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Sequence stratigraphy of the Upper Miocene Stage IVC in the Labuan-Paisley Syncline, northwest Sabah Basin

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Abstract: A sequence stratigraphic study of the Upper Miocene Stage IVC has been carried out in the Labuan-Paisley Syncline, Northwest Sabah Basin with the aim of identifying new hydrocarbon plays in the study area. The Stage IVC contains up to 4,000 m thick, clastic sediments deposited in coastal plain to bathyal environments probably between 8.2 Ma and 10.5 Ma indicating an immense sedimentation rate of approximately 1,700 metres/Ma. The top and base of the Stage IVC are marked by the Shallow Regional and Upper Intermediate Unconformities respectively which are pronounced tectonic boundaries in the NW Sabah Basin.

The overall regressive Stage IVC sediments are characterised by oblique to shingled progradation towards the westerly-northwesterly directions as suggested by the mapping of the pronounced shelf-edges. A generalised third-order sequence within the Stage IVC includes very thin transgressive systems tract and very thick highstand and lowstand systems tracts. A Type-1, third order sequence boundary separates the Stage IVC into two third-order sequences. This sequence boundary is evidenced by the occurrence of a major erosional slump scar at the western part of the syncline. The depositional model derived from this study includes thick shelf sands and basin floor/submarine fans interspersed by thinner sands of the levee-channel complexes at the shelf slopes.

The Intra Stage IVC sequence boundary is thought likely to be caused by the fall in sea-level probably between 8.5 Ma and 9.0 Ma. This fall in sea-level is not represented in the global sea-level chart of Haq *et al.* (1987), suggesting that this fall in sea-level could be small and localised but it is evident in a basin with large sediment supply.

This sequence stratigraphic study has resulted in the identification of various hydrocarbon plays. They comprise basin floor/submarine fans, slope fan/levee channel complex and shelf-edge/slump scar plays. The basin floor /submarine fan play is considered the highest ranked but requires additional seismic coverage for detailed mapping.

INTRODUCTION

The Labuan-Paisley Syncline is a large NNE-SSW trending syncline covering an area of approximately 1,500 sq km. This sub-basin contains very thick Middle-Upper Miocene Stages IVA to IVC sediments. The thickness of the Upper Miocene Stage IVC alone could reach up to 3,000 m. The syncline is located within the southwestern portion of the Inboard Belt of the NW Sabah Basin (Fig. 1). Wells drilled on the flanks of the syncline have led to the discovery of gas in the Middle Miocene Stage IVA sequence (Glayzer gas field). The Stage IVC sequence was found to yield minor gas shows (Keraman and Fury South wells).

The aim of this study is to identify possible new plays in the Stage IVC utilizing the sequence stratigraphic approach. These new plays could include stratigraphic traps of various depositional facies, including deepwater facies as all the obvious structural traps have already been tested in this area.

DATA AVAILABILITY

The data availability for this study includes the following:

i) High quality seismic data of 1976 regional lines (reprocessed) and 1989 regional and Gordon infill lines.
ii) Well composite logs of five wells drilled in this province which include Fury South, Keraman and Glayzer wells. The gamma-ray and resistivity logs are especially useful for this study.
iii) Biostratigraphic and paleoenvironment zonations of the wells if available. This is especially useful for identification of maximum

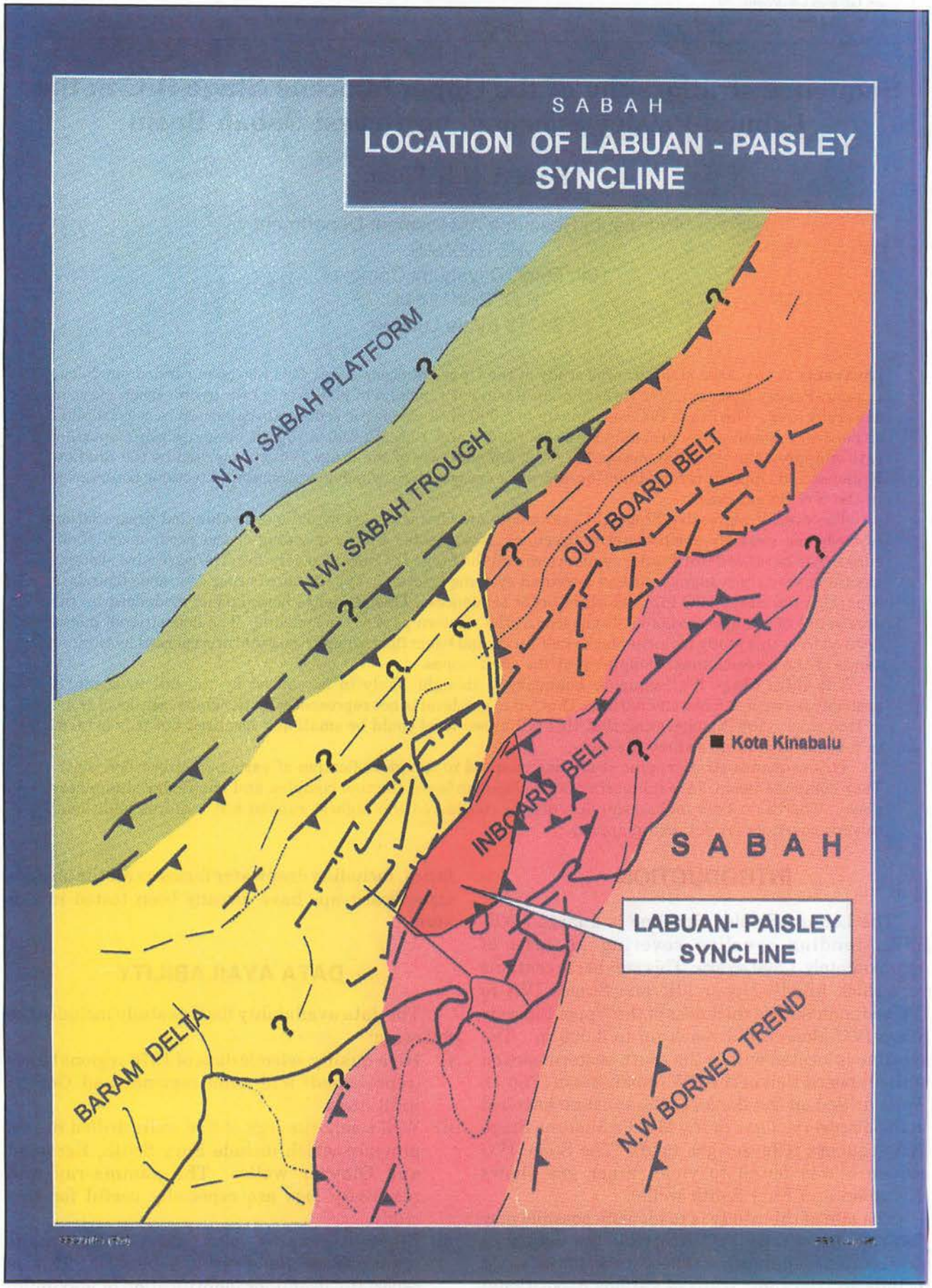

Figure 1. Location of Labuan-Paisley Syncline within the southwestern portion of the inboard belt of NW Sabah Basin.

flooding surfaces.

iv) Time-depth curves of the available wells for the purpose of correlating the drilled sections to the seismic data.

STRUCTURAL SETTING

The Labuan-Paisley Syncline is a large (30 X 50 sq km) NNE-SSW orientated syncline that contains up to 8,000 m of Middle Miocene to Recent sediments. It is delimited to the east by the N-S trending Sabah Ridges; west by the N-S Morris Growth Fault; north by the Hankin-Tulak High and south by the Keraman High. The Stage IVC clastics which is the focus of this study is bounded by the Upper Intermediate Unconformity (UIU) at the base. At the top it is bounded by the Shallow Intermediate Unconformity (SRU) which in turn was overprinted by the Horizon II Unconformity. These are major erosional boundaries which affect a large part of the NW Sabah Basin, principally the Inboard Belt.

Structuring within the Stage IVC comprises normal faulting in the Gordon and Glayzer localities and slump scar unconformity at the Fury South area. Elsewhere, there is little or no deformation. The virtually uninterrupted deposition of the Stage IVC facilitates sequence stratigraphic interpretation with the possibility of delineating stratigraphic traps.

SEQUENCE STRATIGRAPHIC INTERPRETATION

The sequence stratigraphic interpretation of the Stage IVC is a study combining seismic facies analysis, sequence analysis from wireline logs and recognition of faunal abundance or absence from biostratigraphic data. The results of these analyses are integrated ending with a chronostratigraphic correlation detailing the identified sequences. Finally, the interpreted sequences are compared with those of Vail's eustatic cycles (Vail, *et al.* ,1990) to infer whether the occurrences of these sequences are mainly influenced by global sea-level fluctuations or local tectonics.

The stratigraphy of the NW Sabah basin is divided into four main stages (Stages I to IV). The Middle Miocene to Recent is further subdivided into seven substages (Stages IVA to IVG). The Stage IVC is one of these substages. It is situated within the Lower Late Miocene (ca. 10.2 to 8.5 Ma) with a duration of ca. 1.7 Ma. Based on the Haq *et al.*'s chart (1987) of the Cenozoic cycles, the average duration of each cycle is 1.05 Ma. This implies that the Stage IVC could be a composite sequence of two third-order sequences.

Good quality regional lines with horizontal scale of 1:25,000 and vertical scale of 10 cm/sec are very well suited for seismic facies analysis. Altogether, there are five regional lines; two of 1976 vintage which are reprocessed and the others of 1989 vintage. The interpretation are loop-tied by other available seismic data of 1989 vintage to provide a consistent pattern in the regional interpretation. A few seismic facies on Line 76R511 (Fig. 2) can be readily recognised in the Stage IVC. They are the following:

i) Hummocky, discontinuous events mimicking channel-dominated lower coastal plain facies,
ii) Parallel, continuous horizons indicating coastal-inner neritic facies,
iii) Oblique-shingled clinoforms suggesting moderate-high energy deposition of middle-outer neritic facies,
iv) Mounded with gull-wing features located at the shelf slopes representing levee-channel complexes or slope fan facies, and
v) Mounded features sitting on the basin floors indicating basin floor or submarine fans.

Reflection cycle terminations at sequence boundaries are also readily observed in the Stage IVC. At the top of the Stage IVC obvious truncations can be easily interpreted. At the base, onlapping and downlapping reflectors are more evident (Fig. 2). One of the mounded facies onlapping the UIU was penetrated by Gordon-1 (Fig. 4) and it is interpreted to be a slope fan facies. It is a mixture of thin sands and silts exhibiting porosity of 12% to 16%.

An Intra IVC Unconformity is also present which coincides with the occurrence of a major slump scar. This stratigraphic trap has been tested by Fury South-1 (Fig. 4) which was found to be dry. Being located at shallow depths, the charge is perceived to be the main problem. This slump scar which truncated considerable amount of the underlying sediments, is preceded by a rapid northwesterly progradational facies. This is supported by the wide spacing of these mapped shelf edges (Fig. 3) and the dominant coarsening/thickening upward patterns of the highstand systems tract (Van Wagoner, 1990) in the well log that passed through this slump scar (Fig. 4).

This Intra IVC Unconformity is thought likely to be a Type-1 third-order sequence boundary and it separates the Stage IVC into two sequences-the lower Sequence 1 and the Upper Sequence 2 (Fig. 4).

Based on the sequence stratigraphic interpretation of the Stage IVC, a depositional model is developed depicting thick deposition of highstand

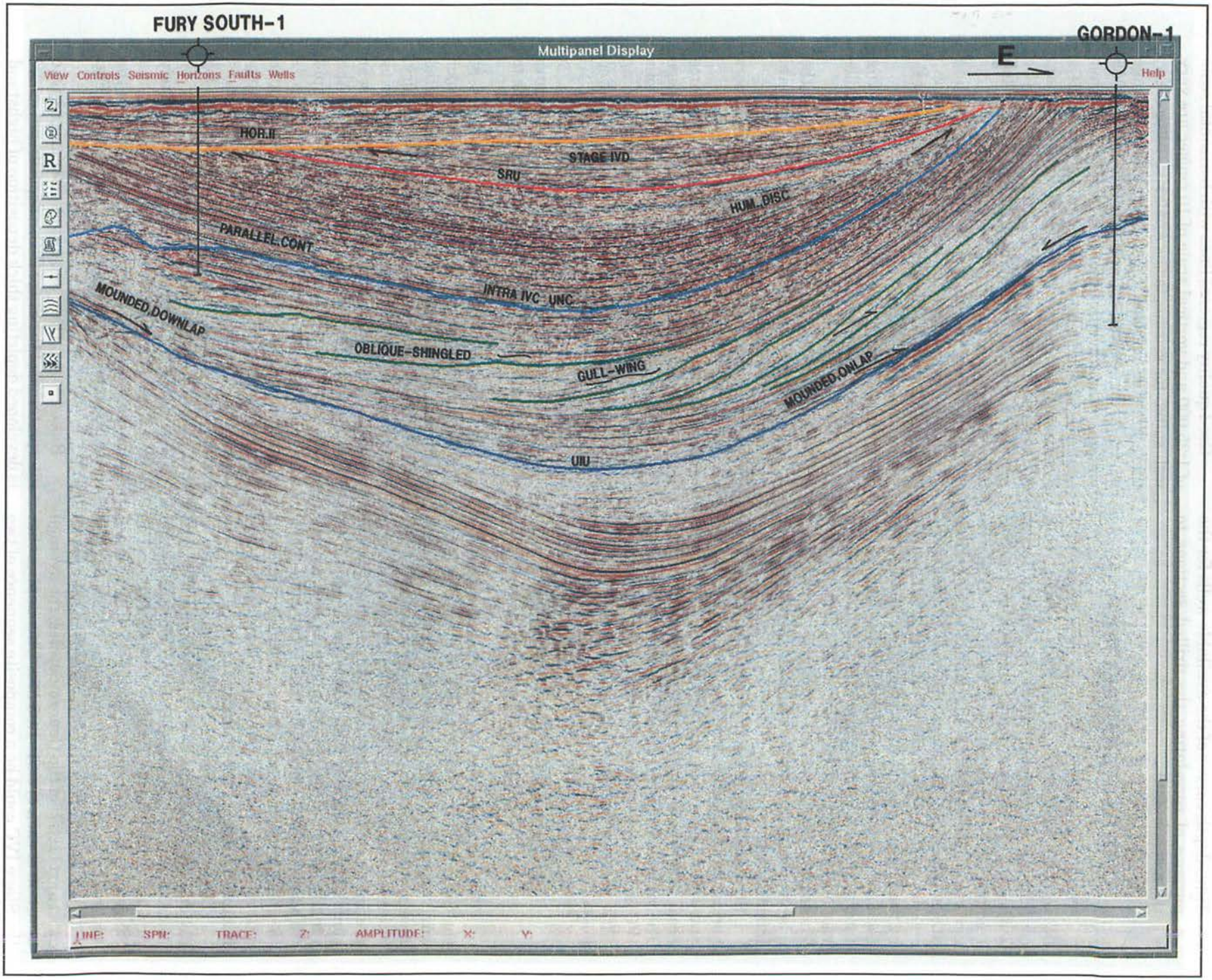

Figure 2. E-W seismic section across Labuan-Paisley Syncline with sequence stratigraphic interpretation including seismic facies analysis of the Stage IVC.

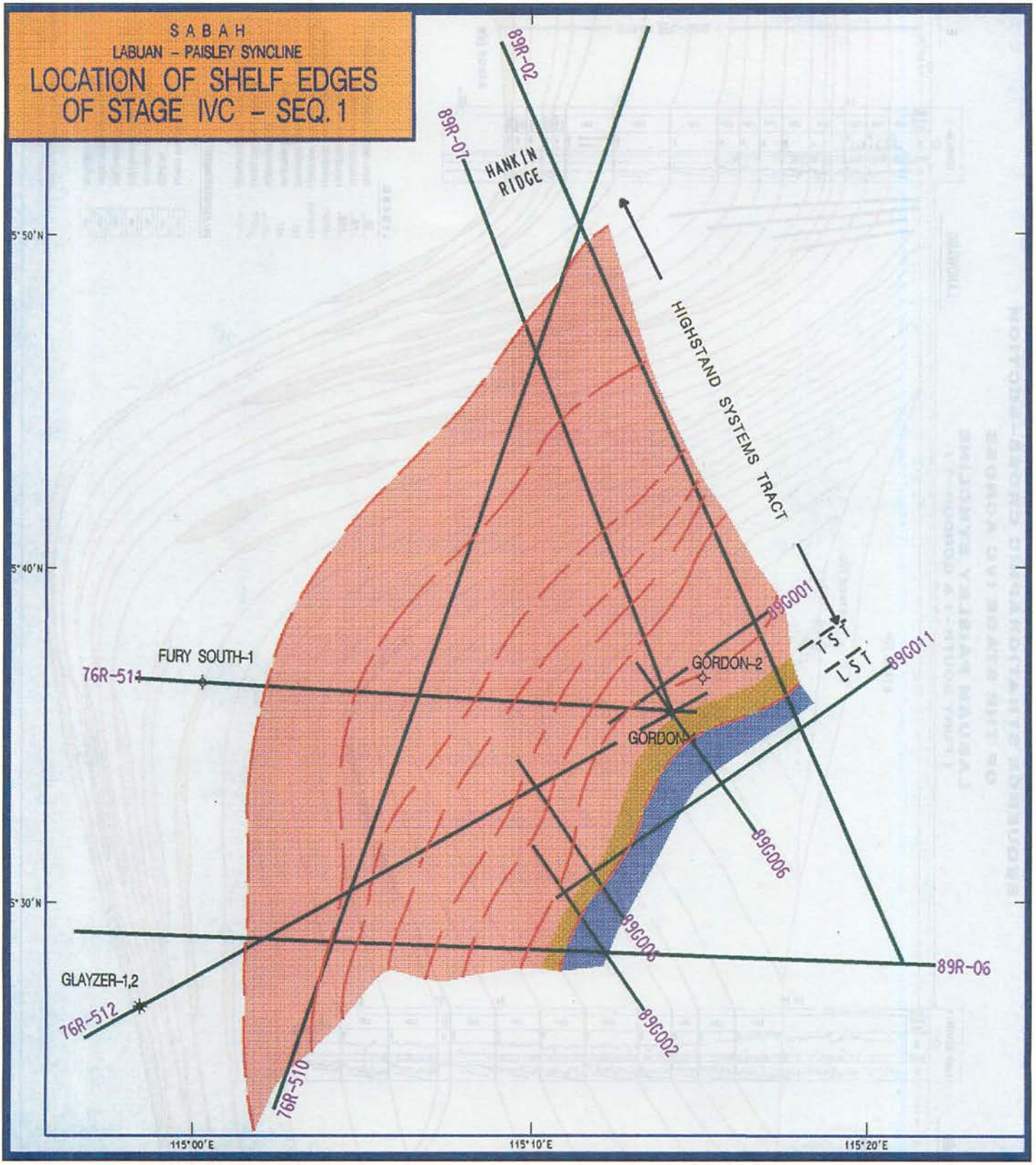

Figure 3. Location of shelf edges of Stage IVC-SEQ. 1, illustrating the northwesterly progradation. The wide spacing of the late highstand systems tract indicates rapid progradation.

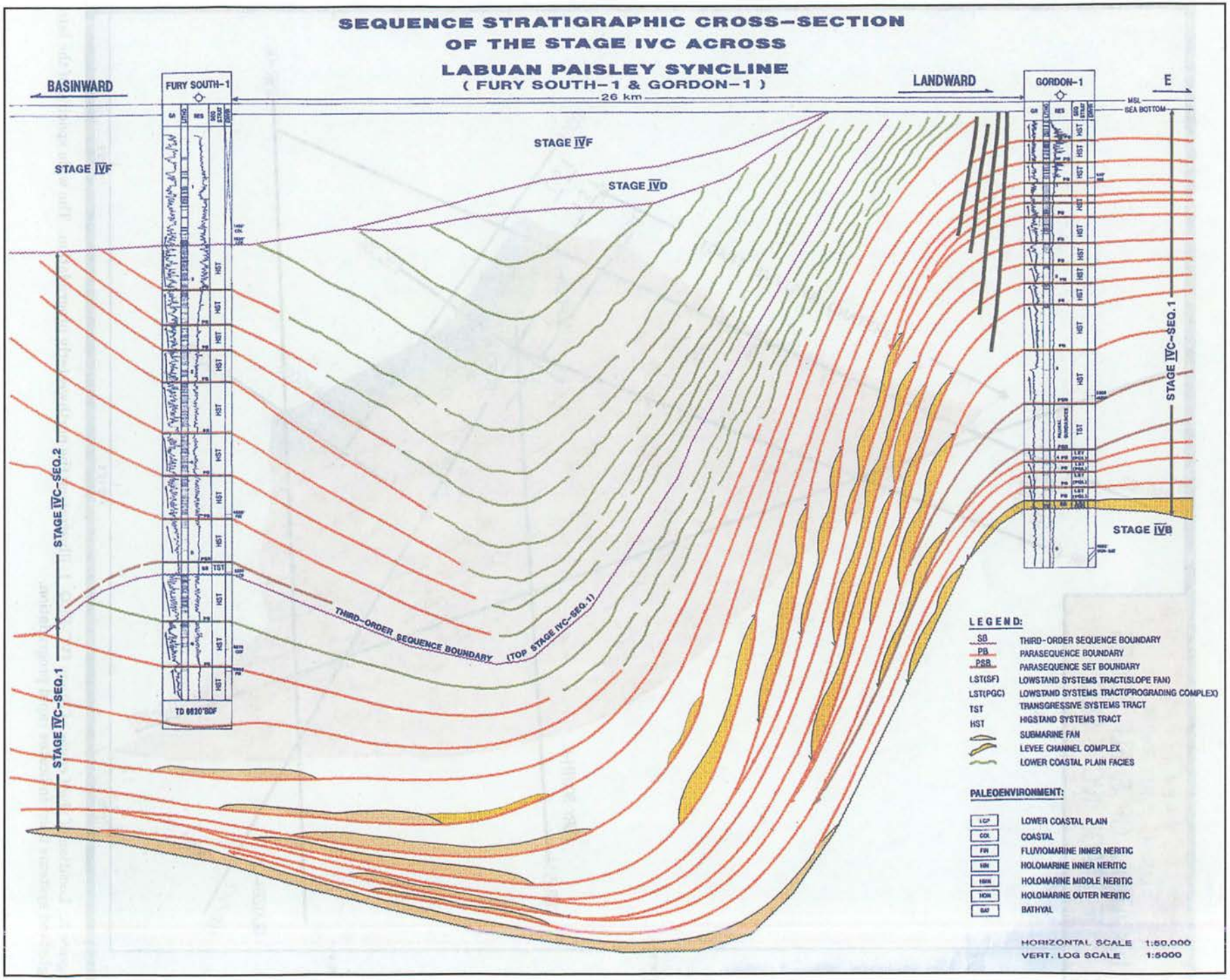

Figure 4. Sequence stratigraphic cross-section of the Stage IVC across Labuan-Paisley Syncline linking systems tracts interpretation of Fury South-1 and Gordon-1.

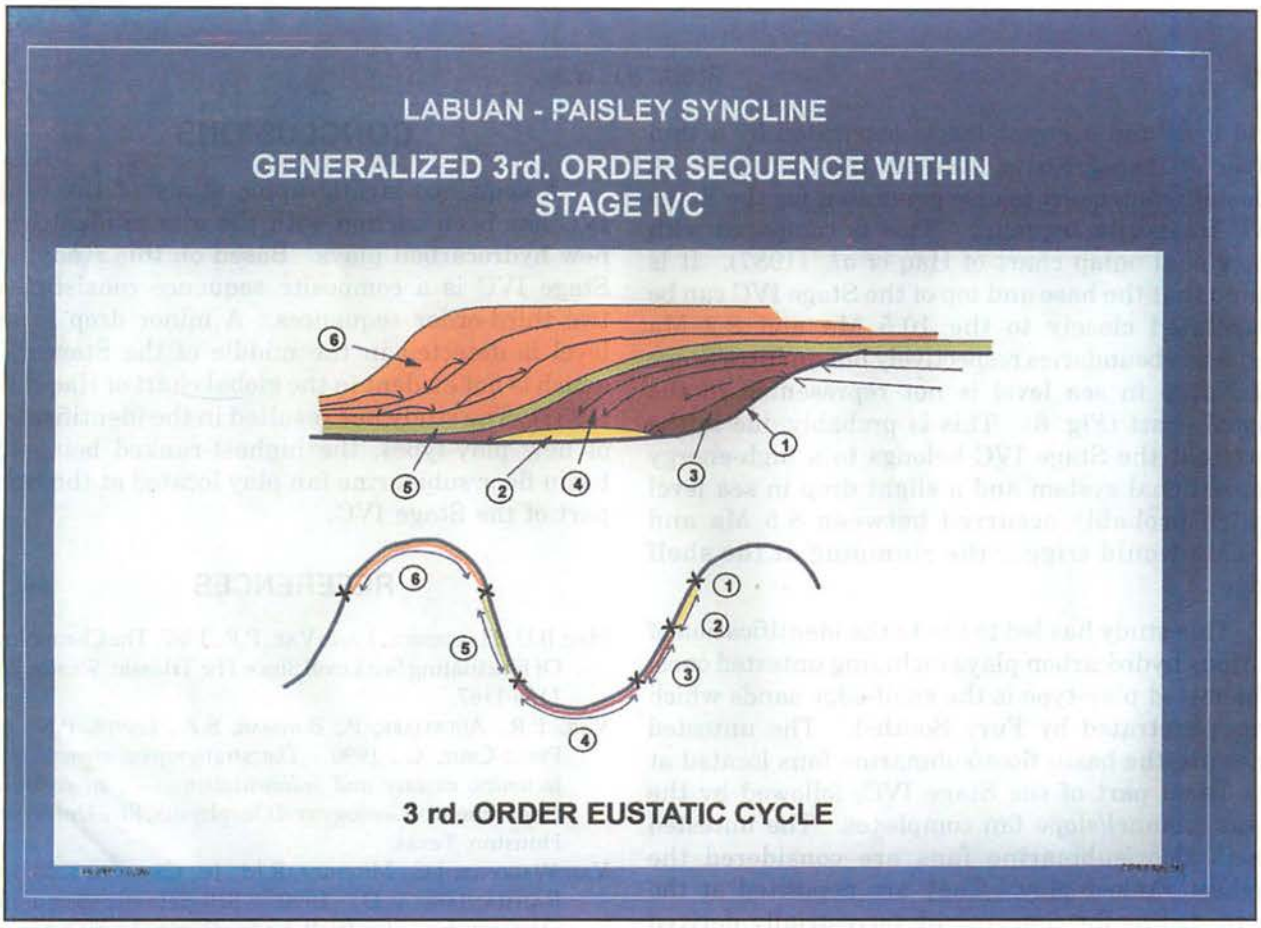

Figure 5. Labuan-Paisley Syncline, generalised 3rd order sequence within Stage IVC. 1. Sequence boundary; 2. Basin floor fan; 3. Slope fan/Levee channel complex; 4. Lowstand prograding complex; 5. Transgressive systems tract; 6. Highstand systems tract.

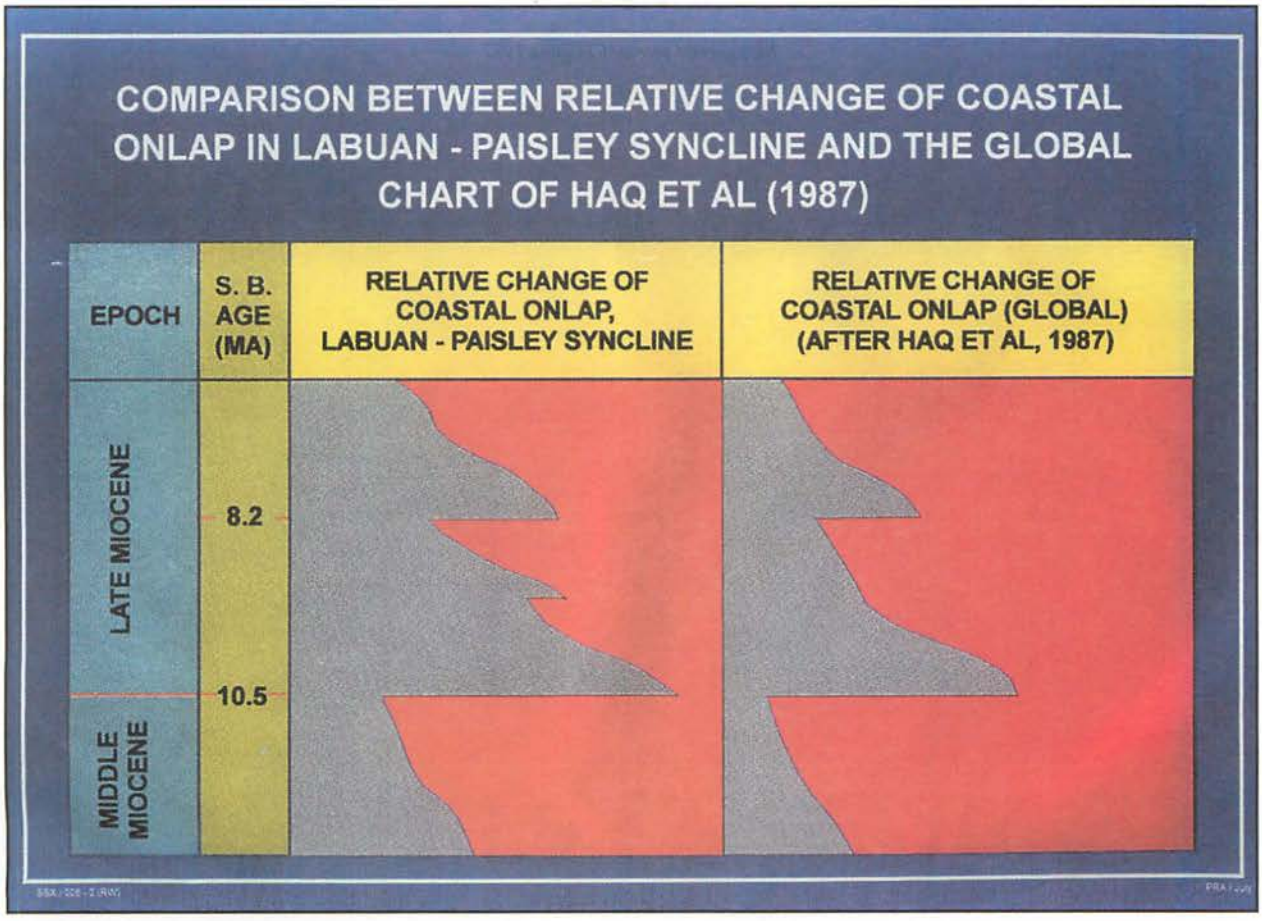

Figure 6. Comparison between the relative change of coastal onlap in Labuan-Paisley Syncline and the global chart of Haq *et al.* (1987). An intra Stage IVC drop in sea-level is highlighted but not represented in the global sea-level chart.

and lowstand systems tracts separated by a thin layer of transgressive systems tract (Fig. 5). A coastal onlap chart is also generated for the Stage IVC composite sequence. This is compared with the global onlap chart of Haq *et al.* (1987). It is found that the base and top of the Stage IVC can be correlated closely to the 10.5 Ma and 8.2 Ma sequence boundaries respectively but an Intra Stage IVC drop in sea level is not represented in the global chart (Fig. 6). This is probably due to the fact that the Stage IVC belongs to a high-energy depositional system and a slight drop in sea level which probably occurred between 8.5 Ma and 9.0 Ma would trigger the slumping at the shelf edge.

This study has led to the to the identification of various hydrocarbon plays including untested ones. The tested play-type is the shelf-edge sands which was penetrated by Fury South-1. The untested ones are the basin floor/submarine fans located at the basal part of the Stage IVC, followed by the levee channel/slope fan complexes. The untested basin floor/submarine fans are considered the highest ranked play. They are deposited at the right depths for charging by terrestrially derived source rocks. Bathyal shales provide the effective seals.

CONCLUSIONS

A sequence stratigraphic study of the Stage IVC has been carried with the aim of identifying new hydrocarbon plays. Based on this study, the Stage IVC is a composite sequence consisting of two third-order sequences. A minor drop in sea level is detected in the middle of the Stage IVC which is not evident in the global chart of Haq *et al.* (1987). The study has resulted in the identification of new play-types, the highest-ranked being the basin floor/submarine fan play located at the basal part of the Stage IVC.

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