

Seismic identification of depositional processes in a turbidite fan environment, Deepwater Block SB-G, NW Sabah

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Abstract: A seismic interpretation and mapping project of the Intra Stage IV F, Upper Ligan Fan Unit was carried out in the deepwater Sabah area 120 km northwest of Kota Kinabalu. The objective of the project was to delineate the internal architecture of the Upper Seismic sequence of Ligan Fan Unit in an attempt to understand the environment of deposition and the processes involved. With the understanding of depositional environment, reservoir characteristics could be interpreted.

The Upper Ligan Fan Unit is a multi-sequence turbidite unit characterised by a period of active channelling and downcutting of earlier deposits as the Ligan Fan progrades basinward. Three seismic facies were delineated from interpreted seismic paper sections of several vintages. Isochores of these three facies were generated and analysed in relation to a depth structure map on Top Ligan Fan Unit.

The mapped turbidite sequence is interpreted to be a combination of: a) channel lobe (Facies I), b) levee-channel/crevasse splay deposits (Facies II) and c) onlapping distal lowstand prograding wedge (Facies III). Identification and interpretation of these facies gives a better understanding of the possible reservoir quality found in any exploration prospects.

The results of this shallow analogue study give a better insight in the complex processes involved in the deposition of a turbidite system. Additionally, it also highlights the complexities and resolution issues to be expected in a seismic interpretation at deeper depths. With the availability of high quality seismic data, it is possible to delineate the internal architecture and constrain the predicted reservoir quality in turbidite prospects.

PROJECT OBJECTIVES AND BACKGROUND

Objectives

The Upper Ligan Fan Seismic Interpretation Project has a two fold objectives:

- a) To delineate the internal architecture of the upper portion of the Ligan Fan through mapping of the different facies.
- b) To interpret the environment of deposition from which the models could be developed and reservoir characteristics could be interpreted.

Study Area and Seismic Data Coverage

a) Study Area

The area covered in the study is approximately 18 km x 22 km, located about 120 km offshore northwest Sabah (see Fig. 1). The Ligan Fan Unit in the area is about 2.0–2.5 TWT deep and lies in a water depth of 2,000 to 3,000 ft and is located

nearby main gas discoveries of the Keabangan and Kinarut fields. The Ligan Fan Unit has only been partially penetrated in the Keabangan and Kinarut wells.

b) Seismic Data Coverage

The area of study is covered by several 2D seismic vintages (see Fig. 2). Majority of the area is covered by the 2 km x 4 km KNR 1987 2D seismic survey (Evaluation Report, 1991). Several infill lines were extended in the area, namely the LGN1991, KN1993 and the deepwater SBG1995 2D seismic. This resulted in a nominal coverage of 1 km x 2 km grid of the different vintages. The quality of the seismic data ranges from fair to very good. For final structural and stratigraphic mapping a combination of the KNR 1987 and SBG 1995 interpretations was chosen. This is mainly due to the abundance of data from the two vintages and also the relatively superior quality of the two vintages to the other seismic data. The seismic horizons were correlated to the nearby Keabangan well.

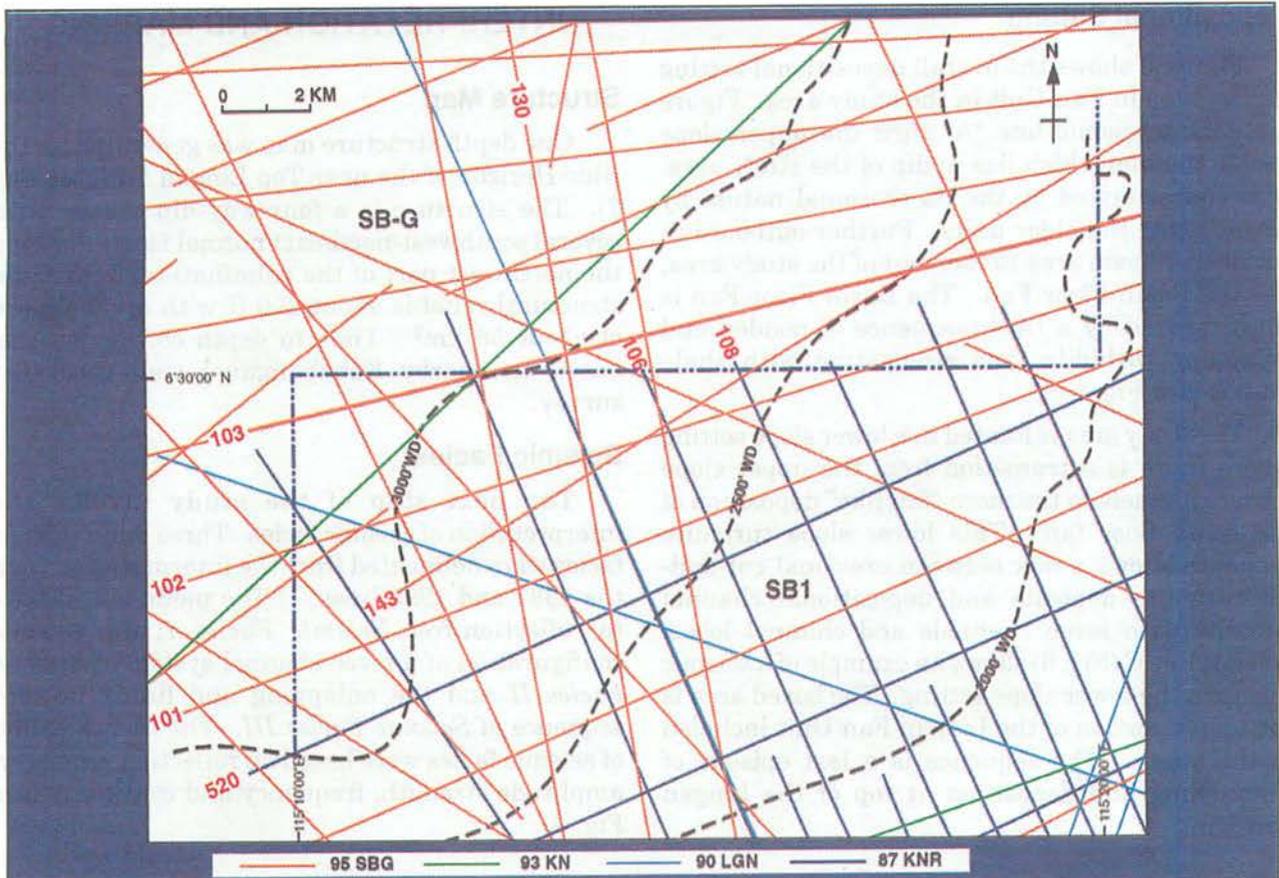


Figure 2. Northeast SB-1 and SB-G 2D seismic coverage map (1987 to 1995).

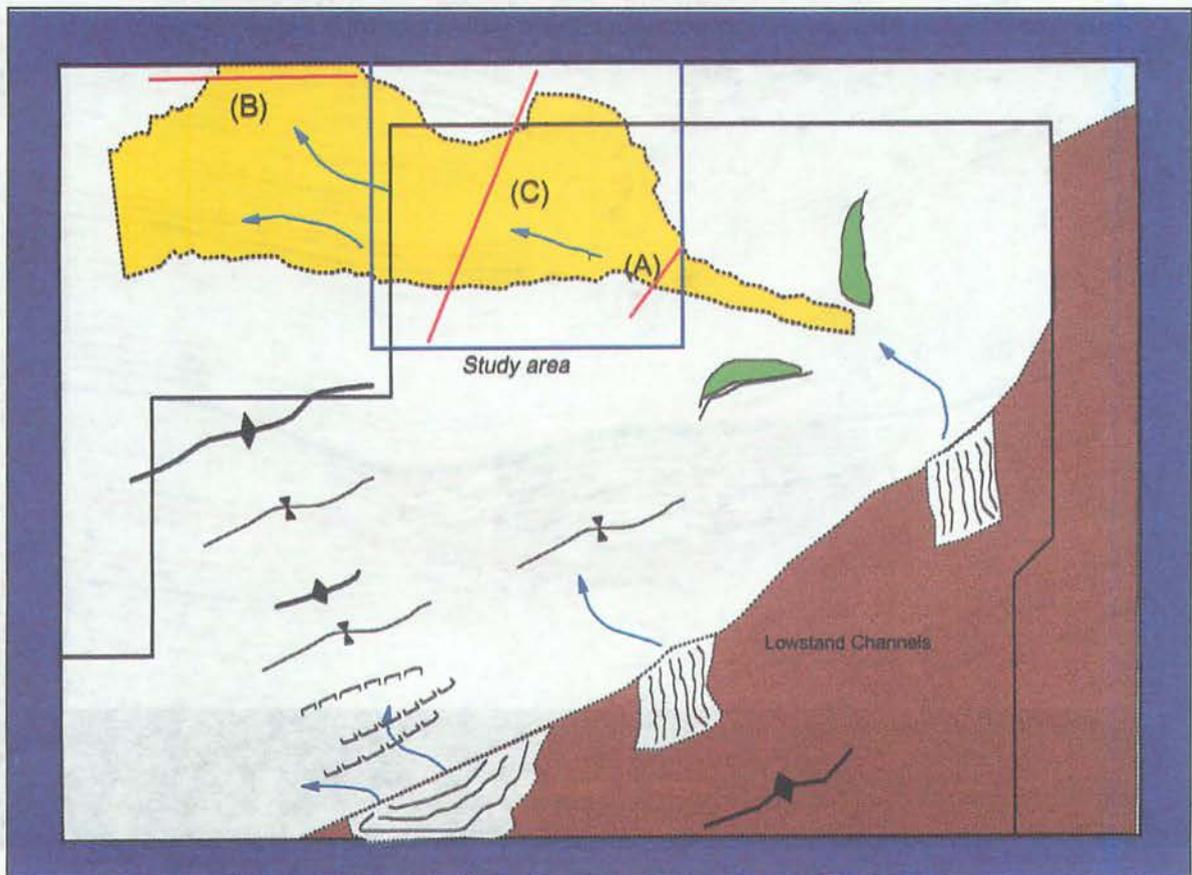


Figure 3. Schematic diagram of depositional setting for Lingan Unit.

Depositional Setting

Figure 3 shows the overall depositional setting for the Lingan Fan Unit in the study area. Figure 4 shows a seismic line "A" thru the upper slope feeder channel which lies updip of the study area. It is characterized by its erosional nature by downcutting the older units. Further outboard in the deeper basin area to the west of the study area, lies the Basin Floor Fan. The Basin Floor Fan is characterized by a thick sequence of ponded and onlapping turbidite fans alternating with shale drapes (see Fig. 5).

The study area is located in a lower slope setting where there is a transition from the upper slope feeder channels to the more "fan like" deposition of the basin floor fan. This lower slope turbidite sequence shows a mix between erosional cut-and-fill turbidite deposits and depositional channel deposits with levee channels and channel lobes. Seismic line C (Fig. 6) shows an example of a seismic line thru the lower slope setting. The boxed area is the upper portion of the Lingan Fan Unit included in the study. The sequence is a last episode of channelling and deposition at top of the Lingan Fan Unit.

INTERPRETATION AND MAPPING

Structure Map

One depth structure map was generated for the Blue Horizon of the near Top Lingan Fan (see Fig. 7). The structure is a four way dip closure with several southwest-northeast normal faults flanking the northwest part of the culmination. Maximum structural relief is about 200 ft with areal closure of about 56 km². Time to depth conversion was based on nearby Keabangan-1 well checkshot survey.

Seismic Facies

The next step of the study involve the interpretation of seismic facies. Three main seismic facies were delineated from the interpretation from the 1987 and 1995 lines; 1) The mounded, chaotic to reflection-free *Seismic Facies I*; the seismic configuration of a levee channel system of *Seismic Facies II* and the onlapping and fining upward sequence of *Seismic Facies III*. The identification of seismic facies were based on reflection geometry, amplitude strength, frequency and continuity (see Fig. 8).

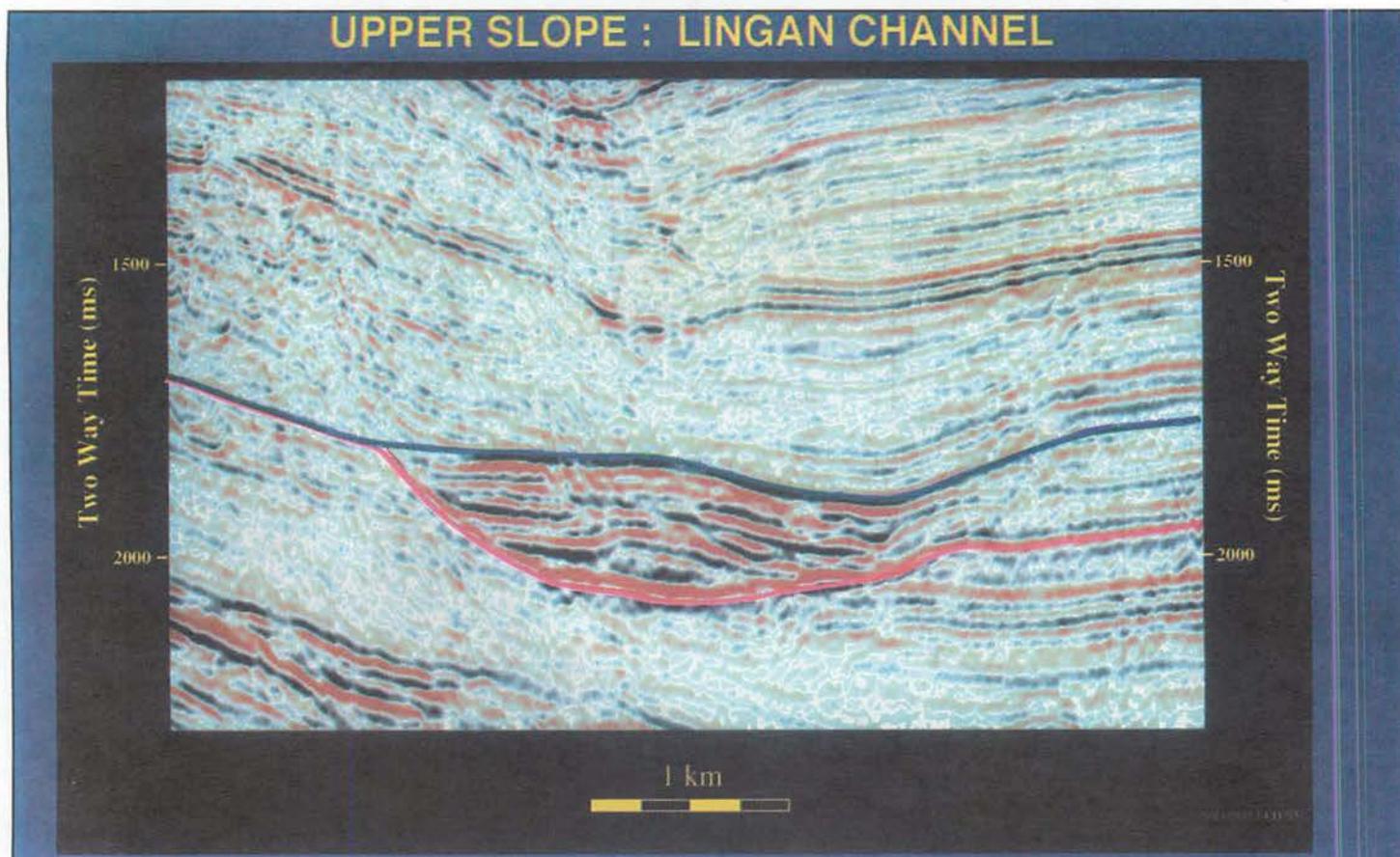


Figure 4. Seismic line "A" across the upper slope feeder channel.

LINGAN BASIN FLOOR FAN

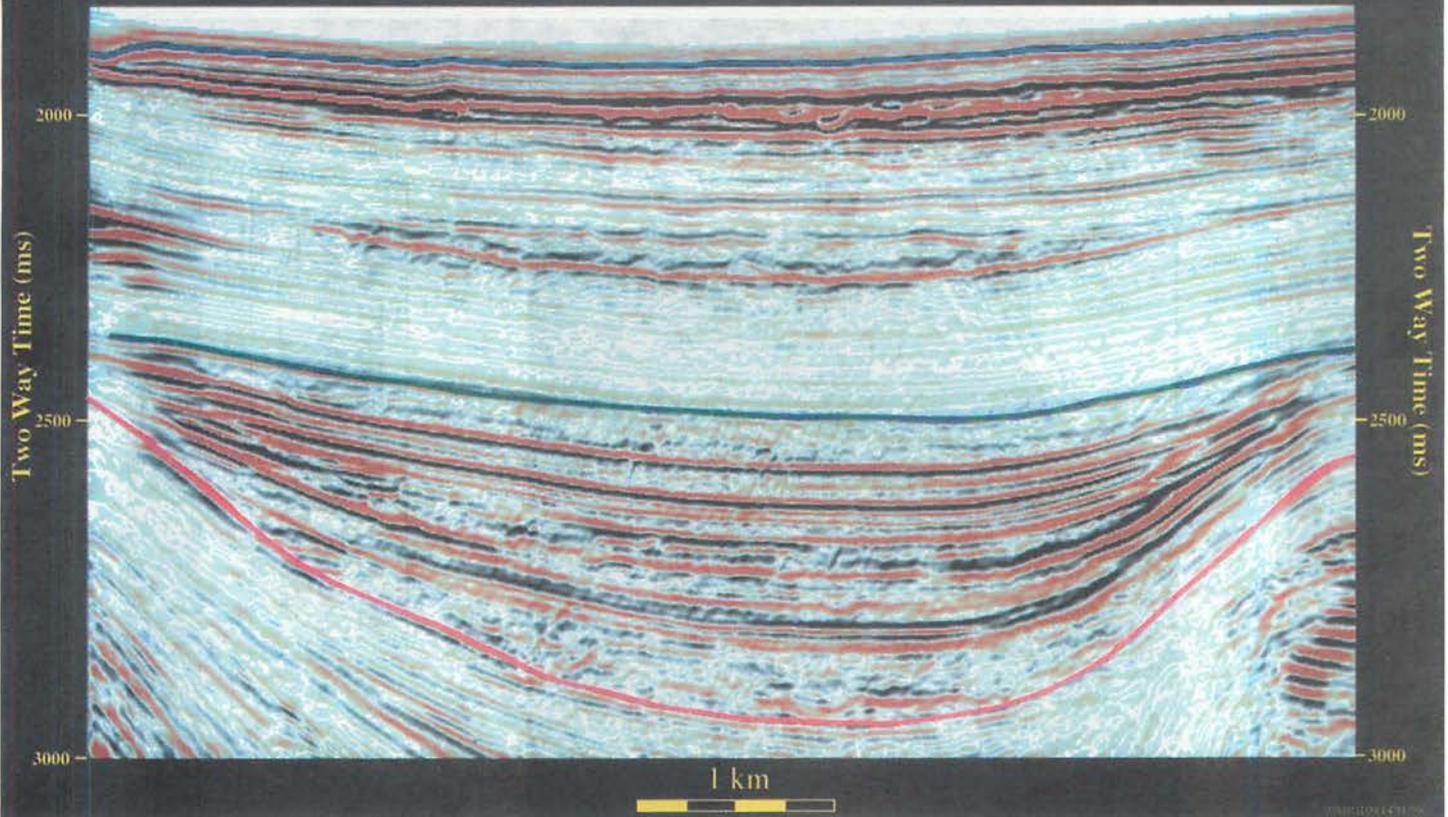


Figure 5. Seismic line "B" across basin floor fan.

LOWER SLOPE : TRANSITION FROM CHANNEL TO FAN

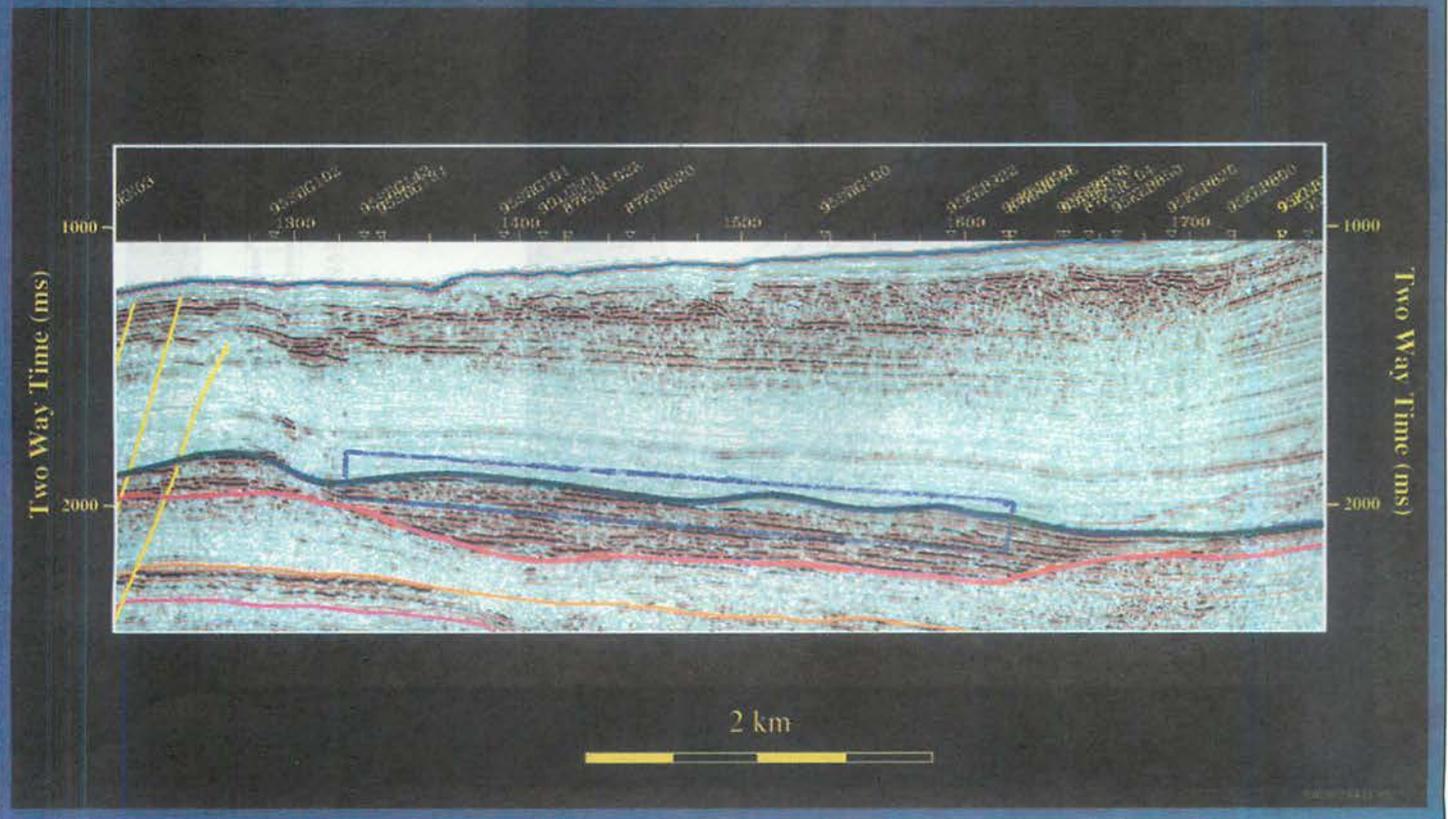


Figure 6. Seismic Line "C" across the lower slope setting of the study area. Blue Horizon is top Lingan Fan Unit while red is the base. The boxed area within Blue and Green is the upper portion of the Lingan Unit included in the study.

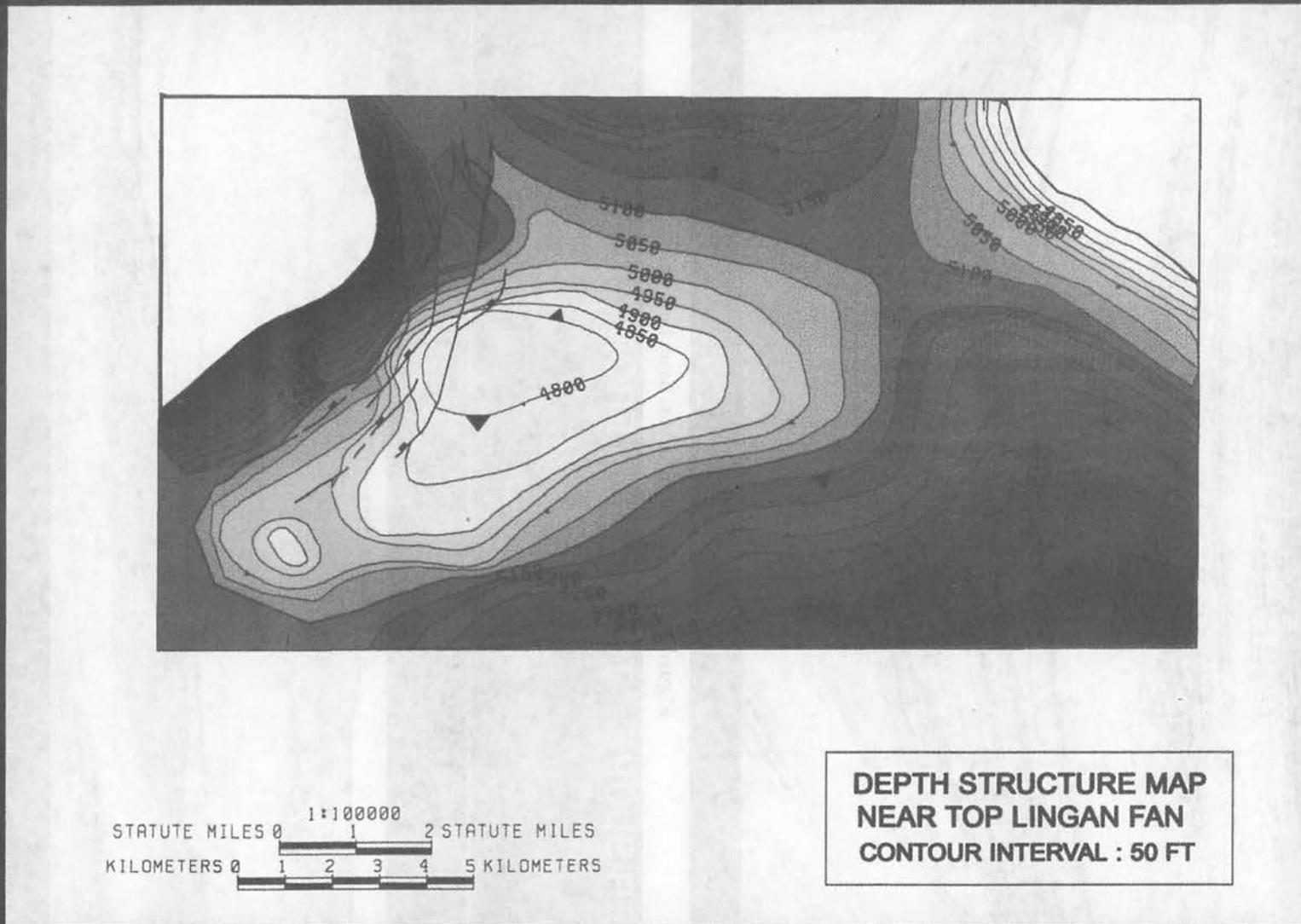


Figure 7. Depth structure map of near top Lingan Fan Unit.

Seismic Facies I is characterized by mounded external geometry with chaotic internal reflectors to reflector free in the thicker parts grading to parallel at facies boundary (see Fig. 9). *Facies II* shows a levee channel "Gull Wing" external geometry with discontinuous low amplitude to reflection free internal form. *Facies II* cuts the underlying facies I resulting in the absence and thinning of *Facies I* in places (see Fig. 10). *Facies III* onlapping wedge possess relatively more continuous reflectors onlapping the earlier facies (see Fig. 11).

Isochore Maps

3 Separate isochore maps were generated for the seismic facies identified. Seismic Facies I (yellow), Seismic Facies II (light blue) and Seismic Facies III (light red) (see Figs. 12, 13 and 14). The isochore map of the Seismic Facies I shows a Fan/lobe like configuration with strong evidence of being cut by the younger Facies II, although it is sometimes difficult to interpret the limit of the body. Possible depositional direction is shown by

the arrow. The thickness part of the lobe is about 80 ms.

Mapping of Facies II suggest that it cuts and deflects around the remnant of Facies I and the paleostructural high (see Fig. 13). Based on the geometry, variation of isochore thickness and levee channel "gull wing" positions, the direction of deposition is interpreted.

Facies III shows a subtle onlapping on the earlier sequences. It is more prevalent in the south and east of the structure and absent to the west and north (see Fig. 14). The relative position of older Facies I and II is shown by the dotted lines.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT AND RESEVOIR DEVELOPMENT

Depositional Environment

The Lingan Fan in the study area is believed to consist of lower slope turbidite deposits which had

		External Geometry	Reflection Attributes
Facies I		Mounded	Chaotic reflectors/reflector free in the thicker parts and grading to parallel at the facies boundaries.
Facies II		Levee Channel "gull wing"	Discontinuous, low amplitude to reflection free
Facies III		Onlapping wedge	Fairly continuous, medium frequency reflectors onlaps earlier facies.

Figure 8. Table of seismic attributes of the three main seismic facies identified.

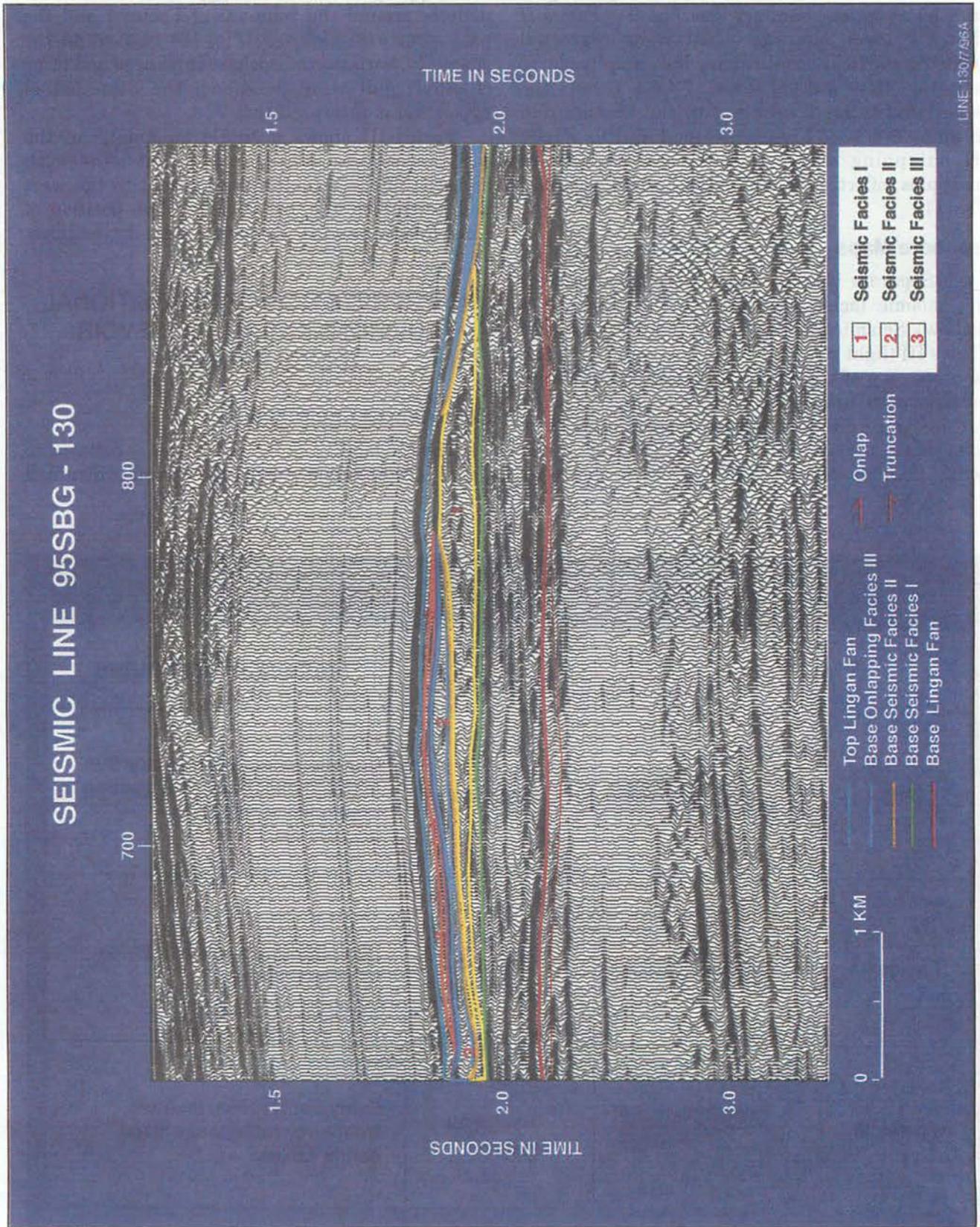


Figure 9. A seismic section showing example of the mounded Seismic Facies I in yellow.

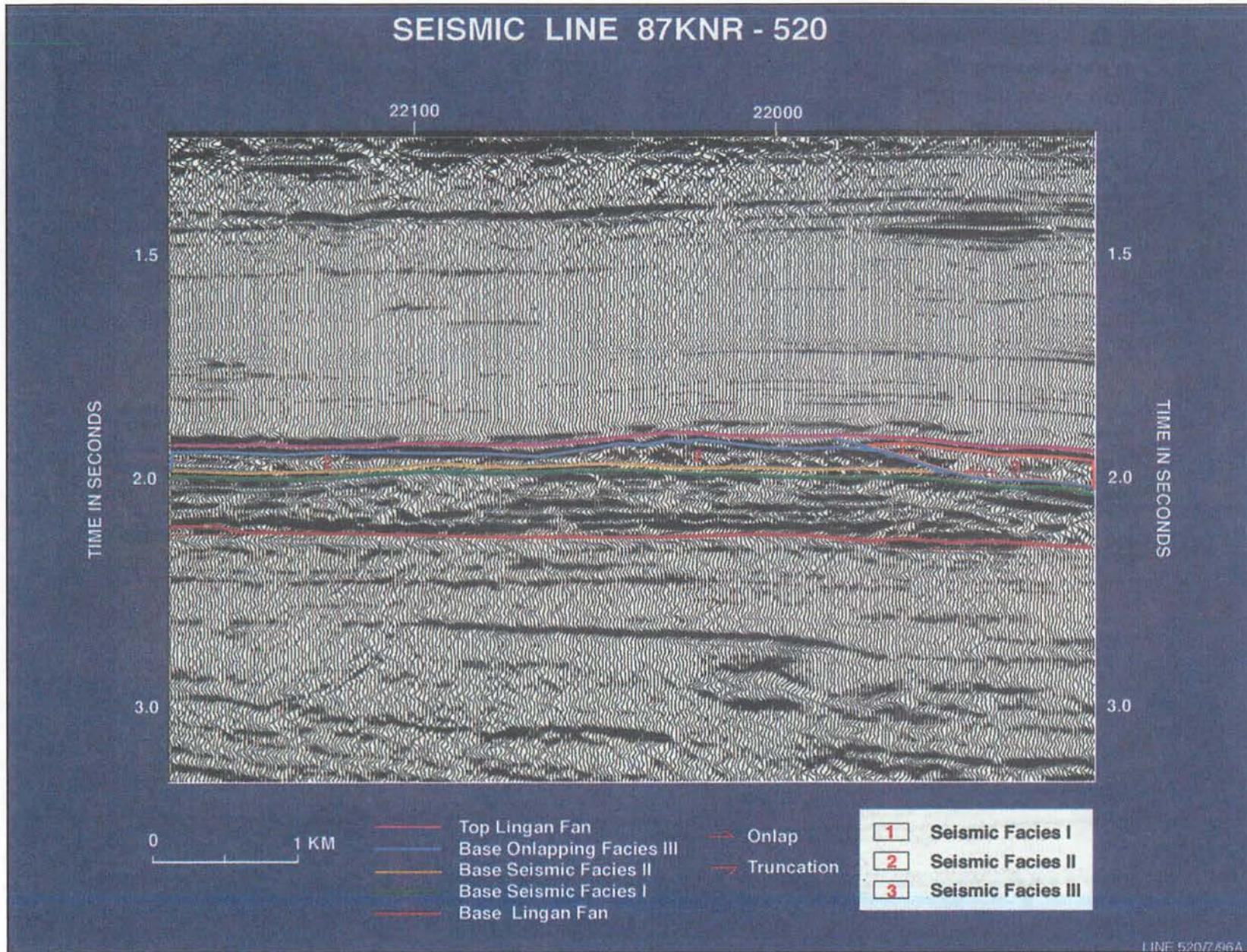


Figure 10. A seismic section showing an example of Seismic Facies II. Notice the "Gull Wing" external geometry.

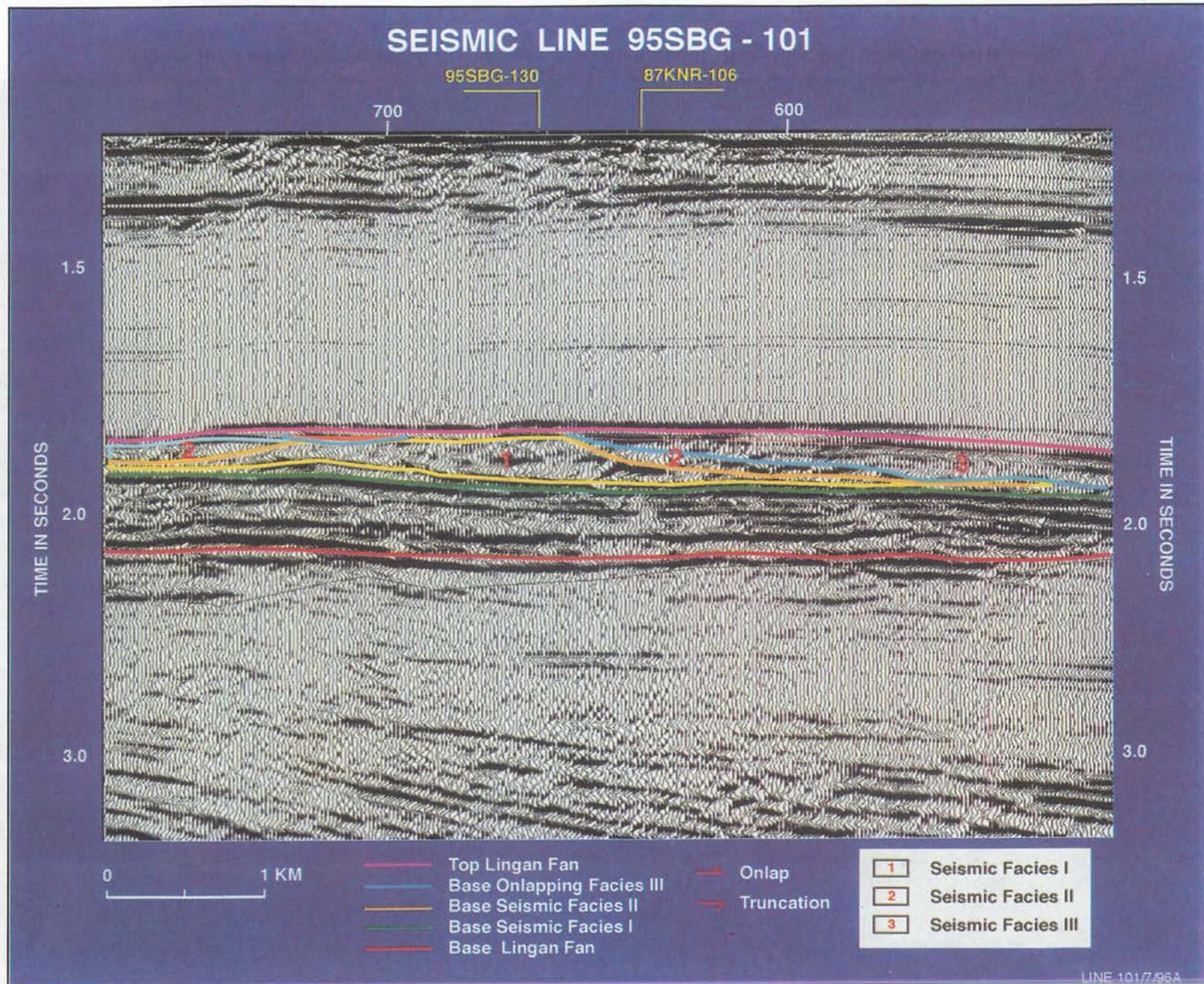


Figure 11. A seismic section showing an example of onlapping Seismic Facies III.

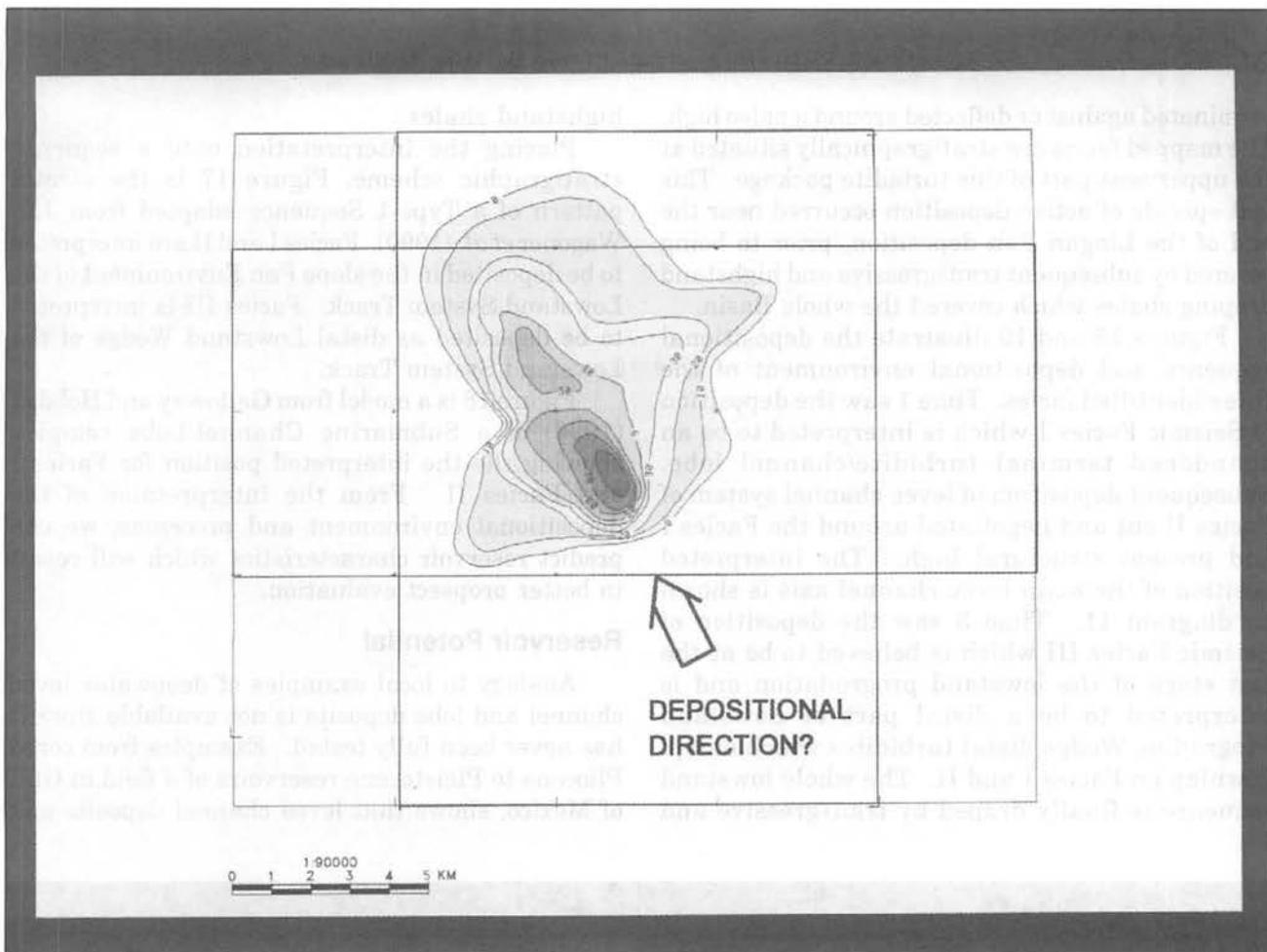


Figure 12. Isochore map of Facies I with possible depositional direction. Thickest part of the "Lobe" is about 80 ms.

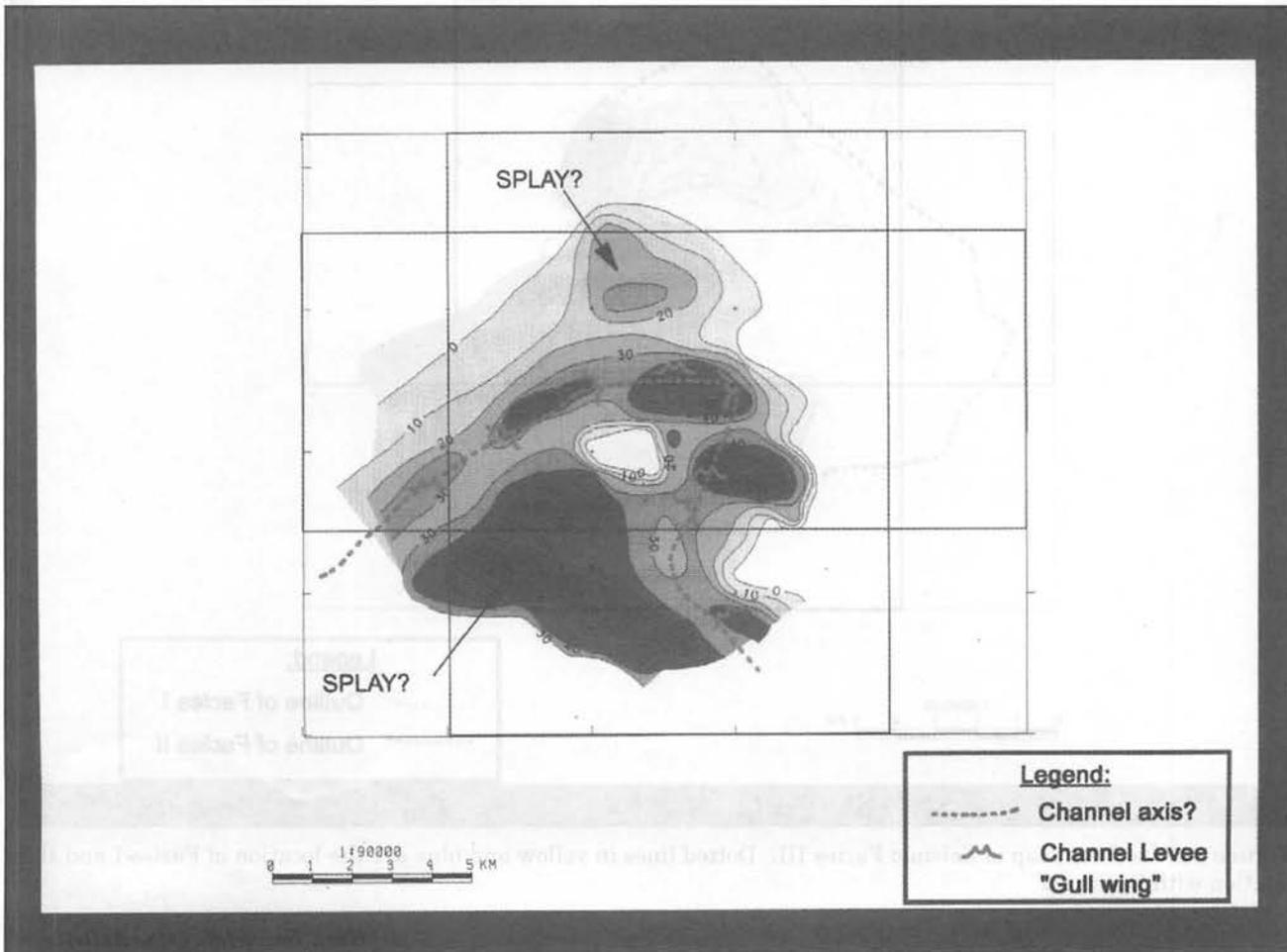


Figure 13. Isochore map of Facies II with the interpreted main channel axis shown by the dashed lines.

terminated against or deflected around a paleo high. The mapped facies are stratigraphically situated at the uppermost part of this turbidite package. This last episode of active deposition occurred near the end of the Lingan Fan deposition, prior to being covered by subsequent transgressive and highstand draping shales which covered the whole Basin.

Figures 15 and 16 illustrate the depositional sequence and depositional environment of the three identified facies. Time 1 saw the deposition of Seismic Facies I which is interpreted to be an abandoned terminal turbidite/channel lobe. Subsequent deposition of levee channel system of Facies II cut and negotiated around the Facies I and present structural high. The interpreted position of the main levee channel axis is shown on diagram 11. Time 3 saw the deposition of Seismic Facies III which is believed to be at the last stage of the lowstand progradation and is interpreted to be a distal part of Lowstand Prograding Wedge distal turbidites which onlap/downlap on Facies I and II. The whole lowstand sequence is finally draped by transgressive and

highstand shales.

Placing the interpretation onto a sequence stratigraphic scheme, Figure 17 is the stratal pattern of a Type-1 Sequence adapted from J.C. Wagoner *et al.* (1990). Facies I and II are interpreted to be deposited in the slope Fan Environment of the Lowstand System Track. Facies III is interpreted to be deposited as distal Lowstand Wedge of the Lowstand System Track.

Figure 18 is a model from Galloway and Hobday (1996) of a Submarine Channel/Lobe complex showing the the interpreted position for Facies I and Facies II. From the interpretation of the depositional environment and processes, we can predict reservoir characteristics which will result in better prospect evaluation.

Reservoir Potential

Analogy to local examples of deepwater levee channel and lobe deposits is not available since it has never been fully tested. Examples from cored Pliocene to Pleistocene reservoirs of a field in Gulf of Mexico, shows that levee channel deposits and

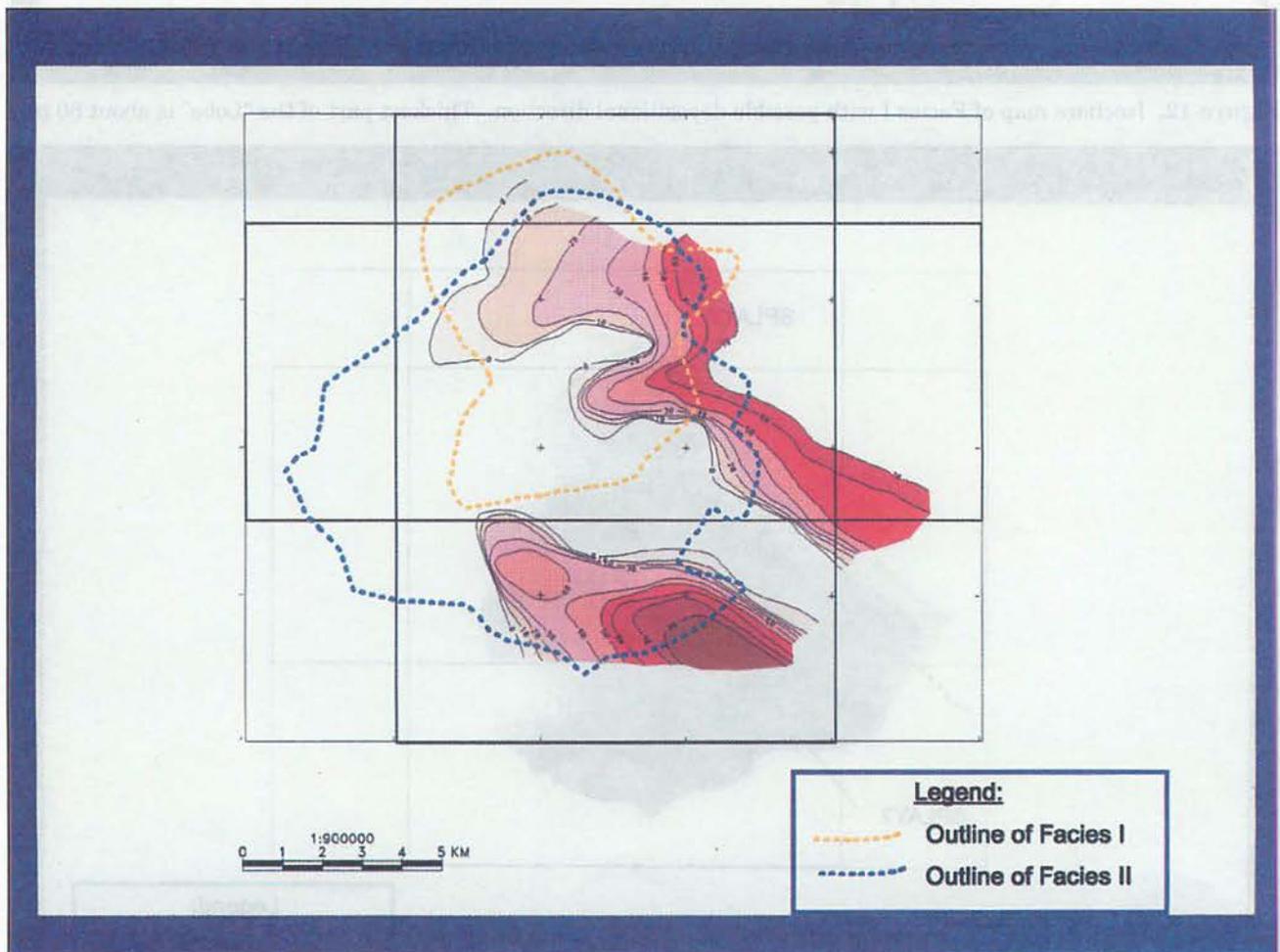


Figure 14. Isochore map of Seismic Facies III. Dotted lines in yellow and blue are the location of Facies I and II in relation with Facies III.

Upper Lingan Fan Depositional Sequence

Time 1

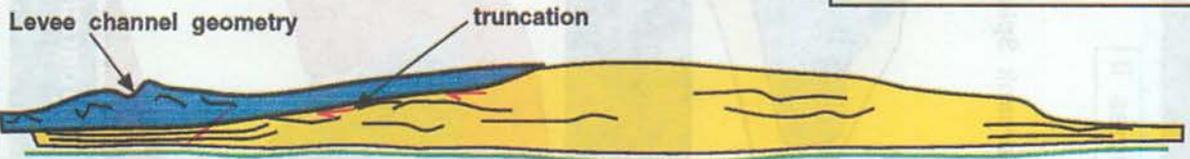
Seismic Facies I
Channel Lobe Deposits



- Mounded. With chaotic reflector/reflector free in the thicker parts and grading to parallel at the facies boundaries.

Time 2

Seismic Facies II
Channel Levee System



- Deposition of facies II, partly controlled by Facies I depositional thick.

Time 3

Seismic Facies III
Prograding wedge/Distal turbidite



- Facies of fairly continuous, medium frequency reflectors onlaps earlier facies.

Time 4

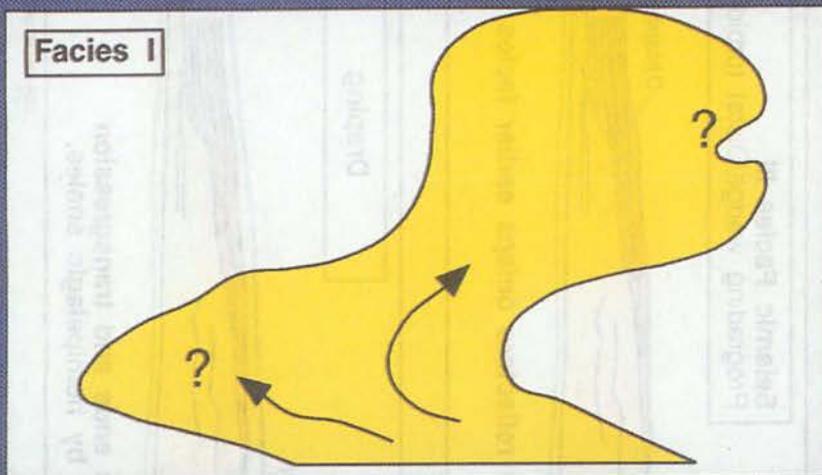
Draping



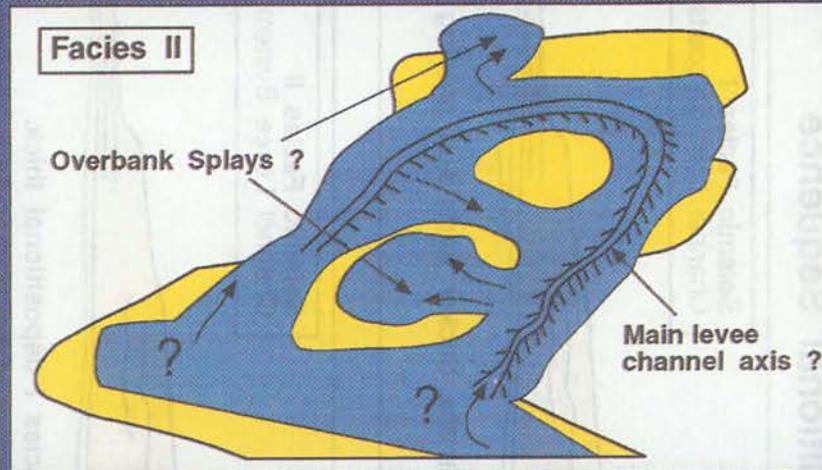
- As the lowstand deposition of the Lingan Fan ends and transgression commences, the turbidite deposits are draped by hemipelagic shales.

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Figure 15. Upper Lingan Fan depositional sequence.



Turbidite Lobe



Levee Channel System



On Lapping Distal Lowstand Prograding Wedge

Figure 16. Upper Lingan Fan depositional environment.

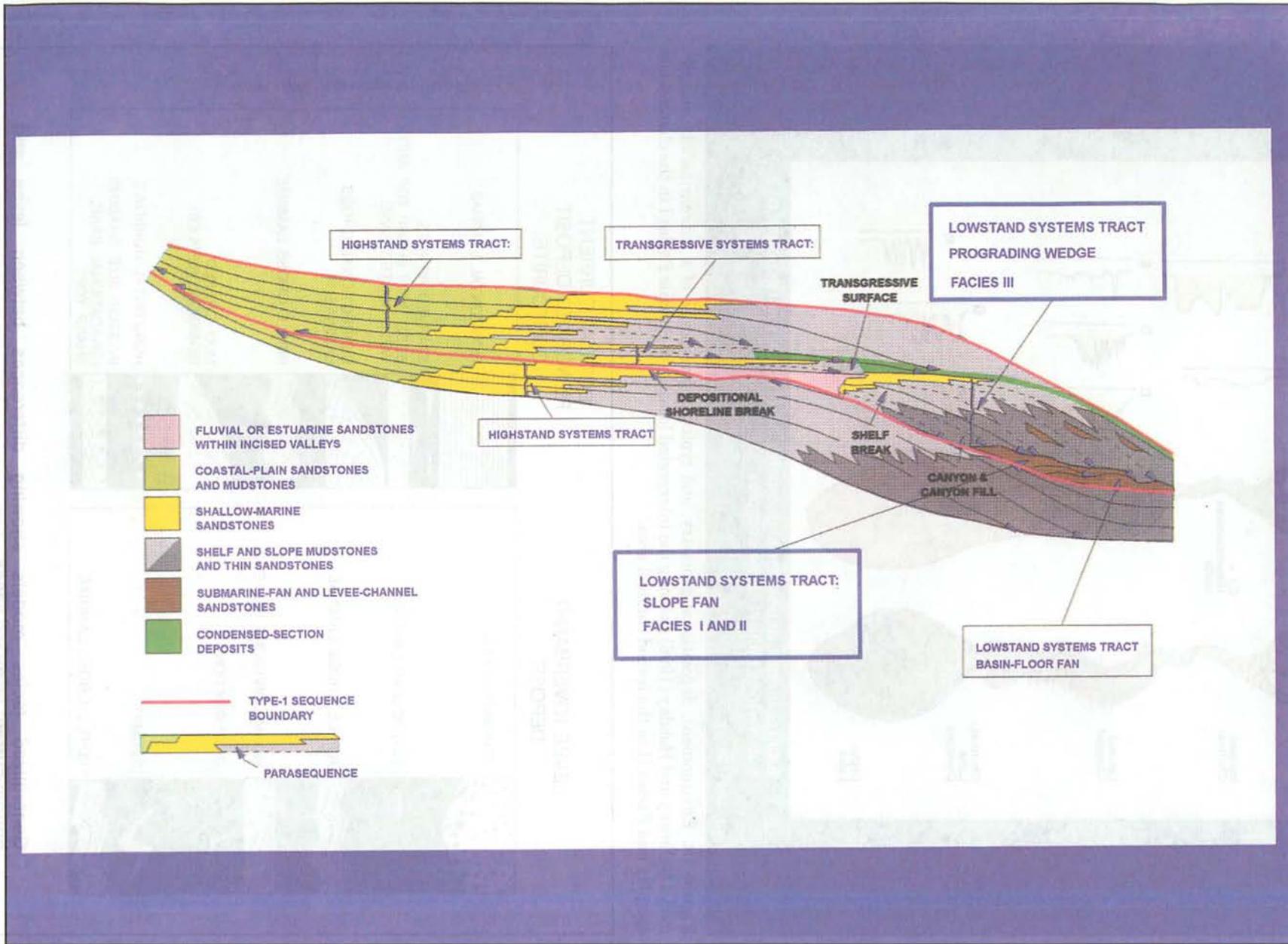


Figure 17. Stratal pattern of Type-1 sequence adapted from J.C. Wagoner *et al.* (1990) showing interpreted sequence stratigraphic location of Facies I, II and III.

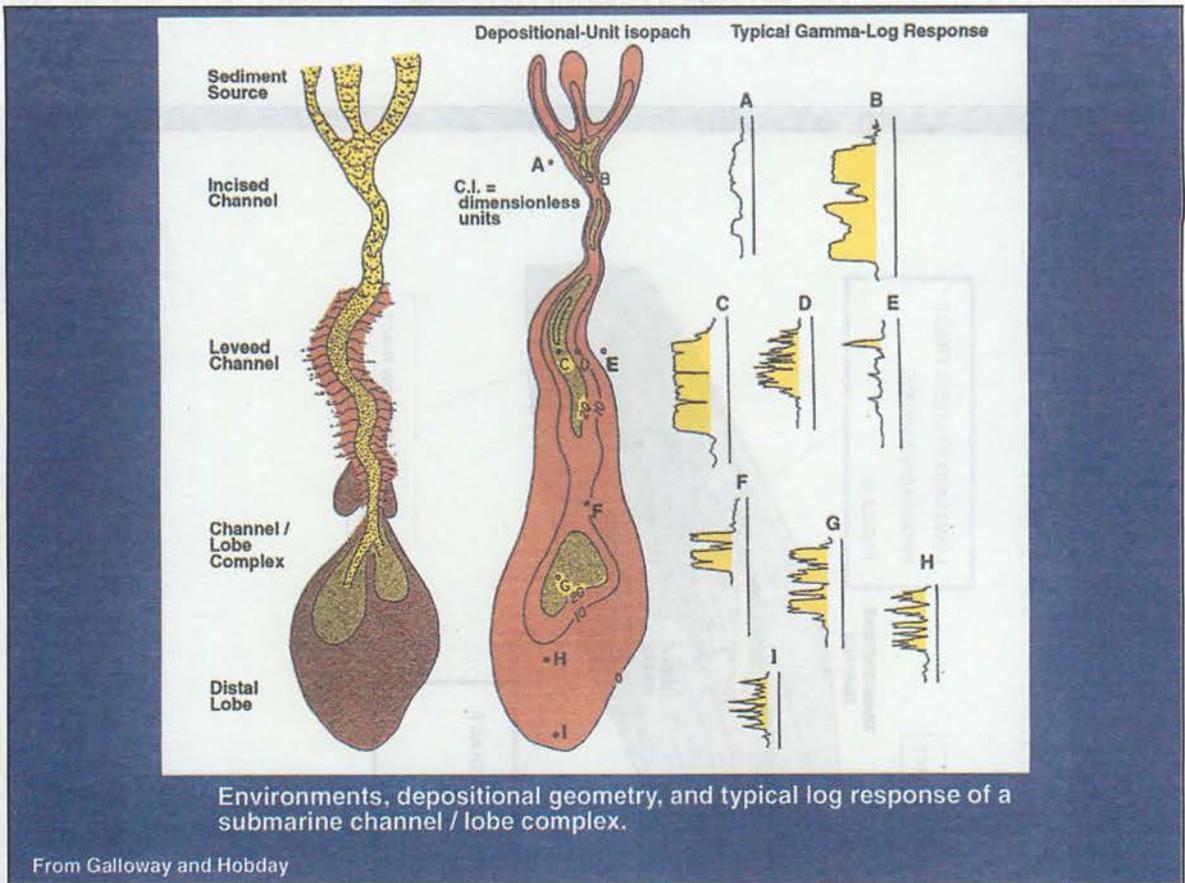


Figure 18. Environment, depositional geometry, and typical log response of a submarine/lobe complex model Galloway and Hobday (1996) showing the interpreted location of Seismic Facies I in the channel lobe complex and Facies II in the leveed channel area.

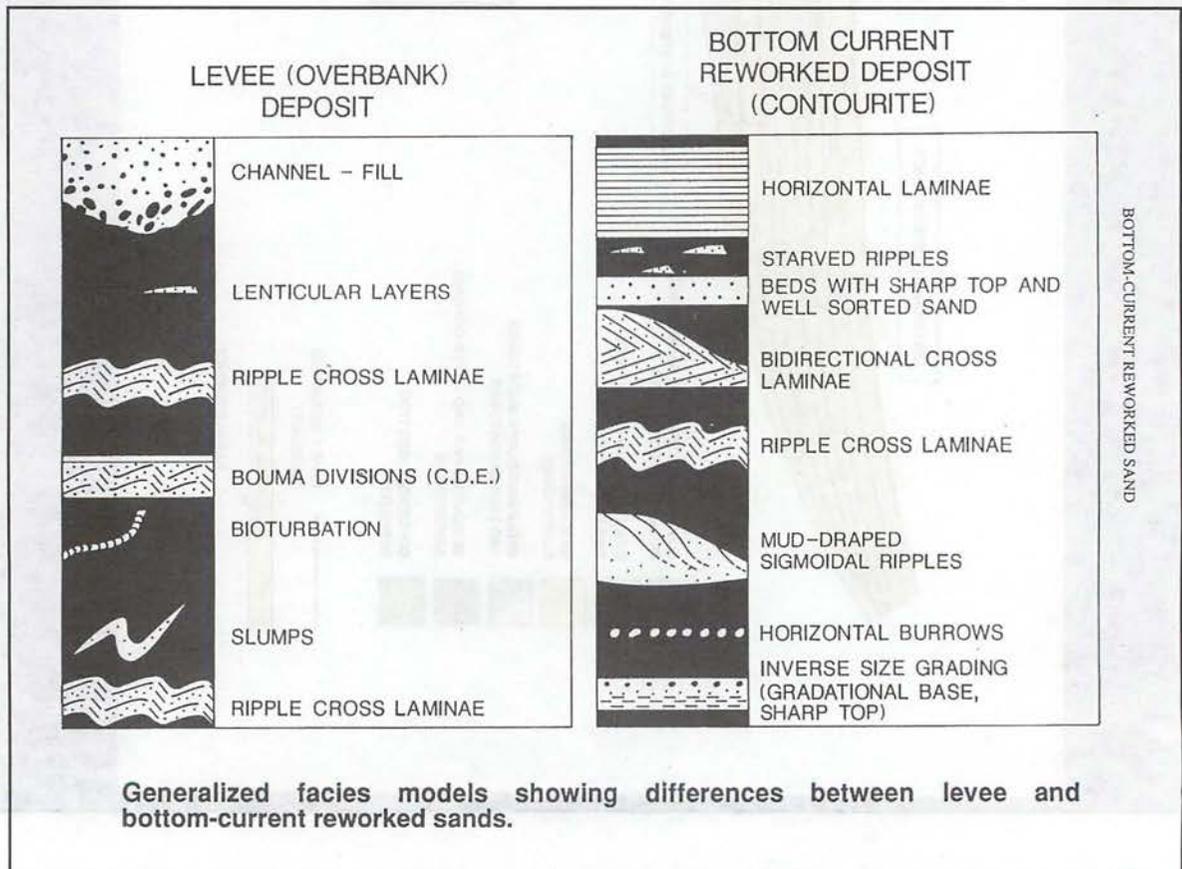


Figure 19. Example of improvement of reservoir quality in a bottomed current reworked sand from Gulf of Mexico. From Shanmugam *et al.* (1995)

interchannel deposits sometimes have quite good reservoir quality. Porosity ranges from 25 to 40% with net to gross ratio of 25%. Permeability ranges from 50 to 800 md. The reservoir quality is further improved if the sands are reworked by bottom currents (see Fig. 19 from Shanmugam *et al.*, 1995).

CONCLUSIONS

A seismic interpretation of the Upper Langan Fan Unit was conducted and three distinct seismic facies was delineated. Isochore maps geometries of the different facies yielded a depositional model and interpretation. The study provides a better insight into the processes, complexities and resolution within a turbidite fan system. The result of the study should provide a constrain on the reservoir quality and prospect evaluation.

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