

**EVOLUTION OF
THE LATE OLIGOCENE KUJUNG REEF COMPLEX
IN THE WESTERN EAST CEPU HIGH, EAST JAVA BASIN :
SEISMIC SEQUENCE STRATIGRAPHIC STUDY**

**Margaretha E. M. Purwaningsih¹⁾, Awang H. Satyana²⁾, Sri Budiyan³⁾
Dardji Noeradi¹⁾, and Nanang M. Halik³⁾**

¹⁾Department of Geology, Institute of Technology Bandung, Bandung ²⁾; Badan Pelaksana Kegiatan Usaha Hulu Minyak dan Gas Bumi, Jakarta ³⁾; Pertamina Upstream, Jakarta
E-mail : Margaretha E.M. Purwaningsih : rethacd@yahoo.com
Awang H. Satyana : awangsatyana@yahoo.com

ABSTRACT

Seismic sequence stratigraphic study was conducted to reveal depositional history and facies distribution of the reefs in the study area located at the western margin of the East Cepu isolated platform. Four sequences, Sequence-1 to Sequence-4, consisting of transgressive and highstand systems tracts of the Late Oligocene Kujung carbonates were identified. The sequences can be recognized as related to the synrift, postrift, and syninversion deposition. Siliclastic and carbonate sediments including facies of reefs, lagoon, talus, and marine condensed sections developed. Deposition of the upper sequences were contemporaneous with the tilting of the platform to the southwest due to a regional inversion forming a northeastward backstepping pattern. Entering the mid – Early Miocene, the episode of the carbonate deposition ended due to deposition of the Tuban siliclastic sediments while the platform tilting more to the southwest. Seismic sequence stratigraphic study considering tectonics and eustacy is a good approach to understand stratigraphic evolution.

INTRODUCTION

The Oligo-Miocene carbonates of the East Java Basin consisting of the Kujung-Prupuh-Tuban-Rancak carbonates constitute the carbonate complex growing at the margin of the Sundaland. The carbonates trend ENE – WSW from the present onshore eastern part of the Central Java to the offshore areas north of East Java and Madura Island. The carbonates developed in various environments from fringing reef at the rim of basement to pinnacle reef over isolated platform (Figures 1, 2).

Kujung Formation in the western margin of the East Cepu High isolated platform grew in several stages causing the distribution of reef complex differs from one place to other place. The identified problems of this study are how to know the depositional facies, sequences, stages, and distribution of the Kujung carbonates in the western East Cepu High area. The

purpose of the study is to understand the depositional history of the Kujung carbonates in the western East Cepu High area, East Java Basin using seismic sequence stratigraphic method. These eventually will aid in explaining and predicting where oil and gas accumulation are found.

GEOLOGIC SETTING

The East Java Basin covers an area of approximately 50,000 sq km from Central Java eastward across East Java, the East Java Sea, Madura, and the Madura Strait (Pertamina BPPKA, 1996). The Karimunjawa Arch separates the East Java Basin from the West Java Basin and the Java volcanic arc marks the southern boundary (Figure 1). The basin passes eastwards into the deep water Lombok Basin, and to the north the basin shallows onto the Paternoster High that separates it from the Makassar Basin. The East Java Basin occupies the position of a back-arc basin since Paleogene time.

Different stress regimes controlled the Paleogene rift – phase and the Neogene inversion phase. The deposits of Middle to Late Eocene Ngimbang Formation overlie the basement. Marine transgression took place during the Late Eocene to Early Oligocene (Figure 3). The sediments shallowed to the north and the “CD” limestones (Ngimbang carbonates) developed. The “CD” limestones consist mainly of limestones, partly reefal, with shale and sandstone interbeds. After a mid-Oligocene uplift and limited sands were deposited at shallow areas, the transgression regionally flooded the basin during the late Oligocene to Early Miocene. Kujung sediments were deposited during this period. Overlying this, the base of the Tuban cycle is defined as the change from the transgressive limestone deposits of the Kujung Formation to the overlying regressive Tuban clastics. The regression marked a major tectonic event that uplifted a large hinterland to the north releasing clastic sediments through erosion. This phase were marked by locally Tuban or “OK” carbonates, marls and sandstones deposition. Reefal carbonates (Rancak reefs) of upper Tuban formation were deposited in the end of Early Miocene. The Ngrayong sediments were deposited during the Middle Miocene. Transgressive shallow marine deposition resumed in upper Middle Miocene through Plio-Pleistocene time. The clastic and carbonate sediments of Wonocolo, Kawengan (Karren, Ledok, Mundu), Paciran and Lidah formations were deposited during this period within depositional environment ranging from deep water to marginal marine – non marine upwards.

There are two principal structural trends of the Tertiary origin : a northeast – southwest extensional fault trend and an east – west wrench fault trend (Brandsen and Matthews, 1992; Manur and Barraclough, 1994; Satyana and Darwis, 2001) (Figure 1). A tensional stress regime was active from the Middle Eocene up to the Early Miocene. The initial stage of extension was marked by rifting in the Eocene, directly followed by a second stage of basin – wide subsidence in the Oligocene. In the early mid-Miocene, uplift of the Sundaland took place. Neogene tectonism is marked by a fundamental change in stress regime leading to widespread inversion in the Middle Miocene with active translational and rotational movement of major fault blocks. Basinal inversion and related shale diapirism are major

structural controls in the region south of the shelf edge that dominated by an east-west trending linear tectonic disturbance called as the Rembang-Madura-Kangean (RMK) Zone or the Sakala Fault Zone, which appears to represent a major sinistral shear zone. This transpressional left-lateral movement runs from west to east the East Java, Madura, eastern coast of Madura, and Kangean.

Geologically, the study area called the “Alpha” area is located at the western of East Cepu High (Figure 2), an isolated carbonate platform in the East Java Basin and, physiographically, the area is included into the Kendeng, Randublatung and Rembang Zones (van Bemmelen, 1970). The East Cepu High is a positive feature trending northeast – southwest, bounded to the northwest by the Tuban Trough, to the southeast by Ngimbang Trough, and to the south by Late Tertiary – Recent Volcanic Arc. The East Cepu High became the important site for carbonate growth during the Oligo-Miocene.

DATA AND METHODOLOGY

The study was based on two-dimensional (2-D) seismic data set and well data. The seismic data were acquired in 1997 comprising an area of 280 km². Nine migrated seismic lines were used for interpretation. The well data consist of a set of “Beta-1” well standard logs including the synthetic seismogram. Biostratigraphic data of “Beta-1” well was used during the study.

The methods of seismic sequences stratigraphy were used during the study. This includes sequence picking on well log; biostratigraphic checking; well to seismic tying; horizon picking and mapping through tracing of reflection continuity; evaluation of reflector characteristics i.e. reflector continuity, amplitude, external geometry and internal characteristics; facies mapping; and stratigraphic reconstruction by flattening.

Interpretation of carbonate sedimentology and sequence stratigraphy was helped by the models developed by Wilson (1975) and Longman (1981) for facies model, Epting (1978) and Erlich *et al.* (1990) for carbonate platform sedimentation, Fontaine *et al.* (1987) for seismic interpretation, Sarg (1988) and Haq *et al.* (1987) for carbonate sequence stratigraphy and global sea level control, and Longman (1993) and Satyana and Darwis (2001) for regional carbonate sedimentation.

IDENTIFIED LATE OLIGOCENE KUJUNG SEQUENCES

Based on : (1) well log analysis of Beta-1 which penetrates the Kujung reef of the “Beta” structure, (2) biostratigraphic analysis of the Beta-1 well, (3) seismic lines across the study area, and (4) global sea level curve (Haq *et al.*, 1987), Kujung carbonates in the study area can be divided into four sequences. Well log analysis provide vertical high resolution sequence identification (Figure 4) which then can be tied laterally into seismic sections while considering seismic characteristics of the sequence terminations (sequence boundary, flooding surface, maximum flooding surface) and the systems tracts (Figures 5,6).

Biostratigraphic data provide the controls for sequence identification and age of the sequences for tying into the global sea level and coastal onlap (Haq *et al.*, 1987).

Based on the biostratigraphy analysis (nanno fossil), the age of the Kujung carbonate penetrated by the Beta-1 well is in the range of NP 24 – NP 25 or Late Oligocene. This means that the rock sequence includes into the second order of the TB 1 (Tejas 1) supercycle. Identified systems tracts are distinguished into colors. The following are the discussion of each sequence and its facies showing the evolution and depositional history of Kujung carbonates in the study area. See Figures 4-11 for the following discussion.

Sequence 1

Sequence 1 is composed of SB (sequence boundary), Transgressive Systems Tract (TST) Deposit (purple color), Maximum Flooding Surface (MFS), and Highstand System Tracts (HST) Deposit (green color). The sequence is bounded by an unconformity at the lower boundary and an onlap reflector of the overlying sequence at the upper boundary (Figures 5, 6). The lower boundary is type 1 sequence boundary. The sequence boundary reflects an erosional surfaces indicated by an erosional truncation which makes up an unconformity contact between “CD” limestones (Upper Ngimbang) and lower part of the Kujung Formation. The TST deposit of this sequence is marked by internal characters of low to moderate amplitude, discontinuous reflections, hummocky and oblique shaped reflectors. The deposit of this system appears thicken basinward to the southwest. It may reflect a tilting of the platform to the southwest. The peak of TST is characterized by a MFS that infilled by marine condensed section (MCS). The internal character of MFS or MCS on the seismic line is marked by high amplitude of peak reflection that is relatively horizontal and can be traced laterally. Overlying the MFS, are the HST deposit which are more extensively distributed than that of the TST deposit indicating a lack of control of pre-existing faults or representing a post-rift deposit. The internal characteristic of seismic shows an amplitude variations, low to moderate reflections, and oblique shelfward progradation. The bioclastic carbonates were formed during this time. The escarpment developed which was became the place for carbonate build-ups.

Sequence 2

Sequence 2 is composed of SB, TST deposit (pale brown color), MFS, and HST deposit (red color) (Figures 5, 6, 7, 8, 10). The sequence generally represents a northeast – southwest trending progradational sediments deposited on the highs. The lower sequence boundary is marked by downlap reflections onto the top of Sequence 1. Based on “Beta-1” well log analysis, the upper sequence boundary is at depth of 3180 m (Figure 4), identified by the change of stratal pattern that have the shape of progradation to aggradation on the gamma ray log value. The TST deposit is characterized by internal characters of moderate amplitude reflections, discontinuous, dimming, onlap reflections onto sequence boundary 1. The clinoform ranges from gently dipping and almost planar ramps to more steeply dipping, oblique surfaces toward the escarpment (Figure 6). Carbonate build-up developed and

internally are characterized by dimming reflections in the mounded indicating porous reservoirs. The MFS is characterized by high gamma ray value at depth 3252 m (Figure 4). The MFS in the seismic lines can be identified by high amplitude and continuity which can be traced laterally in the entire direction. The HST deposition of this sequence is thinner than the underlying TST deposit. The internal character of the system is low amplitude, and high amplitude along the boundaries indicating soft rocks interbedded in the limestones. Based on well log analysis, this HST can be identified by progradation stratal pattern.

Sequence 3

Sequence 3 is composed of SB, TST deposit (yellow color), MFS, and HST deposit (still in yellow color) (Figures 5, 6, 9, 10). The existence of this sequence is based on the identification of stratal pattern of the Beta-1 well. Based on well log analysis, the lower sequence boundary is identified at depth of 3180 m and the upper sequence boundary at depth of 3050 m (Figure 4). In the seismic section, the lower sequence boundary is marked by downlap reflections onto the top of Sequence 2. The upper sequence boundary is marked by concordant reflections or a downlap surface of the Sequence 4. Within the TST deposit, the carbonate buildups developed on the eastern part with internal characters is typified by mounded and dimming reflections within the buildups. The more parallel internal characters occur at the inter-reef platform. To the west, the reef is not found due to deeper depositional environment. The drowning platform occurred as a result of fault reactivation in the western deeper side of the platform. In this area, a thin condensed section with strong reflector developed. The peak of the TST deposit is marked by MFS deposition at depth of 3098 m (Figure 4) characterized by marine condensed section. The internal seismic characters of the HST and TST is difficult to distinguish because both of them have similar appearances of dimming reflections. However, based on well log analysis, the HST is marked by progradation stratal pattern.

Sequence 4

Sequence 4 is composed of SB, TST deposit (still in yellow color), MFS, and HST deposit (blue color) (Figures 5, 6, 9, 10). The existence of this sequence is based on the identification of stratal pattern of the Beta-1 well. Based on well log analysis, the lower sequence boundary is identified at depth 3050 m (Figure 4) and the upper sequence boundary is onlap surface of the lowermost shales of the Early Miocene equivalent Upper Kujung (Prupuh) Formation. The TST deposit can be identified by onlap reflections on the upper boundary of Sequence 3, and internally showing dimming seismic characteristics in the mounded indicating carbonate build-up. Based on well log analysis, the TST can be identified by retrogradation stratal pattern and more shales deposits. The mounded reflectors of TST 3, HST 3 and TST 4 developed in the eastern study area on the inner slope of previous stage. Epting (1978) explained that the type growth formed build-in pattern of carbonate build-up. The MFS in this sequence can be identified by stratal pattern changes from progradation to aggradation stratal pattern. Aggradational stacking pattern reflects the HST event. The internal seismic characteristic of this system is low amplitude, tightly

reflections, with high amplitude on top of the sequence and internally dimming reflectors within the mound. These reflectors were seen in the eastern study area. The HST deposit is thicker than the TST deposit in this sequence. In the western area, this system is marked by very high amplitude (Figures 5, 6) interpreted as a condensed section. The area became deeper in this period due to drowning platform.

The depositional cycles of the Kujung carbonate can be known by the above analysis. These sequences of the Kujung carbonates generally occurred in the transgressive phase. It can be shown that the sequences are composed of transgressive and highstand system tracts. The absence of lowstand systems tract reflects that the study area was located in the shelfal area that not possible to lowstand systems tract deposited.

EVOLUTION OF THE KUJUNG SEQUENCES

A series of flattened sections show the evolution of the identified Kujung sequences in the study area (Figure 12, see also Figures 5 and 6). The base of the East Cepu High in the study area is considered to be basement with thin cover of the Eocene –Early Oligocene Ngimbang sediments (may be the Early Oligocene “CD” carbonates). Before the deposition of the Kujung sediments in Late Oligocene time, the area was uplifted during the mid-Oligocene time. The Ngimbang or “CD” sediments were eroded and left an erosional surface indicated as angular unconformity on the seismic sections. Started in the base Late Oligocene, the Kujung sequence deposition took place.

The deposition was commenced by the Sequence-1 TST purple deposits. The deposition of these sediments in some places was strongly controlled by the pre-existing faults which were still active leading to the synrift sediments of the lowermost Kujung Formation (regionally recognized as Kujung III or Kranji Member). These faults may accommodate the release tension of the mid-Oligocene uplifts. Sediments deposited in the graben area are different with those deposited at the horst area. Low energy sedimentation within the graben caused the finer grained-sediments than those at the horst area.

As the sea level transgressed, all irregular topography due to pre-existing faults was inundated and the deposition of the Sequence-1 HST green deposits representing the post-rift sequence took place. The sediments distribute in relatively constant thickness across the area. The sedimentary pattern was also relatively similar in every place.

Following this period, pre-existing structures were reactivated. High and low areas were established. Sea level initially regressed from the previous sequence and gradually transgressed the area forming the Sequence-2 TST pale brown deposits. Reefs started to develop in this period. All reefs grew in high areas and finer lagoonal sediments were deposited in the intervening low areas (inter-reef lagoons).

Major normal fault situated in the middle part of the study area reactivated in the later period. This caused the eastern half of the area tilted eastward. Isostatically, the western

area was uplifted. The Sequence-2 HST red deposits formed. Reefs of this tract developed above the previous reef position at the eastern half but slightly were built outward on the slope of the previous reefs. Inter-reef lagoon sediments were deposited between the reef complex. At the western area, the uplifted carbonates were eroded the talus sediments deposited eastwardly.

Entering the sequence 3, there was a significant change in the basement configuration. This occurred approximately in the upper Late Oligocene. The basement started tilting to the southwest due to reactivation of the major fault down to the southwest. This means that an inversion to the previous period took place. The tilting of the basement was regionally associated with the initiation of the Neogene inversion in the southeastern Sundaland. Plate readjustment around the Sundaland is considered to cause this. As a response of the southwestward tilting, the sea transgressed to the northeast. Regional transgressive northeastward backstepping pattern was established and resulting in the deposition of the thin and condensed Sequence-3 TST and HST and Sequence-4 TST yellow deposits comprising reefs and lagoonal deposits in the eastern part of the study area. Marine condensed section was deposited in the deeper area to the southwest. The reefs in the eastern area still position above the previous reefs but were built slightly inward due to the inter-reef lagoon slightly submerged.

Peak development of the Late Oligocene Kujung sediments occurred following this in a highstand sea level. The Sequence-4 HST blue deposits formed. The reefs development continued the growth pattern of the previous reefs to build inward due to inter-reef lagoonal subsidence. At the deeper water in the western area, a marine condensed section was deposited.

Entering the mid-Early Miocene, regional inversion was obvious and this contributed a significant volume of the Tuban siliciclastic sediments deposited in the study area while the basement tilted more to the southwest. This has ended the episodes of the carbonate deposition in the study area due to clastic burial and drowning.

CONCLUSIONS

- Seismic sequence stratigraphic analysis considering tectonics and eustacy is a good approach to resolve the problem of stratigraphic evolution. Modeling of horizontal and vertical changes of seismic facies can be used as a basis to identify carbonate depositional sequences and to evaluate the local relative changes of sea level.
- Based on seismic stratigraphic analysis, a number of Late Oligocene Kujung carbonate reefs develop in the western East Cepu High. The carbonates can be divided into four sequences including the transgressive and highstand system tracts. The carbonate facies in the area include : reef, inter-reef lagoon, talus, and marine condensed section which related to local tectonic and sea level changes.

- The development of the carbonates were controlled by fault reactivation, uplift, and subsidence resulting in synrift, postrift, and syninversion sedimentary sequences. The platform inversion from initially tilting eastward to become tilting westward is observed and resulted from fault reactivation causing subsidence. The end of the reef growth was associated with the platform drowning and significant clastic burial .

ACKNOWLEDGMENTS

The paper is derived from the final assignment of the first author conducted in the Pertamina Upstream in 2001. She acknowledges the management of Exploration Division of Sumatra-Jawa Pertamina Upstream for giving a permission to publish this paper. Intensive discussions with geologists and geophysicists have helped the study, particularly with Mr. Pudji Astono, Mr. Herry Sutanto, and Mr. Slamet Riyadhi.

REFERENCES

- Brandsen, P. J. E. and Mathews, S. J., Structural and stratigraphic evolution of the East Java Sea, Indonesia, *Proceedings Indonesian Petroleum Association*, 21st annu. conv., p. 417 – 453, 1992.
- Erlich, R. N., Barrett, S. F., and Guo, B. J., Seismic and geologic characteristics of the drowning events on carbonate platforms, *AAPG Bulletin*, v. 74, no. 10, p. 1523 – 1537, 1990.
- Epting, M., Sedimentology of Miocene carbonate build-ups, Central Luconia offshore Sarawak, *Geological Society of Malaysia, 2nd Petrologist Seminar*, Kuala Lumpur, 1978.
- Fontaine, J. M., Cussey, R., Lacaze, J., Lanaud, R. and Yapaudjian L., Seismic interpretation of carbonate depositional environment, *AAPG Bulletin*, v. 71, no. 3, p. 281 – 297, 1987.
- Haq, B.U., Hardenbol, J., and Vail, P.R., Chronology of fluctuating sea levels since the Triassic (250 my to present), *Science*, v. 235, p. 1156-1167, 1987.
- Longman, M. W., A process approach to recognizing facies of reef complexes, *SEPM Special Publication*, No. 30, p. 9 – 40, 1981.
- Longman, M. W., Southeast Asian Tertiary carbonate reservoirs, *Petroconsultants*, Singapura, 1993.
- Manur, H., and Barraclough, R., Structural control on hydrocarbon habitat in the Bawean area, East Java Basin, *Proceedings Indonesian Petroleum Association*, 23rd annu. conv., p. 129 – 144, 1994.
- Metcalfe, I., Pre-Cretaceous evolution of SE Asian terranes in Hall, R. and Blundell, D. (eds), *Tectonic Evolution of Southeast Asia*, Geological Society Special Publication, No. 106, p. 97-122, 1996.
- Sarg, J.F., Carbonate sequence stratigraphy, *SEPM Special Publication*, no. 42, p. 155-181, 1988.
- Satyana, A. H., and Darwis, A., Recent significant discoveries within Oligo – Miocene carbonates of the East Java Basin : integrating the petroleum geology, *Proceedings*

30th Annual Convention Indonesian Association of Geologists & 10th Geosea Regional Congress on Geology, Mineral and Energy Resources, Yogyakarta, p. 42 – 46, 2001.

van Bemmelen, R.W., *The Geology of Indonesia Vol. IA General Geology of Indonesia and Adjacent Archipelagos*, 2nd ed., Martinus Nijhoff, Den Haag, 1970.

Wilson, J.L., *Carbonate Facies in Geologic History*, Springer-Verlag, Berlin, 1975.

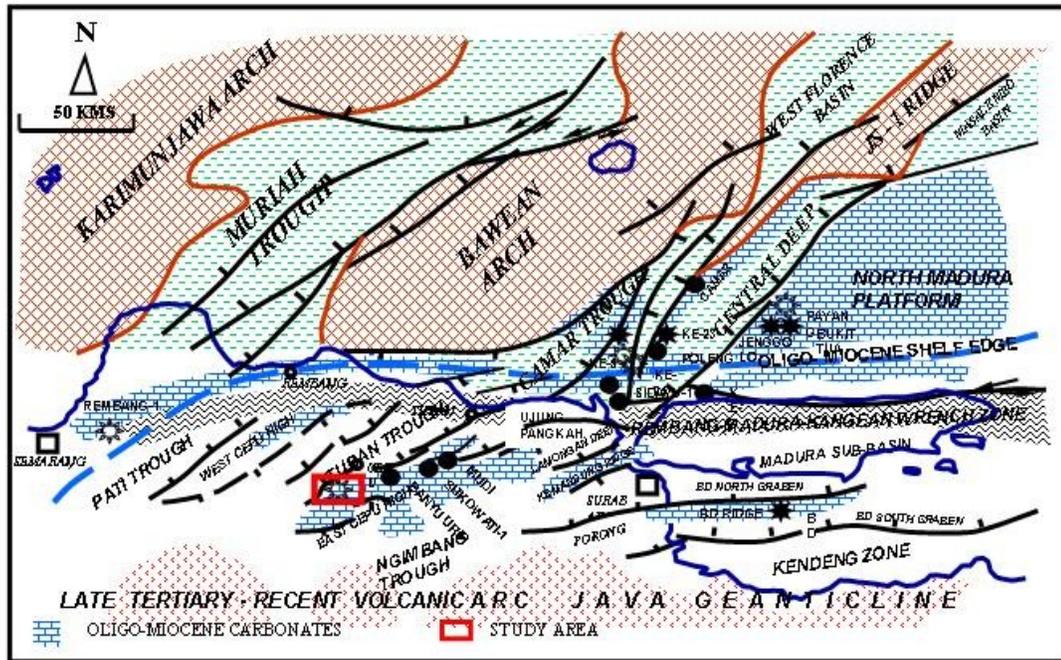


Figure 1 Geologic setting of the East Java Basin (Satyana dan Darwis, 2001).

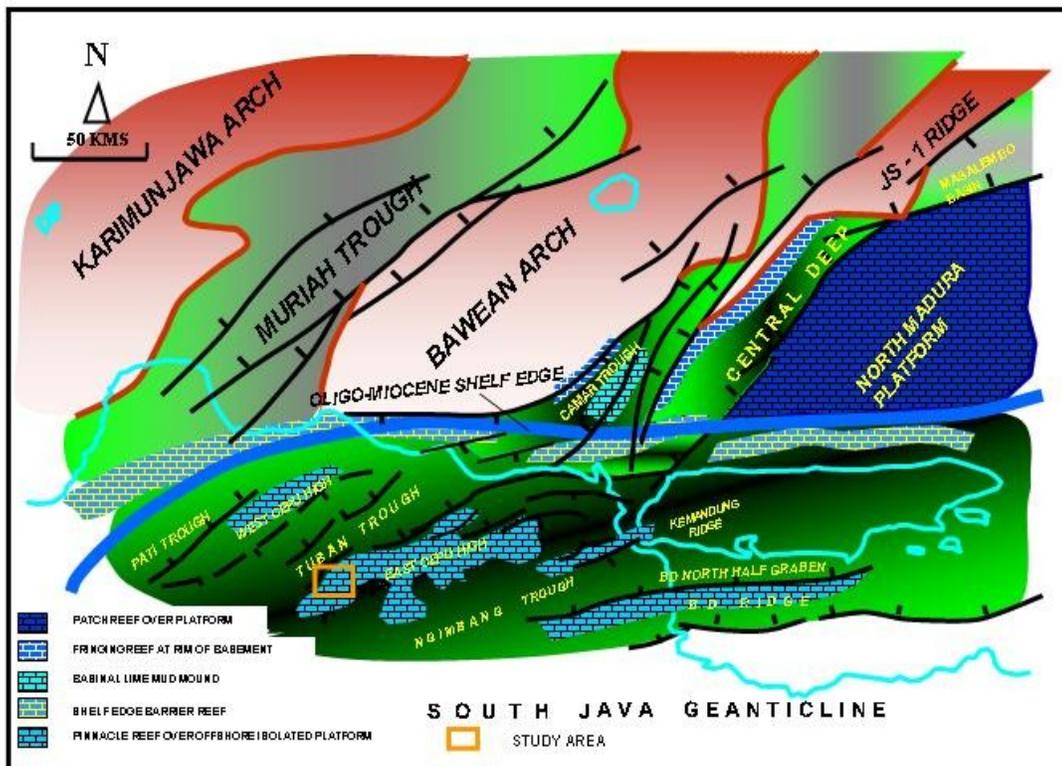


Figure 2 Location of study area within regional Oligo-Miocene carbonates of East Java Basin

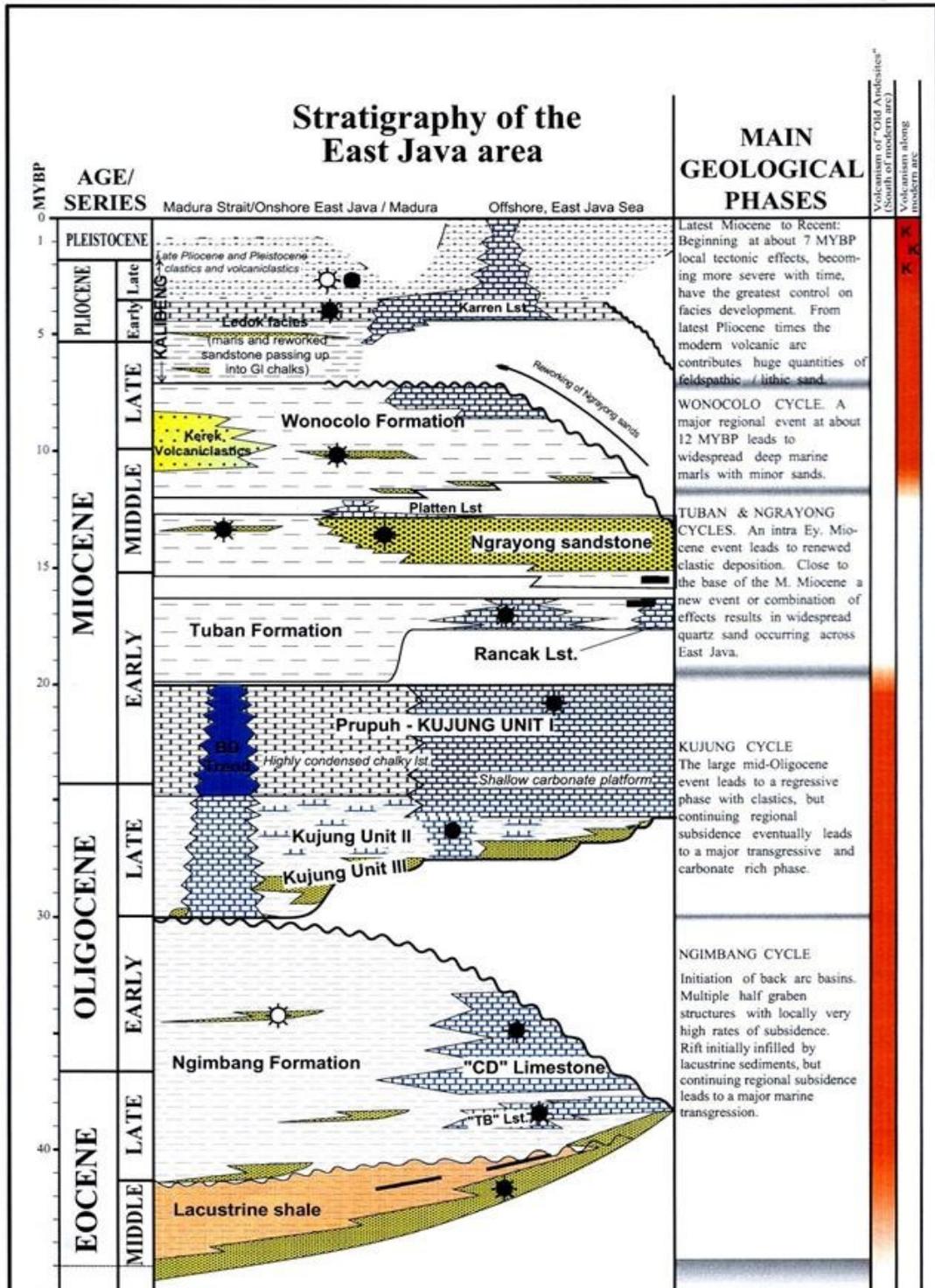


Figure 3 Stratigraphy of the East Java Basin (courtesy of Gulf Ketapang)

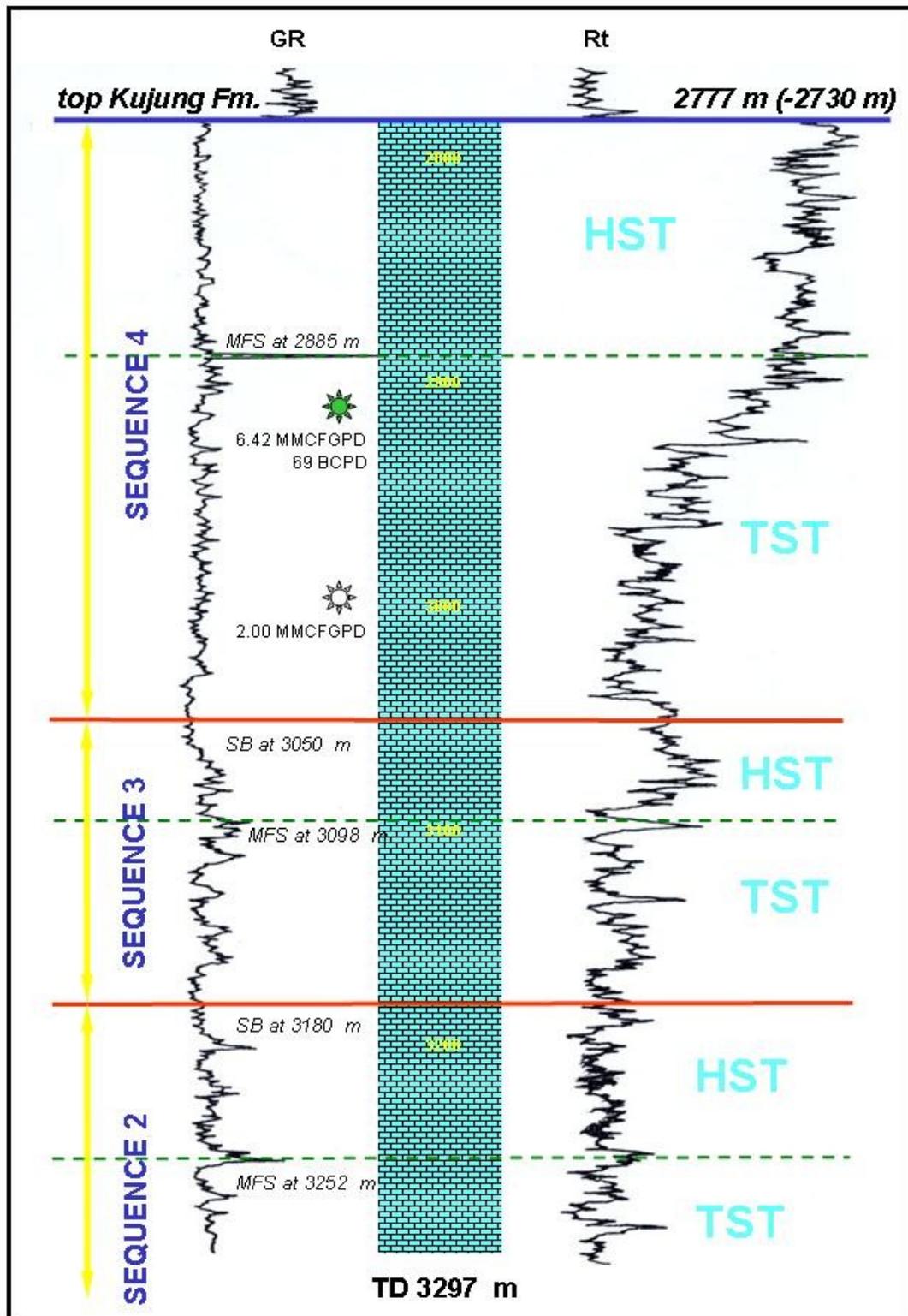


Figure 4 The distribution of depositional sequence in the study area based on "Beta-1" well log analysis.

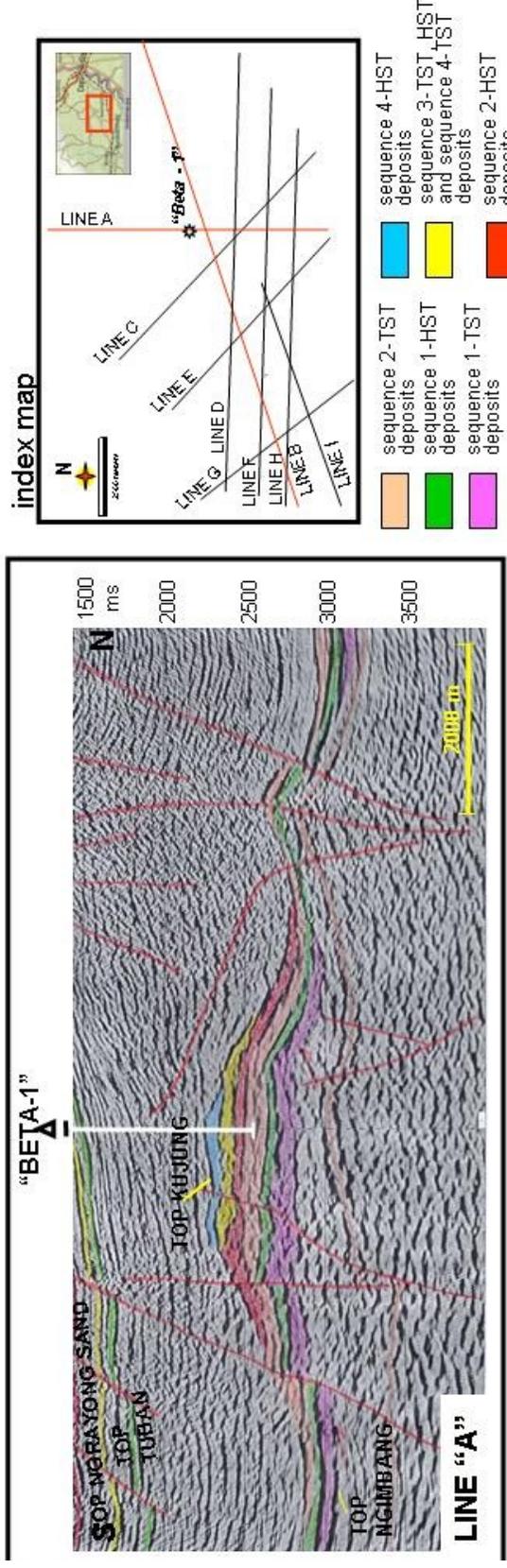


Figure 5 The division of depositional sequences in the seismic line "A".

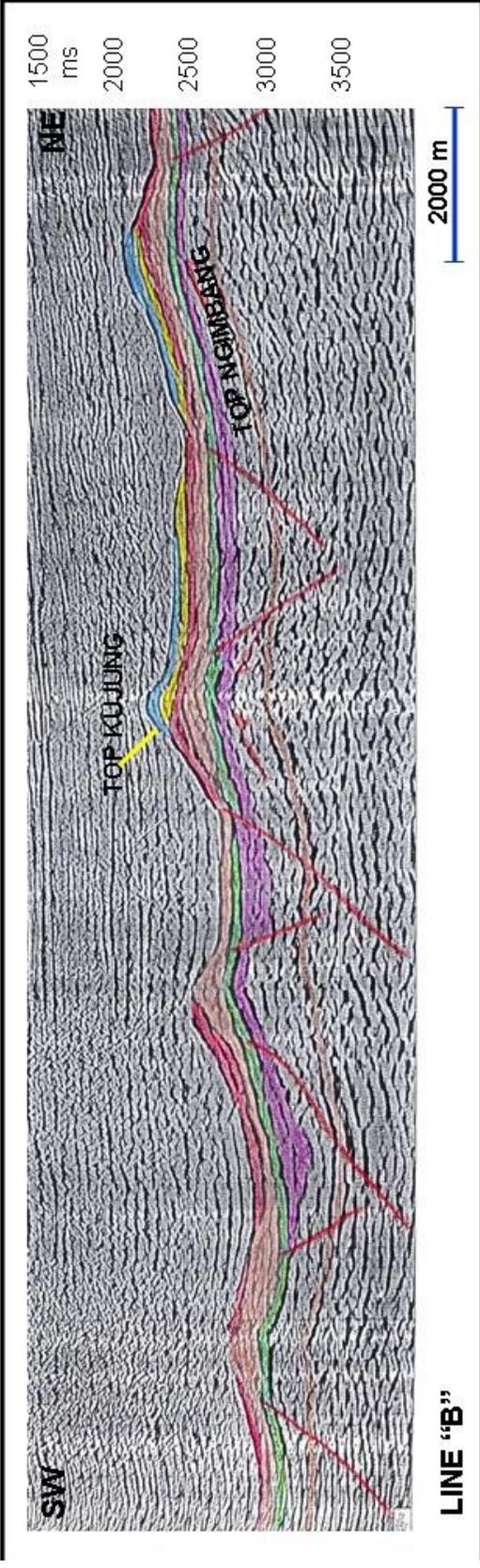


Figure 6 The northeast-southwest trending showing the lateral distribution of depositional sequences in the seismic line "B".

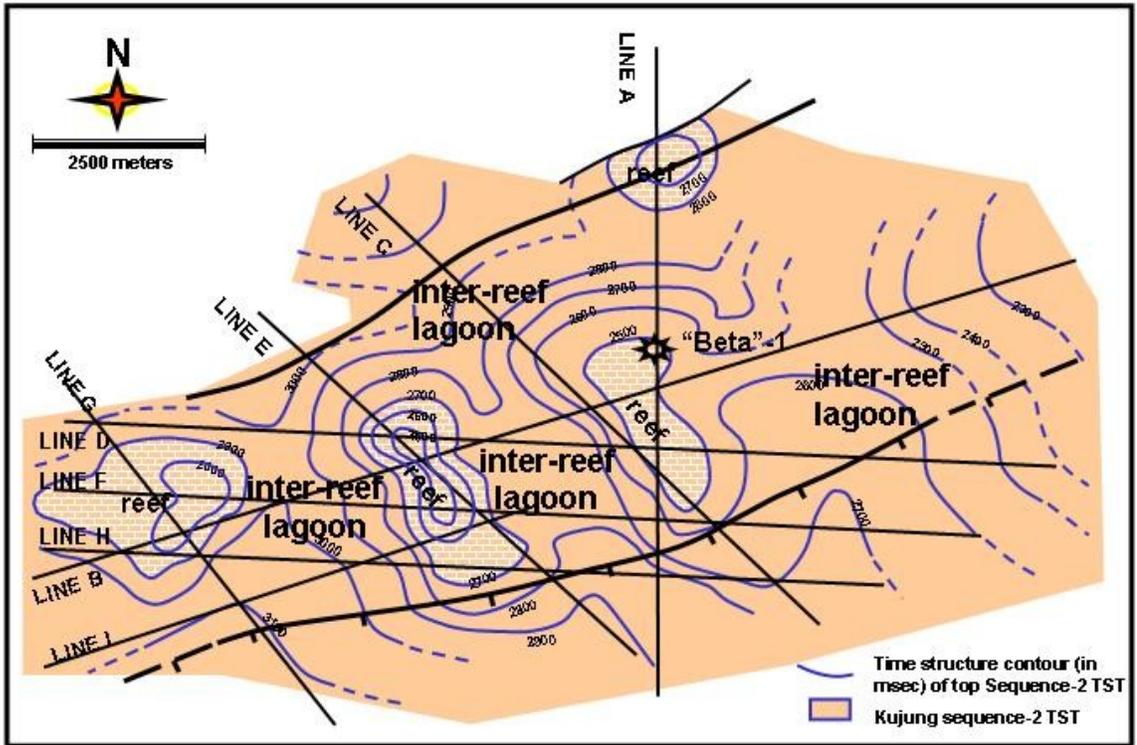


Figure 7 Distribution of facies and sequence 2 TST of Kujung Formation in the western East Cepu High area.

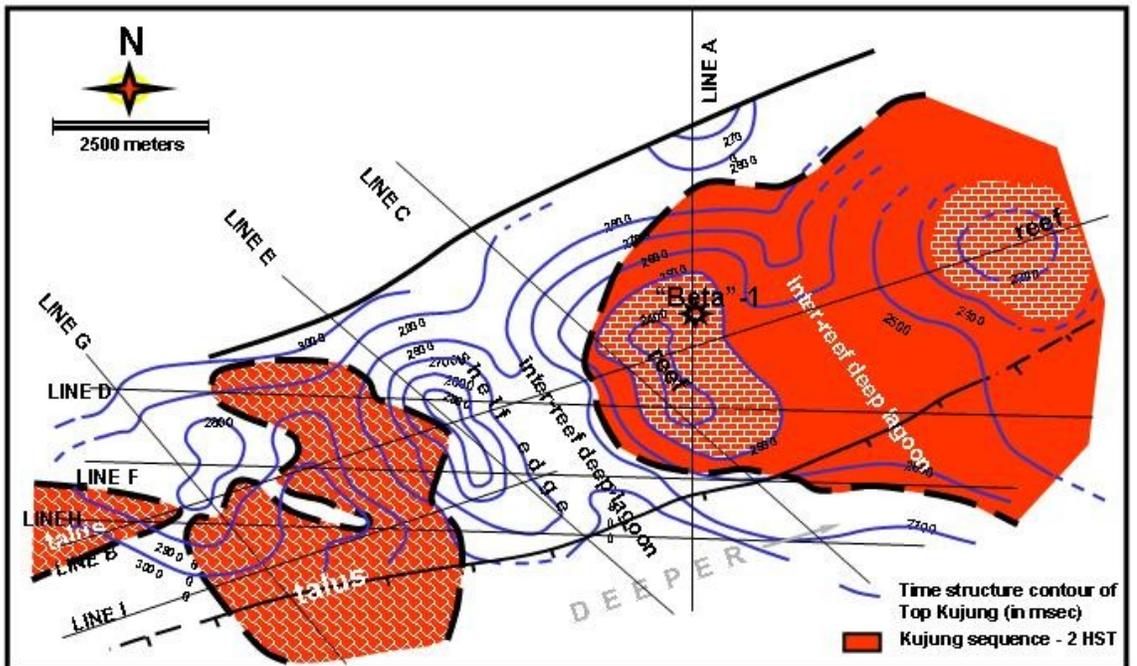


Figure 8 Distribution of facies and sequence 2 HST of Kujung Formation in the western East Cepu High area.

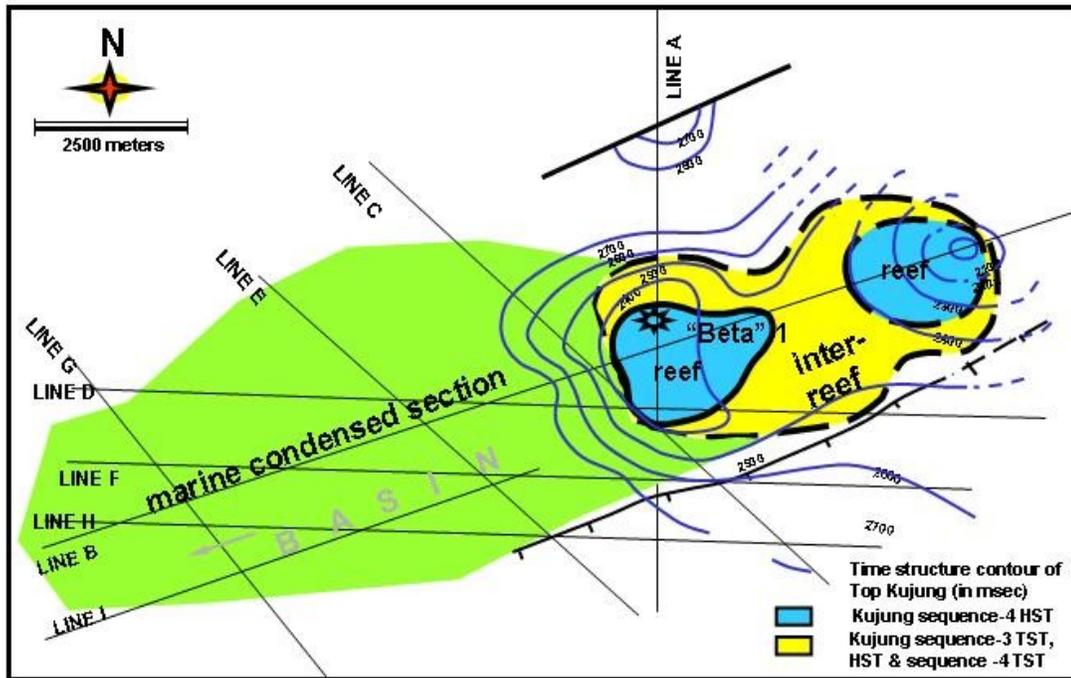


Figure 9 Distribution of facies and sequence 3 TST to Sequence 4 HST of Kujung Formation in the western East Cepu High area.

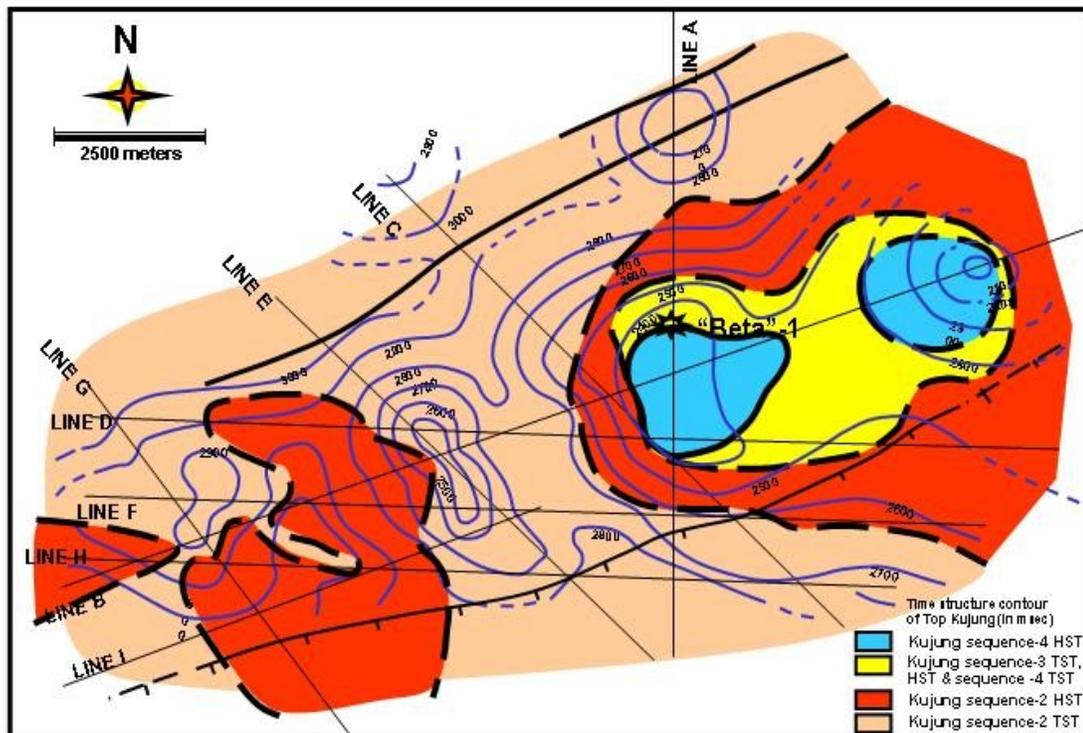


Figure 10 Distribution of sequence 2 TST to sequence 4 HST of Kujung Formation in the western East Cepu High area.

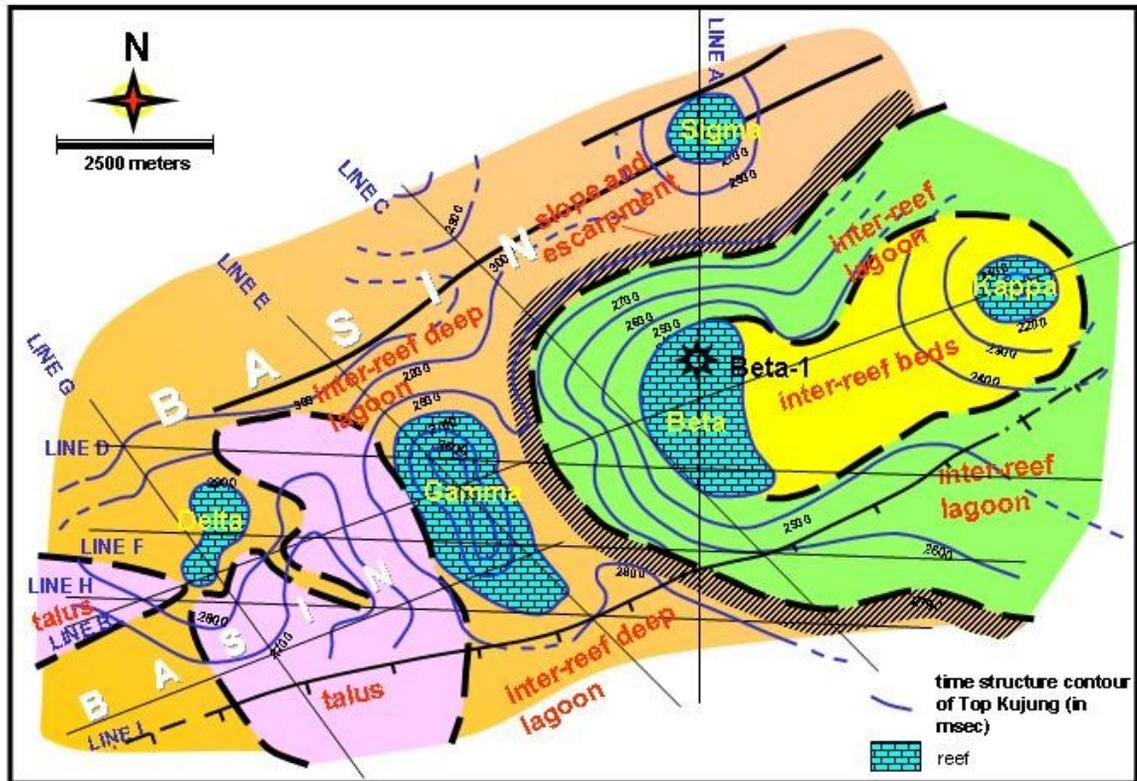


Figure 11 Carbonate facies map at top of Kujung Formation in the western East Cepu High area.

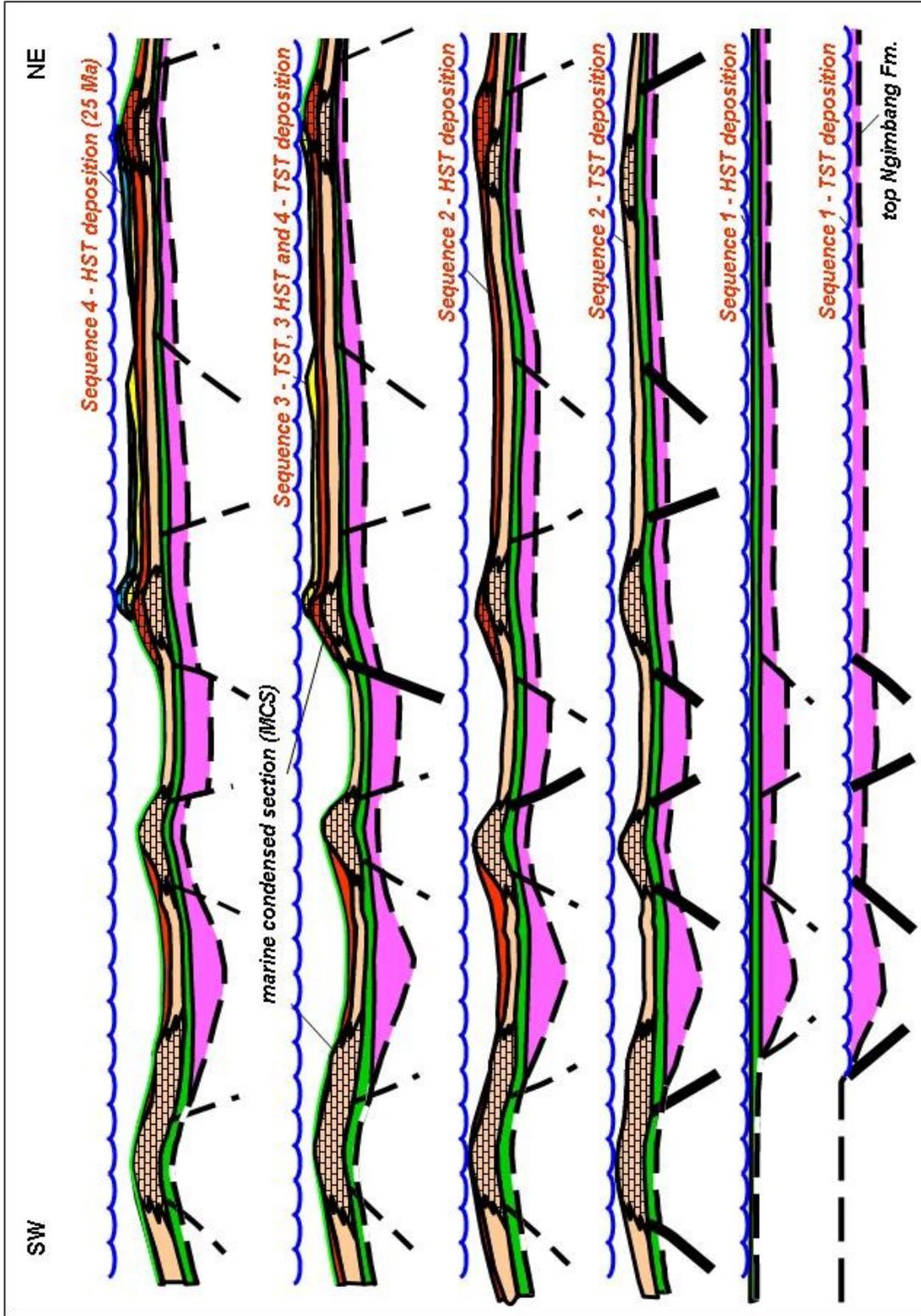


Figure 12 Evolution of the Kujung reef complex in the western East Cepu High area, East Java Basin.