# CHARACTERIZATION OF MIOCENE-PLIOCENE CARBONATE PLATFORMS, SOUTHERN SOUTHWEST PALAWAN BASIN, PHILIPPINES

A Thesis

by

MA. CORAZON VICTOR STA. ANA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2006

Major Subject: Geology

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Approved by:

Chair of Committee, Steven L. Dorobek
Committee Members, Brian J. Willis
Daulat Mamora
Head of Department, Richard L. Carlson

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## ABSTRACT

Characterization of Miocene-Pliocene Carbonate Platforms, Southern Southwest Palawan Basin, Philippines. (August 2006)

Ma. Corazon Victor Sta. Ana, B.S., Mapua Institute of Technology

Chair of Advisory Committee: Dr. Steven Dorobek

Isolated carbonate platforms and buildups of the Likas Formation provide a long record of carbonate sedimentation in the southern end of the Southwest Palawan Basin. While most carbonate platforms terminated in early Miocene and middle Miocene time in northern parts of western offshore Palawan (i.e. Northwest Palawan Basin and central South Palawan), carbonate deposition began later in the south during late middle Miocene time.

Carbonate platforms of the Likas Formation developed in the Paragua sub-basin, which is interpreted to be a depozone eastward of the Palawan accretionary wedge in the structurally complex Southwest Palawan Basin. A regional 2D seismic grid and borehole data from four wells were used to analyze the growth patterns of the carbonate platforms, identify seismic facies, and reconstruct the evolution of the platforms.

The carbonate platforms developed on the folded and faulted middle to pre-middle Miocene siliciclastic strata. These older siliciclastic units were thrusted onto the southern end of the North Palawan microcontinental fragment, which represents a block of continental crust that drifted southward from South China during early Tertiary time. The platforms aggraded over time and backstepped to keep pace with increasing rates of relative sea level rise. Karst features are recognizable on seismic sections and indicate that the platforms were subaerially exposed at various times during their development. The platforms exhibit variable morphology from faulting and tilting. The platforms terminated in early Pliocene time, as relative sea level continued to rise, and were buried by deep-marine siliciclastic units.

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# CHAPTER I

# INTRODUCTION

Southwest Palawan basin is located offshore west Philippines in the southeastern part of the South China Sea. The basin is an elongate, NE-SW trending depocenter that is 44,000 square kilometers in area (Figure 1). The basin is bounded to the east by the Palawan Island, Reed Bank to the west, and is separated from the continental North Palawan Basin by the left-lateral Ulugan Bay Fault (Holloway, 1982). The Southwest Palawan Basin extends southward to the northern parts of Sabah Basin of offshore Borneo.

The study area is located in the Paragua Sub-basin, which is in the southern part of the Southwest Palawan Basin; modern water depths are less than 200 meters. The sub-basin contains late middle Miocene to early Pliocene carbonate platforms and reef buildups of the Likas Formation.

Miocene carbonate units in the Southwest Palawan Basin have been briefly described elsewhere (Park & Peterson, 1979; Bureau of Energy Development, 1986; Dolan & Associates, 1996; Rehm, 2003). Industry well reports focused on reservoir potential of these carbonates facies. No detailed stratigraphic studies, however, have been done on Miocene-Pliocene carbonate platforms and buildups in the Southwest Palawan Basin.

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This thesis follows the style of the American Association of Petroleum Geologists Bulletin.

The objective of this study is to examine the characteristics and evolution of the carbonate facies in the Likas Formation,  and relates the morphology and seismic facies of these deposits to factors that control platform development. Four wells and vintage, regional, 2D seismic grid data were used to analyze carbonate platform history in the Likas Formation.

Growth phases, seismic facies and characteristics of carbonate platforms were identified by seismic stratal relationships and seismic character of the reflectors. Time structure maps of growth phases were generated to show the distribution and dimension of isolated platforms.

The Likas Formation provides interesting examples for investigating the development of isolated platforms in this tectonically complex area.  Results from the study will contribute to the understanding of syntectonic depositional history of Miocene-Pliocene carbonate platforms and reefs across the study area and of the South China Sea region.

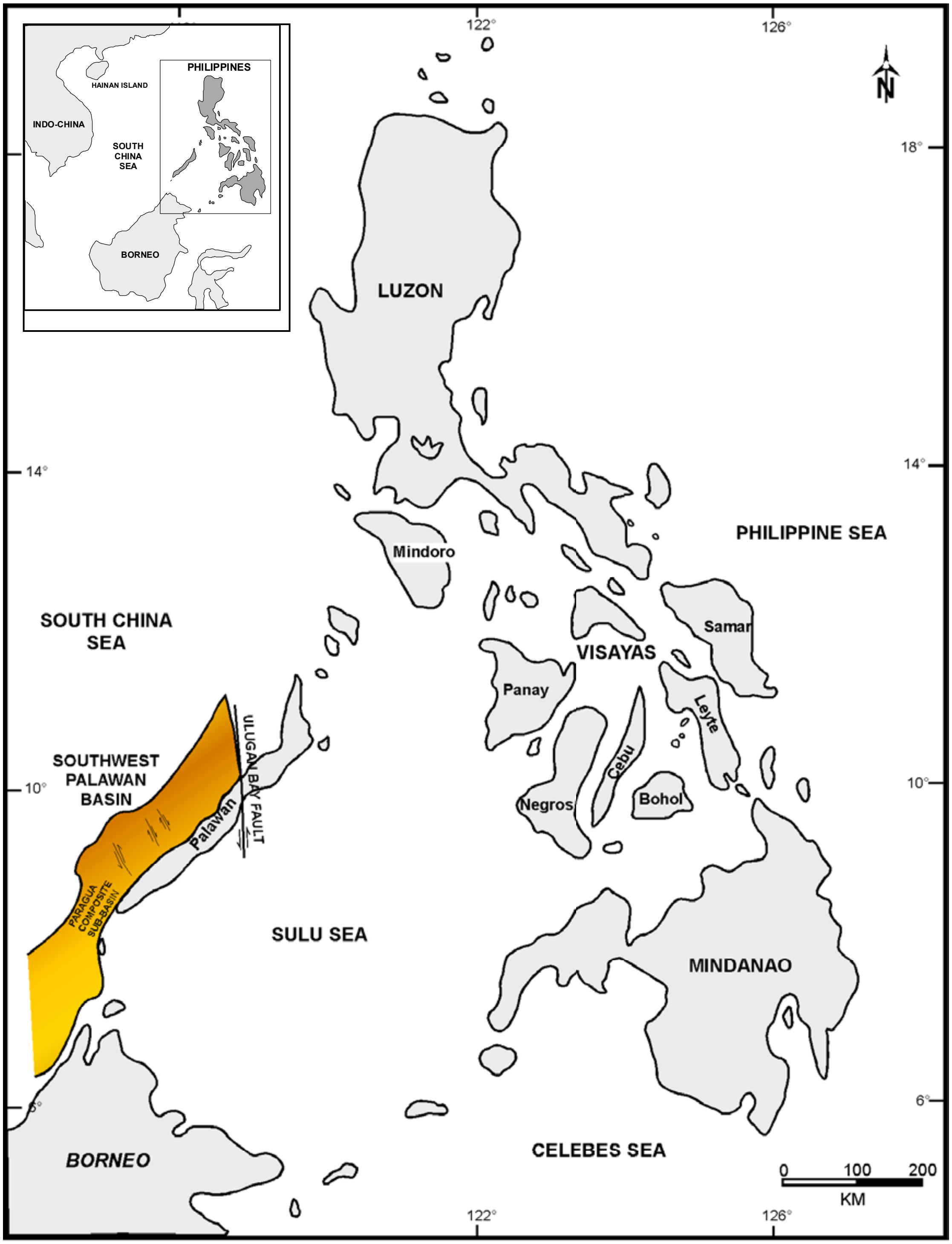


**Figure 1.** Location map of Southwest Palawan Basin (basin outline after DOE, 2001).

# CHAPTER II

# DATA AND METHODS

This study used declassified regional 2D seismic reflection and well data provided by the Philippine Department of Energy.

## Seismic Data

The vintage seismic data sets come from three different surveys: DPS93, PA and SP97 surveys (Table 1).

**Table 1.** List of seismic lines used in this study.

| Survey | PA | DPS93 | SP97 |
|---|---|---|---|
| Lines interpreted | 50 | 1 | 23 |
| Year acquired | 1978 | 1993 | 1997 |
| Company | Pecten (Phil) Co. | Digicon | AGSO |
| Record Length (TWT) | 5 seconds | 6 seconds | 5 seconds |
| Line kms | 1319.00 | 125.54 | 522.05 |
| Final processing | Raw migration | Migration | DMO |

The selected PA lines are reprocessed seismic data from the South Palawan Regional (SPR-94) project by the Department of Energy, PGS Nopec AS and Digicon.

Generally, the seismic lines are oriented NE-SW (parallel to shelf edge) and SE-NW (dip-oriented) (Figure 2). Individual lines have variable spacing that varies from 1 - 7 km for dip lines and 2-12 km for strike lines. The seismic data and navigation data were loaded into Schlumberger Geoquest's interpretation software Geoframe IESX.

## Seismic Interpretation

Interpretation began by mapping major faults on all seismic lines to establish structural features across the study area. Carbonate platform facies were then mapped on the long, regional strike line, DPS93-4b, which ties with Likas-1 well in the south and is located close to the Murex-1well in the north. The top of the carbonate-platform facies is identified as a high amplitude reflector that is persistent on all the seismic sections. This strong, continuous reflector correlates well with a distinct deflection of low gamma-ray response on available logs (e.g. Murex-1 and Kamonga-1). Seismic character of the base of the carbonate platform is less obvious in some sections because of lower signal-to-noise ratio through the carbonates. Mapped surfaces on seismic line DPS943-4b were carried to all intersecting lines in the seismic grid and loop-tied to extend correlations throughout the seismic grid. Internal reflector geometries within many carbonate platforms are difficult to recognize due to the complex and intensely deformed nature of the strata in study area, seismic data sets with variable seismic processing parameters, and the poor to fair data quality of some lines.

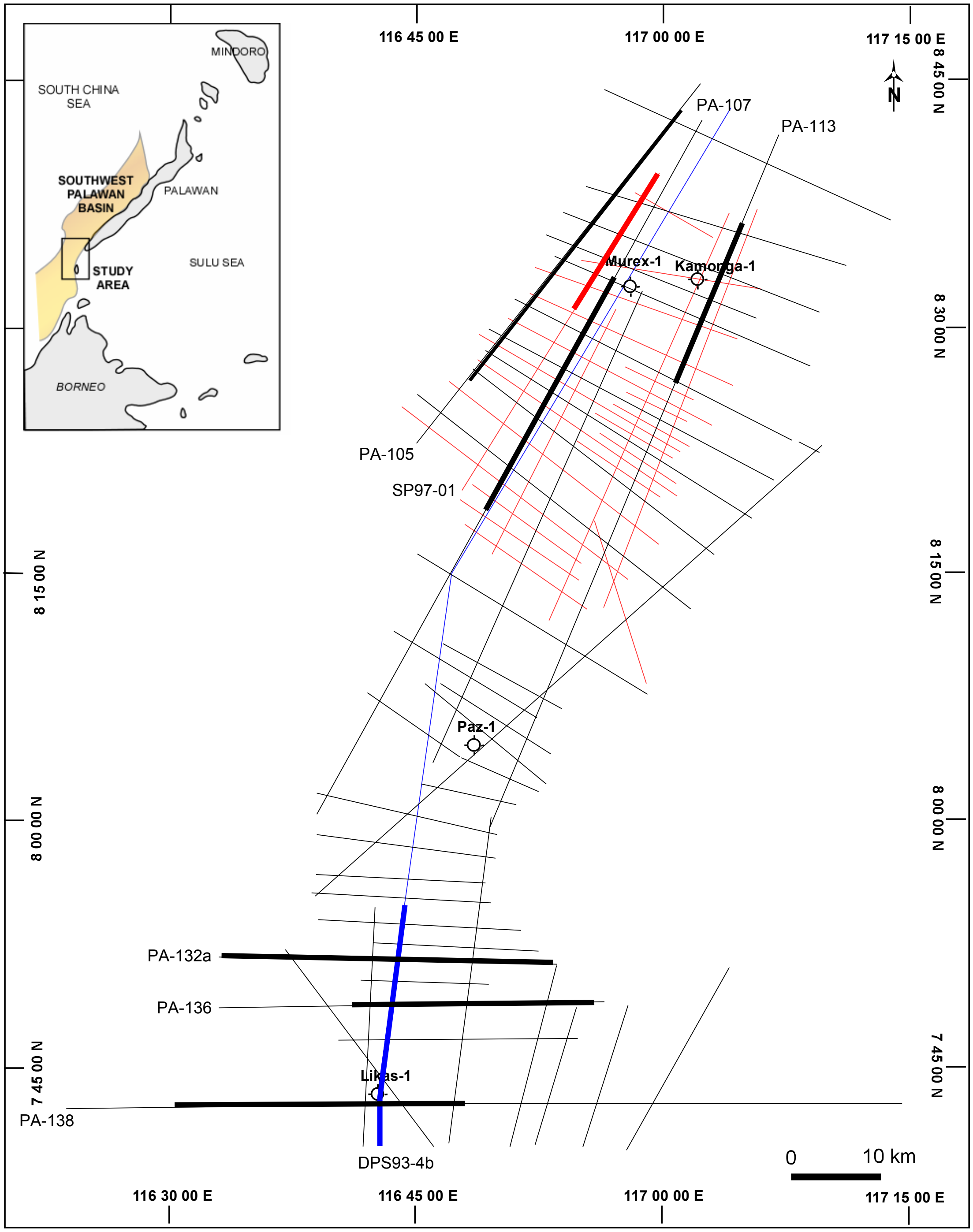


**Figure 2.** Location map of seismic lines used in this study. Black, Pa lines; red, SP97 lines; blue, DPS93-4. Bold lines show the location of seismic profiles in Chapter V.

**Well Data**

Four wells with digital gamma-ray logs were used to aid in the interpretation. Likas-1 and Paz-1 wells are located in the southern part of the study area, whereas Murex-1 and Kamonga-1 are in the northern part (Figure 3).

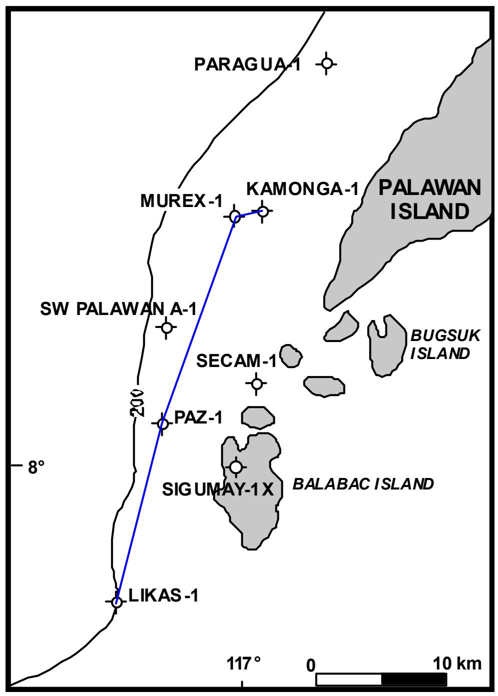


**Figure 3**. Location map of wells used in this study.

Gamma-ray logs were loaded into GeoFrame using the ASCII loader tool. Interval velocities and total vertical depths from checkshot surveys were entered in GeoFrame to tie the well logs to seismic. Reference datum for all the wells is depth to Kelly Bushing. Depths of top and base of the carbonate unit taken from well reports and composite logs were used to create markers on the log curves. Gamma-ray log response of the top and base of the carbonate unit was correlated to the seismic section.

Well Summaries

The discussion below is compiled from industry well completion reports and internal reports (Bureau of Energy Development, 1986; and Dolan & Associates, 1996). Upper Miocene carbonates in the South Palawan Basin are potential reservoirs (BED, 1986). Carbonate facies have good intercrystalline and interskeletal porosity, with porosity values from 18 to 36% (BED, 1986).

*Likas-1*

Likas-1 well lies 7°43’17.79” N and 116° 42’44.25”E offshore in Southwest Palawan Basin. Water depth at the well location is 650 feet and Kelly Bushing elevation is 47 feet. The well was spudded by Pecten Philippines Company on January 18, 1979 with a total depth of 6178ft KB (-1883.54 meters subsea). The well bottomed in Paleocene shale and was completed on February 2, 1979. The well was plugged and abandoned as a dry hole.

Likas-1 was a wildcat well drilled to test a large anticline. No formation names other than the Pliocene-Pleistocene Carcar Limestone were given in the well report by the operator. The well drilled an upper carbonate unit, a clastic sequence, a limestone-clastic unit and basal Eocene sediments.

Limestone was encountered between the depths of 2430 feet and 3740 feet and is described as pyritic skeletal wackestone, fine crystalline, and fossiliferous. Composite log shows a relatively thick carbonate unit with an upper white crystalline limestone interval that grades to a dense crystalline limestone and dolomite sequence starting at a depth of 3310 feet. Biostratigraphic data from the Bureau of Energy Development (1986) shows the base of the carbonate unit as middle Miocene, whereas the top of the unit extends to early Pliocene (?N18-N19).

*Paz-1*

Paz-1 well was drilled on April 15, 1980 by Pecten Philippines in a water depth of 241 feet. It is located at 8°4’22.35” N and 116°48’30.85”E. The well was completed on May 24, 1980 with a total vertical depth of 6157 feet KB (-1877.13 meters subsea). Kelly Bushing elevation is 38 feet above sea level.

The well was drilled to test a speculated lower Miocene reef. Although the well did not encounter the target objective, it penetrated a 15-foot dolomite bed overlying shale with thin sandstone and siltstone. Lithologic descriptions from well report indicated the top of the carbonate unit is at 2,390 feet and the base at 3,470 feet.

Bureau of Energy Development (1986) assigned a speculative middle Miocene-late Miocene (N15-N16) age to the base of carbonate sequence while the top of the carbonate unit is dated late Miocene-early Pliocene (N17-N18). The well was plugged and abandoned as a dry hole.

*Murex-1*

Murex-1 well was drilled by Pecten Philippines on February 2, 1979. It was completed on March 10, 1979 at a total vertical depth of 8533 feet KB (-2607.64 meters subsea). The well is located 8°32’13.22”N and 116°58’01.815” E in water depth of 205 feet.

The well was drilled to test an anticlinal structure with potential Middle and Lower Miocene sandstone reservoirs. Although the well was a valid test of the structural closure, it did not find the target reservoir. Well reports indicate that the well found minor gas shows were observed while drilling.

The well penetrated a carbonate unit between 3200 feet and 3835 feet. No samples were recovered between depths of 3200 feet and 3700 feet due to loss of circulation. Although section of the well had no sample returns, it was interpreted to be limestone based on an electric log. From 3700 feet to 3835 feet, samples recovered consist of packstone with abundant clay, fragmented fossils, and pellets. Sandstone is interbedded in the basal part of the carbonate unit. Below this carbonate unit is a thick clastic sequence that consists of claystone with thin sandstone and siltstone interbeds. The well bottomed in lower Miocene strata. Biostratigraphic studies by the Bureau of Energy Development (1986) indicate tentative N17 to N19 (late Miocene to Pliocene) age for both the top and base of the carbonate unit.

*Kamonga-1*

Kamonga- 1 well was spudded by Pecten Philippines on May 27, 1980. It was completed on June 15, 1980 at a total vertical depth of 5678 feet KB (-1731.10 m subsea). Kelly Bushing elevation is 38 feet. Water depth at the well location is 285 feet.

The well was plugged and abandoned in an overpressured section below the target carbonate reservoir.

The well penetrated the carbonate sequence at 2758 feet. The top section is a tight, dolomitized interval with minor recorded gas shows. The basal sequence is comprised of vuggy wackestone and grainstone with sandstone interbeds. The base of the carbonate is placed at 3430 feet. The gas was not sampled by drill stem testing, however, resistivity logs suggest a 30-40 feet hydrocarbon column in the carbonate sequence (Barber, 1999). Age dating by the Bureau of Energy Development (1986) assigns a middle Miocene age to the base of the carbonate sequence. The top of the carbonate unit is dated tentatively middle Miocene-late Miocene.

**Lithologic Nomenclature and Age of the Carbonate Unit**

Biostratigraphic zones identified in Likas-1, Paz-1, Murex-1 and Kamonga-1 wells are based largely on foraminiferas, nannofossils and to a lesser extent palynomorphs and indicate that the carbonate interval has a late middle Miocene (possibly early late Miocene) to early Pliocene age (BED, 1986). This carbonate interval has been assigned various formation names. The operator inappropriately named it Carcar Limestone (Dolan & Associates, 1996), which actually is a Pliocene-Pleistocene carbonate sequence widely distributed across the central Philippines.

Dolan & Associates (1996) used the term Paragua Limestone for the same carbonate section encountered in Likas-1, Murex-1 and Southwest Palawan-1, and considered Paragua Limestone as a member of the middle Miocene Matinloc Formation.

Barber (1999) also adopted the name Paragua Limestone. Schlüter et al (1996) mentioned widespread deposition of Tabon Limestone above the thrust wedge between middle Miocene and upper Miocene time.

The Bureau of Energy Development (1986) designated the Miocene-Pliocene section as Likas Formation named after Likas-1 well, which encountered a predominantly Miocene-Pliocene carbonate sequence with a basal claystone section. This study also refers these carbonate facies being investigated as the Likas Formation, in agreement with lithostratigraphic nomenclature of the Bureau of Energy Development (1986).

# CHAPTER III

# BACKGROUND

## Tectonic Setting of Southeast Asia

Southeast Asia is a region of various tectonic terranes that is now affected by interaction of three major plates; the Pacific, Eurasian and Indo-Australian plates. The modern-day tectonic framework of Southeast Asia is greatly affected by collision between India and Eurasia, which began ~50Ma. This collision resulted in the movement of the Indochina block to the southeast while South China block was translated to the east-southeast (Figure 4).

Movements from the blocks might have initiated the north-south extension in the South China continental margins that triggered sea floor spreading in the South China Sea (Tapponier and Armijo, 1986), and also caused the formation of sedimentary basins in the region.

Rifting in the South China Sea commenced during late Cretaceous time caused a fragment of the continental south China mainland to separate and move southeastward in what is now the North Palawan Block of the Philippines (Holloway, 1982).

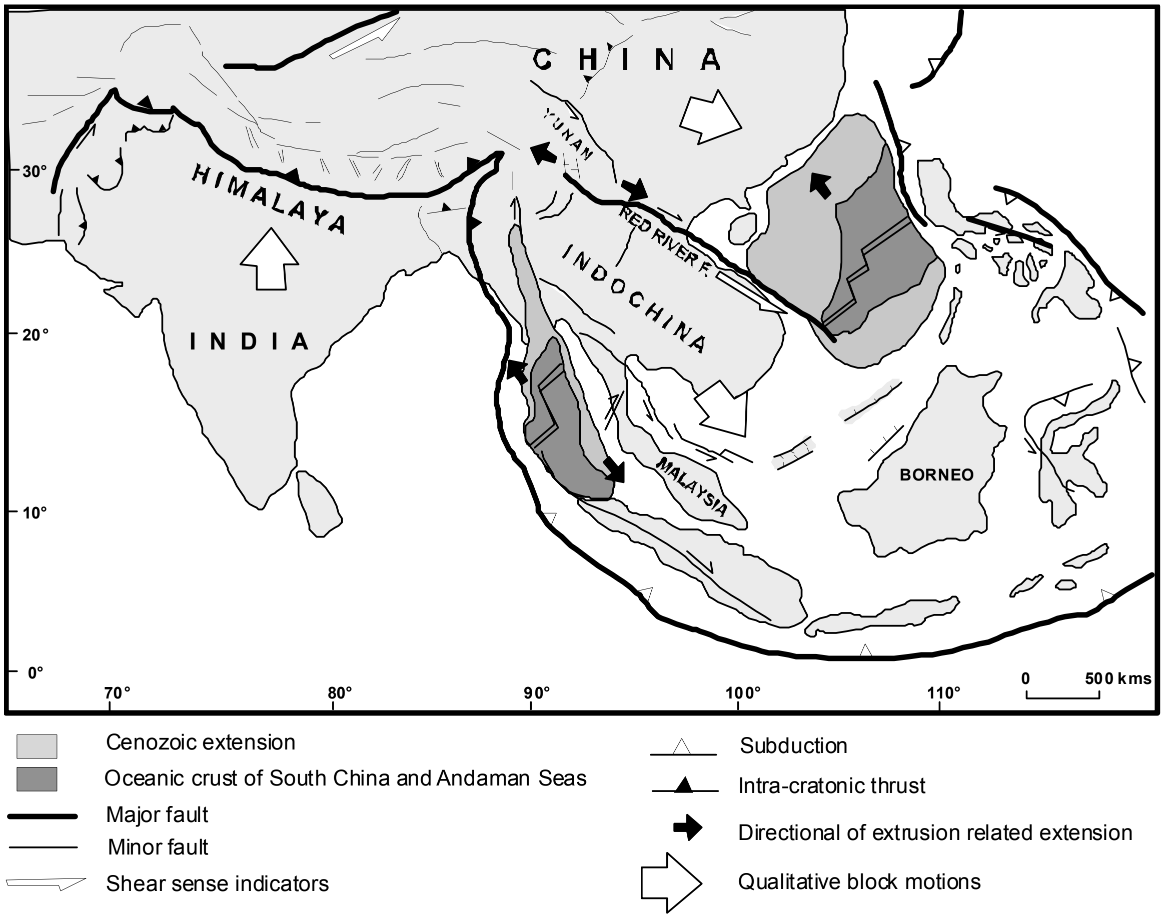


**Figure 4.** Summary of the extrusion model (from Tapponier et al, 1982). The figure shows the tectonic elements related to the collision of India with Eurasia plate and the extrusion of the Indochina and China blocks.

## Tectonic History of Southwest Palawan Basin

Evolution of the Southwest Palawan Basin is closely related to rifting and sea-floor spreading of the South China Sea, which began during late Mesozoic time. Rifting of continental crust along the South China margin began during the late Cretaceous (Holloway, 1982) and created half-graben structures in the South China Sea Basin typical of rift systems. Rifting continued through Paleocene time until the continental crust gave way to the opening of the South China Sea in late Oligocene time (Holloway, 1982; Hinz and Schlüter, 1985; Schlüter et al, 1996).

Opening of the South China Sea resulted to separation of a microcontinental fragment, called the North Palawan Block, from southern Mainland China. North Palawan Block drifted southeastward during sea floor spreading in the northern part of the South China Sea during Late Oligocene time (Holloway, 1982). As the North Palawan Block drifted southeastward during Oligocene-Miocene time, carbonate platforms began to form above Paleogene siliciclastic strata or on remnant synrift highs that became loci for shallow-water carbonate facies.

By early Miocene time, the southern margin of North Palawan Block began to collide with northwest Borneo and a narrow volcanic arc to the north. East-dipping subduction of Proto-South China Sea oceanic crust likely occurred along this margin prior to the collision of  North Palawan Block in early Miocene time (Holloway, 1982). During this time, a small South Palawan landmass might have been located near Reed Bank in the South China Sea and probably was incorporated in the southern part of the present South Palawan Block (Clenell, 1996).

North Palawan Block continued to move southeastward until Middle Miocene time, when the southern margin of the continental fragment completed its collision with the paleosubduction zone. Subduction ceased with arc-microcontinent collision and active seafloor spreading in the South China Sea came to a halt by late middle Miocene time (~15.5Ma; Briais et al., 1993). The subduction complex was thrust onto the North Palawan Block and imbricate thrust sheets developed in the southern part of Palawan Island and northwestern Borneo.

From Late Miocene to Recent time, the South China Sea has undergone mostly quiescent thermal subsidence (Morley, 2002). Along the northeastern margin of the South China Sea, the seafloor is being consumed along the active Manila Trench as the Philippine island arc continues to advance westward (Figure 5).

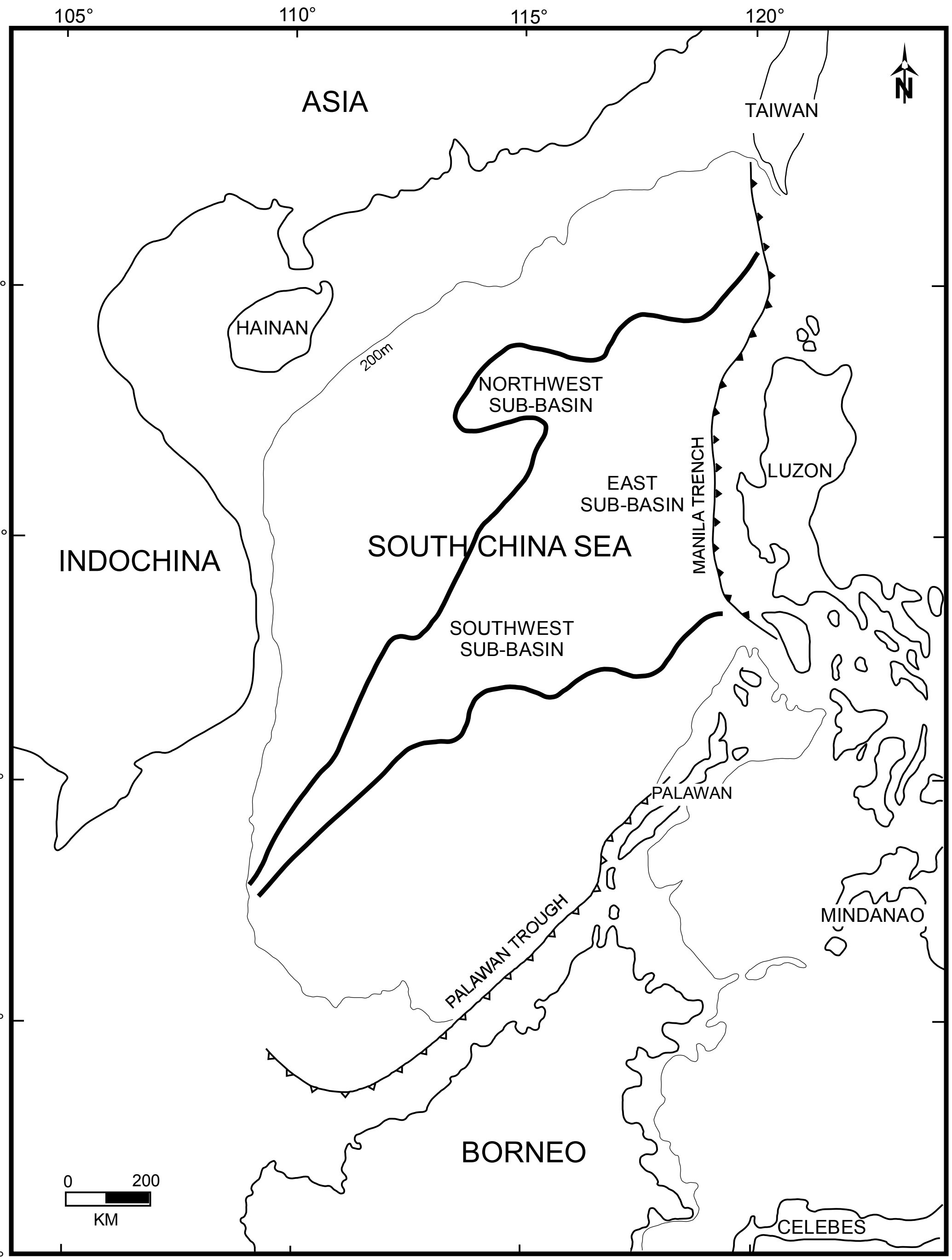


**Figure 5.** South China Sea basin and surrounding areas (from Ru and Pigott, 1986).

**Structural Elements of Southwest Palawan Basin**

Southwest Palawan Basin is an NNE-SSW trending depocenter located within the region of the North Palawan Block. This basin developed as a result of convergence between the North Palawan Block, and the allochthonous wedge that borders the southeastern flanks of the Palawan Trough.

Palawan Trough

Palawan Trough, a major structural feature off the shelf and slope of the South Palawan Basin (also called the Northwest Borneo Trough or Sabah Trough), extends southward to NW Sabah (Morley, 2002) (Figure 6). It is a 2.8 km deep bathymetric depression that is 45 to 55 km wide (Hinz et al.,, 1989; Hutchison, 2004) and is regarded as a fossil subduction zone (Holloway, 1982) or flexural basin (Hinz and Schlüter, 1985; Clennell, 1995). Southern Palawan Island, which is principally made up of ultramafic, plutonic and ophiolitic rocks, is thought to be the accretionary wedge comprised of material scraped off the downgoing oceanic plate prior to the arrival of continental crust at the subduction zone.

Hinz and Schlüter (1985) postulated that Palawan Trough is a flexural basin underlain by stretched continental crust that drifted from South China and ultimately was loaded by the allochthonous wedge that comprises the southern part of Palawan Island. Marine geophysical data collected during 1982-1983 cruises of RV SONNE in Southwest Palawan suggest that Oligocene to Miocene carbonate platforms extend eastward beneath turbidite facies that fill Palawan Trough. The chaotic allochthonous wedge was thrust over some of these carbonate platforms (Hinz and Schlüter, 1985; Schlüter et al., 1996). Farther southwest in the southern South China Sea, Hutchison (2004) described the Northwest Borneo Trough as a collisional foredeep.

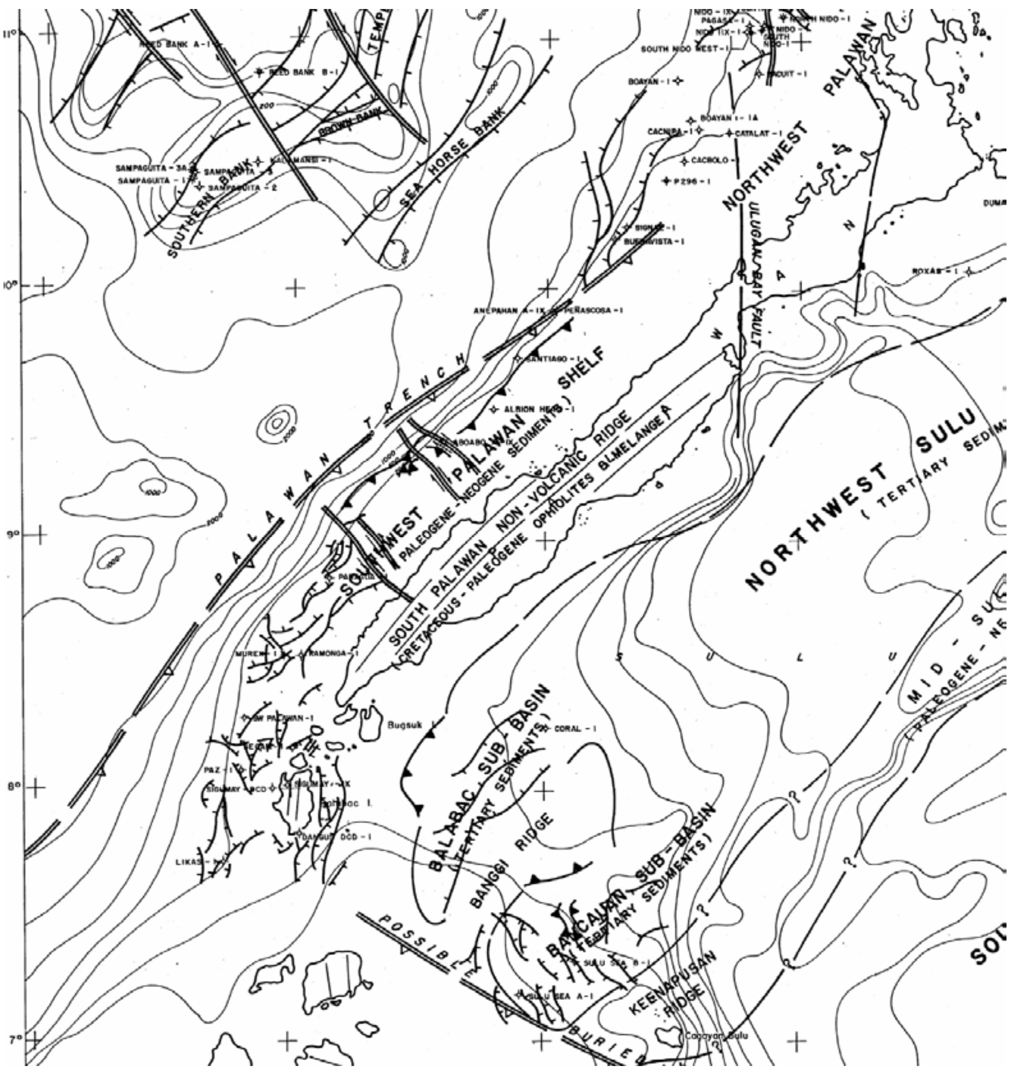


**Figure 6.** Structural and tectonic framework of Southwest Palawan Basin (BED, 1986).

Ulugan Bay Fault

Ulugan Bay Fault is a sinistral strike slip fault (Holloway, 1982) that apparently separates continental crust of northern Palawan Island and an accreted terrane in the southern part of Palawan Island (BED, 1986) (Figure 3 and Figure 7). Ulugan Bay Fault was a zone of offset during early Miocene time when the southward-protruding edge of the North Palawan Block began to collide with against the Palawan subduction system (Holloway, 1982).

Southwest Palawan Shelf

Southwest Palawan Shelf lies between Palawan Trough and the Southwest Palawan Non-volcanic Ridge (Figure 6). The northern limit of this shelf is marked by the Ulugan Bay Fault. Its southern extent merges with the northwestern shelf of offshore Sabah (BED, 1986). Southwest Palawan Shelf is divided into three structural elements that reflect varied geology (Figure 7).

Santiago sub-basin is located west-northwest of Albion Head-1 well. Seismic data indicate that this sub-basin contains a large carbonate complex of Early Miocene age (BED, 1986).

Albion Head and Aboabo Thrust Belts consist of thrusted pre-Miocene to Middle Miocene sediments. These areas represent the accretionary prism of the subduction zone along Palawan Trough (BED, 1986).

Paragua composite sub-basin in the southernmost part of the Southwest Palawan Shelf is located behind the frontal thrusts of the accretionary prism (BED, 1986). The sedimentary fill consists of Eocene to Recent sediments. The study area lies in Paragua composite sub-basin.

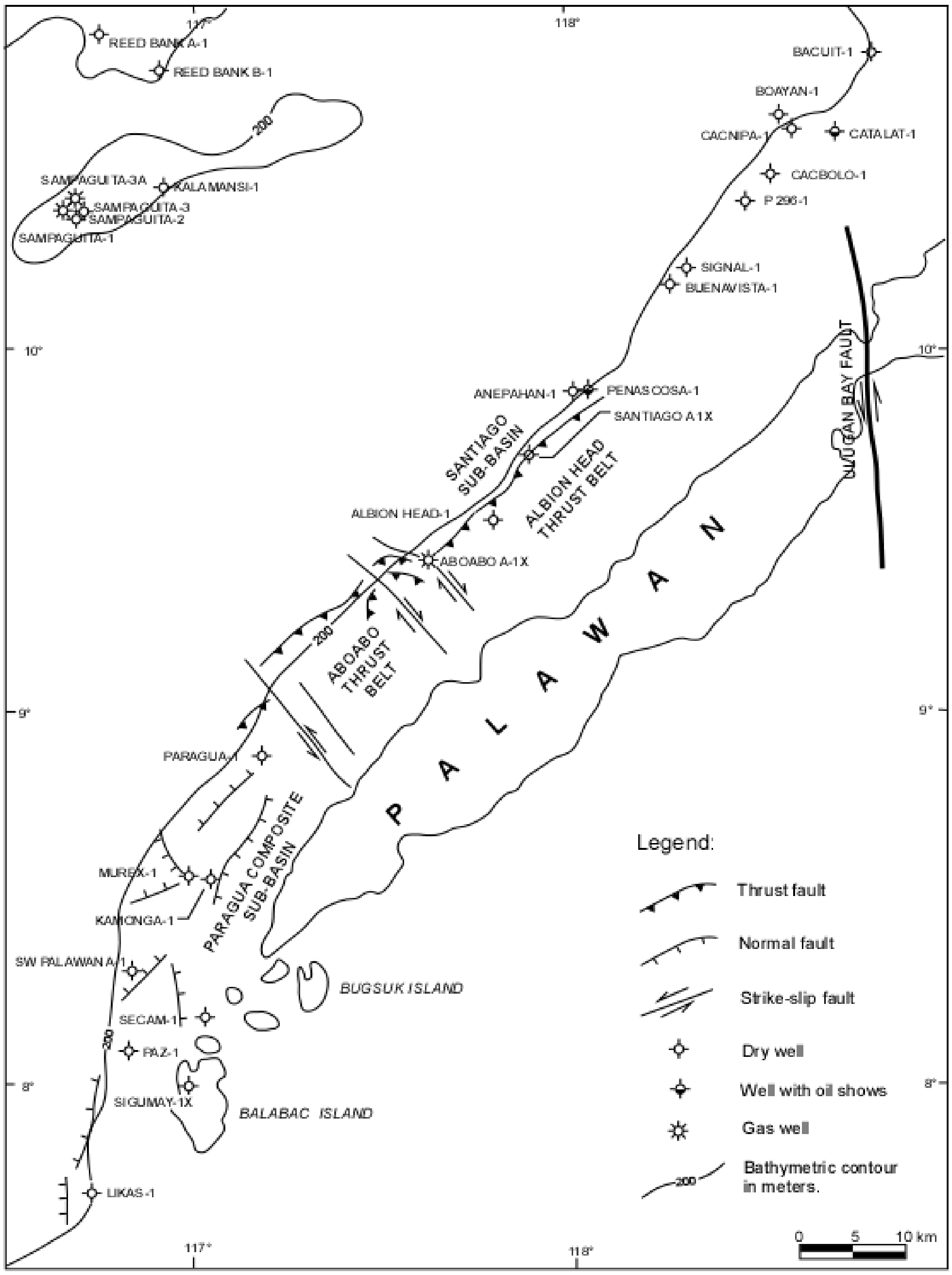


**Figure 7.** Major structural elements of the Southwest Palawan Shelf (redrawn after BED, 1986).

**Stratigraphy of Southwest Palawan Basin**

This study follows stratigraphy of Southwest Palawan Basin established by Bureau of Energy Development (1986) (Figure 8).

Late Cretaceous to Paleocene

Basement beneath South Palawan is composed of a probable Late Cretaceous to Paleocene ophiolite complex called the Chert-Spilite Formation. It is thought to represent oceanic crust that was progressively thrust over the southeastern margin of the western North Palawan continental block during Mid-Oligocene to Middle Miocene time. This basement complex crops out at the central core of southern Palawan Island and in the central eastern portion of Balabac Island, north of Sabah.

Eocene to Early Oligocene

Oldest Tertiary strata in the basin consist of the Crocker Formation, which unconformably overlies the Chert-Spilite Formation. Crocker Formation is a thick, cyclic sequence of sandstone interbedded with claystone and siltstone. Localized conglomeratic lenses and thin micritic limestone are also associated with this formation. Two wells drilled in South Palawan Basin encountered over 1000 meters of Crocker strata without reaching its base. The formation is widespread in northern and central Sabah and its thickness ranges from 6000 to 9000 meters. Paleoenvironmental studies suggested a bathyal depositional setting for the Crocker Formation (BED, 1986; Tongkul, 1994).

Late Oligocene – Early Miocene

Shallow marine conditions during Oligocene time existed across the NW Palawan Shelf and favored extensive carbonate sedimentation of the Nido Limestone. Nido Limestone consists of skeletal packstone, grainstone and wackestone with abundant algae, foraminifera and corals. Nido Limestone is Late Oligocene to Early Miocene age.

Nido Limestone is an extensive carbonate sequence in the Palawan area, and is a proven reservoir of Malampaya field in Northwest Palawan basin (Grötsch and Mercadier, 1999). Wells penetrated Nido Limestone in the northern part of Southwest Palawan Basin but this unit has not been penetrated in the south. Marine seismic data from Sonne Cruises SO-23 and SO-27 indicate that Nido Limestone exists beneath Palawan Trough and beneath the South Palawan Shelf (Hinz and Schlüter, 1985).

In the southern part of SW Palawan Basin, shallow and deep water facies of the Kamonga Formation have been encountered by wells. This unit crops out in central-south Palawan Island and southern Balabac Island. Kamonga Formation is Late Oligocene to Early Miocene and unconformably overlies the Crocker Formation and is mostly age equivalent to the Nido Formation in the northern part of the study area. Kamonga Formation is a transgressive sequence of calcareous claystone with occasional interbeds of siltstone, sandstone and micritic limestone. Coarse-grained sandstone with minor interbeds of thin claystone and siltstone constitute local shallow water facies within this unit.

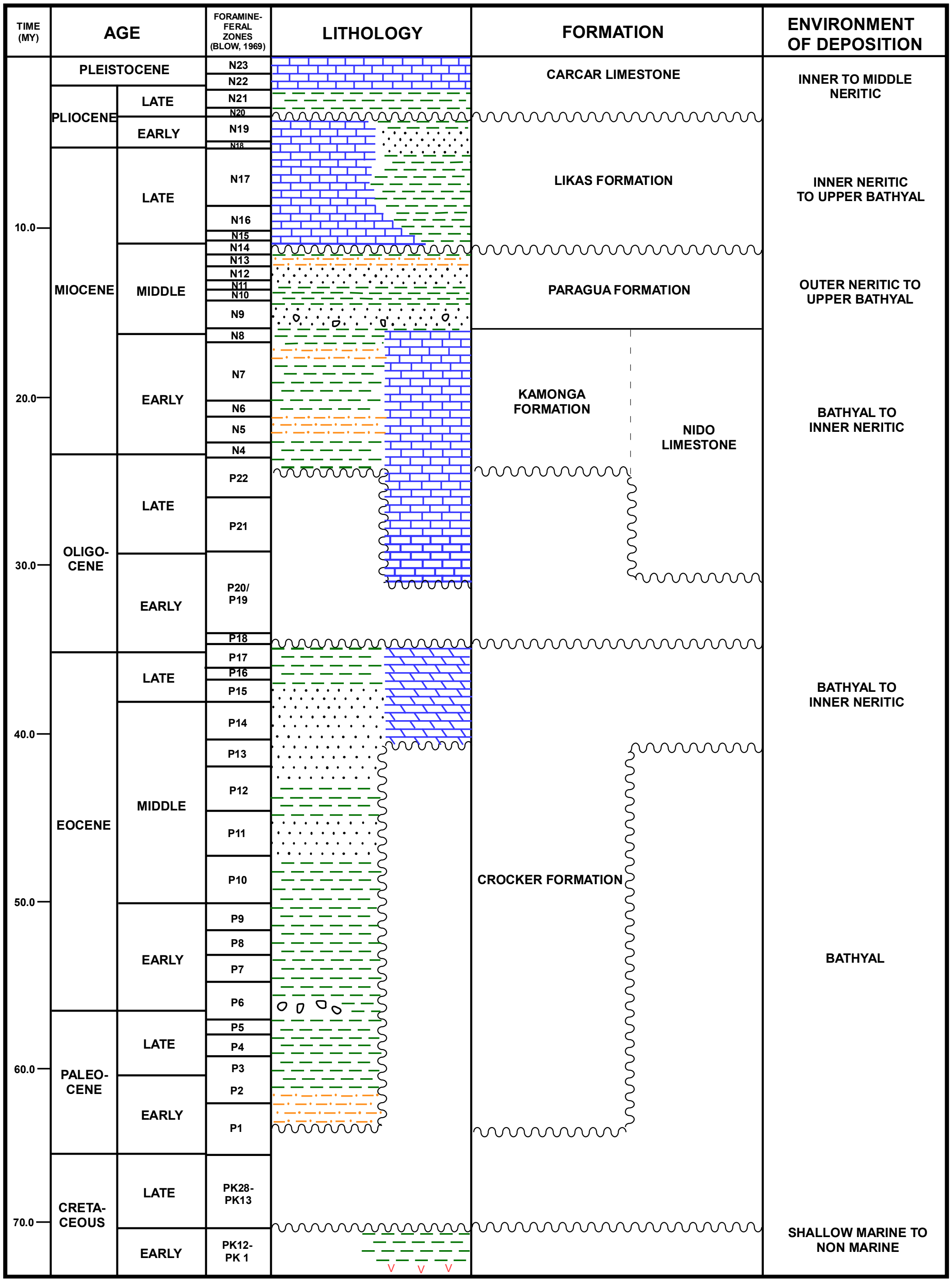


**Figure 8.** Generalized stratigraphy of Southwest Palawan Basin (modified from Bureau of Energy Development, 1986).

Middle Miocene

Deep-water conditions developed in northern and southern Palawan during late Early to Middle Miocene time and siliciclastic sediments began to fill the basins from the east. Paragua Formation in Southwest Palawan basin consists of a predominantly deep marine siliciclastic sequence. The lower portion consists of calcareous claystone with interbedded micritic limestones and arkosic sandstone. Calcarenite and micrite lithofacies are found in its upper part.

Late Miocene-Early Pliocene

The Likas Formation is a large-scale regressive sequence that consists of basal bathyal shale and shallow water claystone, siltstone and sandstone that grade upward into partially dolomitized limestone. Reefal facies in Likas-1well consist of coarse-grained calcarenite with sponge, coral, algal and mollusk bioclasts. The limestone/dolomite section of Likas Formation was also encountered in Paz-1, Murex-1 and Kamonga-1 wells.

Pliocene to Pleistocene

Onlapping lower Pliocene facies are progradational sequences that mainly consists of inner to outer shelf mudstone facies that grade vertically into the Carcar Limestone. Carcar Limestone, the youngest sedimentary sequence found regionally throughout the Philippines, consists of shallow water platform facies with numerous patch reefs.

**Petroleum Exploration History**

Petroleum exploration in Southwest Palawan Basin began in the early 1960s with geological and geophysical surveys. Following the establishment of a Service Contract System in late 1972, and encouraged by discoveries made in the neighboring offshore Sabah, oil companies renewed exploration interests in Southwest Palawan Basin and the amount of marine seismic data increased. In 1973, the first well, South Palawan A-1, was drilled offshore Southern Palawan. This well tested lower to middle Miocene clastics in a subtle anticlinal structure. Exploration slowed down in 1982 when Anepahan-1 well drilled through good reservoir qualities in lower Miocene reef facies and encountered no hydrocarbons.

Drilling efforts resumed in 1991 with the Sarap-1 well and 1998 with Cliffhead-1 well. Both wells tested the upper Oligocene-lower Miocene Nido Limestone. No hydrocarbons were encountered.

# CHAPTER IV

# CENOZOIC CARBONATE DEPOSITIONAL SETTING IN THE PHILIPPINES

Cenozoic carbonate facies in the Philippines developed in various tectonic environments and some carbonate units are considered economic reservoirs (Figure 9).

Thick Tertiary carbonate facies are widespread in Visayan Basin of the central Philippines. Carbonate deposition began during early Oligocene time and became extensive during latest early Miocene and early middle Miocene time. During the same period volcanism was active, and thus these carbonate facies are associated with clastic and volcaniclastic deposits (Porth et al., 1989). Carbonate units in the northern and southern Philippines are often associated with volcaniclastic facies and igneous rocks (Wilson, 2002). An upper Miocene carbonate buildup is a proven gas reservoir in the Cagayan Basin, a backarc basin in northern Luzon (Tamesis, 1981). These regions are situated in the Philippine Mobile Belt which is a zone of active volcanism and complex accretion.

Extensive carbonate platforms and buildups developed offshore Northwest Palawan and Reed Bank in the microcontinental fragment of western Philippines. The carbonates grew on top of tilted fault blocks that formed during Paleogene rifting of continental blocks that eventually drifted away from South China. The carbonate facies in offshore Palawan and Reed Bank areas are generally not associated with volcaniclastic deposits (Wilson, 2002).

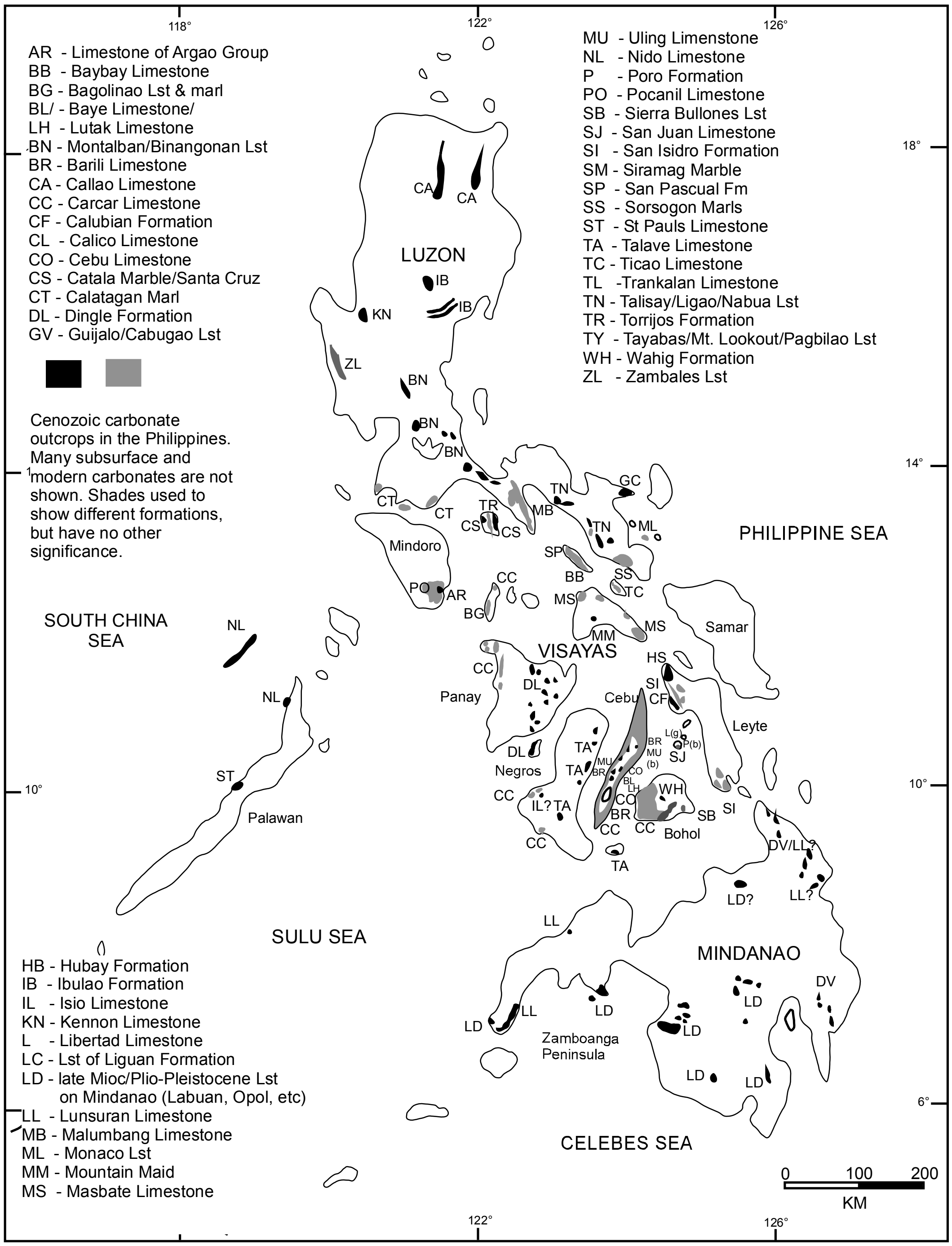


**Figure 9.** Map showing distribution of Cenozoic carbonates in and around the Philippines (redrawn after Wilson, 2002). CA, Callao Limestone and NL, Nido Limestone are commercial petroleum reservoirs.

The late Oligocene to early Miocene Nido Limestone is the primary carbonate reservoir of offshore Palawan. Oil and gas fields have tapped the platform and reefal facies of the Nido Limestone (Longman, 1985; Grötsch and Mercadier, 1999). Broad, carbonate platforms of the Nido Limestone were initiated in late Eocene time, and buildups developed from these platforms during late Oligocene time due to a rapid rise in relative sea level (Grötsch and Mercadier, 1999). Onshore north Palawan, the karsted St. Paul Limestone is interpreted to be an onshore equivalent of Nido Limestone (Wiedicke, 1987).

Nido Limestone is also found in the northern part of the Southwest Palawan Basin (Figure 10) (BED, 1986). Younger carbonate sedimentation during late middle Miocene to early Pliocene time formed carbonate facies in the southern part of this basin (Figure 10) (BED, 1986).

Onshore in central Palawan, early Miocene platforms with localized middle Miocene buildups are interpreted to be age-equivalent to carbonate facies found offshore central Palawan (Rehm et al., 2002).

Carbonate development onshore and offshore central South Palawan record a sea level rise during early Miocene (N5) to late middle Miocene (N14), and locally up to Pliocene time (Rehm, 2003).

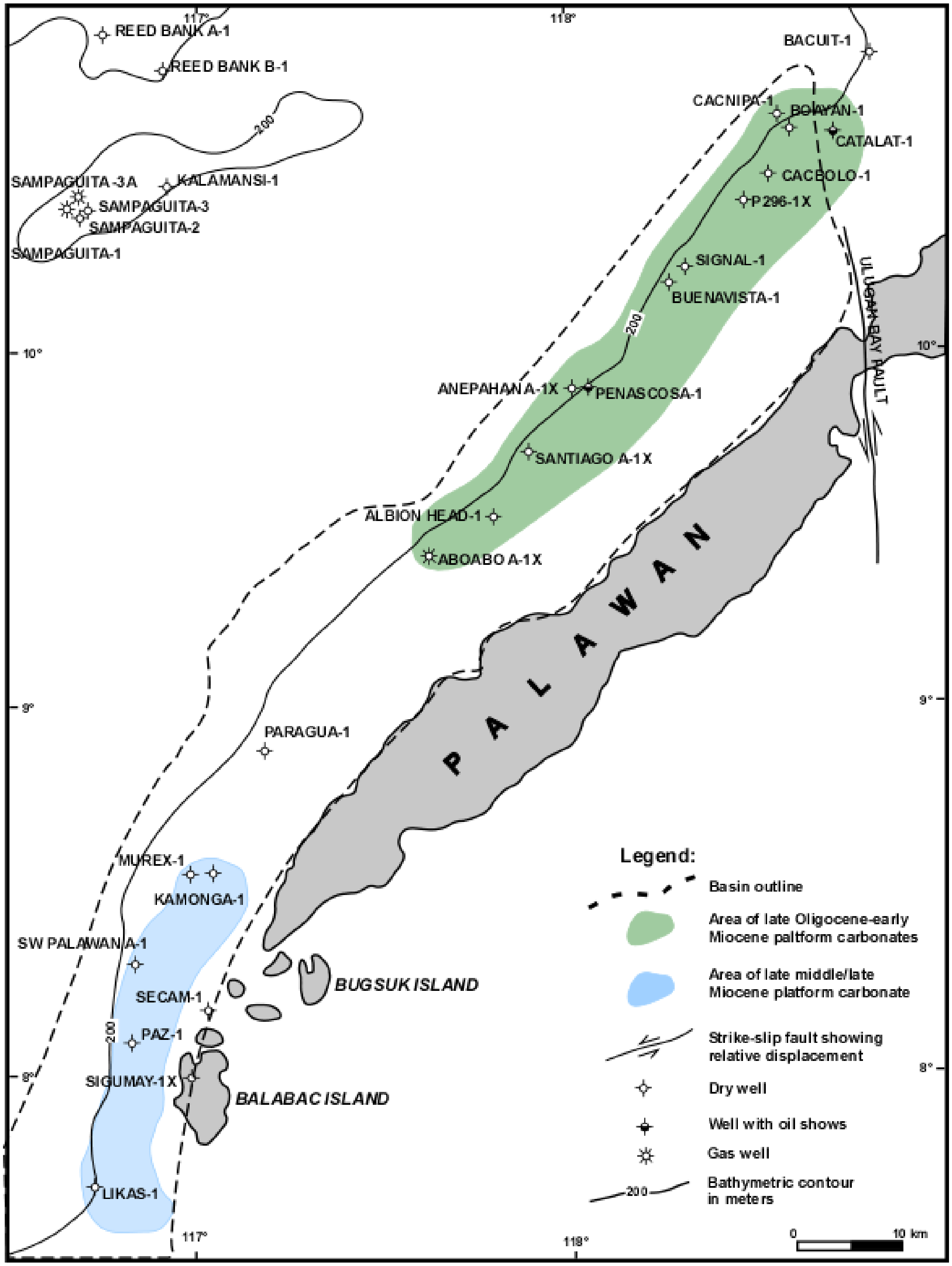


**Figure 10.** Location of platform carbonates with scattered reef buildups in Southwest Palawan Basin. Green is the area of late Oligocene-early Miocene sedimentation. Blue is late middle/late Miocene sedimentation (modified after BED, 1986).

## Controls on Carbonate Platform Development

Based on available biostratigraphic data from four wells, carbonate facies of Likas Formation were deposited from about 11Ma to 5 Ma (N14 to N19). This time interval is generally characterized by a long term rise in sea level as shown in published sea-level curves (Haq et al., 1987) (Figure 11).

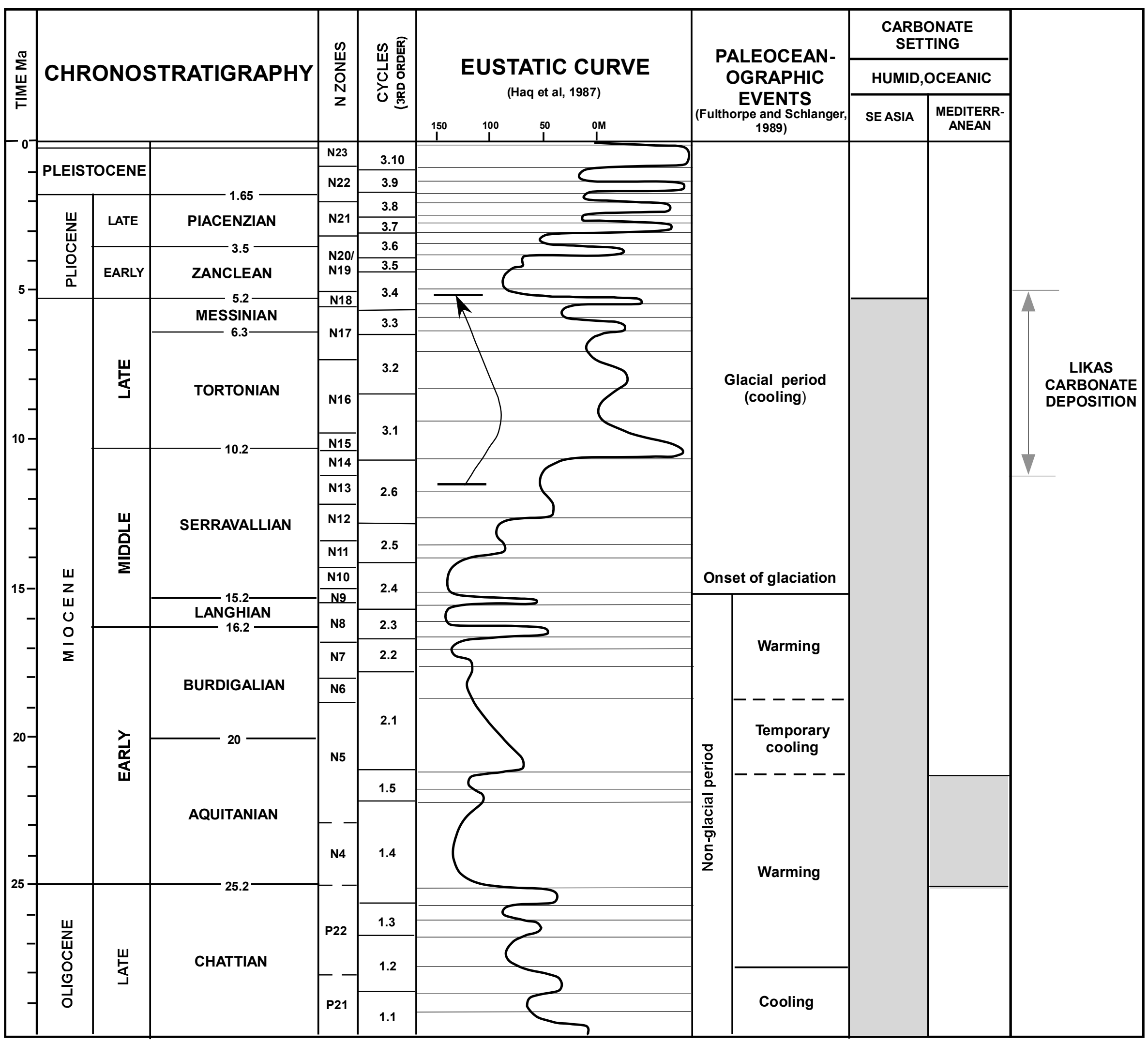


**Figure 11.** Global sea level curve. Modified from Haq et al, 1987 in Sun and Esteban (1994).

Several third-order sea-level cycles (~1-3 Myr) occurred from 11-5 Ma. Warm climatic conditions along with long term eustatic sea-level rise favored the growth of Miocene carbonate in the humid, tropical-subtropical settings of Southeast Asia (Sun and Esteban, 1994).

Faulting and deformation of the underlying clastic strata also influenced the carbonate platform development in the study area. Syntectonic carbonate development is evident in most of Likas Formations platform. Narrow fault-bounded highs show aggradational carbonate growth. Several faults cut through the platform and into the overlying siliciclastic strata, which could suggest continued tectonic deformation during Pliocene time.

# CHAPTER V

# DATA DESCRIPTION

## Profile and Morphology of Likas Carbonate Platforms

Carbonate facies of the Likas Formation are considered isolated platforms, following Read's (1985) classification scheme. Isolated platforms typically are tens to hundreds of kilometers wide, are commonly steep-sided and surrounded by water depths of several hundreds of meters. These isolated platforms develop distinct windward and leeward margins as they grow preferentially toward the prevailing wind direction. The Likas carbonate platforms at the southern end of seismic line DPS93-4b exhibit asymmetric profiles, a steep and narrow windward margin on the southern flank and a wider, gently sloping, leeward side on the northern flank (Figure 12).

Morphology of the Likas Formation carbonate platform tops is variable across the study area. It is controlled by faulting of the underlying siliciclastic unit and localized faulting within the carbonate strata. Wide, flat-topped platforms commonly exhibit less deformation (Figure 12) whereas some mounded platforms are affected by faults that cut through the top of the carbonate platform or just within the carbonate strata (Figure 13).

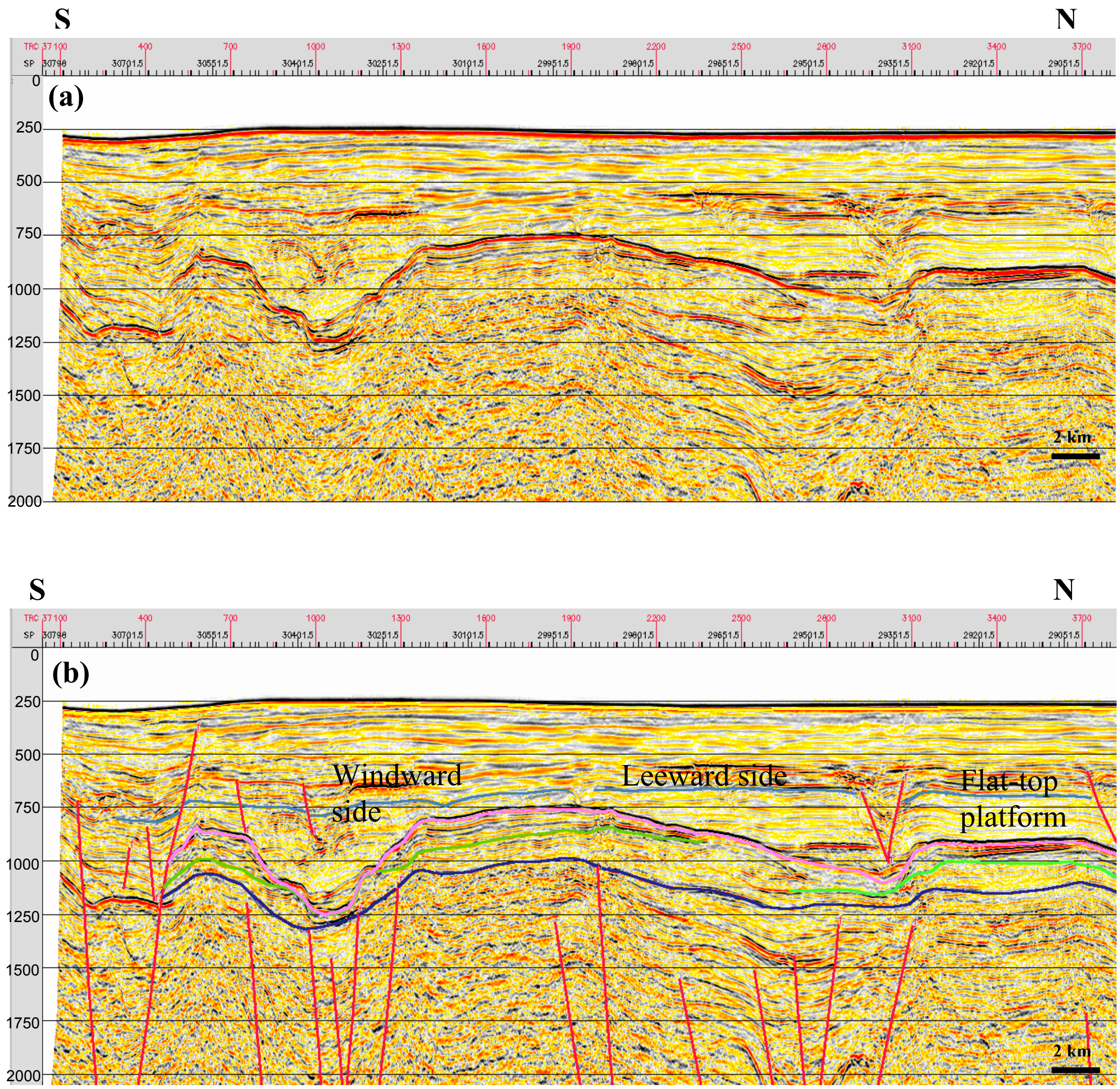


**Figure 12.** Seismic profile along the southern portion of strike line DPS93-4b. (a) Unintrepreted (b) Interpreted. Note generally steeper south-facing side of platform is steeper and north-facing margin has gentler slopes, which reflects prevailing wind direction during platform growth. Faults above the carbonate strata could be due to compaction. Vertical scale is in milliseconds two way time.

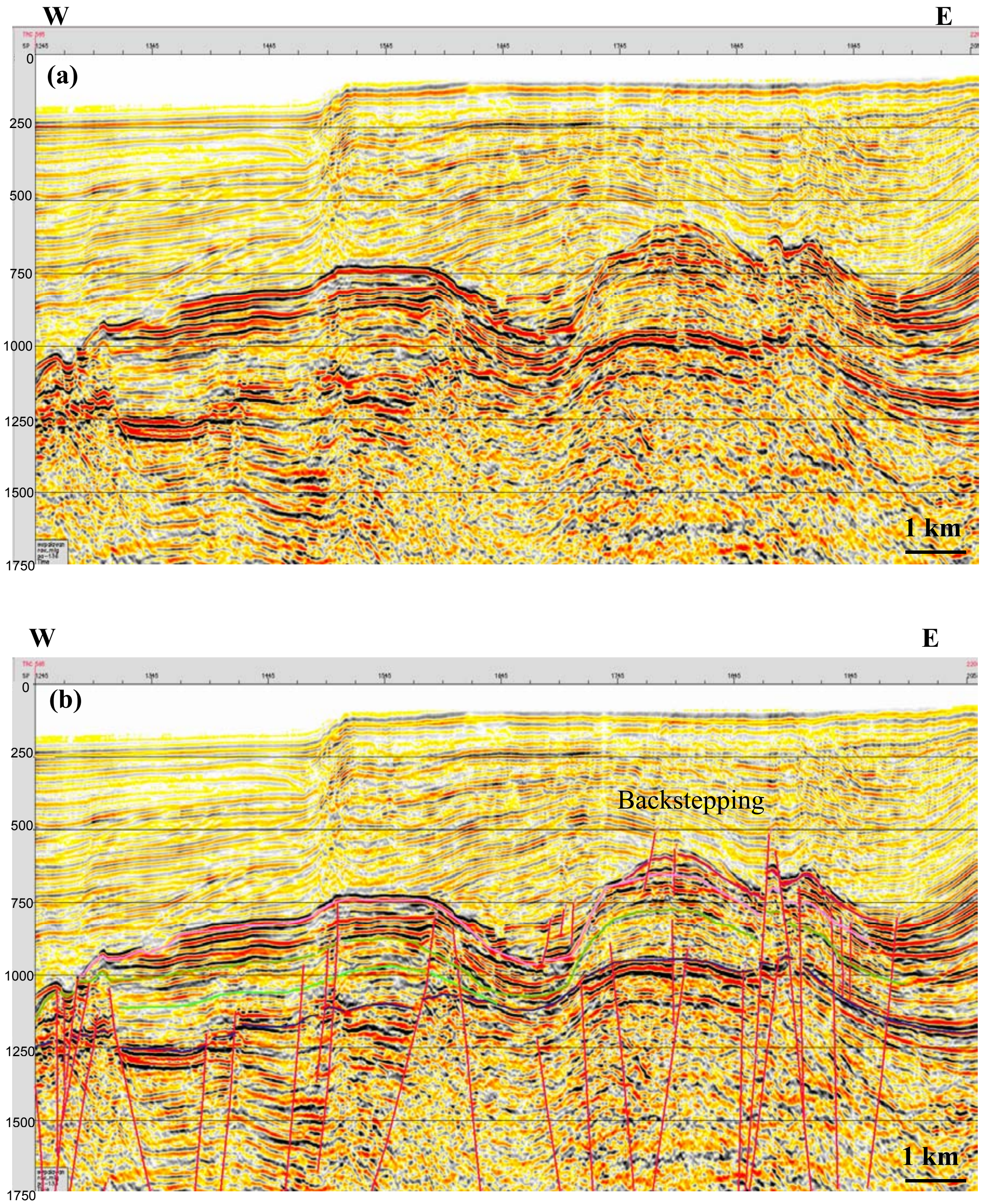


**Figure 13**. Seismic profile along dip line PA-136 showing varied platform morphology. (a) Unintrepreted (b) Interpreted. Faults significantly affected the platform architecture. Vertical scale is in milliseconds two way time.

**Well Data Description**

Borehole data from the four wells used in this study indicate that the middle Miocene to early Pliocene carbonate sequence of Likas Formation is 194 - 400 meters thick. On seismic profiles, carbonate platforms are 100 to 350 milliseconds "thick" (two way time), as measured in the platform interiors. Southern wells penetrated thicker carbonate sequences than in the north. Gamma-ray logs show clear blocky response from carbonate strata in Likas-1, Paz-1 and Murex-1 wells, and indicate a nearly homogeneous carbonate composition (Figure 14). The trend in log response of carbonate strata in Kamonga-1 well is less blocky, particularly in the basal part where sandstone is interbedded with carbonate facies.

Well reports show that dolostone facies were encountered in the carbonate platforms. In Kamonga-1 composite well log, dolostone was penetrated at the top of the carbonate strata and is 117 meters thick. Dolostone facies in Likas-1 wells are found in the basal part of the carbonate unit.

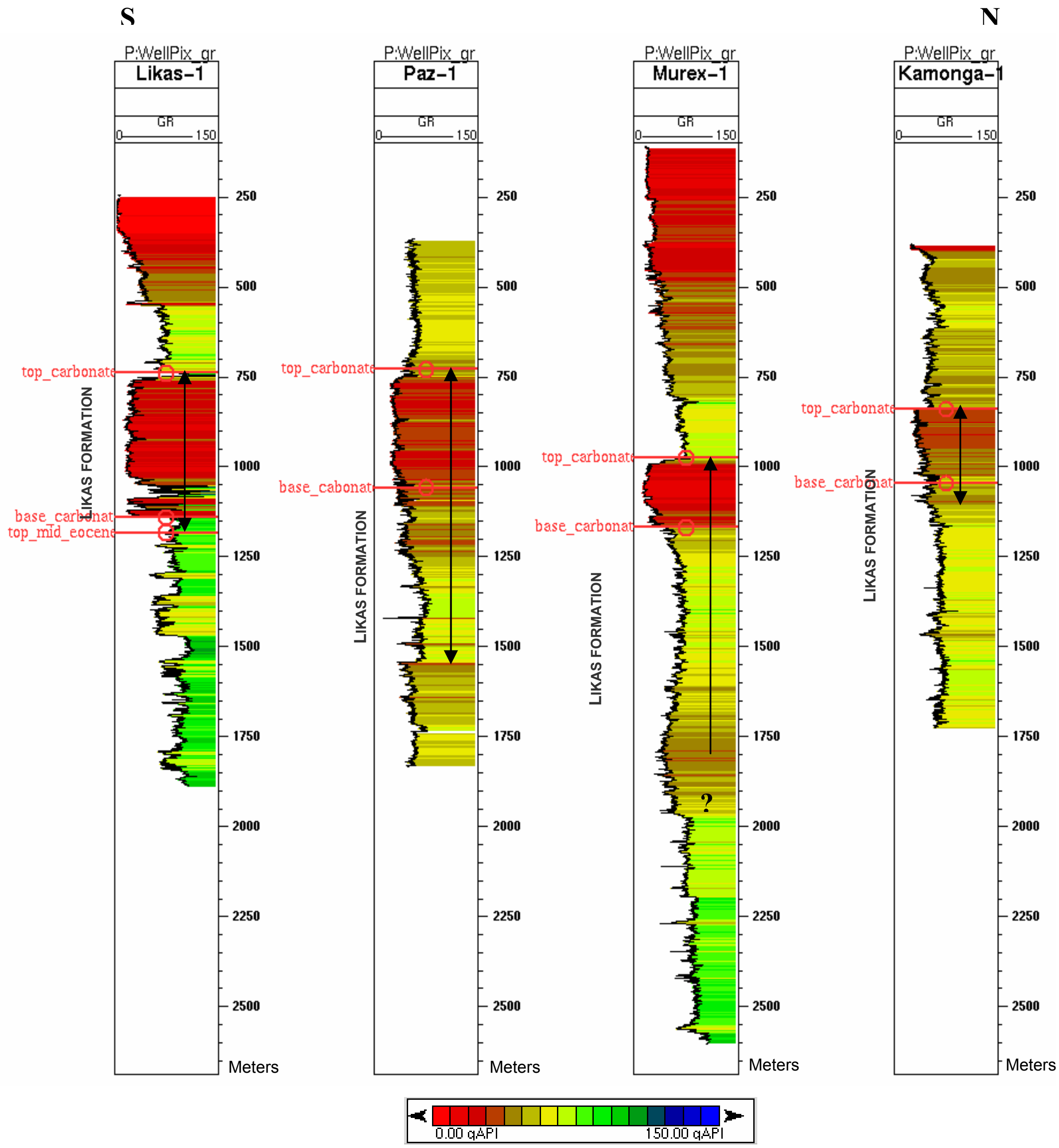


**Figure 14.** Gamma-ray logs of wells used in this study. Formation picks and thickness of Likas Formation is based on well reports. Eocene siliciclastic unit was encountered below the Miocene Likas Formation in Likas-1 well. Paz-1, Murex-1 and Kamonga-1 wells bottomed in early and middle Miocene siliciclastic deposits.

**Seismic Facies in Likas Carbonate Platforms**

Four seismic facies are identified within carbonate platform facies of Likas Formation. The seismic facies are recognized based on the amplitude and lateral continuity of the reflectors and their geographic location within the platforms.

Platform Interior Seismic Facies

The inner platform setting is characterized by discontinuous, gently dipping, parallel to subparallel reflectors with variable amplitude (Figure 15). Locally, inner platform facies have chaotic seismic character. Semi-transparent to chaotic reflectors probably indicate karstification due to subaerial exposure. Such karst features are prevalent in many platforms seen in the study area. Drilling reports from the Murex-1 well support this interpretation, as no samples were recovered from a section within the seismic due to loss circulation.

Platform Margin/Reef Seismic Facies

Seismic facies observed along platform margins exhibit chaotic, mounded and discontinuous reflectors. Seismic character is generally weak amplitude and semi-transparent. Some margins show late-stage pinnacle reef facies with internal semi-transparent seismic reflectors (Figure 16).

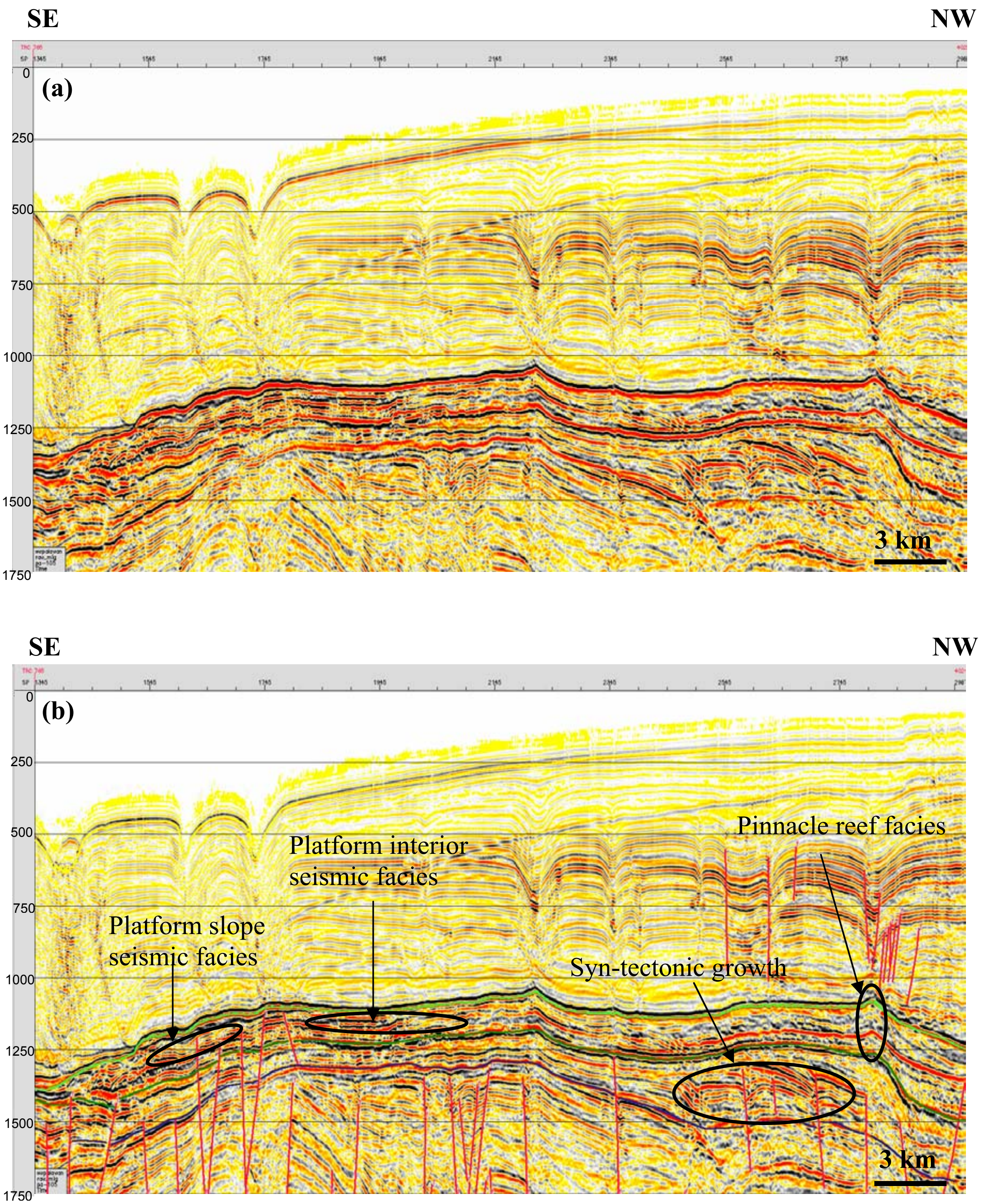


**Figure 15.** Seismic profile along strike line PA-105. (a) Uninterpreted. (b) Interpreted. The profile shows a broad, flat-top platform with late growth stage pinnacle reefs at the margins. Note steep slope and high platform-to-basin relief at the northern edge of the platform. Clinoforms in the northwestern part of the line shows syntectonic platform growth. Vertical scale is in milliseconds two way time.

Platform Slope/Clinoform Facies

Slope facies are characterized by parallel to sub-parallel gently dipping reflectors located basinward from platform margins (Figure 15). Although seismic amplitude character is generally strong, reflectors can also show weak amplitude.

Basinal Seismic Facies

Basinal facies found at the toe of the slope between individual platforms display parallel to sub-parallel, sub-horizontal reflectors. Although generally these facies have strong amplitude seismic character, locally these facies have weak amplitude character. Basin-floor facies exhibit lateral continuity and onlap onto platform edges (Figure 16).

These facies represent deposition in low energy environment. Typically, the continuous, parallel and high frequency reflectors suggest that the facies may consists of carbonate pelagic sediments or interlayered carbonate and shale.

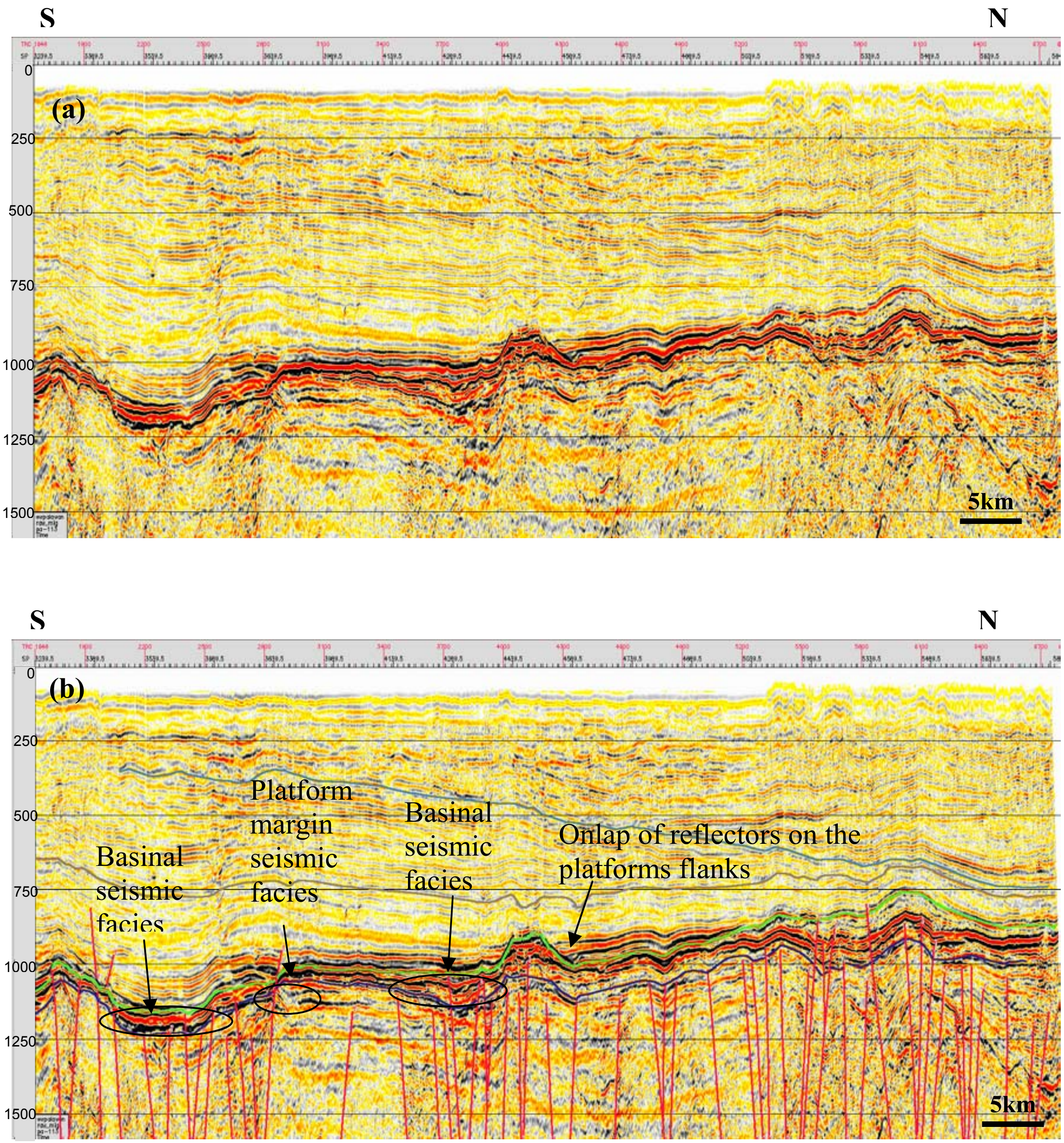


**Figure 16.** Seismic profile along strike line PA-113 showing basinal and platform margin facies. (a) Uninterpreted (b) Interpreted. Note onlap of basinal facies on flanks of the isolated platform. Vertical scale is in milliseconds two way time.

**Growth History of Likas Carbonate Platforms**

Three general growth episodes are recognized within carbonate facies of the Likas Formation based on the reflection configuration and character of the lower and upper sequence boundaries and internal stratal patterns that can be identified within the sequence The episodes are defined by Blue, Green and Pink correlation horizons, respectively.

The Blue horizon marks initial carbonate deposition over the siliciclastic substrate. This horizon follows an undulating to ramp-like profile with low platform-to-basin relief. Most faults from the underlying siliciclastic unit cut through the Blue horizon.

Carbonate facies above the Blue horizon record internal platform growth. Aggradation during deposition of the Green sequence began to increase platform-to-basin relief. This sequence generally has broad, flat-top platform to mounded morphology with strong amplitude reflector mappable across the study area. Plan-view outline shows circular platforms (Figure 17) of the Green sequence with the larger platforms located on the shelf and very few small platforms located basinward. This sequence exhibits variable seismic amplitude and lateral continuity internally within the platforms. The basal part commonly has high amplitude, continuous reflectors whereas the upper part consists of low amplitude, discontinuous to chaotic reflectors. Karst facies that display chaotic, discontinuous reflectors, could suggest that the sequence has experienced repeated exposure events. Seismic character along platform margins are typically low amplitude and chaotic. The Green sequence is about 50 to 250 ms thick

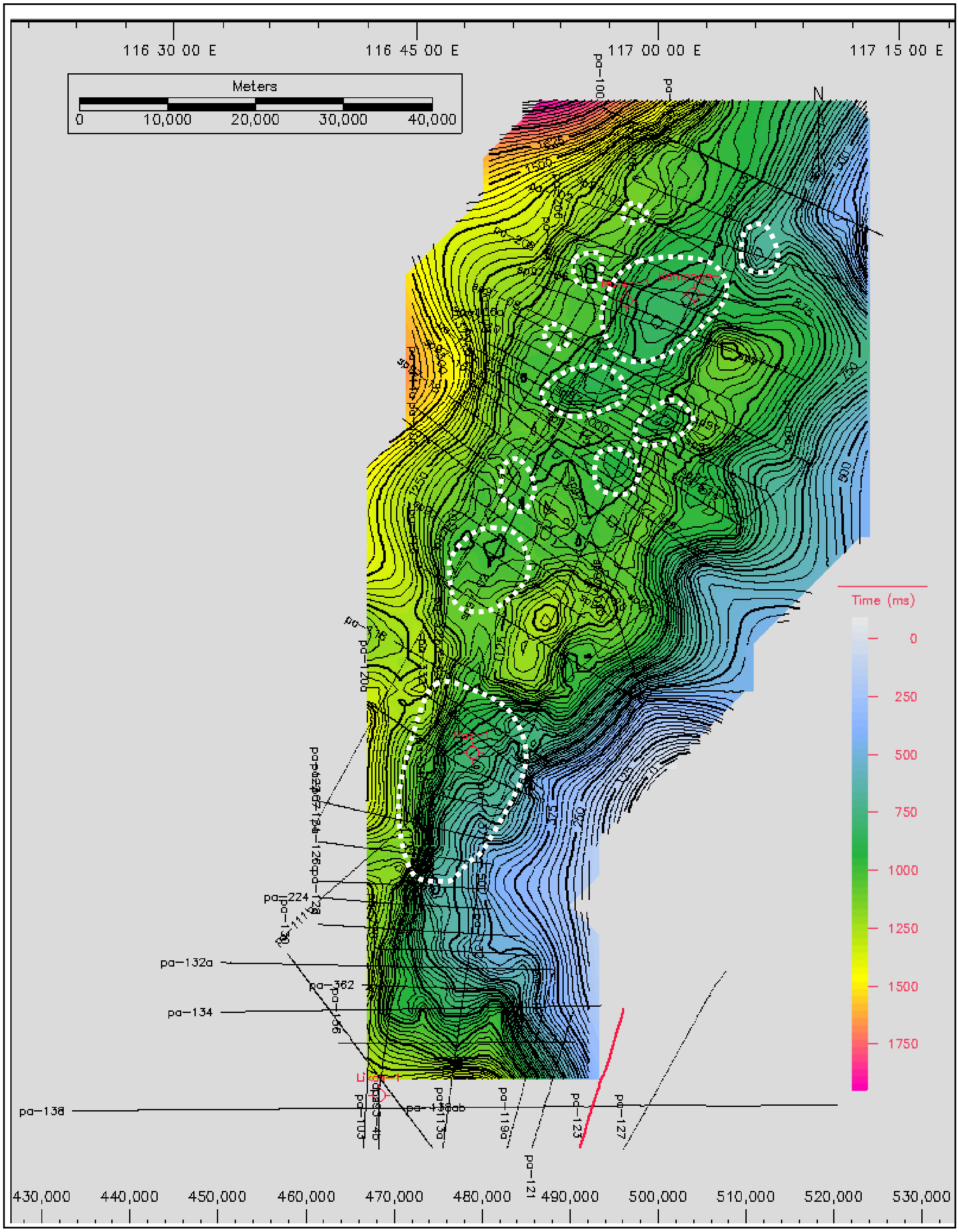


**Figure 17.** Time structure map of Green horizon. Note that the platform outlines (white dotted lines) show little coincidence with time-structure horizon.

TWT and thickness is thinner sequence in the northern part of the study area to thicker sequence in the southern part. Platform tops of Green sequence in the north are buried deeper than in the south. Faulting is also evident in Green sequence.

Pink sequence, constructed on top of the Green sequence, is the backstepping event in the growth history of Likas Formation platforms (Figure 18). This is mapped in central and southern parts of the study area. This growth sequence is affected by major tectonic deformation as the platforms on the eastern part (landward-side) of the study area are tilted to the west (Figure 19). The platform interior commonly exhibits weak amplitude, less continuous reflectors and are semi-transparent. Platform top morphology is variable. Some platforms have mounded tops, while others are flat. Faulting in some platforms created irregular platform tops. Thickness of Pink sequence is 40-240 ms TWT. Thicker carbonate growth is observed in the southern part of the study area. Plan-view outlines of the platforms show circular configuration (Figure 20).

The carbonate platforms of Likas Formation drowned and were buried by the prograding deep marine shales in early Pliocene time. The platforms in the north are covered by thicker siliciclastic deposits and terminated earlier than platforms in the south. Southern platforms were initially able to keep up with rises in sea level by backstepping (Pink sequence) and eventually were drowned and buried at a later stage.

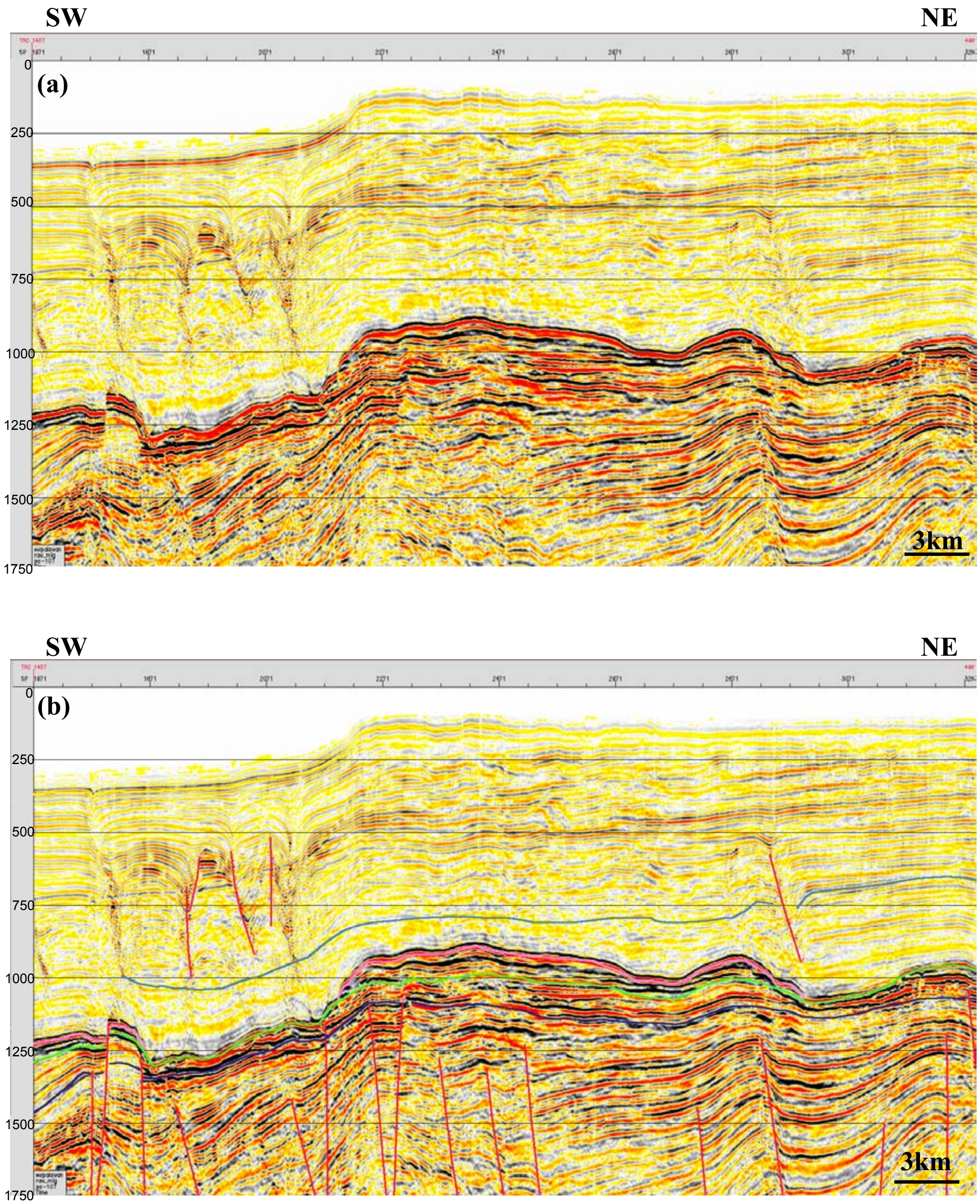


**Figure 18**. Seismic profile along strike line PA-107 showing the backstepping carbonate platform. Platform top of Pink sequence shows higher platform-to-basin relief. Vertical scales is in milliseconds two way time.

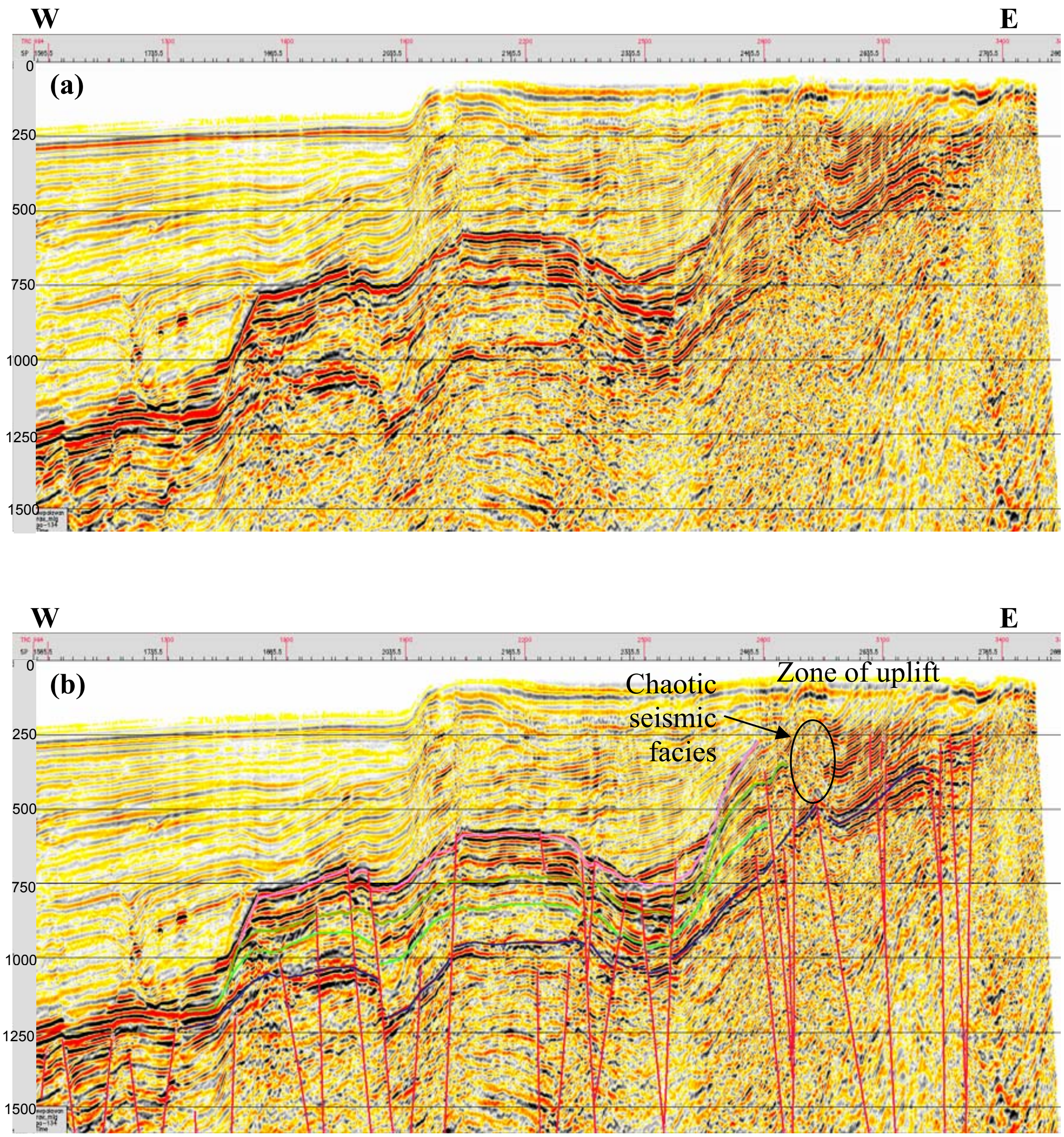


**Figure 19**. Seismic profile along dip line PA-134. (a) Uninterpreted (b) Interpreted. This profile shows the tilted platform on the eastern part of the study area. Notice the chaotic seismic facies at the zone of uplift. This is probably due to fracturing caused by the uplift or karstification. Vertical scale is in milliseconds two way time.

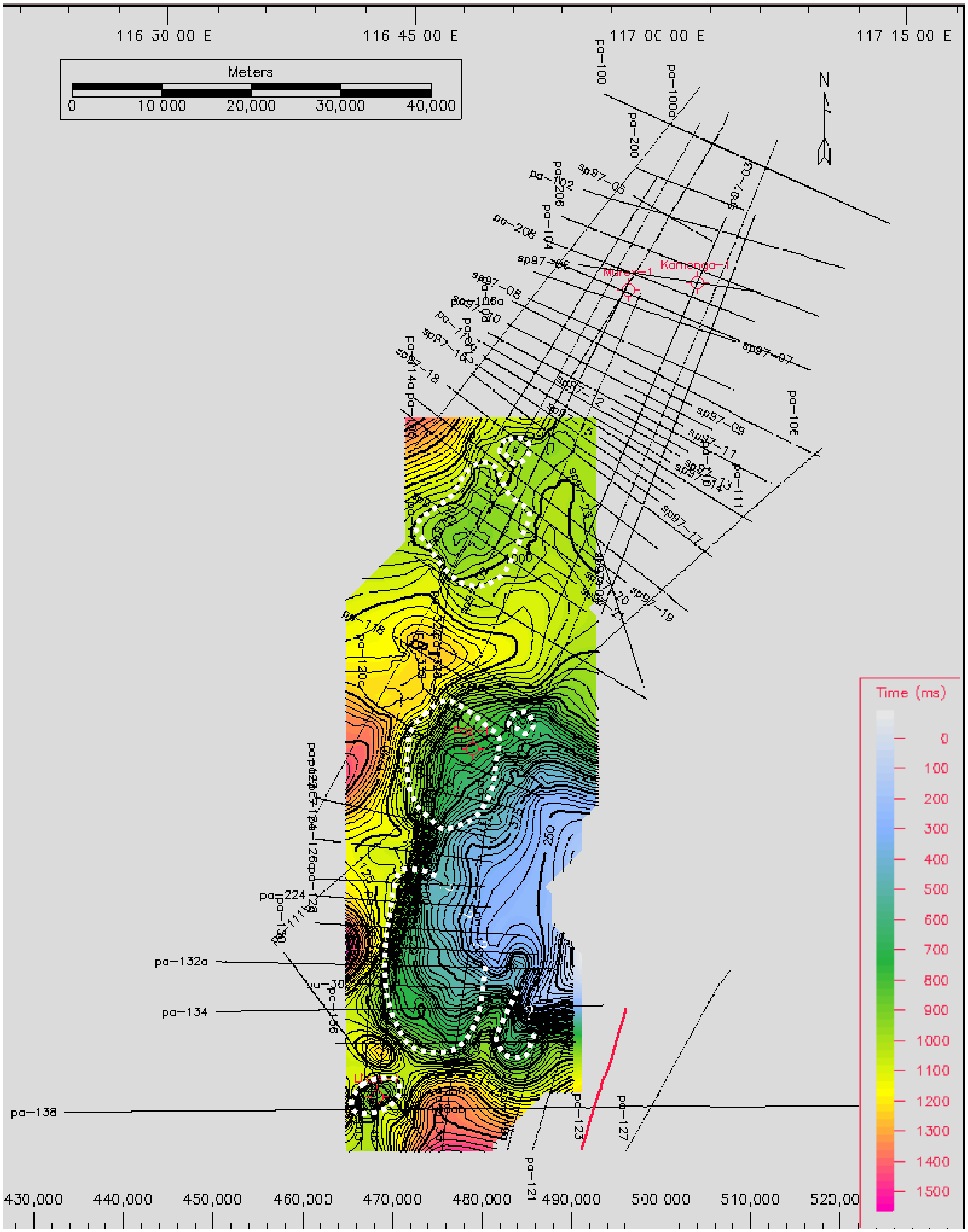


**Figure 20.** Time structure map of Pink horizon. White dotted lines are the outlines of the platform Question marks indicate that the platform edges can not be mapped on seismic due to deformation caused by tilting.

Throughout the evolution of Likas Formation carbonate platforms, faulting has modified the platform architecture and internal stratal geometries (Figures 21 and 22). Seismic facies location and stratal patterns could indicate syn-tectonic platform growth (Figure 21).

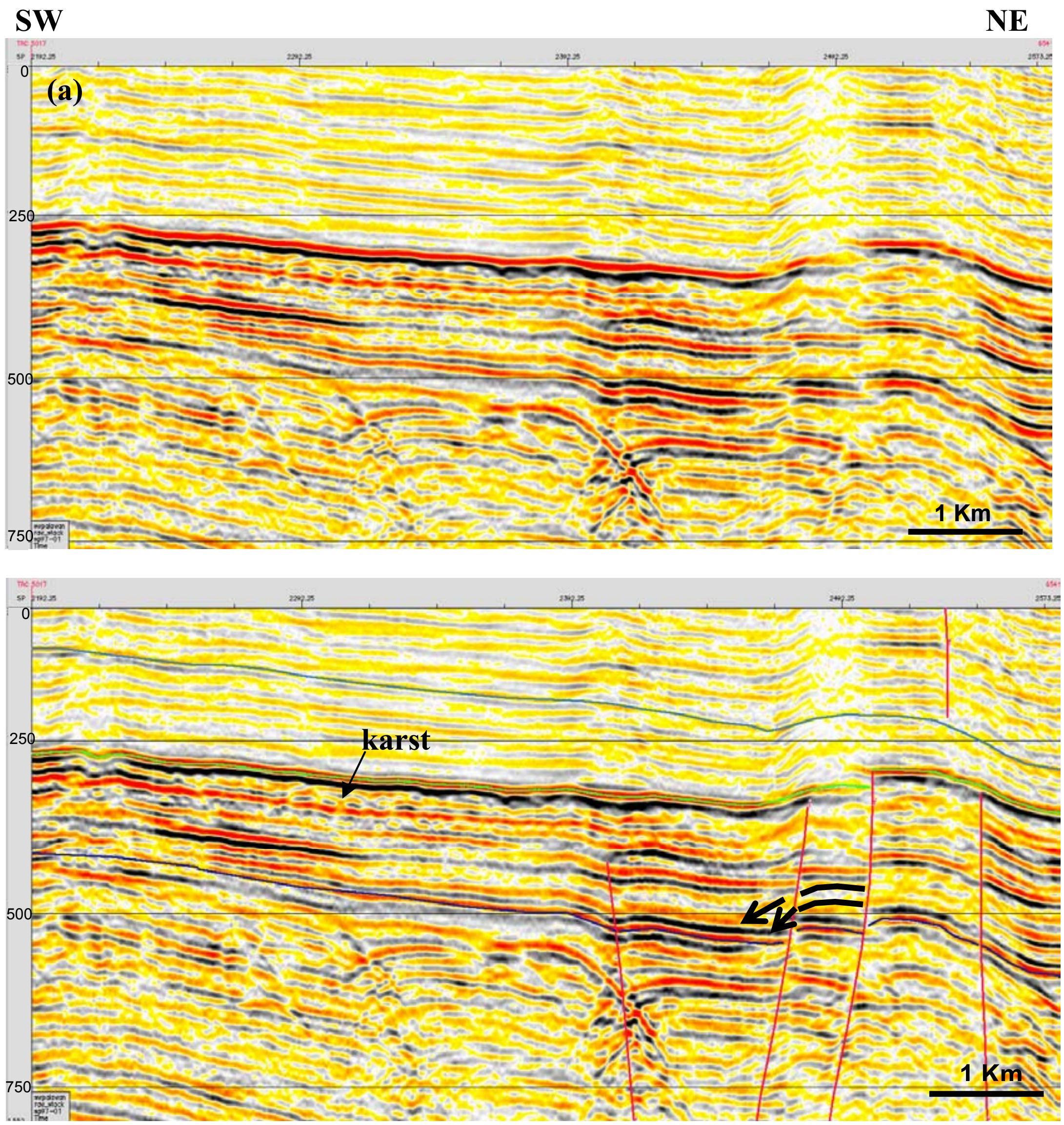


**Figure 21**. Seismic profile along strike line SP97-01. (a) Uninterpreted, (b) Interpreted. Faulting controlled seismic facies location (arrows) which indicate a strong tectonic effect during the platform growth. Vertical scale is in milliseconds two way time.

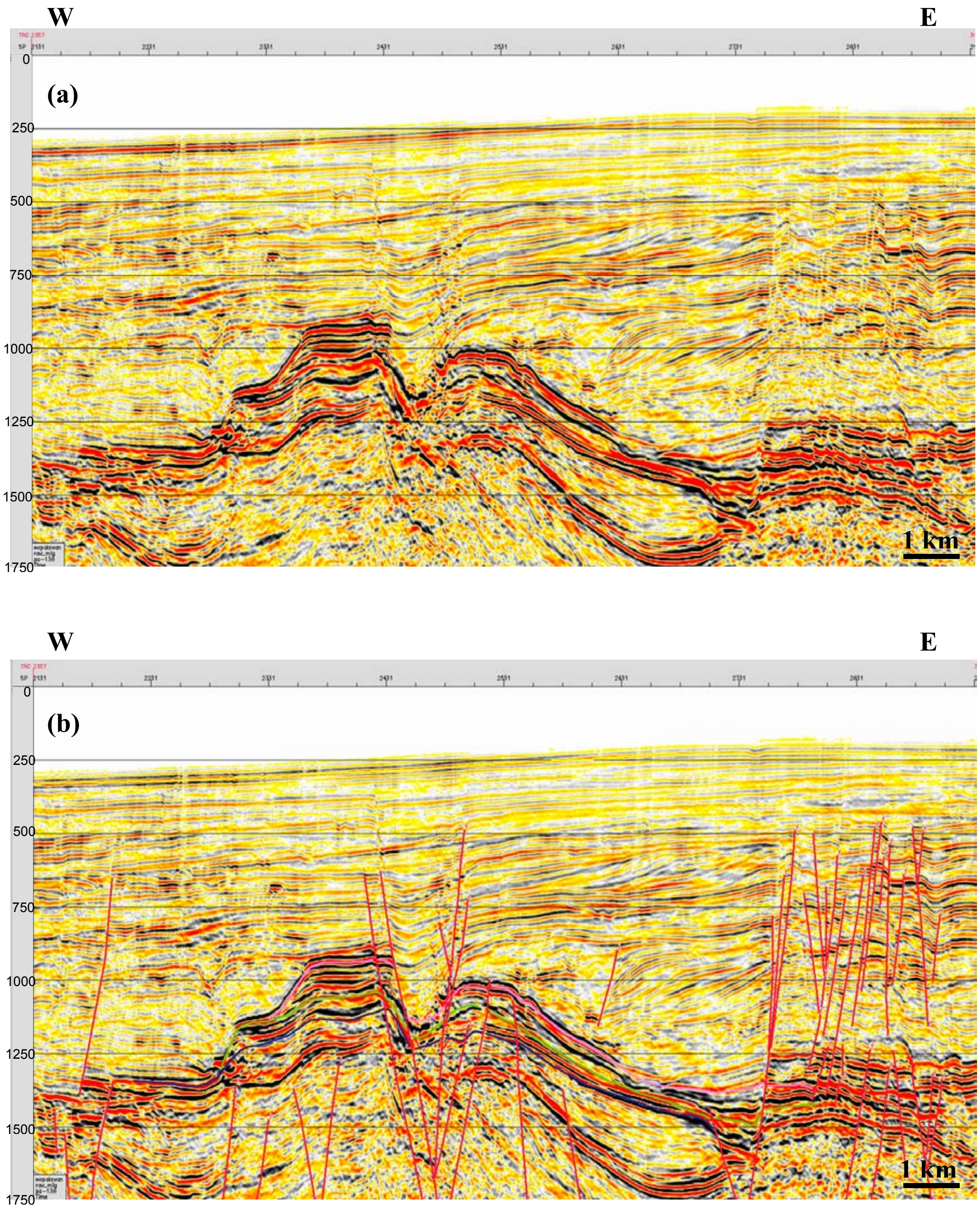


**Figure 22**. Seismic profile along dip line PA-138. Faulting significantly modified the platform morpholody. Note the differences in platform morphology. Vertical scale is in milliseconds two way time.

# CHAPTER VI

# DISCUSSION AND CONCLUSION

## Discussion

Development of carbonate platforms in the Likas Formation can be subdivided into three general episodes: (1) platform initiation, (2) aggradation, and (3) backstepping and drowning.

Growth of the platforms began in late middle Miocene at about 11Ma based on biostratigraphic dating. Platforms were constructed on folded and faulted siliciclastic strata, which provided the antecedent seafloor highs. Fault systems in the substrate extend to the carbonate platforms and modified the platform architecture during growth.

Thickness of carbonate platforms in the northern part of the study area is contrained by the Kamonga-1 well, where 204 meters of platform facies were encountered. Thicker carbonate platforms are encountered by wells in the south. The thicknesses range between 330 and 520 meters.

BED (1986) mapped the interval between the top of the carbonate and a regional late middle Miocene unconformity, and interpreted the sudden thickening of this interval in the vicinity of Southwest Palawan A-1 well as a prograding ramp of late Miocene age. This supposition is supported by this study that shows thicker carbonate platforms in the central and southern part of the study area where aggradation is more pronounced and backstepping is present (Figure 19). Thinner carbonate platforms are seen in the north. In most places, Likas Formation carbonate platforms show no evidence of coalescence.

During their development, platforms maintain a flat top in response to a rise in sea level and reefs grow at the margins (Figure 15). The platform interiors are able to keep-up with the rate of rise in sea level (Kendall and Schlager, 1981).

Well data indicates that carbonate platforms terminated in early Pliocene time at about 5Ma, a period of rapid sea level rise. Platforms in northern parts of the study area terminated earlier than age-equivalent platforms in the south. Platform tops in the north show greater burial depths and thicker overlying deep-marine siliciclastic deposits. Platform tops in the south are shallower.

Variability of platform thickness, backstepping of platforms and timing of termination can be attributed to regional subsidence. Regional subsidence in the north is interpreted to be faster compared to the south and this may have caused these platforms to drown and terminate earlier.

Tilting of carbonate platforms are observed on the eastern side of the South Palawan Shelf. This tilting might be due to young uplift of Southwest Palawan and Balabac Island in the Pliocene which can be associated with reactivation and continued convergence off NW Sabah and Balabac until recent times (Schlüter, et al., 1996).

Environmental controls such as prevailing wind direction also influenced growth of the carbonate platform. Platforms in the south exhibit well-defined windward-leeward margins as south-to-north progradation (Figure 12).

Carbonate platforms of the Likas Formation in Southwest Palawan are younger overall than carbonates platforms and buildups found in other parts of Palawan. Onshore south central Palawan, carbonate platforms and buildups began to develop in early middle Miocene to middle Miocene time (Rehm, 2003). Off Northwest Palawan down to the northern part of the Southwest Palawan Basin, Nido Limestone was initiated in early Eocene and drowned during early Miocene time (Grötsch and Mercadier, 1999). With regard to platform termination, the Nido Limestone, which possibly extends to the South Palawan Shelf, was possibly drowned due to flexural subsidence caused by the thrusting beneath south Palawan (Hinz and Schlüter, 1985; Fulthorpe and Schlanger, 1989) (Figure 23).

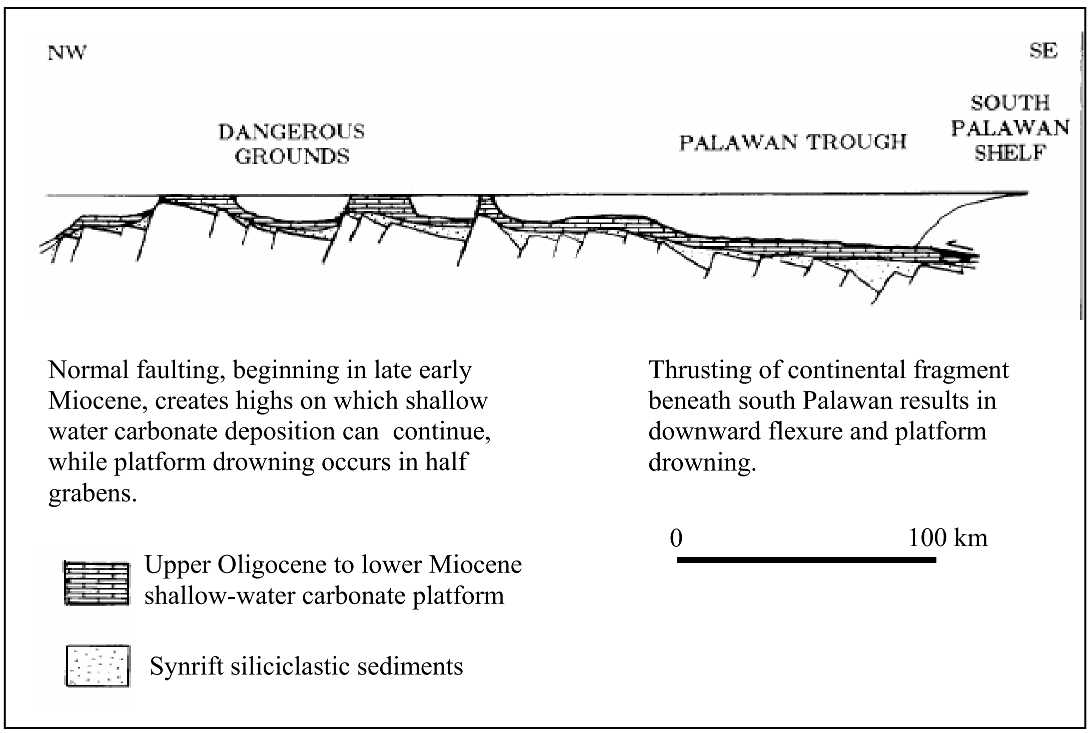


**Figure 23**. Hypothetical section between the Dangerous Grounds and the South Palawan Shelf during early Miocene (18Ma). From Fulthorpe and Schlanger (1989) based on the data of Hinz and Schlüter (1985).

Termination of Likas Carbonate Platforms

Demise of a carbonate platform can be linked to several factors. Large relative sea-level rise may rapidly submerge platform tops to depths below the euphotic zone and cause the platforms and reefs to drown (Schlager, 1981). Conversely, large relative sea-level falls can terminate carbonate production via subaerial exposure of the platform. Burial by siliciclastic strata without subaerial exposure can also lead to carbonate platform termination (Erlich et al., 1990).

A drowned carbonate platform may exhibit good internal reflectors, onlap of horizontal basinal facies, late-growth reefs at some platform margin locations, and facies change to shale along the platform tops (Erlich et al., 1990) (Figure 24a). Carbonate platforms that were subaerially exposed prior to termination will show all or any of the following features: unconformable sequence boundaries with karsted surface, continuous reflectors from shelf to basin, divergent basinal onlap patterns (Erlich et al., 1990) (Figure 24b).

Effects of relative sea level falls and rises are recognized in Likas carbonate platforms. Discontinuous, chaotic seismic reflectors near platform tops indicate that carbonate strata experienced subaerial exposure during its growth history. Evidence for repeated exposure events is observed. Karsted surfaces are present within the two growth sequences of Likas Formation platforms. These exposure events, however, could not be correlated from one seismic line to another due to the wide-spacing of the seismic grid, complex structural setting of the area, and low seismic data quality of some lines.

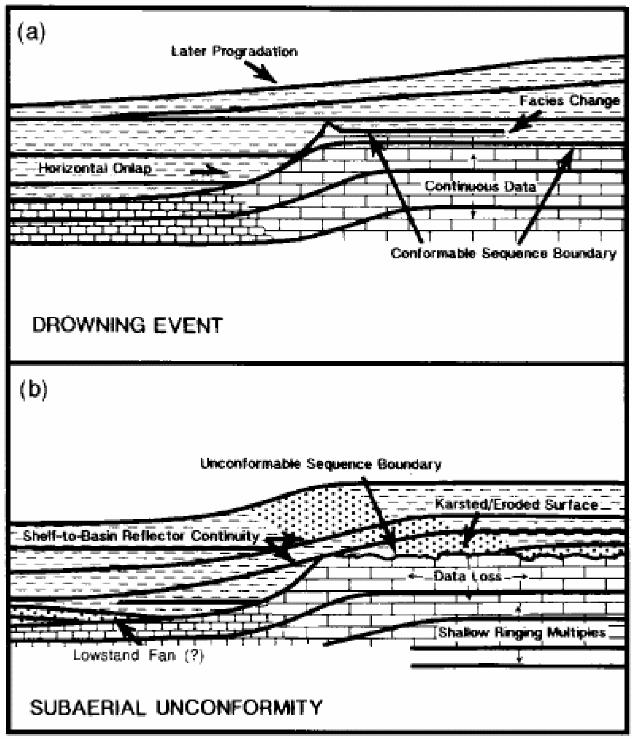


**Figure 24.** Termination of carbonate platforms. (a) drowning by rapid submergence below the euphotic zone and (b) subaerial exposure. In both cases, the carbonate platforms are buried by deep-marine sediments. (from Erlich et al., 1990).

Some isolated platforms and buildups in Likas Formation were probably drowned (sensu stricto; Schlager, 1981) as indicated by basinal reflectors that onlap the platform flanks and platforms were submerged below the photic zone and the "carbonate factory" were drowned.

Clastic influx also contributed to the termination of the carbonate platforms. The northern platforms are overlain by thicker siliciclastic units. Overlying the strong band of reflectors are low amplitude seismic facies which are interpreted to be deep marine shales. Prograding, high to low amplitude seismic facies, probably interbedded sand-shale facies downlapped onto the deep-marine shales.

**Conclusion**

This study illustrates evolution of Likas Formation carbonate facies in three growth phases: (1) platform initiation during late middle Miocene time, (2), aggradation through late Miocene time, and (3) backstepping and drowning in lower Pliocene time.

Growth phases are recognized based on stratal geometries, internal seismic facies and character of the bounding reflectors. Evolution of the carbonate platforms, stratal patterns and morphology of platforms can be related to extrinsic mechanisms such as tectonics, eustasy and environmental controls.

Likas Formation carbonate platforms were initiated on folded and faulted pre-middle Miocene siliciclastic units deposited behind the frontal thrusts of the accretionary prism. Faulting modified platform morphology as the platforms during growth. Mounded platforms commonly are associated with faults. Platform margins where faults deform basal strata usually exhibit chaotic seismic facies. Uplift on the eastern part of the study area caused platforms to tilt basinward. Tectonic subsidence may have been faster in the northern part of the study area as evidenced by the early termination of platforms in the north.

Relative sea level change has significant effects on the timing of sequence development. Sea level falls exposed the platforms and caused karst surfaces within the platforms. Rises in sea level is matched by the growth potential of the platforms and is evident on flat-topped platforms with pinnacle reefs at the margins.

Carbonate platforms probably terminated due to: (1) subaerial exposure during the late Miocene time lowstand, (2) rapid relative sea level rise during early Pliocene, and (3) burial by the deposition of deep-marine shales.

Middle Miocene-lower Pliocene carbonates of the Likas Formation are time-correlatable to other Southeast Asia carbonate platforms in Central Luconia, Malaysia (Epting, 1989) and in Natuna Sea and North Madura Areas of Indonesia (Bachtel et al., 2004; Adhyaksawan, 2002). In contrast, Likas Formation carbonate platforms developed in a structurally complex area and largely reflect a tectonic overprint on the platform evolution.

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