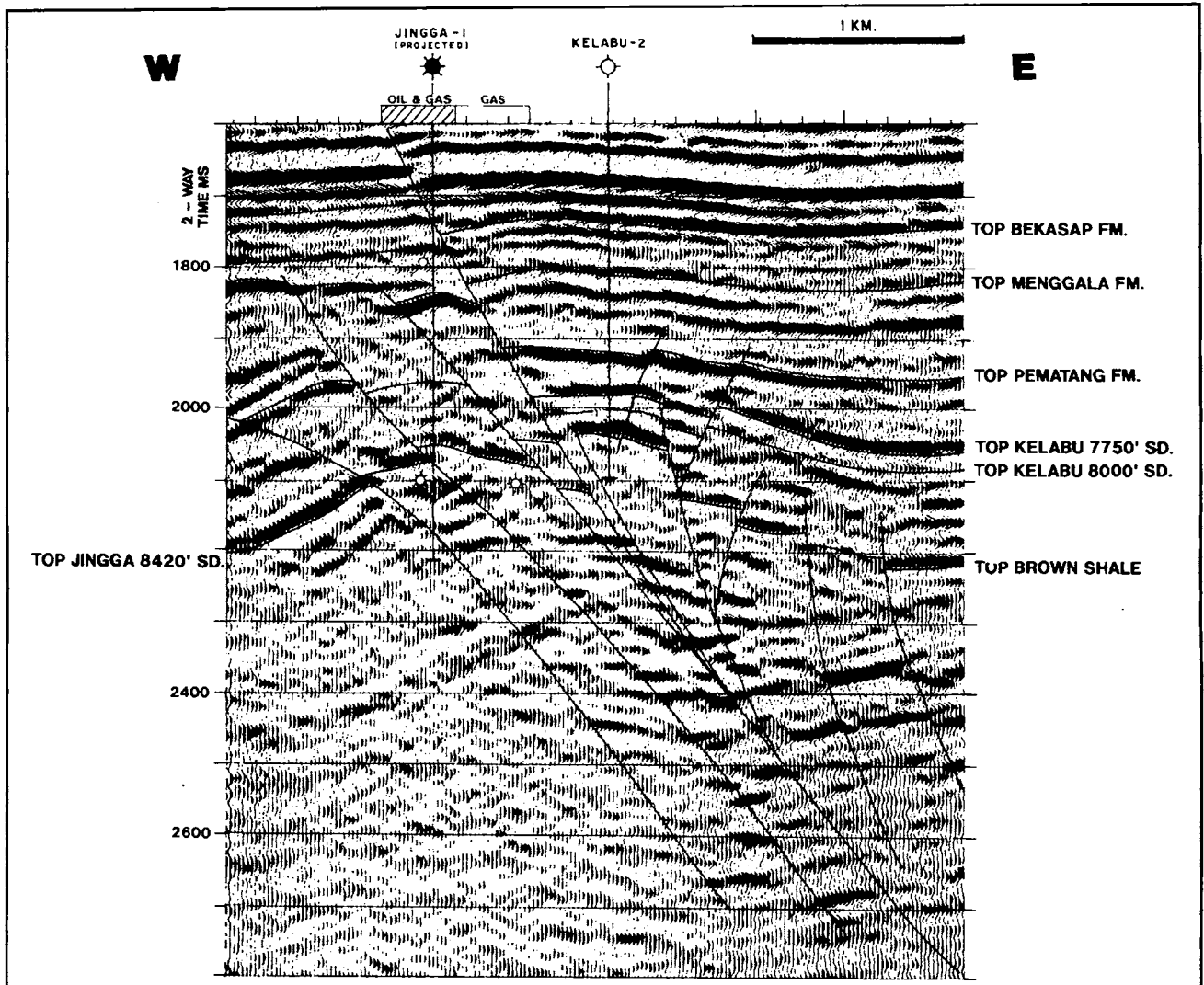


Figure 12. Kelabu-Jingga 3D Seismic Line 505.

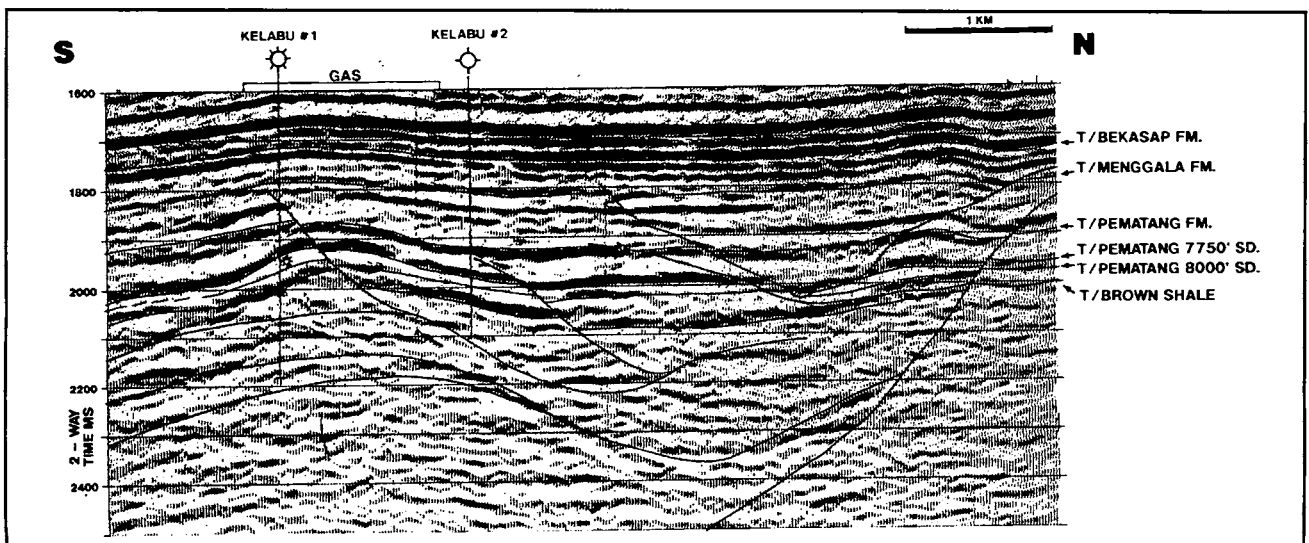


Figure 13. Kelabu Field 3D Seismic Cross Line 644.

Sumatra Basin, many oil and gas fields are not filled to spill-point.

Although extensional faulting is the dominant feature on seismic line 505, some compressional features are evident. Compressional features result from inversion near the end of Pematang time and Plio-Pleistocene NNE-striking dextral wrench faults bending towards the right, resulting in transpression.

3D seismic strike line

Cross line 644 (Fig. 13) runs from south to north through Kelabu #1 and #2, "sideswiping" the NNE-striking faults, so they appear in profile at a low angle. Line 644 shows an apparent normal fault between the Kelabu #1 and #2 Wells. Also note that the Sihapas section is draped over the Kelabu Field anticline. A cross section along the plane of seismic strike line 644 (Fig. 14) shows a Paleogene growth fault which formed during deposition of the upper Pematang Group sands. At the location of Kelabu #1, two Pematang Formation sands, the 7,750 ft and 8,000 ft, overlie the Pematang Brown Shale. At the location of Kelabu #2, a much thicker sand section is penetrated, which filled the downthrown side of a listric normal fault which formed contemporaneously with Pematang sand deposition. Note that the structure is not filled to spill-point.

Growth fault formation during the Paleogene controlled deposition. Figure 15 shows the sequence of growth fault formation in the Pematang Formation during Paleogene rifting. From this model, we expect thicker deposition of sands on the downthrown sides of the listric normal faults. The antithetic faulting as depicted on diagram D is indicated by seismic, wireline log and core data.

Fracture directions from FMS and core data

Core taken from the Pematang 7,750 ft Sand in Kelabu #2 shows mesoscopic-scale extensional fractures in the Pematang reservoir sand. The geometry of the mesoscopic fractures is identical to the macroscopic extensional faulting seen on the seismic lines, although the orientation of the core fractures is unknown. Fracture orientation and depositional environment was determined using Schlumberger's Formation Micro-Scanner (borehole imaging) tool and a dipmeter log. A stereonet plot of slumps and fractures picked from the FMS image indicates that most fractures strike parallel to the prevailing NNE fault strike and dip 70 degrees northwest, antithetic to the main fault strike. A few fractures dip southeast. The depositional environment indicated by both core description,

FMS character and dipmeter is fluvial, with a sand source from the west filling a north-plunging graben.

Transpressional faulting

Figure 16 depicts structural contours on the Pematang 7,750 ft Sand, the main gas reservoir of the Kelabu Field. A NNE-striking fault ends just south of the Kelabu #2 location, and another NNE-striking fault begins just north of Kelabu #2. This fault trend consists of two apparently separate faults, whose traces disappear on the 3D seismic at the location of Kelabu #2. South of Kelabu #2, the fault plane is downthrown to the SE, but as the fault trace is mapped northward, it disappears. Continuing toward the north, another fault trace appears which is downthrown towards the WNW. The two separate faults may actually represent one transpressional fault plane. A block diagram (Fig. 17) illustrates the Kelabu #2 Well at the "scissors point" between an apparent "down-to-the-east" fault and a "down-to-the-west" fault. This representation of fault geometry is useful in explaining why some faults in this predominantly extensional area appear to have a reverse throw. Other fault sets located west of the Kelabu #2 Well have a similar geometry.

Pop-up and pull-apart wedges along a right-lateral fault

A structure contour map on top of the upper Pematang 8,420 ft Sand (Fig. 18) derived from 3D seismic data shows a complex, discontinuous fault pattern. The complex map surface is the result of extensional faulting during deposition, the discontinuous nature of fluvial sands, differential compaction, and an overprint of Plio-Pleistocene wrench tectonics.

The fault on the eastern edge of the map passing close to Kelabu #1 marks the mappable limit of the 8,420 ft sand. The 7,750 ft Sand within the Kelabu Field (Fig. 16) and the 8,420 ft Sand within the Jingga Field (Fig. 18) are mapped separately due to the discontinuous nature of reflectors separating the two adjacent fields. Reflectors are discontinuous due to Paleogene syndepositional faulting.

The structure contour map shows only a two-dimensional view, so 3D block diagrams are necessary to accurately illustrate the fault geometry. Figure 20 is a schematic block diagram showing "pop-up" and "pull-apart" wedges along a right lateral fault. The block diagram shows a simple, parallel strike-slip component, although the fault is expected to have an extensional, oblique-slip component. In cross-sectional view, these wedges would appear as positive and negative flower structures.

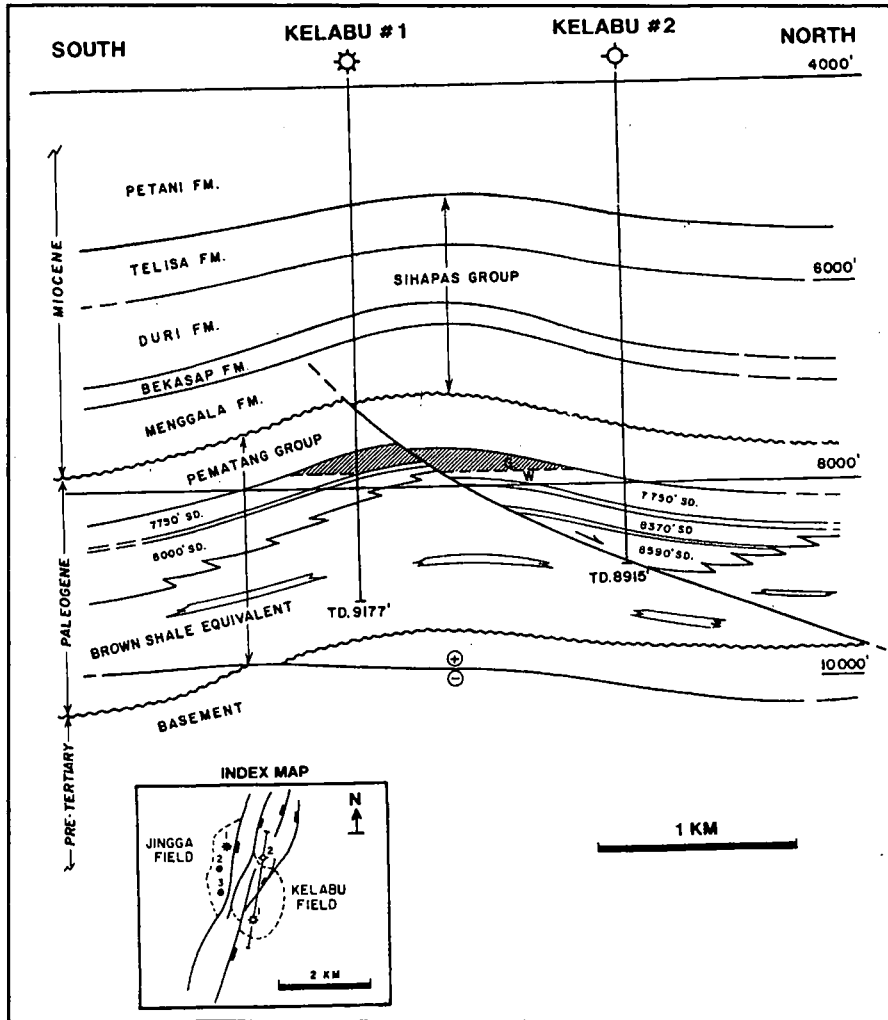


Figure 14. Kelabu Field cross section.

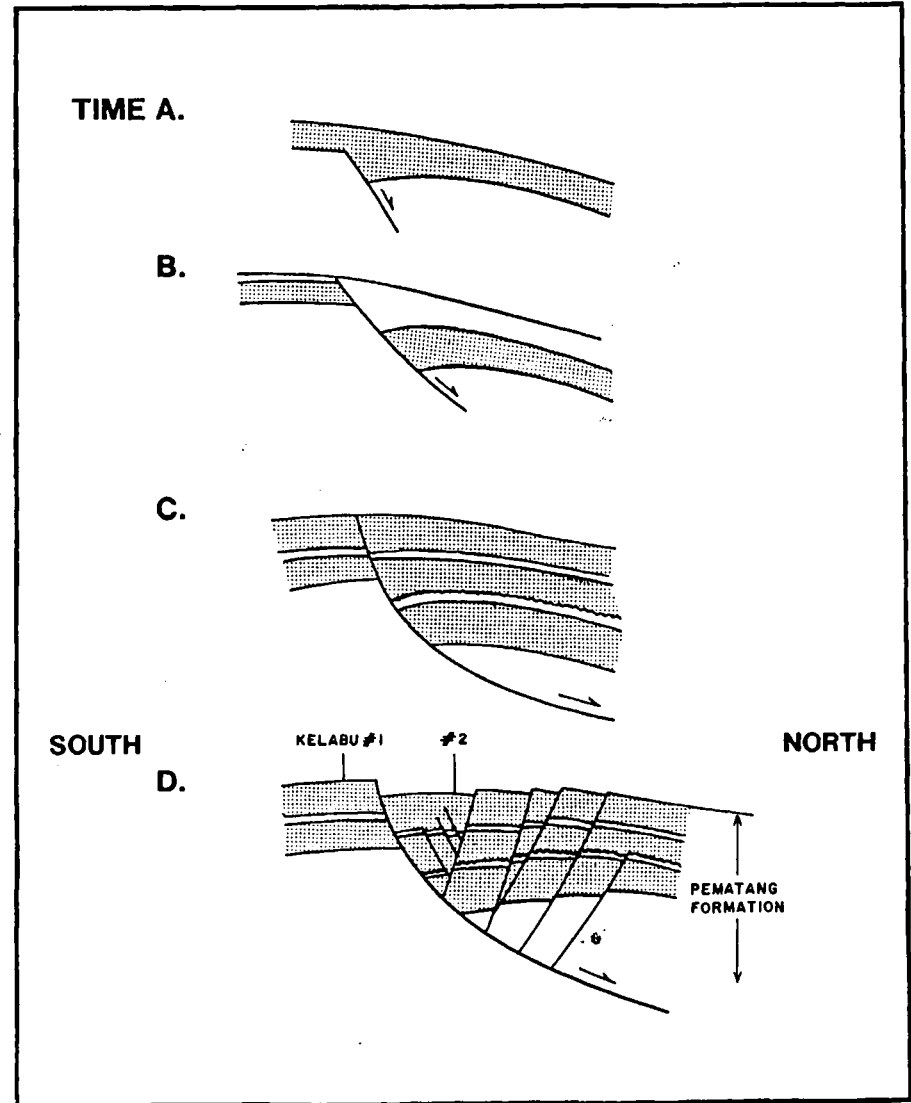


Figure 15. Kelabu Field — sequence of growth fault formation during the Paleogene.

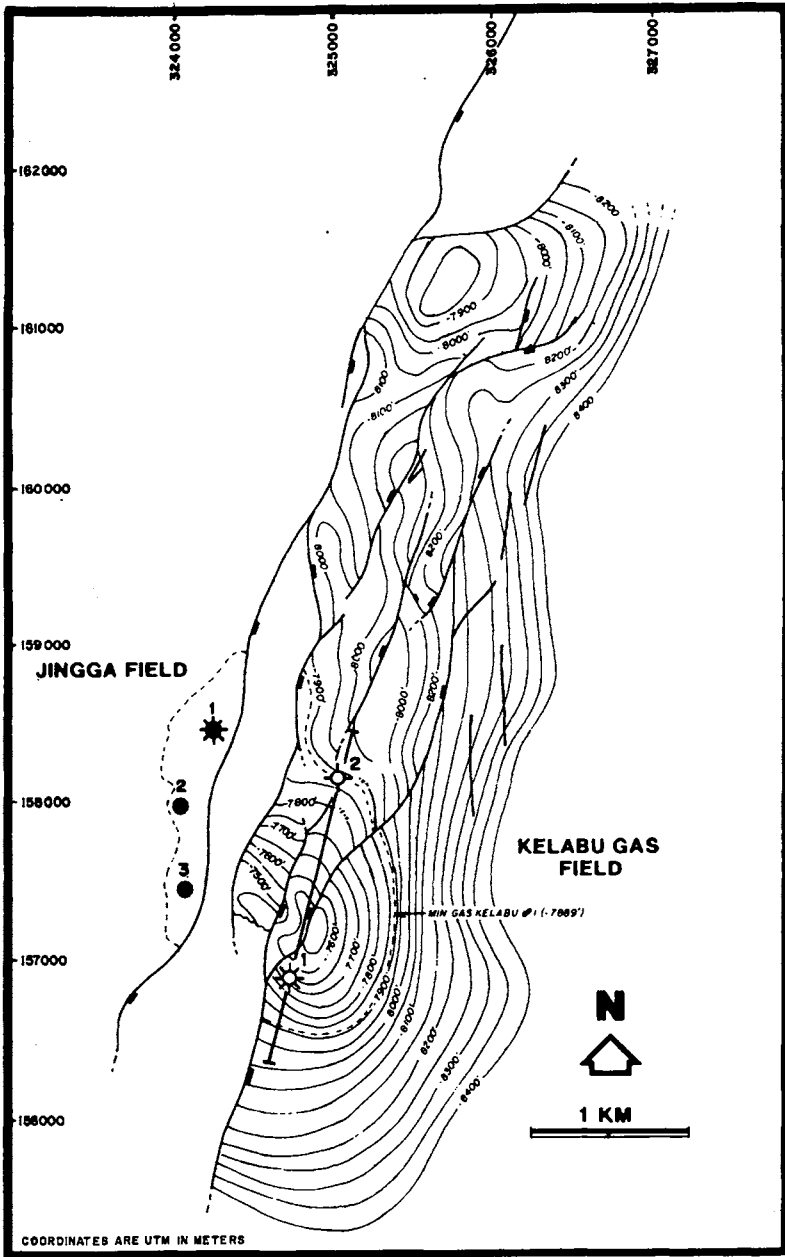


Figure 16. Kelabu Field — structure contours on top of the Upper Pematang Formation 7,750 ft Sand.

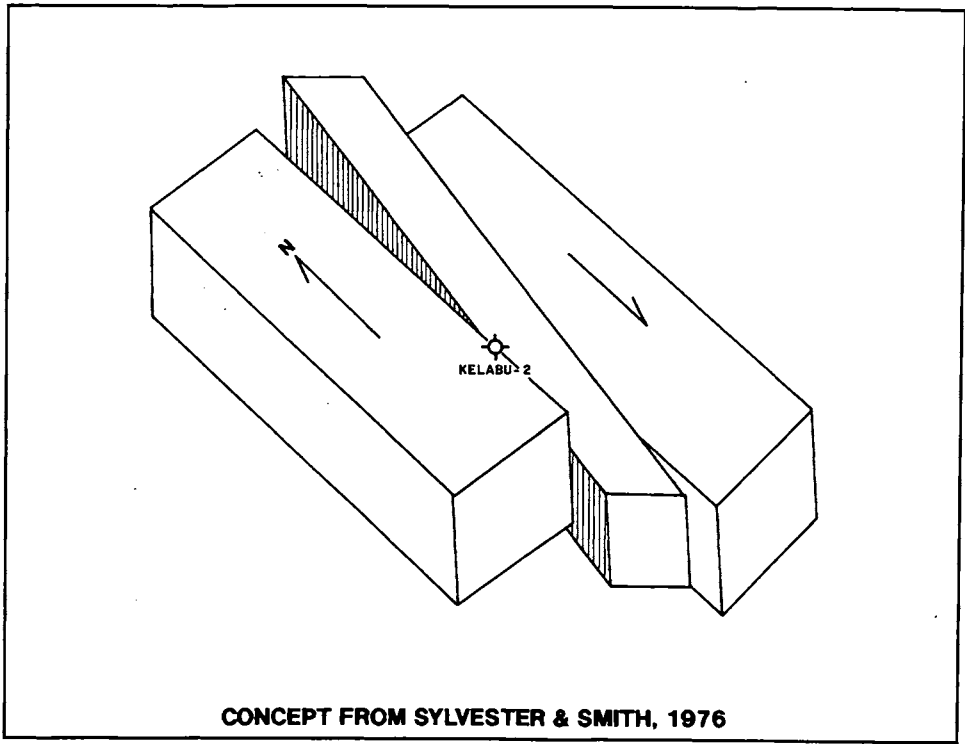


Figure 17. Scissors fault.

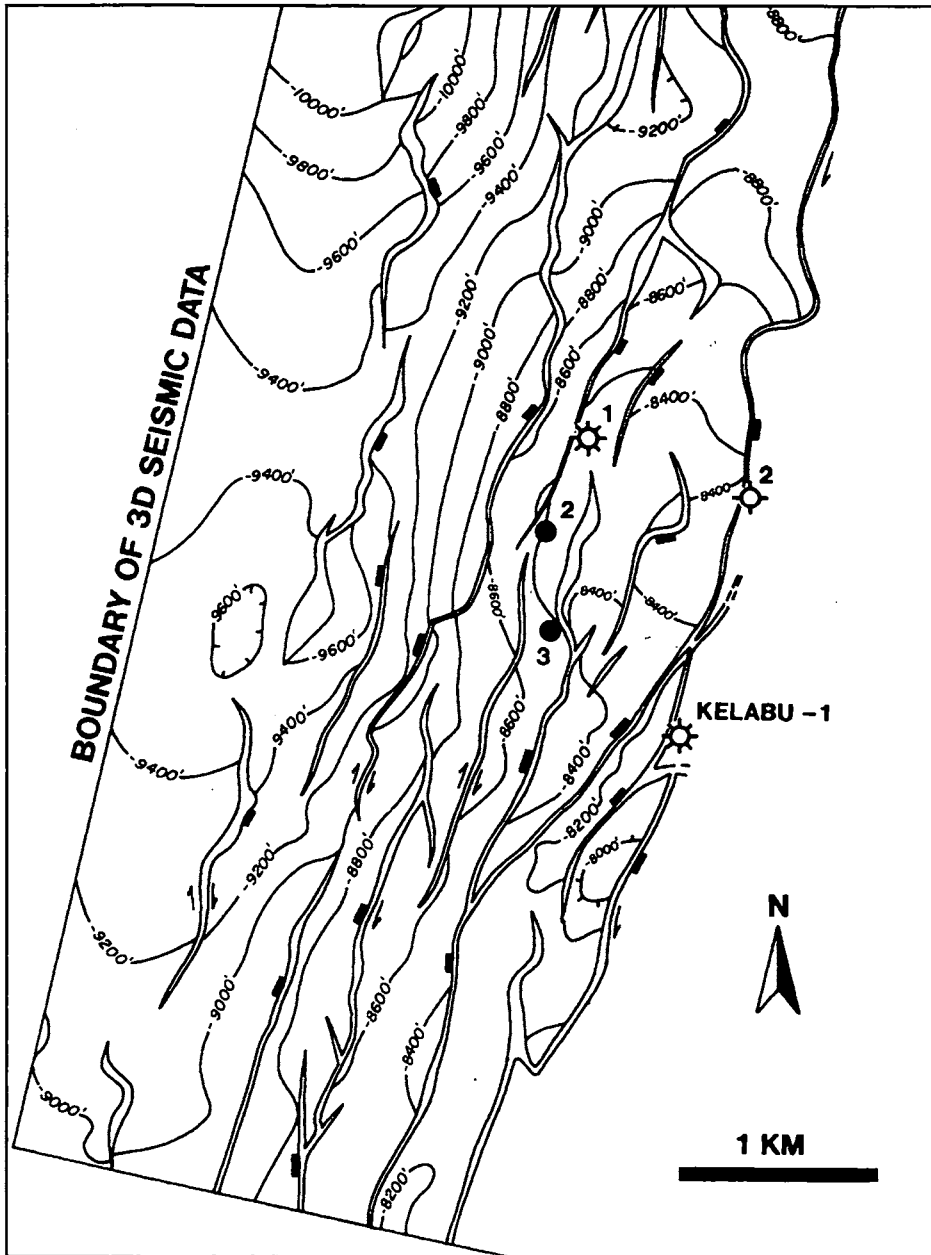


Figure 18. Jingga Field — structure contours on top of the Upper Pematang Formation 8,420 ft Sand.

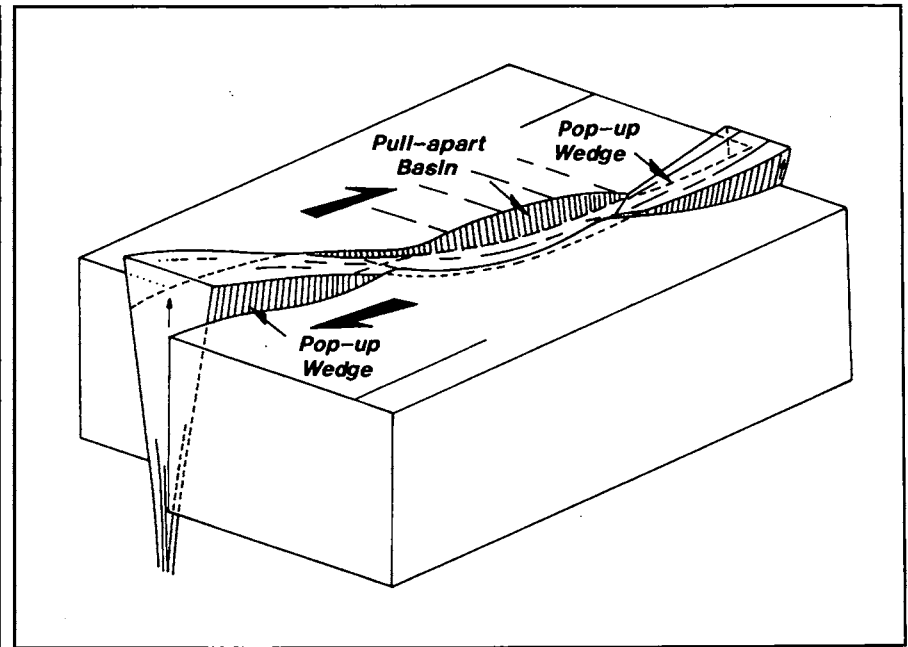


Figure 19. Schematic block diagram showing differential structural elevation of wedges of positive and negative flower structures along the strike of a right lateral fault (Kingma, 1958).

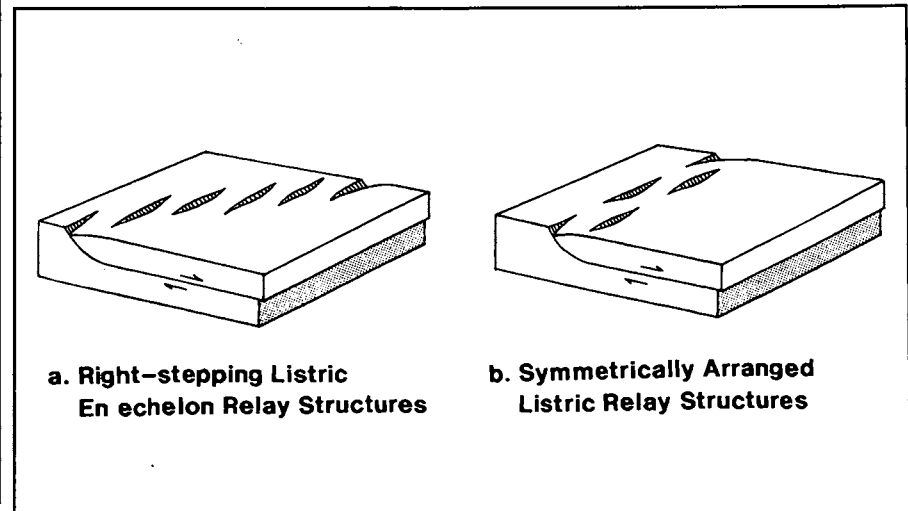


Figure 20. Relay structures (Larsen, 1988).

Relay ramps

3D seismic data indicate that most faults in the Kelabu-Jingga Fields are composed of many overstepping segments linked by areas of complex deformation, termed transfer zones or relay ramps (Peacock and Sanderson, 1994). Relay structures are discontinuous normal fault segments with transfer zones between the fault planes. Figure 20 shows a right-stepping listric *en echelon* relay structure, and a symmetrically-arranged listric relay structure. These models are useful in explaining the small, discontinuous faults mapped in the Pematang in the Kelabu-Jingga Fields. The relay-faults generally merge to a single fault plane downward. The presence of sets of relay ramps may indicate that a fault zone is not a barrier to fluid flow, since the fault plane is not a continuous surface.

En echelon faulting

Above the Eocene-Oligocene age Pematang Group, the fault style changes. Sediments are less consolidated and are consequently less faulted. The overlying Sihapas Formation is plastically draped over a rigid set of moving basement blocks. A time-structure map on top of the Bekasap Formation (Fig. 21) indicates that an *en echelon* fault system separates the Kelabu and Jingga Fields — evidence of wrench tectonics during the late Miocene to Pliocene. In the deeper Pematang Group, the *en echelon* trend is difficult to identify due to the presence of many, earlier, extensional faults.

Faults: conduits or seals?

Because faults occur at the crest of the reservoir, a question often asked by the reservoir engineers is: "Are these faults sealing?" Geologists often use faults as fluid conduits when discussing hydrocarbon migration pathways, then conveniently invoke the same faults as traps when designing a prospect. In the Kiri Trough, the timing and style of faulting suggests that some faults may have acted as both seals and conduits at different times during their history.

A hydrocarbon generation study (Mertani, 1993) of the Kiri Trough suggests that gas in the Upper Pematang sands and the oil in the overlying Menggala Formation originated from different source rocks. Based on analyses of organic material in core, the Pematang gas is close to its source, whereas the Menggala oil reservoir is sourced from deeper area in the Kiri Trough, downdip and east of the Jingga Field. The deep Brown Shale source rock and the relatively shallow Menggala reservoir sands are separated by impermeable shale. Hydrocarbon generation modeling suggests that

expulsion of hydrocarbons did not occur until 12 Ma, after a period of wrench tectonics began in Central Sumatra. So how did oil migrate up into the Menggala Formation?

Cataclastic deformation and dilatancy associated with the Paleogene-aged extensional faulting could have channeled fluid through the fault plane. This may result in precipitation of cement (Hippler, 1993). Precipitation of cement, and cataclastic grain-size reduction can significantly reduce the permeability of sandstone adjacent to the fault plane. As a result, the fault plane becomes a seal. This may have occurred during the Eo-Oligocene age extensional tectonic event in the Kiri Trough.

When a sealing fault was reactivated during Plio-Pleistocene wrench tectonics, brecciation and dilatancy may have occurred adjacent to the hardened, cemented fault zone. Consequently, the wrench-tectonic event does not breach the existing seal, and dilatancy and brecciation adjacent to the cemented fault plane may form a new fluid flow pathway. If this deformation occurs during hydrocarbon generation, hydrocarbons may be channeled through this brecciated zone. Migration of hydrocarbons up the fault plane may have occurred in the Kiri Trough during the Miocene wrench tectonic event, which is coincident with the timing of hydrocarbon generation.

This concept is useful in explaining how the "hydrocarbon kitchen" was accessed during generation, and how migration direction was influenced. Also, the presence of hydrocarbons can inhibit the precipitation of cements. Therefore, during hydrocarbon migration, the fault plane remains open as a conduit. In summary, the fault plane is a seal, but the cataclastic zone adjacent to the fault plane is a migration pathway.

The sealing nature of individual faults in the Kelabu-Jingga Fields is unknown. The above hypothesis can only be tested using future production or pressure data, which may be acquired after drilling additional wells.

CONCLUSIONS

The Pematang Formation in the Kelabu-Jingga Fields has undergone at least three episodes of tectonic deformation, resulting in a complex geometry. This complex geometry has resulted from the overprint of NW-SE wrenching on E-W rifting.

Classifying the timing and style of faulting is important in reconstructing the history of migration and trapping of hydrocarbons. Simply mapping the faults is not enough — a better understanding of how this complicated structural geometry formed

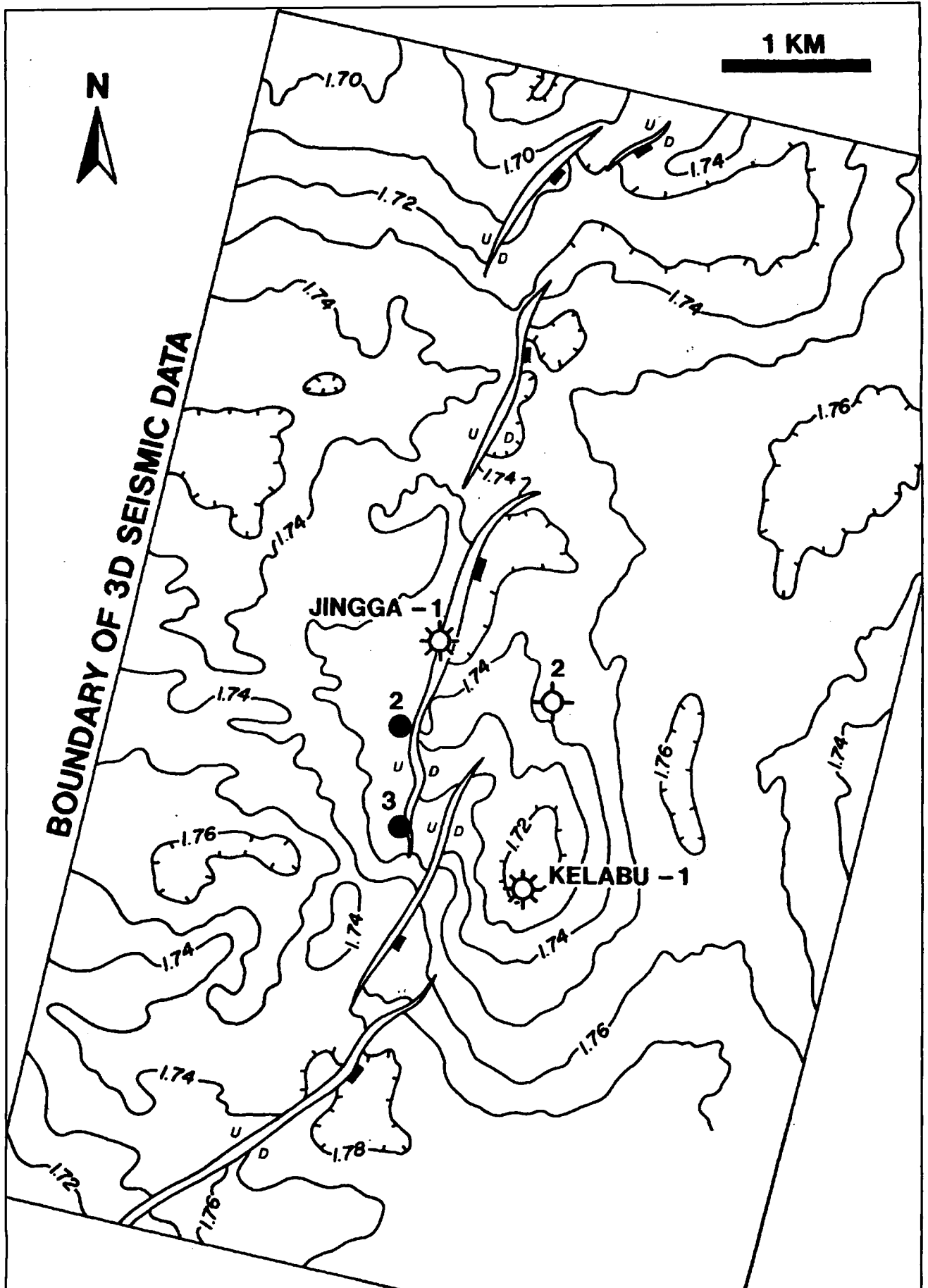


Figure 21. Kelabu-Jingga Fields, top Bekasap Formation time structure map.

is needed to predict where reservoir rocks were deposited.

3D seismic data indicates that the degree of faulting is complex. Consequently, block diagrams showing the types of faulting which occur in the Pematang reservoir are useful in showing fault geometry. Matching a complex fault pattern with idealized, theoretical and existing models is useful in understanding fault mechanics, and in predicting fault geometry. The visual concepts displayed by fault geometry cartoons are useful in making sense of structural anomalies which commonly occur in wrench fault environments

With the existing 3D seismic data, we can successfully map the complex geometry and identify possible hydrocarbon traps. The risk in exploring for these relatively small Pematang gas reservoirs within the Pematang Group involves the lateral discontinuity of individual sands, age and timing of faulting and the questionable sealing properties of faults.

Hopefully, this detailed structural description of the Kelabu-Jingga Fields may act as a model for other local prospects.

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