THE SHOREFACE - FAIRWEATHER WAVE BASE ENVIRONMENT OF THE MID-MIOCENE SANDSTONE IN THE CENTRAL PART OF THE MADURA ISLAND

by

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I. INTRODUCTION

As mentioned in the previous paper (Endharto, 2005) this paper is part of the series of the depositional model of the Ngrayong Sandstone, which takes part especially in the central part of the Madura Island. This study also examines physical evidence of the best exposure of the study area.

The central part is located between 07° 01' 18" S - 113° 32' 56" E and 07° 04' 55" S - 113° 36' 54" E, covering the area of Tanjung - Pasean to the north and Mentok - Kertengeneh - Sentol to the south. (Figure 1)

The Geological work was carried out during June - July 2005, where the particular attention was concentrated within the central region of the island. There are 3 major key outcrop areas were studied and assigned for the depositional setting of this area (i.e., Tanjung toward Pasean River, Mentok - Kertengeneh Oil Field and Sentol Daya sections).

This worked has attempted to sort it out both vertical and horizontal sections with applying the stratigraphic measuring sections (outcrop/surface logs), horizontal distance using passing compass, supported by petrography and paleontology analysis, and trying to look at the internal sedimentological structures to get into broadly image of the depositional system within this area.

II. GEOLOGICAL SETTING

A. *Regional Stratigraphy of the Central Part of Madura Island*

The central part of Madura physiographically incorporates into the Rembang Zone or within the area of back-arc basin setting. Stratigraphic nomenclature of this area correlates to the western portion of this island, which is previously mentioned. Lithostratigraphy names are previously used for Madura Island or East Java Basin, shown in Figure 2 is acceptable for the regional correlations.

The objective of this study is to reconstruct how well the Ngrayong Sandstone was deposited in order to make a plan for the hydrocarbon exploration in the near future as the best reservoir candidate especially in Madura and its surrounding area.

The oldest unit of the regional stratigraphy successions that exposed scattered throughout the Madura Island is the Tawun Formation, which is comparable to the Tuban Formation, introduced by Pringgoprawiro (1980) in Tawun District near Jatirogo, East Jawa. The lithology consists predominantly of silty mudstone with sandstone intercalations and limestone. Trooster (1937), Vischer (1951) and Koesoemadinata (1969) named Boven Orbioten Kalk or Kalksteenen Upper OK or Lower Rembang Bed (Bemmelen, 1949). Based on foraminifera contents imply that the formation is early Miocene age with total thickness 1500 m (Pringgoprawiro, 1983) and was deposited in inner shelf to outer shelf. The formation is widely distributed east - west direction and occupying the northern of the central part of the island. Near Kombangan area The Ngrayong Sandstone and interdigitating conformably overlie the Tawun Formation in part. To the east within the GRDC geological map of the Tanjungbumi and Pamekasan sheet, scale 1:100,000 by Azis, et.al., 1993, indicates that the Ngrayong Sandstone as a sequence consisting predominantly of sandstone with clay intercalation gradually sandy marl and limestone upper part. Quartz sandstone is light brown, medium coarse grained, with east - west distributions (in the middle of geological map; G. Langgulang - G. Tanggeranyar) pursuing the outer inner limb of the anticlinorium and synclinorium plunging systems, which overlies the Tawun Formation.

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The Ngrayong Sandstone subsequently unconformable (fauna hiatus) overlain by the Bulu Formation, the lithology contacts between those two formations are not well exposed. Late middle Miocene age was acknowledged for the Bulu Formation that comprises primarily of sandy limestone at the base, marl intercalation and the whole up section dominated by packstone to wackstone with platen formed, coralline algae fragments are also common. This unit was deposited in middle neritic zone and the thickness reaches c. 200 m. The overlying unit is the Madura Formation correlate to the Kawengan Formation (well exposed in NE Jawa Basin) consists of reefal limestone, sandy limestone and marl. This unit is assigned to be Mio-Pliocene age and was deposited in littoral - sublittoral. The thickness of the unit attains 250m, eastward - westward distribution and occurs along the north coast and in the middle throughout the mainland.

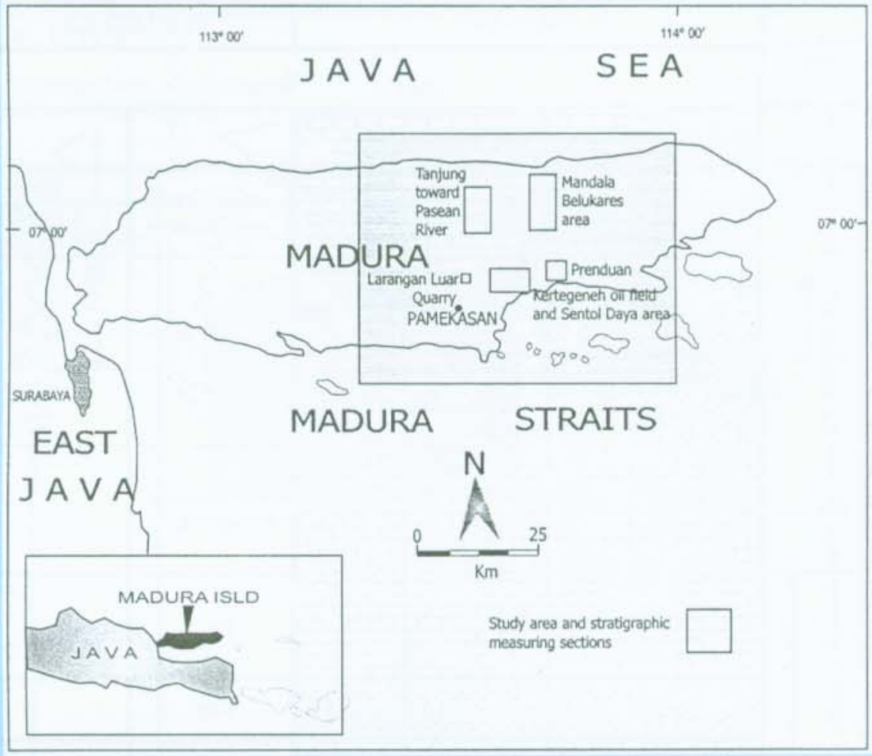

Figure 1
Location map of study area and showing detail measurement of the representative stratigraphic sections, Madura Island

The youngest rock formation of the Madura Stratigraphic sequences is the Pamekasan Formation or comparable to the Kabuh Formation in the NE Jawa Basin composed of claystone, greenish grey, slightly indurated, well bedded (cm-dm bed thickness), columnar and fibrous gypsum like mineral (diagenetic) product and contains molluscs (gastropod and pelecypod). Age determination is difficult due to lack of fossil contents. Koesoemadinata (1969); Pringgoprawiro (1980) propose Pleistocene for that unit and was deposited in littoral environment.

B. *Structural Geology of the Central Part of Madura Island*

An elongated east - west trending structural pattern of the anticlinorium and synclinorium systems with gently limb in both sides and the axial traces are gently plunging, in central part of the island is continuation to the east of the regional structural style of the NE Jawa Basin. This general fold axis pattern is consequently resulted from compressive stress north-south direction due to the northward facing subduction system of the Australia-India plate under the Eurasia plate and its part of the back-arc basin. The observation taken from the field shown that the dip ranges between 10° - 25°. Other structural features are well develop of faults which commonly intersect the main structure with NNE - SSW trend. The faults occur within this area are mainly strike slip, normal and reverse. Most of the structural systems develop within the study area when in the early Pliocene was period where major compression commenced. Wrenching and uplift inversion of the Eocene-Miocene basin south of Madura leads to a series of regressive and transgressive cycles. Facies changes were initiated by the emergence of the volcanic clastics in Pleistocene time especially in the NE Jawa Basin marked by the precipitation of the Lidah Formation.

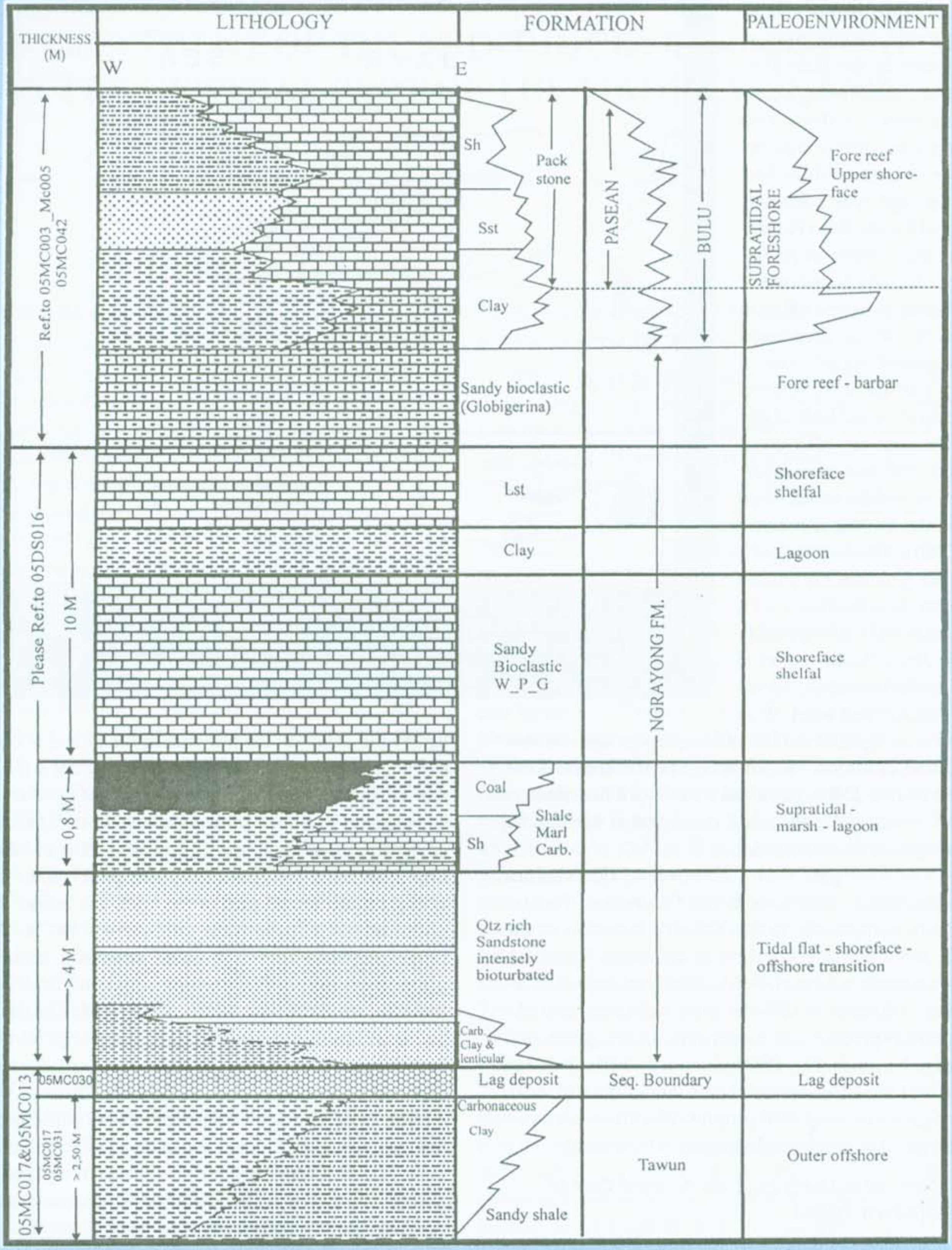

Figure 2
Stratigraphic regional of Madura Island (Endharto, 2005)

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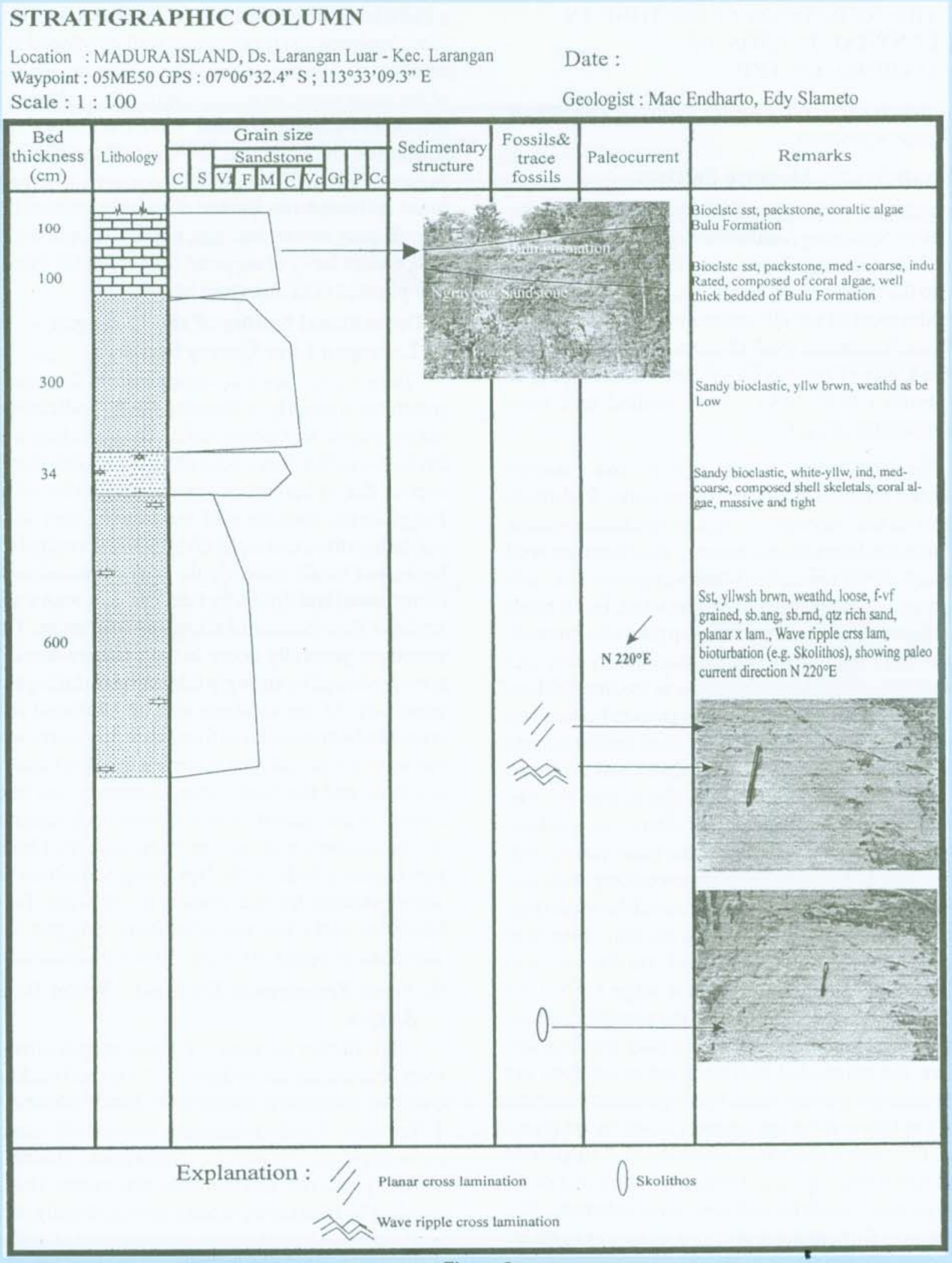

Figure 3
Stratigraphic column of the Larangan Luar section where the Ngrayong Sandstone overlain by Bulu Formation (top), the outcrop is typical of the tidal flat environment

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III. DEPOSITIONAL SETTINGS OF THE NGRAYONG SANDSTONE IN CENTRAL REGION OF MADURA ISLAND

A. *Larangan - Larangan Luar, Pamekasan Quarry Section*

1. Stratigraphic Measure Sections

Larangan - Larangan Luar quarry is one of the excellent Ngrayong Sandstone exposures in Madura other than Gunung Geger waterfall outcrop is situated to the northwest of Pamekasan. This sand quarry provides most (if not all) sedimentological aspects of the rock formation, total 15 m thick of quartz sandstones facies of the Ngrayong Sandstone dipping to the south (090°/20°S), cross-bedded and very bioturbated (Figure 3).

The sand quarry is light brown (iron staining) coloured, friable (indurated- upper part), well-moderately sorted, subangular, slightly micaceous-quartz rich arenite. Internal sedimentary structures are well exposed within arenaceous facies exposure (i.e., low angle trough, large-small cross-bedding, ripple cross lamination, thin clay drip and rip-up clast also present). The north-south cliff trending sand quarry displays bioturbation assemblages possibly as feeding field occupying especially in the northern portion/bottom part of massive arenaceous (c. 2m thick of bed thickness) beds contain of Planolites, Chondrites and Skolithos burrows. An Ophiomorpha ichnofacies was also observed. Internal sedimentary structures are well developed in the south portion of the sand quarry cliff, comprised of planar/tabular cross bedding with significantly paleocurrent direction toward the south (Figure 3 - stratigraphic column and photos). Thin mud drapes occurred upon the foreset (on the lee face) indicates the subordinate current stage eroded the lee face of the dunes formed by the preceding dominant current, reactivation surface may produce and where the suspended sediment concentrations are high enough, during slack water periods. This feature implies that the deposition caused by tidal current. This such condition in which the high suspended load concentrations was formed by combination of low current velocities and low wave intensity after the storm. Bottom portion of the quarry at northern end characterized by good exposure of the bioturbation bedding surface (<2m thick of feeding field) possibly indication of short period of depositional gap. Unlike in northern end of the quarry, the significant some of the internal structures (i.e., ripple cross laminations) is obviously well developed at the southern end of the quarry. These features represent of the wave-ripple cross lamination settings/variations produced by unidirectional wave oscillatory flows (Collinson and Thomson 1987, R.G. Walker and N.P. James, 1992) include undulatory/wavy and irregular lower set boundaries formed discordant internal laminae, draping foreset laminae, opposed ripple lamination, dissimilarity of adjacent ripples, and commonly complicated of in mix cross lamination.

2. Depositional Setting of the Larangan - Larangan Luar Quarry Section

Based upon well development of the internal structures southerly of the sand quarry indicates that the formation was deposited on the shoreface at upper fair-weather wave base or seaward direction upsection due to hummocky cross section (h-c-s) free. Progradation formation of sand dune often wiped-out during storm and replaced by storm deposited (e.g., laminated small scale ripple cross lamination and bioturbated) and driven by tidal currents with a much stronger flow current to southward direction. These structures generally occur in the offshore-transition zone produced by strongly tidal current during storm condition. At the southern section exhibited ripple cross lamination and was formed during storm where the wave action induced sediment transport upon the sea floor and the tidal current becomes less strong current in the offshore zones to form such structures. To the northern end section of the quarry or bottom part of sandy beds of the Ngrayong Sandstone were demonstrated by the presences of trace fossils Skolithos and Cruziana ichnofacies suggest lower shoreface to upper offshore or shelf environment.

B. *North Kertengeneh Oil Field - Sentol Daya Section*

1km further up road off Kertengeneh cross the river, underneath the bridge a well-exposed packstone overlies the sandy shalestone. Sandy shalestone, 1.30m thick, light brownish grey (indurated), massive, carbonaceous, micaceous, calcareous, moderately sorted, quartz rich and less lithic fragments. This unit overlain by packstone, reddish brown, slightly weathered, contains large forams, grain supported, and also occurred overlying micritic sandstone, light grey, slightly indurated, contains fine quartz, micaceous and carbonaceous.

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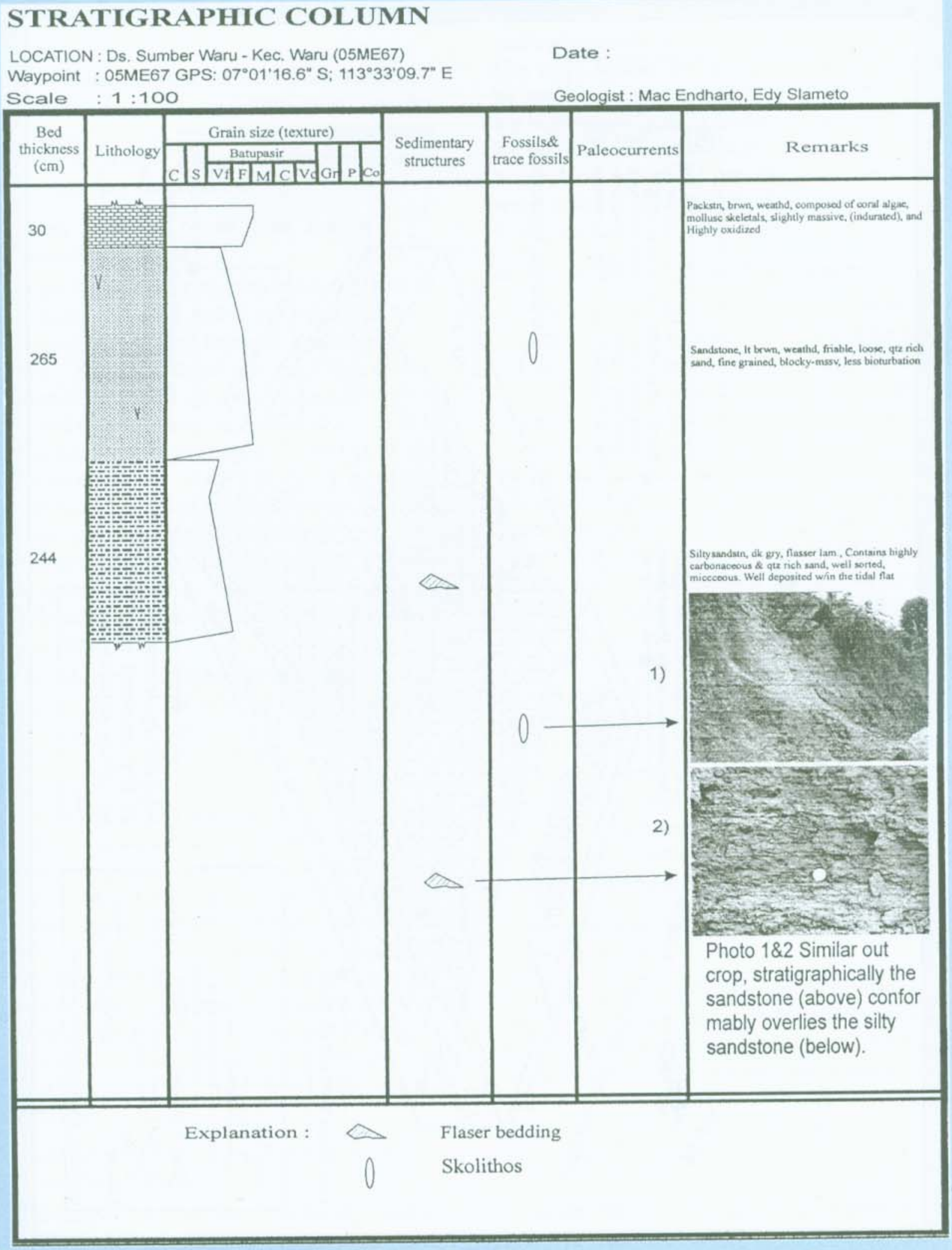

Figure 4
Stratigraphic column of the Desa Sumberwaru, Kec. Waru, Madura section demonstrates that the sequence was deposited within the surface - fair-weather wave base

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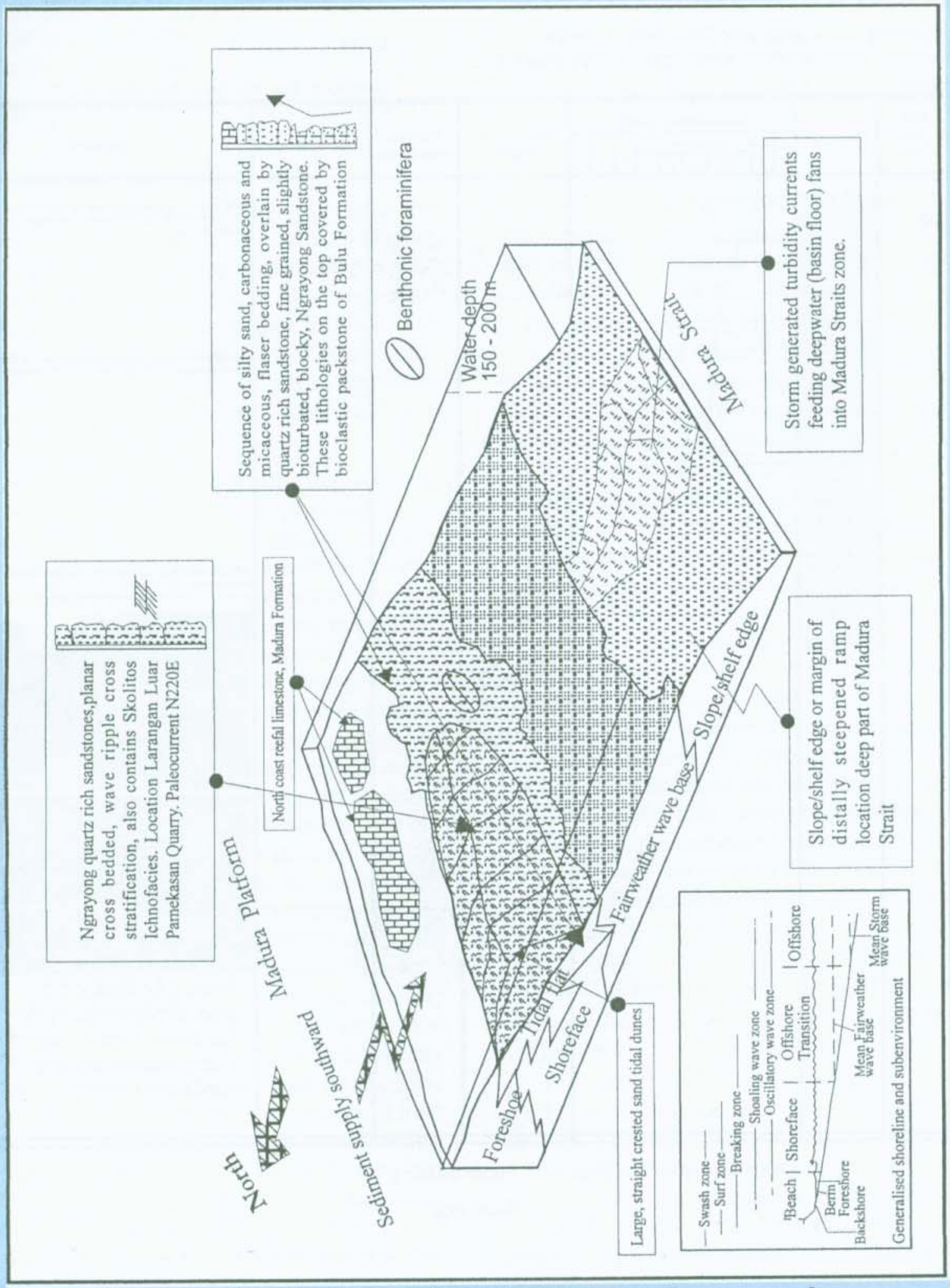

Figure 5
Depositional model for the Ngrayong Formation and simplified logs for early Middle Miocene for Madura Island and Madura Straits

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1. Depositional Setting of the North Kertengeneh Oil Field - Sentol Daya Section

Shallow marine within the offshore transition-lower shoreface high energy (storm wave base) for the transportation to precipitate the packstone/grainstone, shallowing upward (upper portion) with sandier calcareous mudstone on top.

C. *Tanjung Area and North Road Toward Pasean/North Coast*

The geological traverses were following the road cut exposures along the end of the small road track near Tanjung village well exposed of coarsening up sequence 7-8m thick. Basal portion of this section comprises of individual coarsening upward cycles c. 40-50m bed thickness, passing up into lenticular bedding fine sandstone in claystone and finally to thin bed of fine sandstone. More fine quartz sandstone lenticular and wavy bedded within claystone occurred in the upper portion of this section. Primary sedimentary structures (i.e., ripple cross lamination) was also present and evidenced by ripple section signify an originally tidal influence or possibly wave induced oscillatory currents.

Near Muteh-Panglaraan small village group, Tanjung district well exposed of the sandstone sequence (road cut section coordinate 07° 02'42" S & 113°26'10"E; strike/dip N100°E/08°), steeply cliff section of dark brown, parallel laminated shale (basal part), friable, slightly weathered, contains fine quartz, lithic, and micaceous, coarsening upward, 40 - 50 cm bed thickness, passing up into lenticular bedding fine sandstone/shalestone in claystone and finally to thin bed of fine sandstone, total thickness of bottom section 500 - 600 cm thick. Upper section contains of dark brown (iron staining), fine sand, lenticular and wavy bedded with mud drape on top within claystone. On top this sandstone bed well developed of the wave ripple cross lamination with the 7 cm apart ripple crest form discordant laminae, bi-directional upward bundled lenses.

1. *Depositional Setting of the Tanjung Area - Pasean/North Coast*

This spot section specifies a low energy offshore depositional setting below fair-weather wave base where the fine grained mud were deposited during fair-weather condition. Sharp base occurs when the argillaceous sediment abruptly contact into more sandier lithology upward marked by mud drape within the wavy bedding. This coarsening upward indicates shallowing condition of the depositional environment (2m more sandier bedded upper part) accentuated by smaller scale cycle and abruptly deepening. During high energy periods produced ripple cross lamination siltstone and sandstone on upper portion. The depositional processed possibly associate with the wave induced current (?shoaling) reached surface of the seafloor.

D. *Pasean River - North Coast Section*

The traverse shifted to the main south-north direction toward the Pasean river area a series of road site outcrops were observed individually (07° 01' 18" S & 113° 32' 56" E; trike/dip: 080°/28°S). The traverse began on southern limb of major E-W trending anticline. The lithology is characterised by predominantly thickly bedded grainstones with good porosities overlie packstone of Bulu Formation. Down to north - eastwards section fining-up sequence (2m thick), sharp based sandy foram grainstone beds and overlain by dark grey silty mudstone and fine grained bioclastic sandstone contains occasionally resin nodules/fragments. Further to north (down section) small sand quarry was surveyed comprised of friable shelly fine quartz sandstone. Large blocks contain Thallasinoides burrowed grainstones were also present (07° 01' 08" S & 113° 33' 22" E). Down to anticline core, the rocks made-up of siltstone and silty marls with calcite diagenetic. Small cycles of bioturbated free calcareous with sharp based fine sandstone passing up into very nodular (weathered) and intensively bioturbated beds appeared on the northern anticline limb.

1. Depositional Setting of The Pasean River - North Coast

Tanjung-Pasean River traverse reveals sedimentary rock sequences that were deposited under influence of an offshore storm induced the offshore transition environment within the area of fairweathered and storm wave bases (Figure 4). The storm current driven deposition of the bioclastic debris (i.e., benthic forams) had produced sandy grainstone and fining upward sequences (07° 01' 16" S & 113° 33' 15" E; strike/dip: 080°/34°S). High-energy deposition represented by hard part of sharp-based sandstone. During lower energy periods yielded the bioturbated facies (thick bioturbated layers) that tend to decrease to landward.

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IV. CONCLUSION

The depositional model of The Ngrayong Sandstone of the central part of the Madura Island is signified by some of the studied areas from The Larangan Luar sand quarry, the North Kertengeneh oil field-Sentol Daya, the Tanjung area-Pasean/North Coast, and the Tanjung-Pasean River, well explained by the occurrences of some sedimentary structure indicators and bioturbation structures which are well developed within the fine-coarse grained clastic sedimentary rocks. Initiated from the southern regions the internal sedimentary structures indicate that the formation was deposited on the shoreface at upper fair-weather wave base or seaward direction up-section due to hummocky cross section (h-c-s) free (Figure 5). Progradation formation of sand dune often wiped-out during storm and replaced by storm deposited (e.g., laminated small scale ripple cross lamination and bioturbated) and driven by tidal currents with a much stronger flow current to southward direction. These structures generally occur in the offshore-transition zone produced by strongly tidal current during storm condition. At the southern section exhibited ripple cross lamination and was formed during storm where the wave action induced sediment transport upon the sea floor and the tidal current becomes less strong current in the offshore zones to form such structures. To the northern end section of the quarry or bottom part of sandy beds of the Ngrayong Sandstone were demonstrated by the presences of trace fossils Skolithos and Cruziana ichnofacies suggest lower to upper shoreface or shelf environment. To the southeastern part of the central region deposition was shallow marine within the offshore transition-lower shoreface high energy (storm wave base) for the transportation to precipitate the packstone/grainstone, shallowing upward (upper portion) with sandier calcareous mudstone on top. Move to the northern area a low energy offshore depositional setting is considered below fair-weather wave base where the fine grained mud were deposited during fair-weather condition. Sharp base occurs when the argillaceous sediment abruptly contact into more sandier lithology upward marked by mud drape within the wavy bedding. This coarsening upward indicates shallowing condition of the depositional environment (2m more sandier bedded upper part) accentuated by smaller scale cycle and abruptly deepening. During high energy periods produced ripple cross lamination siltstone and sandstone on upper portion. The depositional processed possibly associate with the wave induced current (?shoaling) reached surface of the seafloor. Along the Tanjung-Pasean River (northern portion) the Ngrayong Sandstone outcrops reveal that the sedimentary rock sequences were deposited under influence of an offshore storm induced the offshore transition environment within the area of fairweathered and storm wave bases. The storm current driven deposition of the bioclastic debris (i.e., benthic forams) had produced sandy grainstone and fining upward sequences. High-energy deposition represented by hard part of sharp-based sandstone. During lower energy periods yielded the bioturbated facies (thick bioturbated layers) that tend to decrease to landward.

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