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Seismic sequence stratigraphic interpretation enhances remaining hydrocarbon potential of the SE Collins Field

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Abstract: The SE Collins field is a marginal oil field that was discovered in 1972. It is located within the complexly faulted central portion of the Inboard Belt of the NW Sabah Basin. The field is an elongated, 8 km by 1.5 km, N-S anticlinal structure supported by reverse faults on the north, west and south. The north and central culminations have been tested to be hydrocarbon bearing. The main reservoirs are the Middle Miocene Lower Stage IVA sands.

High quality, close grid seismic data were acquired over the field in 1989. This has enabled seismic sequence stratigraphic interpretation to be carried out. The study has resulted in the identification of two third-order sequences within the Stage IVA. The lower sequence consists of two system tracts — transgressive and highstand. The upper sequence comprises another two systems tracts — lowstand and transgressive.

This work has led to a better understanding of the stratal patterns within the two sequences and hence, the distribution of the reservoirs and seals. The main reservoirs and seals have been correlated and mapped and the reserves estimated. The proven reserves was assessed to be more than twice the amount that was initially predicted.

INTRODUCTION

The SE Collins field is a 1.5 km x 8 km north-south feature located in the complicated middle portion of the Inboard Belt of the NW Sabah Basin (Fig. 1). Despite the complexity of the tectonics in this area, a seismic sequence stratigraphic study has been accomplished. The study was focussed on the hydrocarbon bearing Middle Miocene coastal plain to shallow marine sands. The aim of the study is to gain a better understanding of the distribution of reservoirs and seals which will then lead to the enhancement of the remaining hydrocarbon potential of the SE Collins field.

STRATIGRAPHY AND STRUCTURAL SETTING

The Neogene sequences in the NW Sabah basin have been divided into four sedimentary stages, i.e. Stages I to IV, each stage boundary being defined by a tectonic pulse. The post early Middle Miocene Stage IV is further subdivided into seven substages from Stage IVA to Stage IVG (Fig. 2). The stratigraphy of the Inboard Belt is dominated by coastal plain to shallow marine Stage IVA sediments being separated by the underlying Stage III by the Deep Regional Unconformity (DRU). The top of the Stage IVA is demarcated by the Lower Intermediate Unconformity (LIU). Above the LIU is the shaly Stage IVB being deposited in a neritic setting. The Shallow Regional Unconformity (SRU) is a major erosional surface that divides the Pliocene Stage IVF from the Middle Miocene Stage IVB.

In terms of structural setting, the area in which SE Collins is located is influenced by sets of north-south and east-west wrench-related faults (Fig. 3). These faults controlled the closures of the structures. The main uplift occurred during the SRU. The SE Collins feature is bounded to the west, north and south by reverse faults.

EXPLORATION HISTORY

From 1966 to 1969 seismic data was acquired over the SE collins area. Seismic mapping revealed a N-S structure exists with three culminations. The field was discovered by the drilling of SE Collins-1 in the central culmination with 19 feet of net oil sands and 80 feet of net gas sands in the Stage IVA and 10 feet of net oil sands in the Stage III. Infill seismic lines were acquired between 1973 and 1979 before the second well was drilled in 1980. SE Collins-2 encountered 56 feet of net oil sands and 72 feet of net gas sands in the Stage IVA. Following the remapping, the operator felt that the main hydrocarbon-bearing sands are expected to pinch out towards the south as shown on Line A (Fig. 4). Hence, due to the marginal size of the field, it was relinquished subsequently. Another operator took over the field and high-quality seismic data were acquired in 1989 which enabled this study to be carried out.

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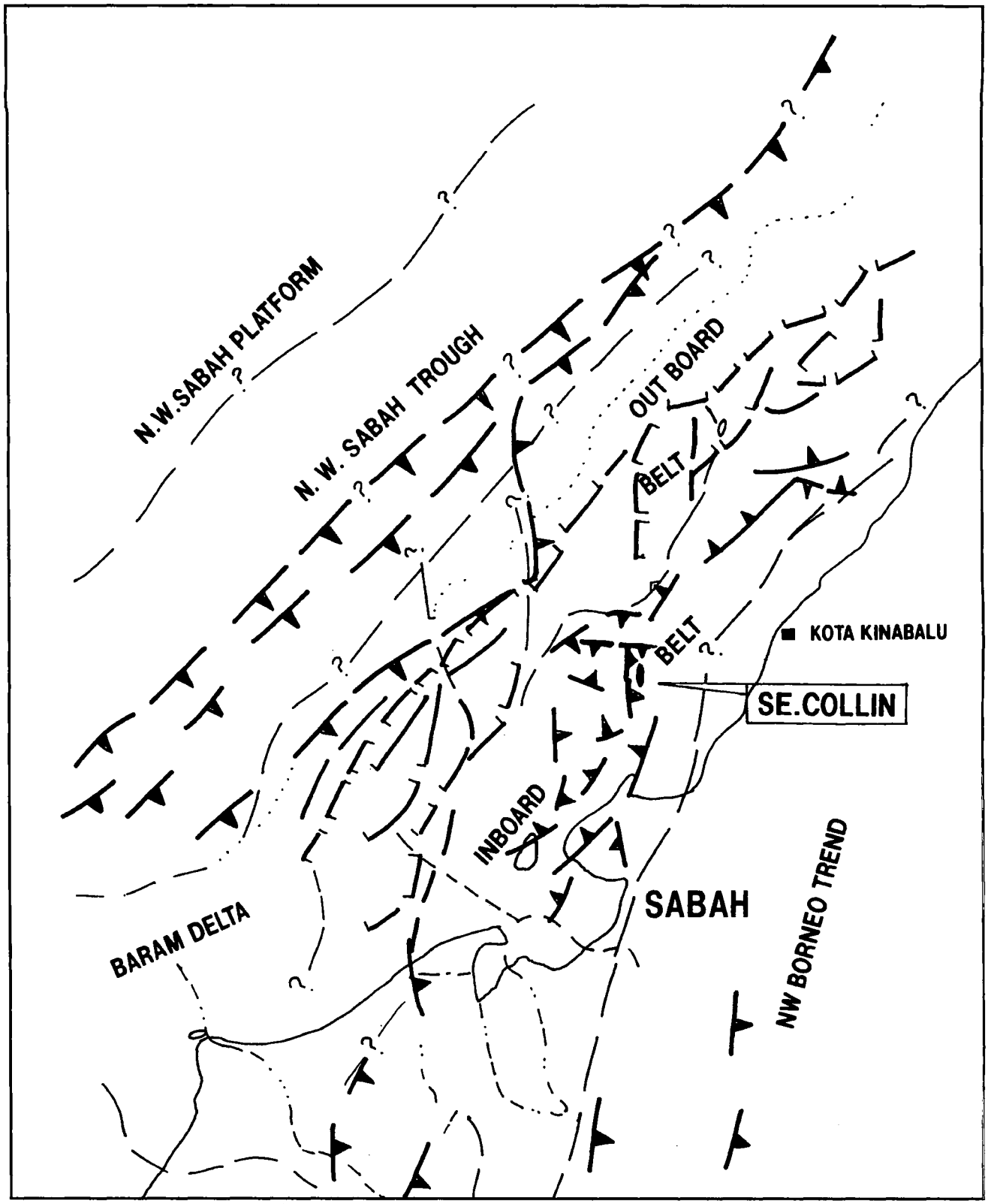


Figure 1. Location of SE Collins Field.

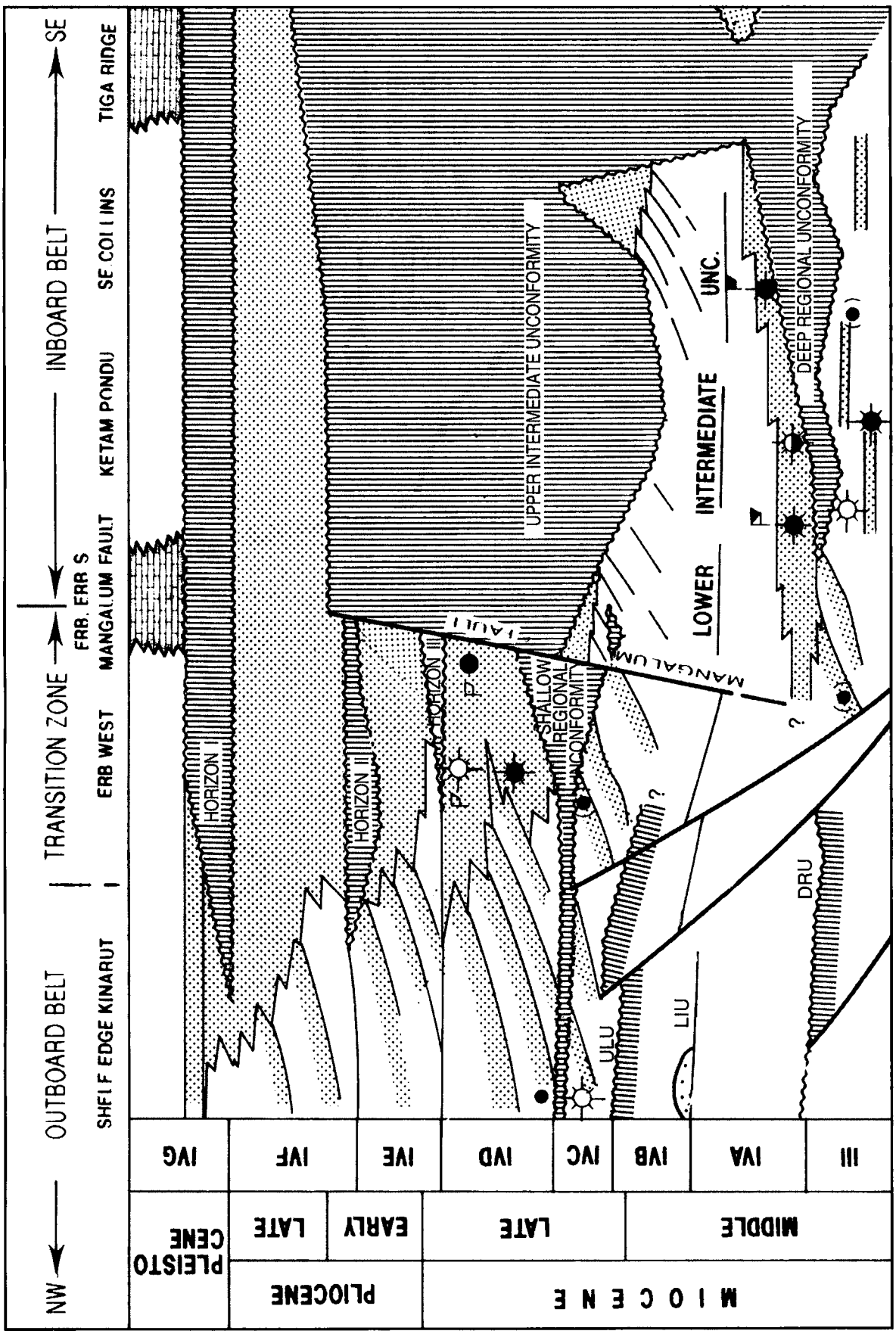


Figure 2. Central Sabah stratigraphy.

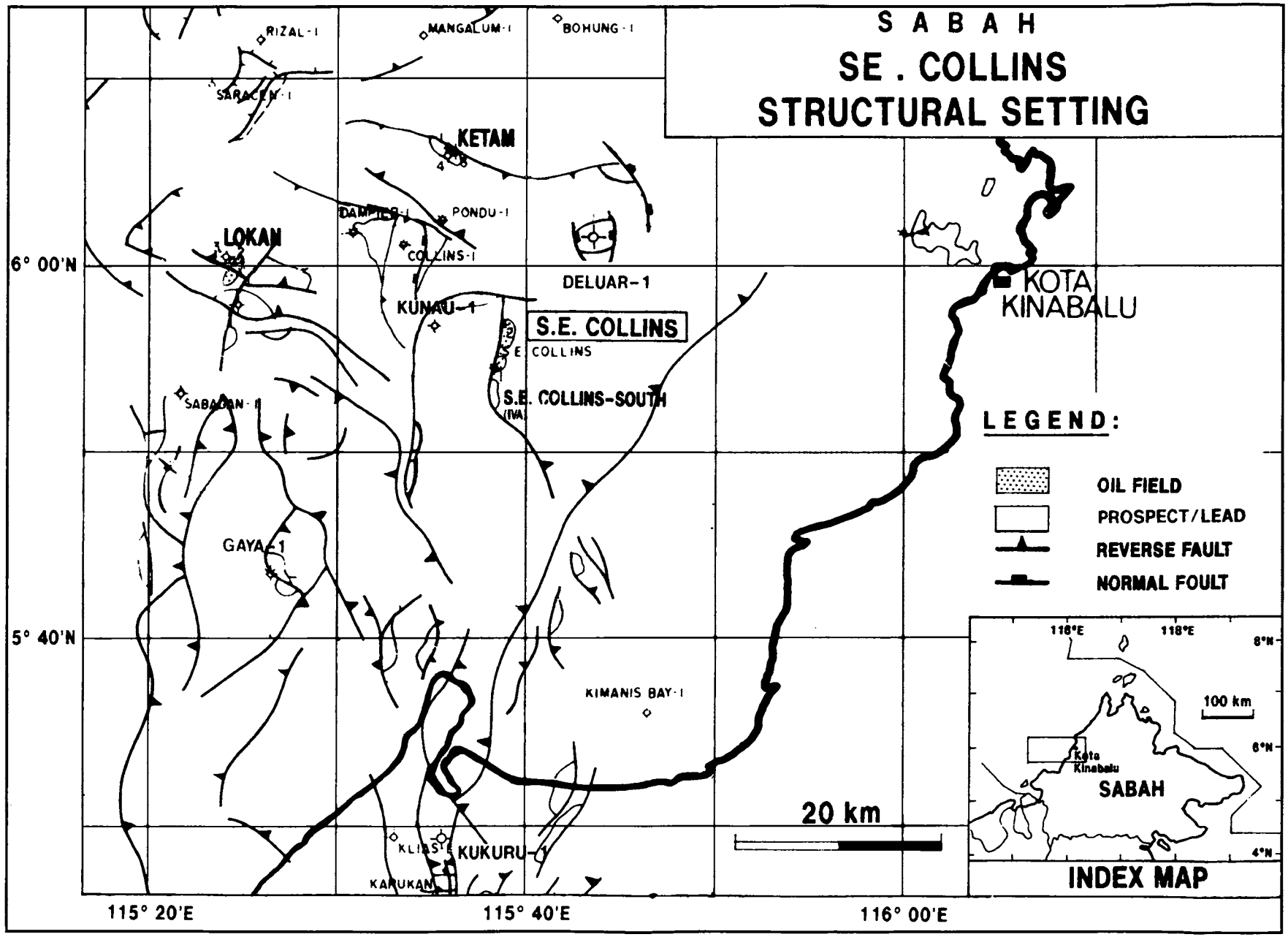


Figure 3. SE Collins structural setting.

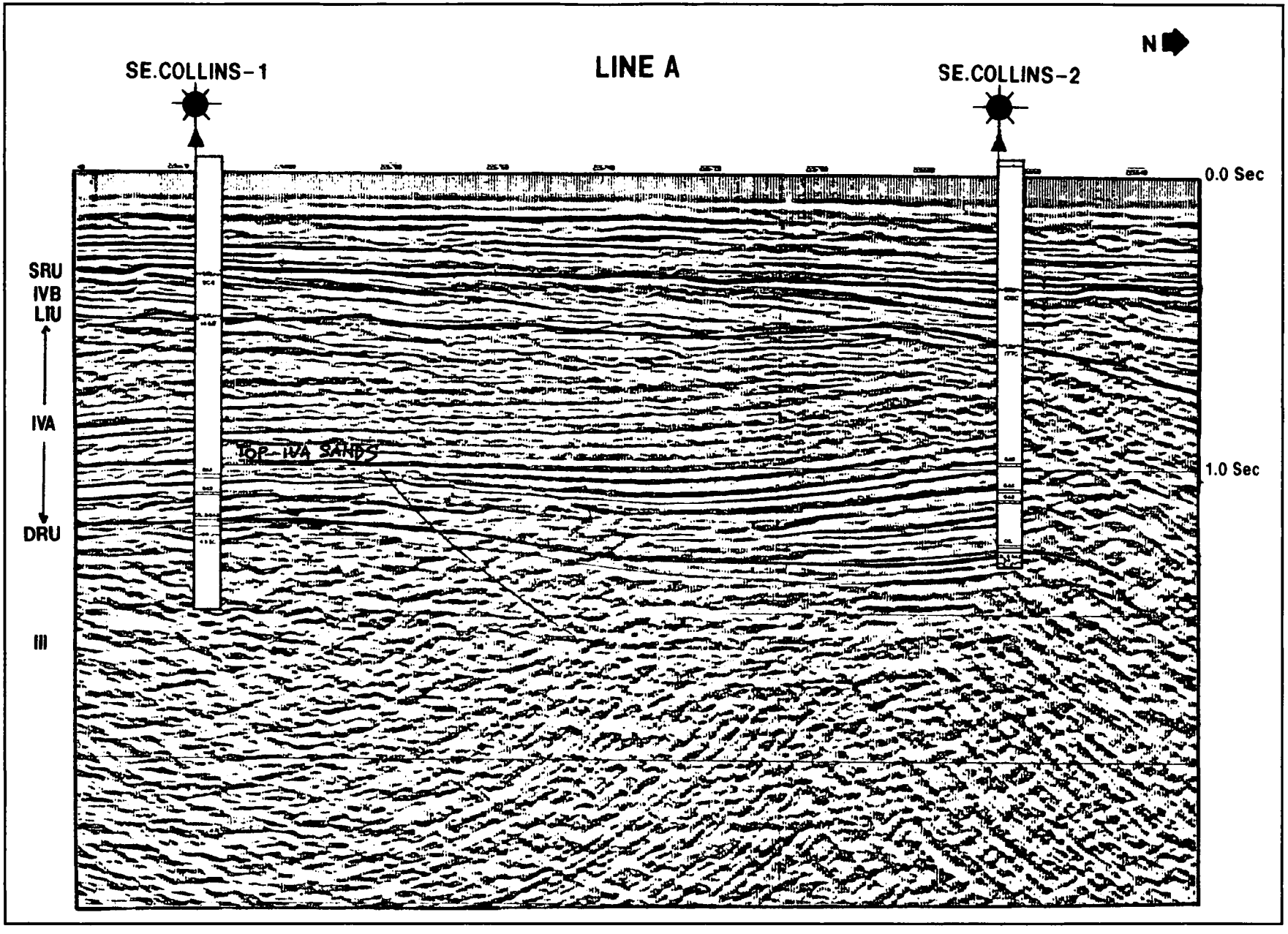


Figure 4. Seismic line a cross SE Collins-1 and -2 interpreted by previous operator.

SEISMIC SEQUENCE STRATIGRAPHY

The study consists of both seismic facies analysis (Mitchum *et al.*; 1977) from seismic data and sequence analysis from well data (Van Wagoner *et al.*; 1990). An example of the seismic facies analysis is demonstrated on Line B with the uninterpreted (Fig. 5) and interpreted (Fig. 6) versions. The well locations were also plotted on the same line.

Based on reflection termination, two major unconformities with erosional truncations are obvious here i.e. the DRU and the SRU. We could also observe onlapping of Stage IVA sediments against the DRU towards the south. The top of the Stage IVA which is interpreted as LIU is characterised by a prominent downlap surface which indicates a maximum flooding surface. Within the Stage IVA, we could identify another sequence boundary by its toplapping progradation or truncation. Hence, the Stage IVA could probably be divided into two sequences. Other horizons within the two interpreted sequences are also included in the interpretation which will be discussed.

The interpreted seismic facies is correlated to the depositional environment. They are confirmed by the two wells. There are three main facies in this area. Firstly, the low-medium frequency, medium-high amplitude, discontinuous, hummocky reflectors indicate deposition of sand-prone lower coastal plain sediments in the Lower Stage IVA. Secondly, low-medium frequency, medium-high amplitude, continuous, parallel horizons are suggestive of sands to silts in a coastal-inner neritic setting in the Middle Stage IVA. Thirdly, medium-high frequency, low-medium amplitude, discontinuous, divergent events represent mainly inner-middle neritic shales in the Upper Stage IVA. The seismic facies analysis is summarised in Figure 7. From the seismic facies analysis of Line B, it can be seen that there is a lateral and vertical facies change from south to north and from bottom to top with parallel, continuous events clearly changing to divergent, discontinuous events (Fig. 8).

The sequence analysis is based on stacking patterns of the wireline logs, depositional environments, lithologies and fossil occurrences in SE Collins-1 and -2. Within the Lower Stage IVA, a sequence consisting of a transgressive systems tract (TST) and highstand systems tract (HST) is interpreted (Fig. 9). The DRU which is referred as Sequence Boundary 1 (SB1) demarcates the sharp change from deep marines shales to coastal plain sands (Fig. 10). The transgressive systems tract is a fining and deepening upward parasequence set of coastal plain to inner neritic sediments. The coastal plain parasequence of SE Collins-2, the top of which is designated by the Brown Horizon (Fig. 10), is onlapped by the SB1 before reaching SE Collins-1. Hence, they are not represented in SE Collins-1. We can also notice the lateral facies change from sand-prone coastal plain facies in SE Collins-1 to shale-prone coastal-inner neritic facies of SE Collins-2, the top of which is marked by the Yellow Horizon (Fig. 9). The highstand systems tract comprises coarsening upward coastal to inner neritic parasequences, topped by Sequence Boundary 2 (SB2). This surface is correlated to a prominent toplap surface towards the south of SE Collins-1 (Fig. 6). Within the HST, the sand thicknesses appear to increase towards the top due to the progradational nature of the parasequences as shown by the Blue Horizon (Fig. 9 and Fig. 10).

The Upper Stage IVA sequence has two systems tracts comprising the lowstand (LST) and the transgressive (Fig. 11). The lowstand systems tract is a prograding complex which thickens upward, the top of which is expressed by a transgressive surface (Pink Horizon). This is a high amplitude, continuous horizon on the seismic data (Fig. 6). Above this is the fining upward transgressive systems tract topped by a prominent downlap surface with high occurrence of fossils. Highest occurrence of Globigerinoides Subquadratus is recorded at this level. This systems tract is translated into divergent, discontinuous events on the seismic data (Fig. 8). It is obvious that the transgressive system tract of the Upper Stage IVA thickens and shales out basinward (Fig. 12). This is clearly defined by the Purple and Red Horizons (Fig. 11 and Fig. 12). The stratigraphic character of this systems tract is due to the relative rise in sea, where the basin is subsiding rapidly in comparison to the slower rate of sediment input.

From the sequence and seismic facies analysis, the strata patterns (Van Wagoner *et al.*; 1990) within the two sequences of the Stage IVA can be delineated. The stratal patterns of the Lower Sequence includes its component transgressive and highstand systems tracts (Fig. 13). The transgressive systems tract consists of backstepping lower coastal plain sands to inner-neritic shales. The highstand systems tract comprises prograding coastal to inner-neritic sands to middle-neritic shales. The stratal patterns of the Upper Sequence encompasses its constituent lowstand and transgressive systems tracts (Fig. 14). The relatively thin lowstand prograding complex includes the coastal to inner-neritic sands whereas the relatively thick transgressive systems tract contains fining and deepening upward coastal sands to middle-neritic shales.

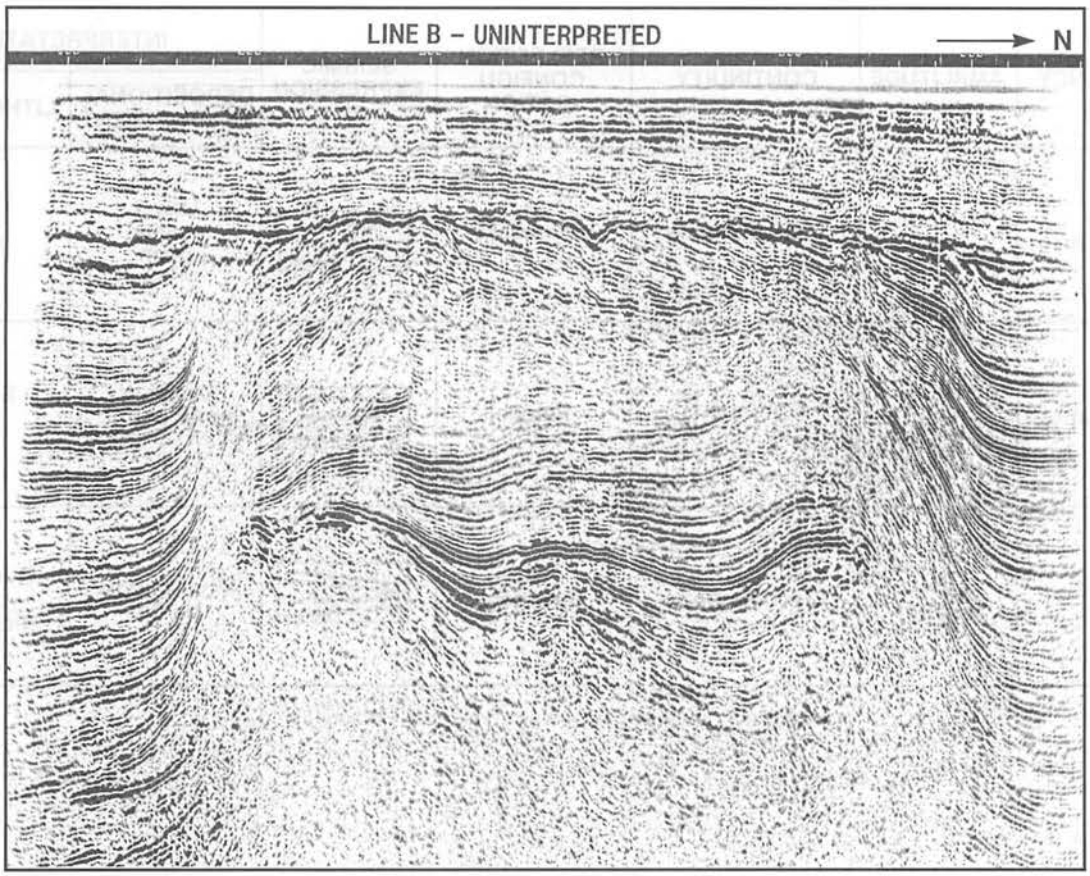


Figure 5. Line B (uninterpreted).

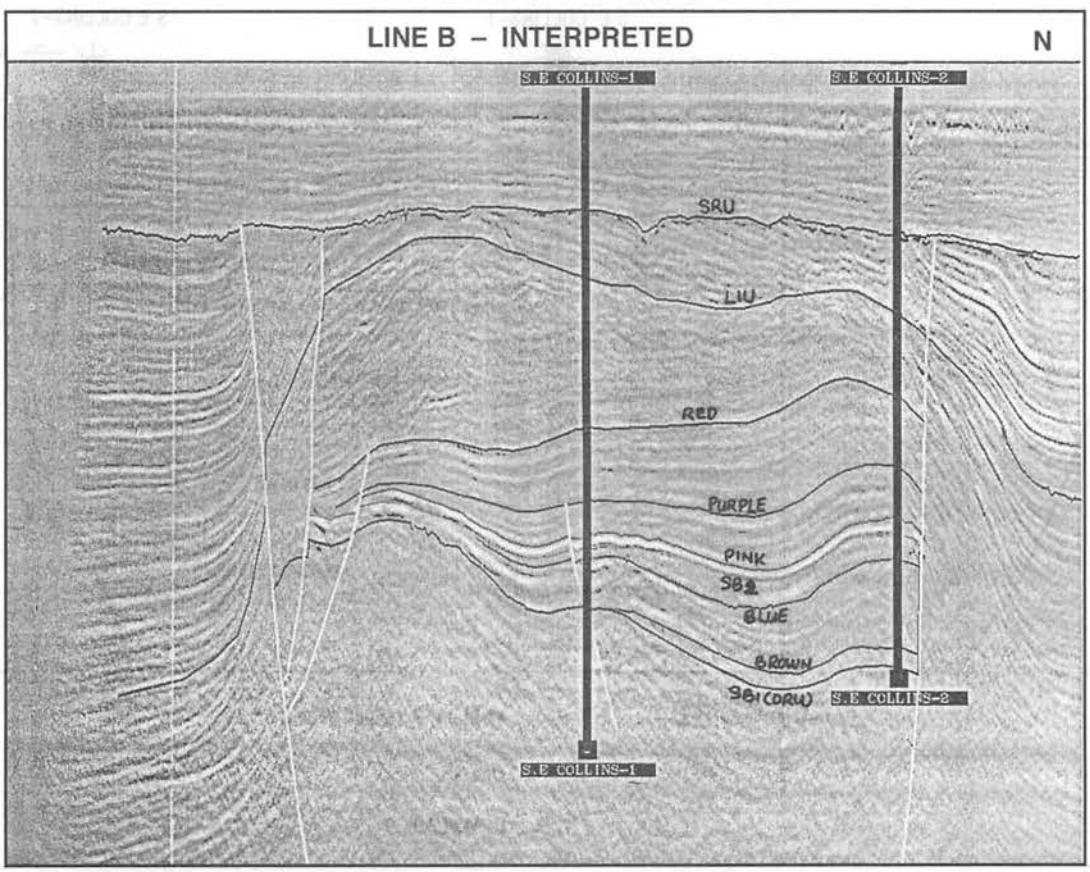


Figure 6. Line B (interpreted).

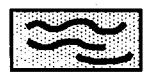
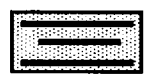
FREQUENCY	AMPLITUDE	CONTINUITY	REFLECTION CONFIGU -RATION	SEISMIC EXPRESSION	INTERPRETATION	
					DEPOSITIONAL ENVIRONMENT	LITHOFACIES
Low-Medium	Medium-high	Discontinuous	Hummocky		Lower coastal plain	Sand prone
Low-Medium	Medium-high	Continuous	Parallel		Coastal-inner neritic	Sand to silt
Medium-high	Low-Medium	Discontinuous	Divergent		Inner-middle neritic	Thin sands to thick shales

Figure 7. Seismic facies analysis, SE Collins Field.

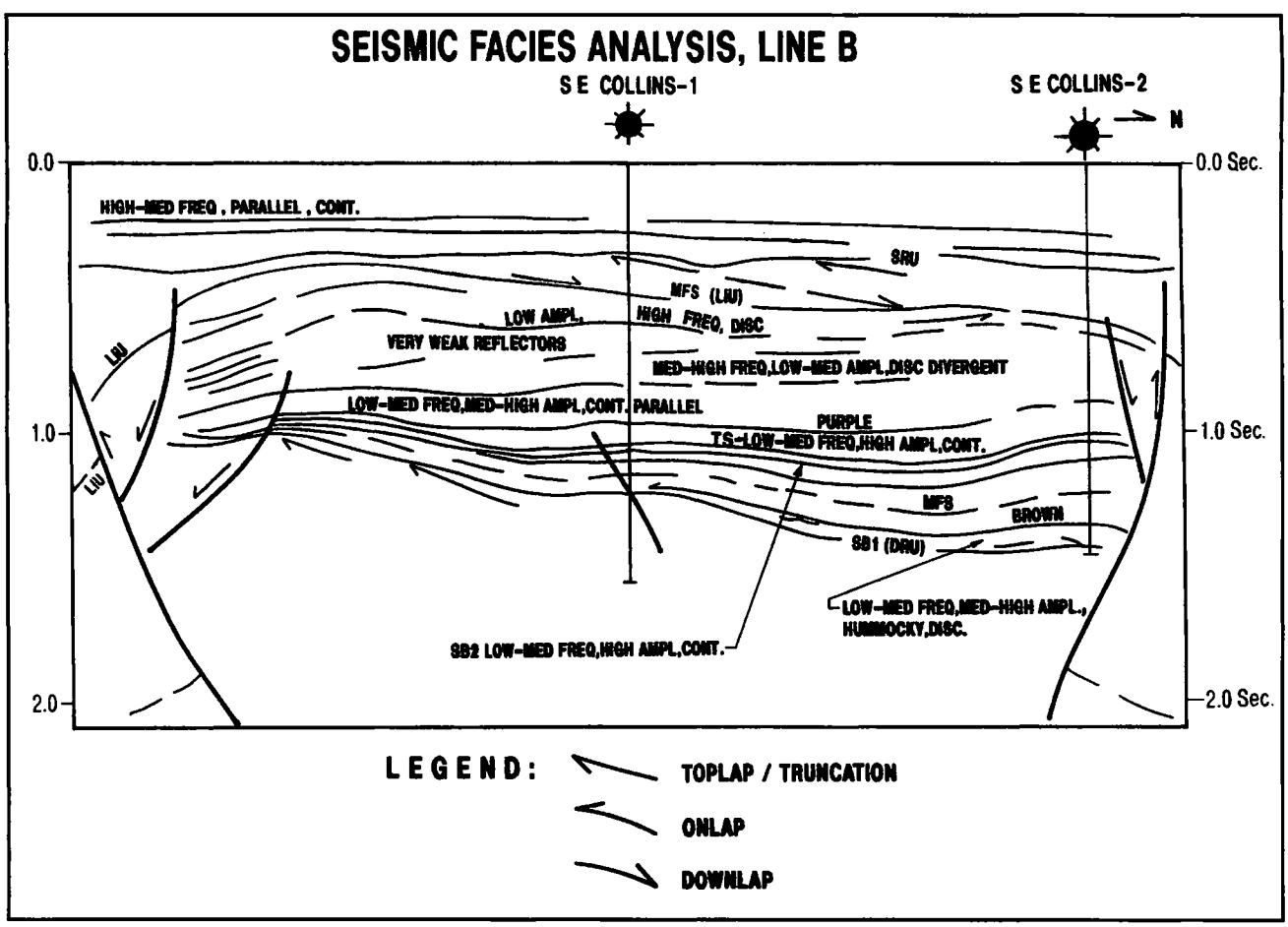


Figure 8. Seismic analysis of Line B.

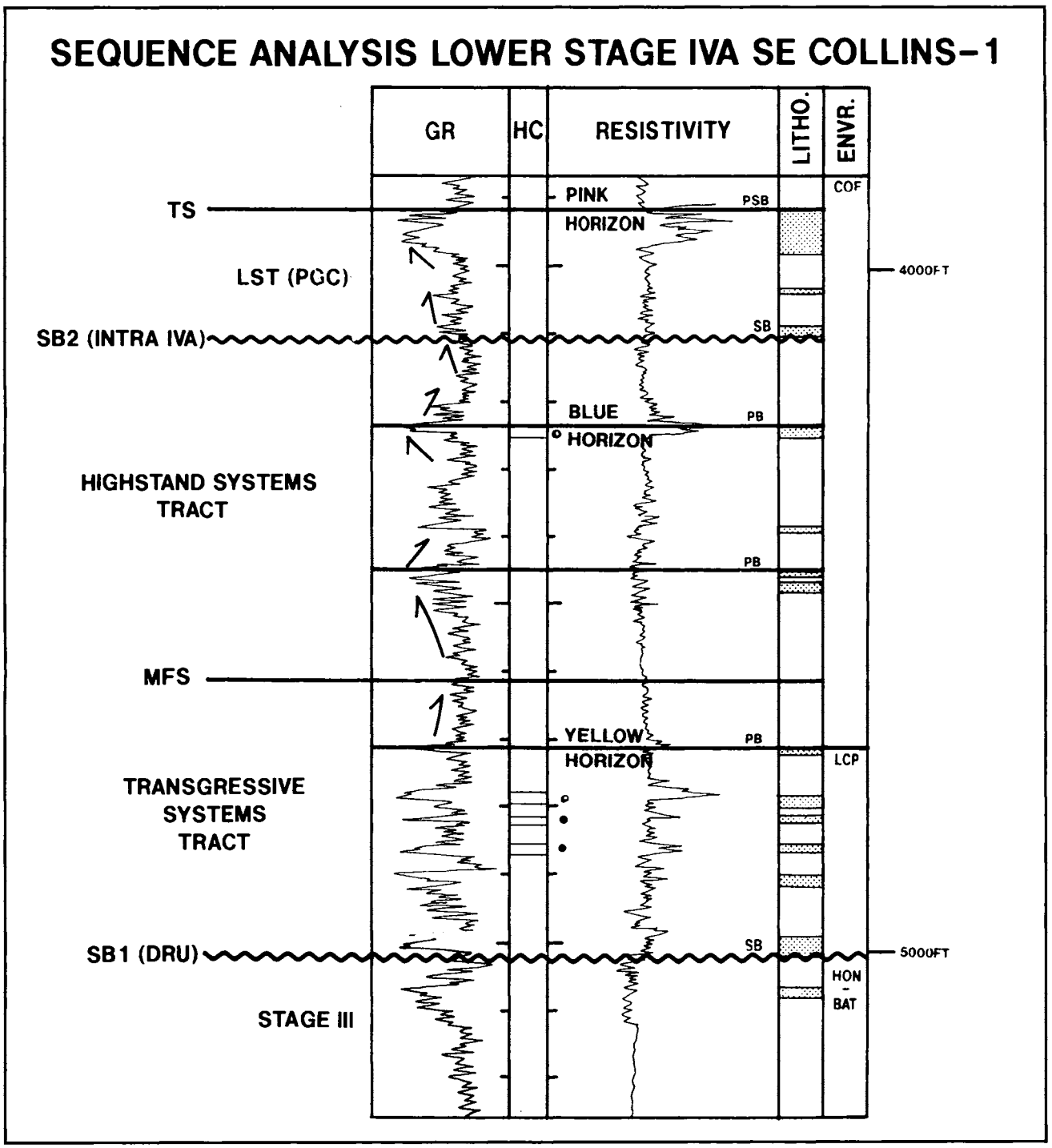


Figure 9. Sequence analysis of Lower Stage IVA, SE Collins-1.

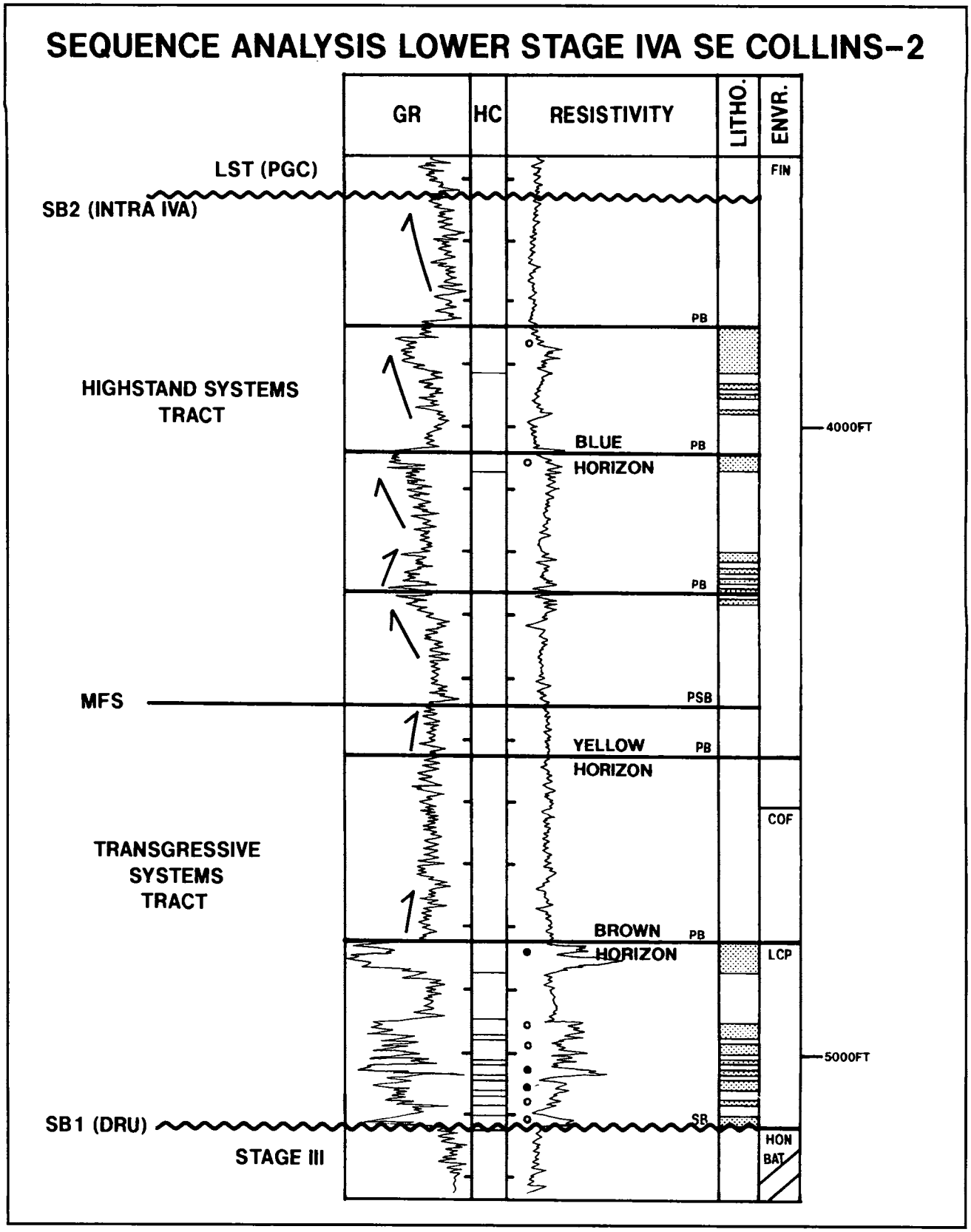


Figure 10. Sequence analysis of Lower Stage IVA, SE Collins-2.

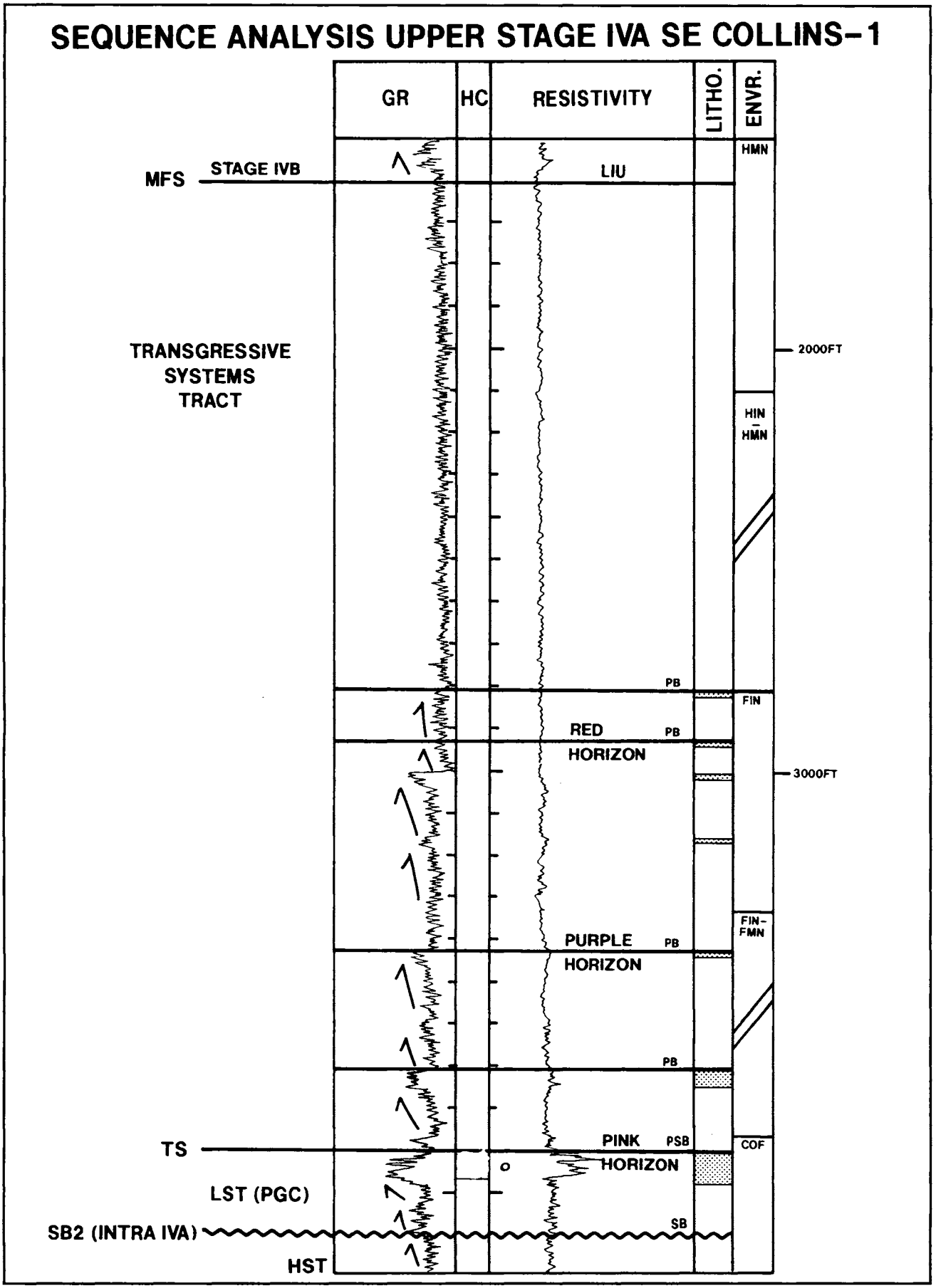


Figure 11. Sequence analysis of Upper Stage IVA, SE Collins-1.

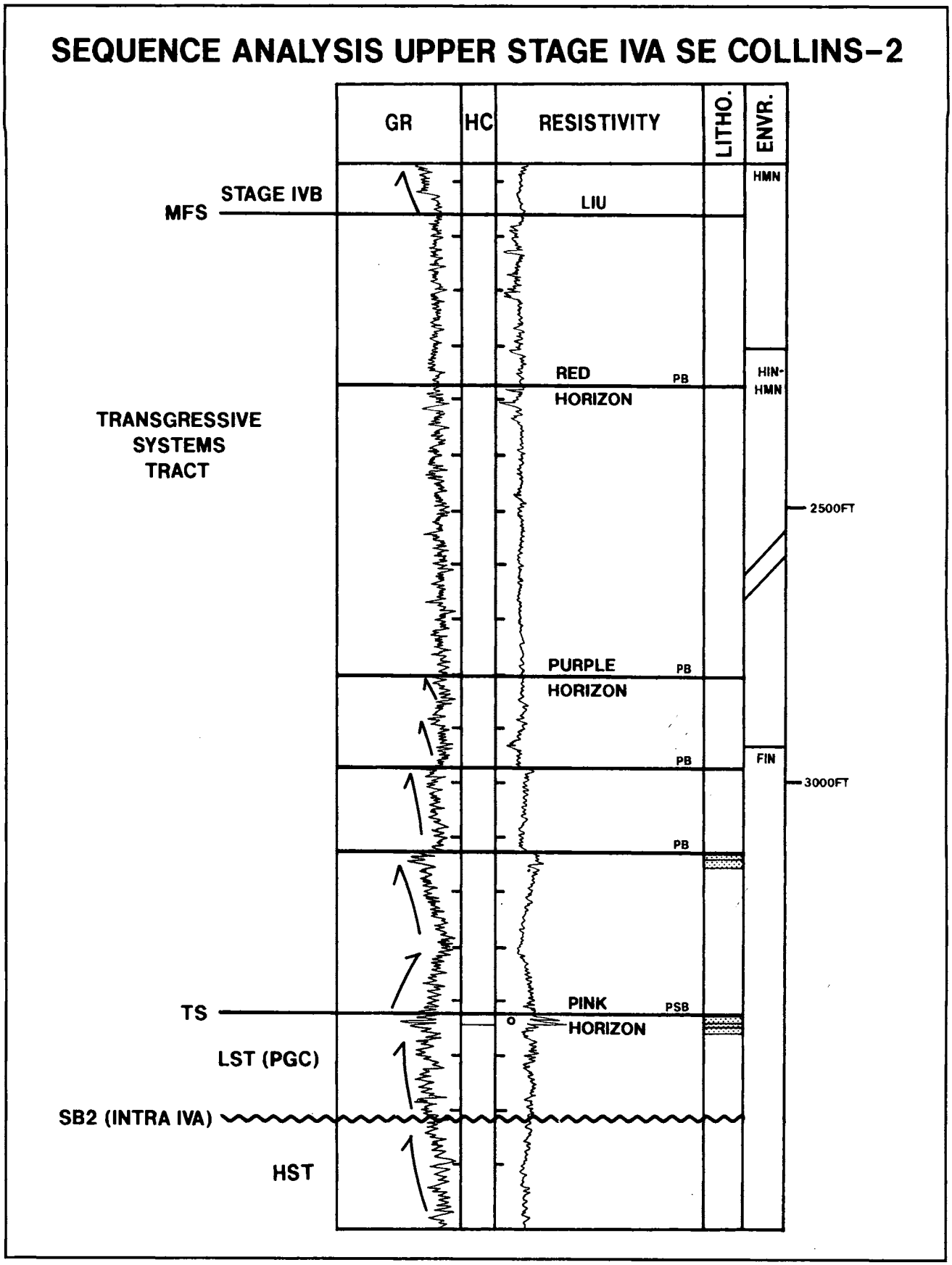


Figure 12. Sequence analysis of Upper Stage IVA, SE Collins-2.

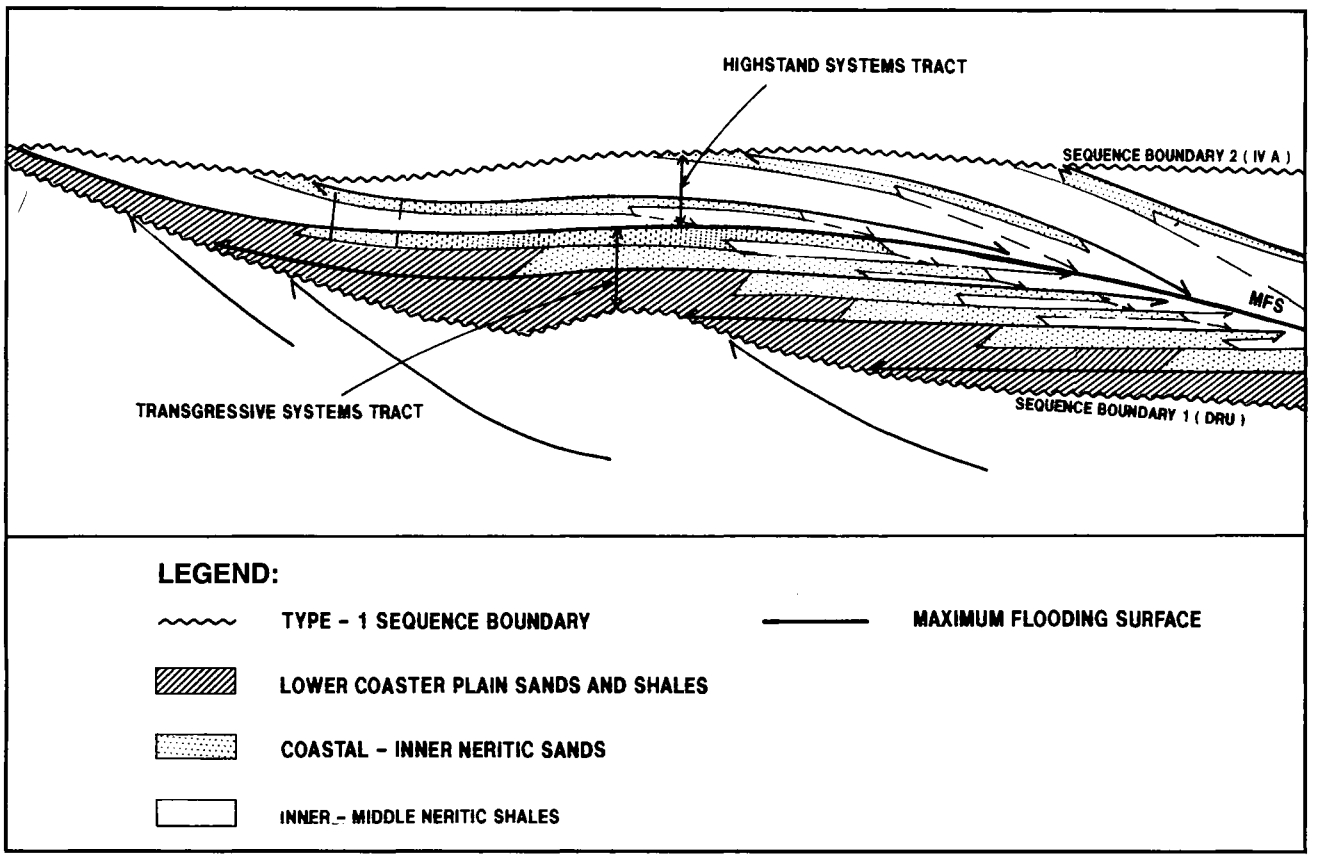


Figure 13. Stratal patterns in lower sequence, Stage IVA, SE Collins Field.

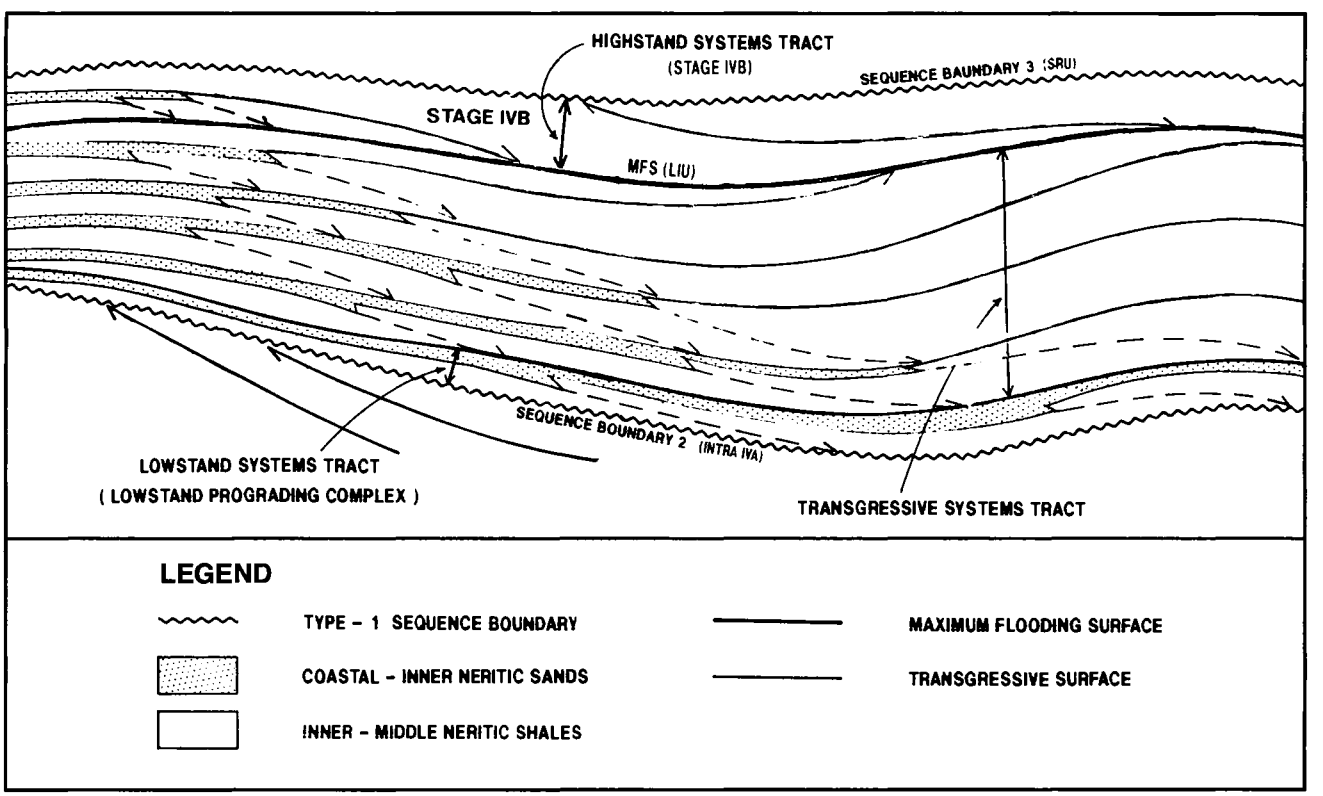


Figure 14. Stratal patterns in upper sequence, Stage IVA, SE Collins Field.

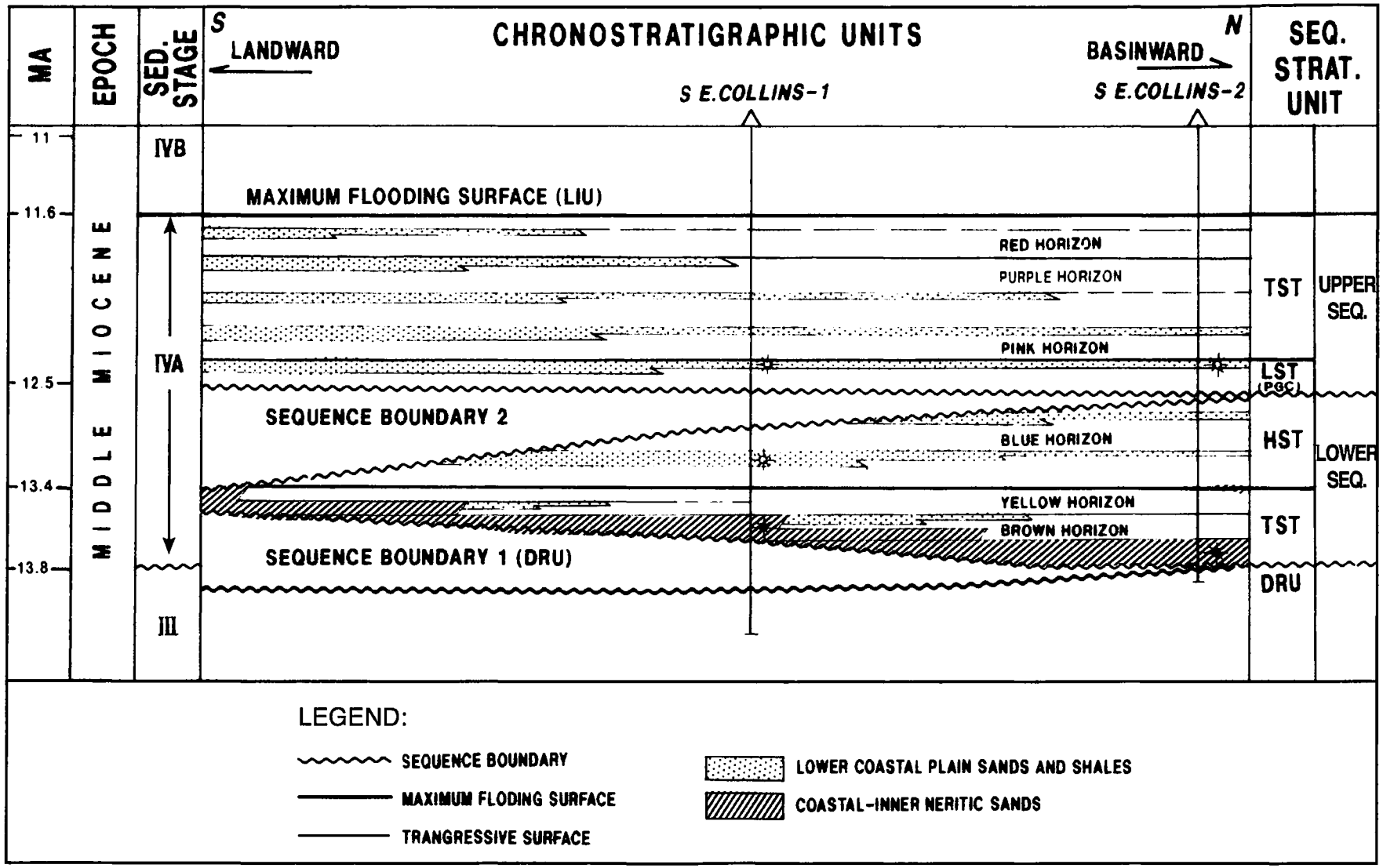


Figure 15. Chronostratigraphic correlation of Stage IVA, SE Collins Field.

A choronostratigraphic correlation of the Stage IVA is then derived from this study. This correlation corresponds to the systems tracts of the two sequences (Fig. 15). As can be observed, a sequence boundary occurred within the Stage IVA (Sequence Boundary 2) which truncated the Blue Horizon. This minor sequence boundary is perceived to be due largely to the lowering of the sea-level. Due to the influence of sea-level fluctuations upon the deposition of the sediments within the Stage IVA, their ages can be compared with the global sea-level chart (Haq *et al.*; 1987).

The Stage IVA occurs within the Middle Miocene epoch. The DRU probably relates to the 13.8 Ma sequence boundary (Fig. 16). The Lower Stage IVA sequence probably falls between the 13.8 Ma and 12.5 Ma sequence boundaries (Fig. 16). The Upper Sequence of the Stage IVA is probably confined between 12.5 Ma sequence boundary and 11.6 Ma maximum flooding surface (Fig. 15).

REMAINING HYDROCARBON POTENTIAL

The seismic sequence stratigraphic study assists greatly in our understanding of the distribution of the reservoirs and seals. This in turn enhances the remaining hydrocarbon potential of this field. A sequence stratigraphic cross-section from south to north which encompasses the hydrocarbon bearing sands was generated to depict the distribution of the main reservoirs and seals (Fig. 17). As can be observed, the upper sands belonging to the transgressive systems tract of the Upper Sequence thicken towards the south. The continuous gas bearing sands belonging to the lowstand prograding complex of the Upper Sequence (Pink Horizon) is obvious. Also shown is the gas bearing sands of the highstand systems tract of the Lower Sequence being truncated by SB2 (Blue Horizon). The hydrocarbon bearing LCP sand of SE Collins-1 shale out towards the SE Collins-2 location. The hydrocarbon bearing lower coastal plain (LCP) sands in SE Collins-2 is onlapped by the SB1 before reaching the SE Collins-1 location. This setting is confirmed by the pressure plot (Fig. 18) which demonstrates that the LCP sands of SE Collins-1 and SE Collins-2 belong to two different pressure regimes.

We have mapped every hydrocarbon bearing sands and potential ones based on our understanding of their distribution and facies variation. A better estimate of their proven and potential reserves which amounted to more than twice the original was the result.

CONCLUSIONS

Finally, some conclusions can obtained from this study.

1. Stage IVA is a composite sequence comprising two third — order sequences, i.e. a Lower and an Upper Sequence.
2. The Lower Sequence consists of a transgressive systems tract and a highstand system tract bounded by two sequence boundaries.

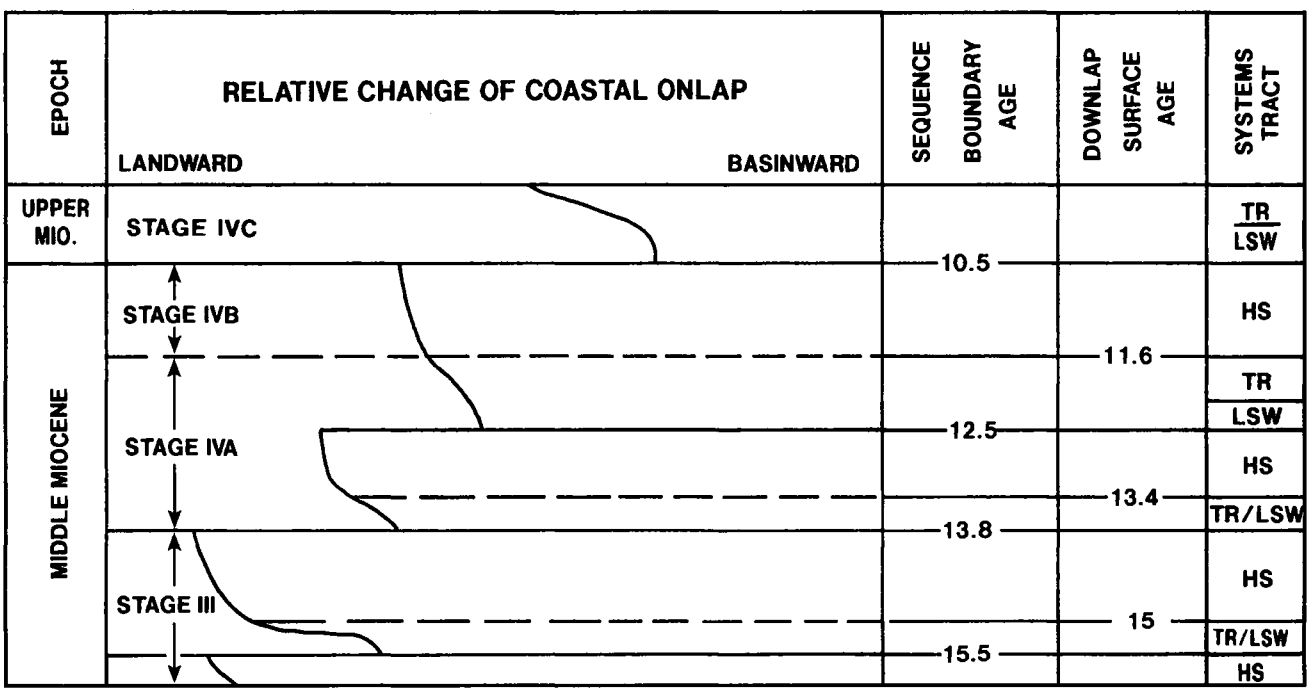


Figure 16. Middle Miocene Eustatic Sea-level Chart (after Haq *et al.*, 1987).

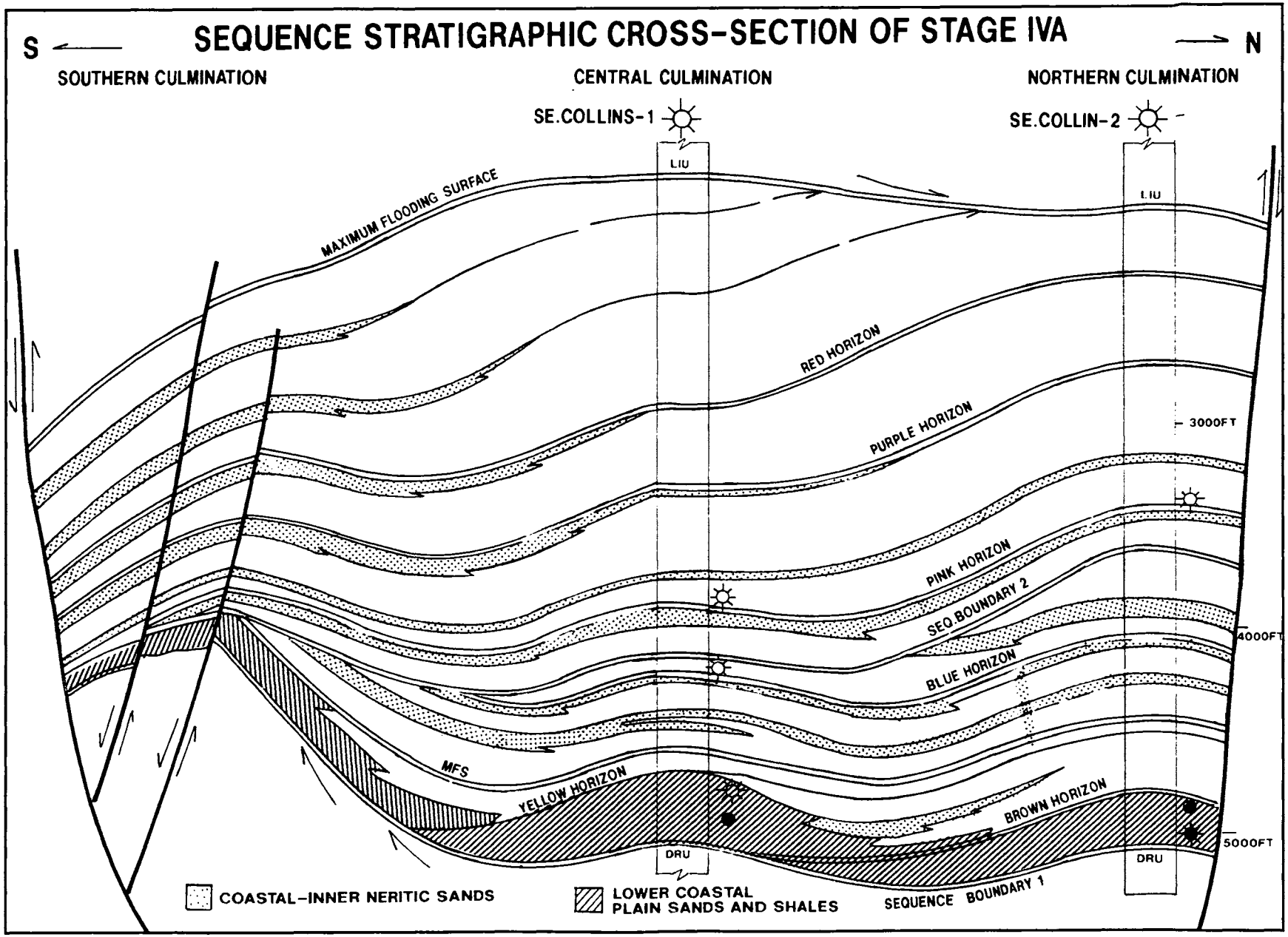


Figure 17. Sequence stratigraphic cross-section of Stage IVA.

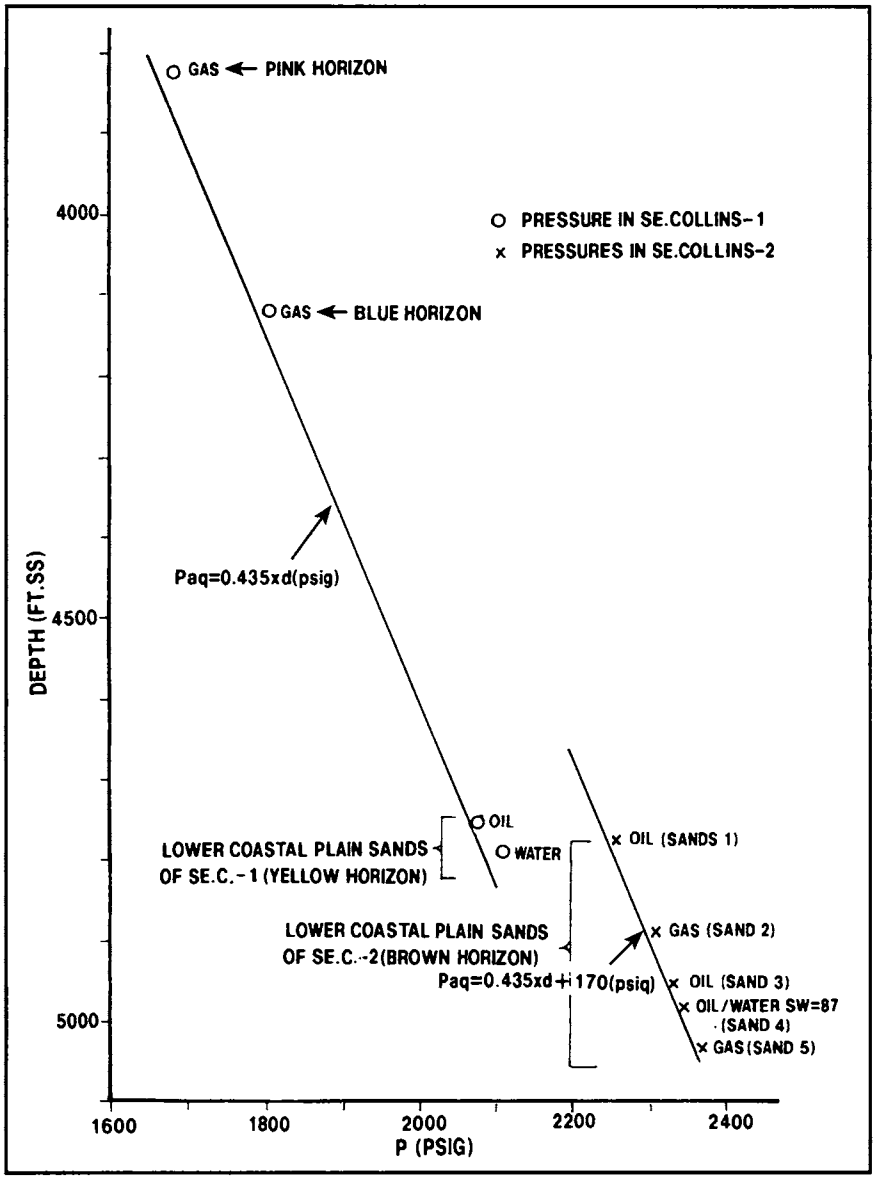


Figure 18. SE Collins area: RFT pressures vs. depth.

3. The Upper Sequence consists of a lowstand systems tract and a transgressive systems tract bounded by a sequence boundary at the base and a maximum flooding surface at the top.
4. The stratal patterns between the two sequences are differentiated. The Lower Sequence consists of a backstepping lower coastal plain sands to inner-neritic shales in the TST and the prograding coastal to inner-neritic sands in the HST. The Upper Sequence comprises the regressive coastal to inner-neritic sands of the LST and the fining and deepening upward coastal sands to middle-neritic shales of the TST.
5. A choronostratigraphic framework is established and the age of the sequence boundaries and the maximum flooding surfaces have been correlated to the Haq's curve. The Stage IVA composite sequence probably falls between the 13.8 Ma to 11.6 Ma.
6. The main reservoirs have been mapped more confidently and accurately and the remaining reserves is enhanced with more than twice the original estimate.

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