THE PALAEOENVIRONMENTS AND DEPOSITIONAL MODEL FOR THE NGRAYONG SANDSTONES AN OUTCROP STUDY IN EASTERN PART OF THE MADURA ISLAND AS A REFERENCE

by
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I. INTRODUCTION

This topic is the most eastern portion of the series depositional model of the Ngrayong Sandstone, which well develops particularly in Madura Island. This study is also observing both vertical and horizontal sequences of the sedimentological aspects and its geological associations of the Ngrayong Sandstone outcrops.

The eastern part is situated between 06° 58' 10" S – 113° 46' 16" E and 06° 59' 47" S – 113° 56' 09" E, that covers the eastern studies area i.e., Mandala –Belukares and Prenduan to the west and Banjar Barat – Gapura – Sema to the eastern margin (Figure 1). These areas are also exemplifying the eastern most of the Ngrayong Sandstone depositional setting.

Like most of the previous Ngrayong Sandstone Studies of these series is to consign the sandstone deposition aspects especially in the main land of Madura to obtain good affiliation within the basin configuration related to hydrocarbon exploration in this region. The worked was converged on the Ngrayong Sandstone exposures to investigate the depositional style of the sandstone in the eastern portion of the island. The data mostly obtained from direct measurement of even single section of the outcrop, paleocurrent analysis and sedimentary structure, collecting the rock samples for petrographic study to see the modal analysis, diagenesis, and reservoir characteristic.

II. GEOLOGIC SETTING

A. *Regional Stratigraphy the Eastern Part of The Madura Island*

The eastern portion of Madura sratigraphically is still integrating with the most common other part of the island (i.e., western and central parts) and also physiographically interrelated to the Rembang Zone to the west. The lithostratigraphy nomenclatures and names suggest to previously use for Madura Island or Northeast Java Basin. Figure 2.

The main purpose of this study is to treat the Ngrayong Sandstone as the best sedimentary clastic reservoir candidate for hydrocarbon exploration in the NE Java and Madura Basins. By knowing the sandstone exposure characteristics will simplify the subsurface geological worked in the near future.

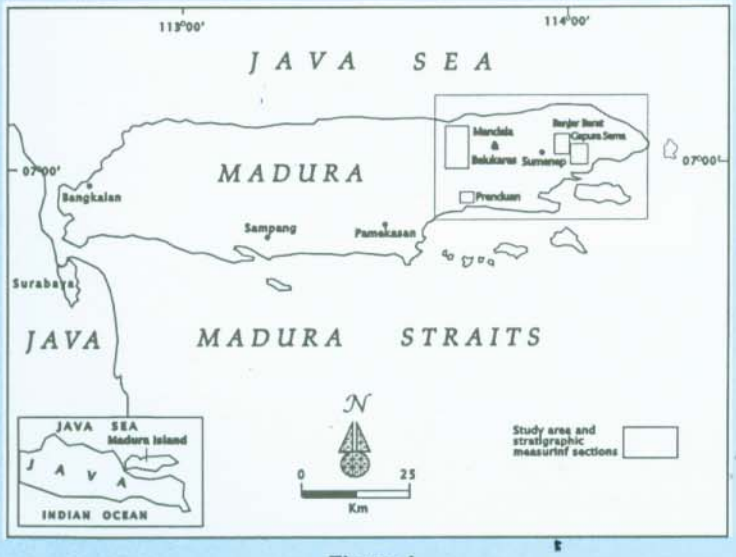

Figure 1
Location Map

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 29. NO. 2, AUGUST 2006: 34 - 45

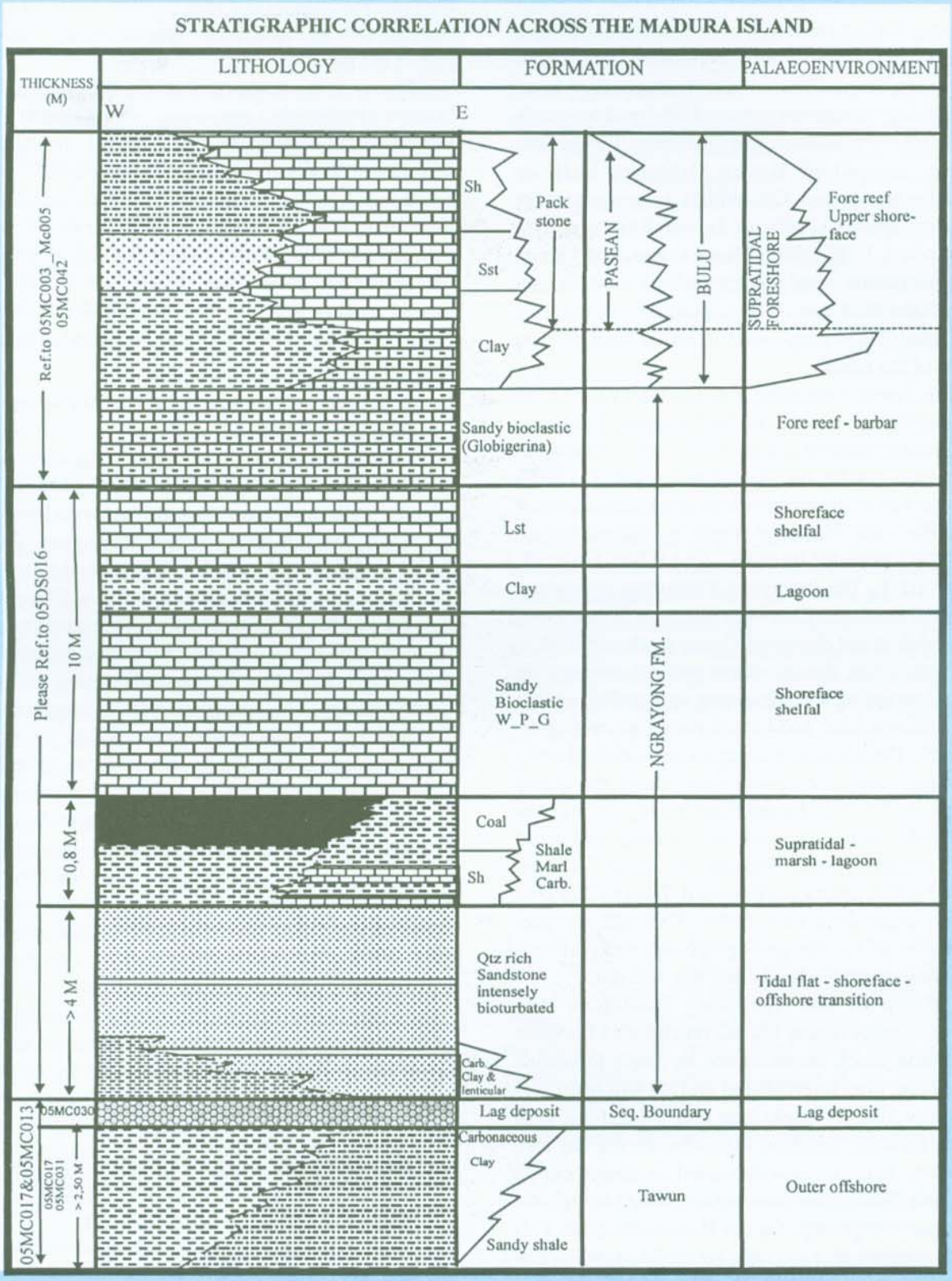

Figure 2
Stratigraphic correlation across the Madura Island

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

Similar to the central and to the west parts of the Madura, the eastern portion the oldest rock exposed is Tawun Formation or Tuban Formation in NE Java Basin as suggested by Pringgoprawiro (1980) well exposed in Tawun District near Jatirogo, East Java. The lithology comprised mainly of silty mudstone with sandstone intercalations and limestone. Tawun Formation instead of Boven Orbioten Kalk or Kalksteenen upper OK which is proposed by Koesoemadinata (1969) or Lower Rembang Bed (Bemmelen, 1949). Early Miocene age is appointed to this formation based on foraminifera contents with total 1500m thick and was precipitate in inner to outer shelf. Distributed east – west direction parallel to its length of the Island.

The Tawun Formation is conformably overlying and interdigitising in part by the Ngrayong Sandstone as noticed indistinctly as poor lithology contacts between those two formations. Situmorang *et.al.*, (1992) suggests that in the most eastern tip of the geological map, Waru and Sumenep Sheet of Madura Island, 1:100,000, bounded by 6° 50' – 7° 15' S and 113° 13' – 114° 10' E, The Ngrayong Formation comprised mainly of interbedded between quartz sandstone, limestone orbitoid and claystone. Quartz sandstone is white brownish white, fine to coarse grained, subangular, loose, coarsening and thickening up, parallel lamination, cross-bedded, and bioturbation (burrowing organism). The formation contains also orbitoid limestone and claystone (2-4m) thick above the quartz sandstone. The fossil comprised mainly of large forams and less molluscs, corals, echinoids and ostracods implying middle Miocene in age and was deposited within littoral environment. Total thickness of the formation deduced c. 600m. This unit occupies more than half of the geological map and performs the anticlinorium and synclinorium structures.

On top of the Ngrayong Sandstone was unconformably (fauna hiatus) precipitated the Bulu Formation which characterized by sandy limestone at the base, marl intercalation and the whole up section prevailed by packstone and wackstone with platen formed, coralline algae fragments are also common. This unit was deposited in middle neritic zone and the thickness reaches c. 200m. Late middle Miocene is appointed for the Bulu Formation. This unit is conformably overlain by the Madura Formation which is equivalent to the Kawengan Formation (displayed in NE Java Basin) contains of reefal limestone, sandy limestone and marl. This unit is designated to be Mio-Pliocene age and was deposited in littoral – sublittoral. The unit is 250m thick, an east-west spreading throughout the rest of the eastern part of the island.

The covering strata most of the lithology of the Madura stratigraphic sequences is Pamekasan Formation which correlates to the Kabuh Formation in NE Jawa Basin, comprises of greenish grey claystone, slightly indurated, well bedded (cm-dm bed thickness), and also contains columnar and fibrous gypsum like mineral (diagenetic product), molluscs (gastropod and pellecypod). Pleistocene age is suggested to this unit by Koesoemadinata (1969); Pringgoprawiro (1980) and was deposited in littoral environment.

B. *Structural Geology in the Eastern Part of Madura Island*

The regional structural pattern of the study area is still similar to the west and central parts of the island, which is influenced by the east-west trending of the anticlinorium and synclinorium systems. These fold limbs gently in both sides and the axial traces are gently plunging and diminished to the east. These fold axes are as a resulted from compressive stress north-south direction due to the northward facing subduction system between the Australia-India and the Eurasia plates. This structural part is incorporated into the back arc setting of NE Jawa Basin. The strata are commonly gently dipping ranges from 10° to 25°. Other structural features are strike slip, normal and reverse faults that generally intersect the main structure with NNE-SSW trending. Pliocene was the period where the major compression commenced in most of the structural occurrences of the island. Wrenching and uplift inversion of the Eocene-Miocene basin south of Madura leads to a series of regressive and transgressive cycles. In Pleistocene time renowned the facies changes initiated by the emergence of the volcanic clastics that was recognized on the upper portion of the Kabuh Formation, in NE Java Basin, which correlates to the Pamekasan Formation in Madura.

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

A. *Prenduan Section (Road Section)*

Road section traversed from south to north started from Prenduan village poorly exposures of

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

the 3m thick of sand quarry, located in 07° 05' 45" S – 113° 40' 74" E, medium – fine grained, off white to brown quart rich sandstone, iron stained, friable, slightly weathered, well sorted, contains mica and rarely present of grainstone fragments, structureless due to vertical bed burrow (Skolithos).

Depositional Setting of the Prenduan Section (Road Section)

Thick massive sand with obliteration bedding plane due to strongly vertical bed bioturbation of *Skolithos* implies deposited within high energy of lower-upper shoreface condition.

B. *Banjar Barat Section*

River traversed section from south to north. This traverse is predominated by the occurrences of carbonate rocks. The lithology exhibits metre scale, bedded bioturbated sandy grainstone that form prominent bars across the present day stream. This grainstone is interbedded with much less resistant lithology (shalestone). Traverse to the north of this river section reveals sand soil and sand rich alluvium possibly derived from erosionally sand outcrop which poorly exposed. The stratigraphic column is shown in Figure 3 (06° 59' 47" S & 113° 56' 09" E) describes 3 m thick of basal section, above river section of grainstone, tan white brown, slightly indurated, weathered, contains less shells and forams. Subsequently this grainstone overlain by 7 m thick of bedded shales. The rest of the traverse (down stream) was dominated by carbonate rock especially tan white – light brown grainstones, cemented by sparry calcite, and commonly contain coral algae, shells and less forams, *Thalassinoides* ichnofacies dipping to the southeast 060°/20°.

Depositional Setting of the Banjar Barat Section

All the way up traverse predominated by grainstone with abundant and lesser amounts of bioclastic fragments, poorly sedimentary structures due to extensive bed bearing bioturbation of *Thallassinoides* ichnofacies suggests this grainstone was precipitated in high tide of foreshore-upper shoreface.

C. *Gapura-Sema Section*

The traverse is mainly along the river section from south to north which is stratigraphically from older to younger. The exposures are moderate to well exposed.

The traverse is started from near Sema village tracking the up-stream along which the exposures were investigated and describes as follow; claystone, grey, with thin bedded of coarsening upward displays flaser and wavy beddings of siltstone outcrop. Further up-stream the coarsening upward sequences were marked by the shale turning gradationally up to sandstone. The medium grained sandstone beds with showing the sharp base of bioturbated features underlies the claystone. Iron staining and Fe-cementation are common in this unit. Two prominent mediums to coarse quartz sandstone beds are also present and carefully examined due to the meandering river. At the river intersections those quartz sandstones exhibits paleocurrent directions with trending to the south, meant direction 000°-180°. Loading structures are also occurred at the base of the sandstone units designated by flame structures, the movement of the silty claystone signifies these. Old direction of the sequences are well exposed to the up-stream, where planar laminated sandy grainstone overlain by heavily bioturbated low angle trough cross bedded sandy packstone/grainstone. Amalgamated beddings, intervening claystone/mudstone to silty claystone, greyish black colour due to carbonaceous contents, less amount of micaceous with small forams and pyritic nodules are observed in downstream. To the north (upstream) the rock units are predominated by the occurrences of the siltstone and claystone (Figure 4).

Three spots of sulphuric water seeps are recognized along this traverse, all well exposed within the riverbanks. At the MI98_58 (06° 58' 40" S – 113° 57' 48" E) lithified iron rich breccias-conglomerate well visualized with reddish brown iron stained sandstone matrix. This breccias-conglomerate was seen in several places rest angular unconformity on the Wonocolo Formation and is interpreted as river gravels unconformably precipitated during ?Pleistocene on the uplifted, folded and eroded of the Wonocolo Formation. (Figure 5).

Depositional Setting of the Gapura-Sema Section

The sedimentary structures are well developed extensively within the sandy units with variably primary sedimentary structures (i.e., tabular cross bedding, parallel lamination, flasser and wavy bedding) and eroded type (load and shole marking) structures. Other load type sand dewatering/intrusion seen as

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

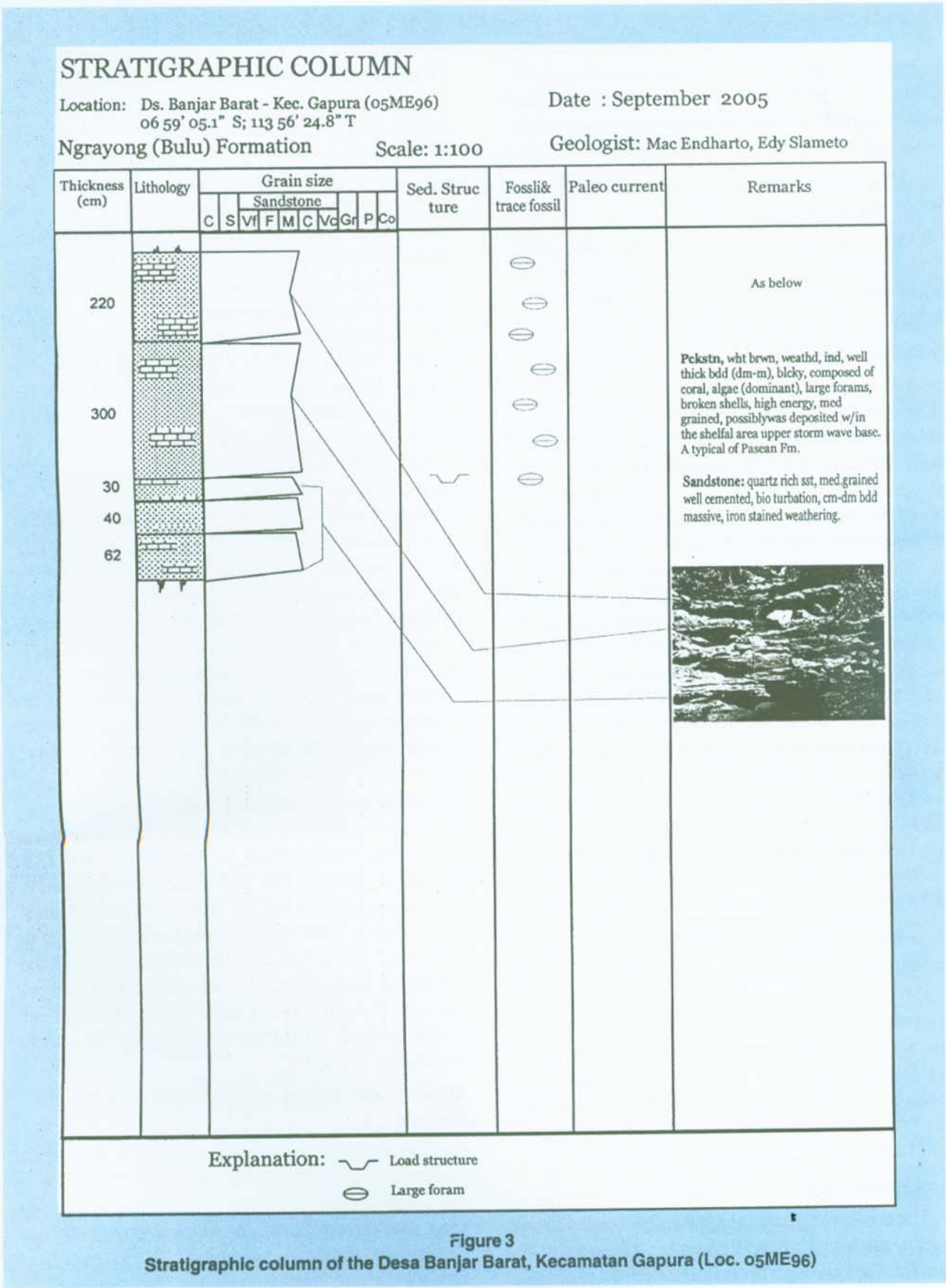

Figure 3
Stratigraphic column of the Desa Banjar Barat, Kecamatan Gapura (Loc. 05ME96)

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

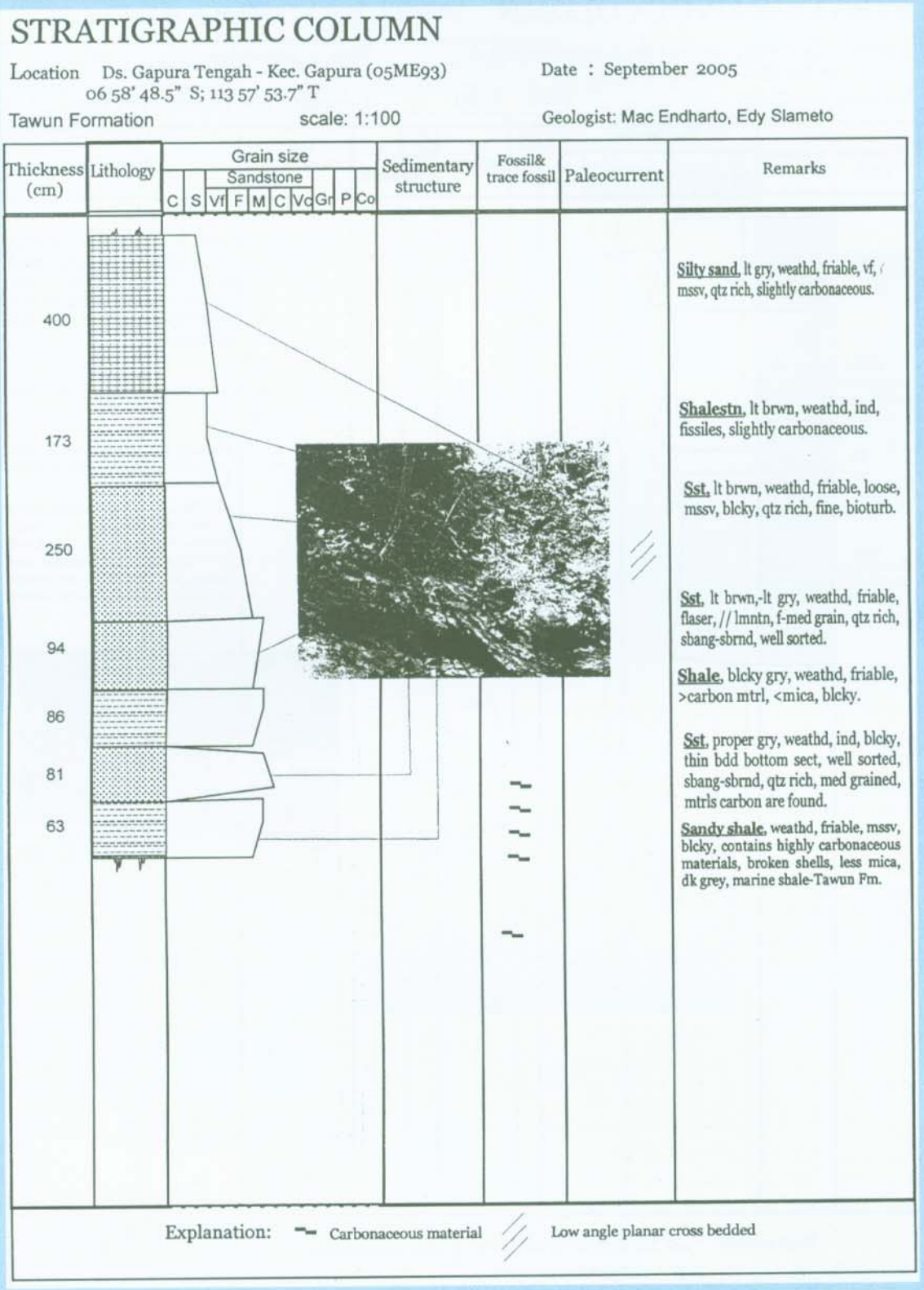

Figure 4
Stratigraphic column of Desa Gapura Tengah, Kecamatan Gapura (Loc. 05ME93)

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

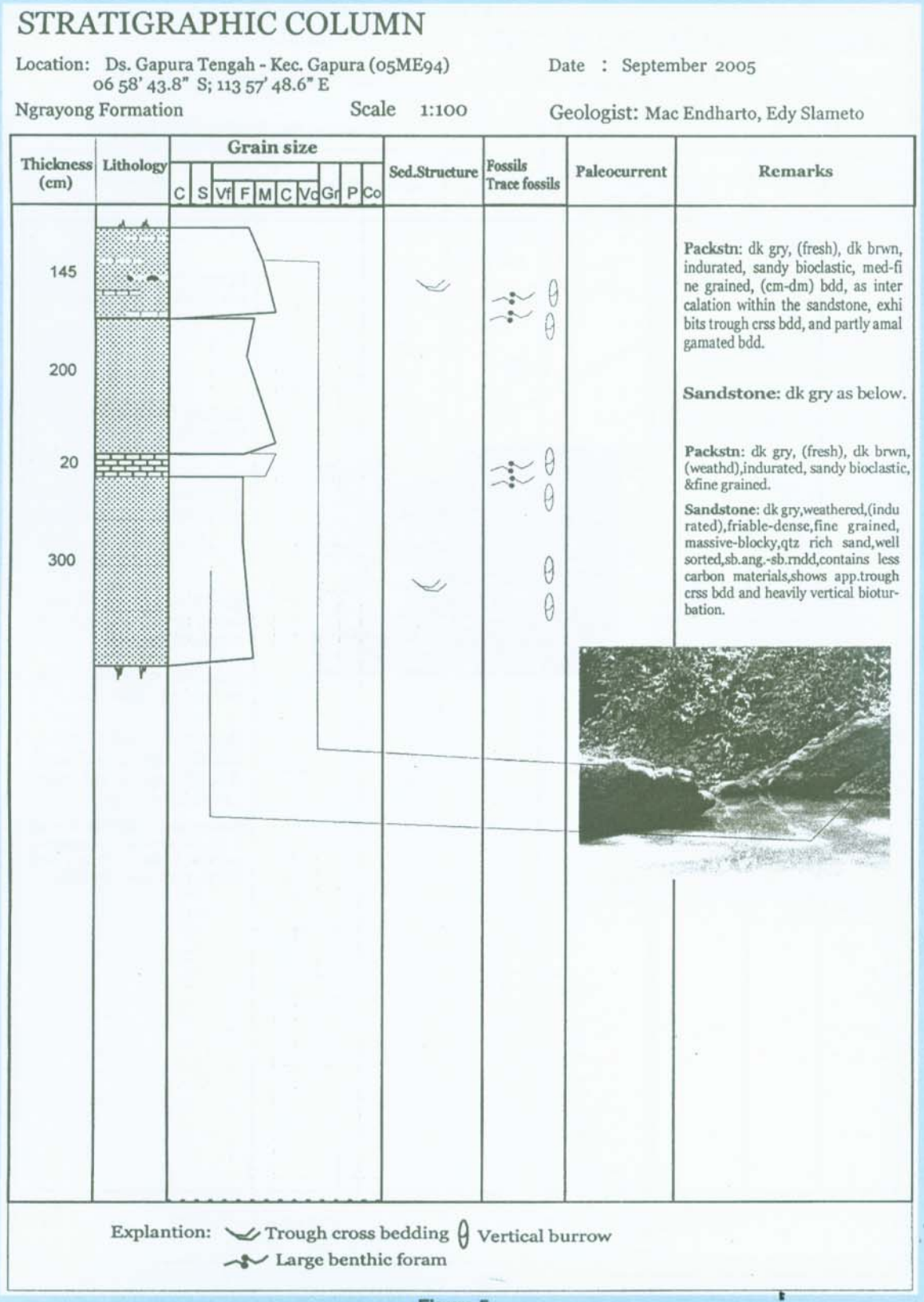

Figure 5
Stratigraphic column of Desa Gapura Tengah, Kecamatan Gapura (Loc. 05ME94)

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VOL. 29. NO. 2, AUGUST 2006: 34 - 45

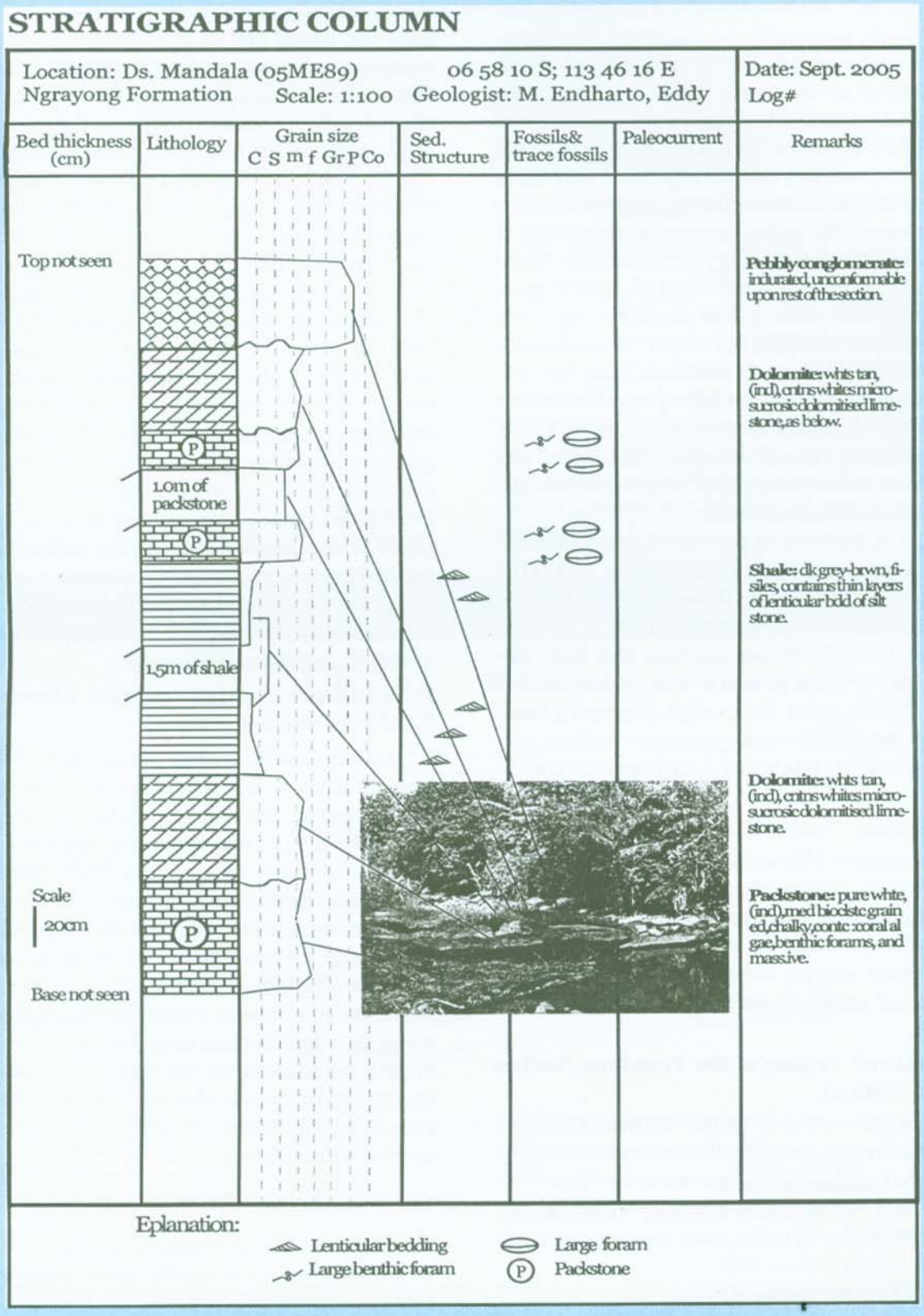

Figure 6
Stratigraphic column of Desa Mandala, Kecamatan Belukares, P. Madura (Loc. 05ME89)

flame structures at least was exposed in one of the sand bed and combined with perpendicular bed bioturbations suggest that the sandstone beds are interpreted to represent offshore environments which characterized by sharp bases by shole marks, parallel laminations, tabular and planar cross bedded. These sedimentary structures indicate waning flow where the planar laminated interval represents deposition from upper flow regime oscillatory currents while the upper planar cross bedded interval is the product of deposition from lower energy storm currents. These two sedimentary structural combinations suggest deposition from waning flow conditions typical of shallow marine condition storm beds. The occurrence of the stormed-emplaced sandstone beds has sole marks indicating dominantly shore perpendicular flow direction (Collinson, J. D. & Thomson, D. B., 1989). The underlying Tuban Formation of this section was exposed in northern area (end of traverse) was deposited in more deeper water.

Age: on the basis of planktonic foram zone and larger foram letter stage determination by GRDC (Geological Research and Development Centre) for Gapura-Sema traverse stratigraphically at the base is of the Tuban Formation not older than Early Miocene and was precipitated in area of deep middle neritic to outer neritic. The overlying Ngrayong Sandstone in this section was deposited in the deep inner neritic to deep middle neritic during early Middle Miocene

D. *Prenduan Section (River Section)*

This traverse followed along the river section from south to north, stratigraphically younger to older, situated in the southeastern part of the Madura Island. The exposures along the river (Pragaan creek near the Pragaan village) were generally poor. Recent gravels and sandstone are more predominant in this section.

Depositional Setting of the Prenduan Section (River Section)

Along the river sections the exposure conditions are generally poor and difficult to interpret accurately. Using the lithology and poor cross bedded indicators this section was deposited gradually within the offshore shallowing up to the lower foreshore or above the fair-weather wave base.

E. *Mandala-Belukares Section*

This traverse was taken along the east-west direction, east Rubaru village, presumably along the strike of the rock formation or along the tarmac road, stratigraphically started from older to younger lithologies. The lowest unit of this traverse displayed by calcareous siltstone (marl) with less bryozoan and foraminifera fragments, supposed this lithology partly of small core of anticline. To the northward traverse is up-section of the fine quartz arenite, oranges red, friable, well sorted and a bit massive. Sedimentary structures such as ripple cross lamination, thin clay drapes, and reactivation surfaces and bioturbations are revealed within the small section near the dirt track. Dark red sandy soil was a characteristic of this section, over this sandy soil, northward direction, dark red of loose block iron rich of medium sandstone grained contains groove cast and parallel lamination. Near the junction between the tarmac covered road and dirt track exhibit foraminifera rich grainstone possibly as part of the Bulu Limestone unconformably overlying the Miocene unit. Interbedded unit was also occurred along this traverse which is thick bedded of bioclastic packstone beds with a diagenetic of micro-sucrosic texture dolomite cap on top of the carbonate bed surface, interbedded with dark silty mudstone and thin lenticular laminae of silty fine sandstone (Figure 6).

Depositional Setting of the Mendala – Belukares Section

Tide dominated current (deeper part of the the internal zone) is documented for the Mandala section to produce the sedimentary facies. Lateral accretion bedding of the asymmetry ripple cross bedded by subordinate current which eroded the lee face of the dunes formed by the preceding dominant current than the reactivation surface was produced. Thin mud draped will be deposited on the lee face during slack water periods (in condition high concentration of suspended sediment). Flasser bedding was formed within the intertidal range (mix flat area), or is typical of the transition from the mix flats to mud flats. High energy deposition was also recognized by the presence of parallel lamination and groove casts within the iron rich sandstone.

IV. PALAEOENVIRONMENT

Based on outcrop observations and descriptions on the sedimentary structures, ichnofacies and facies associations, all was pointing to deposition from wave to storm currents. Both shoreface and offshore conditions (shelfal zones) control the depositional sys-

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 29. NO. 2, AUGUST 2006: 34 - 45

tem of the area. Indications of the shallower depositional environments are also shown by the tidal deposition.

The occurrences of the vertical transition from parallel laminated to planar cross bedded and the presence of amalgamated beds, sharp-based beds interbedded with finer grained mudrocks within the sandstone beds all point to moderately frequent storm-induced sedimentation in offshore-transition region of a shelf (in between fairweather and storm wave base). Fairweather wave base is commonly between 5-15 m depth or depending upon the wave climate of the basin. Storm induced currents have been recorded affecting on the sea floor at water depth in excess 200m despite the fact that this depth of penetration is not common. The damaging many of the primary sedimentary structures in most of the outcrop sections studied due to often intense bioturbation could be a product not only of the abundance of endobenthos churning through sediment in search of food but of the time period between storm events.

The outcrop of the Ngrayong Sandstone studied typically exhibited trace fossils be associated with Skolithos and Cruziana ichnofacies according to Pemberton *et al.* 1992, indicative of foreshore to shoreface and offshore-transition to offshore shelfal environments respectively (Figure 7).

V. CONCLUSION

The depositional setting of Ngrayong Sandstone of the eastern part of the Madura Island is represented by some of the studied areas from Prenduan-road section, Banjar Barat, Gapura-Sema, Prenduan-river section and Mandala-Belukares sections is mostly typified by high energy of lower-upper shoreface condition, and some influenced by the occurrences of extensive bed bearing bioturbation of *Thallassinoides* ichnofacies suggests this grainstone was precipitated in high tide of foreshore-upper shoreface.

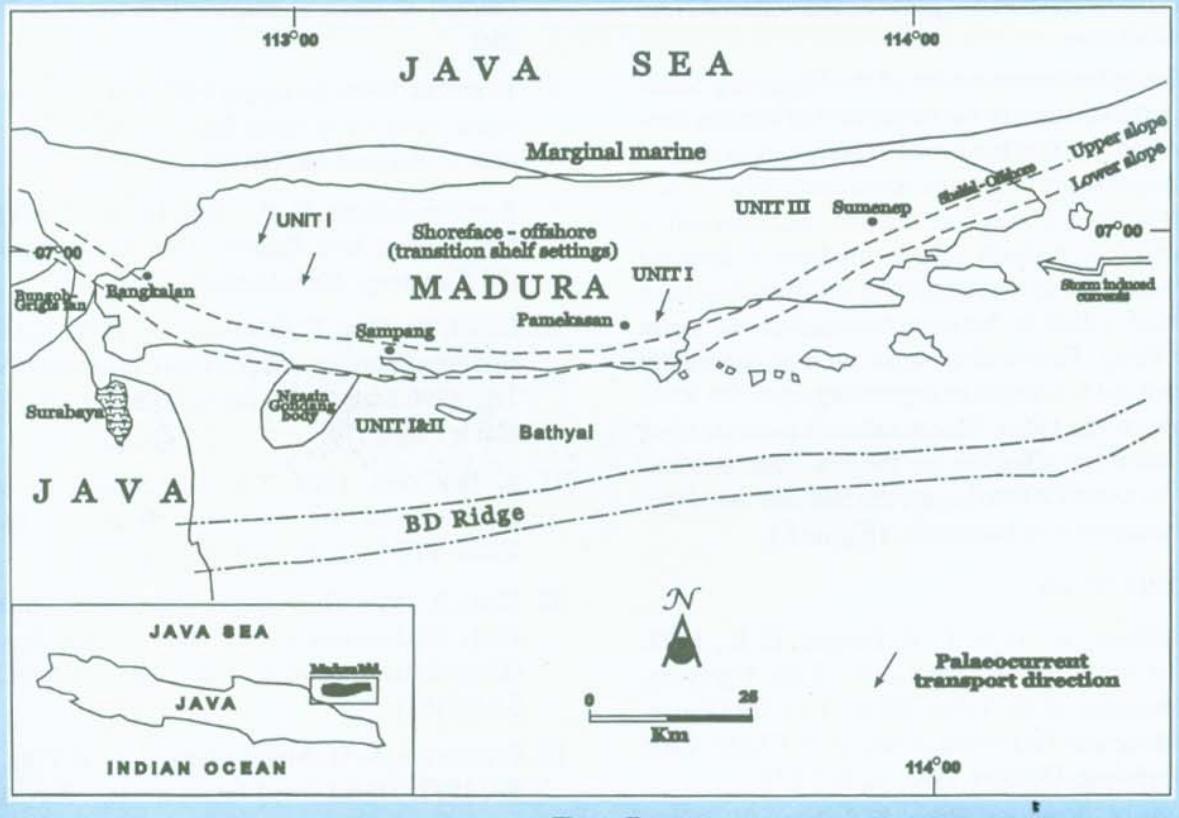

Figure 7
Ngrayong Sandstone study palaeogeography Early Middle Miocene (N9 - N10)
(Modified from Moss, 1999)

In the other areas are signified by the sharp bases by shole marks, parallel laminations, tabular and planar cross bedded. These sediment structures assign waning flow where the planar laminated interval represents deposition from upper flow regime oscillatory currents while the upper planar cross bedded interval is the product of deposition from lower energy storm currents. These two sedimentary structural combinations suggest deposition from waning flow conditions typical of shallow marine condition storm beds. The occurrence of the stormed-emplaced sandstone beds has sole marks indicating dominantly shore perpendicular flow direction. The offshore shallowing up to the lower foreshore or above the fair-weather wave base is also revealed by the dominance of the cross bedding structures. In the northwestern portion of the studies area well documented thin mud draped deposited on the lee-face during slack water periods (in condition high concentration of suspended sediment). Flasser bedding was formed within the intertidal range (mix flat area), or is typical of the transition from the mix flats to mud flats. High energy deposition was also recognized by the presence of parallel lamination and groove casts within the iron rich sandstone.

The palaeoenvironment of the Ngrayong Sandstone exhibits some of the occurences of vertical transition from parallel laminated to planar cross bedded and the presence of amalgamated beds, sharp-based beds interbedded with finer grained mudrocks within the sandstone beds all point to moderately frequent storm-induced sedimentation in offshore-transition region of a shelf (in between fairweather and storm wave base). Fairweather wave base is commonly between 5-15 m depth or depending upon the wave climate of the basin. Storm induced currents have been recorded affecting on the sea floor at water depth in excess 200m despite the fact that this depth of penetration is not common. (Figure 8).

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