Plio-Pleistocene Seismic Stratigraphy of the Java Sea between Bawean Island and East Java

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ABSTRACT

The southeast Java Sea forms a submerged part of the Sunda Shelf and lies on a relatively stable continental shelf, which reached its final form during the Quaternary. Marine geological investigations in this area have mostly been carried out as part of regional studies on the Sunda Shelf. Detailed studies, particularly for younger sequences, are lacking and, as a result, the neo-tectonics and response of the shelf area to extreme sea level fluctuations during Plio-Quaternary times are poorly known.

A set of high resolution reflection seismic profiles totalling some 3750 line km has been studied. All data were acquired by the Marine Geological Institute of Indonesia, which ran the survey in the southeast Java Sea in 1989-1990. The data show that the Late Tertiary sedimentation in the study area partly occurred in half graben basins, mostly bounded by northeastward trending faults which may be related to the regional suture belts running from central Java to south Kalimantan. Towards Pliocene time, the sedimentation occurred in east-trending synclinal basins, which indicate the dominance of a northward tectonic compressional stress. This continued until the Early Pleistocene, as indicated by some local thickening of the Early Pleistocene deposits. Since then, further basin development appears to have ceased, and a tectonically stable condition may have been reached. Quaternary sedimentation gradually changed the basin morphology into a relatively flat plain characterised by multiple erosional features resulting from extreme sea level fluctuations.

Keywords: Seismic Stratigraphy, Pliocene, Pleistocene, Java Sea.

INTRODUCTION

The southeast Java Sea forms the submerged part of the Sunda Shelf and lies on a relatively stable continental shelf (Figure 1). Marine geological investigations in the southeast Java Sea have mostly been carried out as part of regional studies on the Sunda Shelf (e.g. Emery et al., 1972; Voris, 2000; Ben-Avraham & Emery, 1973). Detailed and published studies, particularly for the Plio-Pleistocene periods, are rare, although such studies are necessary in order to understand the tectonic and response of the shelf area to extreme sea level fluctuations during these times.

The present study discusses the sedimentary facies distribution, chronology and the related tectonism in the southeast Java Sea during the Late Tertiary and Quaternary. The discussion relies heavily on sparker single channel seismic data (Figure 2), which have been interpreted by applying the sequence stratigraphic concepts developed by Vail *et al.* (1977) and Posamentier and Vail (1988). However, this study lacks reliable age determinations, as well as other published geological studies. In addition, problems inherent from the equipment include: (1) the limited penetration, (2) and the presence of strong multiple reflections, particularly in the area where surficial reflections are strong.

REGIONAL GEOLOGY

Based on regional geophysical data, Ben-Avraham and Emery (1973) noted that Tertiary sedimentation in the southeast Java Sea occurred in basins which were bounded mostly by northeastward trending faults (Figure 1). Many of these structures are half grabens that formed on the pre-Tertiary shelf (Kenyon, 1977; Bishop, 1980). These major features were interpreted by Ben-Avraham and Emery (1973) as resulting from past interaction between the Eurasian and Indian-Australian lithospheric plates, the principal ridges probably representing part of an island arc system that was active during the Late Cretaceous-earliest Tertiary (Bishop, 1980). Such an island arc complex has been deduced from the occurrence of pre-Tertiary ophiolites cropping out in Central Java and in Southeast Kalimantan (van Bemmelen, 1949) possibly representing a previous subduction complex (Katili, 1989).

The Karimunjawa Arch is the dominant ridge in the eastern Java Sea. It extends into the offshore area of southern Kalimantan as a broad positive feature (Bishop, 1980).

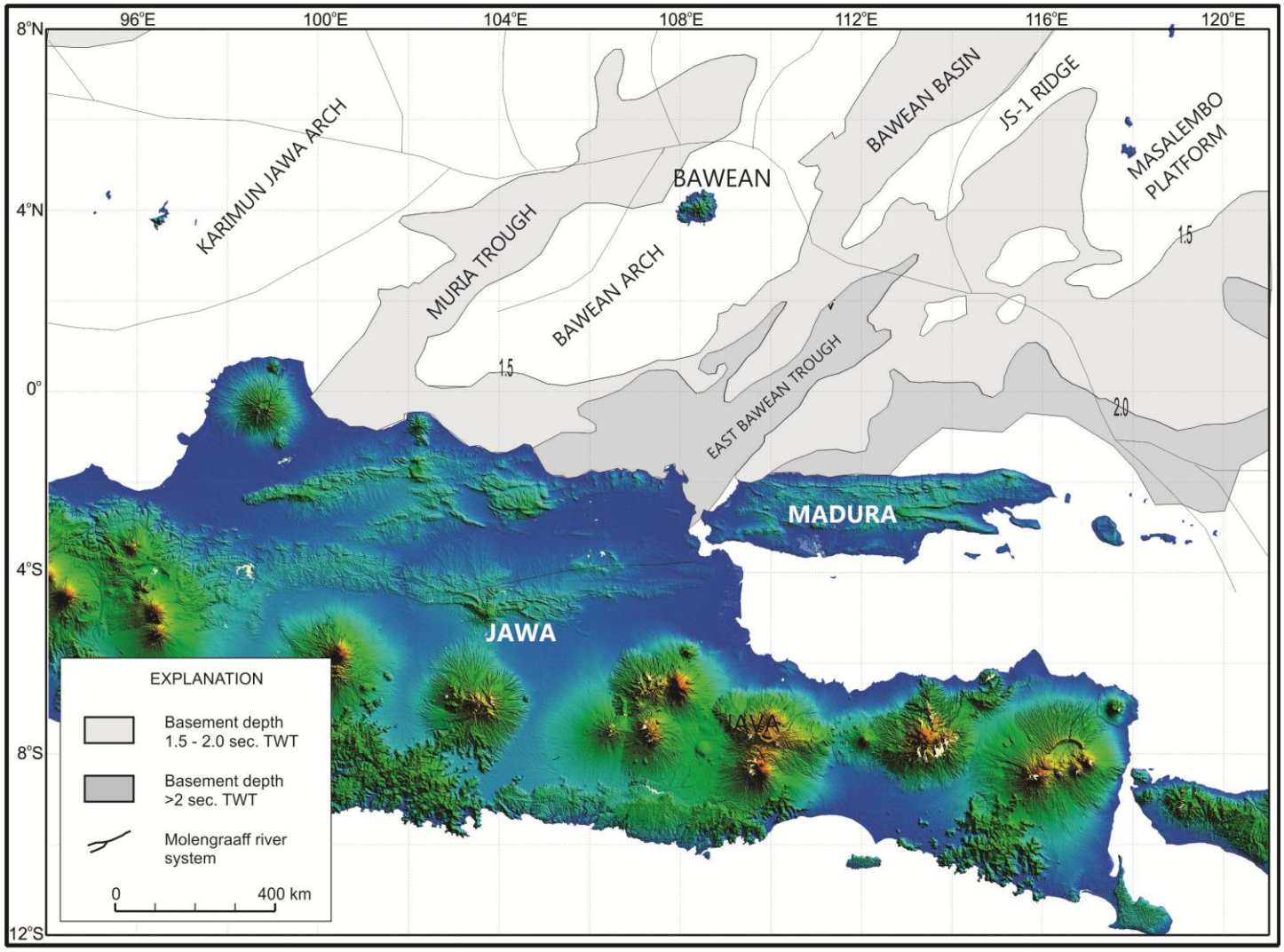


Figure 1. *Location of the study area and the generalized Tertiary basement configuration according to Kenyon (1977). Superimposed on the Java Sea is Molengraaff river system of the last glacial period,which has been deduced from the first Snellius expedition (Molengraaff, 1921; Kuenen, 1950).*

It is capped by the Karimunjawa Islands on which pre-Tertiary quartzite and phyllitic shale, cut by basic dykes, and probable Quaternary fissure-eruptive sheets crop out. This arch is separated by the narrow, northeast trending Muria Basin (West Florence Deep) from the Bawean Arch. The Bawean Arch is characterised by alkaline volcanism of the latest Neogene or Quaternary and steeply dipping Miocene marine strata (van Bemmelen, 1949).

DATA

The data base for this study is drawn from seismic profiles of about 3750 line km in the Java Sea (Figure 2). All geophysical data were obtained from the Marine Geological Institute of Indonesia which ran the survey in 1989/1990. The seismic system used is a single channel 600 Joule sparker system, fired every 1 second. These setting have allowed of about 400 milliseconds penetration below the seabed. The seismic signals were not tape recorded, but were directly band pass filtered (200-2000 Hz) and graphically recorded in analog format during the survey. Due to this technique, no further data processing was carried out. The ship positions during the survey relied mostly on GPS navigation system, and by the time the acquisition was conducted, the horizontal accuracy was not less than 100m. The profiles were mostly oriented north-south and spaced 5 to 10 km apart.

Stratigraphic control for calibration of the seismic data was provided by six petroleum exploratory wells, JS1-1, JS2-1, JS3-1, JS8-1, JS10-1 and JS16-1. However, these data cannot provide a reliable stratigraphic timing resolution as the biostratigraphic and lithofacies analyses done were based on well cuttings which were commonly sampled every 30 ft penetration. Even so, they have narrowed the age estimation of the stratigraphic time markers.

SEISMIC STRATIGRAPHY

Seismic analysis indicates that the Late Tertiary and Quaternary sediments in the study area can be subdivided into three major seismic units. These units correspond to the Miocene, Pliocene and Quaternary and are referred to as Units 1, 2 and 3 respectively.

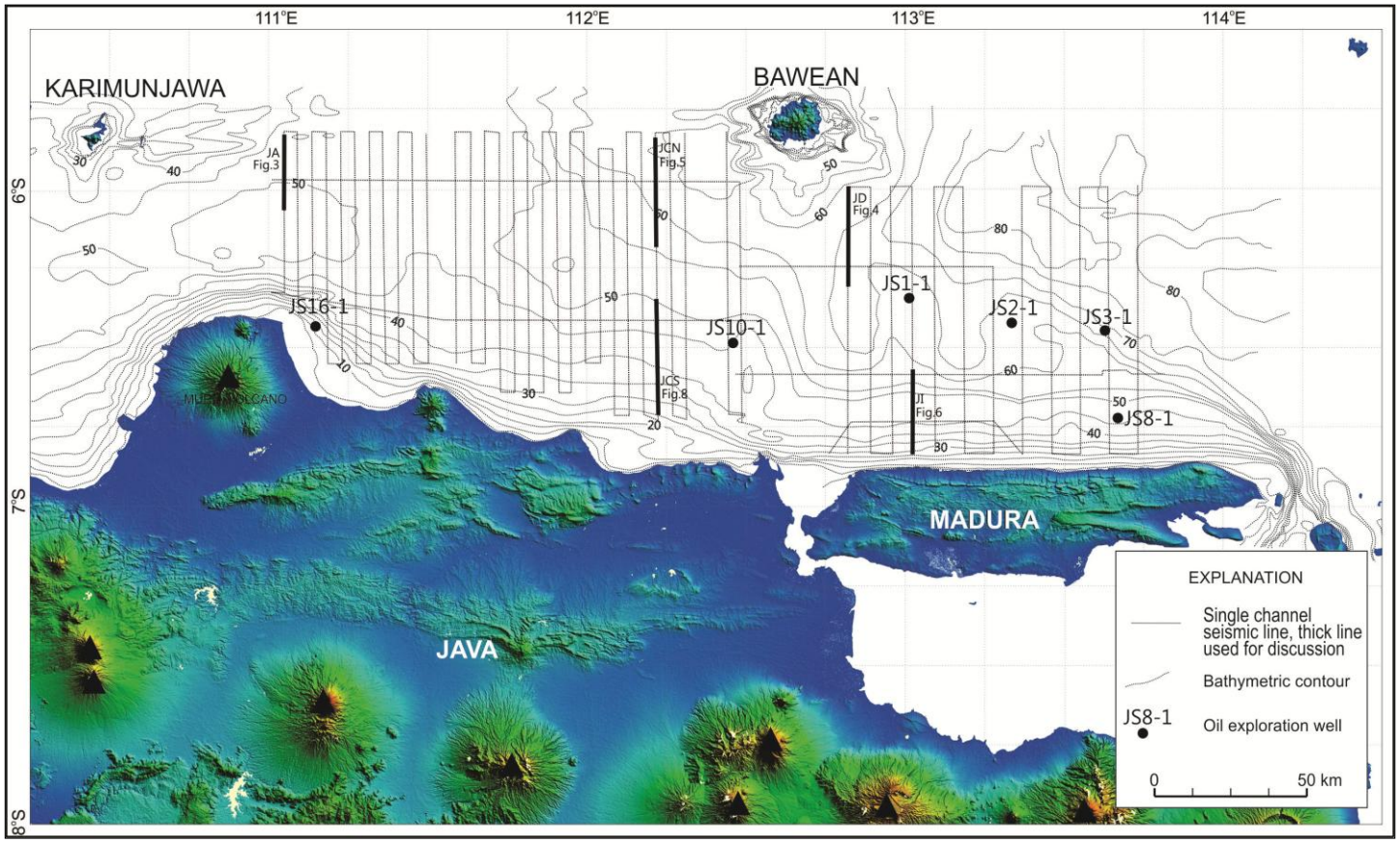


Figure 2. *Tracklines of single channel sparker seismic records used in this study superimposed on the bathymetric map of the study area. Thicker lines are parts of seismic lines presented in this paper for discussion. Dots in the Java Sea represent the oil exploration wells.*

Unit 1

This Miocene unit can only be observed on the structurally high areas, such as near the Bawean and Karimunjawa Arches, and on Madura Island. The age of Unit 1 is confirmed by well data of JS8-1 and JS3-1. The internal seismic reflection patterns and areal distribution are poorly defined, particularly because of the limited penetration of the seismic system used and strong multiple reflections. The lower boundary is unidentifiable, but the upper boundary is a regional unconformity as shown by a pronounced erosional surface on the structurally high areas (Figures 3, 4, 5 and 6). On most of seismic sections, Unit 1 is characterised by a medium amplitude, continuous parallel-subparallel reflection pattern of possibly interbedded sandstone and mudstone (Figures 3, 4 and 5). The sections acquired near the Karimunjawa and Bawean Arches suggest that the lower part of Unit 1 is probably equivalent to the Miocene strata exposed on these islands, which are characterised by the occurrence of limonitic sandstone, interbedded with lignite, marl and crystalline limestone (Bemmelen, 1949). A mounded structure characterised by low amplitude of internal reflectors is observed on the top of Unit 1, and probably represent a highstand reef (Figure 6).

Unit 2

Unit 2 is relatively thick and was deposited following sea level fall at the end of the Miocene. It consists of two subunits: 2a and 2b, with subunit 2a forming the major part of the sequence. Correlation between the seismic and the micropalaeontological data from some petroleum exploratory wells confirmed that this unit developed during the Pliocene. The top boundary of Unit 2 is an erosional surface marking extensive subaerial exposure in the study area. Based on reflection configuration patterns, the sediment sources of these subunits were mainly the Karimunjawa and Bawean Arches in the western half of the study area. In the eastern half, the deposits were sourced from both the Bawean Arch and Madura Island, but the distribution was complicated by the development of folds.

On the stable area, such as on the Karimunjawa Arch, the Pliocene unit was thinly deposited on top of the Miocene unit which suggests that the subsidence rate on the arch was very low. The seismic characters are mainly form a strong amplitude parallel reflection pattern (Figure 3) which is often associated with mounded forms of possibly reefal limestone. In the areas where the depositional slope was high, such as near the margins of the Muria Trough, the East Bawean Trough and the growing Madura Island, the deposition of the lower part of Unit 2 may be divided into two main systems tracts: the lowstand and highstand systems tracts (Figures 5 and 6).

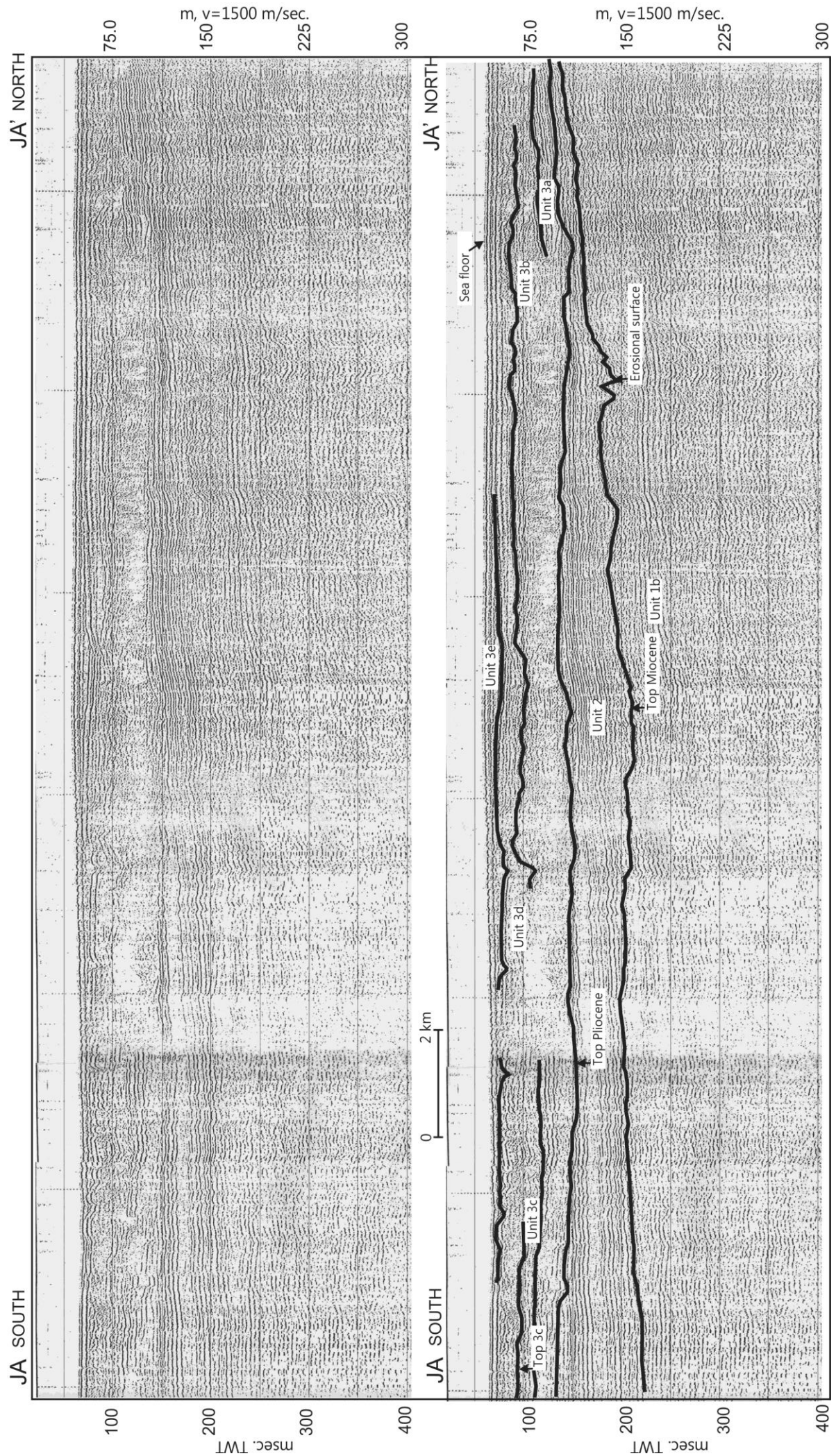


Figure 3. *Seismic line JA from east of the Karimunjawa Islands which comprises a stable area of the Karimunjawa Arch. Pliocene and Quaternary units are thin and nearly flat due to slow subsidence and low depositional slope.*

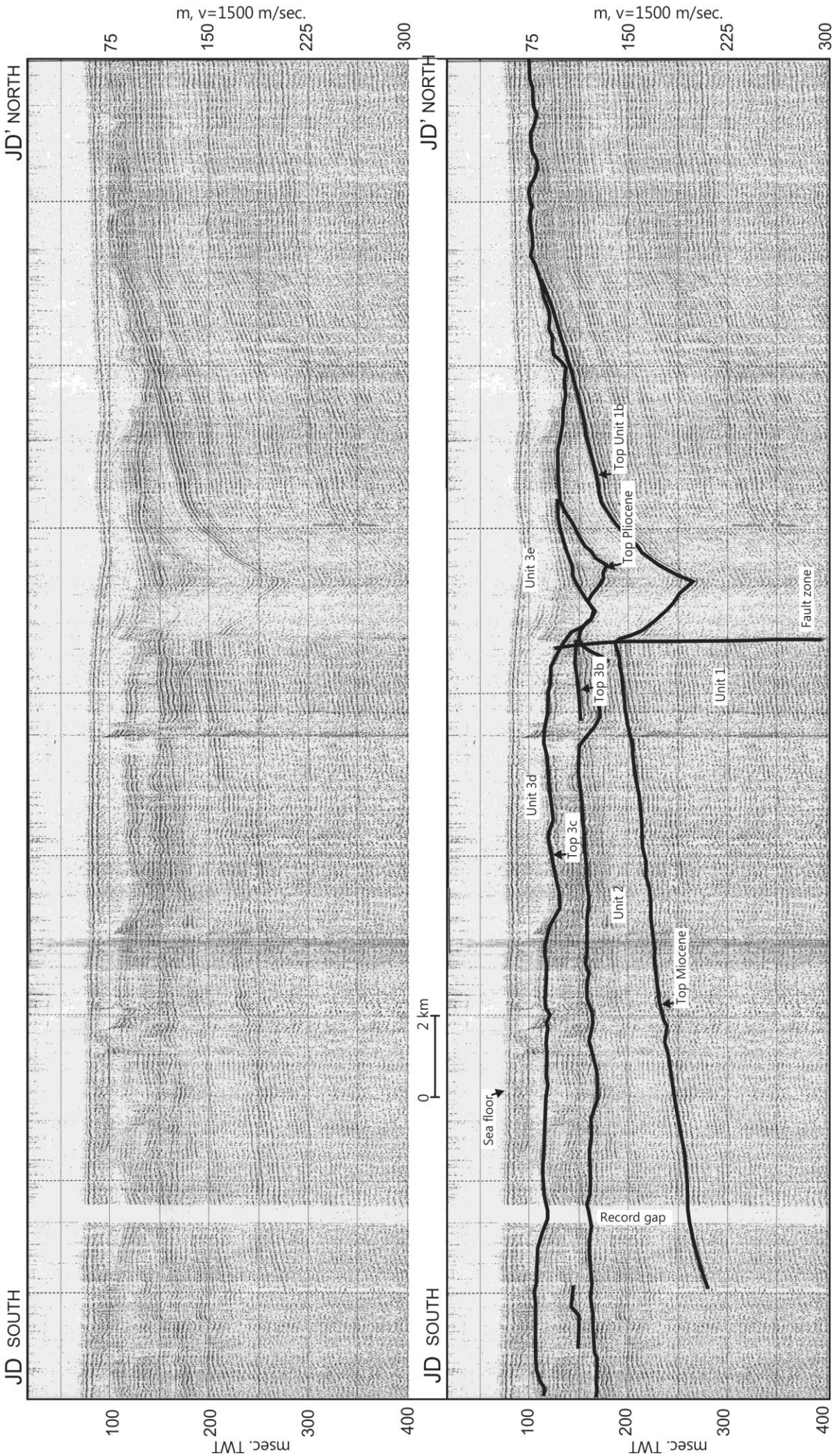


Figure 4. *Seismic line JD which represents southeast margin of the Bawean Arch. A thicker succession of the Miocene units shows stronger parallel reflection amplitudes, indicative of a shoaling upward sequence. The wedge shaped Unit 2 indicates a southward increase of subsidence, which may lessened by the end of Pliocene.*

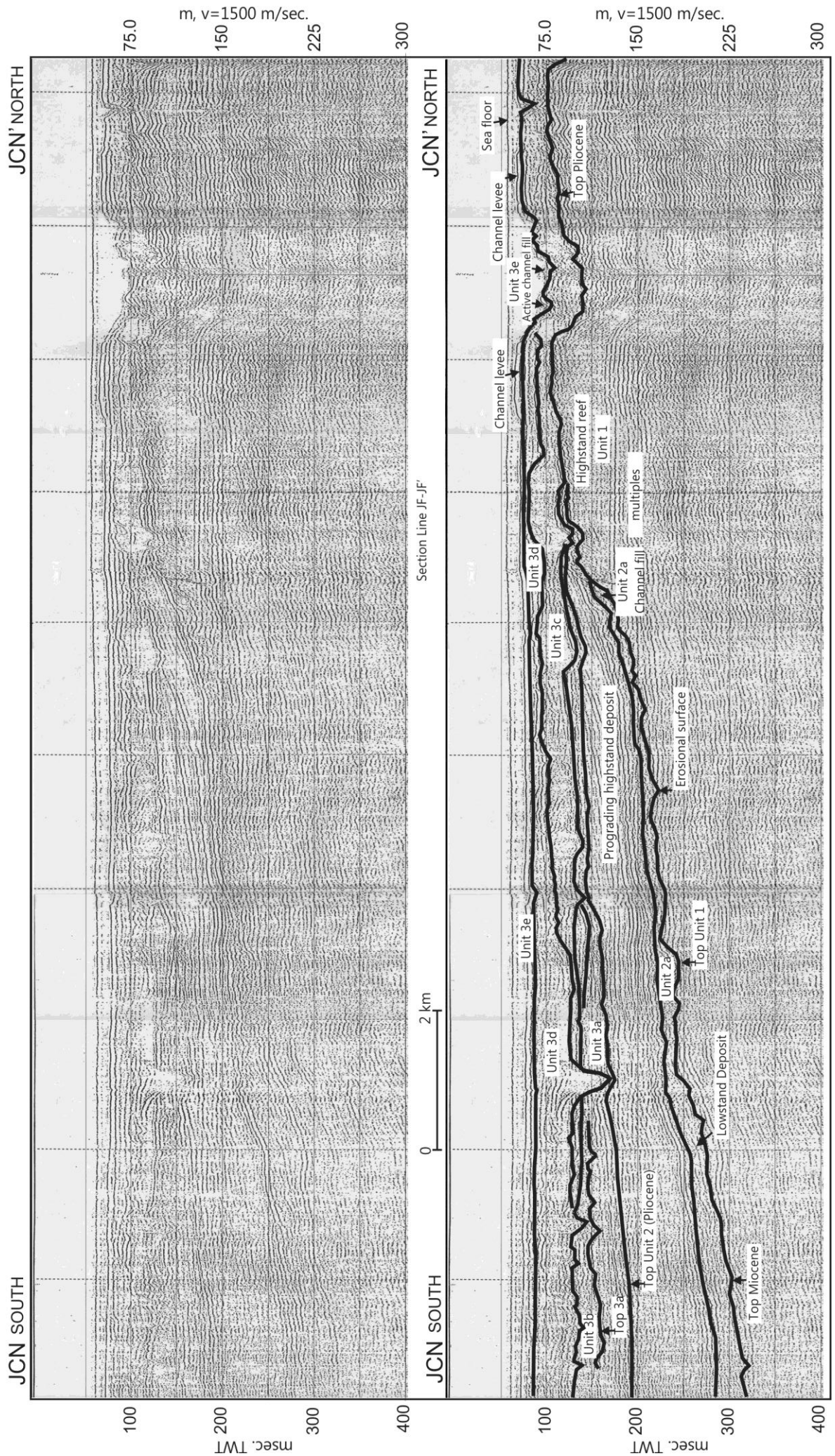


Figure 5. *Seismic line JCN from southwestern slope of the Bawean Arch. The arch was exposed subaerially following highstand reef deposition in the Late Miocene. The pronounced prograding complex on the flank of the arch represents the major highstand deposition in the Pliocene. A major channel observed on top of subunit 3d may result from the last glacial sea level lowstand.*

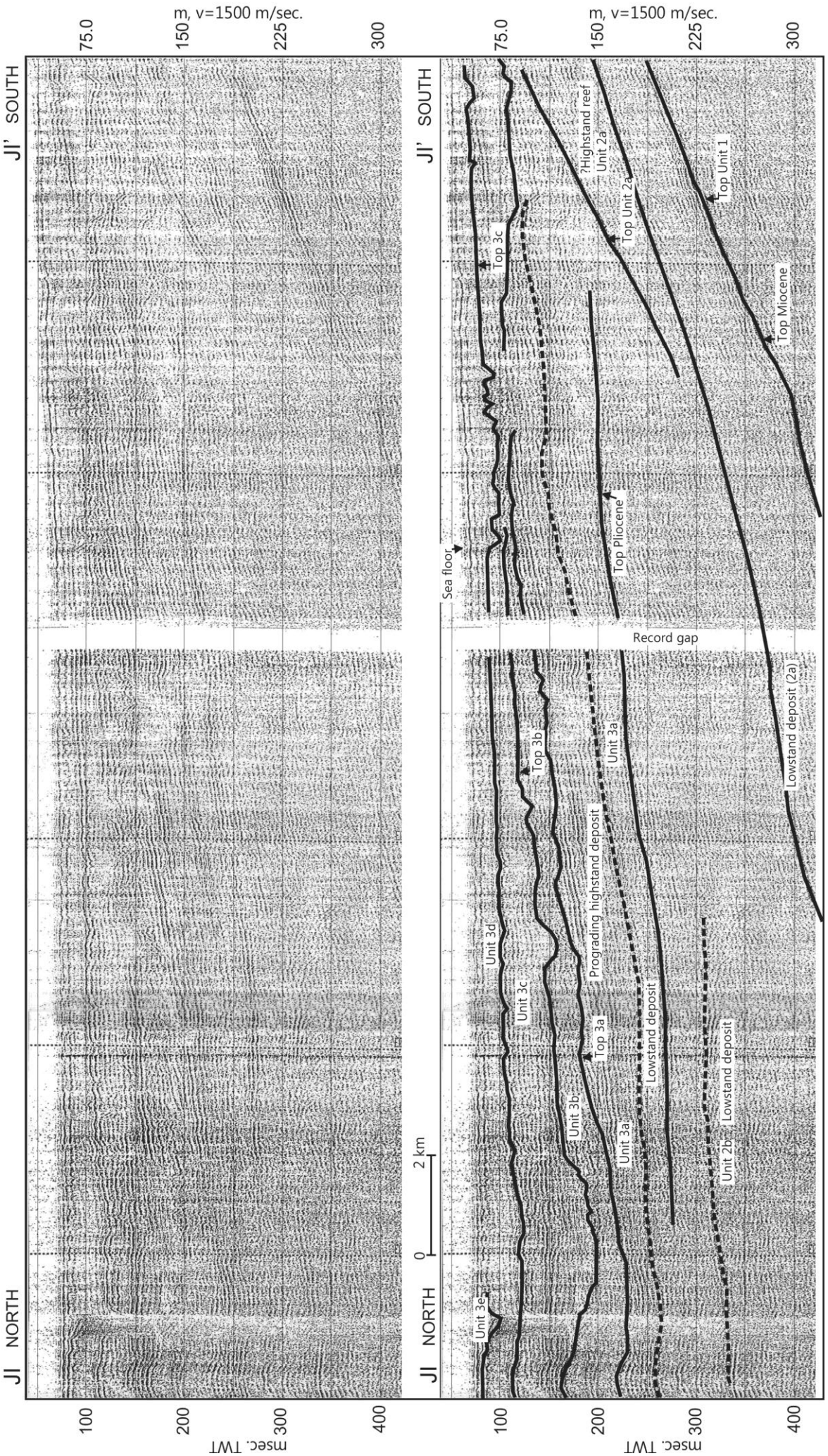


Figure 6. *Seismic line JI from northern flank of Madura Island. The continuous growth of the island has resulted in a pronounced northward progradation of the lowstand and highstand systems tracts in the Pliocene and Early Quaternary. Such conditions may extend towards the northern coast of Java in the study area.*

The transgressive systems tract on most of the seismic lines studied is absent or unidentified, probably due to a rapid sea level rise which did not permit formation of a seismically resolvable transgressive unit.

In the western part of the study area, the upper part of Unit 2 is recognised as a thin prograding complex downlapping onto the erosional surface at the top of Unit 2a (Figure 7). This erosional surface should be correlated with a lowstand of sea level and the prograding complex with the highstand deposits. On the flank of Madura Island a thicker unit was deposited, which may be resolved into lowstand and highstand deposits (Figure 6).

Figure 9 shows palaeogeographic maps during the lowstand period of subunit 2a. These maps indicate that the Pliocene basin in the western half of the study area was still influenced by the normal fault movement of the half graben system in the Muria Trough. The occurrence of the deepest basin and accumulation of the thickest Pliocene sediments in this trough (particularly along the normal faults) has further suggested probable faster subsidence and sedimentation rates. In the eastern half of the area, the influence of the previous structural configuration (Figure 3) is not obvious. The Pliocene structural development (east-west trending folds) had more influence on the sedimentation particularly in the area between Java and Bawean Islands and near the Madura Island, as indicated by the trends of basin morphology and the Pliocene sediment accumulation (Figure 8).

Unit 3

Unit 3 was deposited following a sea level fall which exposed the whole study area at the end of the Pliocene. The seismic characters and sedimentation patterns of Unit 3 differ significantly from those of the preceding Unit 2. They appear to be strongly influenced by extreme and rapid sea level fluctuations. Such fluctuations during the Quaternary have been demonstrated by many workers through the oxygen isotope records of deep sea cores, which they have related with the orbitally-induced fluctuations of global ice volume. These glacio-eustatic sea level fluctuations are particularly apparent since 0.97 Ma (Harland *et al.*, 1989) with a relatively constant period. The global sea level falls may have reached 130 m below present level during the glacial maximum (Bloom *et al.*, 1974; Chappell & Shackleton, 1986; Fairbanks, 1989).

The present seismic study identified five main Quaternary seismic subunits in the area. These subunits are characterised mostly by parallel to subparallel reflection patterns or are reflection free. Each of them ended with channel cut and fill along their upper part and are interpreted to represent marine deposition and fluvial channelling respectively. In some areas the thickness of these subunits appears to be similar, which may indicate constant subsidence rates combined with periods of sea level fluctuation. Because these subunits have a similar seismic character and do not represent thick deposits, lateral correlation is difficult and tends to be speculative. But they can be grouped into five subunits, 3a to 3e, based on the occurrence of widespread unconformities on top of each unit. These unconformities are commonly associated with rather deep and wide fluvial channelling.

a. Subunits 3a and 3b

The subunits 3a and 3b were deposited during the Early Pleistocene, based on their stratigraphic position overlying Pliocene Unit 2. A stratigraphic subdivision between these subunits in the western part of the study area is rather speculative, but clear differentiation can be made in the areas near the Java and Madura Islands due to the higher subsidence rate and the occurrence of a relatively large sea level fall at the end of subunit 3a deposition (Figures 6 and 7). Seismic features, such as rapid basinward thinning (Figure 6) and pronounced anticlines (Figure 7) indicate that their distribution was influenced by local structural development. There, subunit 3a can be further subdivided into subunits 3a-1 and 3a-2 based on the occurrence of an internal erosional surface (Figure 7). The thickness of subunit 3a-1 reaches 100 msec TWT (about 75 m) in the deepest portion of the basin, and it gradually thins toward the basin margin. The maximum thickness of subunit 3a-2 is about 60 msec TWT (about 45 m). The thickness variation is mainly due to local subsidence, post depositional erosion and a gradual thinning because of the rising of the basin margin. Subunit 3a-2 onlaps on subunit 3a-1 on the southern margin, and on Unit 2 when subunit 3a-1 wedges out. The seismic character of these subunits is similar, a subparallel reflection pattern with medium amplitude and medium continuity which suggests deposition in a shallow marine environment (Sangree & Widmier, 1977). To the north of Madura Island a local deepening occurred (Fig. 6), and subunits 3a-1 and 3a-2 are characterised by northward prograding clinoform deposits, indicating that the sediments were derived from the growing Madura Island. Subunits 3a-1 and 3a-2 may be regarded as the units responsible for the flatness of this area.

The subunit 3b was deposited on a flat surface and has an extensive coverage although its thickness is less than 35 msec TWT (26 m). Seismically, this subunit is characterised by a similar appearance to subunits 3a-1 and 3a-2, and probably was deposited in a similar environment. The upper part tends to show subparallel to hummocky patterns with variable amplitude which indicates a shoaling (regression) of the unit before finally being exposed subaerially.

b. Subunits 3c, 3d and 3e

Subunits 3c and 3d can further be subdivided into three (3c-1, 3c-2 and 3c-3) and two (3d-1 and 3d-2) respectively.

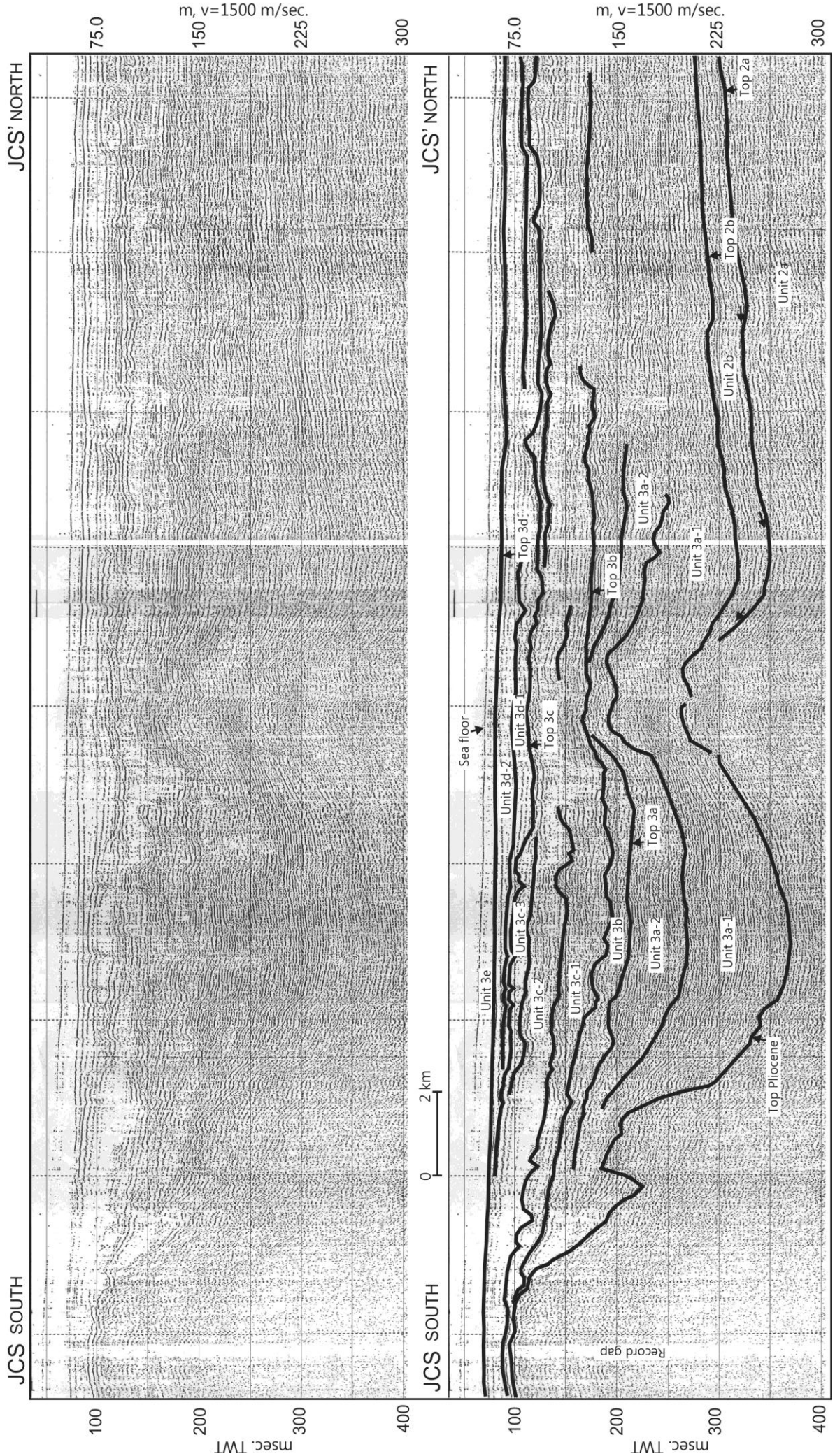


Figure 7. *Seismic line JCS from the north of east Java which represents an area with high subsidence and depositional rates. Local structures observed lie in an E-W direction and are controlled lateral distributions of the Late Pliocene and Early Quaternary subunits.*

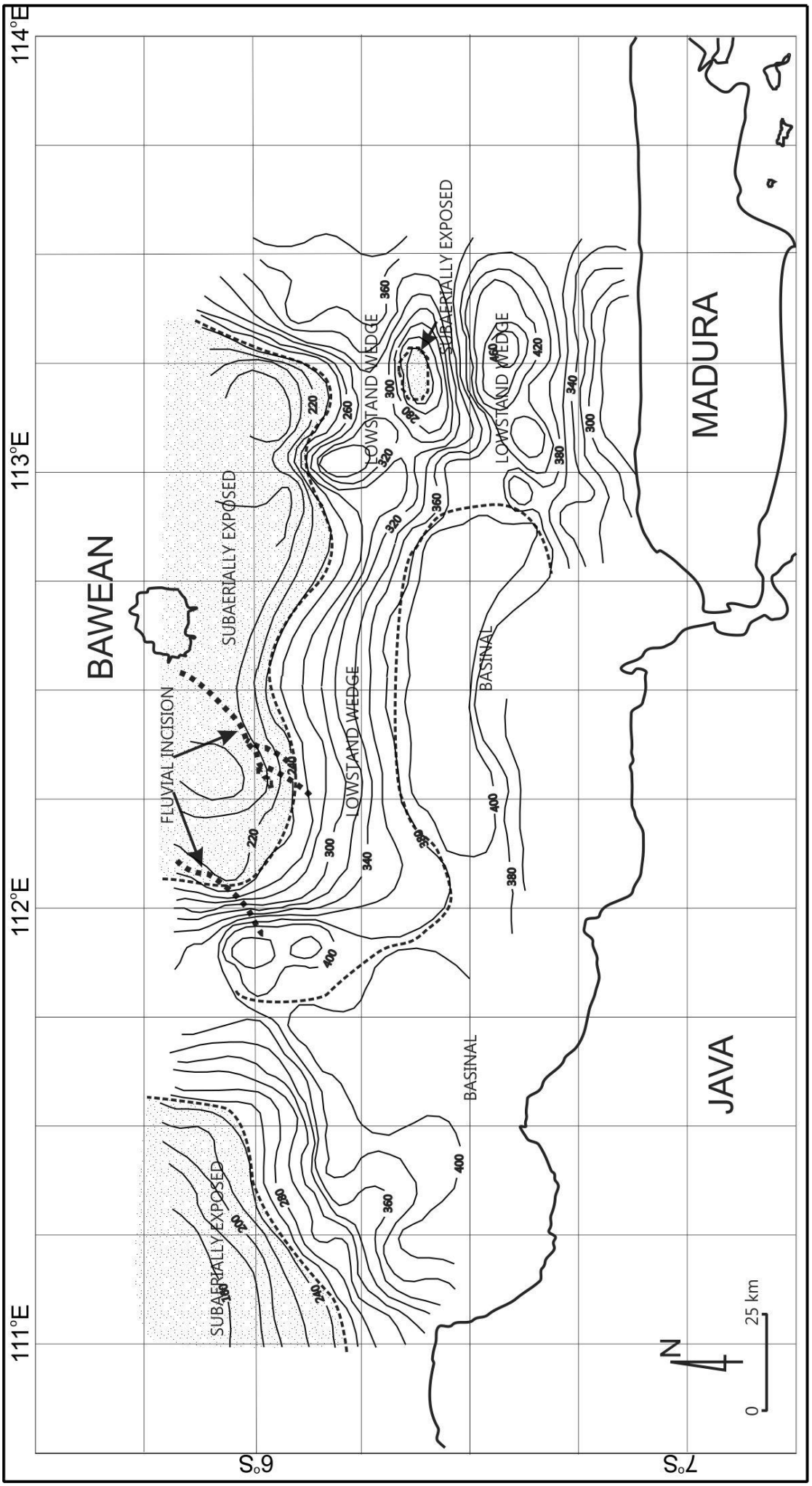


Figure 8. *Palaeogeographic map during the deposition of lowstand systems tract Subunit 2a (Early Pliocene), plotted on the time structure contours (in mSec. TWT) at top Miocene.*

These subdivisions can only be recognised in a limited area where the subsidence and sedimentation rates were relatively high, such as in the area just north of Java (Figure 7).

Subunits 3c-1 and 3c-2 are similar in seismic character, showing a medium amplitude, subparallel reflection pattern which probably represents a shallow marine environment. Subunit 3c-3 is reflection free, indicating most probably homogeneous mudstone. Subunit 3d is extensively distributed and in some areas is characterised by an almost reflection free character suggesting a nearly homogeneous deposit probably of mudstone. In the western part, subunits 3d-1 and 3d-2are very thin to absent, which indicates a low depositional rate.

Subunit 3e consists of a single reflection-free sequence of possibly homogeneous mudstone. The maximum thickness in the basinal area is about 30 msec TWT (about 22 m) with a little variation on the western part of the study area. On some parts to the north of Madura Island this subunit is too thin to be identified, but locally thick deposits of up to 25 msec TWT (about 19 m) occur in a limited area, particularly near the river mouths on the northern coast of Java. The fluvial channelling at the base of subunit 3e in some areas is very pronounced (Figure 6). Its occurrence can be related to the last glacial period, during the oxygen isotope stage 6, when the sea level was -130 m below present level (Chappell & Shackleton, 1986).

DISCUSSION AND CONCLUSION

The Miocene basin configuration of the study area is poorly known, but it is suspected that the basin development was still strongly influenced by the northeast-trending structures related to the basement configuration. These structures are half grabens and have been the major control for the Early Tertiary sedimentation. Although some elements of these structures were still active until the Pleistocene, their effectiveness in controlling the sedimentation during the post-Miocene was diminished. The Pliocene sedimentation, in general, occurred in E-W trending synclinal basins which indicate the dominance of the northward tectonic compressional stress. This continued until the Early Pleistocene, as is indicated by some local thickening of the Early Pleistocene deposits. Since then, further basin development appears to have ceased, and a tectonically stable condition may have been reached.

The Quaternary units, which are represented by nine thin subunits, tend to be distributed widely because of deposition on a relatively flat lying area. The seismic characters are very similar, comprising subparallel reflection or almost reflection free patterns at the bottom which represent marine deposits, topped by extensive fluvial channelling. This repetitive succession is thought to represent highstand and lowstand periods of sea level respectively. Because the average water depth in the study area is about 60 m, the fluvial channelling may be correlated with the major sea level lows during the Quaternary. The bases of subunits 3e, 3d and 3c are tentatively correlated with the glacial periods during oxygen isotope stages 2, 6 and 16 of Harland *et al.* (1989) respectively, while subunits 3a and 3b represent earlier periods. During the glacial periods the Sunda Shelf became widely exposed, and river systems such as the Molengraaff river (Molengraaff, 1921; Kuenen, 1950; Voris, 2000) may have developed in the last glacial period.

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