

SEISMIC STRATIGRAPHY OF THE MAKASSAR BASIN

by

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ABSTRACT

Seismic reflection profiles from the Makassar basin have been analysed in terms of seismic stratigraphy. Systematic patterns of reflection terminations indicate the existence of at least three surfaces of discontinuity across the profiles-designated in order of superposition as C₁, C₂ and C₃ - which define the boundaries of four seismic sequences, i.e. :

- seismic sequence I : topped by C₁
- seismic sequence II : the interval between C₁ and C₂
- seismic sequence III : the interval between C₂ and C₃
- seismic sequence IV : the interval between C₃ and the sea floor

Seismic sequence II is dominated by basin slope and basin floor seismic facies whereas seismic sequences III and IV consist of mainly shelf and shelf margin seismic facies.

Correlation of seismic sequences with well data facilitates the exposition of basin development. The Late Cretaceous-early Tertiary regional uplift and erosion produced a major unconformity C₁, upon which the transgressive facies of seismic sequence II was deposited. A lowstand of sea level due to the so-called intra-Miocene orogeny occurred in the upper Early Miocene and produced the C₂. Deposition of seismic sequence III is marked by a relative rise of sea level, probably followed by another lowstand of sea level during Mio-Pliocene which formed the C₃. The final event is an overall transgression and deposition of seismic sequence IV, with a possible minor lowstand of sea level in Pliocene-Recent.

The occurrence of basin slope and basin floor seismic facies within seismic sequence II suggests that in the pre-Lower Miocene, basin subsidence was slightly greater than the rate of depositions. Since Lower Miocene both subsidence and sedimentation rates were equal and the deposition of shelf and shelf margin seismic facies of seismic sequences III and IV was prevailed in the basin.

I. INTRODUCTION

Situated between the islands of Kalimantan and Sulawesi (Fig. 1), the Makassar Strait has been a focus of attention of scientific community since at least the nineteenth century, when Wallace (1864) established the so-called Wallace Line longitudinally along the line of the Strait. The Line is a faunal boundary between the Asiatic fauna in the west and the Australian fauna in the east and southeast.

As knowledge of the geology of Indonesia expanded through the pioneering work of Dutch geologists, it soon became clear that the Makassar Strait is also a geological boundary. It is the line of demarcation between the stable cratonised Palaeozoic and Mesozoic rocks of the Sunda shield in the west and the active late Tertiary volcanic arc of Sulawesi in the east.

Geological knowledge of the shelf area has in-

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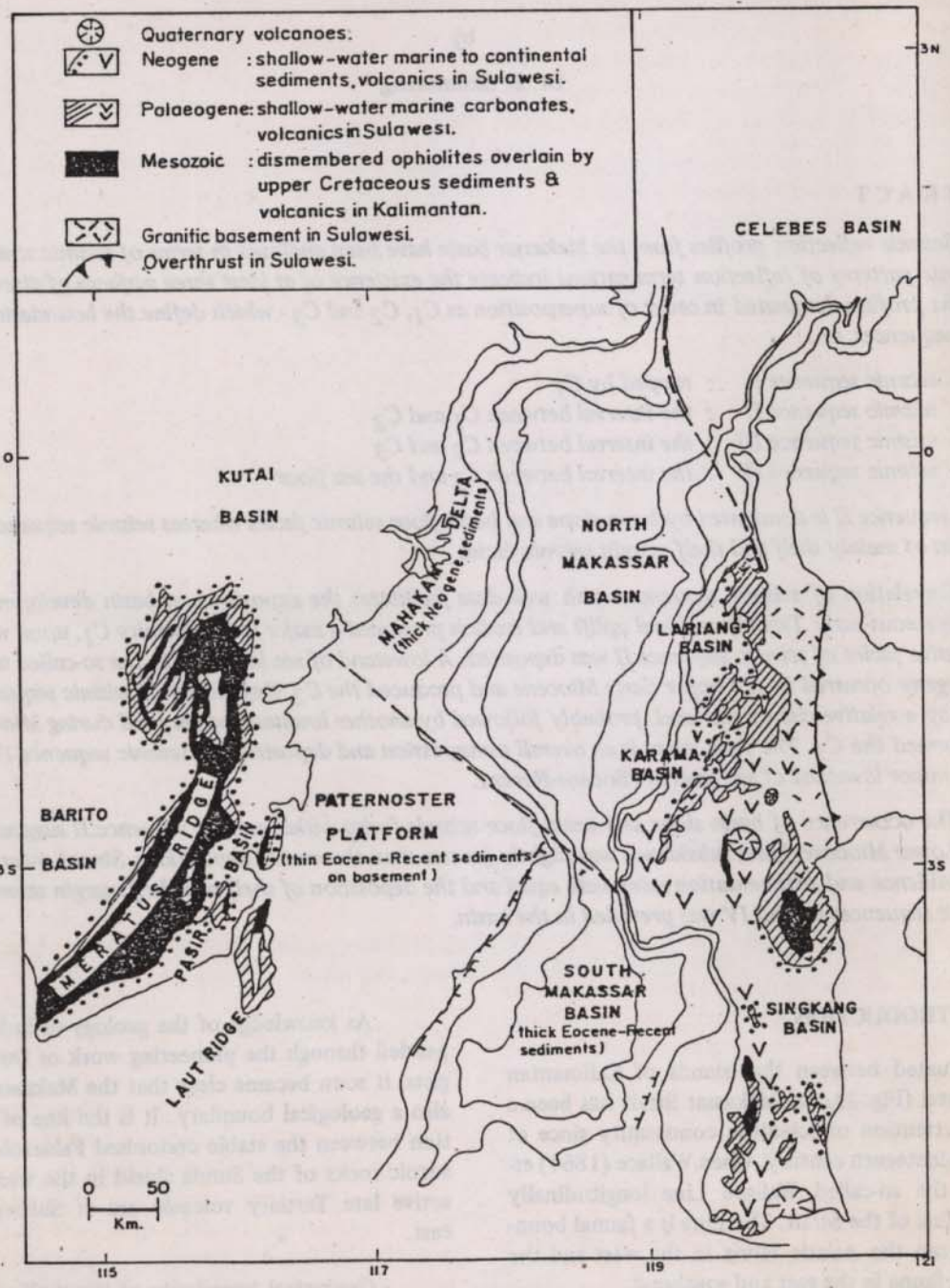


Figure 1 : Location map, Makassar Basin

creased considerably since 1967, due to intensive exploration for hydrocarbons, which subsequently resulted in discoveries of new offshore oil and gas reserves. However, little attention has been given to areas beyond the shelf, which form the Makassar basin, although various marine geophysical cruises have been carried out in this basin, especially since the seventies.

Most previous accounts on the formation and evolution of the Makassar basin are mainly inferred from geological similarity between Southeast Kalimantan and South Sulawesi (e.g. Hamilton, 1979). The formation of the basin in terms of stretching mechanism has been put forward by Situmorang (1982) by make use of offshore well information and limited seismic reflection data. In this paper, an attempt is made to describe the stratigraphy of the basin following the concept of seismic stratigraphy. Correlation with well data permits clarification of depositional history and basin development.

II. BRIEF HISTORY OF GEOPHYSICAL INVESTIGATION

Prior to the fifties, the Makassar Basin was investigated only by gravity measurements. Since then, there were no important geophysical activities in this area until various marine geophysical surveys were carried out by several oil companies and institutions in the early seventies. The result of the pre-1950 surveys has been discussed by Vening Meinesz (1954).

From October 7th, 1970 to July 12th, 1971, Mobil Oil Corporation carried out an extensive marine reconnaissance seismic profiling (12 fold) survey in Indonesian waters, in which the Makassar Basin was included. This survey covers a total of 62,430 km of survey lines in 366 seismic profiles, with gravity and magnetic data recorded simultaneously. In addition, the sea water salinity and temperature were continuously measured.

A similar survey was conducted by Gulf Research and Development Company, covering a total of 18,900 km. The Makassar Strait was covered by Cruise No. 78, from September 10th to 29th, 1971, which started from Davao City (The Philippines) and ended in Surabaya (Indonesia). This Cruise obtained approximately 3,033 km of single channel seismic da-

ta, 3,870 km of gravity and magnetic, and 3,330 km of gas chromatograph data from Celebes Sea, Makassar Strait and the Java Sea.

Also in 1971, Shell Internationale Petroleum Maatschappij B.V. (SIPM) carried out marine reconnaissance reflection seismic, gravity and magnetic surveys in Indonesia. A total of 8,548 km of seismic lines were recorded simultaneously with gravity and magnetic data. The Makassar Basin was covered by profiles P.605 to P.619.

Total - Compagnie Francaise Des Petroles (CFP) performed a seismic survey only in the North Makassar Basin and the western part of the Celebes Basin in December 1974. A total of 1,053 km reflection data were collected.

The Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe) also carried out a marine geophysical survey (reflection seismic, gravity and magnetic) longitudinally across the Makassar Basin in 1977. Again this Institute carried out a similar survey in the South Makassar Basin during the months of January - February, 1981.

The Comite d'Etudes Petrolières Marines (CEPM) carried out seismic reflection profiling simultaneously with magnetic survey in the Makassar Basin and the Flores Sea during February and March, 1981 (Pacific-2 project). A refraction survey (sonobuoy) was carried out along two profiles, i.e. profiles PAC.201 and PAC.202.

Except for geophysical data from the German Cruise all raw data from these surveys (e.g. magnetic tape, monitored sections, etc.) were submitted to the Indonesian Petroleum Institute (Lemigas), who keep and store it on behalf of the Government of Indonesia.

Apart from the above surveys, intensive geophysical surveys have been carried out in the shelf area on both sides of the Makassar Basin by the respective oil companies as part of their exploration programmes. As a result, several new offshore oil and gas fields have been discovered and have been put into production since the seventies. Access to data of this kind is normally very restricted.

The present geophysical accounts are mainly based on seismic reflection data obtained from SIPM,

Total - CFP and CEPM Cruises. The first company also released a preliminary free air anomaly map of the Makassar Basin, together with magnetic (total intensity) profiles. Additional data were obtained from the original records of Gulf profiles MCP.5 and MCP.1 - SSP.9. The line drawings of these profiles have been published previously by Katili (1978). Tracks of these surveys can be seen in Fig. 2.

Commercial reflection seismic data acquired by Mobil Oil Indonesia in 1973, which covered the area beyond the shelf on the western side of the Makassar Basin have also been interpreted, but interpretation diagrams are not presented here due to the confidential nature of the data. The acoustic markers picked out on profile PAC.202 can be traced easily in some of the Mobil's lines.

The SIPM data are based on a 24-trace hydrophone cable and an array of airguns with a total capacity of up to 300 cu. in. for profile P.605 to P.608, and up to 460 cu. in. for profiles P.609 to P.619. All data were commercially processed and consist of editing, collection into CDP gathers, normal move out (NMO) and stack, deconvolution, digital filtering, and the smoothed processing velocities were used to construct the depth sections. Special processing (i.e. migration) was applied to the southeastern part of profile P.611 (SP 1100 to SP 2040).

The Total-CFP data are also of 24-trace, with a Vaporchoc seismic source.

I was able to participate only during the CEPM Cruise. This survey was carried out aboard R.V. Resolution. The seismic sources consisted of two Flexichoc units and the data were recorded by a 48-trace digital recording system. There were onboard facilities to perform 24 fold common depth point stacks, and the interpretation presented here is based on this onboard processed section. The velocity analyses were also carried out at regular time intervals. The positioning was done by an automatic integrated satellite navigation system (IFP-P.606). The North Makassar Basin was crossed by profile PAC.201, whereas the South Makassar Basin was covered by profiles PAC.202, PAC.205, and the northeastern part of profiles PAC.203, PAC.206 and PAC.207. In addition to reflection seismic and magnetic data, a total of 19 sonobuoy refraction profiles were recorded along profiles PAC.201 and PAC.202.

III. SEISMIC STRATIGRAPHY

The regional stratigraphy of the Makassar Basin has been deduced by using the concepts of seismic stratigraphy. In the South Makassar Basin it is based on the analysis of SIPM reflection profiles P.605 through P.608, CEPM profiles PAC.202 and PAC.203, and the Delta line D.658A which extend to the shelf area in the western part of the Makassar Strait. The results can then be correlated with the stratigraphy of the nearby wells TT-2 and TT-1 (Fig. 2).

In the North Makassar Basin, the Total-CFP reflection profiles MK.1, MK.3, MK.4, the SIPM lines P.610 and P.611, the CEPM line PAC.201, and Gulf profiles MCP.5 and MCP.1 - SSP.9 have been interpreted. Although many wells have been drilled in the shelf area to the west of the North Makassar Basin, the well data can hardly be used in correlation with seismic interpretation, since almost all wells terminated in thick Late Miocene deltaic sediments.

The method used is to establish seismic sequences, i.e. identification and interpretation of depositional sequences, followed by seismic facies analysis which involves delineation and interpretation of reflection configuration, continuity, amplitude, frequency, interval velocity and their external form. This approach will lead to the estimation of sedimentary processes, environmental setting and depositional energy (Vail et al., 1977). Once the seismic sequences have been established in a certain profile or area, it is then a matter of correlation with any other profiles or areas.

A. Analysis of seismic reflection profiles

1. Profile P.605

This profile crosses the southern portion of the South Makassar Basin in approximately northwest - southeast direction, and displays an overall picture of the basin (Fig. 3). The slope and rise area extend from SP.3040 to SP.2200 at the northwestern part of the profile (water depth ranges from 358m to 1828m), and from SP.500 to the southeastern end of the line where water depth ranges from 1865 m to 760 m. The central part of the profile, i.e. from SP.2200 to SP.500 represents the abyssal plain where water depth reaches a maximum value of 1938 m. A flat sea floor can be

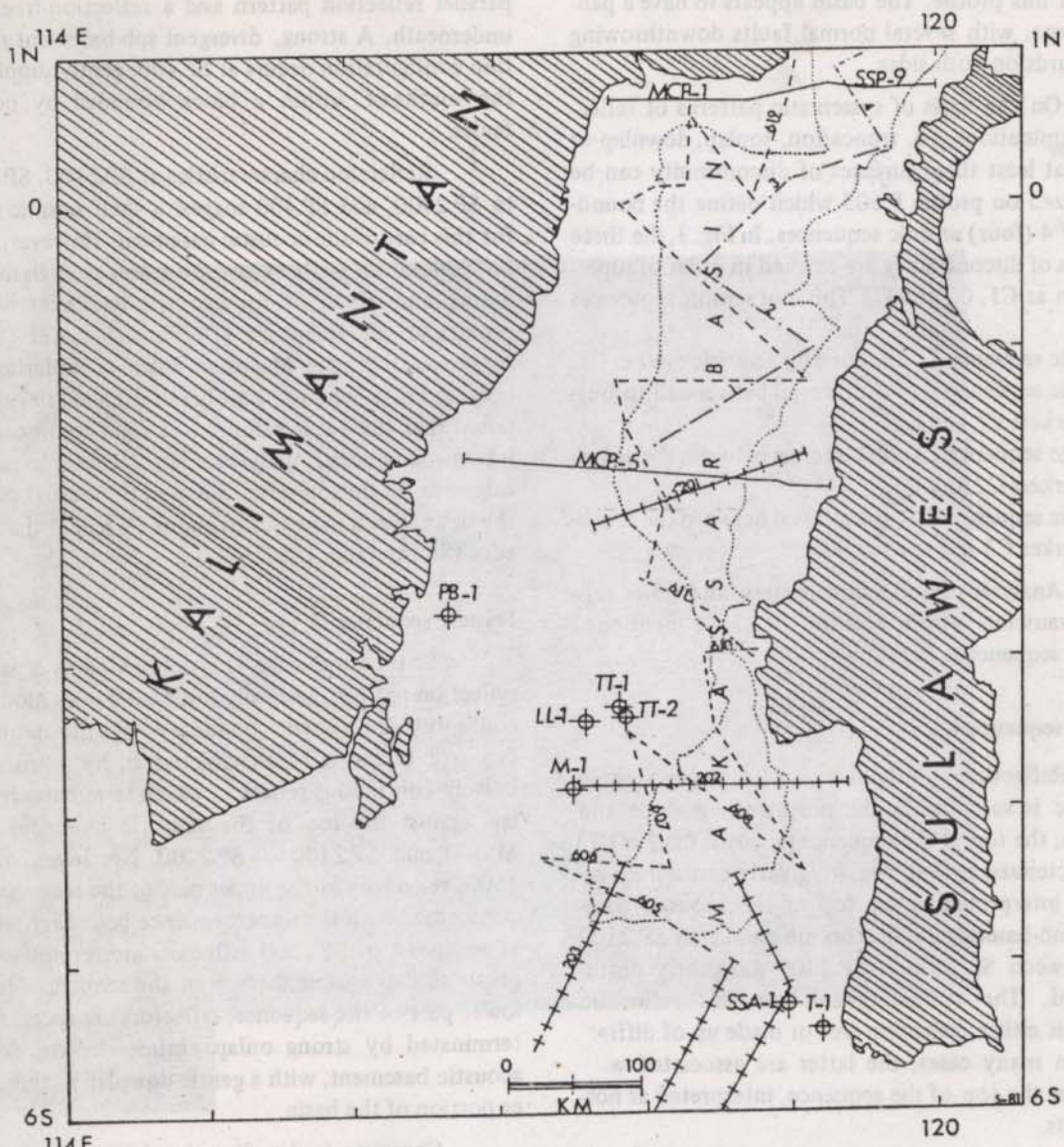


Figure 2 : Tracks of marine geophysical cruises

seen on this profile. The basin appears to have a pan-like shape, with several normal faults downthrowing basinwards on both sides.

On the basis of systematic patterns of reflection terminations, i.e. truncation, toplap, downlap or onlap, at least three surfaces of discontinuity can be recognized on profile P.605 which define the boundaries of 4 (four) seismic sequences. In Fig. 3, the three surfaces of discontinuity are marked in order of superposition as C1, C2 and C3. The four seismic sequences are :

- Seismic sequence I : topped by acoustic marker C1.
- Seismic sequence II : the interval between the acoustic markers C1 and C2.
- Seismic sequence III : the interval between the acoustic markers C2 and C3.
- Seismic sequence IV : the interval between the acoustic marker C3 and the sea floor.

Analysis of reflection pattern and other seismic parameters within each of the above mentioned seismic sequence is as follows :

Seismic sequence I :

Reflection configuration within this seismic sequence is variable. In the northwestern slope and rise area, the top of the sequence (acoustic marker C1) is characterized by a strong, irregularly continuous reflector, interpreted as the top of the acoustic basement. Sub-basement reflectors are parallel at SP.2100 and between SP.2200 – SP.2300 dip gently northward. The remaining sub-basement reflection pattern is either reflection-free or made up of diffractions. In many cases, the latter are associated with offsets in the top of the sequence, interpreted as normal faults.

Within the abyssal plain, seismic sequence I can still be recognized, but the top of the sequence is weak and discontinuous. A reflector-free zone underneath the flat acoustic basement occurs at SP.1450 to SP.1650 and at SP.1700 to SP.1900. Sub-basement diffraction patterns are absent in this part of the basin.

In the southeastern slope and rise area, patterns similar to those in the northwestern slope and rise are observed. The strong, irregularly continuous reflector which represents the top of the acoustic basement can be identified, with both a sub-basement

parallel reflection pattern and a reflection-free zone underneath. A strong, divergent sub-basement reflection configuration occurs at SP.400, gently dipping to the southeast within a block bounded by normal faults.

Reflection characteristics at SP.2100, SP.2200 to SP.2300, and SP.400 suggest a shelf seismic facies for this part of the acoustic basement. However, since no exploration wells exist on the Makassar Basin, the nature and origin of the acoustic basement remain problematical. Hamilton (1979) and Katili (1978) suggested that the Makassar Basin is underlain by oceanic crust, whereas Burolet and Salle (1979) proposed that the basin belongs to a rigid continental or intermediate crust. Analysis of subsidence curves indicates crustal thickness of 15 Km in the central part of the basin which increases to about 19 Km at the basin edge (Situmorang, 1982).

Seismic sequence II :

Seismic sequence II is dominated by a parallel reflection pattern, generally horizontal with moderate continuity. The upper boundary of the sequence (acoustic marker C2) is characterized by a strong, relatively continuous reflector, which terminates by onlap against the top of the acoustic basement near SP.300 and SP.2100 – SP.2200. Northwest of SP.1500, reflectors in the upper part of the sequence are concordant with the upper sequence boundary, whereas southeast of SP.1500 reflectors are terminated by gentle toplap against the top of the sequence. In the lower part of the sequence, reflectors are successively terminated by strong onlap against the top of the acoustic basement, with a gentle downlap in the deeper portion of the basin.

Contrasts in dip direction between reflectors within seismic sequence II and reflectors within seismic sequence I can be seen at SP.2200 – SP.2300 and at SP.400. At the first locality, gently southeasterly dipping reflectors of seismic sequence II successively onlap the northwesterly dipping top of the acoustic basement with parallel reflectors underneath. At SP.400, the southeasterly dipping reflectors within seismic sequence I are overlain by the relatively horizontal reflectors of seismic sequence II. This situation, together with the faulted nature of seismic sequence I indicates that the acoustic marker C1 represents a surface of erosional truncation. Faulting appears to ex-

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Fig. 3a

SE

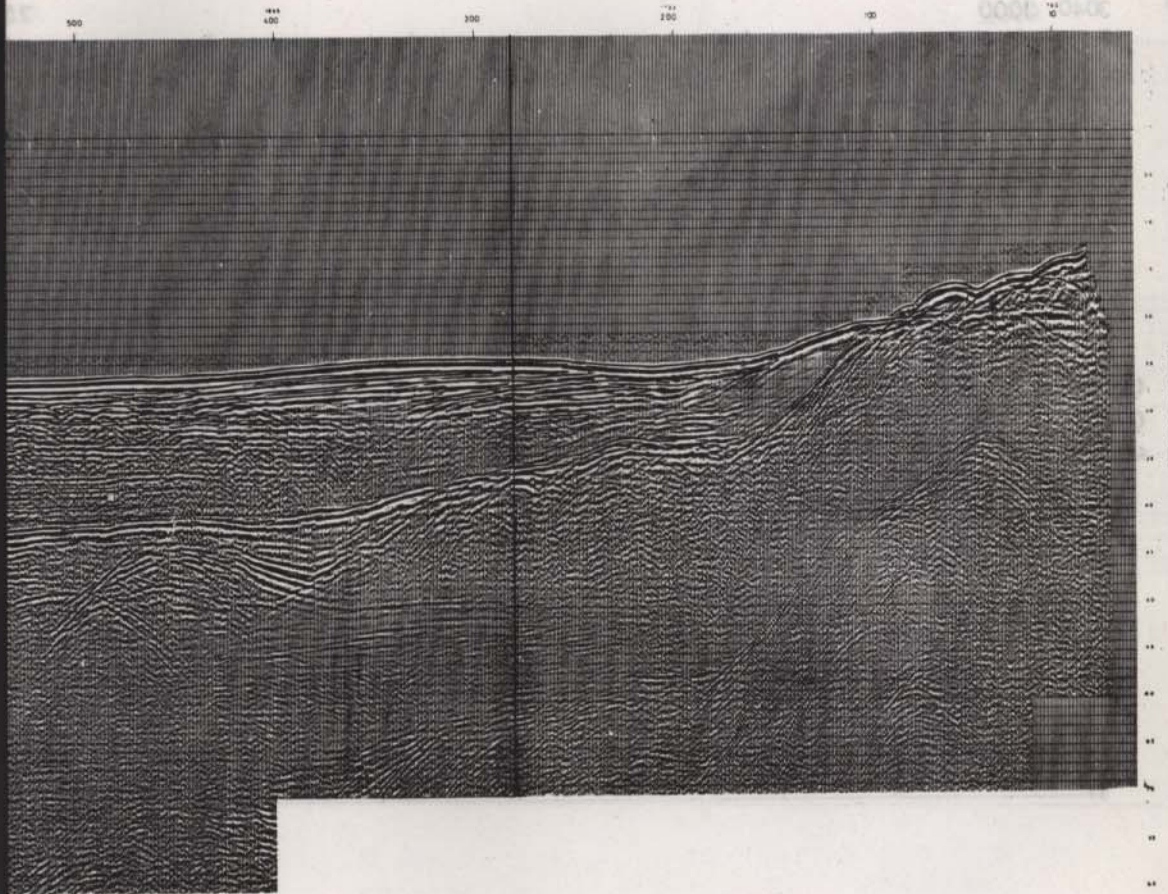


Figure 3 : Reflection seismic record (a) and line drawing (b) of profile P.605.

tend upward into seismic sequence II, and terminate close to the acoustic marker C2. The thickness of seismic sequence II is variable, indicative of infilling of the faulted and irregular basement topography.

The external form of seismic sequence II can be classified as fill-type, indicative of an onlapping-fill seismic facies with predominantly low energy, probably deposited on the basin slope and basin floor. A small mounded onlap-fill seismic facies occurs at SP.2300. The onlapping nature and parallel reflection pattern within this sequence suggest that deposition is due to relatively low energy turbidity currents (Vail et al., 1977). The lithology probably consists of clay and silt, with possible interbedded thin sandy layers which are usually below seismic resolution. The occurrence of a mound at SP.2300 is due to the existence of a basement low at SP.2300 and a basement high at SP.2200. The latter acted as a barrier for the flow of clastic detritus into the deeper part of the basin.

The nature of the normal faulting which extends well into this sequence indicates that extensional processes took place following deposition of seismic sequence I and terminated slightly after or coincide with the end of deposition of seismic sequence II. Hence the acoustic marker C1 can be designated as the top of the pre-rift reflectors, and the acoustic marker C2 as the top of the rift-phase reflectors.

Seismic sequence III :

Seismic sequence III is also dominated by a parallel reflection pattern, with a minor subparallel configuration in several parts of the profile (e.g. at SP.200). This sequence consists of continuous, high amplitude reflectors interleaved with relatively broad bands of weak, low continuity reflectors.

The top of the sequence (acoustic marker C3) is defined by a strong, but discontinuous reflector against which the reflectors in the upper part of the sequence are terminated by toplap. In the central part of the basin, the top of the sequence is slightly contorted. The maximum thickness of the sequence is about 2.3 sec. twt. in the central part of the basin, thinning to 0.3 - 0.5 sec. twt. in the rise area on both sides of the profile. A wedge-like external form is observed in the rise area, whilst sheet external form can be seen in the abyssal plain.

At SP.2100 to SP.2200, reflectors in the middle and lower part of seismic sequence III are ter-

minated successively by onlap against the top of the acoustic basement. In the southeastern part at SP.800 to SP.1100, however, reflectors in the lower part of the sequence are gently onlapped against the top of seismic sequence II.

Seismic sequence III is interpreted as a sequence of interbedded nearshore sandstones and massive shales. The occurrence of the massive shales suggests that deposition of seismic sequence III took place mainly in a low, uniform energy regime.

Seismic sequence IV :

This sequence is the uppermost in the sedimentary section. At the base of the sequence, the reflection pattern is subparallel, then followed upwards by a closely spaced subparallel, contorted, occasionally hummocky reflection configuration, which is finally topped by the strong and flat reflector of the sea floor. Continuity is generally low and amplitude is variable. At SP.200 to SP.300, reflectors at the base of the sequence are terminated by gentle downlap against the acoustic marker C3. The average thickness in the abyssal plain is ca.1.0 sec. twt., but decreases to 0.5 - 0.7 sec. twt. in the rise area.

The nature of reflection pattern within seismic sequence IV suggest that deposition of the sediments occurred in a variable, high energy regime, associated with slumping and turbidity current processes.

There are no structural disturbances observed in seismic sequence III and IV, which suggests that they can be considered as the post-rift depositional sequence.

The overall reflection pattern within seismic sequences II, III, and IV is parallel to subparallel. This indicates that deposition took place in a uniformly subsiding basin at uniform sedimentation rate, without any significant tectonic disturbance.

2. Profile PAC.203

The acoustic markers C1, C2 and C3, can be traced on profile PAC.203 which trends in a NE-SW direction and intersects profile P.605 in the vicinity of SP.1800. The depth to each acoustic marker at several places along the northeastern part of the line is presented in Table 1.

The calculated interval velocity at SP.774 (water depth 1800 m) gave the values of 1654 m/sec for se-

Table 1 : Depth to acoustic markers C1, C2, and C3 at selected points on profile PAC.203.

| Marker | Depth (sec. twt.) | | | | | |
|-----------|-------------------|--------|--------|--------|--------|---------|
| | SP.100 | SP.300 | SP.600 | SP.774 | SP.800 | SP.1000 |
| Sea floor | 2.62 | 2.60 | 2.50 | 2.40 | 2.39 | 2.22 |
| C3 | 3.65 | 3.53 | 3.35 | 3.20 | 3.19 | 2.95 |
| C2 | 4.45 | 4.30 | 4.06 | 3.74 | 3.74 | 3.48 |
| C1 | 6.79 | 5.55 | 5.31 | 4.30 | 4.25 | 3.80 |

ismic sequence IV, 2074 m/sec for seismic sequence III, and 2870 m/sec for seismic sequence II. An interval velocity of the acoustic basement cannot be determined due to the occurrence of the first sea floor multiple just below the acoustic marker C1.

The overall reflection configuration in the northeastern portion of the line is parallel to subparallel, continuous, and slightly folded and less continuous within seismic sequence IV.

3. Profile P.606

This profile trends in W-E direction with only the western half of the line processed and presented as Fig. 4. The slope and rise area extend from the western end of the line where water depth is 500 m to the vicinity of SP.700 with water depth 1800 m.

Diffraction patterns beneath the top of the acoustic basement appear in most parts of the line. At SP.300 to SP.500, seismic sequence I is cut by normal faults downthrowing towards the deeper part of the basin.

Seismic sequence II is characterized by parallel reflections with good continuity, which successively onlap against the top of the acoustic basement.

Seismic sequence III is dominated by a broad interval of parallel, less continuous and low amplitude reflection with fewer interbedded high amplitude continuous reflectors than in seismic sequence III on profile P.605. The thickness of the sequence de-

creases westward, where internal reflectors onlap the top of seismic sequence II.

A continuous strong reflector forms the lower boundary of seismic sequence IV. The lower part of the sequence is made up of a narrow interval of parallel - subparallel reflections, slightly contorted in some parts, less continuous and of low amplitude. The upper part of the sequence exhibits a reflection pattern similar to that observed within seismic sequence IV on profile P.605, i.e. mainly subparallel reflections, closely spaced, continuous in several places, ending up with the flat, strong, continuous reflectors which are topped by the sea floor. The external form is similar to that interpreted for profile P.605. However, on the basis of the internal seismic reflection pattern it is possible to subdivide seismic sequence IV into seismic sequence IVA, topped by the acoustic horizon C3a, and seismic sequence IVB which is topped by the sea floor (Fig. 4).

4. Profile P.607

The previously identified acoustic markers C1, C2 and C3 can be traced on this NNW-SSE trending profile. The seismic time section and its interpretation diagram can be seen in Fig. 5.

Seismic sequence I exhibits a reflection-free zone, whereas seismic sequence II displays a similar reflection configuration to those observed on profiles P.605 and P.606.

Within seismic sequence III, two distinct re-

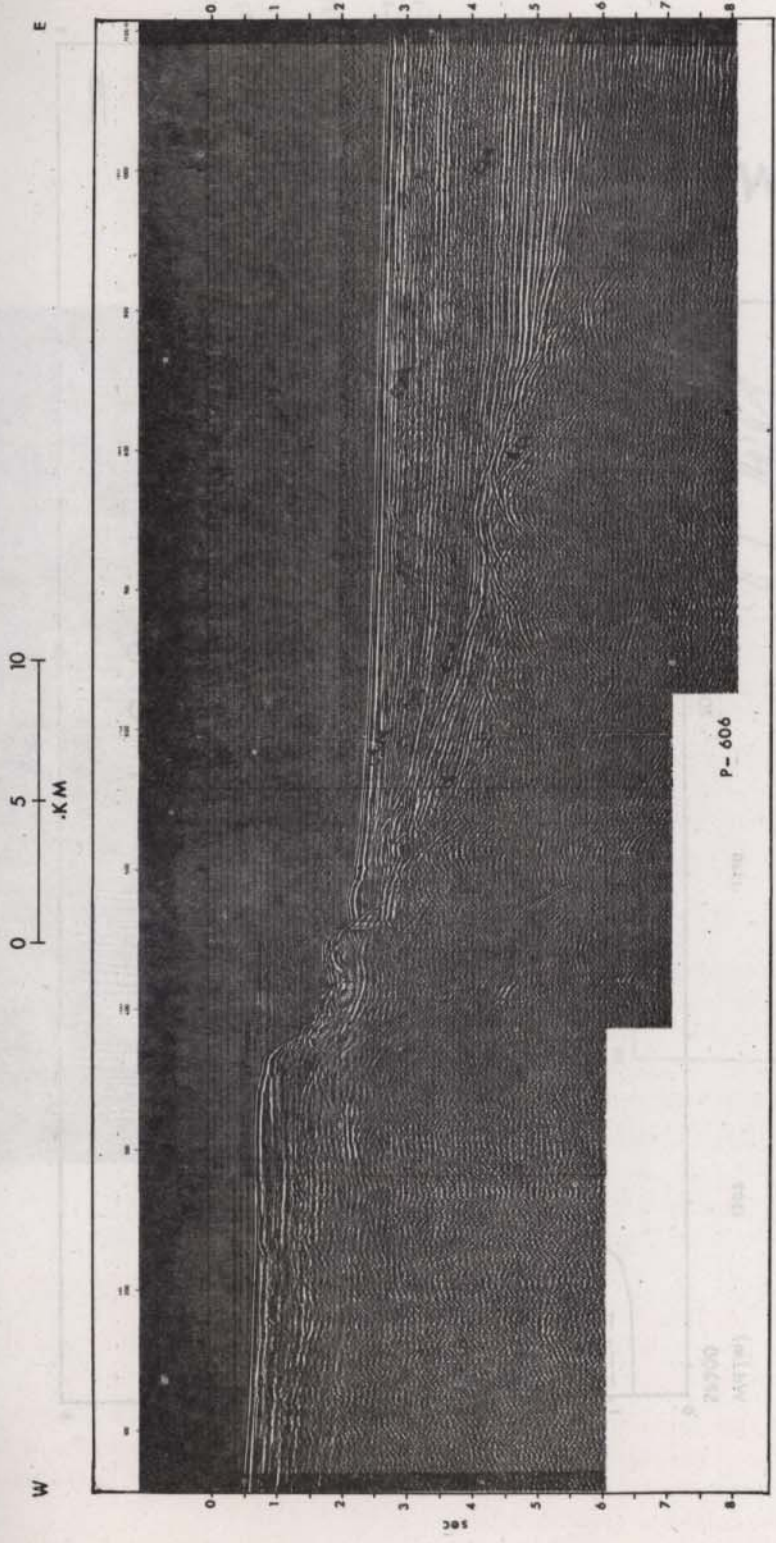


Figure 4 : Reflection seismic record (a) and line drawing (b) of profile P. 606.

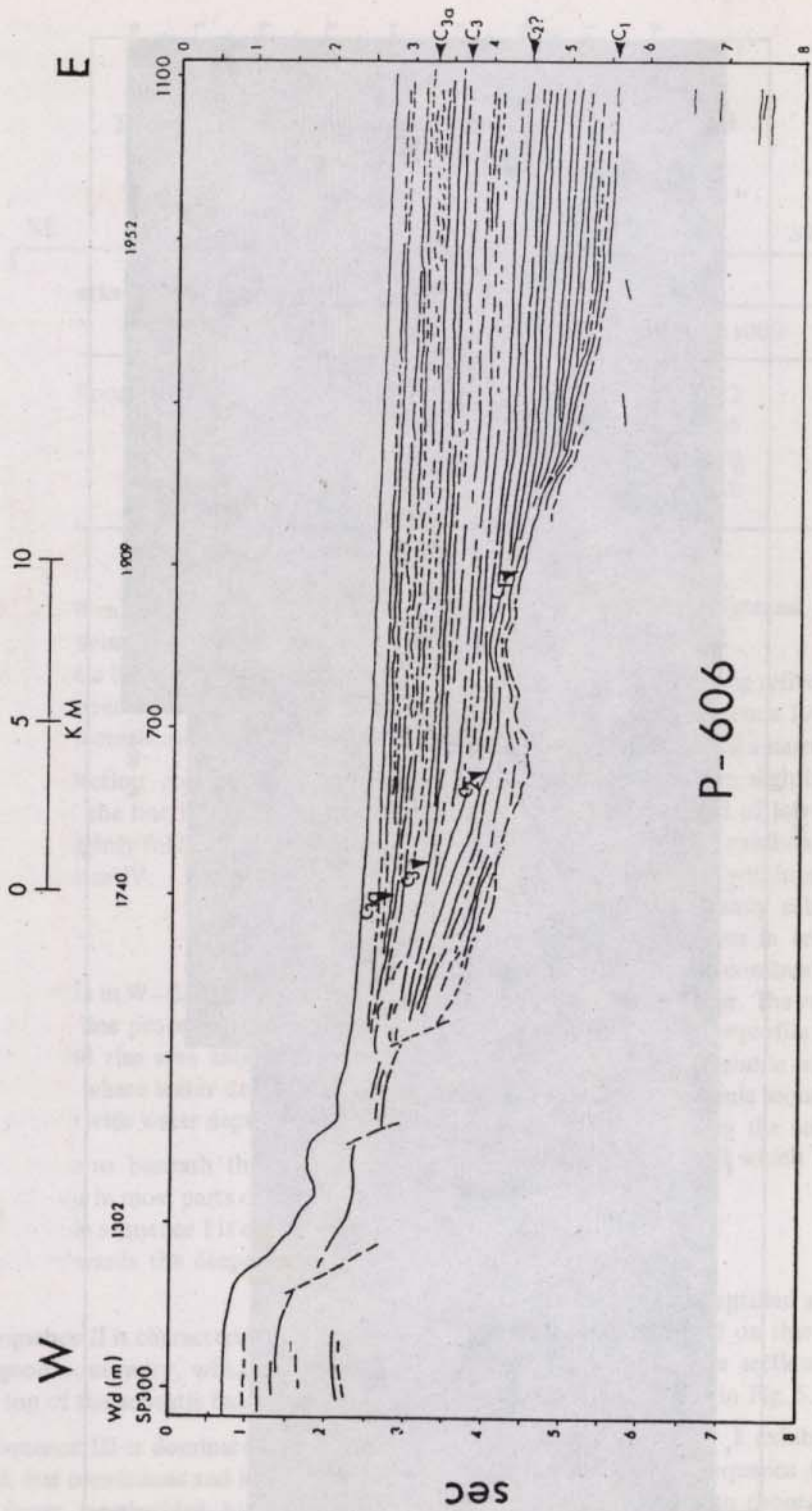


Figure 4b.

Fig. 5a

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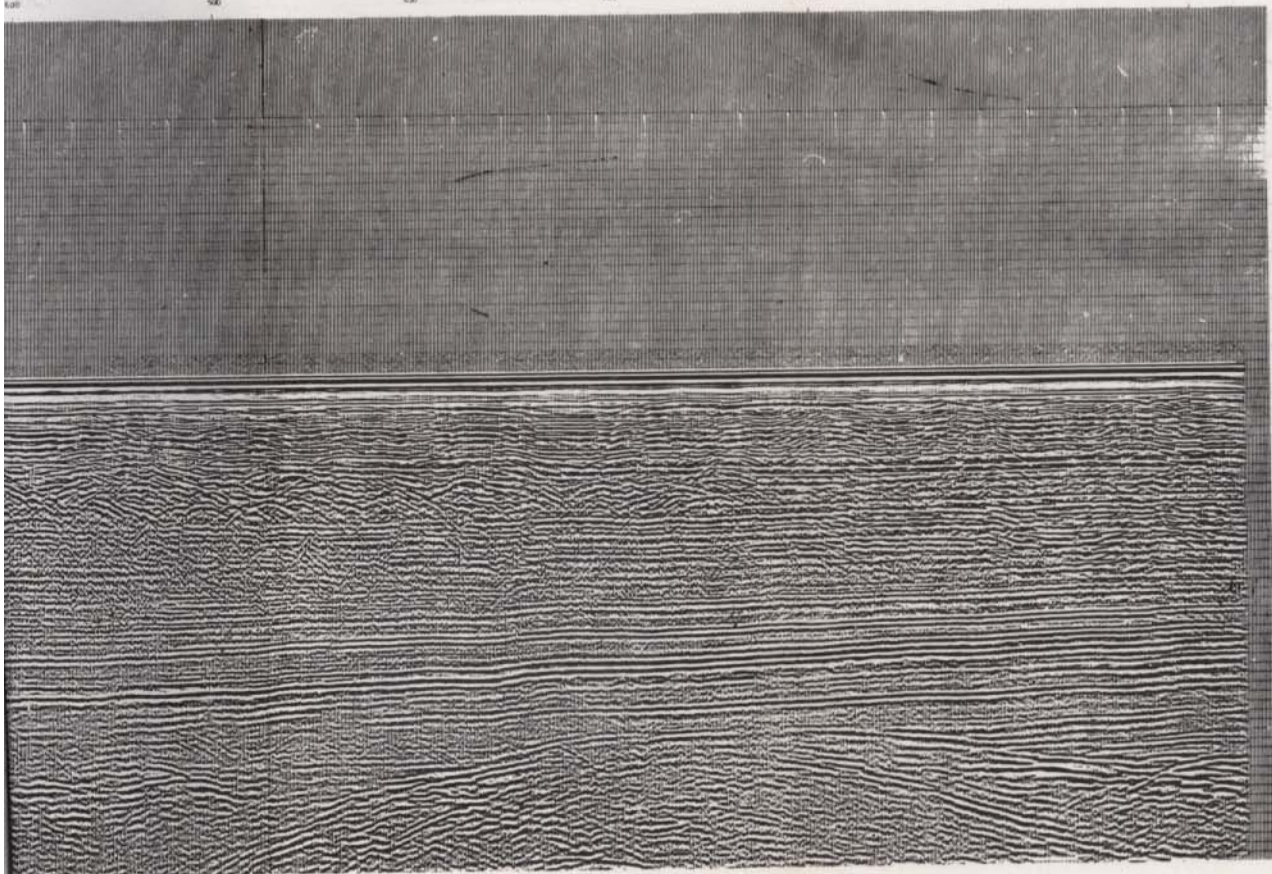


Figure 5 : Reflection seismic record (a) and line drawing (b) of profile P. 607.

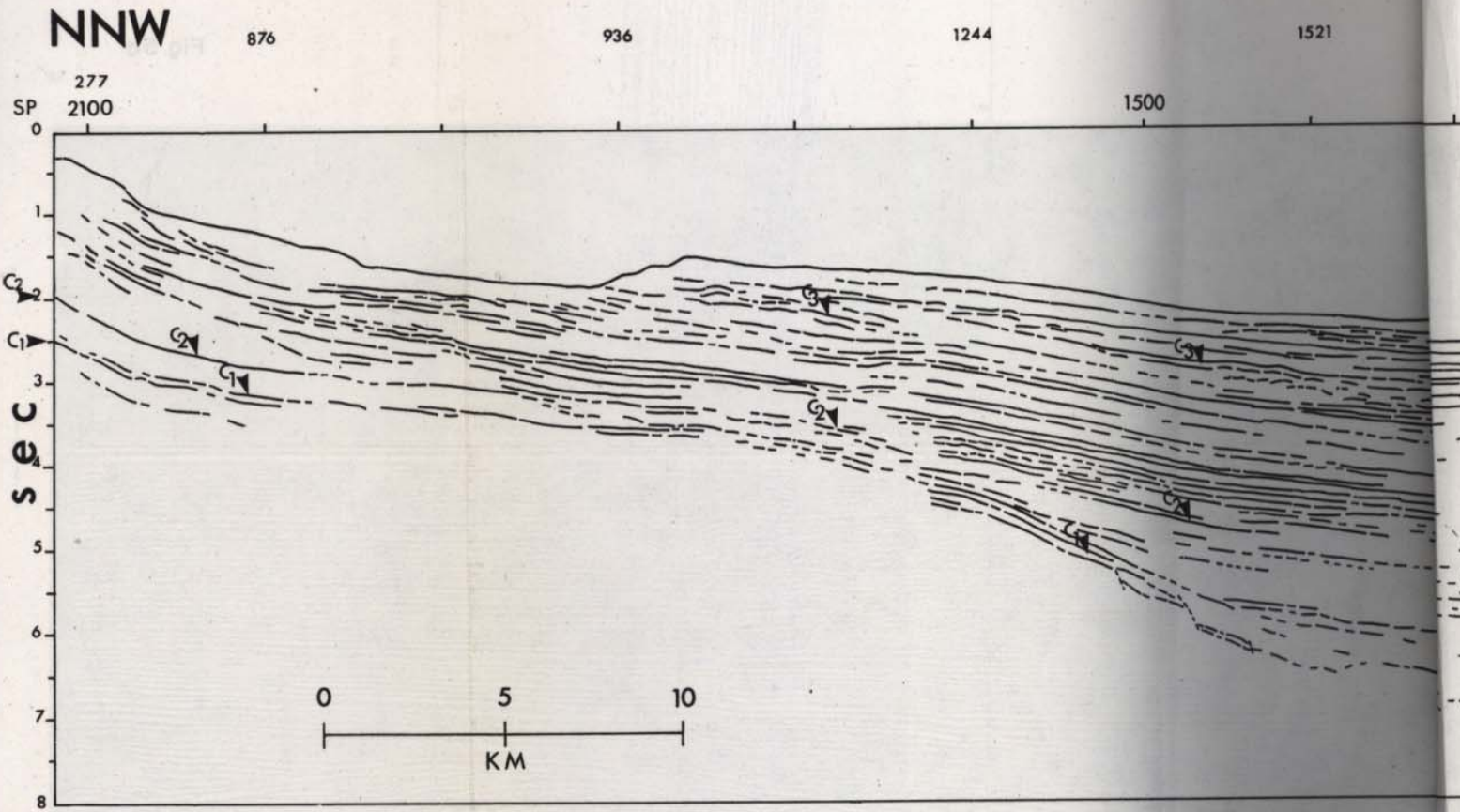


Figure 5b.

flection patterns can be observed. Relatively broad bands of weak, low continuity, low amplitude reflectors are interleaved with zones of strong, almost flat, continuous high amplitude reflectors which predominantly occur in the northwestern half of the profile. In the southeastern half of the line, the reflection pattern is mainly hummocky to chaotic. Here, reflectors are contorted and discontinuous. A chaotic reflection pattern interbedded with strong, slightly discontinuous reflectors is observed from SP.500 to the southeastern end of the line.

Interbedded massive shales and nearshore sandstones are interpreted as present in the northwestern half of the profile, grading laterally into a sequence of slumped material, turbidite and sandstones in the southeastern part.

Downward facing parabolic reflectors occur at SP.800 to SP.900. On the basis of reflectors continuity, absence of dissolution features on top of the reflectors, and the absence of edge-syncline, it is interpreted as a shale diapir. It is directly topped by the strong and flat reflector of the acoustic marker C3. Shale diapirs are also known to occur in some parts of the onshore portion of the Kutai Basin, e.g. in the west - northwest of the Mahakam delta.

The reflection pattern within seismic sequence IV is variable. From the northwestern end of the profile to SP.2000, the pattern appears to be dominated by a progradational configuration with toplap terminations near the sea floor, and downlap against the top of seismic sequence III. This part of the profile is interpreted as a shelf margin and prograded seismic facies, consisting of sediments deposited in neritic conditions. From SP.2000 to SP.1600, the reflection pattern is mainly subparallel, to slightly folded, discontinuous and contorted, and rather chaotic at SP.1600. It is interpreted as due to sediments deposited by turbidity current processes which belong to basin slope seismic facies. The group of slightly chaotic reflections with mound-like shape at SP.1600 is interpreted as a slump mass.

From SP.1550 to SP.550, reflection pattern is parallel to sub-parallel, of good continuity, with moderate to high amplitude, indicative of deposition at a uniform sedimentation rate on a uniformly subsiding basin. It probably consists of mainly neritic sediments (shelf seismic facies). Reflections are generally concordant both at the top and at the base of

the sequence.

From SP.550 to the southeastern end of the line, reflection pattern is subparallel, closely spaced, discontinuous and slightly folded in several places. Reflections are concordant at the top and at the bottom of the sequence. It appears that reflection pattern in this part of the line is similar to that at SP.1550 - SP.550, except that in the southeastern part it is characterized by a prominent discontinuity. It is interpreted as shelf seismic facies frequently affected by marine currents and other flow processes.

5. Profile P.608

This profile trends NW-SE : only the northwestern end of the line (SP.10 - SP.861) is processed and this is presented as Fig. 6.

A strong discontinuous reflector marks the top of the acoustic basement (acoustic marker C1). Seismic sequence I is characterized by a reflection-free zone. Between SP.300 - SP.600, diffraction patterns occur beneath the acoustic marker C1, which are interpreted as a series of normal faults downthrowing towards the basin. Onlapping against the acoustic marker C1 are parallel, weak and discontinuous reflectors belonging to seismic sequence II (SP.500 - SP.861). Northwestward at SP.10 - SP.400, seismic sequence II exhibits a reflection-free pattern, wedging out towards the continental rise at SP.400 - SP.500. The upper boundary of the sequence is marked by a strong, continuous reflector. At SP.500 - SP.861, reflectors at the upper part of the sequence appear to be concordant with the acoustic marker C2. Seismic sequence II is interpreted as shelf seismic facies, probably dominated by calcareous shale (low amplitude seismic facies) deposited in a uniform low-energy regime.

Seismic sequence III also displays parallel reflection pattern, with good continuity, especially in the southeastern part of the profile (SP.500 - SP.861). Relatively closely spaced reflectors occur in this part, in contrast to the broadly spaced reflectors in the northwestern part (SP.10 - SP.300), whilst the rest of the sequence displays a reflection-free pattern. This sequence is interpreted as shelf seismic facies, built up by massive shales with intercalation of sandstones in the northwestern part (SP.10 - SP.350), grading laterally into shales interbedded with sandstones, siltstones or carbonate rocks (SP.350 - SP.861). Diffraction

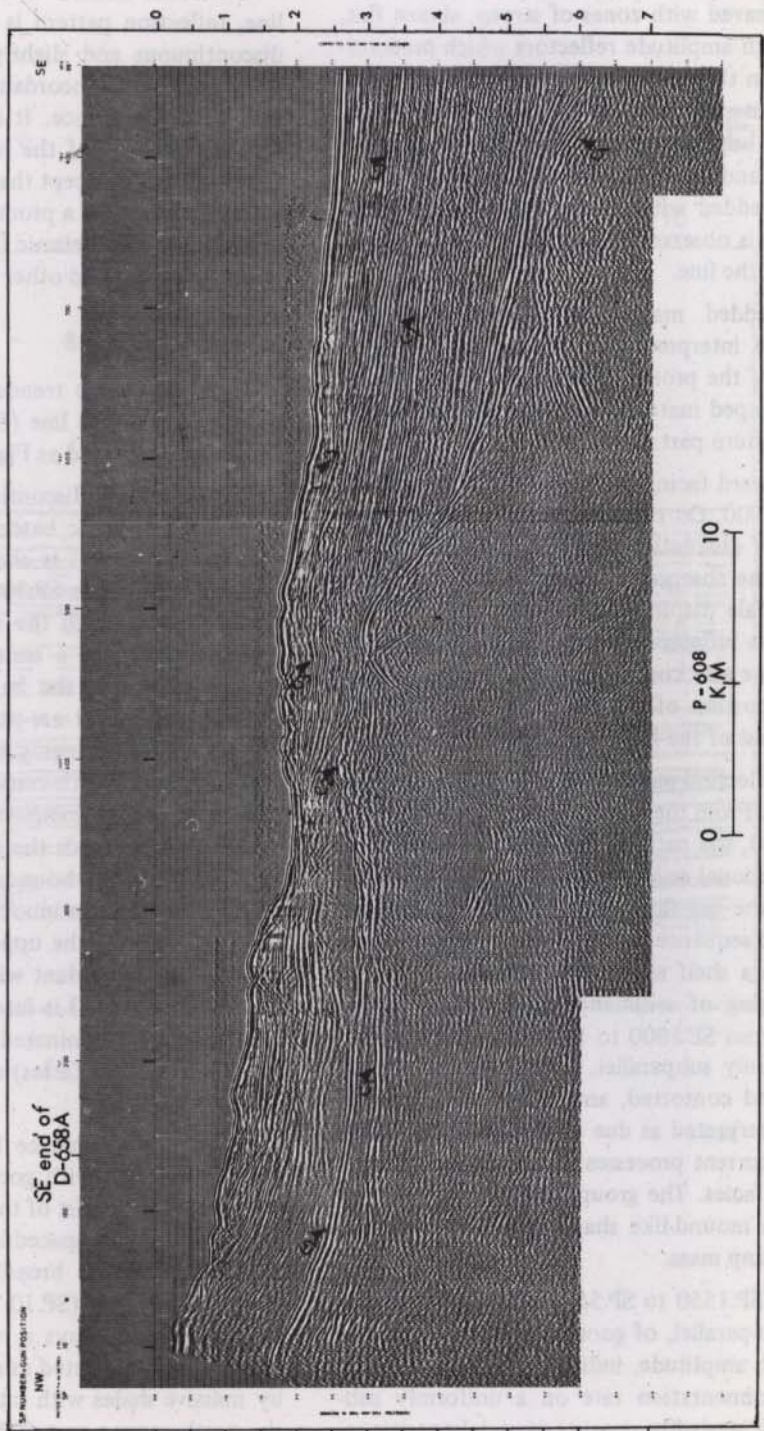


Figure 6 : Reflection seismic record (a) and line drawing (b) of profile P. 608.

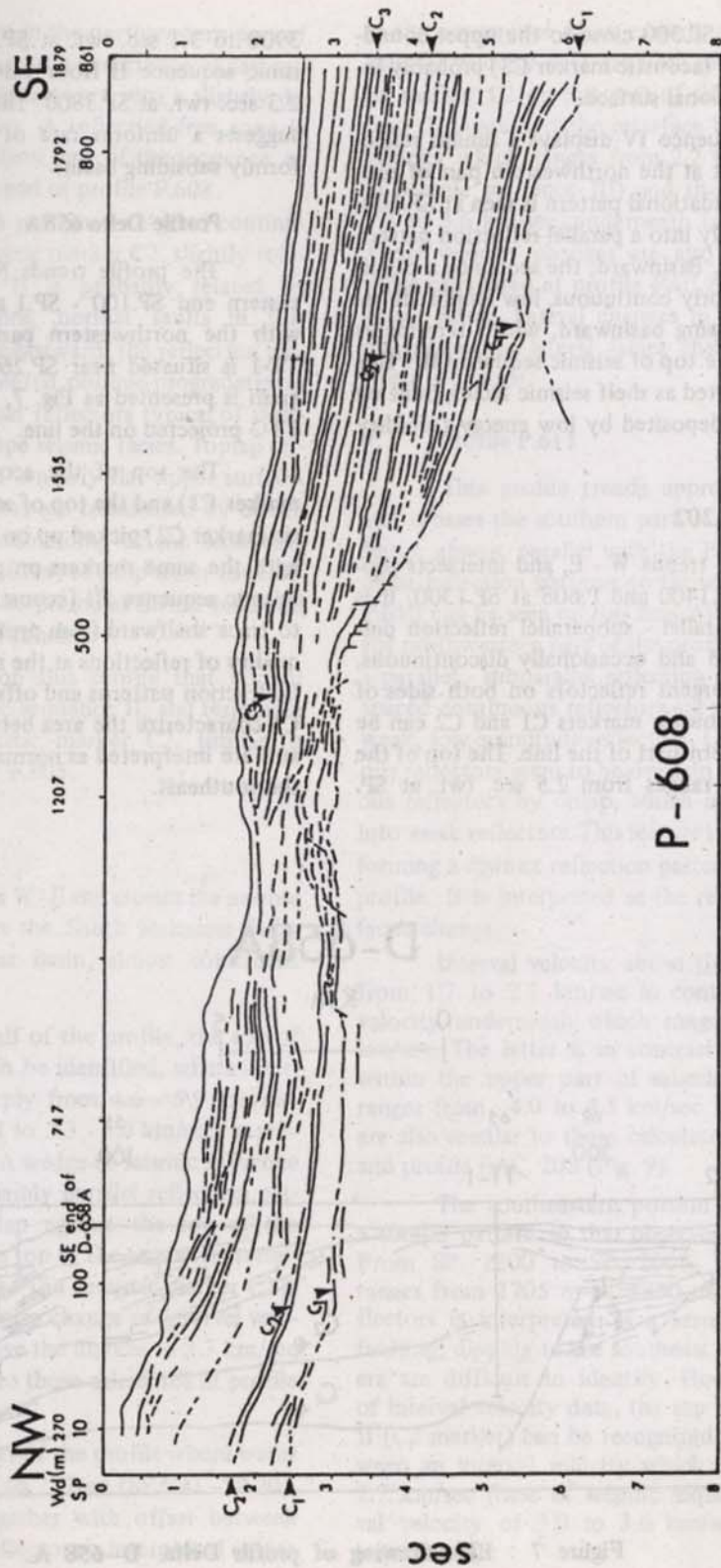


Figure 6b.

tion hyperbolae at SP.300 close to the upper boundary of the sequence (acoustic marker C3) probably indicate a buried erosional surface.

Seismic sequence IV displays a similar reflection pattern to that at the northwestern part of profile P.607. A progradational pattern is seen at SP.100, which passes laterally into a parallel reflection pattern at SP.200 - SP.300. Basinward, the sequence is dominated by weak, poorly continuous, low amplitude reflectors, gently sloping basinward, which terminates by onlap against the top of seismic sequence III. This sequence is interpreted as shelf seismic facies, built up by marine clastics deposited by low energy turbidity currents.

6. Profile PAC.202

This profile trends W - E, and intersects profiles P.607 near SP.1400 and P.608 at SP.1300. It is dominated by a parallel - subparallel reflection pattern, slightly folded and occasionally discontinuous, with upslope convergent reflectors on both sides of the profile. The acoustic markers C1 and C2 can be traced on the western part of the line. The top of the acoustic basement ranges from 2.5 sec. twt. at SP.

3900 to 3.1 sec. twt. at SP.3800, and the top of seismic sequence II from 1.84 sec. twt. at SP.3900 to 2.3 sec. twt. at SP.3800. The reflection configuration suggests a uniform rate of sedimentation in a uniformly subsiding basin.

7. Profile Delta 658A

The profile trends NW - SE with the southeastern end SP.100 - SP.1 approximately coincident with the northwestern part of profile P.608. Well TT-1 is situated near SP.260. An interpretation diagram is presented as Fig. 7, with the location of well TT-2 projected on the line.

The top of the acoustic basement (acoustic marker C1) and the top of seismic sequence II (acoustic marker C2) picked up on this profile correlate well with the same markers on profile P.608. The top of seismic sequence III (acoustic marker C3) is difficult to trace shelfward from profile P.608 due to the poor quality of reflections at the northwest end of the line. Diffraction patterns and offset of the acoustic marker C1 characterize the area between SP.360 and SP.240, and are interpreted as normal faults downthrowing to the southeast.

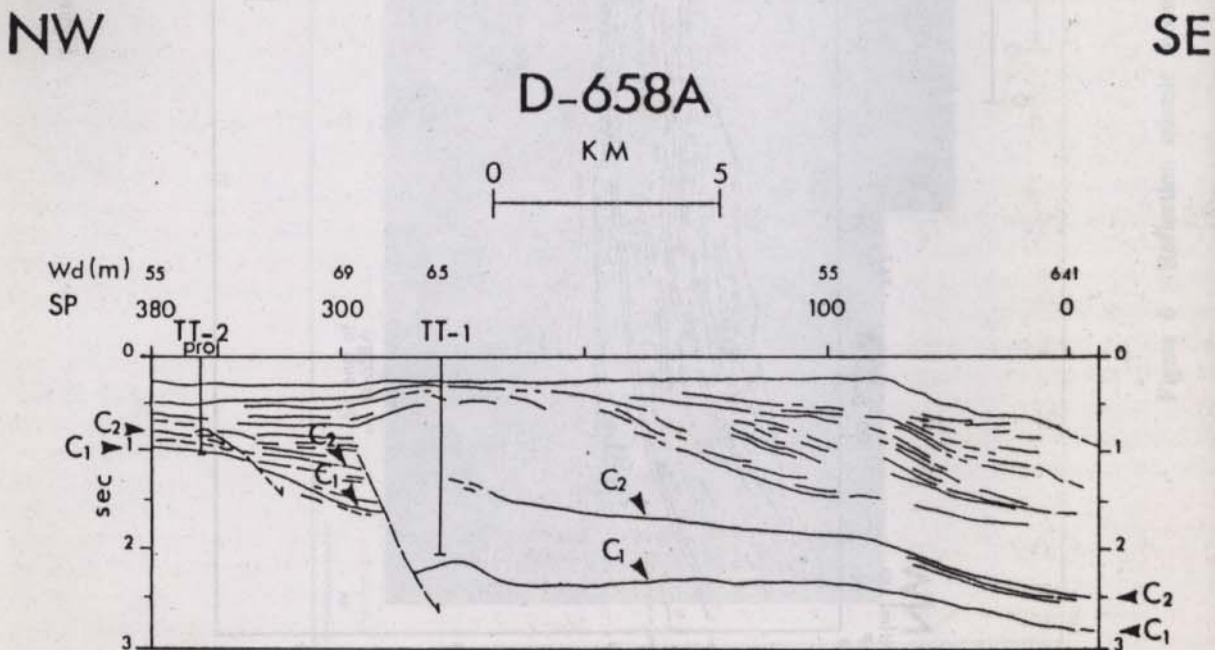


Figure 7 : Line drawing of profil Delta D-658 A.

Reflection pattern in the northwestern part of seismic sequence II suggests the occurrence of carbonate buildup, grading southeastward into a slightly divergent reflection pattern. A reflection-free zone is observed in the southeastern part of the sequence, as seen in the northwestern end of profile P.608.

Parallel reflection pattern with good continuity occurs above the acoustic marker C2, slightly folded toward well TT-1. It is probably related to vertical movements along normal faults in this part of the profile. Southeastward, the reflection pattern passes into a tangential oblique-progradational pattern with some sigmoid reflectors typical of shelf-margin and prograded slope seismic facies. Toplap terminations can be seen at a nearly flat upper surface, whereas the base reflectors are terminated by downlap, indicative of the outbuilding of the sediments from shallow water (55 - 65m) to deep water (641m). This part of the line is interpreted as fluvial delta and associated coastal-plain sediments.

It also appears on this profile that normal faults extend into seismic sequence II, and terminate slightly above the acoustic marker C2, similar to those observed on profile P.605.

8. Profile P.610

This profile trends W - E and crosses the narrow abyssal plain which links the South Makassar Basin with the North Makassar Basin, almost coincident with 3°S latitude.

In the western half of the profile, the top of the acoustic basement can be identified, where interval velocity changes sharply from 4.6 - 5.9 km/sec. within seismic sequence I to 3.3 - 3.6 km/sec. in seismic sequence II (Fig. 8). A wedge of seismic sequence II is characterized by mainly parallel reflection pattern, terminated by onlap against the top of the acoustic basement. At the top of the sequence, termination is by gentle toplap. The acoustic marker C2 is also characterized by a sharp change of interval velocity from 2.4 km/sec. above the marker to 3.3 km/sec. underneath, comparable to those calculated at profile PAC.203.

On the eastern part of the profile where water depth ranges from 710m to 2176m (SP.600 - SP.20), a diffraction pattern together with offset between predominantly parallel reflectors is interpreted as due

to the occurrence of an easterly dipping thrust fault. Interval velocity data are used to delineate the acoustic marker C2 on this part of this profile. It appears that C2 marker is the interface between the interval velocity which ranges from 2.2 to 2.7 km/sec. (base of seismic sequence III) and the interval velocity of 3.3 to 3.6 km/sec. underneath (seismic sequence II). These velocity changes are also in agreement with those calculated at profile PAC.203 in the South Makassar Basin. Lateral changes in interval velocity are interpreted as lateral facies changes within depositional sequence.

9. Profile P.611

This profile trends approximately NW - SE, and crosses the southern part of the North Makassar Basin, almost parallel with the Paternoster Fault. Similar reflection patterns to those observed on profile P.610 can be seen on this line. All seismic sequences in the northwestern part of the profile are dominated by a parallel - subparallel reflection pattern. The closely spaced continuous reflectors are grading laterally into weak, low amplitude reflectors. Upwards the continuous reflectors seem to be overlain by the next continuous reflectors by onlap, which in turn pass laterally into weak reflectors. This feature is repeated vertically, forming a distinct reflection pattern in this part of the profile. It is interpreted as the result of rapid lateral facies change.

Interval velocity above the C2 marker ranges from 1.7 to 2.1 km/sec in contrast to the interval velocity underneath which ranges from 3.3 to 3.8 km/sec. The latter is in contrast to interval velocity within the upper part of seismic sequence I which ranges from 4.0 to 4.5 km/sec. These velocity data are also similar to those calculated on profile P. 610 and profile PAC. 203 (Fig. 9).

The southeastern portion of the line exhibits a similar pattern to that observed on profile P. 610. From SP. 1200 to SP. 2000, where water depth ranges from 1705 m to 1850 m, offset between reflectors is interpreted as a result of mainly thrust faulting, dipping to the southeast. The acoustic markers are difficult to identify. However, on the basis of interval velocity data, the top of seismic sequence II (C2 marker) can be recognized as an interface between an interval velocity which ranges from 2.0 to 2.7 km/sec (base of seismic sequence III) and interval velocity of 3.0 to 3.6 km/sec (top of seismic sequence II).

tion hyperbolae at SP.300 close to the upper boundary of the sequence (acoustic marker C3) probably indicate a buried erosional surface.

Seismic sequence IV displays a similar reflection pattern to that at the northwestern part of profile P.607. A progradational pattern is seen at SP.100, which passes laterally into a parallel reflection pattern at SP.200 - SP.300. Basinward, the sequence is dominated by weak, poorly continuous, low amplitude reflectors, gently sloping basinward, which terminates by onlap against the top of seismic sequence III. This sequence is interpreted as shelf seismic facies, built up by marine clastics deposited by low energy turbidity currents.

6. Profile PAC.202

This profile trends W - E, and intersects profiles P.607 near SP.1400 and P.608 at SP.1300. It is dominated by a parallel - subparallel reflection pattern, slightly folded and occasionally discontinuous, with upslope convergent reflectors on both sides of the profile. The acoustic markers C1 and C2 can be traced on the western part of the line. The top of the acoustic basement ranges from 2.5 sec. twt. at SP.

3900 to 3.1 sec. twt. at SP.3800, and the top of seismic sequence II from 1.84 sec. twt. at SP.3900 to 2.3 sec. twt. at SP.3800. The reflection configuration suggests a uniform rate of sedimentation in a uniformly subsiding basin.

7. Profile Delta 658A

The profile trends NW - SE with the southeastern end SP.100 - SP.1 approximately coincident with the northwestern part of profile P.608. Well TT-1 is situated near SP.260. An interpretation diagram is presented as Fig. 7, with the location of well TT-2 projected on the line.

The top of the acoustic basement (acoustic marker C1) and the top of seismic sequence II (acoustic marker C2) picked up on this profile correlate well with the same markers on profile P.608. The top of seismic sequence III (acoustic marker C3) is difficult to trace shelfward from profile P.608 due to the poor quality of reflections at the northwest end of the line. Diffraction patterns and offset of the acoustic marker C1 characterize the area between SP.360 and SP.240, and are interpreted as normal faults downthrowing to the southeast.

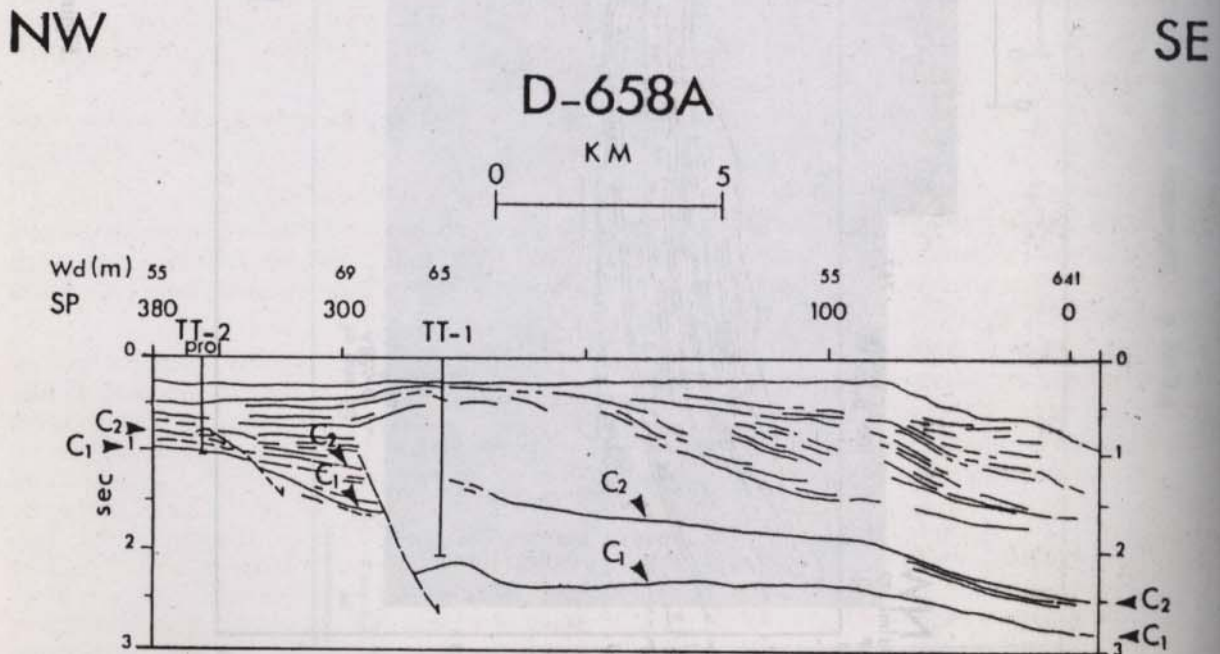


Figure 7 : Line drawing of profilr Delta D-658 A.

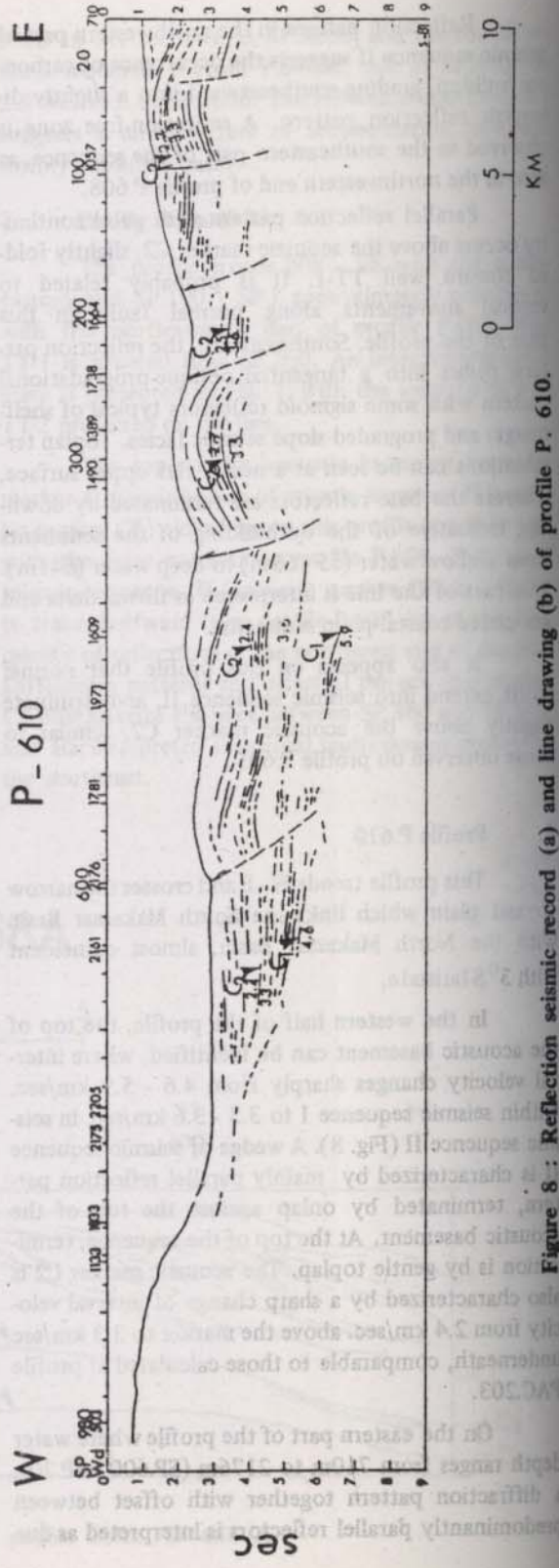
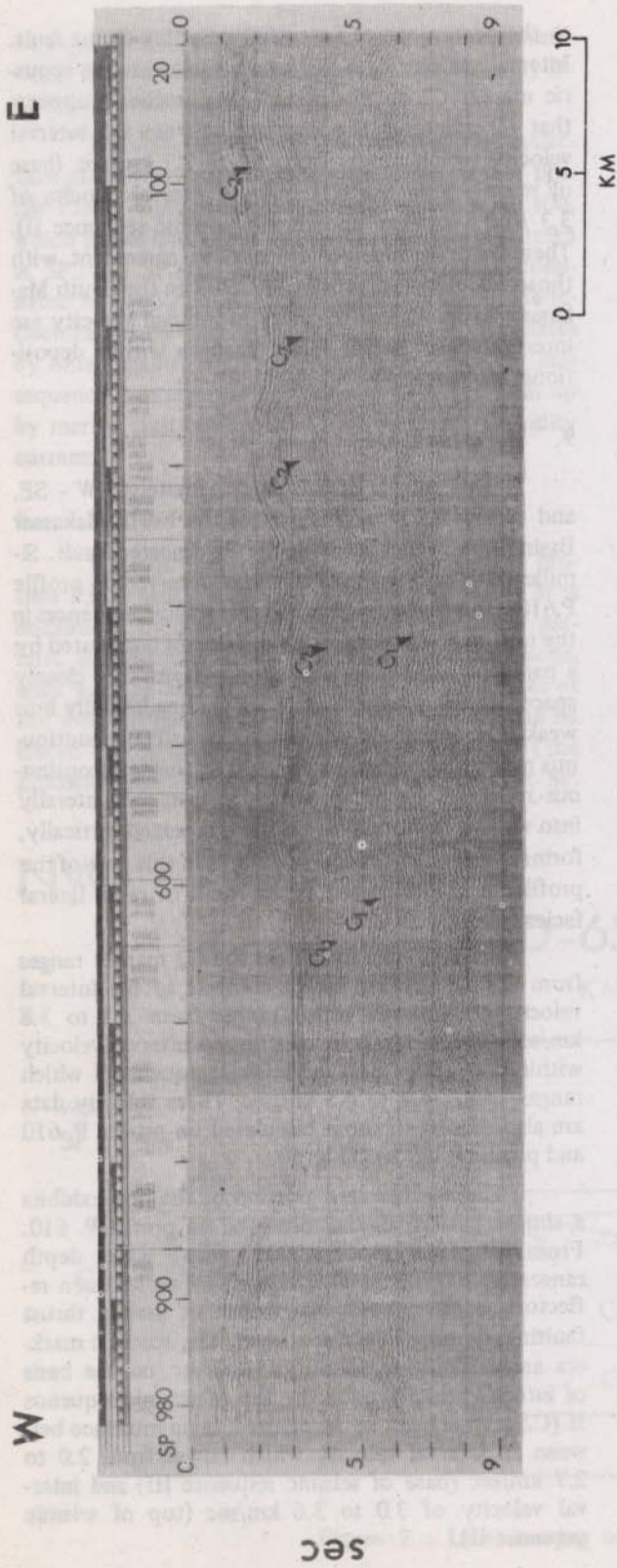


Figure 8.: Reflection seismic record (a) and line drawing (b) of profile P. 610.

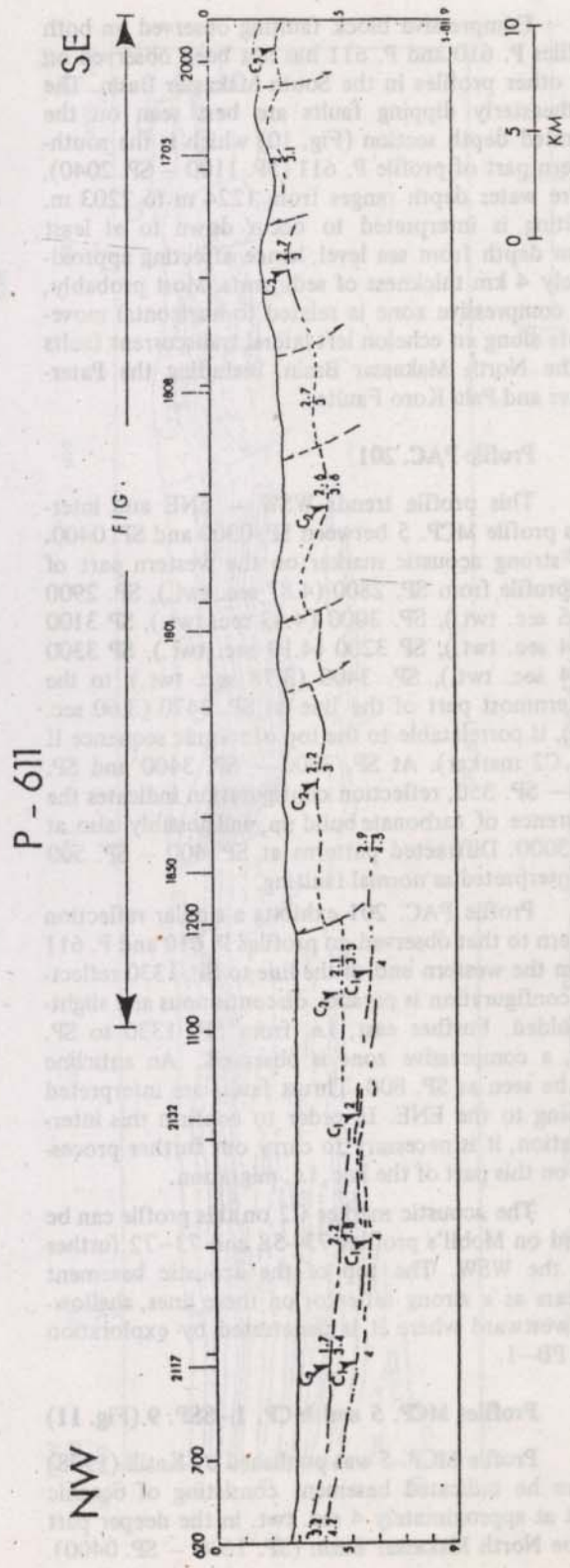
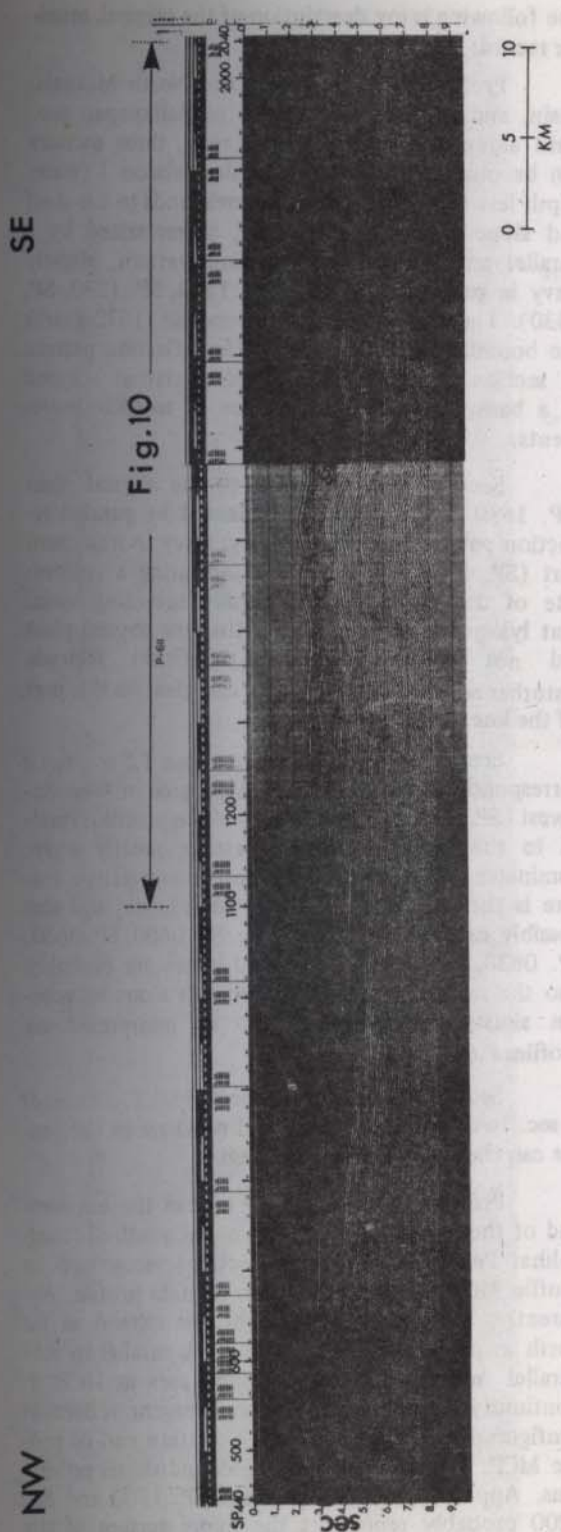


Figure 9 : Reflection seismic record (a) and line drawing (b) of profile P. 611.

Compressive block faulting observed on both profiles P. 610 and P. 611 has not been observed on any other profiles in the South Makassar Basin. The southeasterly dipping faults are best seen on the migrated depth section (Fig. 10) which is the southeastern part of profile P. 611 (SP. 1100 – SP. 2040), where water depth ranges from 1224 m to 2203 m. Faulting is interpreted to occur down to at least 6 km depth from sea level, hence affecting approximately 4 km thickness of sediments. Most probably, this compressive zone is related to horizontal movements along an echelon left lateral transcurrent faults in the North Makassar Basin, including the Pateroster and Palu Koro Faults.

10. Profile PAC. 201

This profile trends WSW – ENE and intersects profile MCP. 5 between SP. 0300 and SP. 0400. The strong acoustic marker on the western part of the profile from SP. 2800 (4.87 sec. twt.), SP. 2900 (4.65 sec. twt.), SP. 3000 (4.43 sec. twt.), SP. 3100 (4.24 sec. twt.), SP. 3200 (4.19 sec. twt.), SP. 3300 (4.04 sec. twt.), SP. 3400 (3.78 sec. twt.), to the westernmost part of the line at SP. 3470 (3.60 sec. twt.), is correlatable to the top of seismic sequence II (the C2 marker). At SP. 3300 – SP. 3400 and SP. 270 – SP. 350, reflection configuration indicates the occurrence of carbonate build up, and possibly also at SP. 3000. Diffracted patterns at SP. 400 – SP. 500 are interpreted as normal faulting.

Profile PAC. 201 exhibits a similar reflection pattern to that observed on profiles P. 610 and P. 611. From the western end of the line to SP. 1330 reflection configuration is parallel, discontinuous and slightly folded. Further east, i.e. from SP. 1330 to SP. 840, a compressive zone is observed. An anticline can be seen at SP. 800. Thrust faults are interpreted dipping to the ENE. In order to confirm this interpretation, it is necessary to carry out further processing on this part of the line, i.e. migration.

The acoustic marker C2 on this profile can be traced on Mobil's profiles 73–58 and 73–72 further to the WSW. The top of the acoustic basement appears as a strong reflector on these lines, shallowing westward where it is penetrated by exploration well PB–1.

11. Profiles MCP. 5 and MCP. 1–SSP. 9 (Fig. 11)

Profile MCP. 5 was published by Katili (1978) where he indicated basement consisting of oceanic crust at approximately 4 sec. twt. in the deeper part of the North Makassar Basin (SP. 1630 – SP. 0400).

The following is my description of the original monitor record:

Profile MCP. 5 crosses the North Makassar Basin, and extends from south of Balikpapan eastward along 2°S latitude. In general, three sections can be observed along the profile. Section 1 (water depth less than 1.5 sec. twt.) corresponds to the shelf and slope area of Kalimantan, characterized by a parallel and subparallel reflection pattern, slightly wavy in parts (SP. 1030 – SP. 1100, SP. 1230, SP. 1430). The structural high around SP. 1630 marks the boundary with section 2. The reflection pattern in section 1 indicates that sedimentation occurred in a basin with minor influence of tectonic movements.

Section 2 corresponds to the abyssal plain (SP. 1630 to SP. 0400), dominated by parallel reflection pattern, good continuity, wavy in its eastern part (SP. 0330 – SP. 0400), indicating a uniform rate of deposition in a uniformly subsiding basin. Flat lying sediments indicate that the abyssal plain did not experience any significant tectonic disturbances. A flat sea floor is also clear on this part of the line.

Section 3 (water depth less than 1.5 sec. twt.) corresponds to the shelf and slope area of West Sulawesi (SP. 0430 to eastern end of the profile). Parallel to subparallel reflection pattern, mostly wavy, dominates this section. The most characteristic feature is the existence of several fold zones, and also possibly carbonate mounds (e.g. SP. 0600, SP. 0630, SP. 0830, SP. 0900)). The fold zones are probably also the manifestation of movements along an echelon sinistral transcurrent fault as interpreted on profiles P.610 and P.611.

Sediment thickness on profile MCP. 5 exceeds 5 sec. twt. below sea level, and nowhere in the profile can the basement be identified

Profile MCP. 1–SSP. 9 crosses the northern end of the North Makassar Basin just south of Mangkalihat Peninsula. The three sections recognized on profile MCP. 5 cannot be seen on this profile. Apparently, the abyssal plain does not extend as far north as profile MCP. 1 – SSP. 9. A parallel to subparallel reflection pattern can be seen at MCP. 1. Continuity is poor. A slightly divergent reflection configuration is observed at the western end of profile MCP. 1, due to thickening of individual reflections. Apparent downlap between SP. 1500 and SP. 1200 probably represents the upper surface of the acoustic basement. The shallowest depth can be

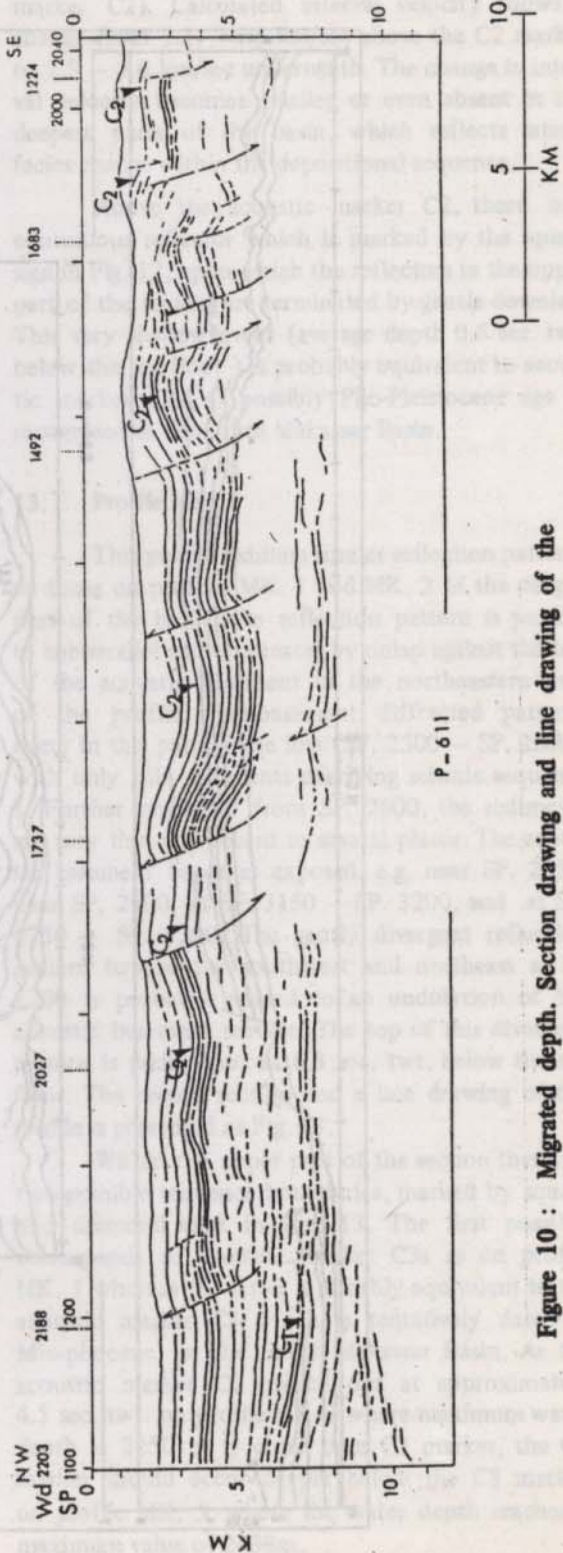
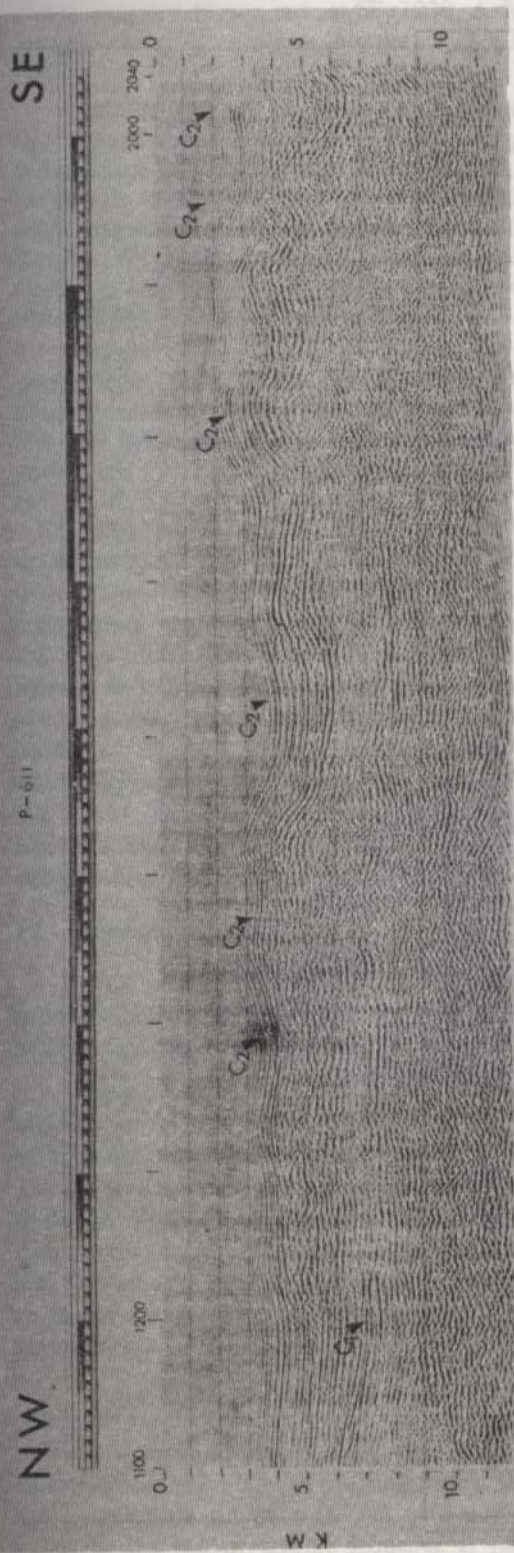


Figure 10 : Migrated depth. Section drawing and line drawing of the Southeastern part of profile P.611.

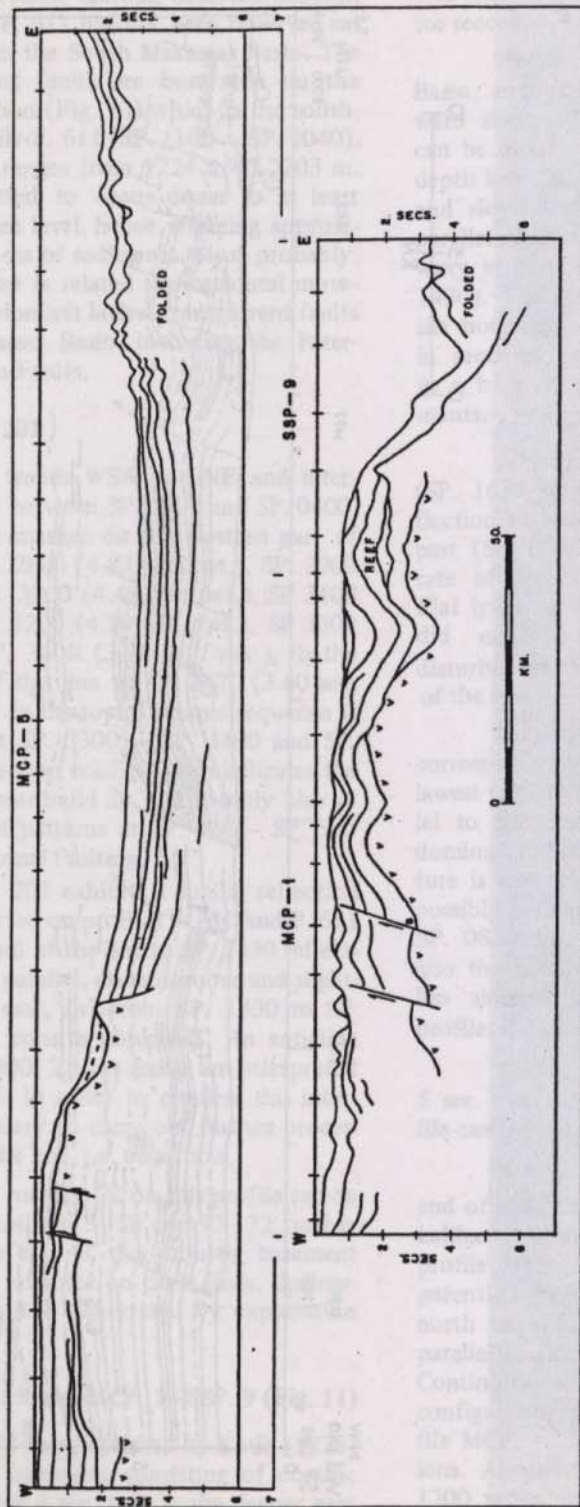


Figure 11. Line drawing of profile MCP. 5, and MCP. 1-SSP. 9 (Katli, 1978).

picked out at 1.45 sec. twt. at SP. 1230. A diffraction pattern at SP. 1500 is interpreted as a reverse fault.

Profile SPP. 9 is dominated by a rather chaotic, discontinuous reflection pattern, suggesting deposition in high energy sedimentary regime. Onlap fill is seen at SP. 0000 and between SP. 0200 and 0400, interpreted as Recent undeformed sediments. East of SP. 0700, there is a change in reflection continuity, arranged in an onlapping-like feature, that probably indicates a carbonate build up.

Shelf seismic facies are interpreted along profile MCP. 1. Penecontemporaneous deformation probably affected the northern margin of the North Makassar Basin, resulting in folded strata as seen on profile SSP. 9. The basement is detected at 3 sec. twt. on SP. 1500 and less than 2 sec. twt. at SP. 1300 – SP. 1200 (profile MCP. 1). This is probably related to the offshore extension of Mangkalihat High. If the northwest extension of Palu Koro Fault as interpreted from the bathymetry is correct, the fault will cross profile SSP. 9 at around SP. 0500. A relatively smooth sea floor can be seen to the west of this point, whereas slightly rough morphology occurs to the east. Along Mobil's profile 71–36 which approximately coincides with profile MCP.1, the top of the acoustic basement is interpreted at less than 2 sec. twt. at SP.1700–SP. 1800, deepening toward east to 3 sec.twt.at SP.2000.

12. Profile MK. 1

This profile crosses the North Makassar Basin in SW–NE direction, where the sea floor appears as a flat surface throughout the line.

Seismic sequence I can be seen at the northeastern part of the profile (SP. 2300 – SP. 2900), with mainly parallel sub-basement reflectors (Fig. 12) The top of the acoustic basement can be traced south westward, deepening suddenly at SP. 2200 and is then covered by the first sea floor multiple reflection. The acoustic marker C1 is also characterized by an abrupt change of interval velocity from 2.1 – 2.5 km/sec to 4.2 km/sec underneath.

A parallel to subparallel reflection pattern dominates most of the profile. The strong continuous reflector at approximately 4.5 sec. twt. designated as an intra-Miocene horizon of probably Upper Miocene age by Buroillet and Salle (1979), probably corresponds to the top of seismic sequence II (acoustic

marker C2). Calculated interval velocity shows a change from 2.1 – 2.6 km/sec above the C2 marker to 2.5 – 3.6 km/sec underneath. The change in interval velocity becomes smaller or even absent in the deepest parts of the basin, which reflects lateral facies change within the depositional sequence.

Above the acoustic marker C2, there is a continuous reflector which is marked by the square sign in Fig. 12, upon which the reflectors in the upper part of the section are terminated by gentle downlap. This very shallow event (average depth 0.5 sec. twt. below the sea floor) is probably equivalent to acoustic marker C3a of possibly Plio-Pleistocene age as recognized in the South Makassar Basin.

13. Profile MK. 3

This profile exhibits similar reflection patterns to those on profiles MK. 1 and MK. 2 In the deeper part of the basin, the reflection pattern is parallel to subparallel and terminates by onlap against the top of the acoustic basement in the northeastern part of the profile. Sub-basement diffracted patterns occur in this part of the line (SP. 2300 – SP. 2600), with only thin sediments overlying seismic sequence I. Further northeast from SP. 2600, the sediments are very thin and absent in several places. The acoustic basement becomes exposed, e.g. near SP. 2850, near SP. 2900, at SP. 3150 – SP. 3200, and at SP. 3250 – SP. 3300. The gently divergent reflection pattern toward the southwest and northeast at SP 1300 is probably related to an undulation of the acoustic basement surface. The top of this divergent pattern is picked out at 6.3 sec. twt. below the sea floor. The record section and a line drawing of the profile is presented as Fig. 13.

Within the upper part of the section there are two possible sequence boundaries, marked by square and diamond signs in Fig. 13. The first possibly corresponds to acoustic marker C3a as on profile MK. 1 whereas the latter is possibly equivalent to the acoustic marker C3 which is tentatively dated as Mio-pliocene in the South Makassar Basin. As the acoustic marker C2 picked out at approximately 4.5 sec. twt. on profile MK. 1 where maximum water depth is 2250 m is older than C3 marker, the C2 marker should occur deeper below the C3 marker on profile MK. 3, where the water depth reaches a maximum value of 2438m.

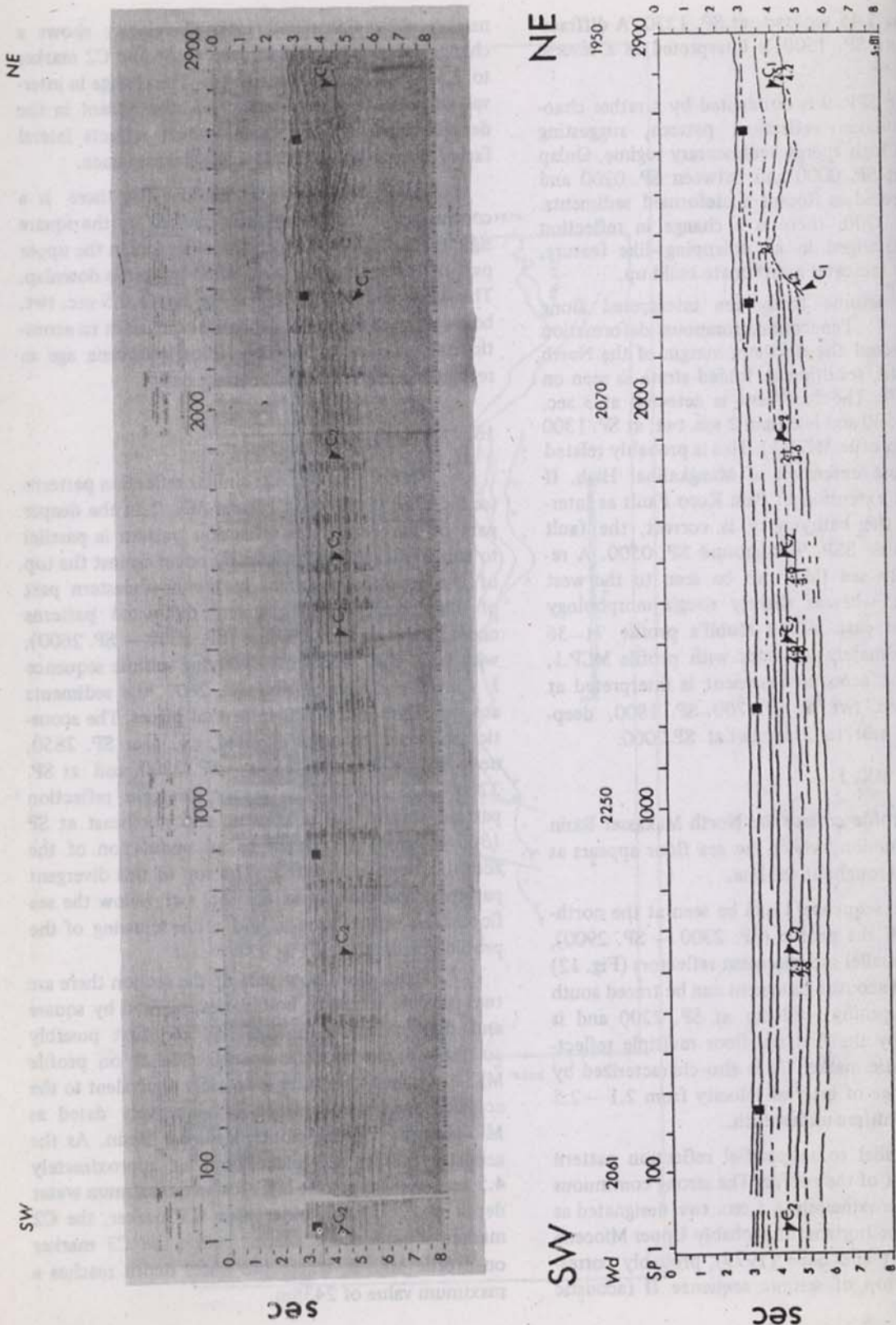


Figure 12 : Reflection seismic record (a) and line drawing (b) of profile MK. 1.

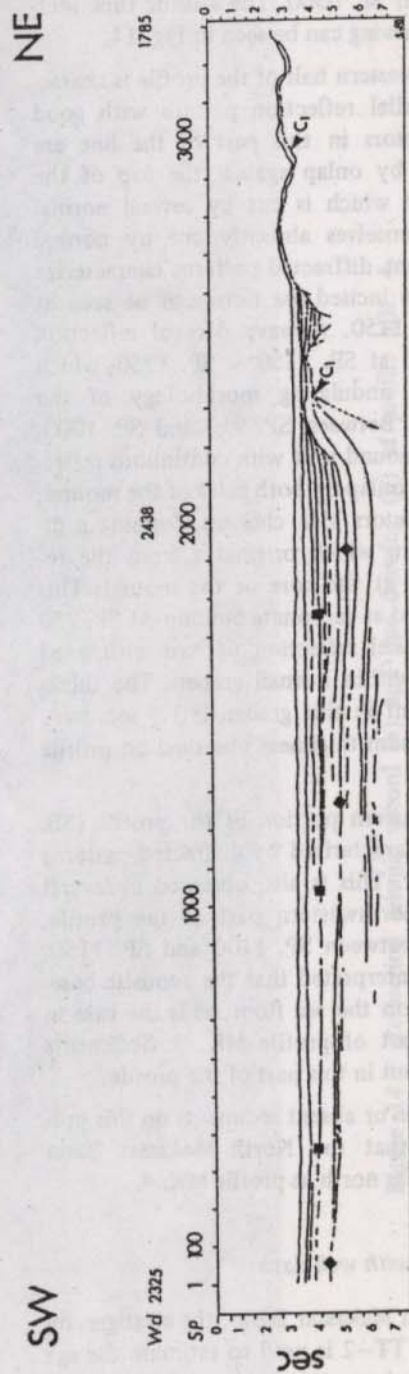
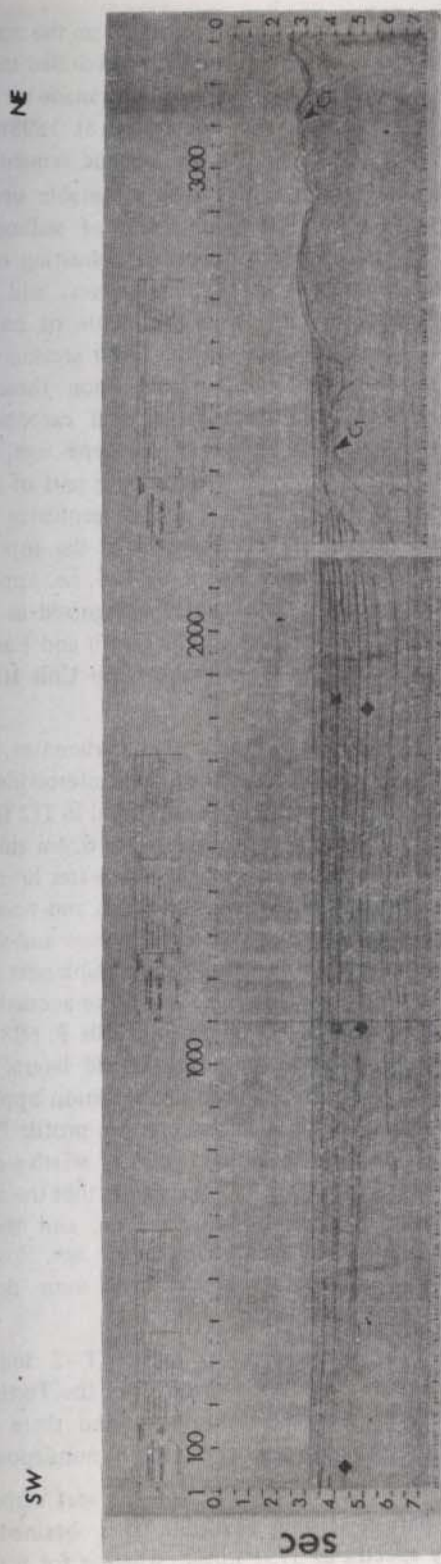


Figure 13 : Reflection seismic record (a) and line drawing (b) of profile MK. 3

14. Profile MK. 4

This profile trends NW-SE and intersects profile SSP. 9 near SP. 0300. The seismic time section and the line drawing can be seen in Fig. 14.

The northwestern half of the profile is characterized by a parallel reflection pattern with good continuity. Reflectors in this part of the line are terminated either by onlap against the top of the acoustic basement which is cut by several normal faults or are themselves abruptly cut by normal faults. Sub-basement diffracted patterns characterize the whole line. An incised sea floor can be seen at SP. 1100 - SP. 1150. A wavy parallel reflection pattern is observed at SP. 1150 - SP. 1250, which is related to the undulating morphology of the acoustic basement. Between SP. 950 and SP. 1000, reflectors from a mound unit with continuous reflectors terminated by onlap on both sides of the mound. The slope of reflectors also changes, forming a divergent-like pattern which originates from the reflection-free zone at the core of the mound. This feature is interpreted as carbonate buildup. At SP. 750 - SP. 800, a parallel reflection pattern with good continuity occurs within a small graben. The thickness of the sediment in this graben is 1.5 sec. twt., which is the maximum thickness observed on profile MK. 4.

The southeastern portion of the profile (SP. 700 - SP. 1) is characterized by diffracted patterns up to the sea floor. This is also observed in several places along the northwestern part of the profile, e.g. at SP. 1300, between SP. 1100 and SP. 1150, and SP. 850. It is interpreted that the acoustic basement is crops out on the sea floor, as is the case in the northeastern part of profile MK. 3. Sediments are very thin or absent in this part of the profile.

The very thin or absent sediments on this profile demonstrates that the North Makassar Basin does not extend as far north as profile MK. 4.

B. Correlation with well data

In the South Makassar Basin, the stratigraphy of wells TT-1 and TT-2 is used to estimate the age each of the previously mentioned seismic sequences and their corresponding boundaries, i.e. the acoustic markers C1, C2 and C3.

Well TT-2 which is situated on the upthrown side of Taka Talu Fault (Fig. 7), was drilled to a total depth of 1601m, and the basement, made up of dolerites and gabbros, was penetrated at 1598m. This level corresponds to the top seismic sequence I or the acoustic marker C1. Unconformable upon the basement, some 106m thickness of sediments of Late Eocene age were deposited consisting of argillaceous sandstones, sandy limestones, and subordinate conglomerates with fragments of basement rocks. These correspond to the lower section of seismic sequence II. Conformable upon these basal clastics is a 588m thickness of reef carbonates of Lower Oligocene - Early Miocene age, which correspond to the middle and upper part of seismic sequence II. At the top of seismic sequence II, the acoustic marker C2 corresponds to the top of the reef carbonates, dated as top of Te5, i.e. upper part of Early Miocene. It is widely recognized as an important regional marker in the South and East Kalimantan Basinal Areas known as top Unit III, Ashland Indonesia, 1972).

Conformable upon the carbonates, some 200m thickness of claystones with interbedded thin argillaceous carbonates were deposited in Tf2 (Middle Miocene), followed conformably by 624m thickness of Middle Miocene Recent shallow water limestones with rare intercalations of clay bands and occasional argillaceous limestones. These claystones and shallow water limestones constitute seismic sequences III and IV. The boundary between them (the acoustic marker C3) cannot be traced from profile P. 608 on to profile Delta 658A due to the rapid lateral facies change in this area. The same condition applies to the acoustic marker C3a detected on profile P. 606. Correlation with the global cycles of relative change of sea level (Vail et al., 1977) suggests that the age of C3 marker is possibly Mio-Pliocene, and the C3a marker is possibly of Plio-Pleistocene age. However, this dating remains speculative until more detailed data from the basin becomes available.

The stratigraphy of well TT-2 indicates continuous sedimentation throughout the Tertiary in a fluctuating marine environment, and there is no indication of any period of erosion or nondeposition.

The interval velocity for the reef carbonate (upper part of seismic sequence II) is obtained from velocity spectra as 3751 m/sec, whereas for the sedi-

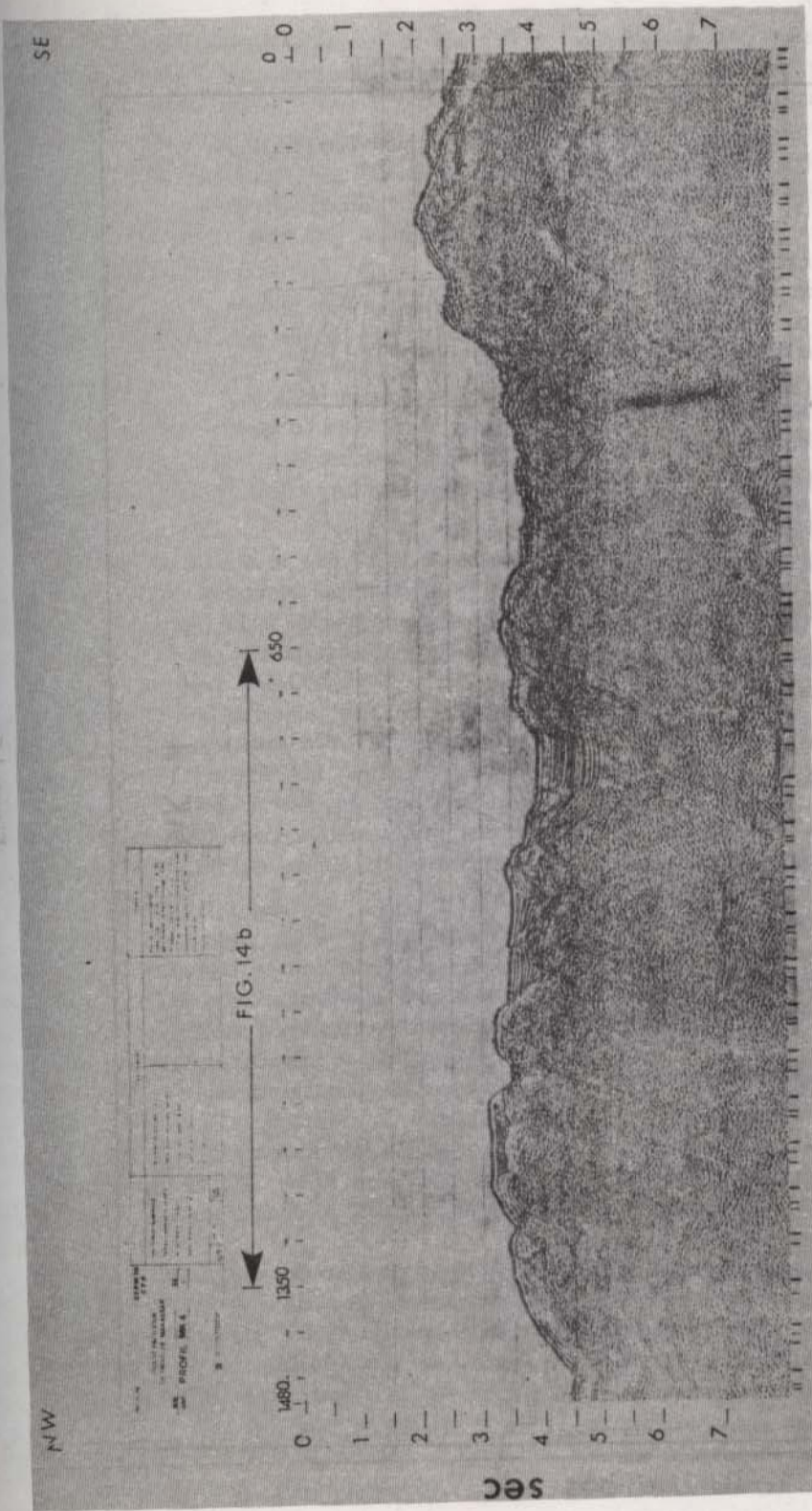


Figure 14 : Reflection seismic record (a) and line drawing (b) of profile MK. 4.

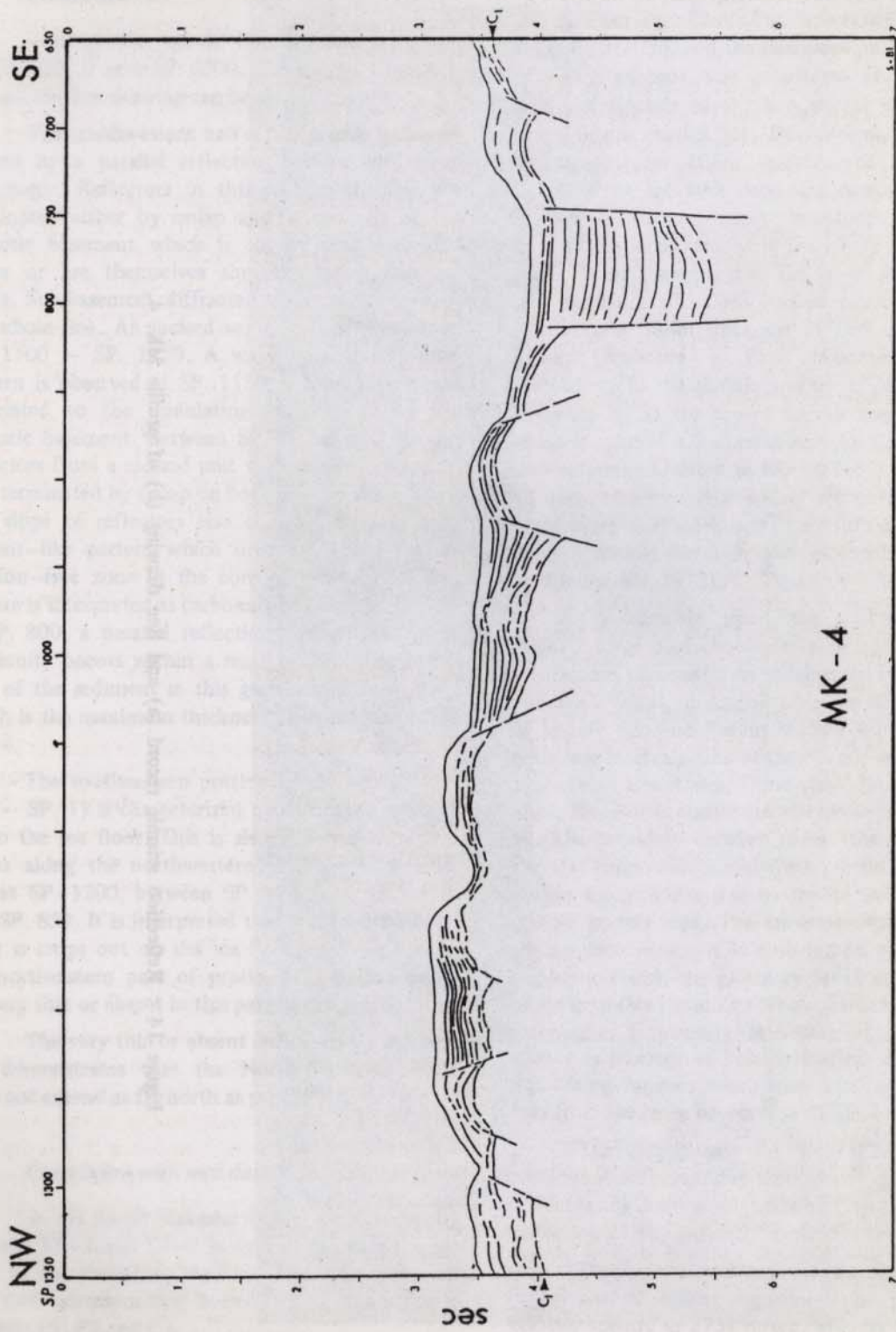


Figure 14b

ment column above (seismic sequences III and IV) it is 2271 m/sec based on velocity spectra or 2196 m/sec if based on sonic data.

Well TT-1 which is situated on the down-thrown side of Taka Talu Fault (Fig. 7) was drilled to a total depth of 3238m into the Eocene basal conglomerates. This well is situated only 4 miles to the southeast of well TT-2.

The acoustic basement was not penetrated by well TT-1, but data from velocity spectra indicate a sharp velocity contrast at 2.29 sec. twt. where interval velocity changes from 4236 m/sec to 4879 m/sec. Using an average velocity of 3109 m/sec for the sedimentary column above 2.29 sec. twt., the depth to basement is inferred at 3560m (Ashland Indonesia, 1972).

The Eocene section in well TT-1 is at least 979m thick, almost ten times the thickness of the Eocene section in well TT-2. Moving upwards from the bottom-hole depth, it starts with 39m thickness of basal conglomerates, followed by 67m of argillaceous sandstones with siltstones, then 163m of claystones and argillites and ends with 710m of conglomeratic limestones interbedded with claystones. This column is followed by 944m of Upper Eocene-Lower Miocene conglomeratic limestones, whose top corresponds to the top seismic sequence II (the acoustic marker C2).

Conformable upon those clastics and the conglomeratic carbonate section which constitute seismic sequence II, are some 1046m thickness of Middle - Lower Miocene claystones with intercalations of thin carbonates, followed by 184m of Middle Miocene - Pliocene shallow water limestones which are then topped by 7m thickness of Pliocene - Recent surface clays. These sediments belong to seismic sequences III and IV. As in well TT-2, their boundary (C3 marker) cannot be identified in well TT-1.

As in well TT-2, the stratigraphy of well TT-1 indicates that there is no break in sedimentation throughout the Tertiary. The depositional environment varies from near shore conditions in the Eocene, to a neritic-subneritic environment in the Upper Eocene - Middle Miocene, and to shallow water carbonate deposition in Middle Miocene - Recent.

Based on the sonic data, the average interval

velocity for the massive conglomeratic limestones ranges from 3200m to 5334m/sec, and it is 3353m/sec if based on velocity spectra data. For the sediment column above the top of conglomeratic limestones, interval velocity is 1796 m/sec if based on sonic data and 2194 m/sec if based on velocity spectra.

In the southern portion of the North Makassar Basin, the acoustic markers C1 and C2 can still be traced, but not the acoustic marker C3. Further north those three markers are rather difficult to delineate and, as a result, the four seismic sequences recognized in the South Makassar Basin are also difficult to outline. This is probably due to the rapid lateral facies change in this area. A very thick sequence of deltaic sediments has been observed in almost all wells drilled in the shelf area to the west of the North Makassar Basin. This basin is situated just east of the Mahakam delta system, known to be active since at least Miocene times. Well data cannot be used to check the seismic interpretation since almost all wells are terminated in Late Miocene deltaic sediments.

IV. DEPOSITIONAL HISTORY

Although all seismic sequences observed in the South Makassar Basin can not be precisely delineated in the North Makassar Basin, it appears that the pattern of deposition is similar in both basins. Both basins are characterized by a mainly parallel to sub-parallel reflection configuration, indicative of uniform deposition in a uniformly subsiding basin. It is therefore believed that both basins experienced the same depositional history.

Following Late Cretaceous - early Tertiary uplift and erosion, extension occurred in this region, centered in the present Makassar Basin. Rifting was accommodated by a series of normal faults on both sides of the basin, downthrowing basinward. The early Tertiary transgression resulted in the existence of shallow area, and seismic sequence II was deposited unconformably upon an irregular pre-Tertiary basement surface. This sequence, dated as pre-Lower Miocene, shows strong basal onlap in the area of the continental slope and rise of the South Makassar Basin. Movements along normal faults on both margins of the basin continued throughout deposition

of seismic sequence II, as seen in seismic reflection profiles and evidenced by a contrast in thickness of seismic sequence II in wells TT-1 and TT-2.

The top of seismic sequence II (the acoustic marker C2) is correlatable with the interface between the claystone sequence and the underlying carbonates in wells TT-1 and TT-2, and with a hiatus in well PB-1 which is dated as upper Early Miocene (top of Te5). This is probably the reflection of the so-called intra-Miocene orogeny, which is known to occur regionally in Western Indonesia.

A lowstand of sea level in the upper Early Miocene produced the acoustic marker C2 in the Makassar Basin, whereas the shelf area is subjected to sub-aerial erosion. A relative rise of sea level marked the deposition of seismic sequence III as indicated by the stratigraphy of wells TT-1 and TT-2, probably followed by another lowstand of sea level during Mio-Pliocene times, which produced the acoustic marker C3. Finally this is followed by an overall transgression with a possible minor lowstand of sea level in Pliocene - Recent times, as indicated by the basinward progradation and downlap of seismic sequence IV.

The rate of subsidence was probably slightly greater than the rate of deposition in the beginning, which resulted in the formation of the basin slope and basin floor seismic facies of seismic sequence II. Since Lower Miocene, however, both subsidence and sedimentation rates were more or less equal and the shelf and shelf margin seismic facies of sequences III and IV were deposited in the basin. Those seismic facies are generally comparable to the depositional environments observed in well TT-1.

As already mentioned, the contrast in thickness of seismic sequence II between wells TT-1 and TT-2 is due continuous vertical movements along the Taka Talu Fault during Eocene - Lower Miocene. The magnitude of these movements was greater during Eocene times (the thickness of the Eocene section in well TT-1 is 979m compared with 106m of Eocene sediments in well TT-2). Movements became less during Oligocene - Lower Miocene, as reflected by the smaller difference in the thickness of the Oligocene - Lower Miocene sediments (944m in well TT-1 and 588m in well TT-2). After cessation of fault movements in the upper Lower Miocene or at the beginning of Middle Miocene, there is no

significant difference in depositional environments between the two wells. Seismic sequences III and IV were deposited in shelf conditions. The stratigraphy of these wells reveals that rift-phase sedimentation lasted at least from Middle Eocene to Lower Miocene, subsequently followed by post-rift deposition from Middle Miocene to Recent times.

Based on interpretation of seismic reflection profiles, an isochron map of the top of the acoustic basement (C1 marker) in the South Makassar Basin is presented in Fig. 15. The thickness of the Tertiary sediments reaches a maximum value of more than 6km in the vicinity of intersection of profile P. 606 and P. 607 (Fig. 16).

In the case of the North Makassar Basin, a high influx of deltaic sediments into the basin occurred at least since Miocene times. The thickest sediments are observed in the western part of this basin, becoming thinner or even absent in the eastern part. The top of the acoustic basement can be seen at approximately 3 sec. twt. in the western part of profile MCP. 5 (Fig. 11), shallowing to 2.3 sec. twt. at the western end of the line. In the eastern part of the basin, the top of the acoustic basement can be seen at approximately 4.5 sec. twt. along the eastern part of profile MK. 1 and at 2.5 sec. twt. along the eastern part of Profile MK. 3. In the abyssal plain, a possible indication of the acoustic basement high is seen at about 6.5 sec. twt. at SP. 1300 on profile MK. 3. At present, the top of the acoustic basement in this basin cannot be mapped due to limitations in seismic resolution. The thickness of the Tertiary sediments is more than 4 sec. twt. (below the sea floor), probably just like the thickness observed in the South Makassar Basin.

The acoustic stratigraphy of the Makassar Basin can be summarized as presented in Table 2.

V. CONCLUSIONS

Interpretation of seismic reflection profiles reveals that deposition of the sediments in the Makassar basin occurred at uniform rate while the basin itself uniformly subsided. Correlation of seismic data with well information enable us to trace the depositional history in the basin.

More than 6 Km thickness of relatively un-tectonised Tertiary sediments with good lateral

Table 2 : Acoustic stratigraphy of the Makassar Basin.

| Seismic sequence | Reflection pattern | Reflection geometry at boundaries | Seismic facies | Acoustic marker | Inferred age | Lithology (in wells TT-1 and TT-2) |
|------------------|---|---|---|-----------------|-----------------------------|---|
| IV (post-rift) | Oblique progradational to parallel-sub-parallel, occasionally hummocky in the upper part. | Concordant with gentle downlap at base, concordant with top lap at top. | Shelf-shelf margin and prograded slope. | Sea floor | Late Miocene-Recent | Limestones |
| III (post-rift) | Parallel to subparallel, occasionally chaotic | Onlap at base, toplap at top. | Shelf | C3 | Middle-Late Miocene | Claystones |
| II (sya-rift) | Parallel | Onlap with gentle downlap at base, concordant with toplap at top. | Shelf to basin slope and floor (onlap fill) | C2 | Middel Eocene-Lower Miocene | Mainly limestones, minor sandstones and claystones. |
| I (pre-rift) | Minor sub-basement parallel, pattern reflector-free, diffracted in slope and rise areas. | Base unknown erosional truncation at top. | Shelf (?) in the uppermost part. | C1 | Pre-Tertiary | Gabbros-diabase |

Fig.15

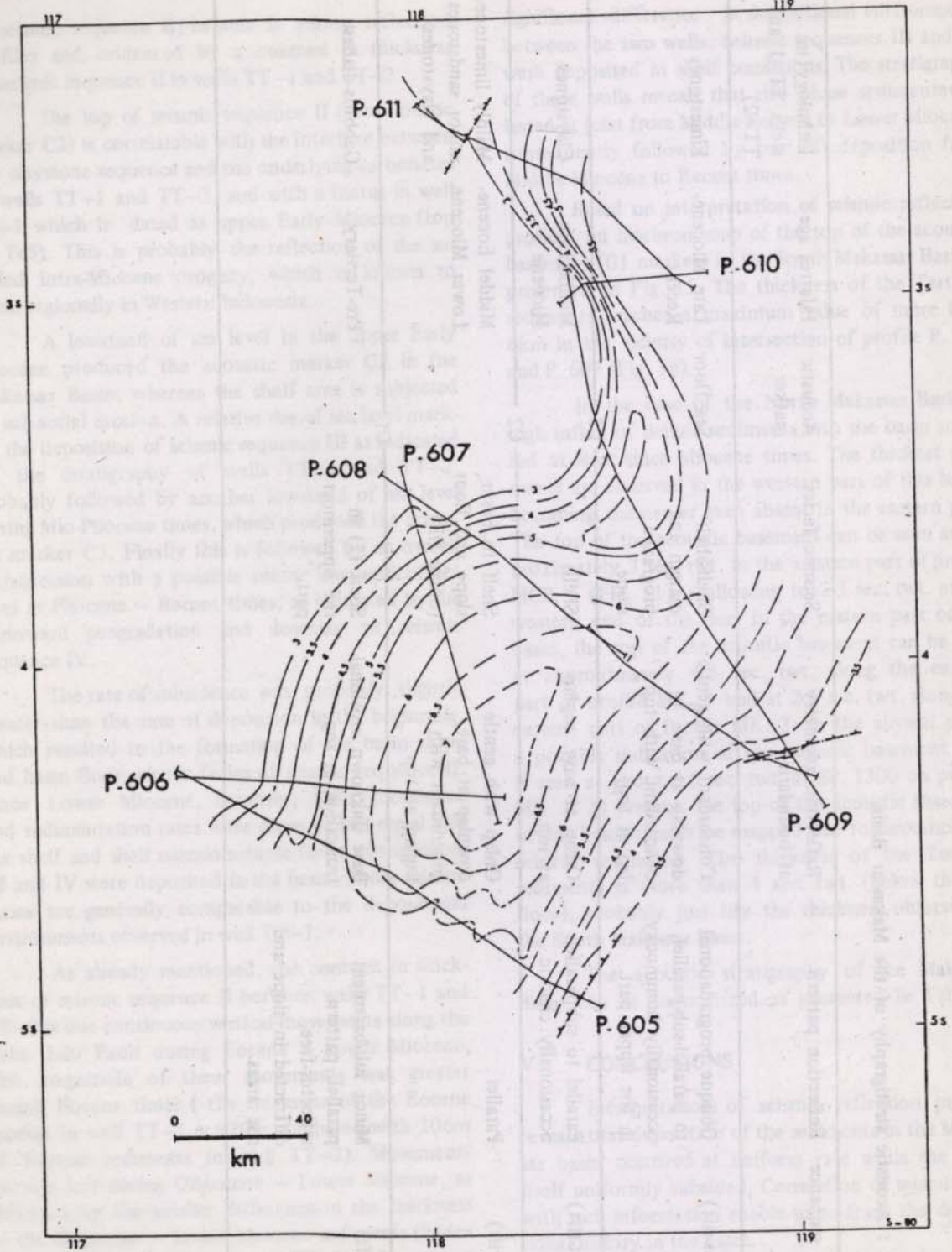


Figure 15 : Time contour map of the top of the acoustic basement, South Makasar Basin.

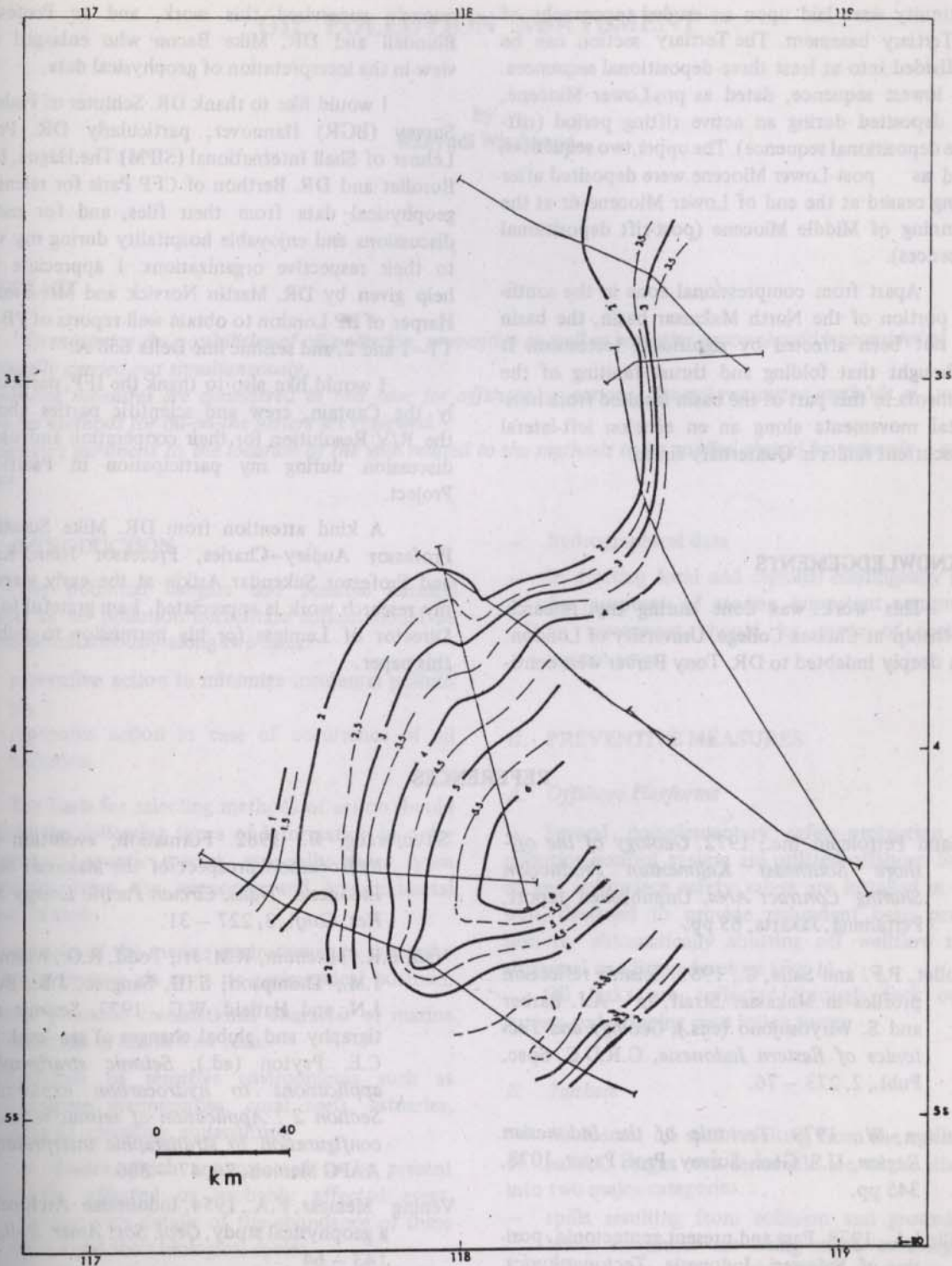


Figure 16 : Isopach of Tertiary sediments, South Makasar Basin.

continuity were laid upon an eroded topography of pre-Tertiary basement. The Tertiary section can be subdivided into at least three depositional sequences. The lowest sequence, dated as pre-Lower Miocene, was deposited during an active rifting period (rift-phase depositional sequence). The upper two sequences, dated as post-Lower Miocene were deposited after rifting ceased at the end of Lower Miocene or at the beginning of Middle Miocene (post-rift depositional sequences).

Apart from compressional zone in the southern portion of the North Makassar basin, the basin has not been affected by significant tectonism. It is thought that folding and thrust faulting of the sediments in this part of the basin resulted from horizontal movements along an en echelon left-lateral transcurrent faults in Quaternary times.

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