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Trap styles of the Tenggol Arch and the southern part of the Malay Basin

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Abstract: The Tenggol Arch and the southern part of the Malay Basin are situated in offshore Terengganu, Peninsular Malaysia. They are believed to form parts of an Early Oligocene (?) rift system.

Drape and anticlinal features and fault/dip closures have been identified in the area. The drapes are common features of the Tenggol Arch, and they are generally of low reliefs associated with basement topography. The anticlinal features are characteristics of the Malay Basin, and they are generally elongated with great reliefs. Fault/dip closures are found near the eastern flank of the basin against the faulted margin of the Tenggol Arch. These anticlines and fault/dip closures are believed to be related to the shear movement during Miocene.

The above trap styles have been tested and commercial hydrocarbons accumulations have been found in some of them.

INTRODUCTION

A total of 23 exploration and delineation wells have been drilled on the Tenggol Arch and the southern part of the Malay Basin by CONOCO and PETRONAS Carigali Sdn Bhd. Twenty of these wells were drilled in the southern part of the Malay Basin, and only 3 wells on the relatively unexplored Tenggol Arch. Most of these wells penetrated the entire Tertiary section.

About 14,000 kms of seismic data have been acquired from 1968 to 1985. The seismic data acquired from 1968 to 1974 are of fair quality biased towards low frequencies and were mostly acquired as regional seismic lines. However seismic data acquired from 1981 to 1985 are of good quality, and were acquired for prospect delineation.

REGIONAL SETTING

The Tenggol Arch plunges south-eastwards, and it separates the Malay Basin from the Penyu Basin (Fig. 1). The arch is a relatively stable block which has not seen to be affected by later tectonics. Sediment thickness averages about 1000 m in the Tenggol Arch.

The Malay Basin, which is situated north of the arch is a Tertiary basin filled with more than 10,000 m of sediments at the depocentre. However thickness of sediments in the southern part of the basin is observed to be only about 5000 m. This basin is elongated and it extends approximately 500 km along it's northwest-southeast axis and is approximately 200 km wide. *En echelon* anticlines and north trending faults are the dominant structural features.

The north eastern margin of the Tenggol Arch is marked by a normal fault. This north-

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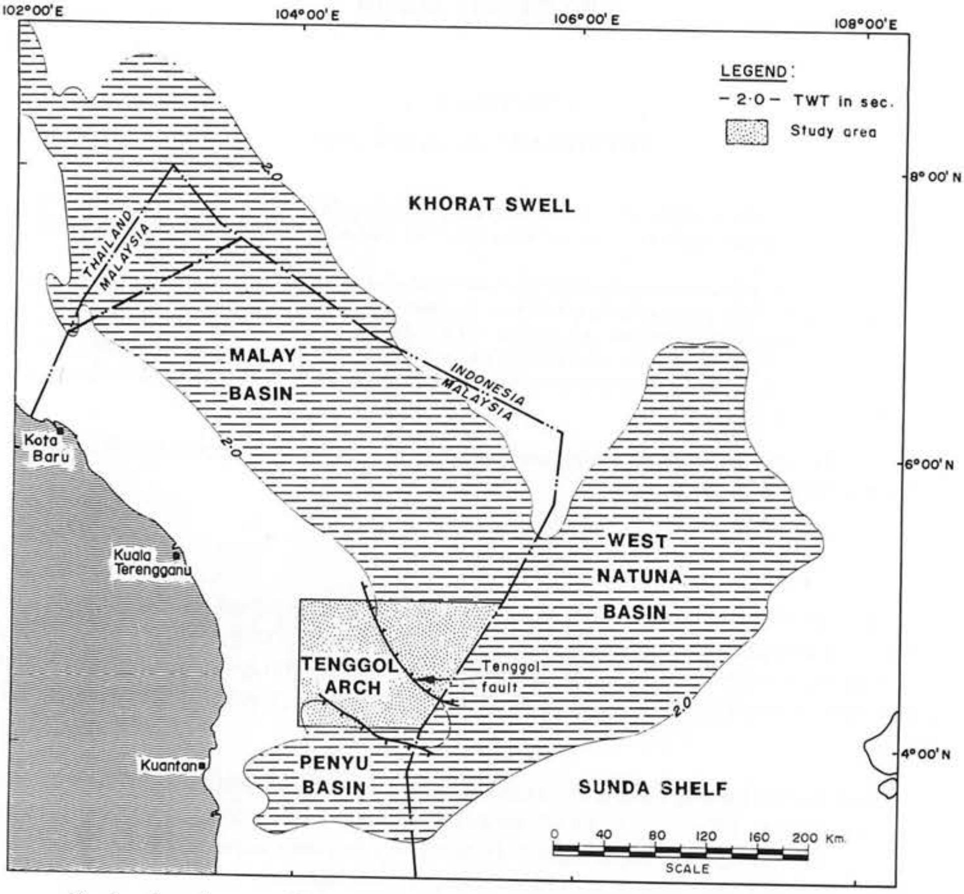

Fig. 1. Location map of Malay Basin, Penyu Basin, West Natuna Basin and Tenggol Arch.

east hading fault has a maximum throw of approximately 2500 m at the basement level, and it marks the geological boundary between the Tenggol Arch and the southern part of the Malay Basin.

Biostratigraphic data suggest that the depositional environment in the Tenggol Arch and the southern part of the Malay Basin from Oligocene to Early Miocene were predominantly non-marine with minor marine transgressions in the Early and Middle Miocene. This was followed by the deposition of marine sediments during post Late Miocene.

Trap styles in the area are believed to be associated with two major Tertiary tectonic episodes (Fig. 2). The first episode was probably an extensional phase relating to rifting and basin subsidence during Early Oligocene. The second episode involved compressional stresses during the Miocene, which resulted in the development of anticlines.

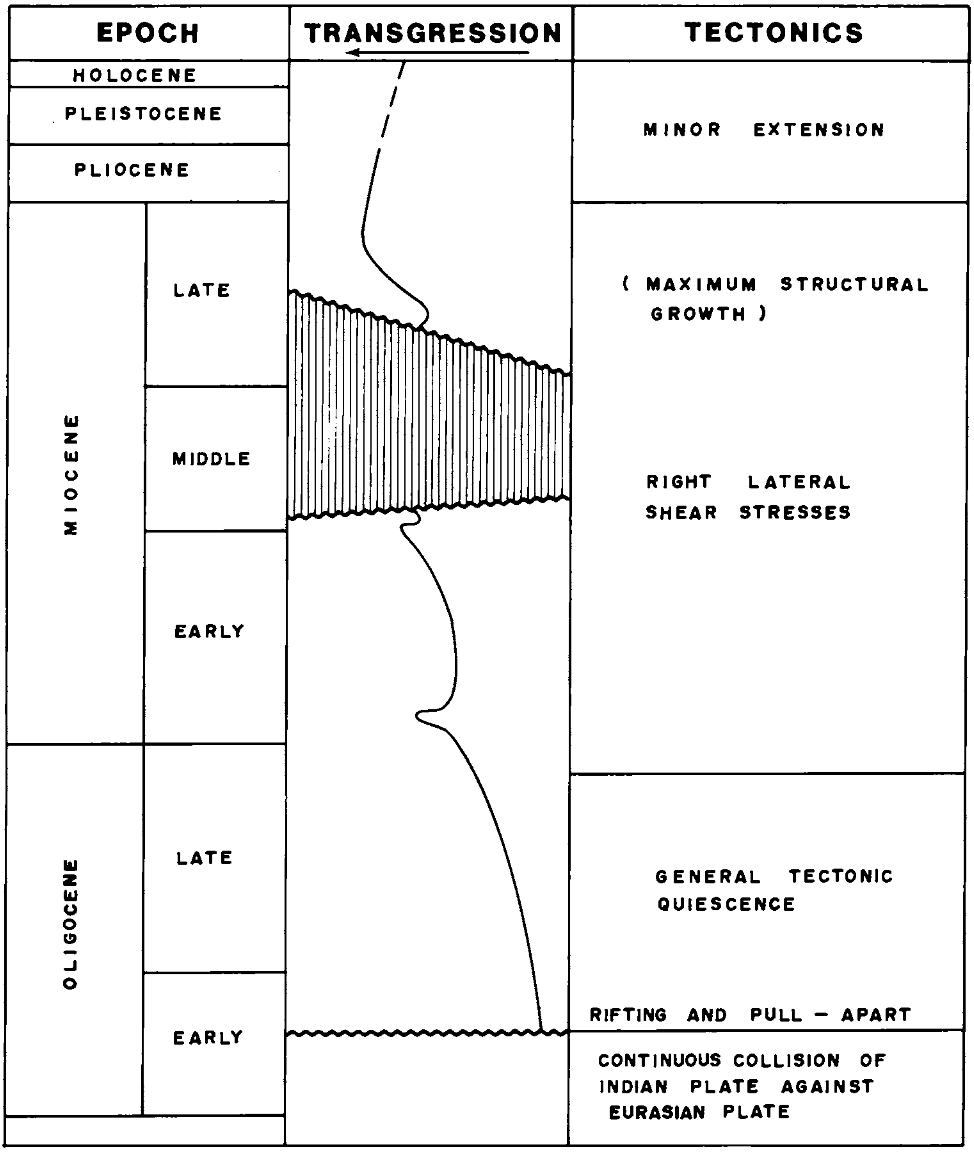

Fig. 2. Time-table of the major tectonic history of the Malay Basin and the Tenggol Arch.

STRUCTURAL HISTORY

During Early Oligocene much of the topography of the Tenggol Arch was eroded to a peneplain (Fig. 3). Dipping seismic reflectors seen on seismic data imply the presence of older sedimentary layers beneath the deep regional unconformity. These sediments which constitute the basement rocks could be as thick as 2500 m. The Kempas well which was drilled into this interval has encountered highly compacted argillaceous sandstone, with

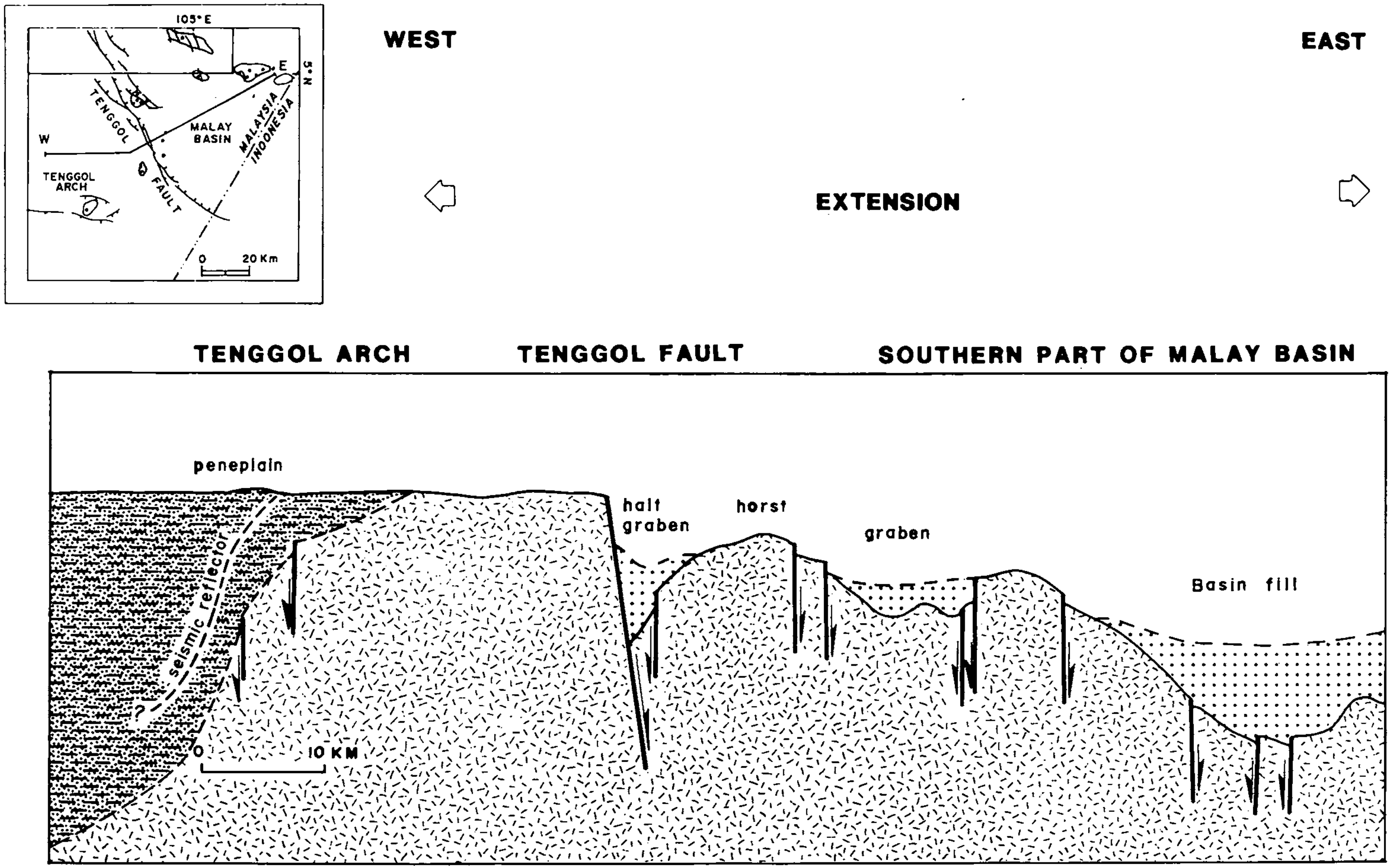

Fig. 3. East-West cross-section across the Tenggol Arch and the southern part of the Malay Basin highlights the geomorphology during early Oligocene. Peneplain, half graben, graben and horst block were the early structures formed.

higher sonic responses compared to the overlying sediments. Elsewhere in the area, the basement rocks encountered consist of granite, volcanics, phyllite, argillite and limestone.

Basin inception in this region could be the result of the Indian plate colliding against the Eurasian plate, creating an extensional regime in the Sunda Land (Tapponnier *et al.*, 1982). Grabens, half grabens, horsts and tilted blocks were the early structures formed.

Most of the sediments were sourced from the Tenggol Arch and the nearby horsts and tilted blocks. However in the northeast corner of the study area, some could have been sourced from the Khorat Swell. Dip-meter study of the Duyong wells suggests this possibility. Alluvial fan deposits provided much of the initial fill of the basin and later during Late Oligocene a widespread shale was deposited in the southern part of the Malay Basin. In the Anding area the shale thickness ranges from 40 to 70 m, which progressively thickens east-wards (Fig. 4).

Compressional (right lateral shear) stresses occurred during Miocene, which resulted in structural reversal and formation of anticlines (Fig. 5). Consequently the Tenggol fault was reactivated, together with the development of other faults in the area. Fault/dip closures were formed on and along the downthrown side of the Tenggol fault. However, the Tenggol Arch continued to remain relatively stable.

Structuring of the Duyong anticline continued up to Late Miocene and ceased in Pliocene (Fig. 6). A minor extensional tectonic phase during Pliocene resulted in the formation of younger normal faults.

TRAP STYLES

The structural trap styles observed in the Tenggol Arch and southern part of the Malay Basin consist of drape features, compressional anticlines and fault/dip closures (Fig. 7). Stratigraphic traps are also observed in the area but they will not be discussed in this paper.

Drape Features

In general the drape features display low relief four-way dip closures. Some of these features are fault assisted dip closures. Average vertical closure of the drape features is in the order of 10 to 50 m, while their areas range from 3 to 20 sq kms. These subtle traps can only be confidently delineated by a dense grid of 1 by 1 km high resolution seismic data.

Drapes are usually associated with basement 'highs' and were believed to have been formed as a result of post-depositional differential compaction of Oligocene sediments overlying the basement highs (Fig. 8). Along the western flank of the southern part of the Malay Basin the basement 'highs' constitute horsts and tilted blocks. The Sotong structure is a typical example of a drape feature which developed over a basement tilted block (Fig. 9). This is a fault assisted closure. The major fault at Sotong is believed to have been reactivated during Miocene. Onlapping of the Oligocene sediments is seen on the seismic line. Southeast of the Sotong structure is the Delah structure which has the same characteristic features as Sotong (Fig. 10).

On the Tenggol Arch the drape features are usually associated with basement 'highs' which are erosional remnants. The basement 'high' of Malong is made up of the more-

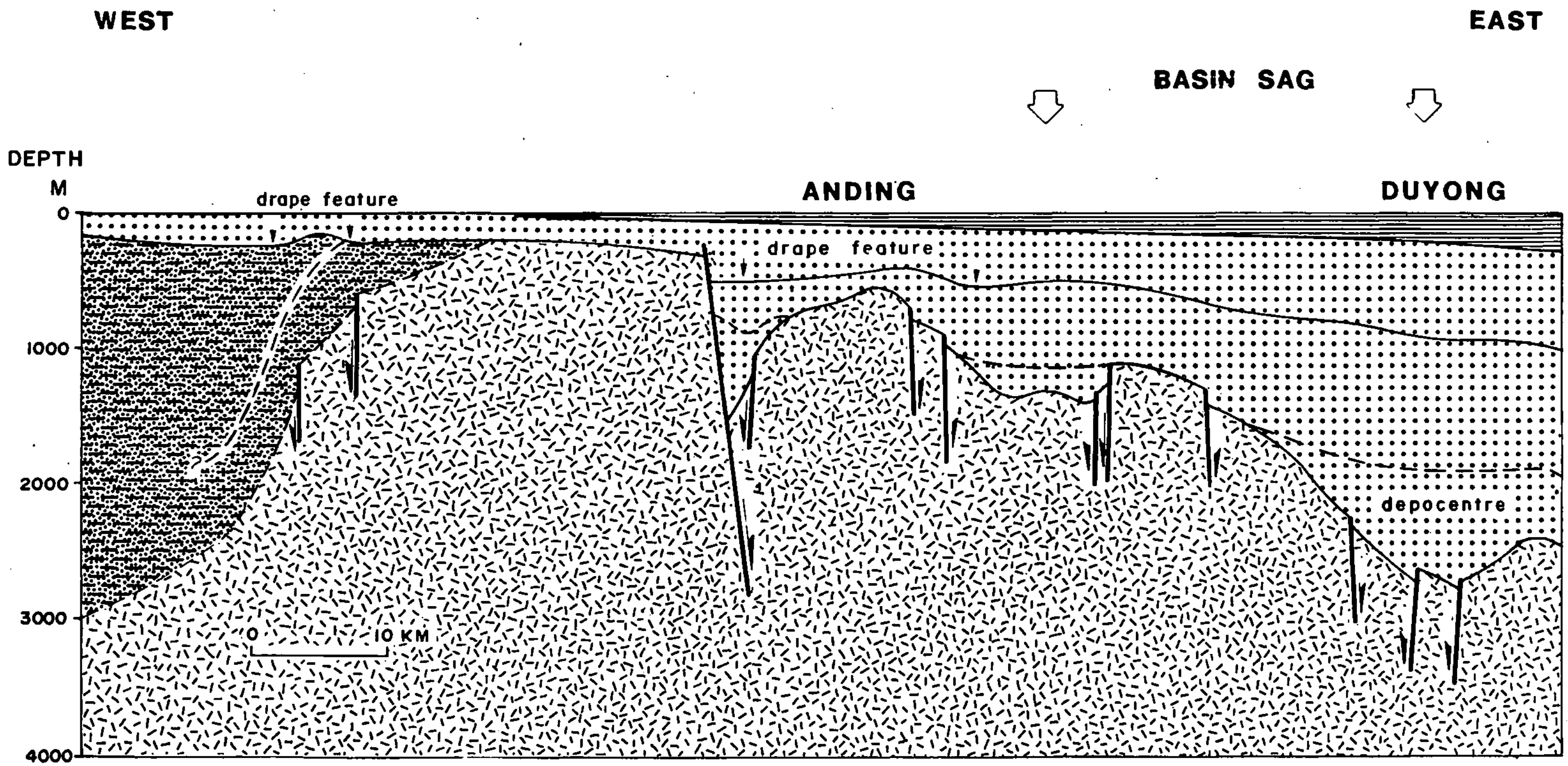

Fig. 4. East-West cross-section highlights structural evolution during Late Oligocene. The top sediment is a regional shale marker. Drape features over basement 'high' are the common feature.

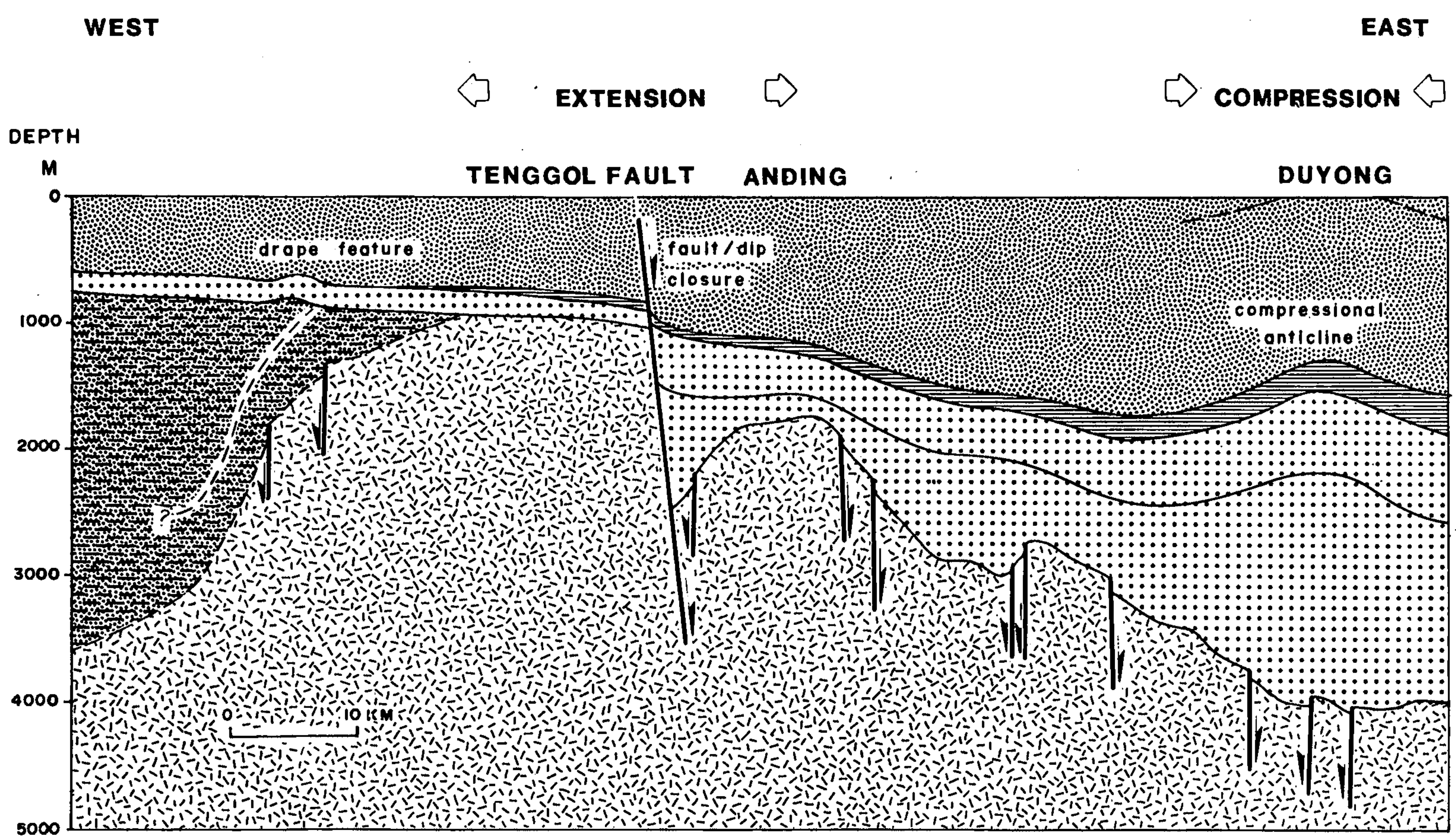

Fig. 5. East-West cross-section highlights structural evolution during the Late Miocene (Regional Uncf). Formation of compressional anticline at the Duyong structure.

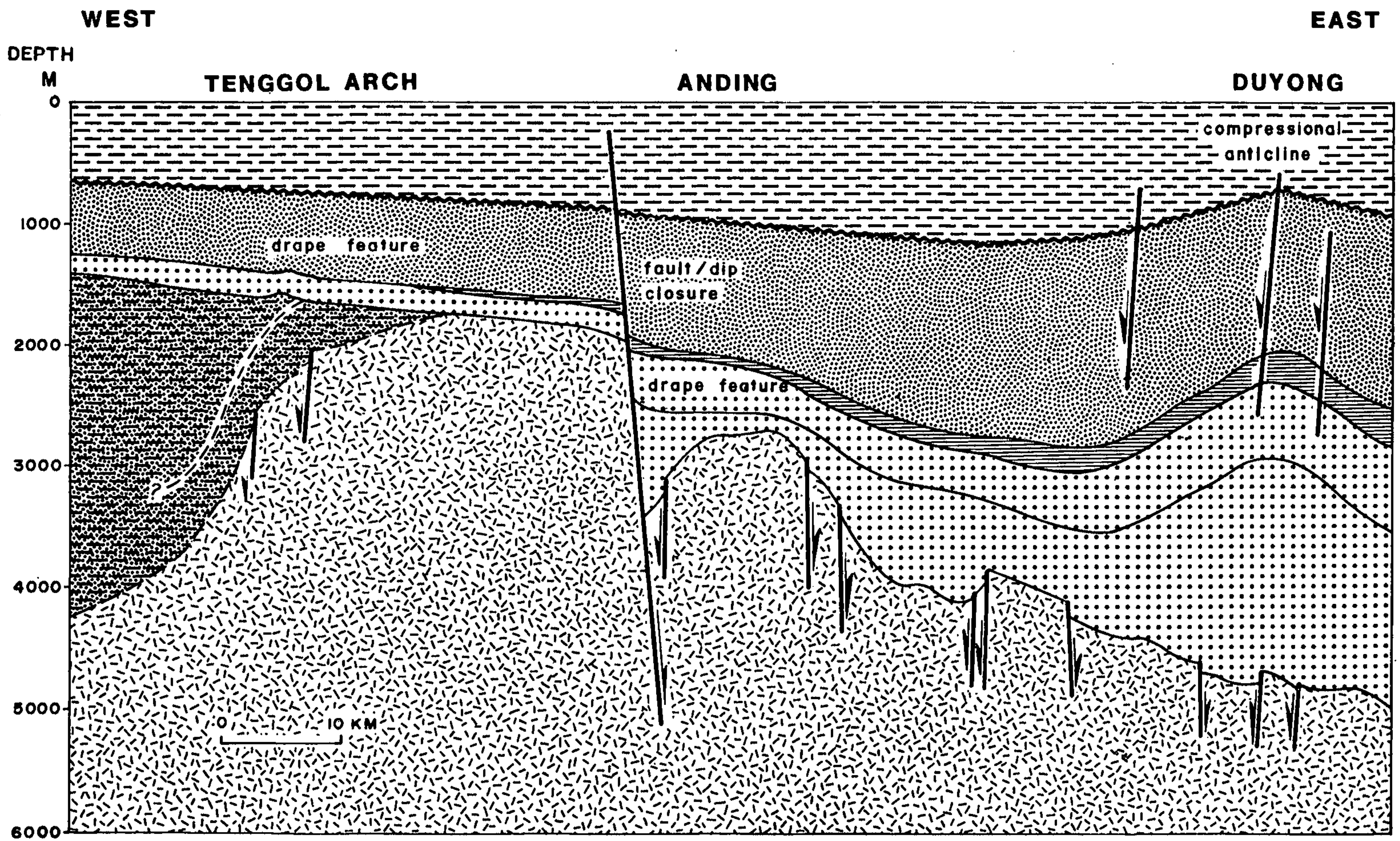

Fig. 6. East-West cross-section as constructed from seismic sections highlights the present day subsurface structure.

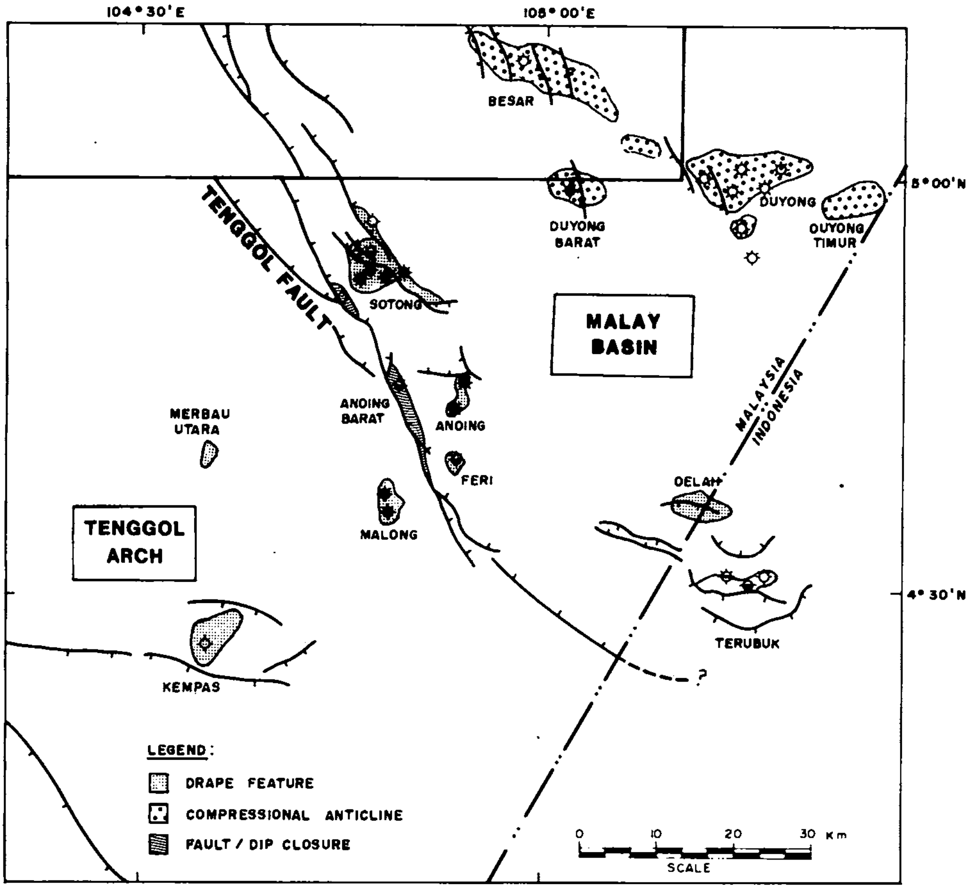

Fig. 7. Distribution of the trap/style found in the Tenggol Arch and the southern part of the Malay Basin. Drape features are located in the western part while compressional anticlines in the north-eastern part. Fault-dip closures are located on the downthrown side of the major Tenggol fault.

resistant igneous rocks (Fig. 11). Onlapping of sediments onto the basement 'high' flank is also observed around the Malong structure. East of Malong, the sequence underlying the deep regional unconformity is interpreted to consist of older sedimentary rocks (Fig. 12). At Merbau Utara, the basement 'high' is probably associated with a more resistant sedimentary unit, such as sandstone.

Anticlines

Compressional anticlines characterise the north and north-eastern corner of the study area. The anticlines are usually stretched and elongated, and oriented in the general west-northwest and east-west directions. They are aligned in an *en echelon* pattern. The Duyong structure is part of a prominent west-northwest Angsi-Besar-Duyong feature. Hamilton (1979) inferred that this obligue orientation of the *en echelon* structures could be related to right-lateral shear which oriented in the northwest direction.

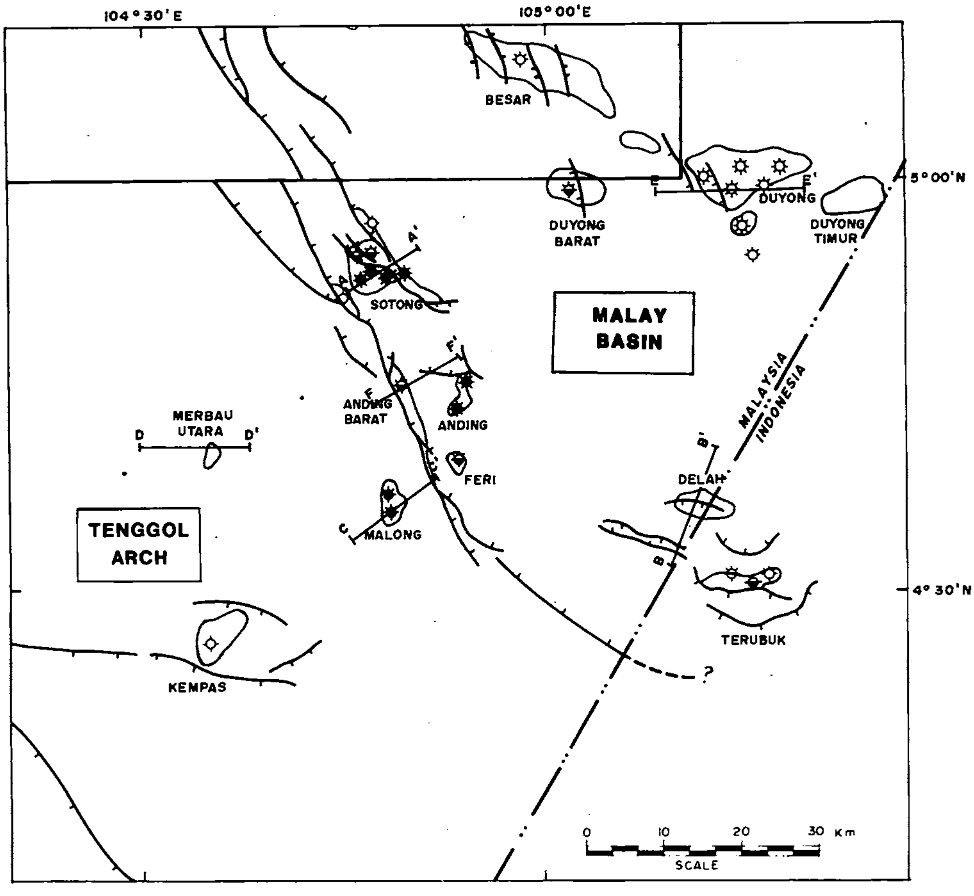

Fig. 8. Location map of seismic line AA', BB', CC', DD', EE' and FF' as shown in Figs. 9, 10, 11, 12, 13 & 14.

Over the Duyong area the result of this right-lateral shearing is illustrated in Figure 13 showing structural inversion phenomenon. This phenomenon is believed to be most intense during Late Miocene. The Duyong structure has structural closure of 100 sq km and vertical relief in the order of 200 m.

Fault-dip Closures

The third structural trap style found close to the Tenggol fault is formed by dip closure of Oligocene and Early Miocene sediments against the downthrown side of the fault. These structures tend to be elongated. In Anding Barat, the maximum length to width ratio is about 10 and the vertical closure is about 80 m at the late Oligocene level. Near the vicinity of Anding Barat (Fig. 14) a fault throw exceeding 1000 m at the basement level has been observed. Reactivation of the fault has occurred up to recent times resulting in a throw of only 150 m at the Top Oligocene level. To date, only negative drilling results were obtained from such structures.

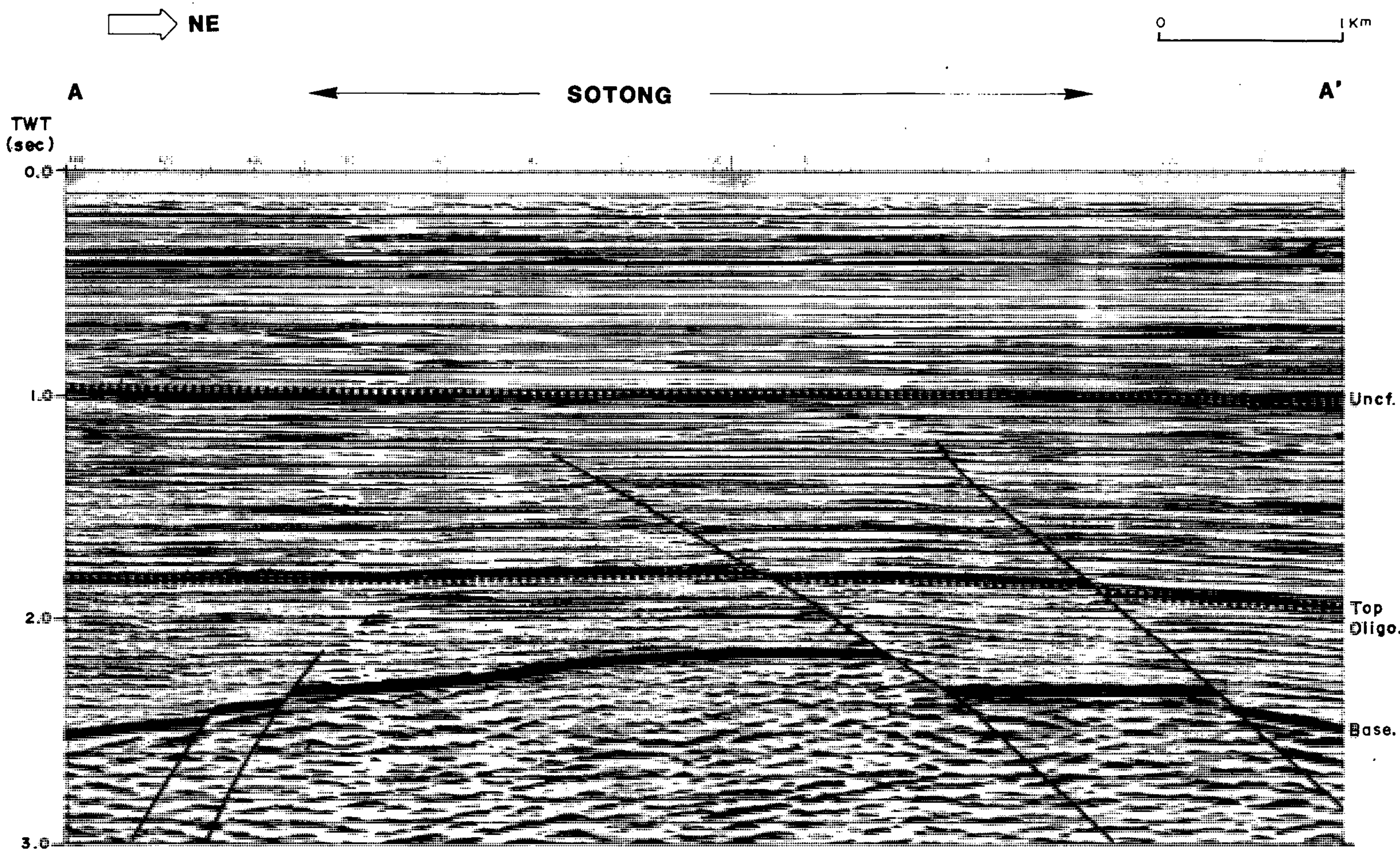

Fig. 9. Seismic profile AA' shows drape features of the Sotong structure where the tilted block forms the basement 'high'. Structural closure is present at Top Oligocene.

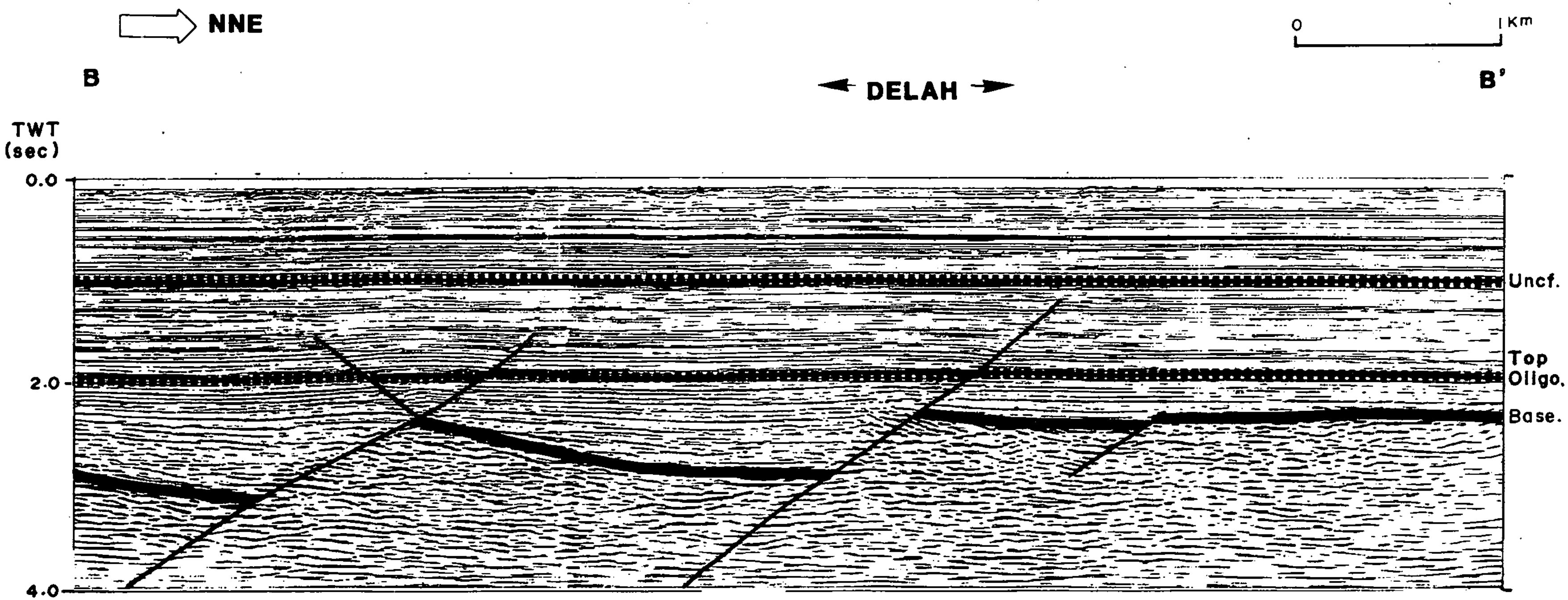

Fig. 10. Seismic profile BB' shows drape features in the Delah structure. The fault throw at the basement level in the Delah structure is of higher magnitude than in the Sotong structure.

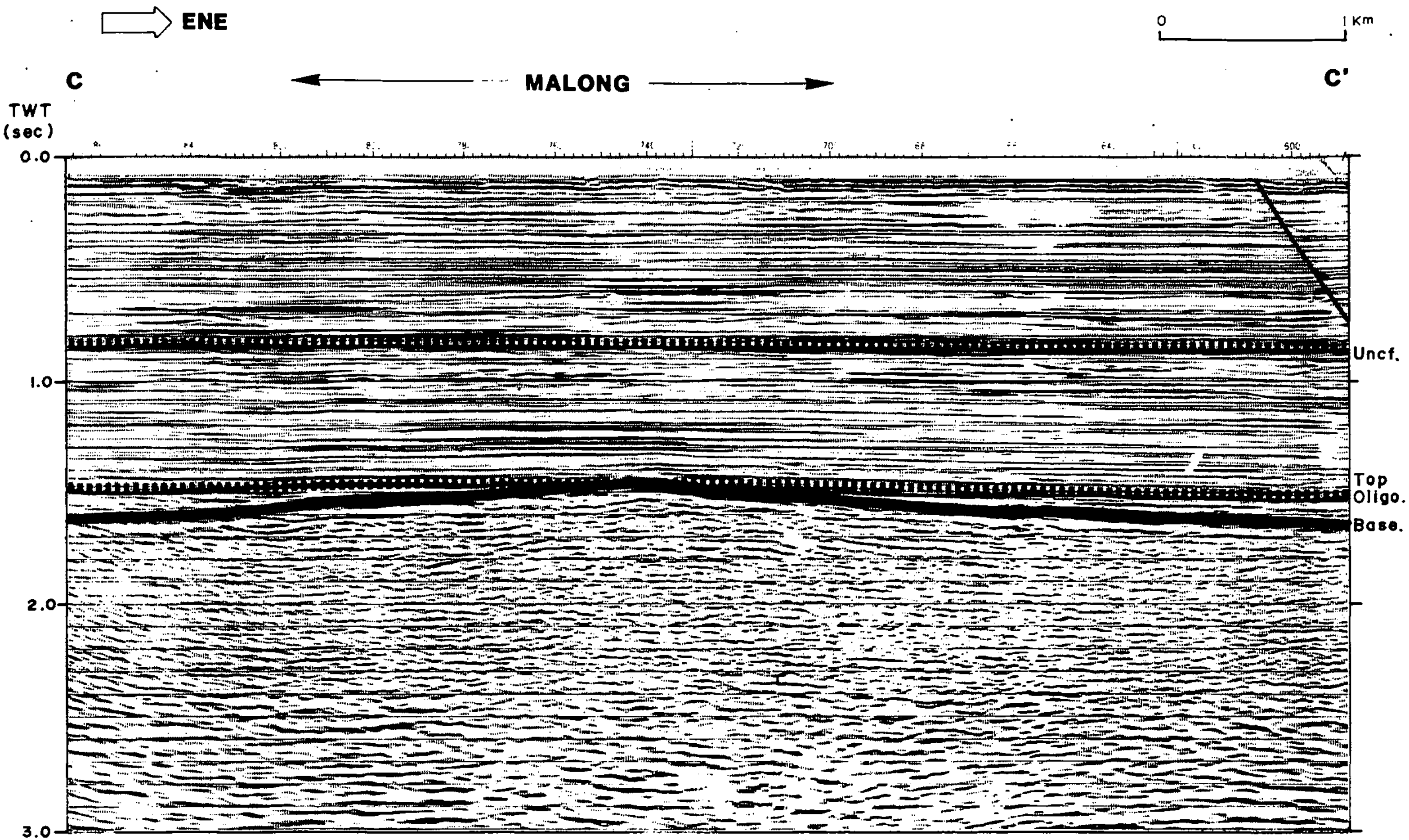

Fig. 11. Seismic profile CC' is a dip section across the Malong structure. The geomorphological basement 'high' provided the necessary condition for overlying sediments to form drape features.

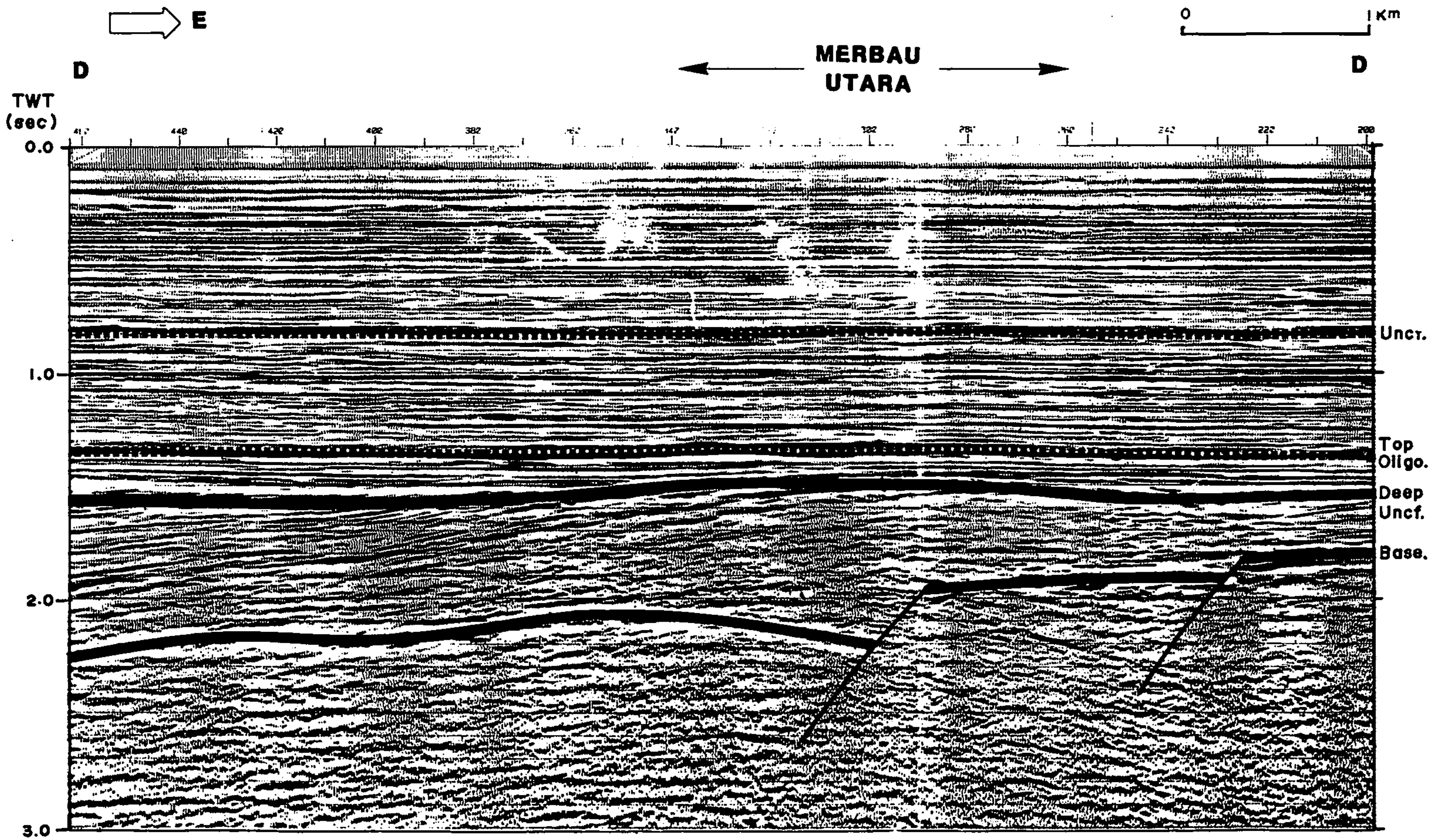

Fig. 12. Seismic line DD' showing drape feature over the Merbau Utara structure. The geomorphological 'high' at the deep unconformity is probably associated with a more resistant sedimentary unit.

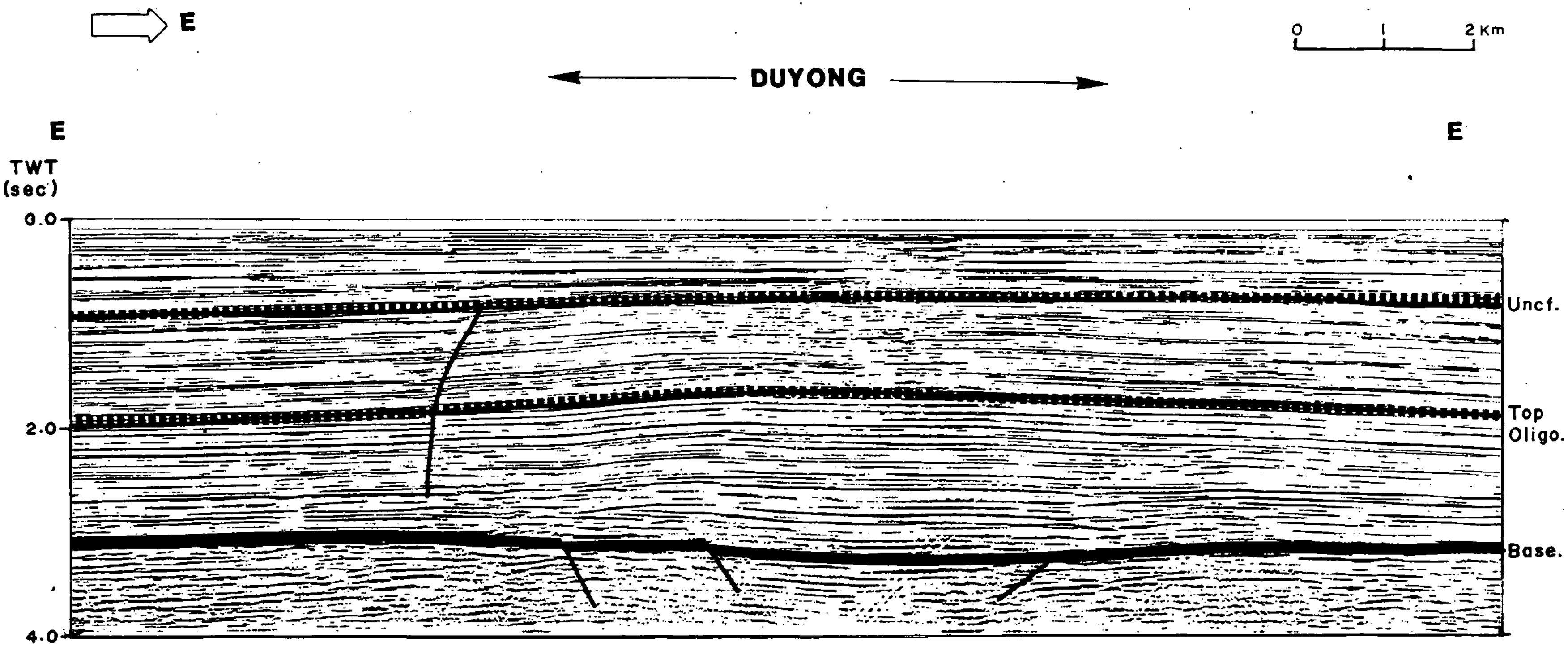

Fig. 13. Seismic profile EE' along the dip direction across the Duyong structure highlights structural inversion.

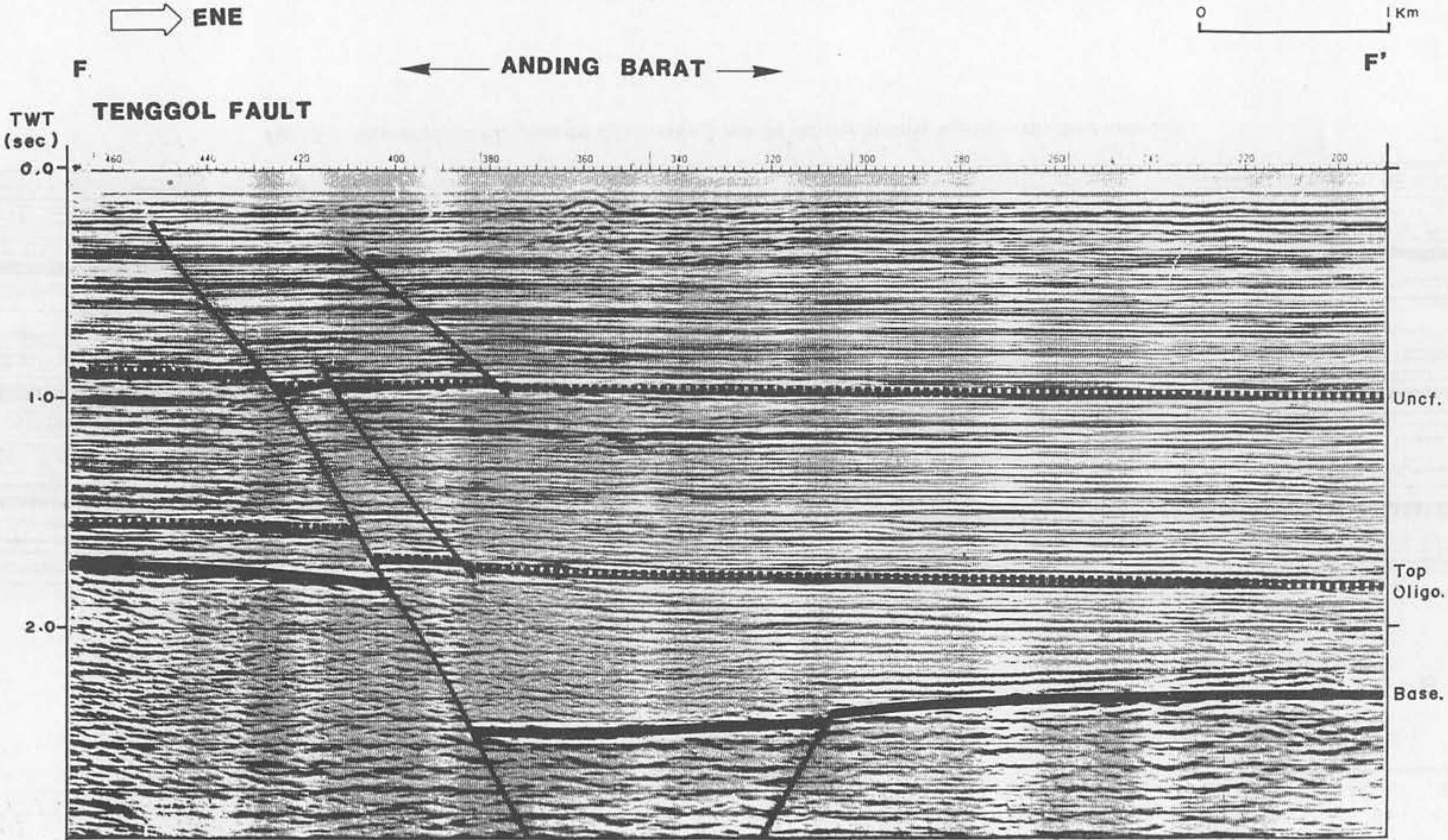

Fig. 14. Seismic profile FF' along the dip direction across the Anding Barat structure. The fault-dip closure is found on the downthrown block of the Tenggol fault at Top Oligocene level.

CONCLUSION

The Tenggol Arch was relatively stable whilst the southern part of the Malay Basin was affected by extensional and compressional tectonics, most probably associated with shear stresses during Neogene.

The early structural traps formed in the area are drape features. However subsequently Miocene stresses modified some of these features and developed new ones, such as *en echelon* folds and fault/dip closures.

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