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Seismic stratigraphy and Cenozoic evolution of the Lombok Forearc Basin, Eastern Sunda Arc

W. van der Werff [a], H. Prasetyo [b], D. Kusnida [b], T.C.E. van Weering [a]

[a] *Netherlands Institute for Sea Research, P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands*
[b] *Marine Geological Institute, Jl. Dr. Junjunan 236, Bandung, Indonesia*

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Abstract

On the basis of single and multi-channel seismic reflection data, the stratigraphic framework and geologic history of the Lombok Forearc Basin is discussed. The Lombok Basin is built on the Southeast Sunda Shelf Continental Margin, and probably underlain by basement of thinned rifted continental crust. It represents a broad-ridged residual forearc basin which is still in an early stage of evolution.

Five seismo-stratigraphic sequences reflecting the Cenozoic history and development of the forearc basin south of the islands of Bali and Lombok were identified. The lowermost sequence (1) probably is composed of synrift deposits of Paleogene age, which predate the initiation of the present convergent margin. Sequences (2) and (3) reflect two major phases of tectonic evolution of the accretionary prism, between the late Oligocene and mid-Miocene. Sequences (4) and (5), represent slope front fill deposits and reflect both volcanic activity as well as tectonic uplift of the magmatic arc from mid-Miocene times onwards.

By the late Miocene, increased convergence between the subducting Indian and overlying Asian plates resulted in a stronger mechanical coupling between both plates. This was expressed in the southern forearc basin by folding of the oldest basin fill deposits.

The present tectonic activity in the Lombok Basin is governed by the late Pliocene collision of the accretionary prism with the Scott marginal and Roo Rise oceanic plateaus. This resulted in uplift of both the outer-arc ridge and the southern part of the forearc basement.

1. Introduction

Forearc regions of arc–trench systems generated by plate consumption can be found in active continental margins and oceanic island arcs (Dickinson and Seely, 1979). The various configurations of convergent margin systems arise from differences in the initial geological setting, and structural evolution during the process of subduction.

The structural evolution of the accretionary prism is governed mainly by the thickness, nature and age of subducting oceanic layers, by the variable thicknesses of trench and slope sediments, the rate and obliquity of plate convergence, and the collision of buoyant crustal blocks (Dickinson and Seely, 1979). These parameters also determine whether a plate-tectonic regime is compressional or extensional (Hamilton, 1988). The evolution of the magmatic arc is characterized by crustal thickening, regional uplift, and blockfaulting (Ingersoll, 1988). The forearc basins, situated between the accretionary prism and the magmatic arc record the tectonic history of these two morpho-tectonic units.

The Sunda Forearc (Fig. 1) is a broad-ridged

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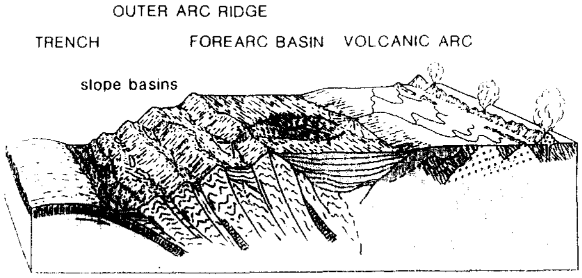


Fig. 1. Diagramatic sketch of the eastern Sunda Forearc region after Moore et al. (1980b) showing the major structural elements.

forearc system, which developed along a complex Asian plate boundary comprising continental, transitional and oceanic crustal elements (Dickinson and Seely, 1979; Hamilton, 1988).

Recent studies on the northwestern part of the Sunda Forearc resulted in a detailed analysis of the geological history of this active margin system (Karig et al., 1979, 1980; Beaudry and Moore, 1981, 1985; Howles, 1986; Curray, 1989). Oil exploration and geological studies yielded a wealth of information on the evolution of the volcanic arc and the backarc regions of Sumatra, Java and the Sunda Shelf (Van Bemmelen, 1949; Hamilton, 1979; Letouzey et al., 1990; Rangin et al., 1990; Daly et al., 1991).

By contrast, the geological history of the Eastern Sunda Forearc (Java and Lombok Basins) has been discussed only briefly and provide a broad outline of the basin geometry and sedimentary sequences (Bolliger and De Ruiter, 1975; Curray et al., 1977; Honza and Ganie, 1987; Van Weering et al., 1989). In this study, we discuss the seismostratigraphy and structural evolution of the Lombok Basin.

2. Regional setting

The Sunda Arc forms part of a large continuous subduction system which swings from Burma to the Banda Arc (Hamilton, 1988). The forearc is characterized by its arcuate shape and has an estimated length of about 3000 km (Fig. 2). Along this plate boundary, oceanic crust of late Jurassic to early Paleocene age is subducted in the Java Trench (Moore et al., 1980a).

The character of the Sunda convergent margin system as reflected by the lithologies of the volcanic arc, changes from continental in Sumatra, through transitional in Java, Bali, Lombok and Sumbawa, to oceanic in Flores. Volcanoes of late Quaternary age erupt in a belt located at about 100 km above the top of the inclined Wadati–Benioff zone of mantle earthquakes (Hamilton, 1988). The tectonic hinge, where the subducted plate tips downward into the mantle is situated about 100–200 km to the north of the trench (Hamilton, 1988). Between the magmatic arc and the outer-arc ridge are situated a number of forearc basins of about 50 to 100 km wide and a few hundred kilometers length separated by transverse highs.

The Lombok Basin, at the eastern end of the Sunda Arc is bounded to the north by the islands of Eastern Java, Bali, Lombok and Sumbawa, and to the east by the island of Sumba, which separates the Lombok Basin from the Savu Basin more to the east. Towards the west, the basin is separated from the Java Basin by a structural high characterized by a positive gravity anomaly (Watts et al., 1978). The Lombok Basin has an elongate shape which is oriented WNW–ESE, subparallel to the present island arc. With an areal extent of 70,000 km^2 and a water depth of more than 4 km, it is one of the largest and deepest forearc basins of the Sunda Arc (Kartaadiputra et al., 1982).

Bali, Lombok and Sumbawa came into existence on the leading edge of the continental Sunda platform (Letouzey et al., 1990). Volcanic rocks on these islands have a mafic to intermediate composition reflecting the near-continental character of the basement (Hamilton, 1988).

Late Oligocene volcanics have been encountered in several wells offshore immediately south of Java and on South Java where they have been described as "Old Andesites" (Van Bemmelen, 1949; Bolliger and De Ruiter, 1975). They possibly represent an old volcanic arc, which extended to the islands of Bali, Lombok and Sumbawa (Barberi et al., 1987). Early to mid-Miocene shallow water carbonate platforms overlie eroded and subsided volcanic

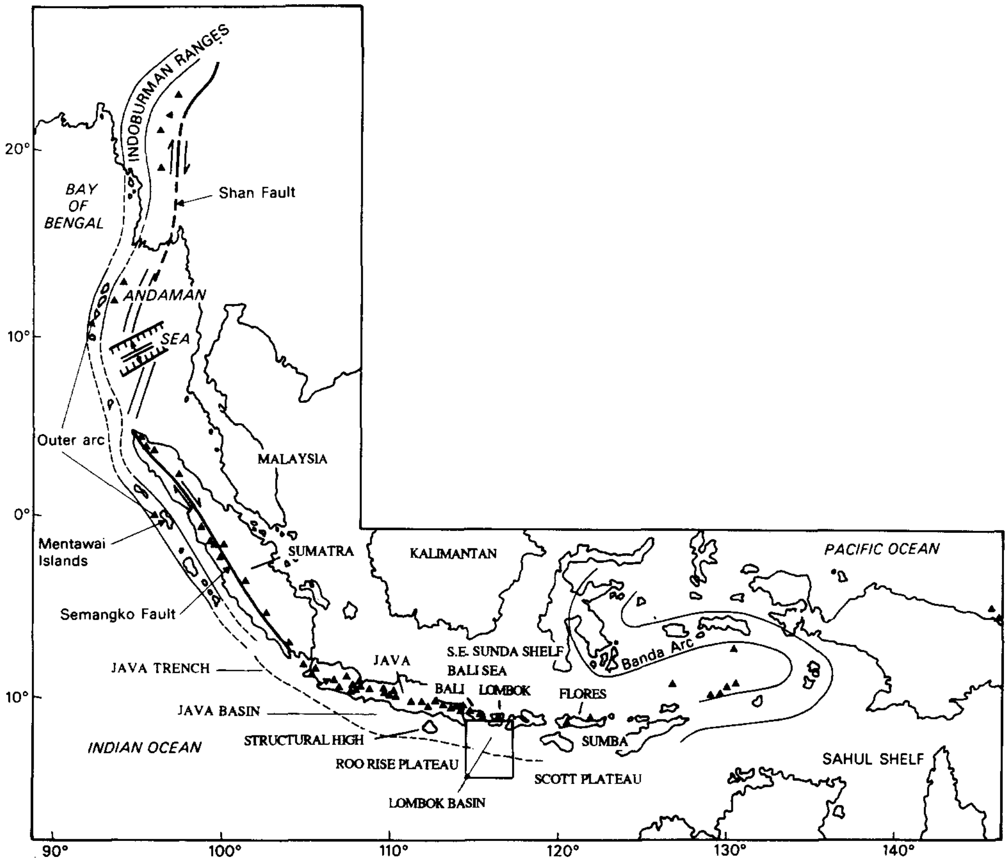


Fig. 2. General map of the Sunda Forearc region. Dashed line indicates position of the Java Trench. Triangles indicate presently active volcanic islands. Inset shows location of study area. Drawing adapted from Katili (1989).

basement highs south of Java (Bolliger and De Ruiter, 1975). Mid- to late Miocene carbonate platforms developed in a similar tectonic setting on Bali, Lombok and Sumbawa (Van Bemmelen, 1949; Barberi et al., 1987). During the Neogene, the volcanic arc (from Java to Sumbawa) migrated north, towards its present position.

Backarc thrusting along the northern slope of the volcanic arc, from Bali to Sumbawa, may indicate the initial stage of arc polarity reversal (Silver et al., 1983; Prasetyo and Dwiyanto, 1985). Although magmatism associated with the north dipping subduction system is still active, its intensity is decreasing within the late Quaternary (Hamilton, 1988).

North of the volcanic arc, the Bali Sea forms the southern part of the Southeast Sunda Shelf Margin. It represents a basin with water depths of up to 1 km. The basement is characterized by WNW–ESE trending thrusts that originated as graben structures during the Paleogene, and is covered by 2 km of Tertiary sediments (Tyrrel et al., 1986; Letouzey et al., 1990).

3. Geological history of the Eastern Sunda Arc

A melange of Cretaceous and early Paleogene age, paired to widespread Cretaceous granitic and volcanic rocks, dominates the basement in a broad belt trending northeast from Java, across the shelf to southeast Kalimantan (Hamilton, 1979). This suggests that a "proto Sunda Arc" existed from Java to Kalimantan.

During the late Paleogene, both Western and Central Java and the Java Sea were tectonically and magmatically dormant and fused to the Asian subcontinent (Hamilton, 1988).

The collision of India with Eurasia in the Eocene resulted in extension along the Sumatra convergent margin and the initiation of many basins in Southeast Asia (Daly et al., 1991).

The Southeast Sunda Shelf experienced a period of major extension with non-marine graben fill during the Paleogene (Letouzey et al., 1990). In this period, the Sumba continental fragment, which has been interpreted as originally belonging to the Sunda Shelf (Van der Werff et al., 1993), actually drifted over a distance of 17° to the south, with a counterclockwise rotation of 85°. It then became trapped in the evolving Sunda–Banda Arc system (Wensink, 1993). A tectonically quiet period during the Oligocene and early Miocene with a general subsidence was terminated by folding, inversion and thrusting.

Subduction along the present convergent margin takes place since the late Oligocene (Sclater and Fisher, 1974; Molnar and Tapponier, 1975; Rangin et al., 1990; Daly et al., 1991). The rate of plate convergence has been estimated as 5 cm/yr between 44 and 10 Ma. After 10 Ma, the plate convergence increased to 7 cm/yr (Karig et al., 1979, 1980; Liu et al., 1983; Curray, 1989).

Late Oligocene tectonic activity is expressed by block faulting and subsidence in the northern part of the Java forearc basin (Bolliger and De Ruiter, 1975). This major tectonic phase formed the structural setting which controlled the sedimentary fill in the present Eastern Sunda forearc during the Neogene.

During the mid-Miocene, volcanic activity was widespread from Sumatra to Western Flores. It ceased during the late Miocene (on Sumbawa) but resumed in the early Pliocene (Barberi et al., 1987). Volcaniclastic submarine fan deposits on Sumba, suggest an early to late Miocene arc, south of Sumba (Fortuin et al., 1994). East of Sumba, strata with NNE-dipping foresets, probably form the offshore equivalent of these submarine fan deposits (Van der Werff et al., 1994).

During the late Pliocene, the volcanic arc and the accretionary wedge were elevated and the present volcanic island arc originated (Bolliger and De Ruiter, 1975; Hamilton, 1979).

4. Methods

A tectonic map of acoustic basement structures has been constructed from the interpretation of seismic profiles, for the Lombok Basin between 114° and 118°E (Figs. 3 and 4). The data set available for this study consist of single-channel *Snellius*-II profiles (partially published by Van Weering et al., 1989). Additional multi-channel profiles have been supplied by *Shell Internationale Petroleum Maatschappij* and the Geological Survey of Japan. Well data other than DSDP Site 262, and published commercial sites in the backarc area were not available to us (Erickson, 1974; Tyrrel et al., 1986).

Sequence boundaries, reflection patterns and depositional environments have been interpreted by seismic facies analysis as outlined by Vail et al. (1979). The seismic criteria used to characterize the sequences are summarized in Table 2. Each sequence is assigned a number, for ease in discussion.

In general, the multi-channel data yield a penetration of up to 8 km with a relatively low resolution, enabling recognition of large scale seismic sequences and facies only (Fig. 5). For the calculation of the thicknesses of the respective sequences, we used the interval velocities given on the Japanese profile L-19 (Table 1; Fig. 7A).

5. Results

5.1. Accretionary wedge

The accretionary wedge represents a well-developed body of imbricated thrust sheets and melange sediments, which can be subdivided into a deformation front, an inner-trench slope, trench slope break, slope basin and wedge high (Figs. 5 and 6A). It is characterized by a convex shape with an average inner-trench slope of 3°, and a relief of 5 km. The wedge is about 100 km wide and has a maximum thickness of 8 km, underneath

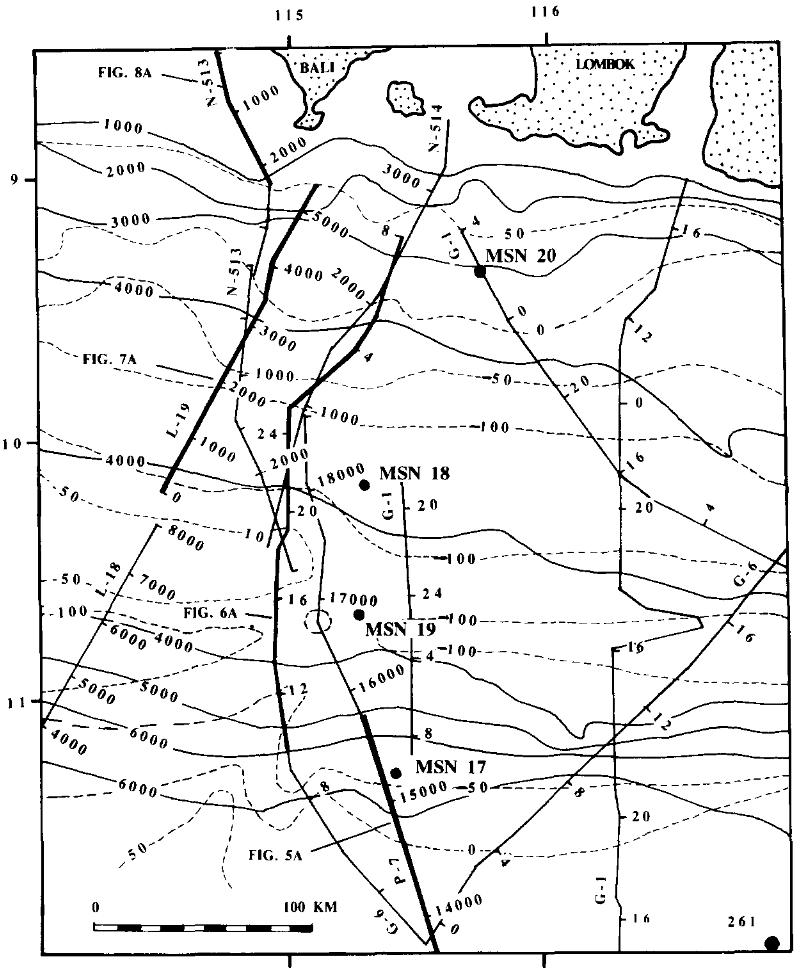


Fig. 3. Track chart of the seismic profiles used for this study. Figure numbers *5A–9A* indicate location of profiles reproduced in text.

the trench slope break. The wedge displays a seismic facies that can be described as a chaotic pattern of diffraction hyperbolae (Fig. 6B) and north-ward dipping reflectors. It is covered by a relatively thin layer of slope sediments which thickens from 200 m at the inner-trench slope towards 600 m in a slope basin on top of the accretionary wedge.

The transition zone between the accretionary prism and the forearc basement is marked by a relatively sharp topographic break. The forearc basin, just north of the accretionary prism, has been affected by compression which resulted in folding of the older basin fill deposits (Figs. 6A and 8A). Subsequent uplift caused northward tilting of the basement and lower basin fill deposits. Towards the north, blocks are downfaulted by normal faults.

5.2. *Forearc basin*

The forearc basin is approximately 65 km wide (Fig. 4). It is underlain by basement blocks of up to 35 km wide, with interval velocities of 3700–4500 m/s (Fig. 7A). The basement has a seismic chaotic facies (Fig. 7B). A major block in the northern part of the basin, is slightly tilted towards the north, and cut by north and south dipping near vertical, normal faults, with offsets

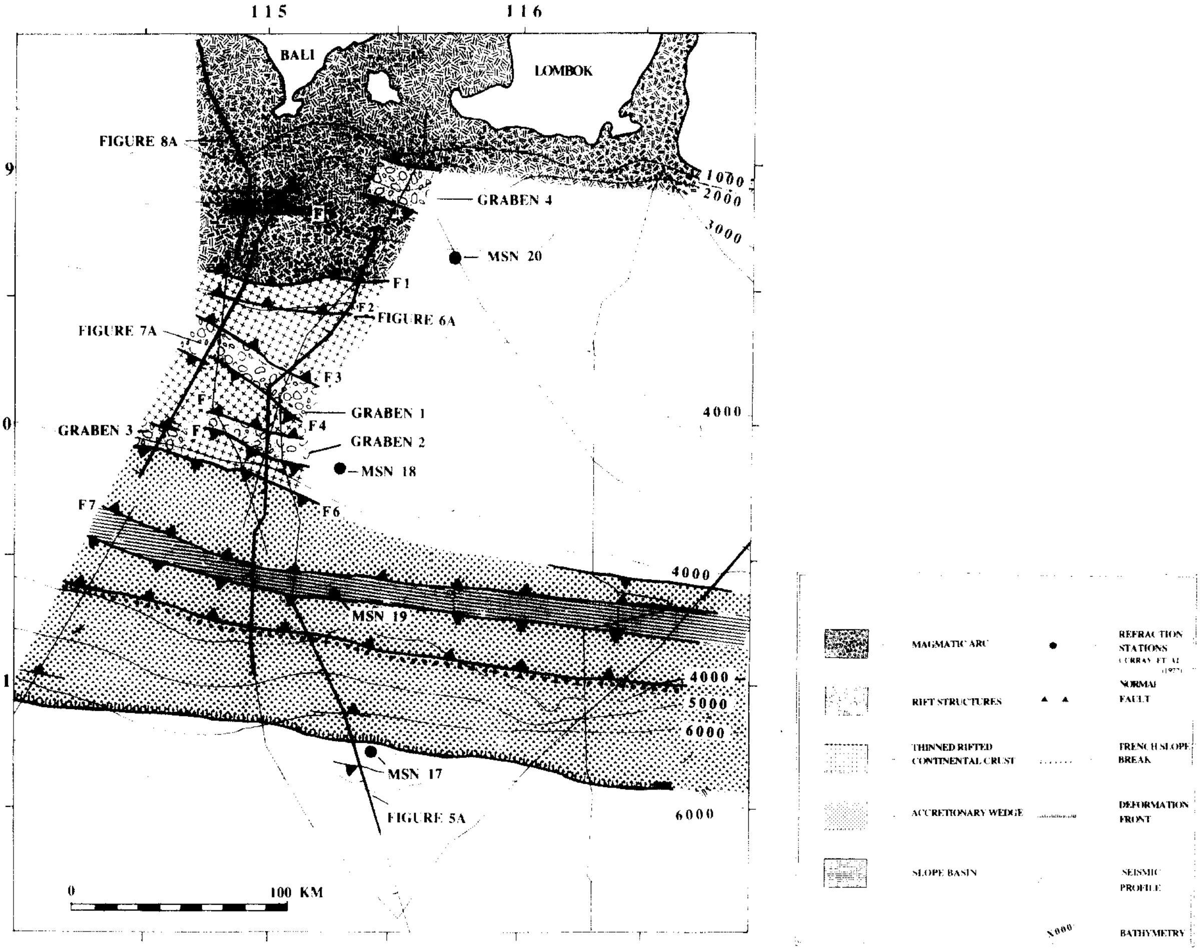


Fig. 4. Morphotectonic map of the acoustic basement structures superimposed on the seismic lines used for the interpretation. For legend, see map.

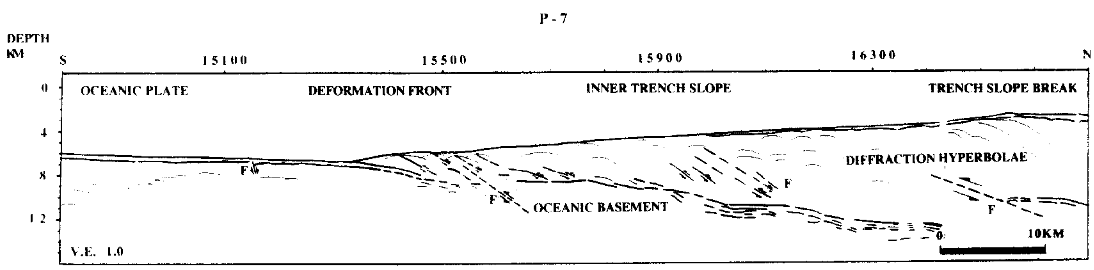


Fig. 5. Line drawing and interpretation after seismic profile P-7 across the accretionary wedge. Location is shown in Fig. 3. Vertical and horizontal scale are in kilometers. Arrows along fault planes indicate direction of relative basement movement.

of about 2 km (Fig. 7A, SP 2600–3700). In the center of the basin, a 15 km wide rift structure, trends in an ESE–WNW direction at an angle of about 20° oblique to the accretionary prism (Fig. 4, graben 1). There are two other graben structures (Fig. 4, grabens 2 and 3) just north of the accretionary prism. On top of the northern basement high flanking graben 1, a mound charac-

Table 1
Sound velocities from seismic profile L-19, southern, center and northern forearc basin (Japanese Geological Survey). For location see Figs. 3 and 5

Time (s)	Depth (m)	V_{rms} (m/s)	V_{int} (m/s)
(A) *Shotpoint 205 (Figs. 4 and 7A)*			
0.000	0	1450	1450
4.200	3045	1450	1450
4.510	3348	1490	1963
5.100	4136	1670	2671
5.450	4744	1840	3476
6.490	8518	2170	3412
9.000	14143	3700	6075
(B) *Shotpoint 2305 (Figs. 4 and 7A)*			
0.000	0	1490	1490
5.500	4088	1490	1490
5.810	4446	1540	2249
6.320	5146	1670	2746
7.380	6786	1940	3094
9.110	10584	2590	4390
1.000	17724	3920	7556
(C) *Shotpoint 3365 (Figs. 4 and 7A)*			
0.000	0	1540	1540
5.510	4243	1540	1540
5.670	4483	1600	3008
6.170	5376	1840	3570
7.220	7648	2370	4328
9.790	14758	4390	5533
1.000	19367	4150	7617

terized by wavy seismic reflection patterns may indicate a buried reef (Fig. 7A and B).

5.3. Magmatic arc

The southern half of the magmatic arc is about 90 km wide. The arc gradually slopes down to the south until 9°25′S where a sharp topographic break marks the abrupt transition from magmatic arc to the forearc basin (Figs. 4 and 7A). This break is underlain by a normal fault with a vertical offset of 700 m. The boundary between the forearc basin and the magmatic arc coincides approximately with the transition from negative to positive free air gravity anomalies (Watts et al., 1978). Basement blocks have widths of about 30 km, and are cut by normal faults with offsets of about 700 m (Figs. 4 and 9A). The acoustic basement is characterized by a seismic transparent facies (Fig. 9B).

West of Bali, a deeply incised submarine canyon with thick sediments on its flanks, and a wavy morphology suggesting turbidite overbank deposits is present (Fig. 9A). Underneath this canyon, a strong north-dipping reflector within the basement may represent the top of a dome-like structure. This structure is in line with the volcanic arc and could represent plutonic intrusive bodies. The sediment deposits down lap the basement blocks south of the volcanic arc and have a thickness of 2 km.

A rift structure has been recognized southeast of Bali (Fig. 4, graben 4). Its regional geometry remains undefined because of the limited penetration of the seismic profiles. A major amount of sediments derived from the volcanic arc has been trapped in this graben.

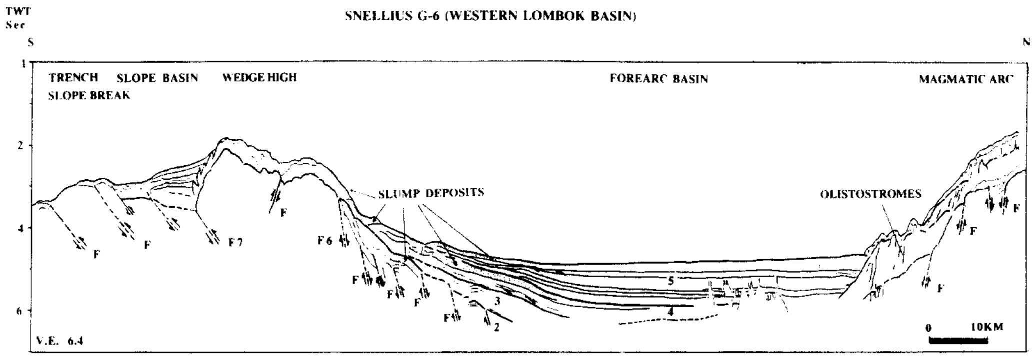
On the south flank of the magmatic arc, a mound characterized by wavy bedding and southward dipping reflectors may indicate a second shallow water carbonate platform (Fig. 7A, SP 4000–4300).

5.4. Seismic stratigraphy

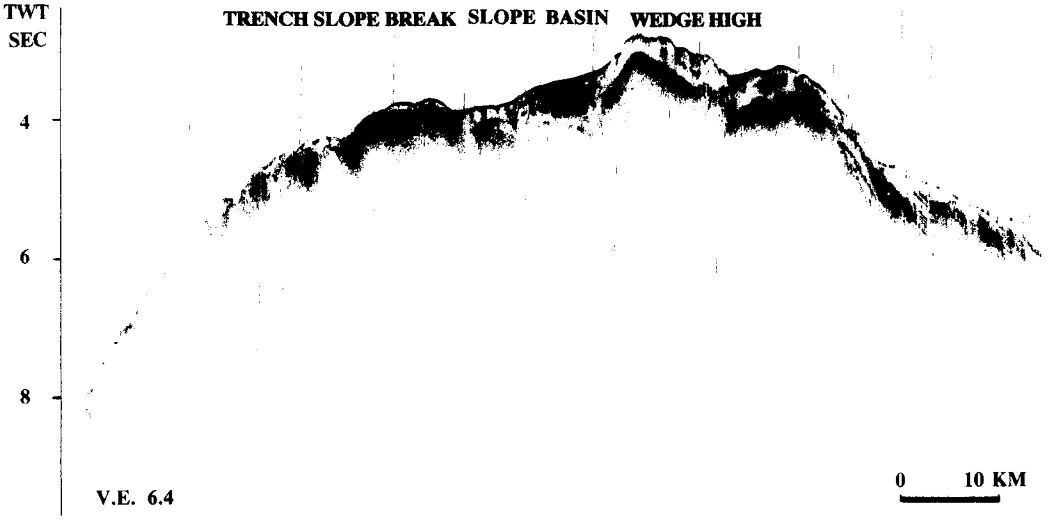
The forearc basement is covered by approximately 4.5 km of sediments above the grabens and about 3 km above the basement highs (Fig. 7A). Five major seismic sequences can be discriminated in the sedimentary column of which the seismic facies characteristics are summarized in Table 2.

Seismic sequence (1)

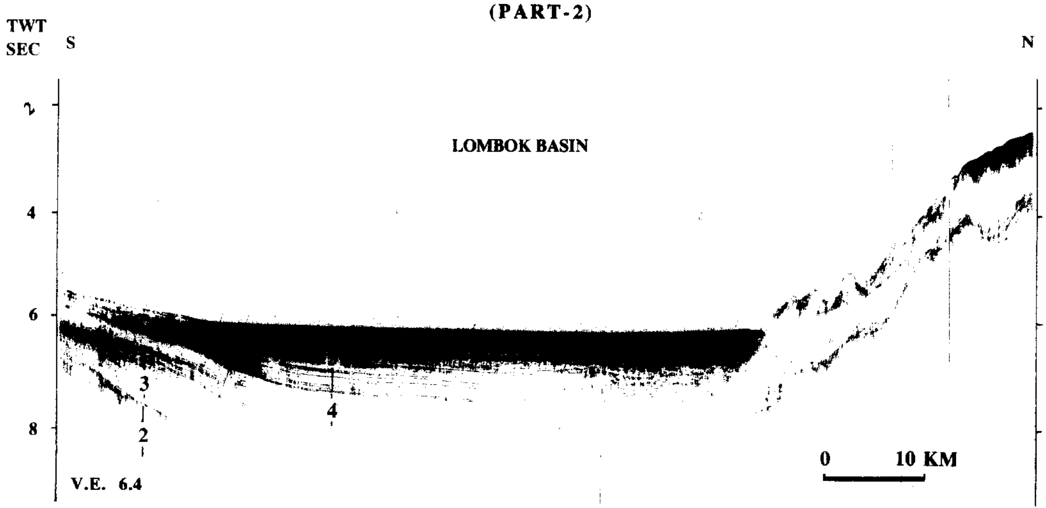
The basal unit sequence (1) consists of wedge-shaped graben deposits which fill the depressions between the basement highs (Fig. 7A and B). It has a thickness of up to 1700 m in the center of the grabens and pinches out against the basement highs. The lower sequence boundary is formed by seismic reflection terminations which onlap the basement. In the south of the forearc basin, the strata are tilted to the north (Fig. 7A, SP 300–800). This tilt has been estimated at 700 m over 15 km from the upper sequence boundary, which supposedly originally was sub-horizontal. In the center of the basin, the sequence boundary



G-6 (WESTERN LOMBOK BASIN)
(PART-1)



G-6 (WESTERN LOMBOK BASIN)
(PART-2)



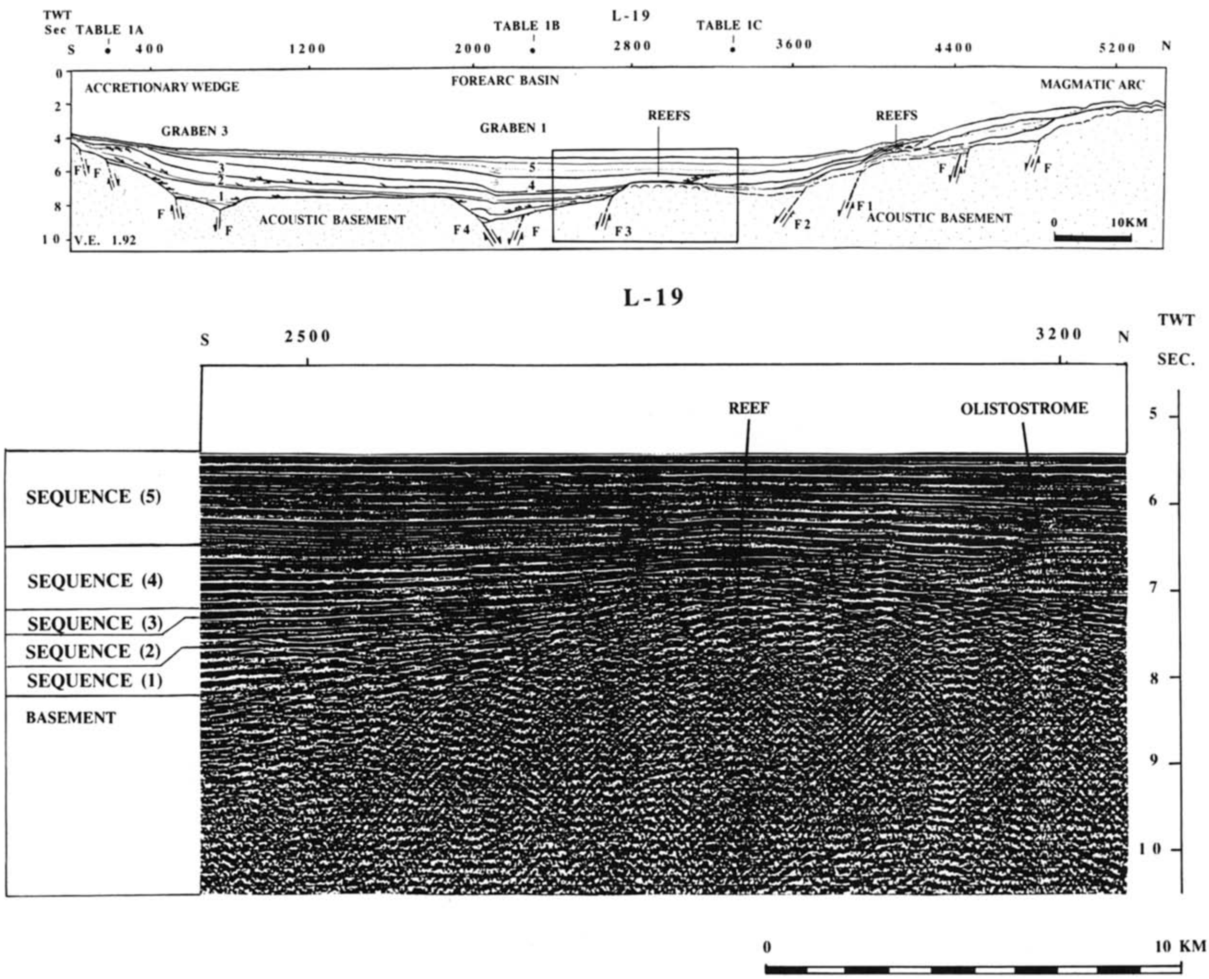


Fig. 7. (A) Line drawing and interpretation of seismic profile L-19. For location see Fig. 3. Legend as in Figs. 5A and 6A. Vertical scale in seconds two way travel time (TWT). Inset shows section of seismic profile reproduced as Fig. 7B. (B) Section of seismic profile L-19. For location see Fig. 3. Vertical scale in seconds of two way travel time (TWT). Horizontal scale in kilometers.

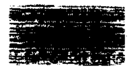
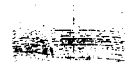
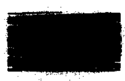
is slightly erosional to paraconformable and is covered in the south by the downlapping reflectors of sequence (2). The seismic facies is characterized by continuous, even-bedded, high amplitude, low frequency reflectors and has an interval velocity of 3500 m/s (Table 1B). On the basis of its depositional setting and reflection configuration (Table 2), the lithofacies is interpreted as an alternation of pelagic clays or marls with turbidites.

Seismic sequence (2)

Sequence (2) has a bank shaped geometry and is only present in the southern part of the forearc basin (Fig. 7A). Just north of the accretionary prism between SP 200 and 400, the sequence has

Fig. 6. (A) Interpretation of seismic profile Snellius G6 (Western Lombok Basin). For location see Fig. 3. Arrows in sedimentary sequences indicate cycle terminations (Vail et al., 1977). Sequence numbers *1*, *2*, *3*, *4* and *5* indicate seismic sequences mentioned in text. Vertical scale in seconds of two way travel time (TWT). Further as in Fig. 5A. (B) Seismic profile G6 (western Lombok Basin). For location see Fig. 3. Vertical scale in seconds of two way travel time (TWT). Horizontal scale in kilometers.

Table 2
Seismic and geologic criteria used for sequence comparison

Seismic Interval	Seismic Facies Unit	Depositional Setting	External Form	Reflection Geometry at Boundaries	Reflection Config.	Reflection Character	Inferred Age	Seismic appearance of Facies	Geological Interpretation
5	Slope front fill	Basin floor	Wedge	Concordant-gentle onlap at base	Divergent	High ampl. High cont.	Plio/Pleistocene		Alternation of volcaniclastic/melange turbidites with pelagic clays
4	Slope front fill	Basin floor	Wedge	Concordant-slightly erosional at top Concordant-gentle onlap at base	Divergent	Semi transp. Weakly refl.	Mid-Late Miocene		Alternation of volcaniclastic slumps and turbidites with pelagic clays
3	Progradational	Basin slope	Bank	Onlap at top Concordant-downlap at base	Parallel	Moderate Refl.	Early Miocene		Alternation of "reworked melange" turbidites with pelagic clays
2	Progradational	Basin slope	Bank	Downlap, onlap, concordant at top Downlap at base	Parallel Divergent	High ampl. High cont.	Late Oligocene		Alternation of "reworked basement and melange" turbidites with pelagic clays
1	Onlap fill	Basin floor	Wedge	Concordant-slightly erosional at top Onlap at base	Parallel Even	High ampl. High cont.	Paleogene		Non marine clastics marls and shales
Basement	Grabens, Highs	Shelf margin Basin floor		Slightly truncated at top		Opaque Amorphous	Mesozoic ?		Basement of continental origin

a maximum thickness of 700 m. From SP 200 to 1200, it rapidly thins to a few hundred meters, and extends northward across graben 1 in the center of the basin, as a parallel bedded depositional unit. Sequence (2) onlaps the northern basement high at SP 2800. The seismic facies is composed of relatively steep north-dipping oblique progradational reflectors which downlap sequence (1) and have an interval velocity of 2100 m/s. The reflection pattern is characterized by continuous, even-bedded, high amplitude, low frequency reflectors. Between SP 250 and 500, the sequence is truncated by younger sediments (Fig. 7A). The upper sequence boundary is erosive and characterized by a high amplitude reflector. The depositional setting and seismic facies (Table 2) are typical for active slope progradation of a submarine fan complex. The reflection character and configuration suggest an alternation of turbidites (possibly consisting of reworked melange) and pelagic sediments.

Seismic sequence (3)

Sequence (3) is bank shaped and its distribution is also restricted to the southern part of the forearc basin. The sequence has a maximum thickness of 550 m between SP 500 and 1200, and an interval velocity of 2100 m/s (Fig. 7A). It extends into the central graben, and gradually thins to a few reflectors indicating a thickness of less than 100 m. The sequence pinches out against the top of the northern basement high. The inclination of the north-dipping reflectors is about half that of sequence (2). The seismic facies can be subdivided into two units with different reflection characters. The lower has a thickness of 0.3 s TWT and is composed of transparent to weakly reflective beds of a limited continuity. At the base, minor base of slope mound deposits are found between SP 800 and 1000. The upper is 0.4 s TWT thick and consists of a band of continuous, even-bedded, high amplitude, low frequency reflectors. The geometry and seismic facies of both subunits indicate active slope progradation similar to sequence (2). Both the weak reflectivity and the low seismic coherence of the lower seismic facies unit indicate slump deposits. The high amplitude reflections of the upper unit suggest an alternation of turbidites and pelagic sediments.

Seismic sequence (4)

Sequence (4) is wedge shaped and is found in the entire forearc basin. In the center of the basin it has a maximum thickness of about 1200 m (Fig. 7A, SP 2000–2800). Above both the magmatic arc and accretionary wedge, the sequence thins to a few hundred meters and has been lifted up. The sequence has an interval velocity of about 1900–2300 m/s (Table 1), and an internal reflection pattern characterized by weakly reflective to transparent beds. The lower sequence boundary is formed by "cycle" terminations which onlap sequence (3). The upper sequence boundary is characterized by a major continuous high amplitude reflector. Seismic facies patterns suggest slope front fill deposits formed by marls and pelagic clays, inferred from the low density contrasts (Table 2).

Seismic sequence (5)

Sequence (5) is also wedge shaped and covers the entire forearc basin. Its interval velocity is 1900–2300 m/s. In the center of the basin above graben 1, the sequence reaches a maximum thickness of 900 m (Fig. 7A, SP 2200–2700). Towards both the north and the south, it gradually thins to a few hundred meters. Both edges of the sequence have been uplifted about 0.3 s. TWT and tilted. Local unconformities within sequence (5) probably reflect episodic uplift of the magmatic arc and of the outer-arc ridge. The lower sequence boundary is marked by a continuous high amplitude reflector and is paraconformable in the center of the basin (Fig. 7B). The seismic facies is characterized by an alternation of continuous, very high amplitude reflectors with moderate to weakly reflective beds. These alternations have been subdivided by Van Weering et al. (1989) into 9 cycles, interpreted as alternations of turbidites and pelagic clays. The reflectors downlap sequence (4) northward of the accretionary prism and onlap this sequence in the north (Figs. 6A and 8A). The divergent reflection configuration of sequence (5), is caused by the increasing uplift and northward tilt of the older deposits on the outer-arc side of the basin. This resulted in a continuing arc-ward shift of the depocenter during the deposition of this sequence (Fig. 6B). Acoustic voids occur in the north of the forearc basin (Fig. 6B).

Seismic facies patterns (Table 2) and widespread volcanic activity suggest an alternation of volcaniclastic turbidites with pelagic sediments.

6. Discussion

A preliminary seismo-stratigraphic framework of the Lombok Basin was provided by Van Weering et al. (1989). A more extensive set of seismic profiles, makes it possible to propose a modified seismo-stratigraphic interpretation.

6.1. Basement

Several interpretations have been suggested to explain the nature of the basement underlying the Sunda Forearc Region. Karig (1977) and Karig et al. (1979) in studies on Nias (Mentawai islands) and the forearc basin offshore West Sumatra, proposed that the basin is underlain largely by a pre-Miocene accretionary complex. Dickinson and Seely (1979) and Hamilton (1988) suggested that the forearc is underlain by a wide strip of oceanic crust which extends towards the outer-arc ridge where it serves as a "deep" buttress where off-scraped wedge sediments accumulate.

Earlier seismic refraction studies in the Lombok and Sumatra forearc basins gave no conclusive interpretation of the forearc basement character (Curray et al., 1977; Kieckhefer et al., 1980). The Sunda forearc basin is underlain by crust of intermediate thickness (18–25 km), with seismic velocities ranging from oceanic (7.0 km/s) to continental (6.0 km/s).

Curray et al. (1977) concluded that offshore Bali and Java, basement and lower crustal layer velocities of the overriding plate, indicate oceanic crust and suggested that in a compressive plate tectonic setting, the oceanic basement is thickened by imbricate faulting. On similar data in the Western Sumatra Forearc Basin, Kieckhefer et al. (1980), however, considered the thickness of the basement more suggestive for continental crust. Both papers conclude that velocities of forearc basin basement are probably too high to represent

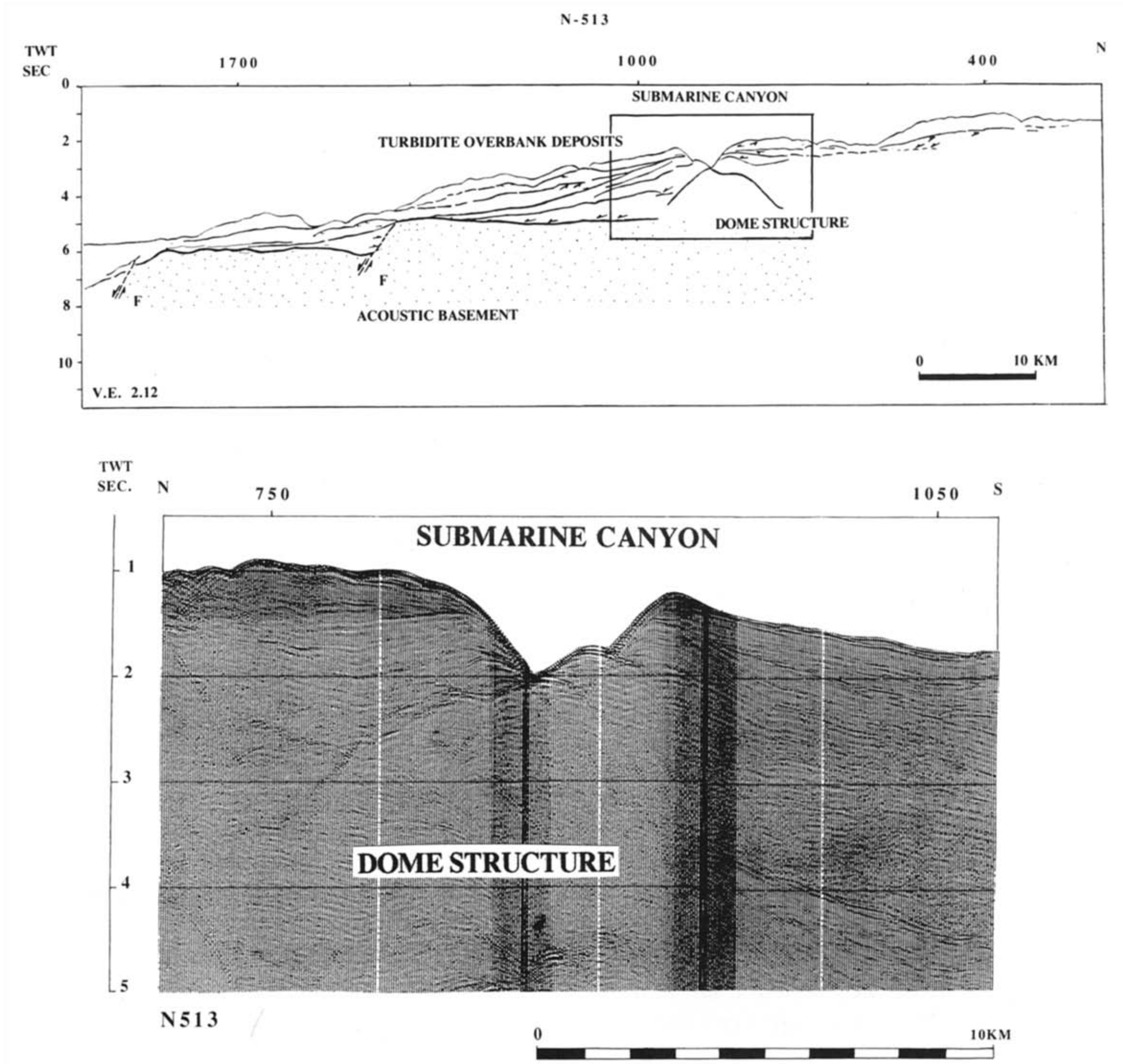


Fig. 8. (A) Line drawing and interpretation after seismic profile N513—part 1. For location see Fig. 3. Vertical scale in seconds of two way travel time (TWT). Legend as in Figs. 5A and 6A. Inset shows section of seismic profile reproduced as Fig. 9B. (B) Section of seismic profile N513. For location see Fig. 3. Vertical scale in seconds of two way travel time (TWT). Horizontal scale in kilometers.

accretionary wedge sediments or metamorphosed melange lithologies.

Seismic profile L-19 (Figs. 4 and 7A) shows basement blocks separated by a major graben in the center of the basin. The orientation of this graben is roughly parallel to structures formed during the Paleogene in the Bali Basin (Letouzey et al., 1990). In our opinion it is unlikely that the extensional setting of the acoustic basement blocks, supports the interpretation of Curray et al. (1977), that imbricate faulting could have served as a mechanism of oceanic basement thickening. The greater part of the forearc basement could be underlain by rifted continental crust. The continental crust could have extended from the Southeast Sunda Shelf into the forearc region.

Station MSN 18 (Curray et al., 1977), in the forearc basin south of Bali, gives a velocity of 6.2 km/s and a thickness of 18 km, suggesting thinned continental crust (Fig. 4). The velocities of station MSN 18 compare with their stations MSN A and B, north of Bali on the Sunda Continental Shelf. At station MSN 20, south of Lombok on the magmatic arc, a velocity of 6.9 km/s was recorded, representative for a magmatic island arc type crust (Hamilton, 1988).

Thinned, rifted continental crust may have become incorporated into the accretionary wedge during its evolution. Both the presence of grabens 2 and 3, in front of the wedge, and the north-ward tilt of sequence (1), suggest that the northern slope of the accretionary prism is partially underlain by basement of continental origin.

6.2. Cenozoic evolution of the Lombok Basin

A model illustrating the evolution of the Lombok Basin is presented in Fig. 9. If the acoustic basement should consist of rifted continental crust similar to the Southeast Sunda Shelf, sequence (1) probably consists of synrift deposits which predate the evolution of the convergent margin system. In the Bali Basin, these deposits are Paleocene non-marine clastics, covered by Late Eocene marls and shallow water carbonates (Letouzey et al., 1990).

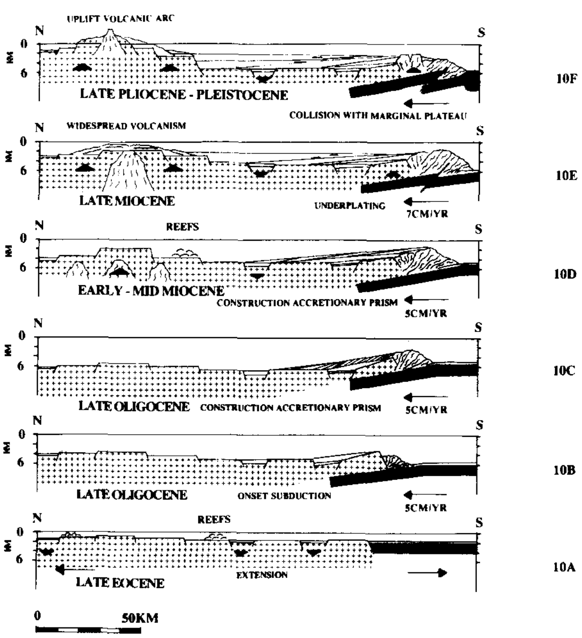


Fig. 9. Model of Tertiary evolution of the Lombok Forearc Basin.

In the Lombok Basin, synrift deposits possibly will be more marine (Fig. 9A). The mound, located to the north of graben 1 may represent a buried Eocene reef (Fig. 7A). Similar lithologies also of Eocene age, occur in the backarc area (Letouzey et al., 1990). The presence of an Eocene shallow water carbonate platform south of the present volcanic arc, would then indicate that the basin subsided from near surface waterdepths to a present depth of 5.5 km since the late Oligocene evolution of the convergent margin system.

Sequence (1) which is tilted towards the north, onlaps the basal part of the accretionary wedge. This suggests uplift of the evolving accretionary prism (Fig. 9B).

Sequence (2) fills the forearc basin from the south indicating that the accretionary prism had evolved sufficiently to form a major sediment source for the forearc basin. The evolution of the accretionary prism is expressed in vertical uplift and northward tilting of the backstop, resulting in slope steepening and submarine fan progradation into the southern part of the forearc basin (Fig. 9C). The sediments may consist of both reworked basement and accreted material carried down the slope by turbidity currents and slumping. There was practically no sedimentation in the northern part of the forearc basin. The magmatic arc had not yet developed and probably was below sea level. Sequence (2) is interpreted to post-date the late Oligocene convergent margin initiation.

Sequence (3) fills the forearc basin from the south as sequence (2) did, but also reflects a change in accretionary prism dynamics. The initial rapid uplift of the prism has slowed down after which a new small second pulse has triggered a rather thick sequence of prograding wedge deposits with a lower north-dipping inclination. This change in the depositional pattern may be explained by lateral, ocean-ward growth of the inner-trench slope. Increased accretion at the toe of the wedge may result in uplift of young segments of the inner-trench slope, as opposed to the relative subsidence of older parts of the accretionary wedge which are located more to the north (Fig. 9D). The northern part of the forearc basin was still sediment starved, and thus sedimentation also must have predated the evolution of the magmatic arc. Therefore, we propose an early Miocene age for sequence (3). Differential uplift in the northern part of the forearc basin reflects the effects of magmatic intrusions; this resulted in the formation of the first major olistostromes from the north due to slope instability (Fig. 6A). On the magmatic arc, shallow water carbonate platforms developed, as suggested by the mounds on profile L-19 (Fig. 7B, SP 4000–4300).

Sequence (4) reflects basin fill sediments which onlap sequence (3). This sequence is found in the entire forearc basin. It most logically consists of pelagic sediments and erosional products derived from the evolving northern volcanic arc and its associated shallow water carbonate platforms (Figs. 7A and 9E). Because volcanic activity in the area started approximately in the mid-Miocene, this sequence has been attributed a mid- to late Miocene age (Katili and Hartono, 1983; Barberi et al., 1987). Some of the sediments derived from the volcanic arc were trapped in grabens within the basement of the magmatic arc (Fig. 4, graben 4). These grabens may have resulted from extension in the crust above evolving magma chambers or caused by the collapse of these chambers after volcanic eruptions (Dickinson and Seely, 1979). Subsequently, the northern side of the accretionary prism stabilized and subsidence may have started as described for the Western Sunda Arc by Karig et al. (1976).

Sequence (5) also represents basin fill sediments, presumably of Plio-Pleistocene age. Deposition of this sequence coincides with uplift of the volcanic arc above sea level (Fig. 9F) (Bolliger and De Ruiter, 1975). The uplift is evidenced by the flexure of sequence (4) and (5) above the basement in the northern part of the forearc basin and is estimated to be a few hundred meters (Fig. 7A). Local unconformities may reflect depositional changes as a consequence of periods of strong volcanic activity and continuing uplift of the magmatic arc. Tilted sequences at the northern side of the forearc basin mirror three distinct periods of magmatic arc uplift (Fig. 7A, SP 3500–4500). Renewed compression of the accretionary prism is expressed by uplift of the outer-arc ridge and a north-ward tilt of the forearc strata in the southern part of the forearc basin. This resulted in slope steepening, slumping and the generation of a number of turbidite cycles which downlap sequence (4) to the north (Figs. 6A and 8A). The renewed compression may result from increased convergence rates between the Asian and Indian Plates since the late Miocene (Karig et al., 1979, 1980; Liu et al., 1983). The Pliocene collision of the Eastern Sunda Arc with the Scott Marginal and the Roo Rise Oceanic Plateaus additionally increased inter-plate coupling. Deformation in the forearc basin is expressed by reactivation of the south flank of graben 1, which in turn caused flexure of the Neogene forearc deposits (Fig. 7A).

The distribution patterns of the seismic sequence thicknesses suggest that Paleogene depocenters were located around structural low areas. In the Neogene, areas of maximum sediment deposition gradually migrated north-ward from the accretionary wedge to the center of the forearc basin. This occurred in response to a change in sediment source areas from the accretionary prism to the volcanic arc, and by the late Neogene compressional tectonic setting.

7. Conclusions

A detailed seismo-stratigraphic analysis of the Lombok Basin south of Bali and Lombok resulted in the identification of 5 regional seismic sequences. Seismic sequence patterns reveal that both the initial geologic setting and subsequent changes in plate dynamic behaviour have controlled the evolution of this forearc basin.

We suggest that the Lombok Basin is underlain by continental basement, most probably forming the continuation the Southeast Sunda Shelf.

The initial evolution of the accretionary wedge resulted in forearc basin sedimentation with a provenance area from the south. Two distinct tectonic phases in accretionary wedge formation can be distinguished between the late Oligocene and mid-Miocene.

The evolution of the magmatic arc is reflected by high sedimentation rates, resulting in two sequences representing a slope front fill facies. Local unconformities probably are caused by uplift of the magmatic arc with episodes of increased, volcanic activity.

Late Miocene increased convergence rates and the late Pliocene to Recent collision of the Scott and the Roo Rise plateaus with the arc–trench system resulted in a stronger inter-plate coupling. This is expressed by uplift of the accretionary prism and the southern basement high of the forearc basin.

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