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Structural Styles in Western Sabah Offshore

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Abstract: Exploration activities in Sabah have revealed that in Sabah Shell's contract area two structural provinces, differentiated by the age of the main phase of deformation, can be recognised in the Neogene basin west of the Sabah mainland.

In south and central Sabah, between Labuan and Mangalum, the main tectonic phase occurred during Upper Miocene times. It led to the formation of steep, upthrusted, rather narrow anticlinical trends separated by broad, deep, gently folded synclines. The anticlines, which have been referred to as ridges, are thought to be related to basement-induced faulting.

The Upper Miocene Foldbelt is separated by important fault zones from a province in which similar structural movements took place during the Pliocene. This tectonic phase primarily affected the area between Mangalum and Kudat where upthrusted anticlinal trends were formed, separated further basinwards by large normal faults from gentle anticlinal uplifts with crestal faults. The intensity of deformation is greatest in the Mantanani area where the E-W oriented Sulu trend bends into the SW-NE Borneo trend. It decreases towards the southwest (Mangalum) and is only mildly expressed in the area west of the Upper Miocene Foldbelt (Samarang).

INTRODUCTION

The tectonic configuration of the Tertiary sequences outcropping in western Sabah and known from Sabah Shell's exploration activities in the adjacent offshore allows a major two-fold subdivision into a Palaeogene and a Neogene belt, the latter partly overlying but mostly occurring basinwards of the former (Fig. 1). Ample evidence suggests that the site of deep marine sedimentation and subsequent orogenesis shifted progressively basinwards with time. Successive Tertiary sedimentary units are separated by strong angular uncomformities at the basin margin, but basinwards the sequence becomes conformable.

The Palaeogene Foldbelt in western Sabah, composed of deep water sediments deformed during the Lower Miocene, has a north-south structural grain referred to as the NW Borneo trend. In north and eastern Sabah it has a E-W orientation designated as Sulu trend, which is associated with basic and ultra-basic intrusives and volcanics (Fig. 1). The intersection of these two trends is marked by the occurrence of a large granite massive (Mt. Kinabalu) formed by a number of intrusions during Upper Miocene and Pliocene times.

The structural trends of the Neogene belt closely follow the grain of the Palaeogene Foldbelt. In southern Sabah and north Sarawak the trends have a N-S orientation, but they bend into an E-W orientation towards the northeast (Figs. 1, 3). This change in strike, which coincides, with a broad province of complex structures extending eastwards into Kudat Peninsula, lies in the prolongation of the NW Borneo/Sulu Palaeogene trend intersection on land.

Four major tectonic provinces can be recognised (Table 1), aligned parallel to each other, which have been affected by several, partly overlapping phases of structural deformation (Figs. 1, 2):

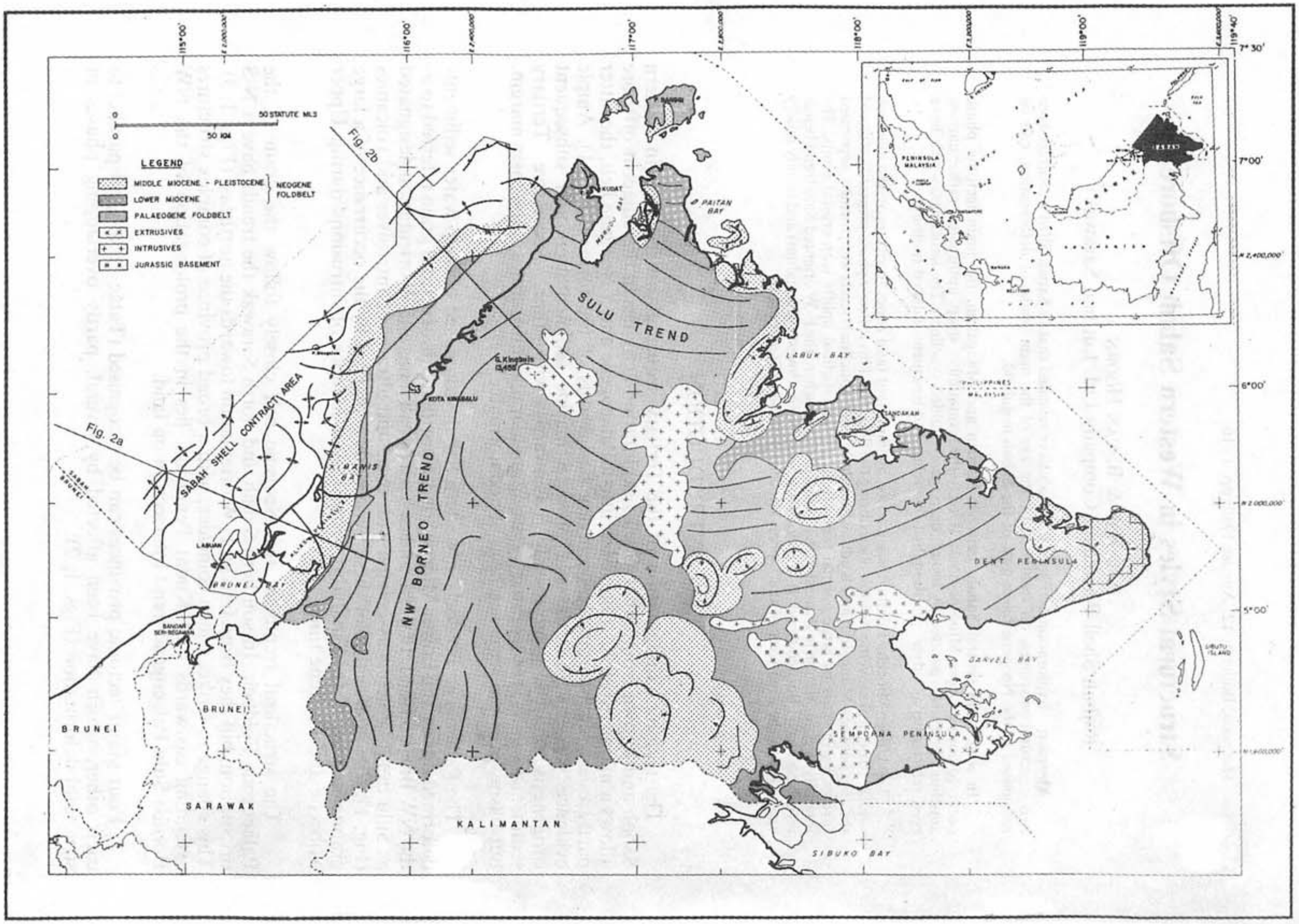


Fig. 1. Sabah schematic geological map.

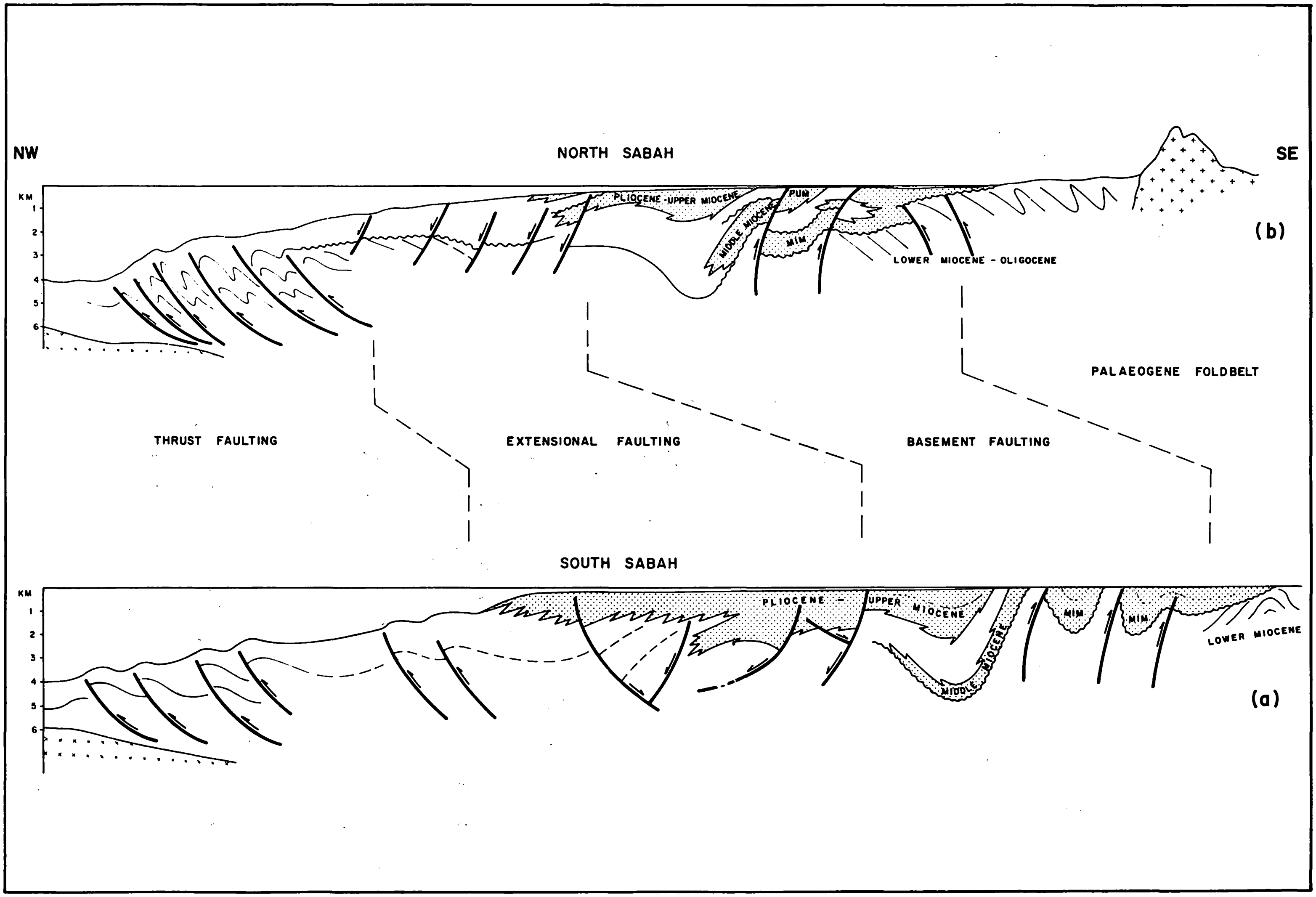


Fig. 2. Regional cross sections.

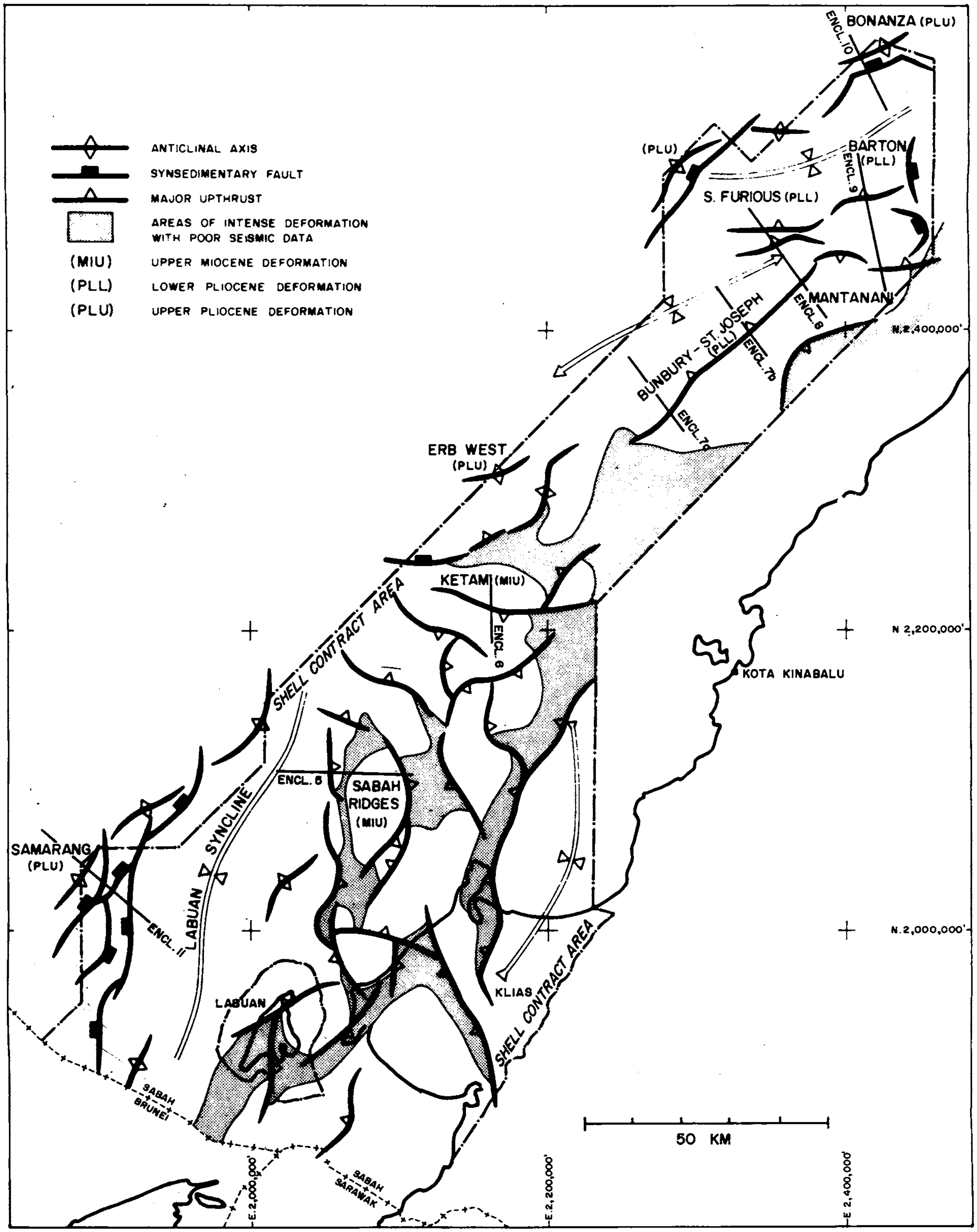


Fig. 3. Structural sketch map of Sabah Shell Contract area.

Table 1

4 TECTONIC PROVINCES IN WESTERN SABAH

AREA	SEDIMENTS	TIME OF DEPOSITION	STRUCTURAL STYLE	TIME OF DEFORMATION
ONSHORE	DEEP MARINE	PALAEOGENE	INTENSE DEFORMATION	LOWER MIOCENE & PLEISTOCENE (CROCKER RANGE)
TO Ca. 50 KM FROM COAST	DEEP MARINE TO CONTINENTAL	LOWER/MIDDLE MIOCENE	BASEMENT FAULTING	UPPER MIOCENE / LOWER PLIOCENE
Ca. SAMARANG/ ERB WEST/ BONANZA BELT	DELTAIC/SHALLOW MARINE	UPPER MIOCENE /LOWER PLIOCENE	EXTENSIONAL FAULTING	UPPER PLIOCENE
DEEP WATER AREA	DEEP WATER	NEOGENE	THRUST FAULTING	PLIOCENE

a) An inner province of Palaeogene deep water sediments, deposited in the north-south trending NW Borneo geosycline and mainly deformed during Lower Miocene times. Pleistocene epeirogenic movements have resulted in a rugged mountain range parallel to the west coast of Sabah (Crocker range).

b) A province of Lower and Middle Miocene deep marine to continental sediments folded into tight, narrow, partly upthrusted trends during the early Upper Miocene and Lower Pliocene, possibly as the result of deep-seated basement faulting.

c) A province of extensional, partly synsedimentary faulting, with a thick succession of Upper Miocene and Lower Pliocene deltaic to shallow marine sediments, mildly affected by Upper Pliocene compressional movements.

d) An outer province of intensely folded, overthrusted and imbricated Neogene deep water sediments, which have been deformed during Pliocene times.

STRATIGRAPHY

The stratigraphic subdivision in western Sabah is based on the correlation of the nine uncomformities recognised in the Tertiary of the west Sabah mainland and the adjacent offshore. The sedimentary sequences in between these uncomformities are informally called 'Stages' (Fig. 4).

The two oldest Stages consist of deep marine sediments forming the infill of the Late Cretaceous-Oligocene, N-S trending NW Borneo geosyncline.

Stage III, of Lower to Middle Miocene age, comprises north-westerly prograding coastal sediments outcropping in south Sabah, but in the offshore consists of deep marine shales locally alternating with turbidite sands.

Stage IV consists of 7 distinct substages, labelled A to G, which are regionally mappable as seismic horizons. Sub-stages A and D, of Middle and Upper Miocene age respectively, represent periods of relative tectonic quiescence during which coastal/coastal plain sequences were deposited. They are overlain by transgressive sediments formed contemporaneously with deformation at the basin margin and hinterland. A subsequent rapid regression moved the shoreline further basinwards contemporaneous to or followed by basin folding.

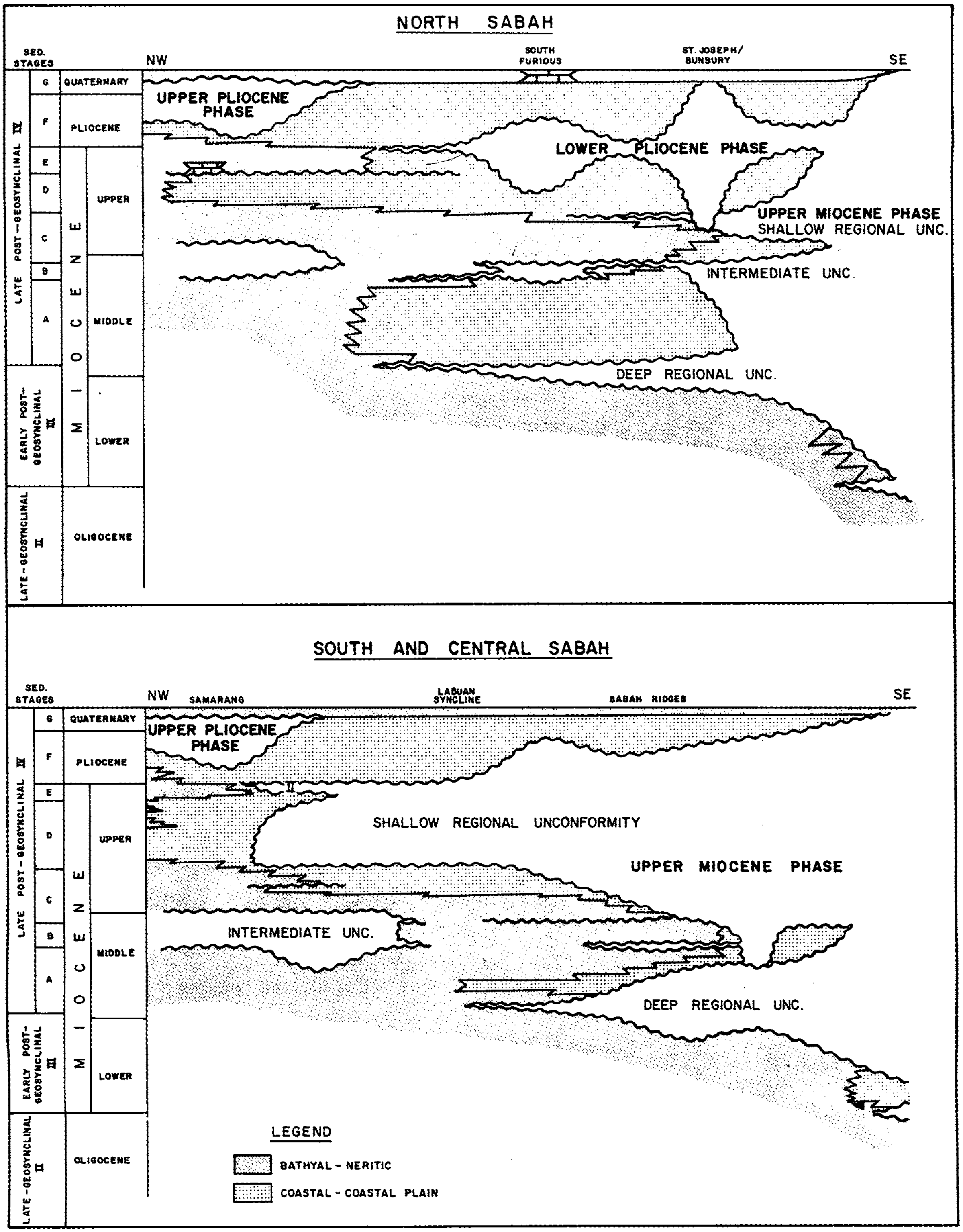


Fig. 4. Time stratigraphy.

STRUCTURAL DEFORMATION

Well results and seismic correlations show that the structures in Sabah Shell's contract area were formed during three phases of deformation: an Upper Miocene phase in central and south Sabah, a Lower Pliocene folding in north-northeast Sabah and an Upper Pliocene phase along the western margin of SSPC's contract area (Fig. 3).

Upper Miocene Deformation

The structural style of the Upper Miocene foldbelt is characterised by steep, rather narrow anticlinal trends separated by broad, deep, gently folded synclines. The crestal part of these narrow highs, in particular in south Sabah, is mostly associated with zones of poor or no coherent seismic reflections and have been referred to as 'ridges' (Fig. 5).

The formation of these ridges has been originally ascribed to flow and diapirism of undercompacted clay as a result of excessive loading by the overlying sediments. Various compelling arguments counter this hypothesis:

a) The absence of slow continuous growth which would be expected by the viscous flow of clay;

b) The absence of clay withdrawal features in the synclines;

c) The synchronous origin of these ridges;

d) The presence of continuous trends associated with positive gravity anomalies, suggesting basement involvement;

e) The tightly folded, indurated state of the Lower Miocene clays in some of the ridge cores (i.e. Labuan, Klias) suggesting absence of ductile flow;

f) The apparent absence of a major detachment horizon underneath the ridges.

Modern seismic data disprove conclusively the clay diapiric origin of the ridges and suggest that the cause of the structures is compressional stress in the overburden. Because of deep erosion the upper, more concentric, part of these folds has been removed and today only the steeply compressed core of the structures remains (Fig. 5). Seismic interpretation shows that the crestal part of the ridge is characterised by steeply dipping upthrusts. The rapid changes in orientation and dip direction of the fault planes and evidence of reversals in throw along faults, suggest basement-induced faulting. The precise nature of this faulting is unknown but is thought to be related to strike-slip movements. Since the resulting principal compressive stress may vary from horizontal to vertical a wide range of unpredictable structural styles can therefore be anticipated in the sedimentary cover.

Towards central Sabah the overall NNE-SSW alignment of the ridges bends into a WNW-ESE orientation (Fig. 3). Structures in this area have been considerably less uplifted. A typical example is the Ketam feature, a tight assymetric anticline separated to the north by southerly hading reverse faults from two underthrust fault blocks (Fig. 6).

Lower Pliocene Deformation

The Lower Pliocene tectonic phase primarily affected the north-eastern part of SSPC's area and its continuation into the Kudat Peninsula. The direction of the fold

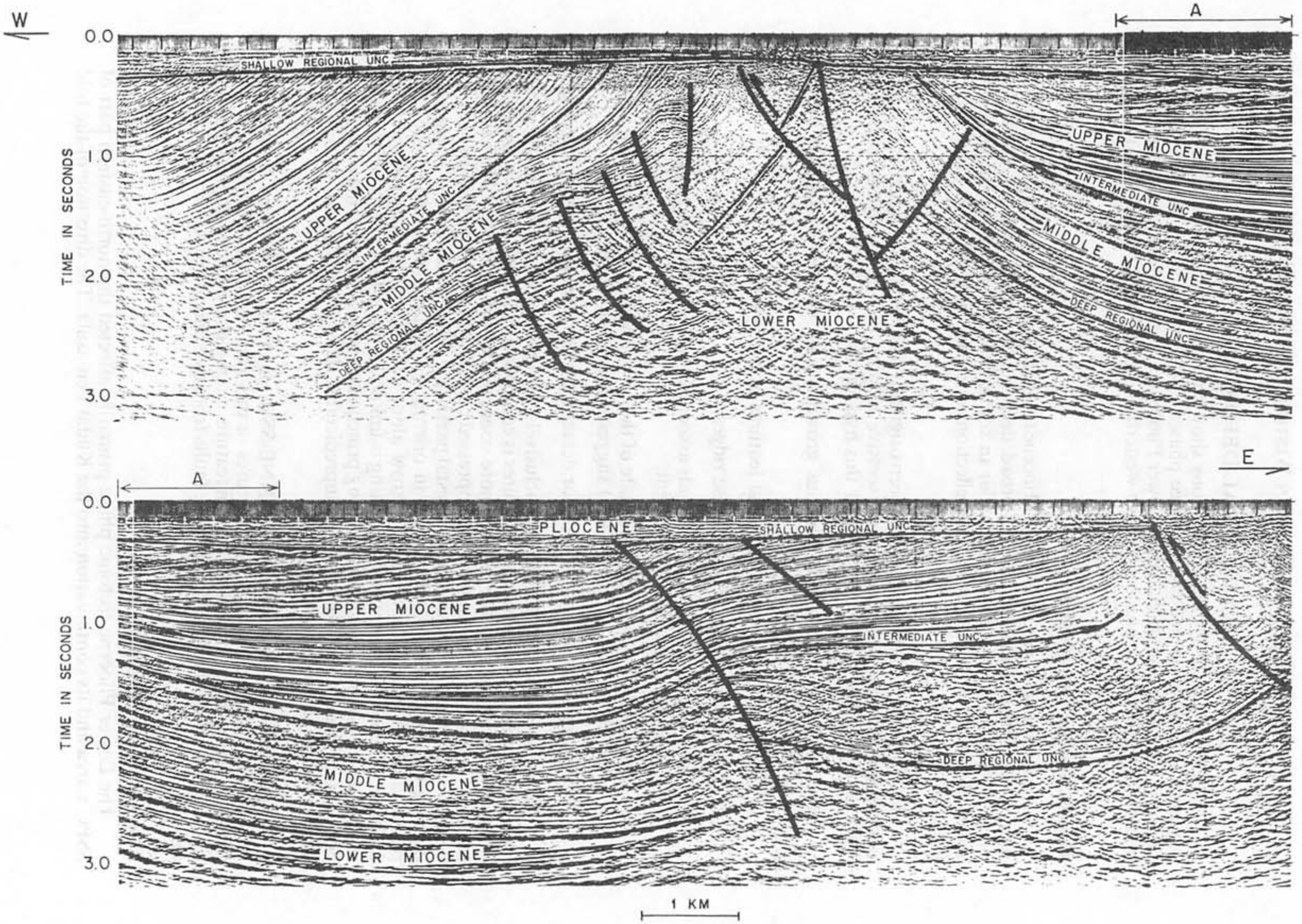
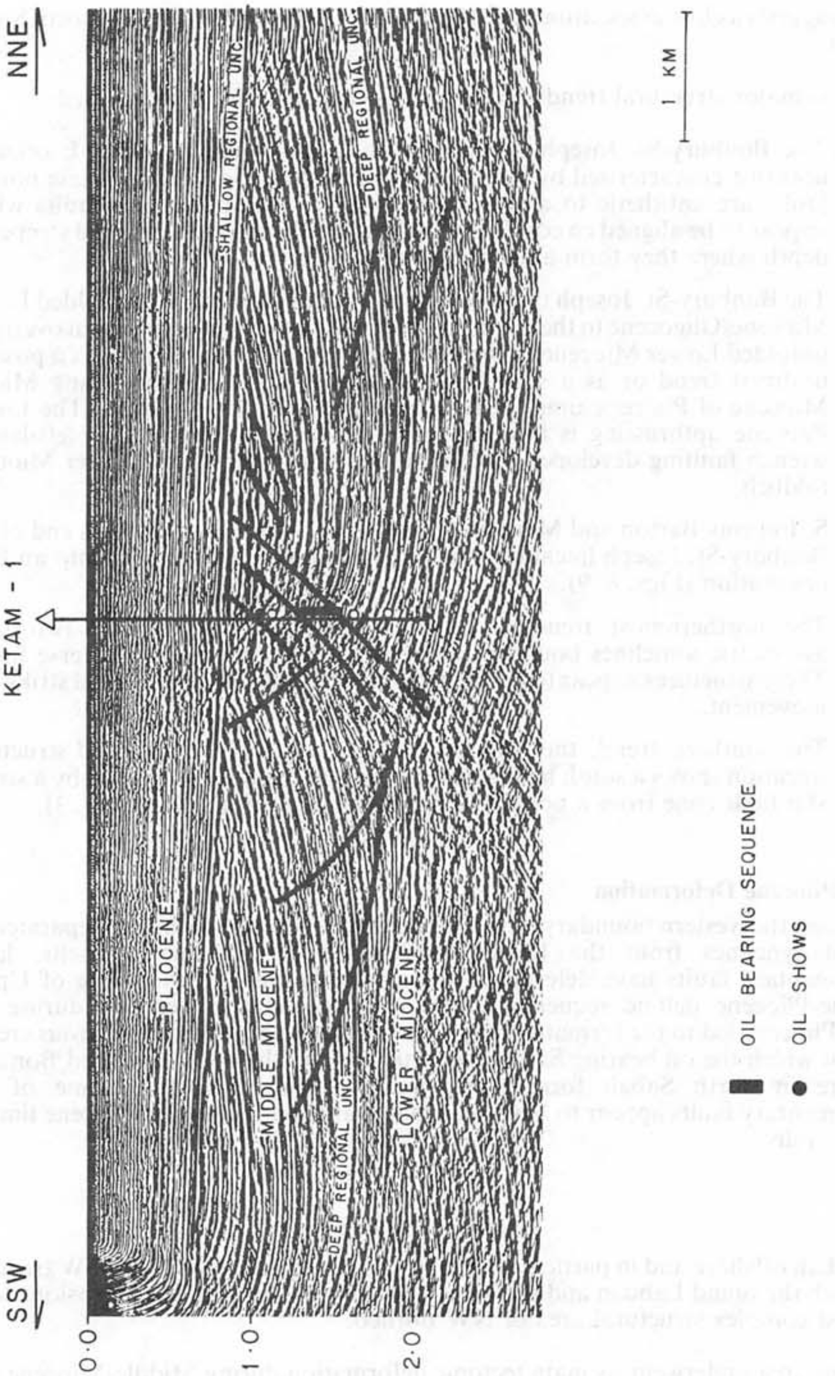


Fig. 5. Migrated seismic section: Sabah Ridges.


SSW
NNE
KETAM - 1
1 KM
TIME IN SECONDS
0.0
1.0
2.0
PLIOCENE
MIDDLE MIOCENE
LOWER MIOCENE
SHALLOW REGIONAL UNC.
DEEP REGIONAL UNC.
DEEP REGIONAL UNC.
OIL BEARING SEQUENCE
OIL SHOWS
GAS SHOWS

trends suggests a close association with the grain of the Palaeogene belt in north Sabah (Fig. 3).

Two major structural trends of Lower Pliocene age can be recognised:

a) The Bunbury-St. Joseph trend, a northeasterly plunging SW-NE oriented upthrust characterised by extensive crestal faults (Figs. 7a, b). These normal faults are antithetic to a set of northwesterly hading reverse faults which appear to be aligned en echelon at shallow depths but converge and steepen at depth where they form a near-vertical fault zone.

   The Bunbury-St. Joseph trend separates a relatively high area of folded Lower Miocene/Oligocene to the southeast from an actively subsiding basin overlying unfolded Lower Miocene to the northwest. Its varying character as a positive upthrust trend or as a subsiding synsedimentary hingeline during Middle Miocene of Pliocene times demonstrates basement involvement. The Lower Pliocene upthrusting is thought to be the result of deep-seated left-lateral wrench faulting developed parallel to the outer edge of the Lower Miocene foldbelt.

b) S. Furious/Barton and Mantanani structures. At the northeastern end of the Bunbury-St. Joseph lineation structural trends change abruptly into an E-W orientation (Figs. 8, 9).

   The northernmost trend of S. Furious/Barton trend shows two large assymetric anticlines bounded to the south by north hading reverse faults. These structures appear to be offset from each other by a left-lateral strike-slip movement.

   The southern trend, the Mantanani high, a steeply upthrusted structural lineation shows a south hading reverse fault in the west, separated by a strike-slip fault zone from a north hading reverse fault in the east (Fig. 3).

Upper Pliocene Deformation

Along the western boundary of the Sabah Shell's contract area, and separated by regional synclines from the Lower Pliocene/Upper Miocene foldbelts, large synsedimentary faults have determined the accumulation of a thick pile of Upper Miocene/Pliocene deltaic sequences. Mild compressional movements during the Upper Pliocene led to the formation of gentle anticlinal uplifts with numerous crestal faults of which the oil bearing Samarang structure and the densely faulted Bonanza structure in north Sabah form clear examples (Figs. 10, 11). Some of the synsedimentary faults appear to have been reactivated during Upper Pliocene time as reverse faults.

CONCLUSIONS

Sabah offshore and in particular the approximately 50 km wide NE/SW trending zone with the island Labuan and the Klias Peninsula as the southern extensions form the most complex structural area of NW Borneo.

This area underwent its main tectonic deformation during Middle-Miocene and Pliocene times, these movements appearing to be related to basement wrench faulting.

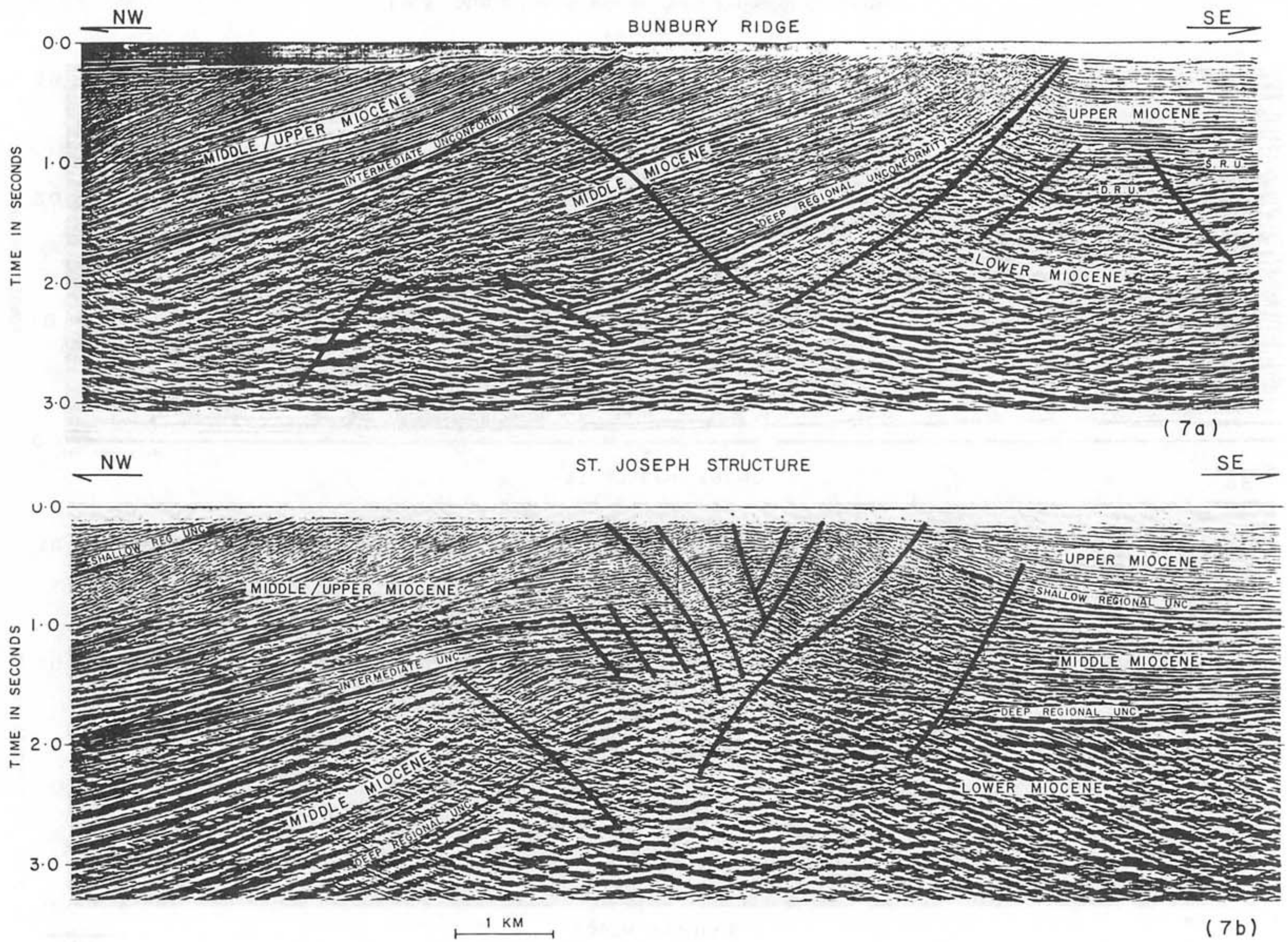


Fig. 7. Migrated seismic section: Bunbury Ridge-St. Joseph structure.

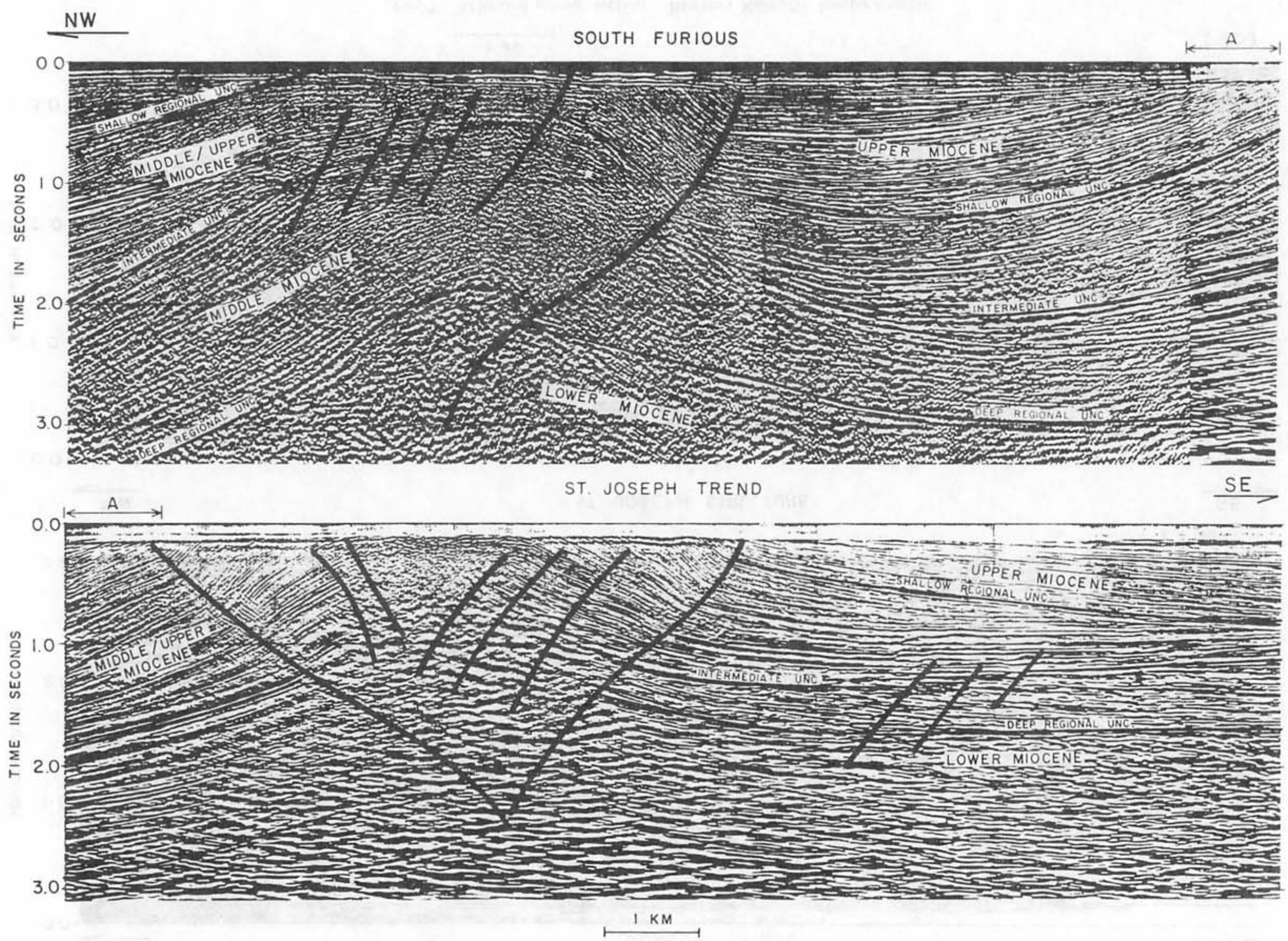


Fig. 8. Migrated seismic section: South Furious-St. Joseph trend.

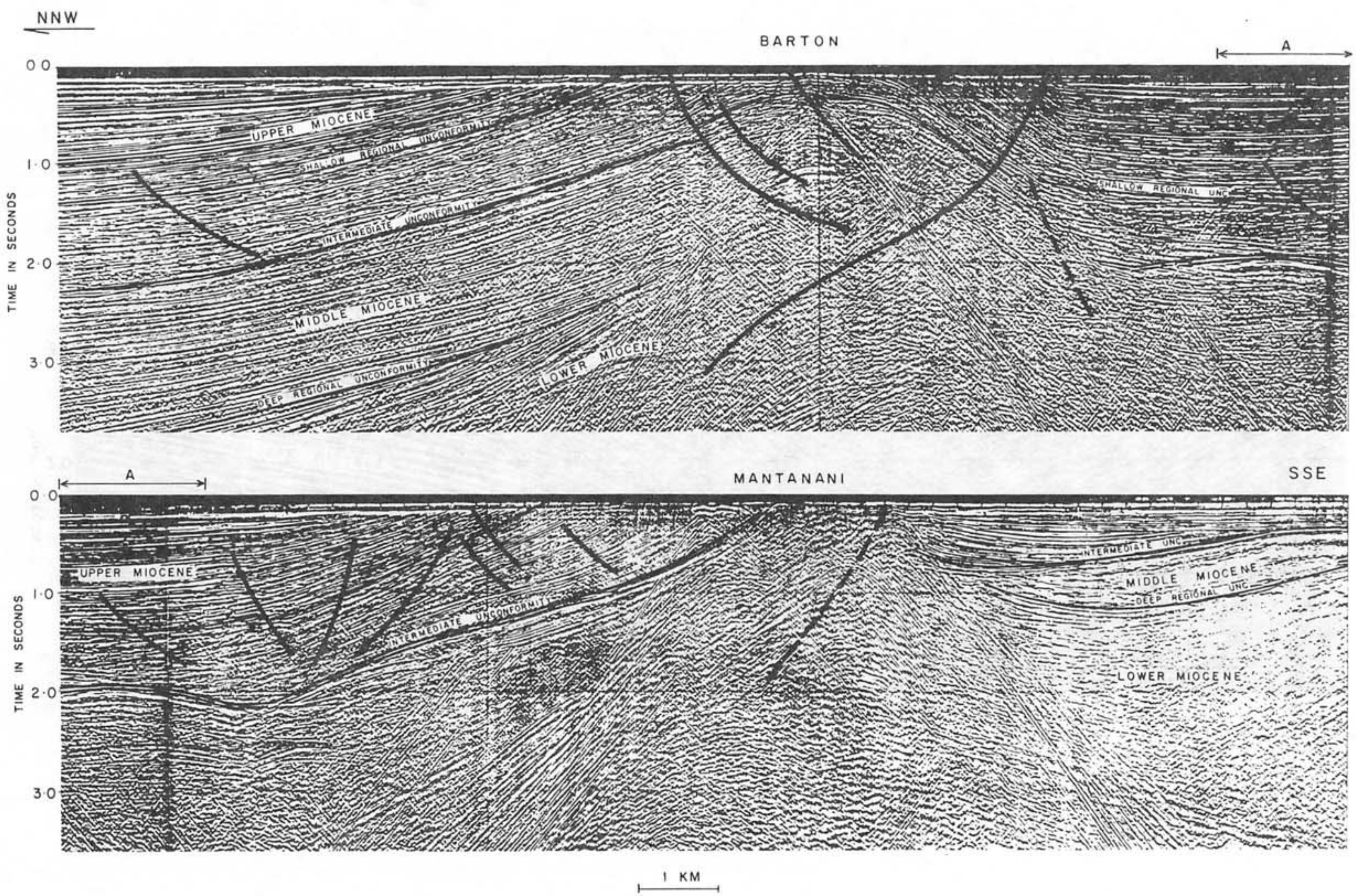


Fig. 9. Migrated seismic section: Mantanani-Barton trend.

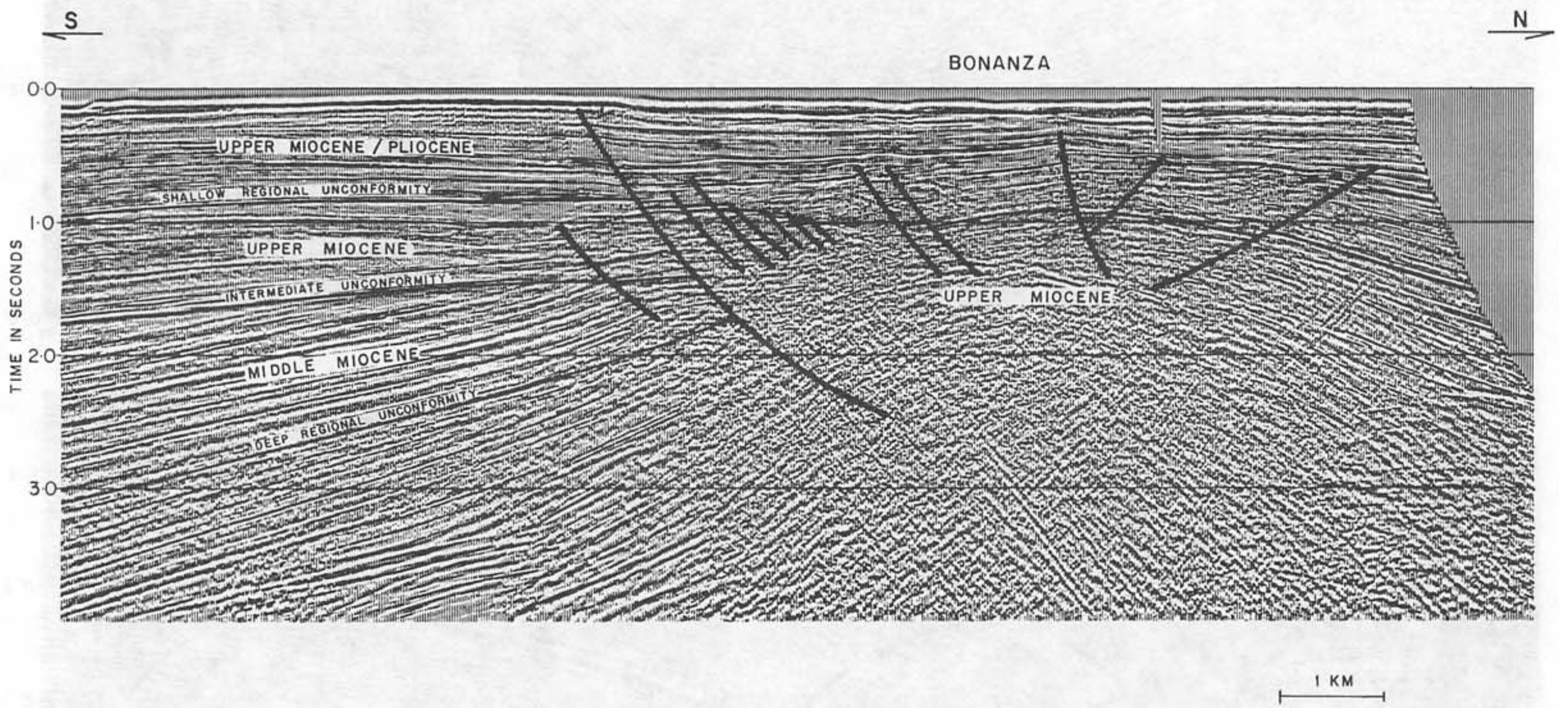


Fig. 10. Migrated seismic section: Bonanza structure.

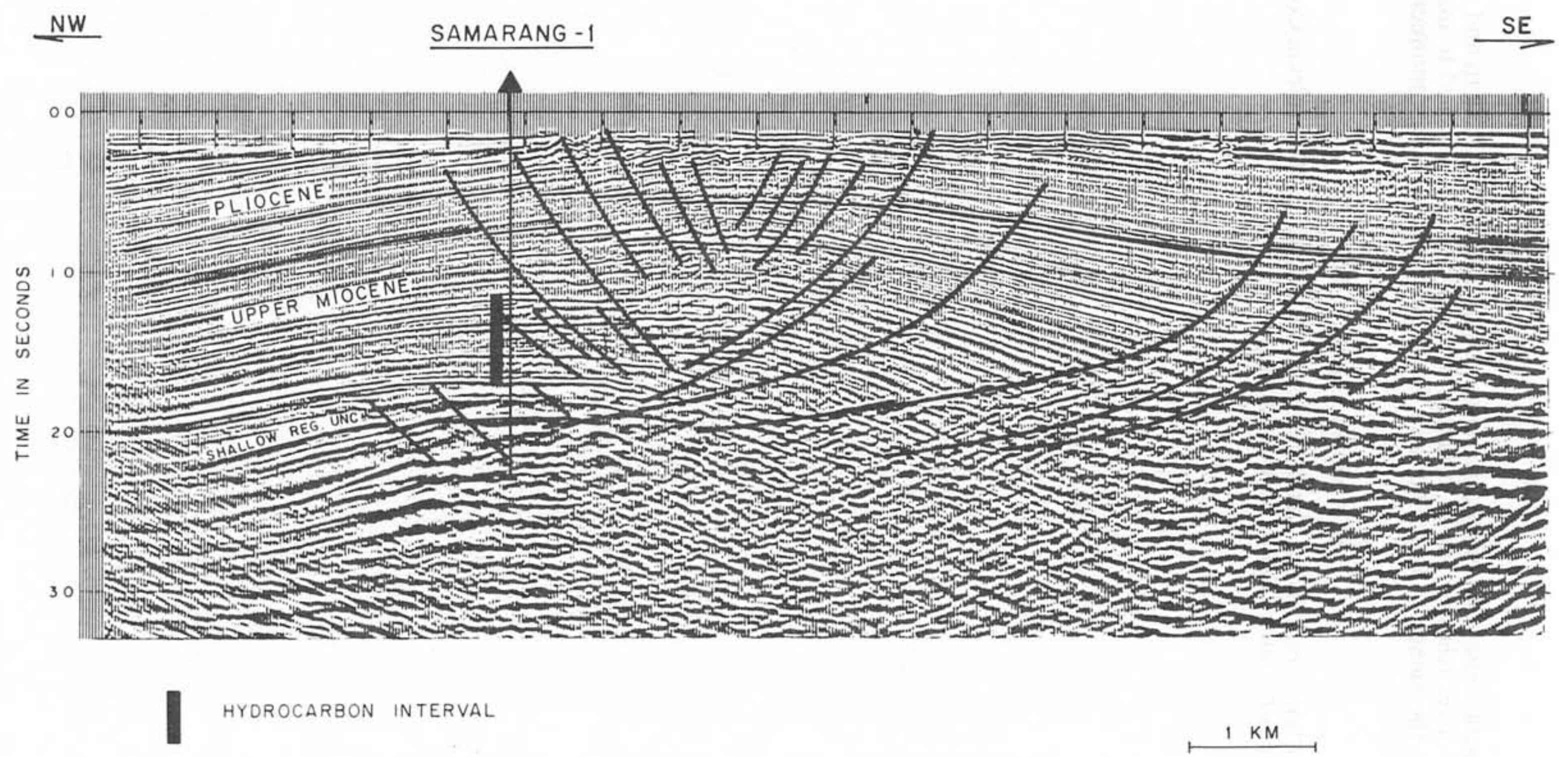


Fig. 11. Migrated seismic section: Samarang structure.

Even with dense grids of modern seismic data it is a difficult task to find reliable correlations over relatively short distances. Well correlations are hard to make not only due to the numerous faults but also due to the presence of discontinuous sand bodies.

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