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Geometrical Characteristics of Structural Inversion on the Offshore of Miaoli, Taiwan

HSIEN-CHUAN SHEN*, SHIUH-TSANN HUANG*, CHEN-HUI TANG† AND YEONG-YAW HSU‡

ABSTRACT

Structural deformation caused by inversion tectonics, a consequence of arc-continent collision in Taiwan since late Miocene, is well preserved in the foreland basin of the offshore Hsinchu-Miaoli area, northwestern Taiwan. Extensional fault systems of Paleogene through Miocene age had still divided the area into groups of grabens and horsts. Reactivation and inversion of pre-existing normal faults have played an important role in the structural deformation and influenced hydrocarbon accumulations in the region.

Major tectonic elements in the study area include the Waihsiangshan fault, Paishatun graben, and Wulipai graben. The Paishatun graben is bounded by the Chunan fault in the northern side and by the Paishatun fault in the southern side. The Wulipai graben is bounded by the W1 fault in the northwestern side and bounded by the W2 fault in the southeastern side. All of these faults are normal faults in origin and have been reactivated and inverted during the latest Cenozoic orogeny, the Penglai Orogeny.

A time structure map of the Nanchuang formation was prepared, and used to evaluate the characteristics of inversion structures in the study area. The Waihsiangshan normal fault been reactivated and inverted to become a dextral strike-slip fault with a series of en'echelon folds and variable structure in the hanging wall. All the boundary faults of the Paishatun graben and Wulipai graben have inversion-structure characteristics with a special arrays of the normal fault-null point-reverse fault occurring sequentially along the same boundary fault.

A null line was completed by connecting the null point in each major fault. Westward of the null line, it is difficult to find reverse faults, so that the null line could be somewhat considered as westmost boundary of the influence by the Penglai Orogeny. The east side of the null line is characterized by minor and remarkable reverse faults, and considered as the unstable inverted area, whereas the west side of the null line is dominated with normal fault, and considered as the stable area. The W1 fault and P1 fault identified as thin-skinned thrust faults could be regarded as the front thrust of the Penglai Orogeny.

The stable area is probably advantageous for the accumulation of hydrocarbon due to good horizontal fault seal rather than that of unstable area. But in the east side of the null line, structural high near the W2 fault determined as the westmost anticline influenced by the Penglai Orogeny would still be high in hydrocarbon potential in combination with good

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* Exploration and Development Research Institute, Chinese Petroleum Corporation, P. O.Box 166, Miaoli,Taiwan, R.O.C.

† Chinese Petroleum Corporation

‡ Offshore and Overseas Petroleum Exploration Division, Chinese Petroleum Corporation, P.O. Box 24-727 , Taipei, Taiwan, R.O.C.

closures of this structural high in the hanging wall and footwall of the Oligocene horizon could be possibly interconnected each other and let the fluids flow across the fault plane as the null point took place in the horizon of the Oligocene.

INTRODUCTION

Cenozoic basins of Taiwan have undergone a basin inversion with a change from rift basins of Paleogene through Miocene age to a foreland basin formed as a consequence of arc-continent collision since late Miocene (Sun, 1982; Teng, 1992). Structural deformation caused by inversion tectonics is well preserved in the foreland basin of the onshore and offshore Hsinchu-Miaoli area, northwestern Taiwan (Chen and Tang, 1993; Chen *et al.*, 1994; Chi *et al.*, 1993; Chung *et al.*, 1989; Hu and Hsu, 1987; Huang *et al.*, 1986; Huang *et al.*, 1993; Lee, 1986; Lee *et al.*,1993; Lee and Chang, 1994; Lin *et al.*, 1994; Suppe, 1984, 1986; Wu and Hu, 1987, 1988; Yang *et al.*, 1994, 1995).

In previous studies(Huang *et al.*,1993; Chen *et al.*, 1994), we proposed a basin inversion model to interpret inversion structures of this area. The objective of this study is to study the characteristics of inversion structures in terms of hydrocarbon accumulations by reviewing 25 well data and reinterpreting seismic lines of about 950 km^2 (Fig. 1).

The present study focuses on the offshore Miaoli area. Scale maps of 1: 50,000 were used for seismic interpretation and structural analysis. Two structure contour maps, one on top of the late Miocene Nanchuang Formation and the other on top of the Oligocene strata, were compiled for this study.

The foreland basin in northwestern Taiwan has undergone multiple stages of deformation (Huang *et al.*, 1993). Major tectonic events in this area are as follows :

- Pre-rift stage: Cretaceous,
- Synrift stage: Paleocene or Eocene to Oligocene,
- Post-rift stage: early Miocene to middle Miocene,
- Tectonic inversion stage: late Miocene to Pleistocene.

The top of Nanchuang Formation, with its typical regressive flooding surface, is a regionally traceable unconformity, marking not only a good formation boundary but also the change between rifting and compressional tectonic regimes. The time structural map (Fig. 2) of this horizon is therefore very helpful for the inversion structural analysis.

PREVIOUS STUDIES

The Taihsi basin was first named by Sun(1982), and generally known as the late Tertiary foreland basin of Taiwan. It is bounded by the Kuanyin basement high to the north, the Peikang basement high to the south, and the Nanjihtao ridge to the west.

The study area is located around the central part of the Taihsi basin, where more than 7500 meters thick Tertiary sediments were accumulated. The basin developed in a rifting regime during Eocene through middle Miocene age with its major tectonic trend keeping about N79°E direction while since the late Miocene, the basin has been subjected to convergent tectonic deformation due

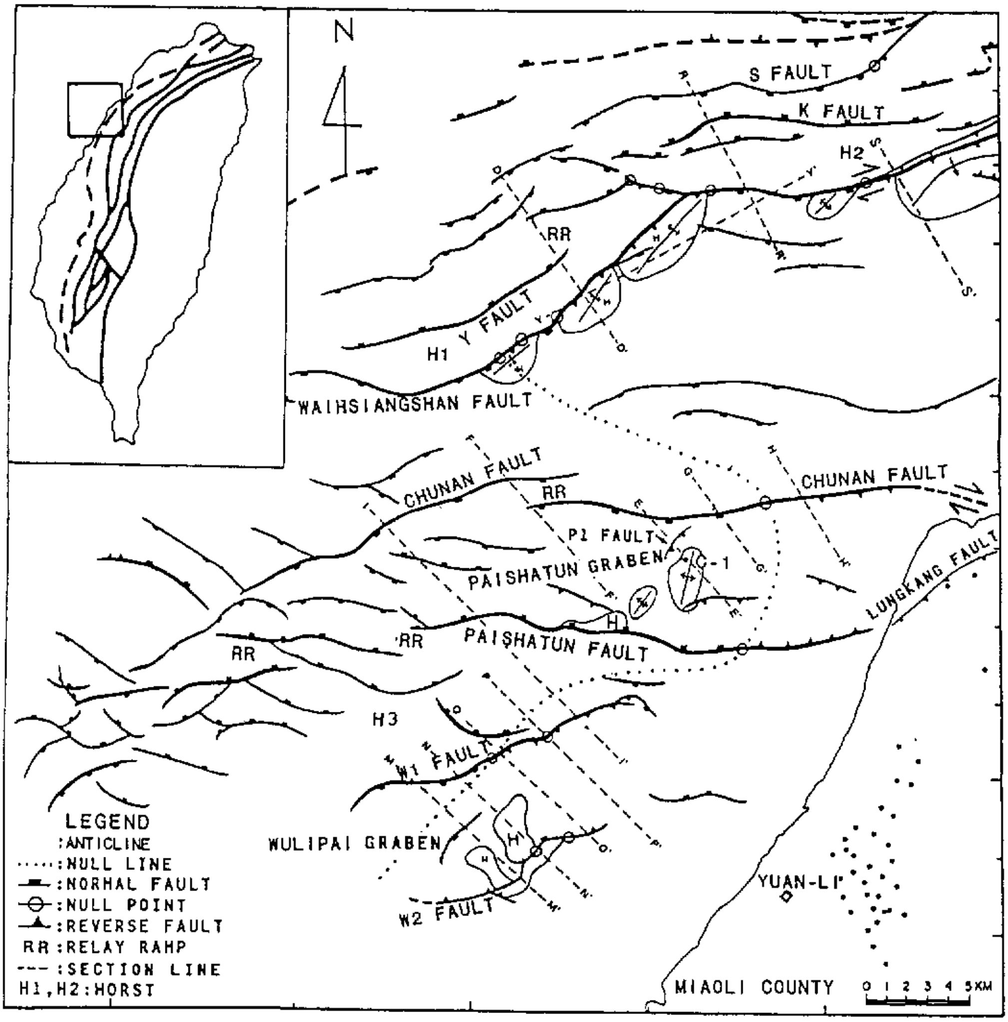

Figure 1. Map of the offshore of the Miaoli-Hsinchu area, northwestern Taiwan showing the location of seismic lines in this study and major tectonic elements.

to the arc-continent collision between the Euasian and Phillippine Sea plates. The N79°E trending horst-graben, developed in the basin, has then undergone the inversional tectonic deformation. In consequence, the resulted inversion structures such as strike-slip faulting, compressional folding, reverse faulting, and minor flower stuctures, mainly developed in the postrift sequence, were superimposed upon the older structures. In general, the inverted reverse faults are most widely observed at the major boundary faults of grabens. The authors also noticed that the extent of inversional deformation decrease both from the Kuanyin basement high southward to the offshore Hsinchu-Miaoli area and from the coastal area of Hsinchu-Miaoli westward to the Nanjihtao ridge.

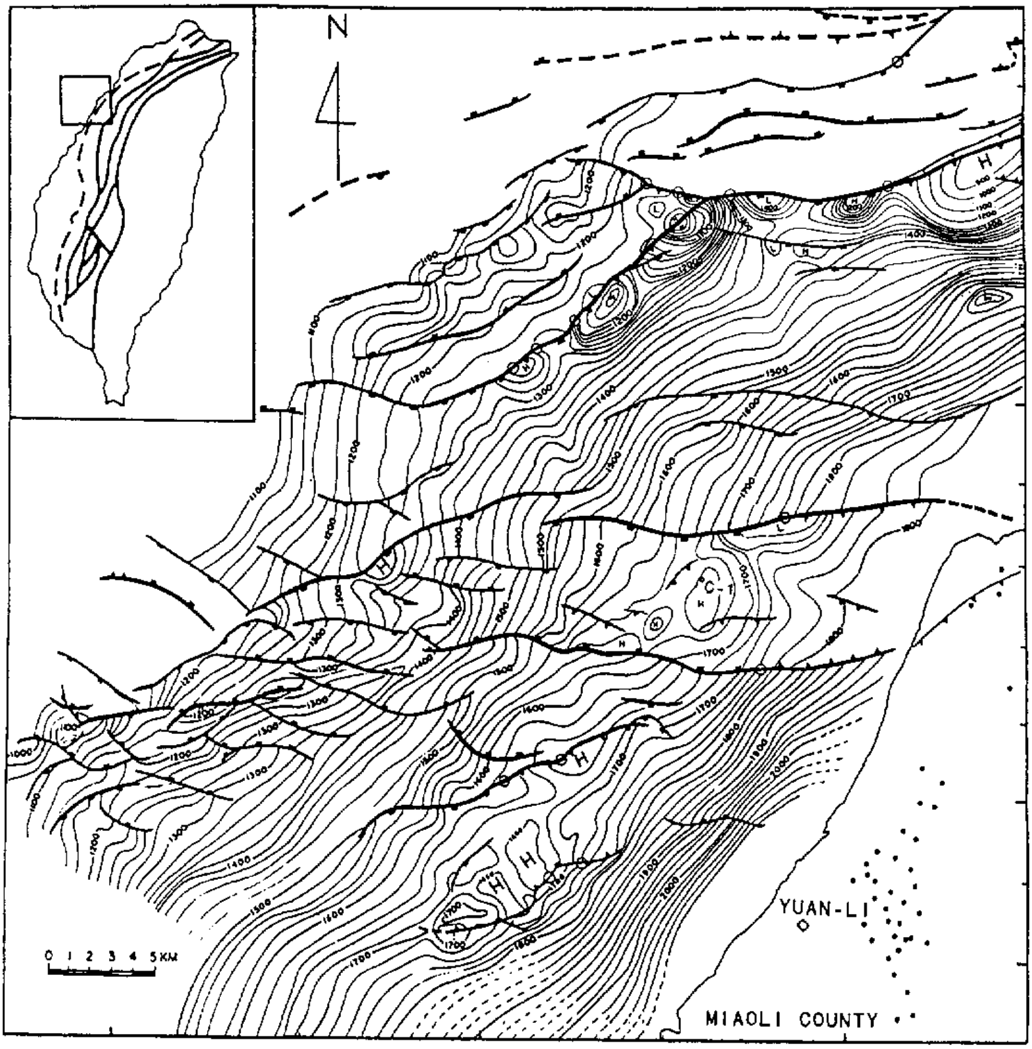

Figure 2. Time structural contour map at the Nanchuang top.

GENERAL STRUCTURAL FRAMEWORK

The Tertiary Taihsi basin was developed under two different phases of tectonic regime, an earlier extensional regime and a later compressional regime. The normal faults were the main structural feature during the extension stage. Based on en'echelon alignment and general E-W trending of the normal faults ,it is judged that, during the rifting stage, the basin was, as a whole, developed under transtension with the main block moving direction or rifting direction facing relatively toward north. As the result, the E-W treding horsts and grabens, associated with ramp or relay ramp structures, are predominantly develped in the study area (Fig. 1).

The normal faulting continued until the late Miocene, when the orogenic belt advancing northwestward at a certain distance to the foreland area. As revealed in the regional structural map, shown in the index map of Figure 1, a crescent shape of thrust front protruded northwestward to the immediate east of the study area. Under this compressive tectonics, the vertical reversal faulting as well as the horizontal strike-slip faulting will easily take place along the E-W trending pre-existing normal fault. In consequence, the compressional shearing stress caused by strike-slip motion, may in turn induce a series of drag foldings along the strike-slip fault. Those sturctures, known as the WHS, CBM, Tung, CBA, and the CBL, which are seen to be arranged more or less en'echelon and closely associated with the C-TL-TA faults, being now regarded as the products of the said drag foldings. These associated structures are now included together to be called the Waihsiangshan strike-slip fault system in this study. Two grabens, named the Paishatun graben on the north and the Wulipai graben on the south, and developed in the southern part of the Waihsiangshan fault system under the earlier extensional phase, still retain as a whole in the normal extension state, although some parts of them being slightly suffered by the latter compressional deformation. Characteristics of the inverted structural deformation will be discussed in the following section.

GEOMETRICAL CHARACTERISTICS OF THE INVERSIONAL STRUCTURES

Three representative structures, namely from north to south: the Waihsiangshan (or C-TL-TA) strike-slip fault system, the Paishatun graben, and the Wulipai graben are discussed respectively as follows.

The variation of vertical thrown along the horizontal extension of the major boundary faults of the Paishatun and Wulipai grabens are diagramatically analysed to show their geometrical characteristics of inversional deformation. The null points are one of important geometrical characteristics in this study area. Therefore the schematic model of null point is also essential to illustrate in Figure 3 as well as to interpret the change of fault mechanism from net extension to net contraction in this region(after Williams *et al.*,1993).

Waihsiangshan Strike-slip Fault System

Waihsiangshan fault, trending from NE, turned to NEE, then merged eastward with the Hsinchu fault, may be easily considered as a series of the reverse faults if the faults were studied with each of the associated fault-anticlines indivisually.

As shown in the structural contour map of the Nanchuang top (Fig. 2), at least five null points are mapped along the Waihsiangshan faults. The characteristics of the strike-slip faulting is most obviously revealed by the variable apparent vertical displacement traced along the Waihsiangshan fault trend. The apparent throw changed westward successively from reverse faulting (Fig. 4) to normal faulting (Fig. 5), then again to reverse faulting (Fig. 6), and finally to normal faulting (Fig. 2).The alternative appearance of reverse and normal offset express the variable geometrical characteristics of the Waihsiangshan fault.

The amplitude of the associated anticlinal folds is coincident with the amount of relative vertical displacement of the reversed faulting; that is, the larger the vertical displacement, the higher

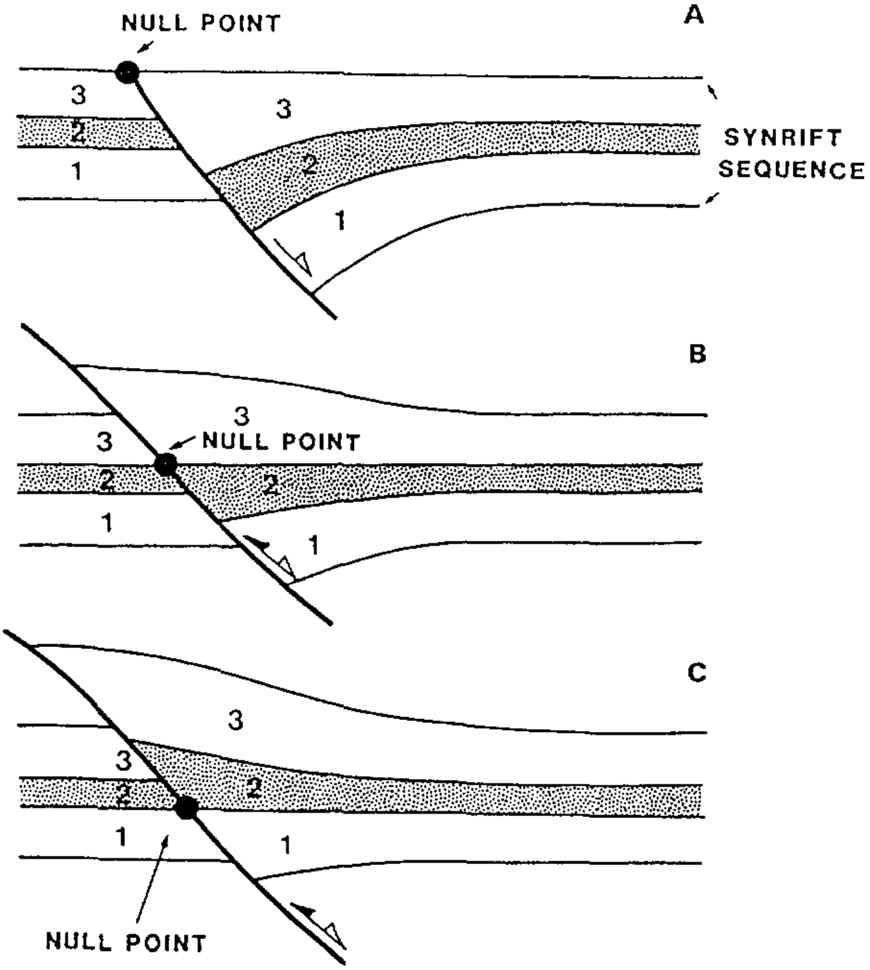

Figure 3. The development of null point and the defimition of null point delineate as the change point from net extension to net contraction at the same fault plane(after Williams *et al.*,1989).

the folded amplitude. Synthetic analysis of the Waihsiangshan faults together with the associated foldings verified that it is actually the inverted reverse faults with strike-slip displacement. Reactivation may take place through a simple shearing strss along the pre-existing normal fault. A series of the induced drag foldings, arranged en'echelon lying on the southern downthrow side of the pre-existing normal fault, form the present Waihsiangshan dextral strike-slip fault system(Fig. 2). This kind of dextral structure model would seem what is shown in the San Andreas fault as described by Sylvester(1988) and Dibblee(1977). Figures 4 and 5 show one of the typical inverted rollover structure. Westward compressional stress, causing the strike-slip faulting is also clearly represented by the associated minor thrust faults, shown in the left part of the seismic profile YY'(Fig. 7).

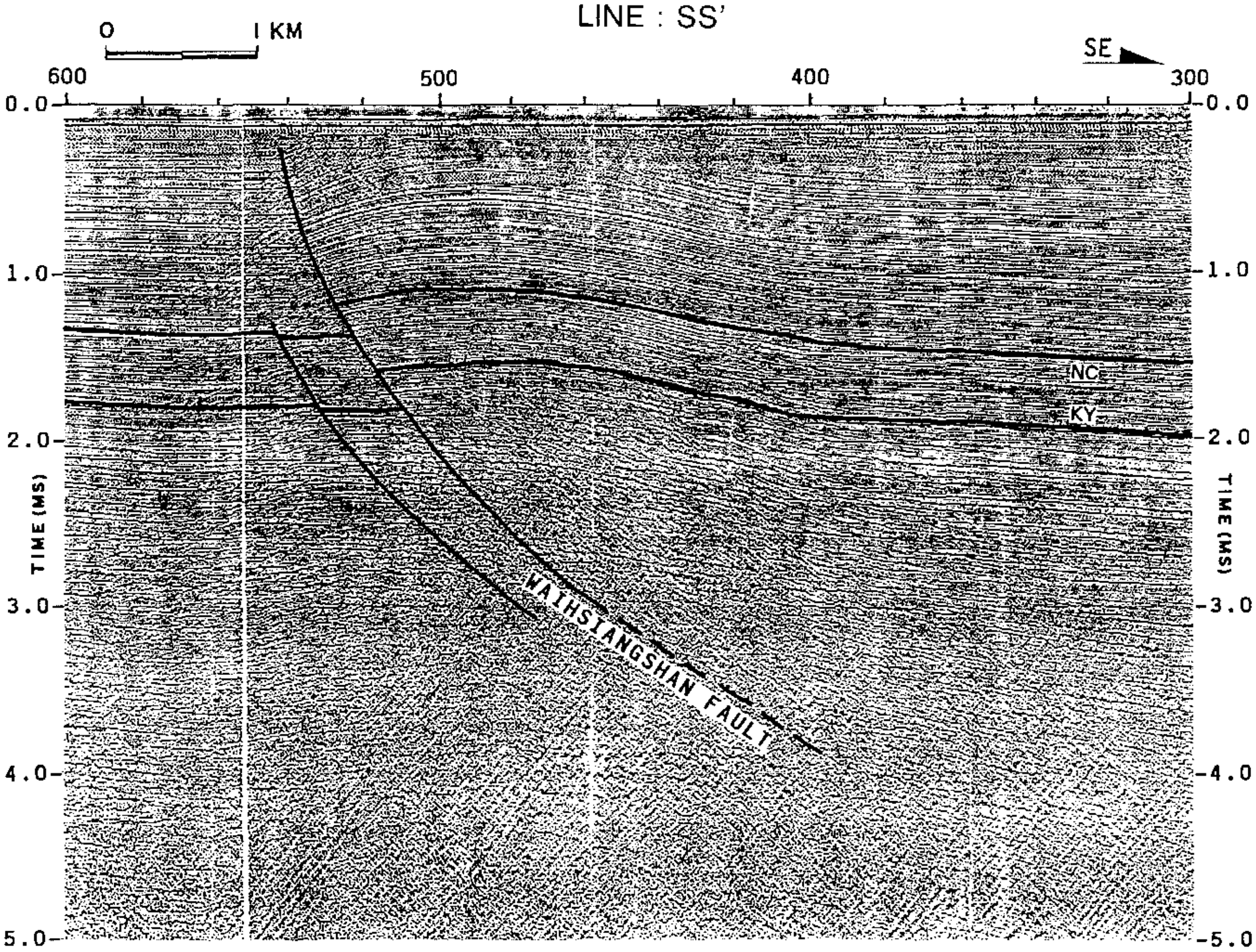

Figure 4. Seismic line SS' showing a faulted-anticline within Waihsiangshan fault system.

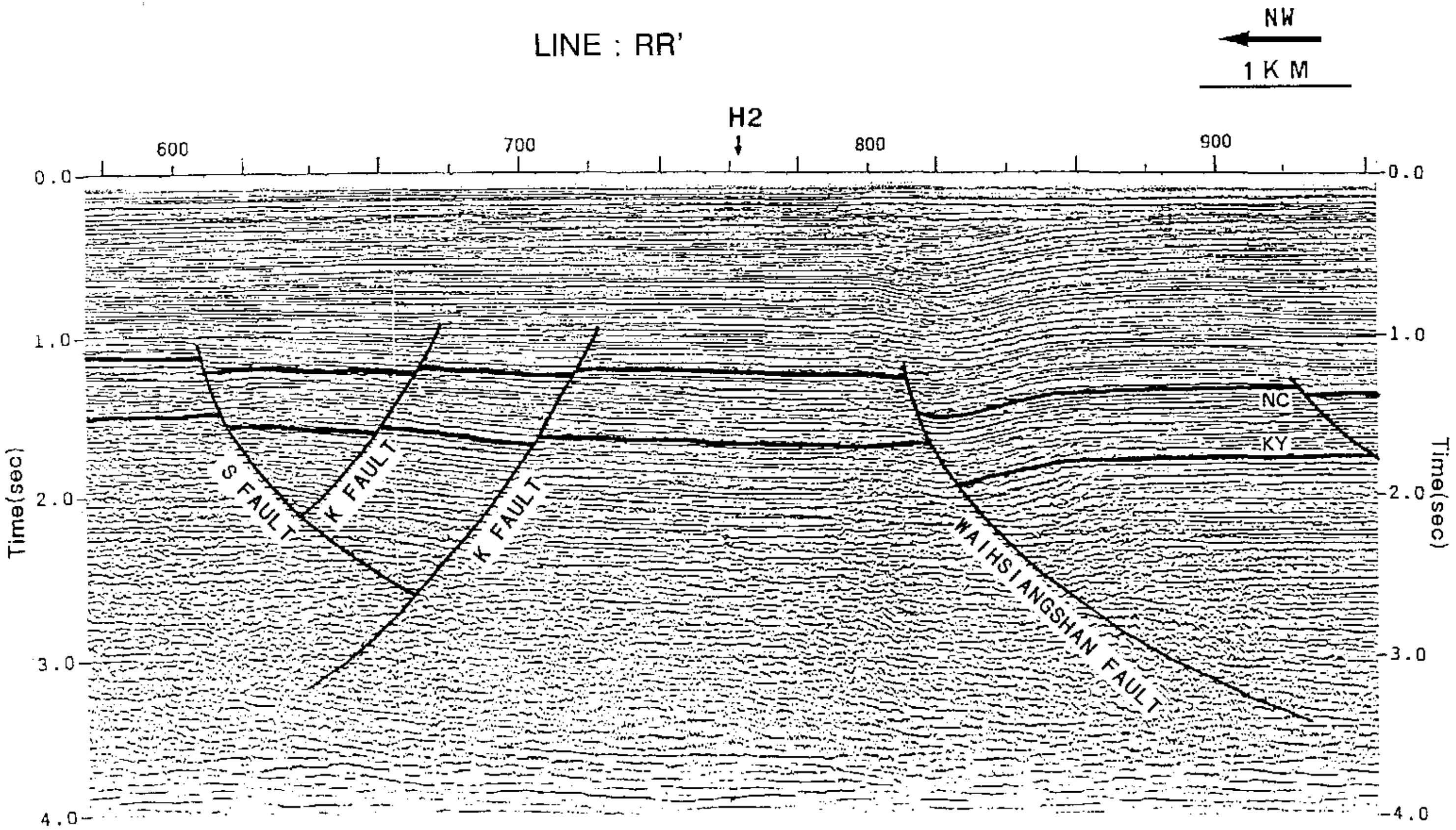

Figure 5. The Waihsiangshan fault exhibiting normal offset and rollover structure in seismic line RR'.

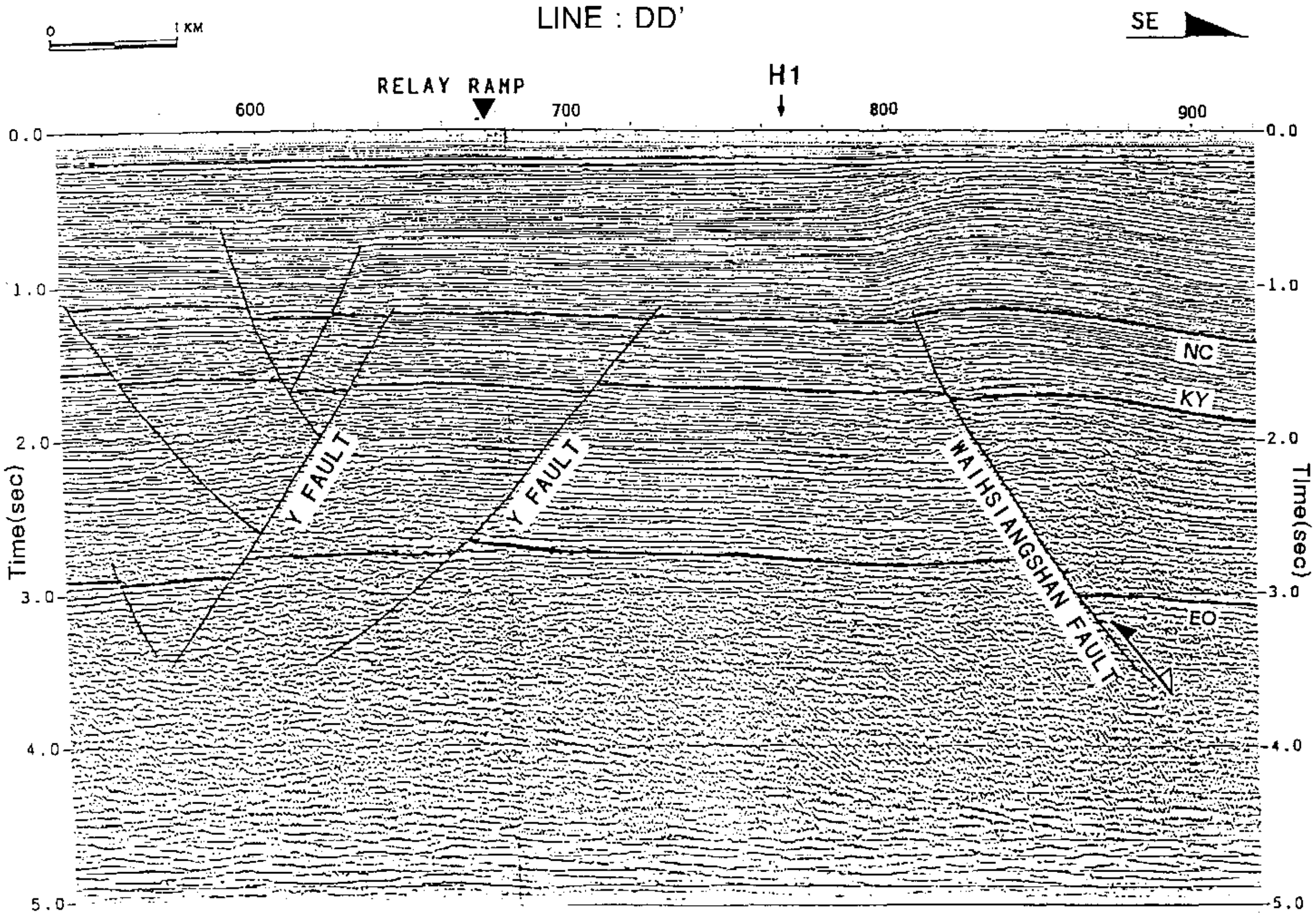

Figure 6. The Waihsiangshan fault showing the characteristics of reversal offset and associated fold in seismic line DD'. Pre-existing relay ramp occurring within Y fault system in the northwest side of H1 horst.

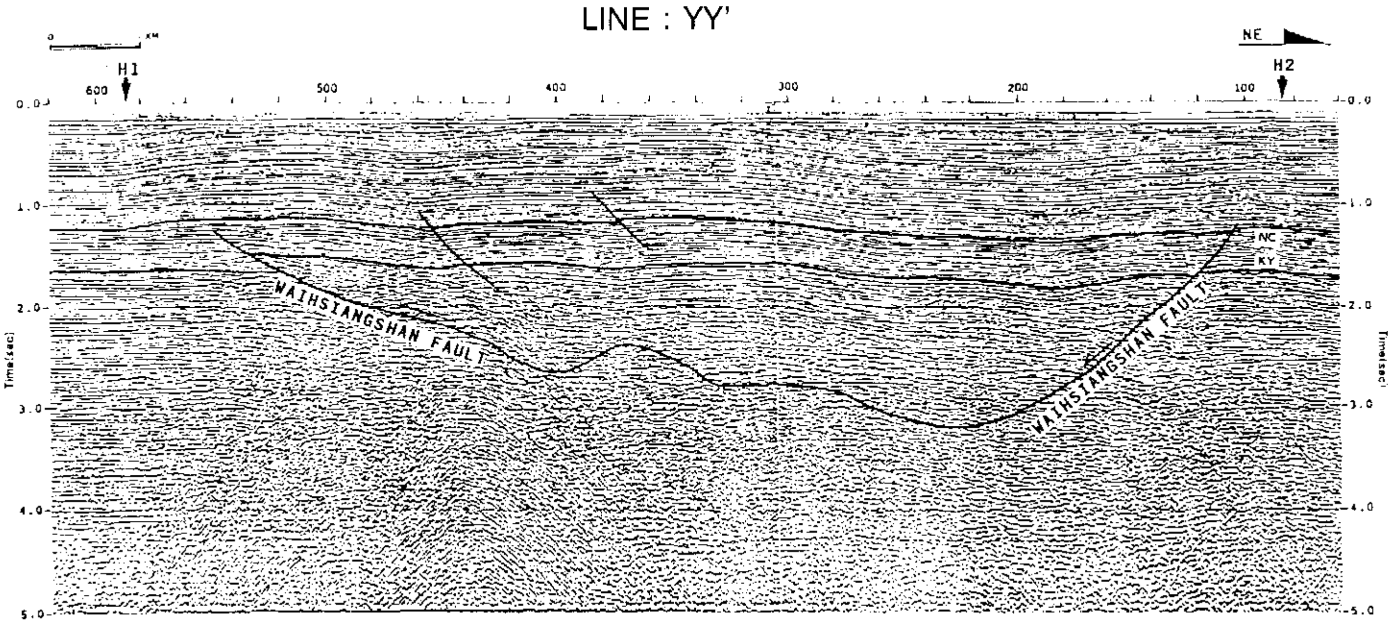

Figure 7. Seismic line YY' showing the strike-slip motion of the Waihsiangshan fault. The Waihsiangshan strike-slip fault intersects different formations and expresses normal faulting in east side and reversal faulting in west side.

Paishatun Graben

The Paishatun graben almost trending from W-E is bounded by two major faults: Chunan fault to the north side and the Paishatun fault to the south side. The maximum reversed displacement of Chunan fault is about 70 meters but the maximum reversed displacement of the Paishatun fault is only about 10 meters (Figs. 2 and 8). Passing through the null point, the Chunan fault and

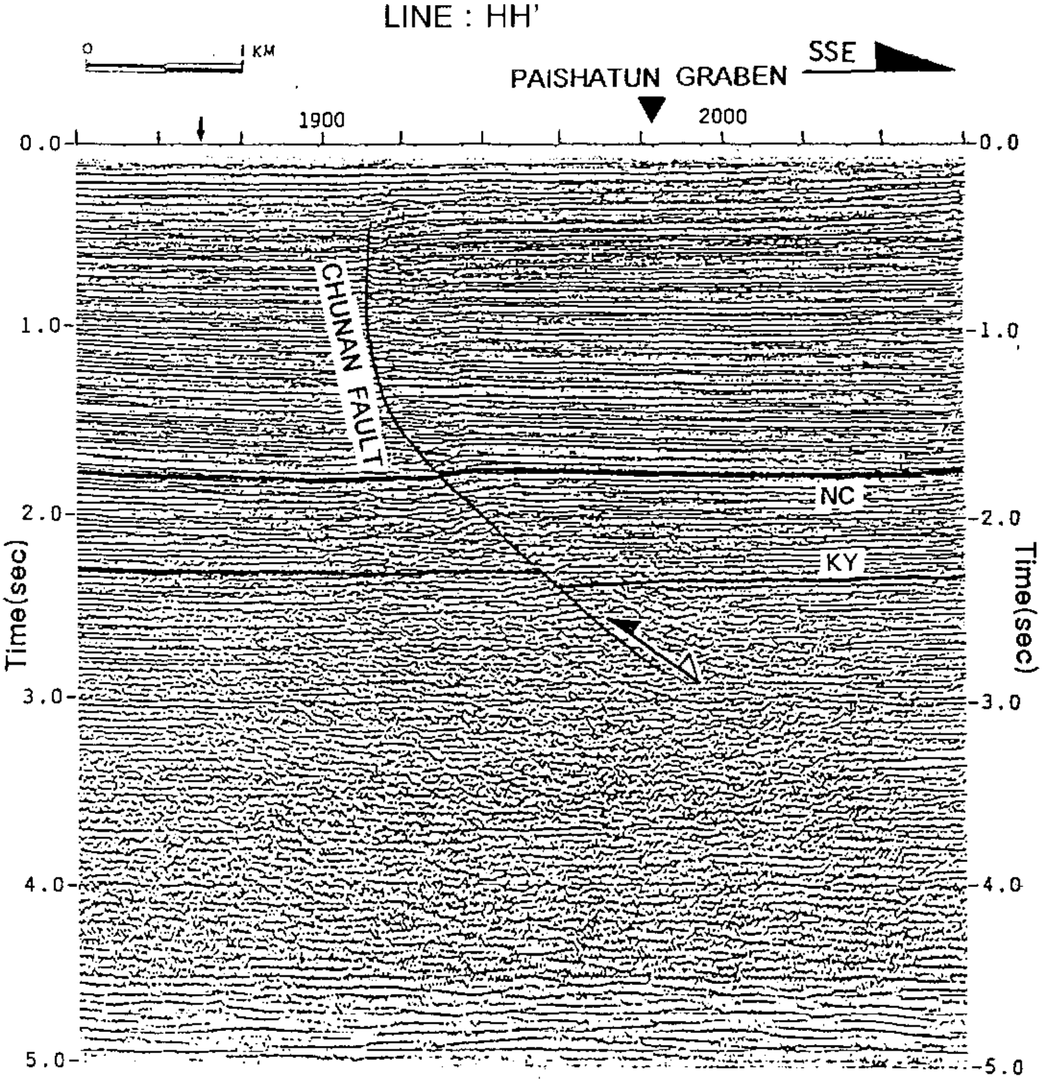

Figure 8. Seismic profile HH' illustrating the characteristics of reverse faulting of the Chunan fault.

Paishatun fault remain the normal faults (Fig. 9). As the Chunan fault and Paishatun fault extend toward the west, all the associated fault system still keep net normal fault offset (Fig. 2). Obviously, the root of the Paishatun fault at deeper part become an antithetic fault of Chunan fault (Fig. 10). Variation of fault vertical displacement of these two major faults in Figure 11 is also utilized to explain the above structural changes. The horizon of the Nanchuang formation top is generally dipping toward the east. With the null points as divides, the vertical displacements in the west are in a normal offset state while in the east side they turn to reverse offset, and offset continues to increase toward the Taiwan Island. The relay ramp of stage 2 in Peacock and Sanderson (1994) also appears within these two boundary faults and probably provide the path for hydrocarbon migration (Fig. 1 and example shown in Fig. 12).

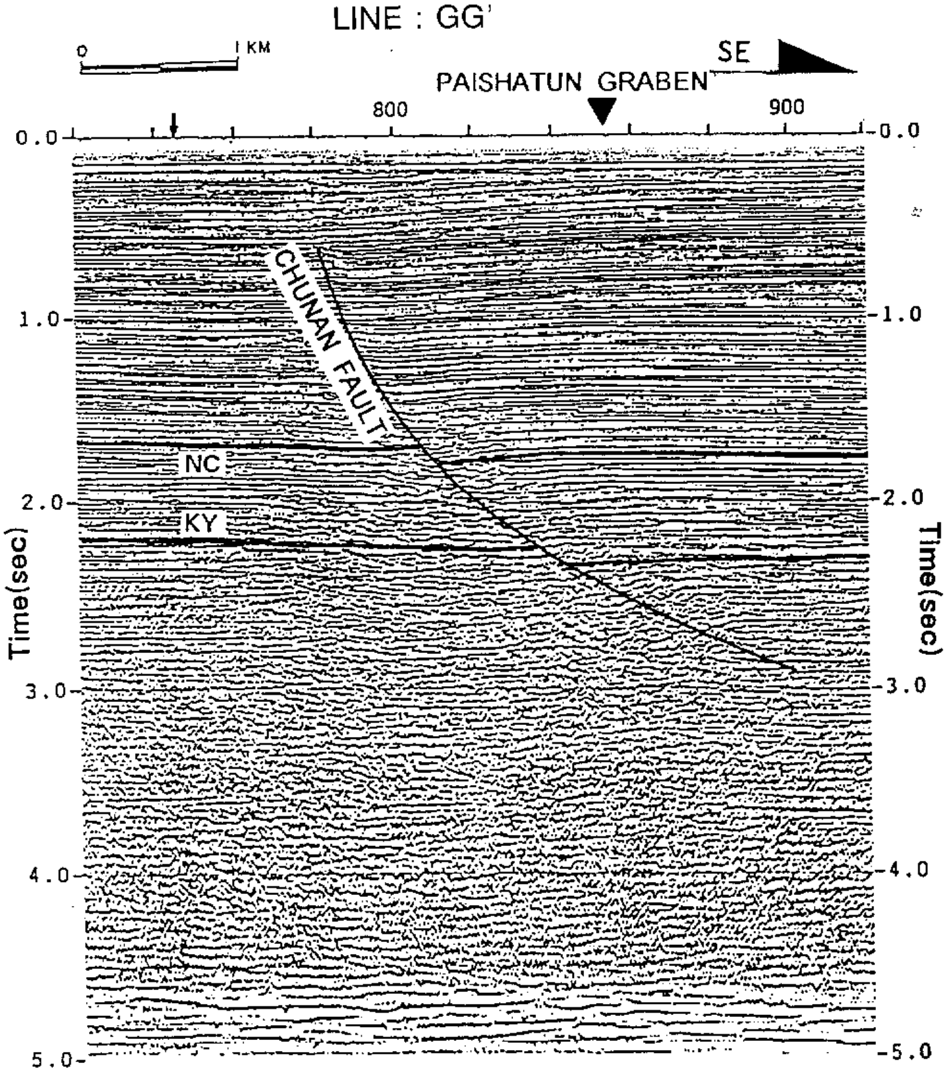

Figure 9. Seismic profile GG' showing the normal offset of the Chunan fault.

Anticlines associated with low angle thrust fault P1 occurred in the Nanchuang formation just near the west side of null line within Paishatun graben (Figs. 1 and 2). The low angle thrust fault P1 with the strike matched with the trend of the long axis of the anticline is confirmed in both the well logging and seismic profile (Figs. 13 and 14). The P1 thrust fault encountered at the depth of 3348 meter in C-1 well shows a repeated interval of about 86 meters in the Talu sandstone. As shown in Figure 2, the structural trend of the P1 faulted anticline intersects at an angle of about 45° to the Chunan fault. It is deduced from the intimate relationship between their structural intersection as well as their faulting mechanism that, the P1 faulted anticline might be formed by the drag folding under the dextral shearing stress along the Chunan normal fault, the inverted reverse faulting as revealed on east side of the Chunan fault being then developed at the same time. Therefore, it could be concluded that the extensional Paishatun graben was subjected to inversion during the late Miocene and resulted in the north-south graben bulk contraction and back propogating thrusting in accompany with low extent of dextral strike-slip motion due to partially east-west thin-skinned shortening. A schematic model shown in Figure 15 is prepared to illustrate the relationship of structural changes occurred in the Paishatun graben.

Wulipai Graben

Compressional inversion in the NE-SW trending Wulipai graben is restricted to northeastern margin of the graben. The geometry of the inversion structures along the W1 fault is similar to what is described for the Paishatun graben. Representative seismic lines showing the typical inversion structures in the Wulipai graben are illustrated in Figures 16,17,18, and 19. As shown in Figure 20 the thrown variation of the W1 fault is similar to the boundary faults of the Paishatun graben. Normal thrown occurred in the southwest side of null point and reverse thrown in the east. A special feature of the W1 fault is that the normal fault and reverse fault horizontally die out at both end of the fault. Another special feature of the W2 fault is that the vertical displacement of the W2 fault is revealed entirely as a reverse faulting state .

The shortening across the Wulipai graben was taken up by the development of the fold with gentle relief nearby the W2 fault.

Based on the thickness variation across the hanging wall and footwall of the W1 fault, it could be found that the W1 fault took place normally during the Nanchuang- Kuanyinshan stage, and could be considered as a growth fault (Fig. 16). The root of the growth fault have died out into the Oligocene basal part. During the late Miocene Penglai Orogeny, the W1 fault was inverted into reverse fault as shown in line II' of Figure 10. A null point at the Nanchuang formation top occurred on the W1 fault as shown in Figure 18. The typical null point express the point of the change from net extension in the southwest part of the W1 fault to net contraction in the northeast part. The W2 fault is an associated antithetic normal fault of the W1 fault, and the root of the W2 fault also die out at the top of the Eocene (Figs.16,17,18,19). Since onset of the Penglai Orogeny, the W1 fault and associated W2 fault have undergone structural inversion. Except some part remains normal offset (Figs. 1, 2, and 20), most of the W2 fault has been inverted into minor reverse fault (Figs. 16 and 18). On the northwest part of W1 fault , no track of reverse faults observed. Therefore, it is reasonable to assume that the structural inversion of Wulipai graben

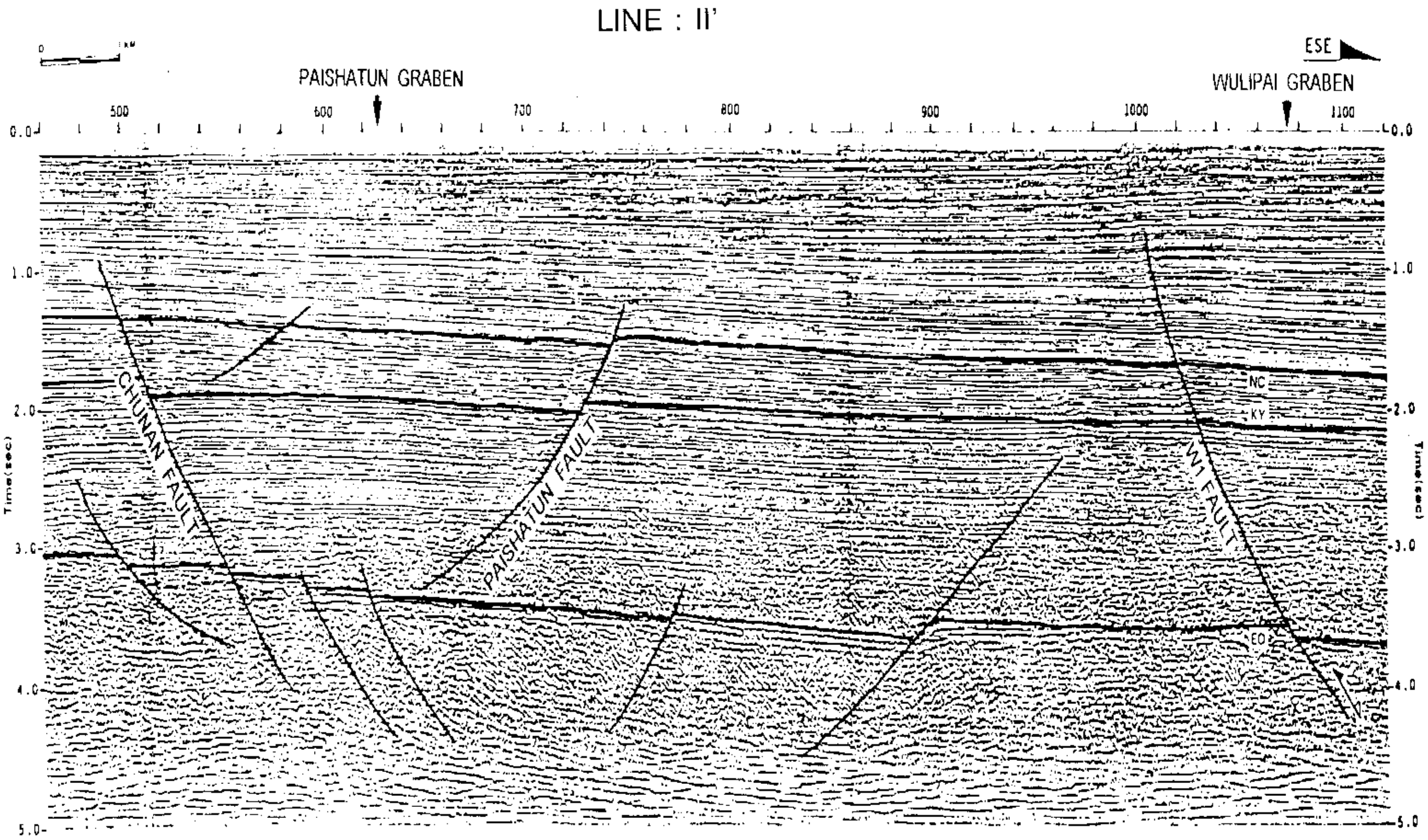

Figure 10. Seismic profile II' showing the geometrical features of Chunan fault, Paishatun fault and W1 fault.

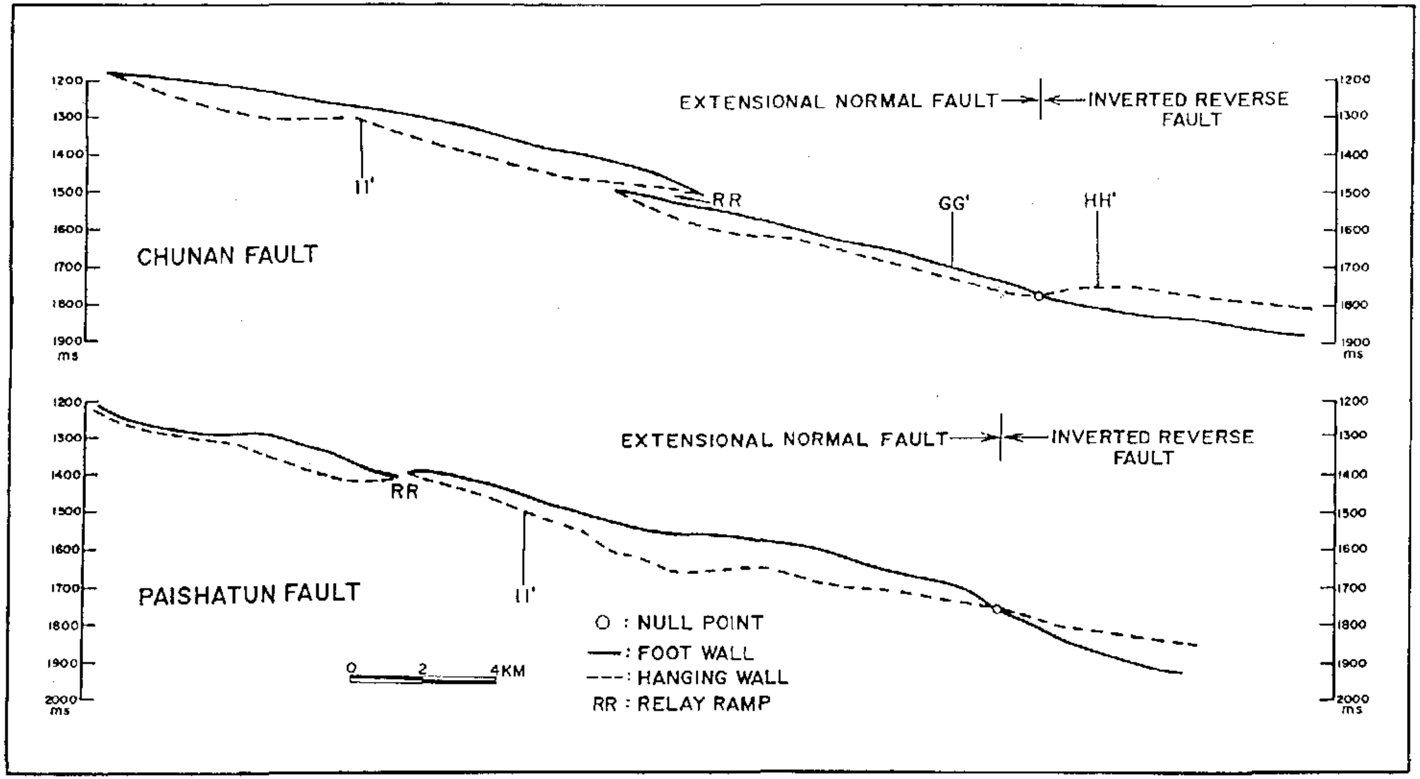

Figure 11. Relation of vertical offset vs distance for the boundary faults in the Nanchunang formation of Wulipai graben. Block line is defined as hanging wall and dash line as footwall (Fault distance is also projected to E-W line. Unit of vertical offset is determined by miniseconds, and distance by kilometers).

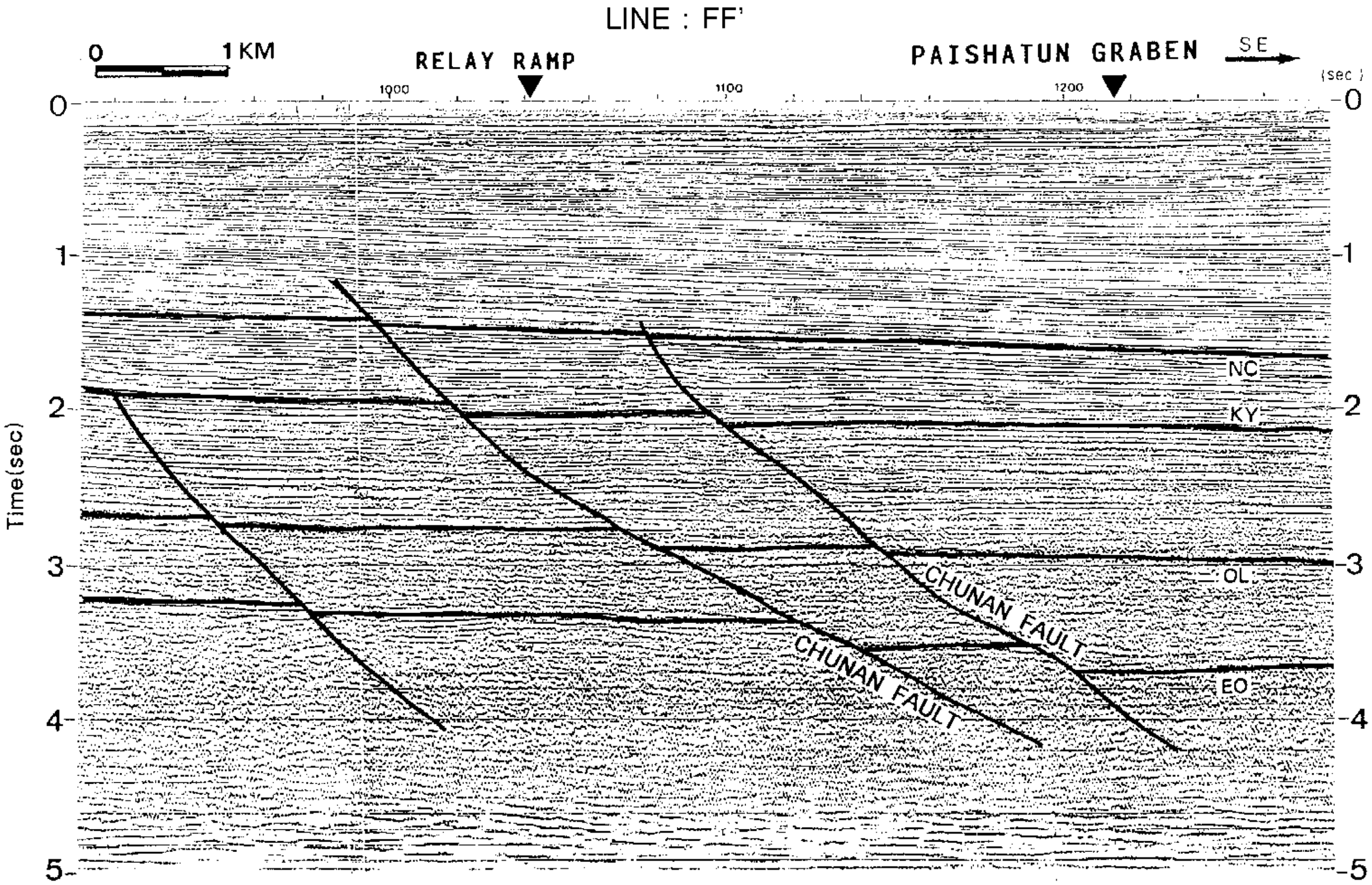

Figure 12. FF' seismic profile exhibiting the relay ramp within Chunan fault system.

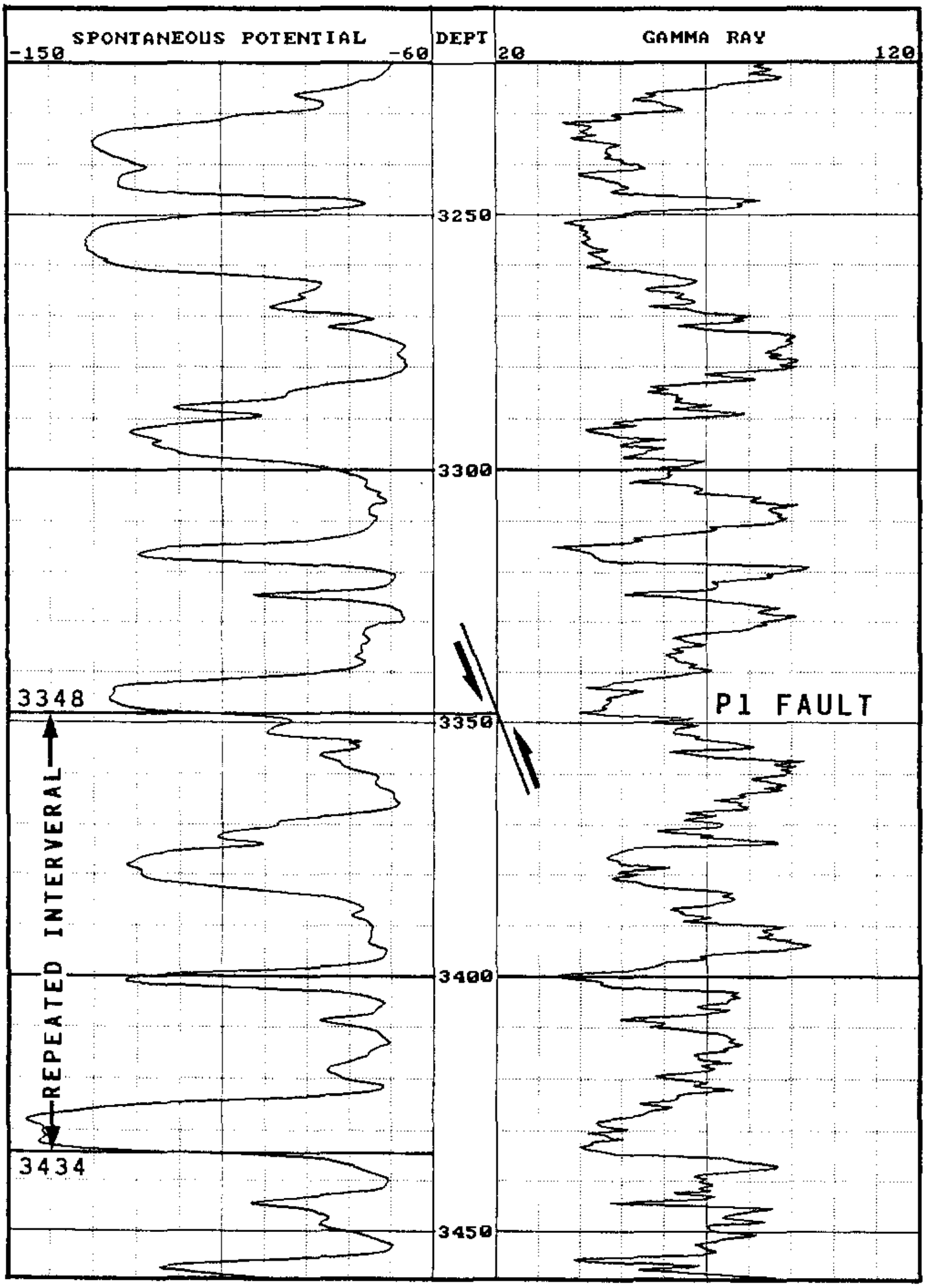

Figure 13. The repeated interval at 3348-3434 meter of C-1 well was produced by P1 thrust fault(after Tseng *et al.*, 1984).

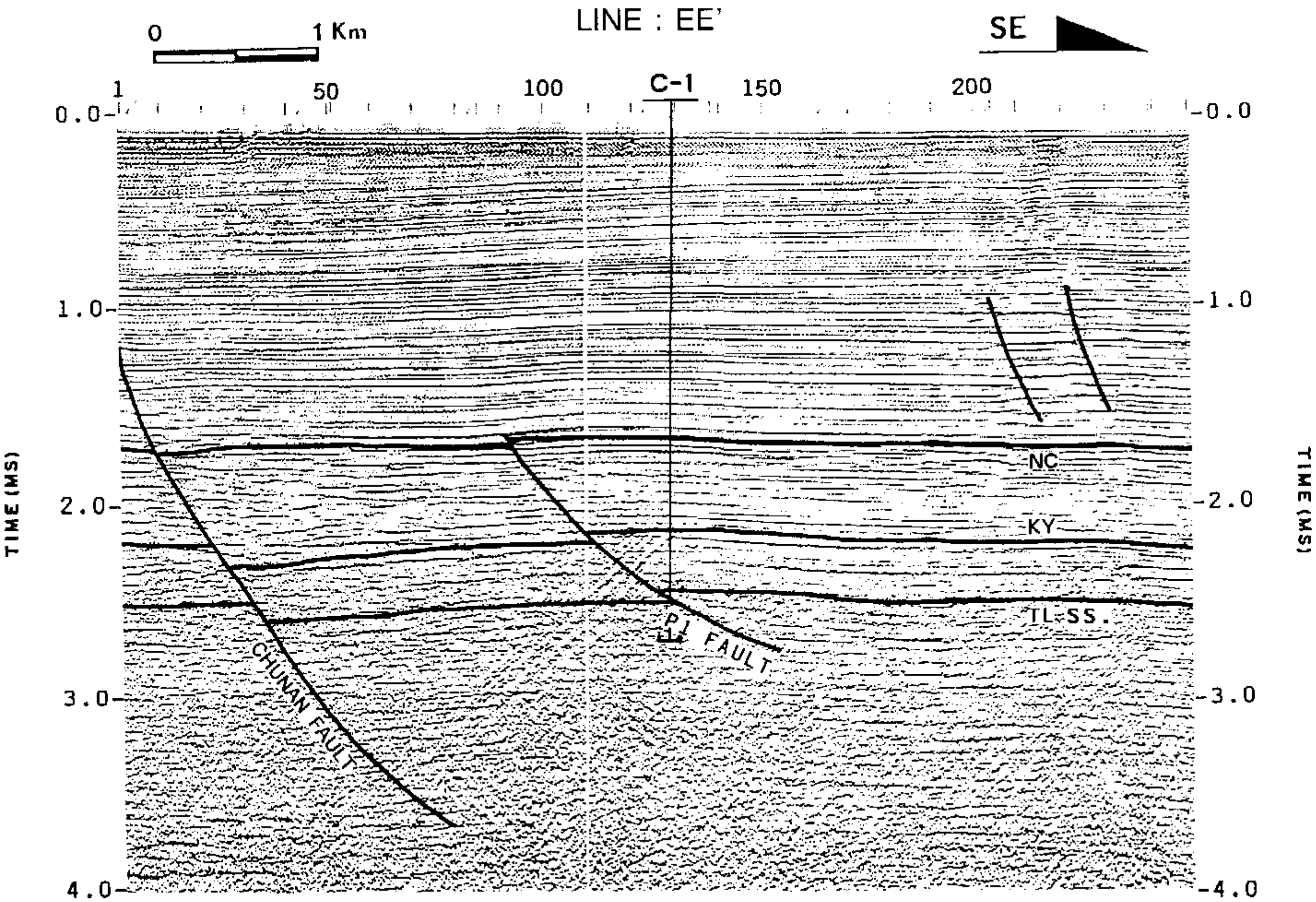

Figure 14. Seismic profile EE' illustrating that the low angle thrust fault P1 occurred in Talu sandstone(after Tseng *et al*., 1984).

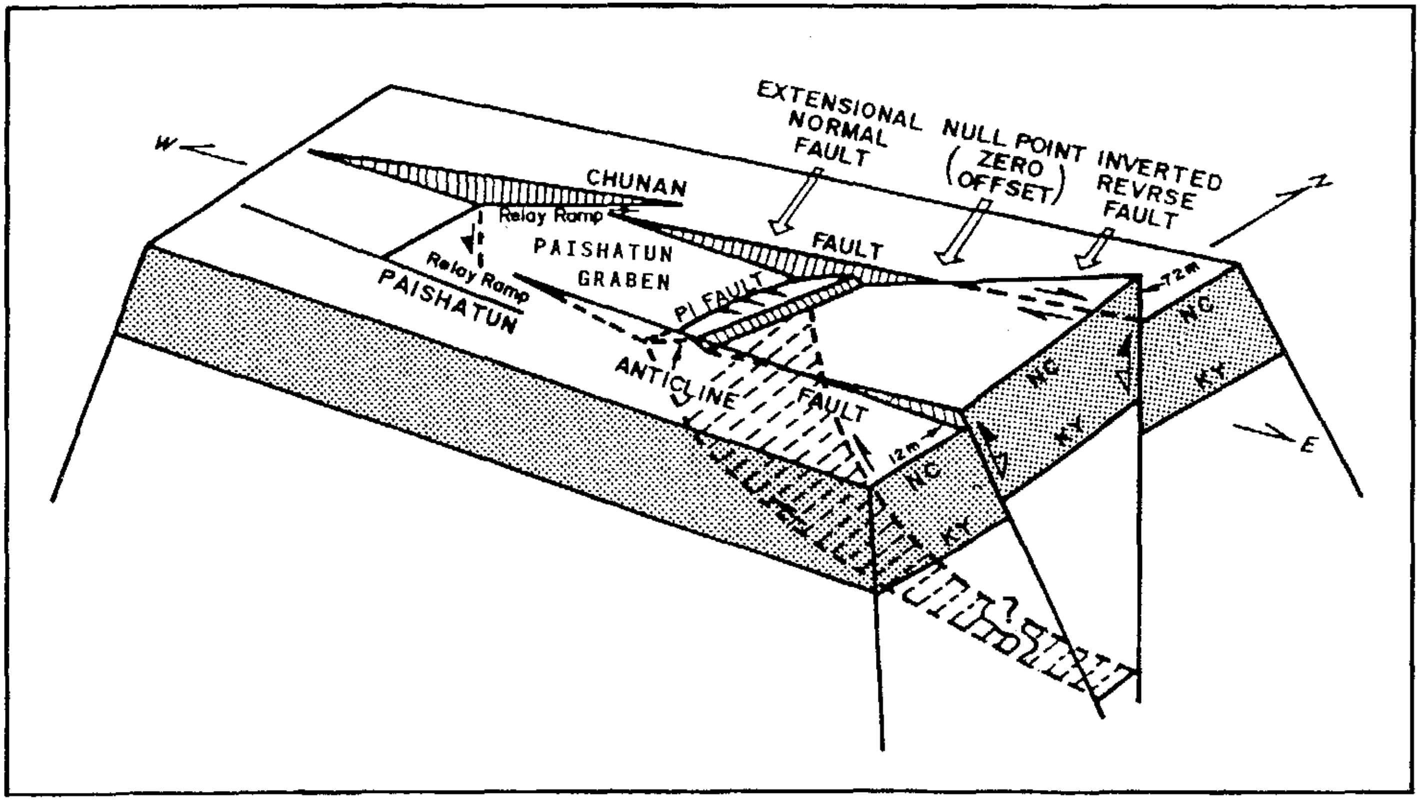

Figure 15. A schematical model of structural geology for Paishatun graben. Two boundary fault systems, the Chunan fault and Paishatun fault are characterized by normal offset, null point, and thrusting offset. Antincline within this graben inclined at a angle about 45° to Chunan fault.

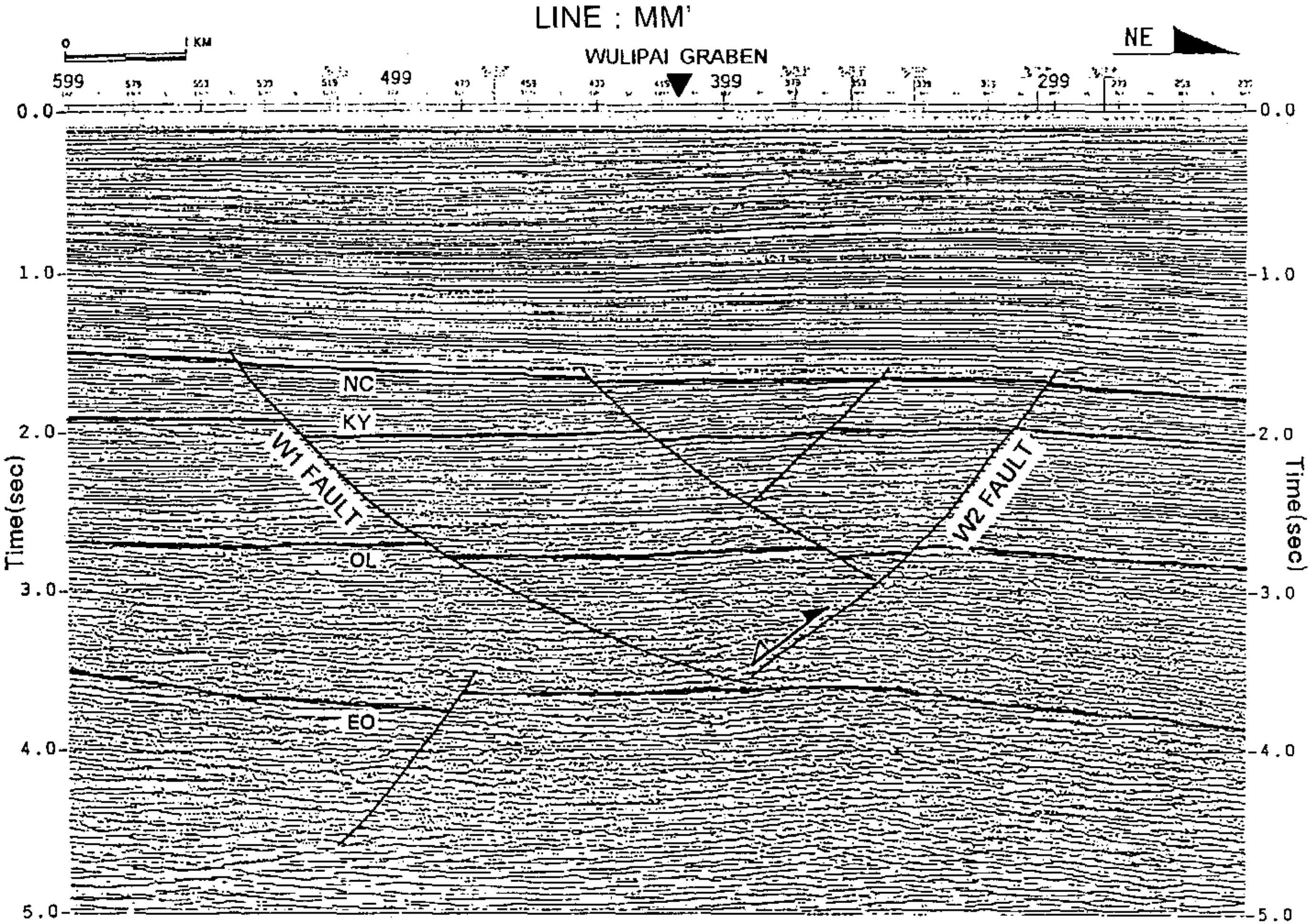

Figure 16. Seismic profile MM'showing the stratigraphy features. Notice W1 fault and W2 fault sole out into the Eocene top or the Oligocene base.

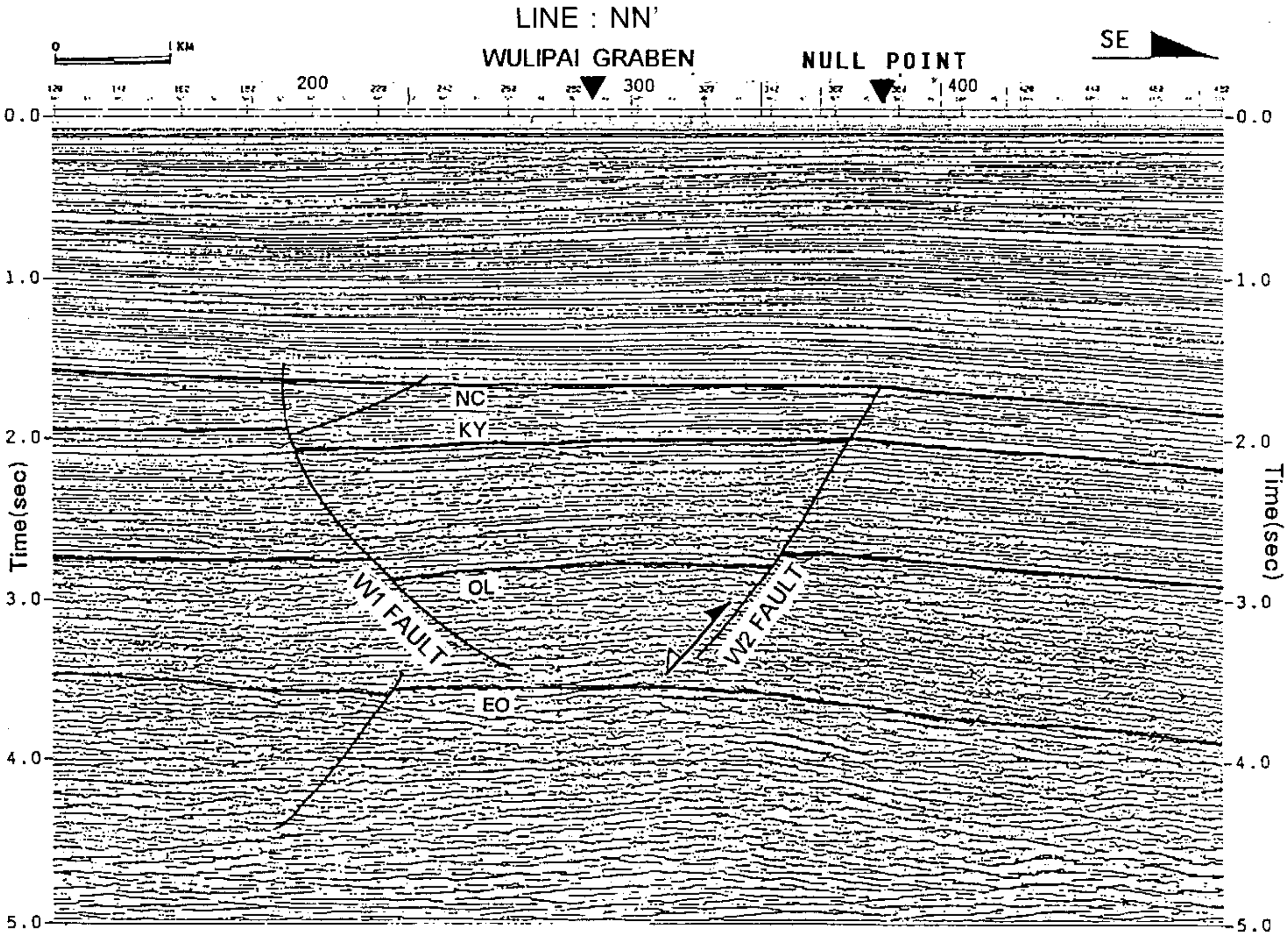

Figure 17. Seismic profile NN' express the feature of the null point of W2 fault.

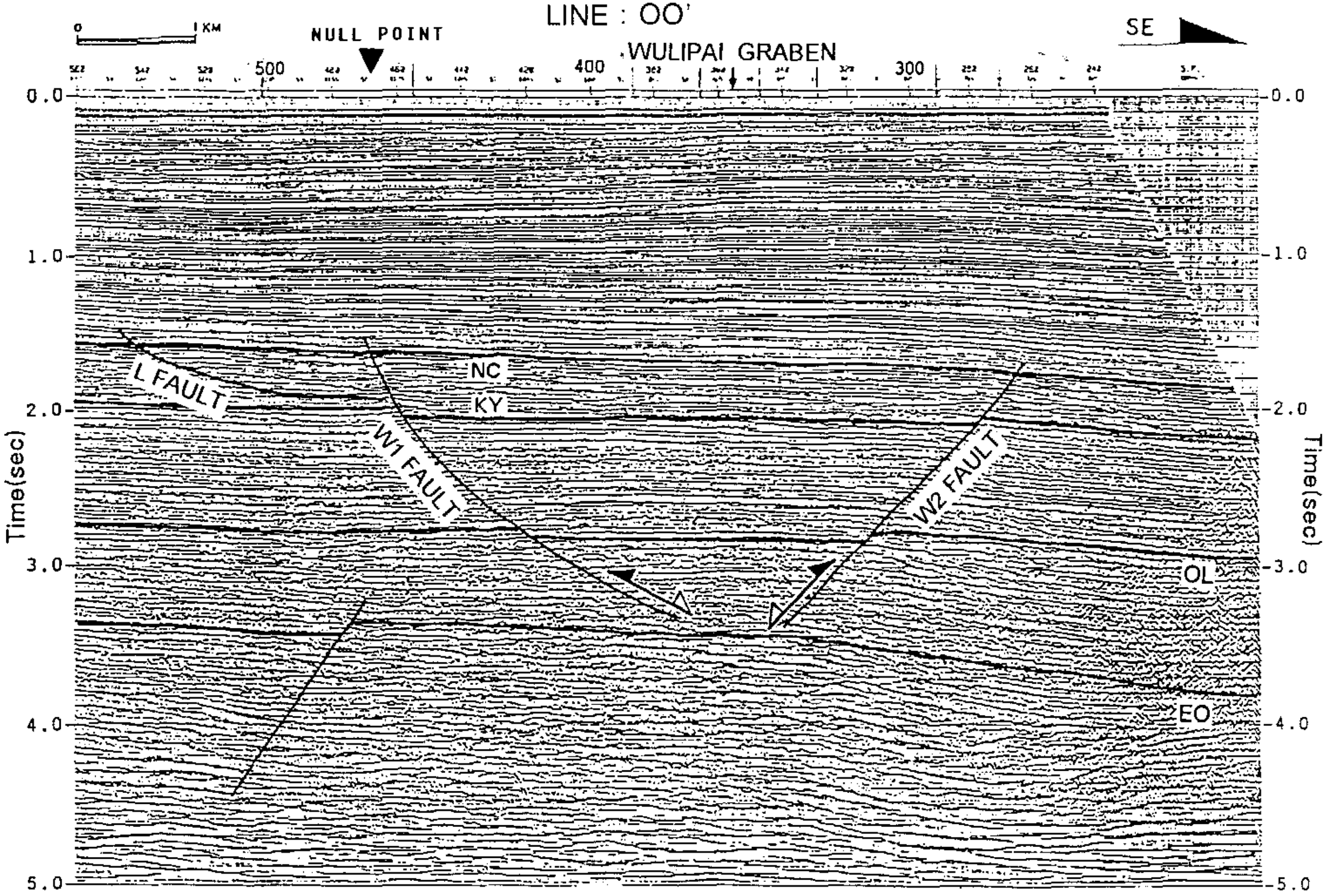

Figure 18. A null point took place in the W1 fault system.

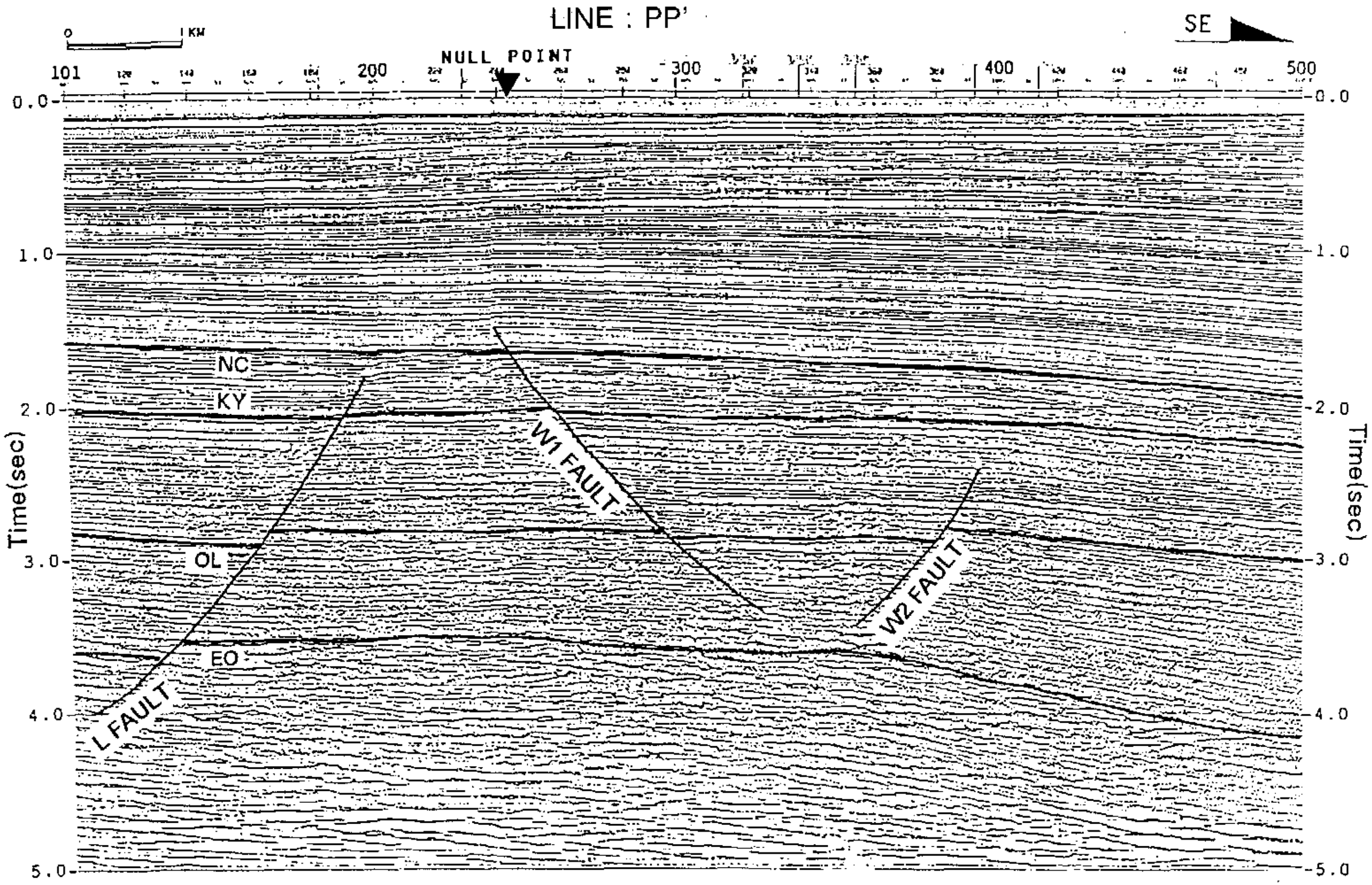

Figure 19. Seismic profile PP' express the W2 fault ends up at the lower Miocene and not develop into NC-KY sequence.

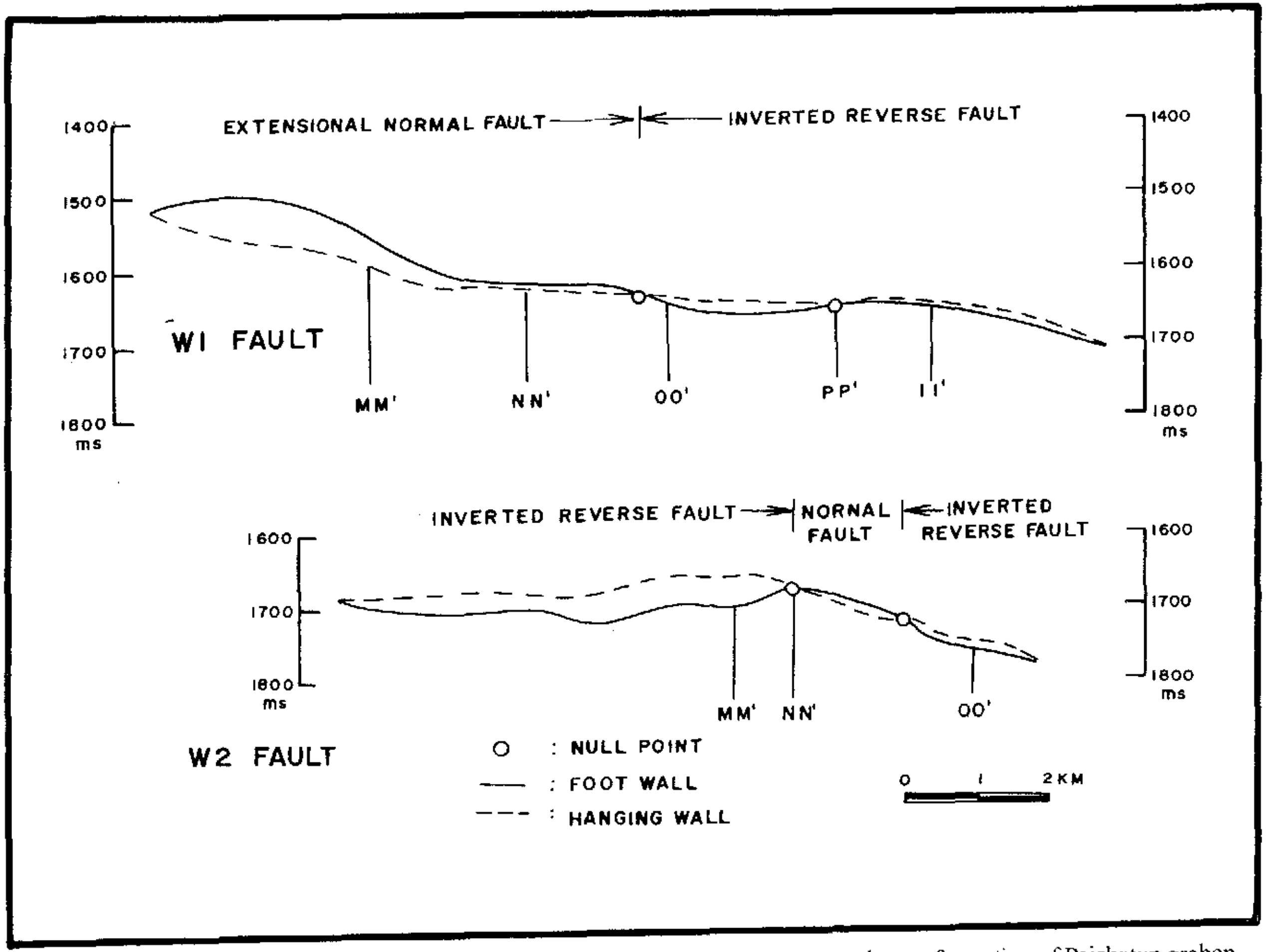

Figure 20. Relation of vertical offset vs distance for the boundary fault in the Nanchuang formation of Paishatun graben. Block line is defined as hanging wall and dash line as footwall (Fault distance is projected to E-W line. Unit of vertical ofset is determined by miniseconds, and distance by kilometer).

could be thought to be the western thrusting-front by the late Miocene Penglai Orogeny in the offshore Miaoli area. To inquire into the deeper structural geometry around the W2 fault , a time structural map of the Oligocene top was completed as shown in Figure 21. It shows that the offset in the Oligocene strata still remains normal faulting state, while normal offset in the Nanchuang formation has been inverted and turned to minor reverse fault except some part of normal offset. An unusual null point is mapped in the mid part of the W2 fault. The closures in both hanging wall and footwall possibly interconnected with each other due to the null point,and could possibly provide path of migration for hydrocarbons. Therefore, the entire clousure is estimated to be about 25 km^2 at the Oligocene top.

IMPLICATION IN HYDROCARBON ACCUMULATION AND PROSPECT

Status of Hydrocarbon Accumulation

Major gas reserves in Taiwan are preserved in the foothills of the Miaoli-Hsinchu area, and most of the hydrocarbons are mainly accumulated in the anticlinal traps. Some of the anticlines are apparently formed by high angle thrust faulting. The others are merely due to folding and apparently are not related to any of thrust faulting observed on the surface. Namson(1981,1983,1984) applied the Suppe's idea of low angle thrust faulting principle in the foothills thrust-folding belt, presenting a favorable solution for the interpretation of the subsurface structures developed in the Miaoli-Hsinchu foohills belt. Yang *et al.* (1994) paid special attention to the sequential deformation of the imbricated thrust fault system developed in the same area, and revised some of the cross sections previously published by Namson. After the structural analysis, they reached a conclusion that the development of thrust faulting in the foothills belt was in sequence: the shallower low angle thrusts were developed prior to the deeper de'collment, and the high angle thrust faults were earlier than or coeval to the shallower low angle thrust faults. Most of the structural traps in the foothills belt of the Hsinchu-Miaoli area were formed by the thrusting along the de'collement. The structures developed along the pre-existing normal faults might be favorable for hydrocarbon prospect, because their associated structures might have accumulated hydrocarbons that were formed during the stage of normal faulting (Lee *et al.*, 1993; Lee and Chang, 1994; Yang *et al.*, 1994).

The drilling result obtained from total of 50 wells in the offshore Hsinchu-Miaoli area, indicated that, being contrary to the onshore area, the recoverable hydrocarbons were accumulated in the traps formed by normal faulting, with a small amount of hydrocarbons recovered in the anticlinal traps. As for the CBK gas field, the gas is accumulated in the northern part of the H2 horst , which is bounded by the antithetic normal fault K. Close study of the K fault shows that the fault grew during the early Miocene and terminated at the end of the late Miocene Nanchuang stage, no more faulting activity being observed since then indicating the fault trap was not affected by the later inversion-tectonics movement. While the analysis of those anticlinal structures with

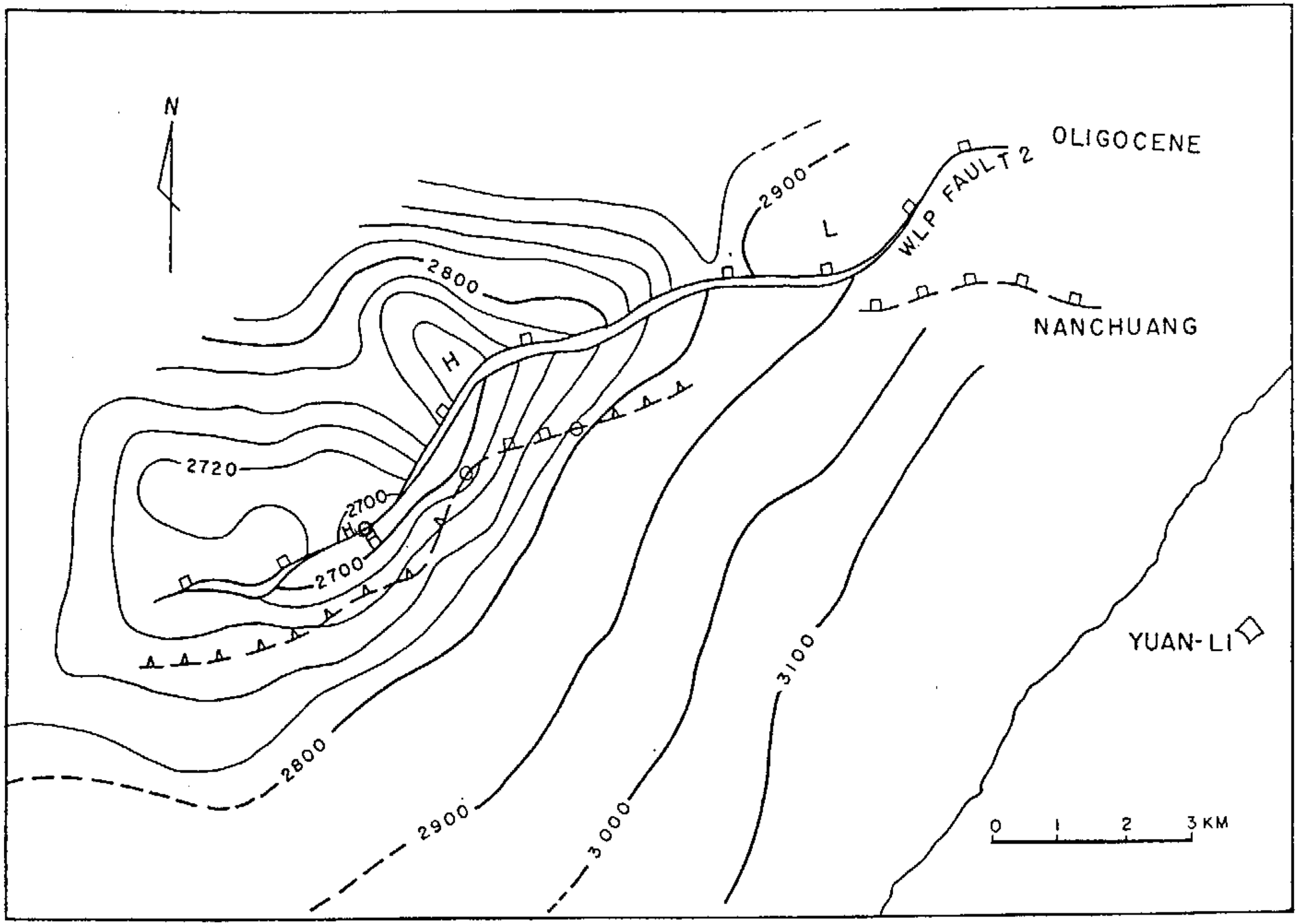

Figure 21. Time contour map at the Oligocene top near W2 fault. Fault offset in the upper Miocene Nanchuang formation is clearly reactivated, while in the Oligocene strata still remain apparently normal faulting. One null point is mapped in the Oligocene. An estimated closure of about 25 km2 is measured at the Oligocene top.

bearing of hydrocarbons shows that, some of those might be developed originally as a rollover structure along the normal fault, which was reactivated in the strike-slip tectonic regime, and finally inverted to the present fault-anticline, with its reverse faulting reached to the surface(Fig. 2). The hydrocarbons originally traped in the rollover structure might remigrate to the surface through the inverted reverse fault plane.

Hydrocarbon Prospects

- The H1 horst, lying to the immediate west of the H2 horst, in which the CBK gas field being located, will be considered a potential block for hydrocarbon prospect, simply because of their identify in general geologic characteristics. Any structural closures of normal fault traps, confirmed in the H1 horst or in between the H1 horst and the H2 horst, are proposed to be drilled to the lower Miocene potential hydrocarbons.
- The H3 horst, bounded by the Paishatun graben in the north and by the Wulipai graben in the south, will be a favorable block for hydrocarbon prospect, because it is free from the influence of the inversion tectonic deformation. Actural testing of one well drilled in the western homoclinal part of the H3 horst, proved productive oil shows in the lower Miocene horizons. Further drilling in the structural closures confirmed in the H3 horst is highly encouraged.
- It is easily found in the illustrated seismic profiles shown in Figures 16 to 19 that, the Wulipai graben is developed on the immediate north of the Eocene basement hinge scarp, from which the Oligocene and Miocene sequences being thicken southeastward for about 20 kms in distance to their supposed depocenter located somewhere around what was called the Taichung basin by Schreiber(1965). As shown in Figure 21, a well defined spindle-shaped structure is developed along the marginal W2 fault of the Wulipai graben. Although the structure is devided by the W2 fault into the apparent two blocks, as the thrown of the fault being horizontally died out in the null point located at the middle part of the structure, they may be interconnected with each other to form a complete structural closure. Therefore, in combination with good seal by the overlying thick and wide younger formation, this spindle-shaped structure with an estimated areal structure closure of 25 km^2 is regarded as the most potential prospect to accumulate the earlier hydrocarbons migrated updip from the supposed depocenter.

CONCLUSIONS

The top of Nanchuang formation is a regressive flooding surface. It is a regionally traceable unconformity, marking not only a good formation boundary but also the change between rifting and compressional tectonic regimes. The time structural map of this horizon is very helpful for the inversion-structure analysis.

The Waihsiangshan fault was determined as dextral strike-slip fault based on the en'echelon arrangement of a series of shear folds occurring in the hanging wall block of Waihsiangshan fault as well as the variable structural change.

The Paishatun graben and Wulipai graben are two major inverted grabens and characterized by a special fault array of reverse fault-null point-normal fault along the same boundary fault of both grabens.

For Paishatun graben, the extent of inversion or reactivation of the Chunan fault is larger than that of Paishatun fault. Ellipsoidal anticlines took place within the central part of the graben and the axis of folds inclined at an angle to the fault zone of the graben margin. The direction of fold axis is more or less coinsistent with the trend of Lungkang fault in the onshore area. Based on the above two points, it can be concluded that the Paishatun graben was subject to bulk contraction of structural inversion, and also accompanied with low extent of strike-slip motion.

In Wulipai graben, the W1 growth fault was highly developed during the Nanchuang-Kuanyinshan stage, and inverted during Penglai Orogeny. It is also noted that the W1 fault is the westmost front-thrust generated by the Penglai Orogeny. Most of the listric surface of the W1 fault soled out into the Eocene top or the Oligocene base. The W2 fault is one of the important associated antithetic faults of the W1 fault.

The W1 fault and W2 fault are not extended into onland of Taiwan. They die out at the coastal area of northwestern Taiwan. There are two null points on each boundary fault W1 and W2 in the Nanchuang formation top. Closing to these null points, both of normal or thrusting offset within these faults of Wulipai graben margin are gradually decreasing.

Both of the Paishatun graben and Wulipai graben have been subjected to structural inversion. The W1 fault and P1 fault are thought to be fronts thrusts of the Taiwan orogen. West of the W1 fault and P1 fault, it is difficult to find systematic thrust faults.

A null line, connecting with each null point of the inverted major faults, is drown to define the possible extension area of the inverted tectonic deformation. The west side of the null line is generally considered free from structural deformation, and is characterized by being dominated with extensional normal faults, providing a favorable condition to accumulate hydrocarbons in the normal fault traps. The CBK gas field in the H1 horst is a typical example of the normal fault trap in origin. Any confirmed closures of the normal fault traps developed in the H1 and H3 horsts, will be considered the ideal prey for hydrocarbon prospect.

Synthetic analysis of the Waihsiangshan fault and its associated foldings has verified that it is acturally the inverted reverse fault with strike-slip displacement. The reactivation may be conducted through a simple shearing stress along the pre-existing normal fault. A series of the induced drag foldings, which is known as the WHS, Tung, CBA and the CBL structures, arranged more or less en'echelon lying respectively on the C-TL-TA faults to form the present Waihsiangshan strike-slip fault system. Actural drillings obtained from these folding structures indicated most of them are bare of hydrocarbons.

The spindle-shaped structure, developed along the southern marginal fault W2 of the Wulipai graben, is regarded as the most potential hydrocarbon prospect in the study area. Because the structure is grown on the Eocene basement hinge scarp, which is located to the immediate north of the depocenter, where the supposed prolific lower Miocene and Oligocene organic source of hydrocarbons are generated. What is more, the structure is not destroied by the latter thin-skinned inversional tectonic disturbances. An estimated areal structure closure of 25km^2, being measured on the top horizon of the Oligocene, will be sufficient to accumulate a commercial size of hydrocarbons. Closures in the hanging wall and footwall of W2 fault in the Oligocene horizon could be possibly interconnected each other, in consideration of the hydrocarbon migration and accumulation, as the null point took place in the horizon of the Oligocene age.

In the near future, extending the study of the inversion structural styles, the structures and structural traps with hydrocarbon bearing to be expected in inverted basin of the offshore of Miaoli-Hsinchu, Taiwan can be predicted with increasing a high degree of confidence.

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苗栗外海的地質構造逆轉特徵

沈顯全　黃旭燦　湯振輝　徐永耀

節要

從中新世的晚期開始，臺灣西北部的苗栗新竹外海的前淵盆地良好地保留了臺灣地區因弧陸碰撞而造成的構造逆轉變形。古第三紀張裂性的正斷層系統，雖經過了中新世時期，仍可區分為數個地塹及地壘。先前存在的正斷層的再活動和逆轉在構造變形及油氣儲集方面扮演了重要的角色。

在本研究區主要的構造單元包括外香山斷層、白沙屯地塹以及五里牌地塹。白沙屯地塹的邊界斷層在北側是竹南斷層，而南側則為白沙屯斷層。五里牌地塹的邊界斷層在西北側是W1斷層，東南側是W2斷層。所有的這些斷層原先是正斷層，在晚新生代的蓬萊運動期間，再復活及產生構造逆轉。

在本研究區內，南莊層的頂部構造圖被用來分析解釋逆轉構造的特徵。由於一系列雁行排列的褶皺出現於外香山斷層的上盤以及多變化的構造特徵，外香山斷層可被證實為右移橫移斷層。白沙屯地塹及五里牌地塹的所有邊界斷層共同的逆轉構造特徵是：正斷層、逆轉零點、逆斷層有順序地排列沿著這些邊界斷層出現。

聯結這些斷層的逆轉零點，得到一條所謂的逆轉零線。此逆轉零線約略可視為蓬萊運動所影響至最西緣的構造逆衝界線，往此線之西北方向很難再發現逆斷層。在逆轉零線的東側，小而明顯的逆斷層非常發達，在構造上可以說是較不穩定的構造逆轉地區，然而在逆轉零線的西側是屬於張裂性正斷層發達的較穩定地區。W1斷層及P1斷層被證實是淺層的逆衝斷層，可認為是蓬萊運動的最前緣逆衝斷層 (front-thrust)。

就油氣的儲聚觀點，穩定區塊是較有利於油氣的儲聚，因為有較優良的橫向斷層封閉效果。但是，在逆轉零線東側，接近W2斷層的構造高區是蓬萊運動所影響最西側的背斜，由於有面積寬廣且鉅厚的年輕地層為垂直蓋層封閉，故具有極高的油氣潛能。但必須注意位於漸新統頂部的逆轉零點可能會使W2斷層上下盤的圈合之間，互相連通而讓流體流過W2斷層面。