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Baram field — the 3D marine re-processing challenge

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Abstract: The Baram Field is the largest field in the Baram Delta Operations/Sarawak Oil portfolio and forms part of the PETRONAS Carigali/SSB joint venture agreement. Several development projects are currently being considered for the Baram Field. In order to resolve the structural complexity and provide more information for future drilling campaigns a 3D marine seismic survey was acquired in 1988 over the Baram Field. The 1989 processing results suffered from severe statics still present in the final data caused by shallow gas effects. The fault resolution was considered poor throughout the survey. Several DHI's had been identified and used during interpretation of the data set. The reliability and usefulness of these DHI's and other seismic anomalies was doubtful in areas affected by shallow gas and close to faults. Initial suggestions of re-shooting the data in 1997 were rejected due to cost and timing considerations.

In order to address the observed uncertainties a re-processing project was awarded to the SSB/SSPC in-house processing centre in 1997. Within tight deadlines comparisons between 3D post-stack time migration, 3D pre-stack time migration and 2D pre-stack *depth* migration were made available and the latest processing technology was employed. Based on these results the processing route for the entire data set was determined.

In this paper displays of the seismic data set illustrate the observed problems. Comparisons with the former processing results highlight the benefits of the re-processing project.

INTRODUCTION

The Baram Field (Fig. 1) is located some 12 km north-west of Tanjong Baram in up to 70 m of water. It was discovered in 1963 by SSB and development started in 1970. It is the largest field in the Baram Delta Operations/Sarawak Oil portfolio and is currently being operated by PETRONAS Carigali. It is the most complex field in the Baram Delta Province, with more than 746 hydrocarbon-bearing reservoirs identified. Structurally the Baram Field comprises an anticline to the north of an east-west trending major growth fault. The anticline is heavily faulted and has two main culminations, forming the eastern "Baram A" area and the western "Baram B" area (Fig. 2). The southern flank of the anticline, south of the main growth fault, is unfaulted and termed the "Baram South" area.

Hydrocarbons, predominantly 33-40 degree API oil but with some associated gas, are found in stacked reservoir sands between 3,000 and 9,500 ft bmsl. Ultimately recoverable oil was 283 MMSTB

and cumulative production 201 MMSTB (as of 1.1.97).

The current 3D interpretation is based on the 1989 processed Baram 3D data set. The data has been extensively studied and DHI's have been recognised and mapped. The field as a whole has been interpreted and mapped (Hemmings, 1995), but much more information which would be of use in the further development of the field remains to be extracted. This includes detailed fault plane mapping and the mapping of seismic anomalies in Baram A and Baram B areas to extract data on reservoir quality and hydrocarbon occurrence. Problems during depth conversion made it very difficult to tie seismically derived data with well data and also to produce seismic depth maps that conform to the clear seismic anomalies recognised in the Baram South area.

1988/89 DATA ACQUISITION AND PROCESSING

The Baram 3D seismic survey was acquired in 1988 by Western Geophysical Company covering

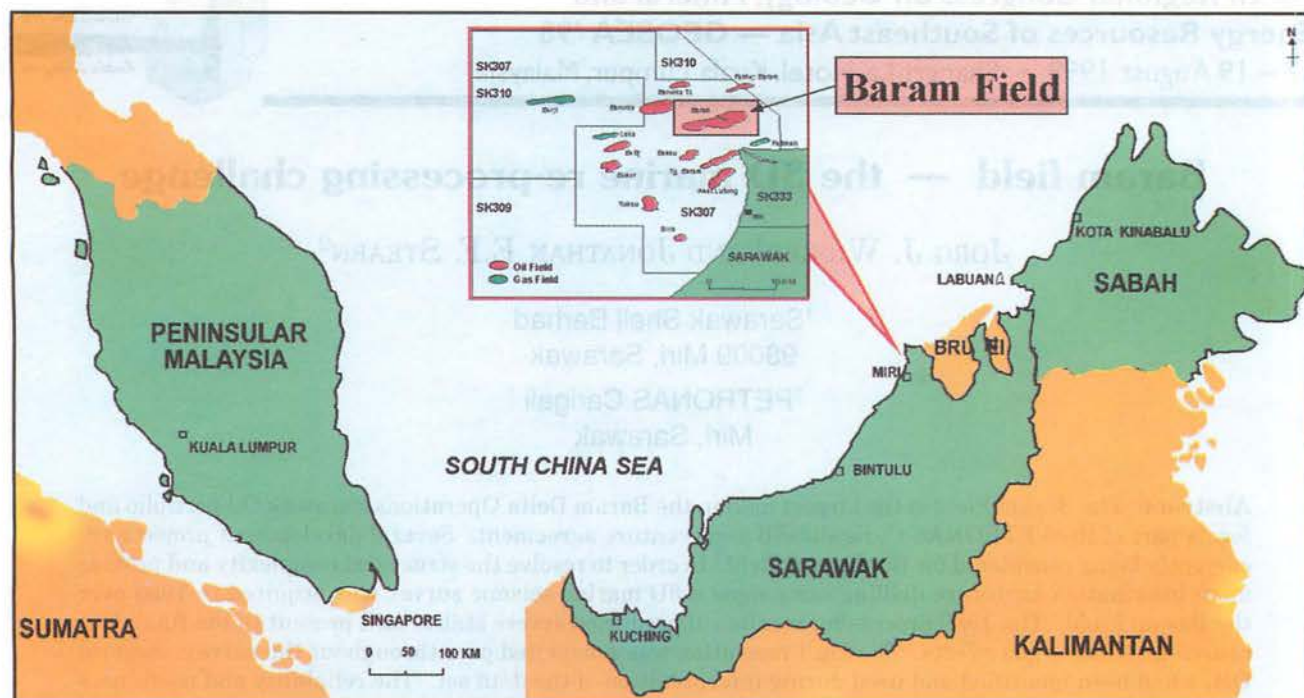


Figure 1. Location map: Baram field.

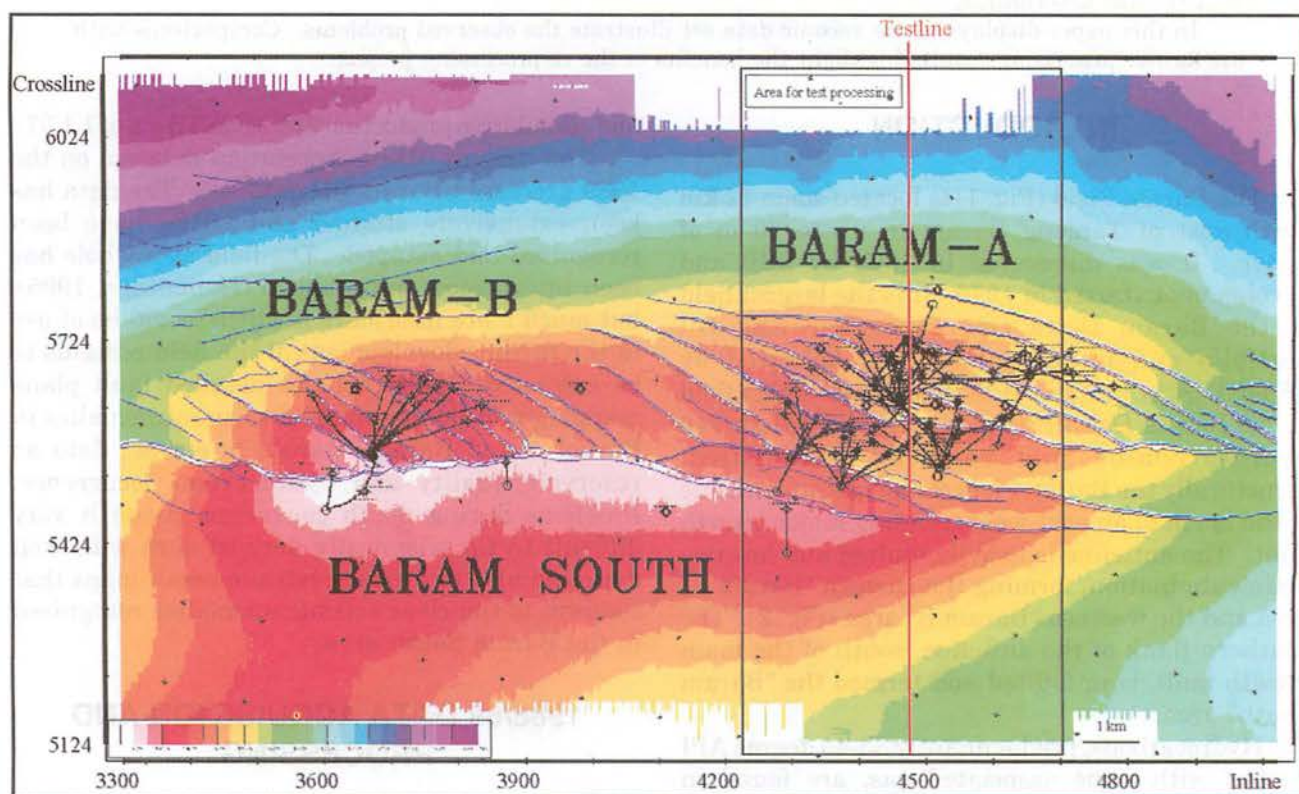


Figure 2. Two way travel times — N3.0 horizon.

265 km² (Fig. 3). The single vessel operation was performed with a shot point and group interval of 25 m while the line spacing was 37.5 m. A total of 8,373 km of lines with cable lengths of 2,400 m, 1,200 m and 600 m were shot across the area giving maximum of 48 fold coverage for prime lines. Infill lines were shot to increase the fold in areas with irregular streamer feathering and presence of platforms over the prospect.

The problems encountered during data acquisition were mainly created by the physical location of the survey. Because of the closeness to the river mouth, the influx of fresh water had a major impact on buoyancy control and a strong current contributed to the severe feathering problems. Water depths were adequate (up to 70 m) with the exception of a shallow water region (< 10 m) in the south-eastern part of the survey requiring the use of a shallow draft. Obstructed areas were created by the platforms leading to poor and uneven subsurface coverage as these were not undershot (Fig. 4). Heavy commercial boat traffic and fishing vessels were present in the area, along with submerged logs and other debris, which caused downtime and damage to the equipment. Severe signal attenuation was experienced in areas, caused by near surface localised velocity anomalies associated with shallow reefs and gas chimney effects referred to as gas masking.

The data was originally processed by Geophysical Services (Malaysia) in 1988/89 (Baram 3D Survey, 1989) following a standard marine processing sequence including residual statics, 2D DMO, and D2D post-stack time migration. The residual statics were derived on overlapping subsets of the data set with edge effects showing up in the crossline direction. It was noted that the statics had only partially been solved. Moreover, the application of an essentially 2D based processing run stream might have impacted on the overall quality of the data.

CURRENT INTERPRETATION

The quality of the data is generally good except under the crest of the field where shallow gas creates problems, resulting in noisy, discontinuous data with a reduced bandwidth (Fig. 5). In this area of most interest faults and horizons could be identified and correlated but the uncertainty in their positioning both laterally and in depth is unacceptably large (Stearn, 1998).

Depth Conversion

The depth conversion of interpreted seismic horizons constituted a major problem in the Baram Field and no totally satisfactory solution has been found. Depth conversion turned out to be critical in

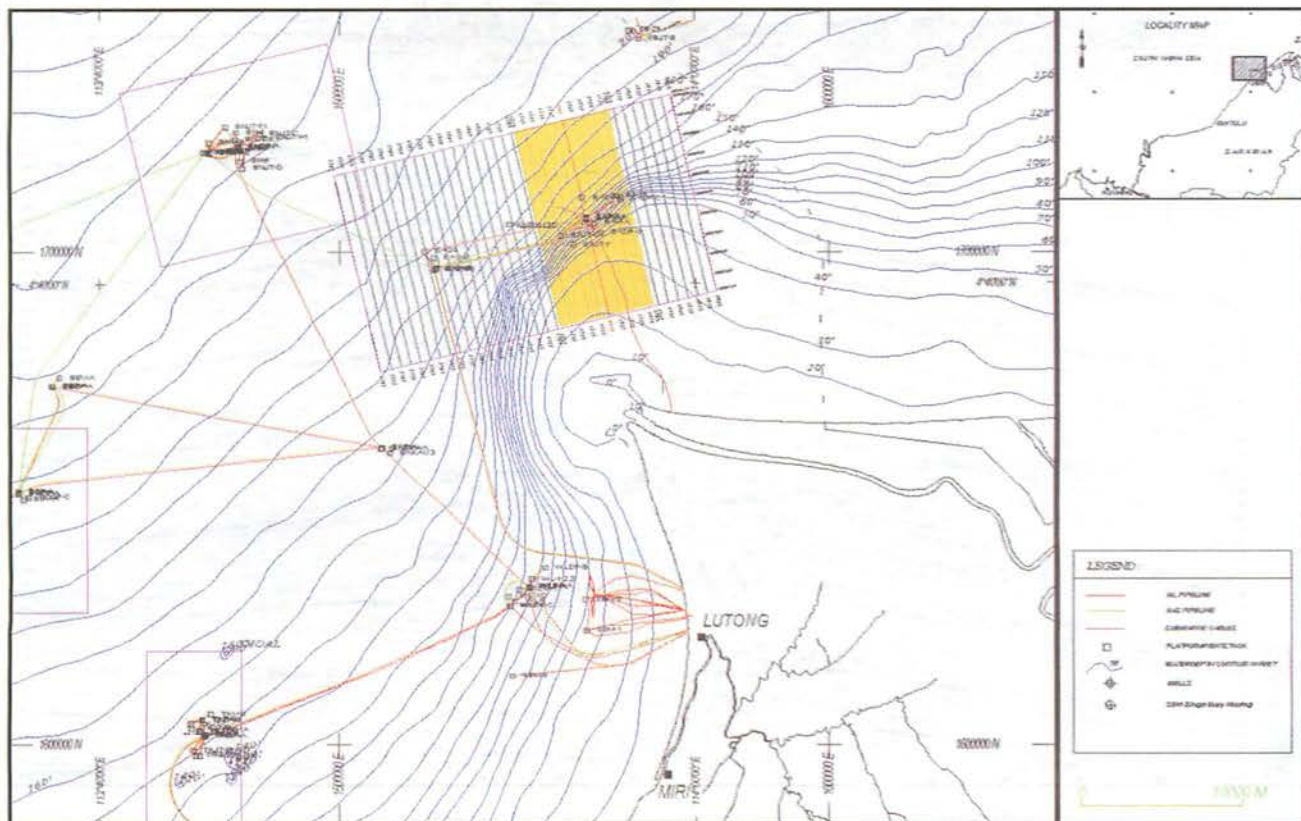


Figure 3. Location map: 3D seismic survey.

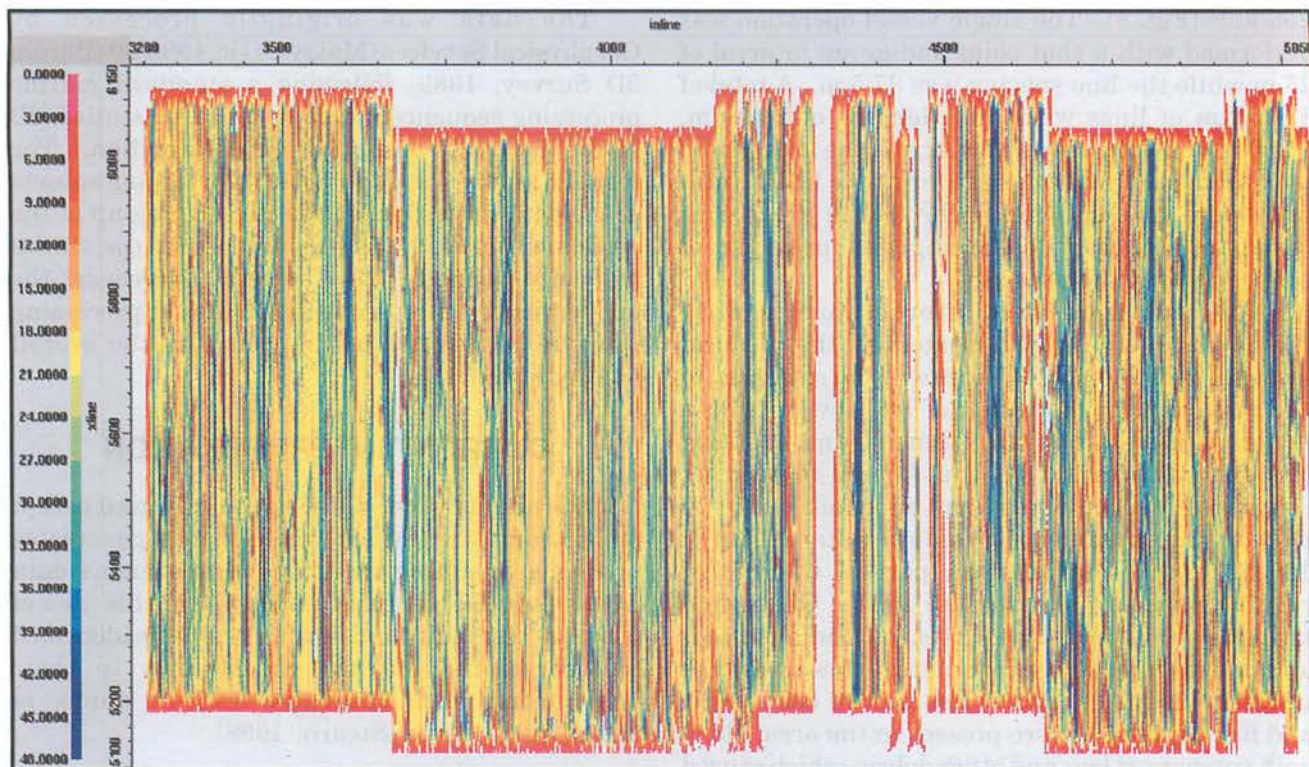


Figure 4. Bin multiplicity for offsets > 1,600 m.

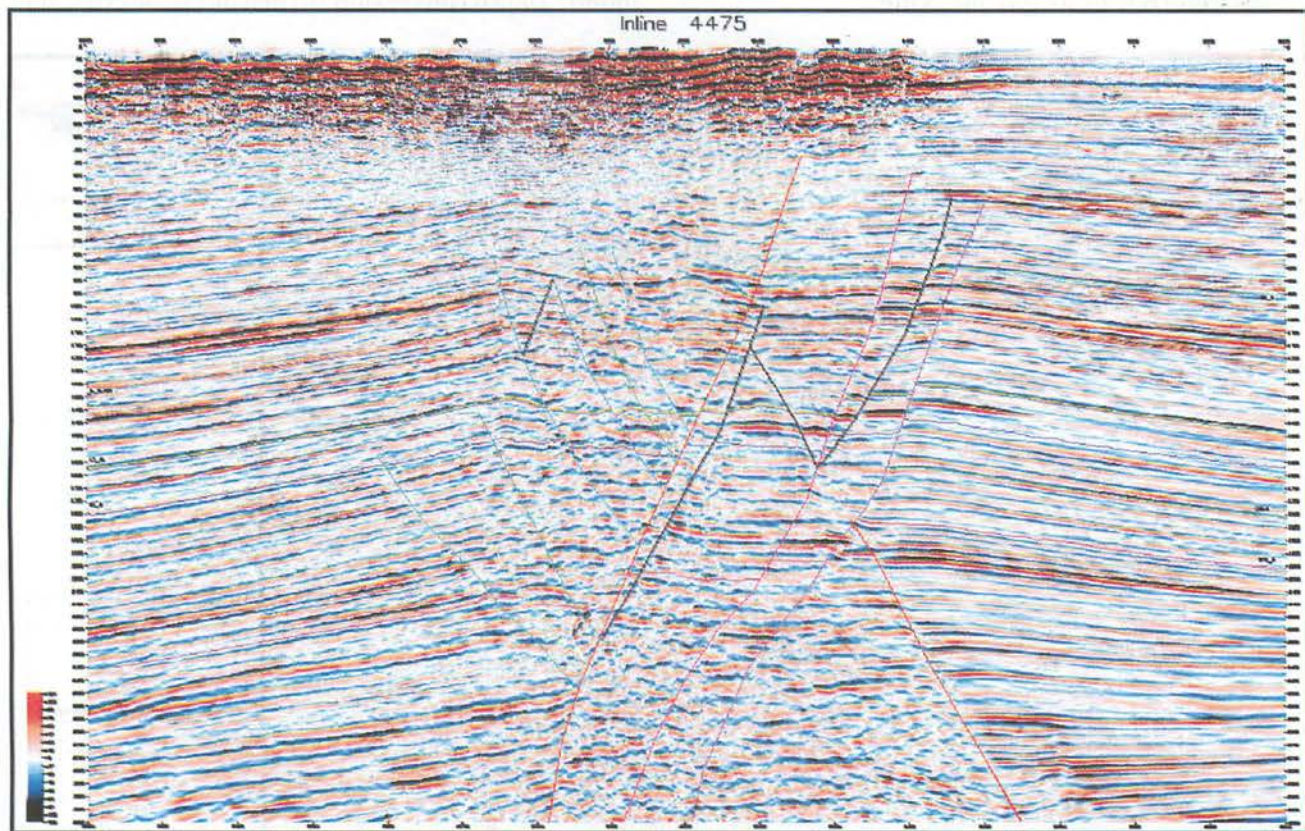


Figure 5. Inline 4075: current interpretation, 1989 processing.

this area because of the lack of well control and the elongate shape and low amplitude of the structure. An acceptable field-wide velocity model could not be obtained with the available data. The reason for this failure was primarily due to the inherent velocity problems associated with extreme shallow gas effects coupled with the structural complexity of the Baram field itself.

Apart from velocity increase with depth, the Baram Field is characterised by an apparent strong lateral velocity increase from east to west across the field, which is complicated by the gas mask effect. Figure 6 shows the interval velocity map derived from the seismic stacking velocities for a theoretical layer from sea bed to a constant time horizon at 950 ms, red colours indicating lower interval velocities. This flat surface was created for depth conversion purposes following earlier studies indicating that most of the lateral velocity variations occur in the top 950 ms. The interval velocity map correlates well with the intensity map measured from 0-300 ms (Fig. 7), where high values annotated in red represent the presence of shallow gas. Additionally this area required the largest residual statics corrections during processing.

For all layers below this flat surface a single velocity function which linearly increased with depth was used, derived from the available well velocity surveys. The resulting maps were calibrated with the well data by application of residual corrections. The greatest errors in the depth maps prior to well calibration were caused by the long wavelength static anomalies, possibly up to 50 ms, corresponding to 75 m at a velocity of 3,000 m/s. The depth map would generally be too deep. The well calibration of the depth maps removed the long wavelength errors, but also introduced new short wavelength distortions because of the insufficient number of wells to properly correct for the distortion of the depth surface by velocity anomalies related to HC accumulations in the near-surface layer and deeper.

An attempt was made to derive a post-stack "static correction" from the intensity map resulting in time maps that fitted the well and DHI data better than the conventional depth maps; thereby showing less velocity variations over the Baram Field but for the price of an increased "noise" component.

Amplitude Analysis

After horizon interpretation several seismic attribute maps (amplitude, reflection intensity, dip, azimuth and reflection heterogeneity) were created and analysed. However, the data quality over much of the field was too poor for horizon consistent attribute measurements to be of much use.

Several DHI's were identified and used during interpretation of the data set (Fig. 8 shows the amplitude map at the N3.0 level). All these anomalies displayed a high probability of being related to the presence of HC, and were judged to conform to structure, given the uncertainties in the definition of the structure. They are especially important in the largely undeveloped Baram South area where depth conversion has been difficult. However DHI's are consistent with the available well data and are being used to pinpoint the position and extent of HC accumulations.

The shape of the anomalies differed from the structural contours only in areas where remaining statics in the data caused depth conversion problems. The reliability and usefulness of these was doubtful close to faults and in zones affected by shallow gas.

SEISMIC DATA RE-PROCESSING

The main objective of re-processing the Baram 3D data was to help identify remaining reserves in the Baram field by evaluating areas not covered by recent interpretation or those affected by poor imaging.

The original processing of the Baram 3D survey was far from ideal because of the 2D nature of the applied processing steps. The 3D processing techniques have advanced tremendously since 1989. The improved handling of 3D residual statics, 3D DMO and 3D one-pass migration techniques together with other imaging methods like pre-stack time and pre-stack *depth* migration could further improve the data quality. With optimal up-to-date processing techniques, it was believed that uncertainties of the interpretation could be much reduced. The cost of the re-processing would be more than recouped if only one well could be saved or prevented from missing its objective.

After careful consideration of the available options especially looking at the ability of the contractor to produce the desired improvement in data quality, as well as timing and price aspect it was decided that SSB would undertake the re-processing work for the following reasons:

- The in-house SSB SIPMAP (Shell proprietary software) processing centre is capable of delivering a superior product compared with other contractors in the region (based on availability of expertise and computer resources); moreover SIPMAP is able to test the most complete range of processing options.
- Shell is a partner (50% equity) with a stronger interest in the re-processing results in comparison to third party contractors and therefore would ensure the best outcome from

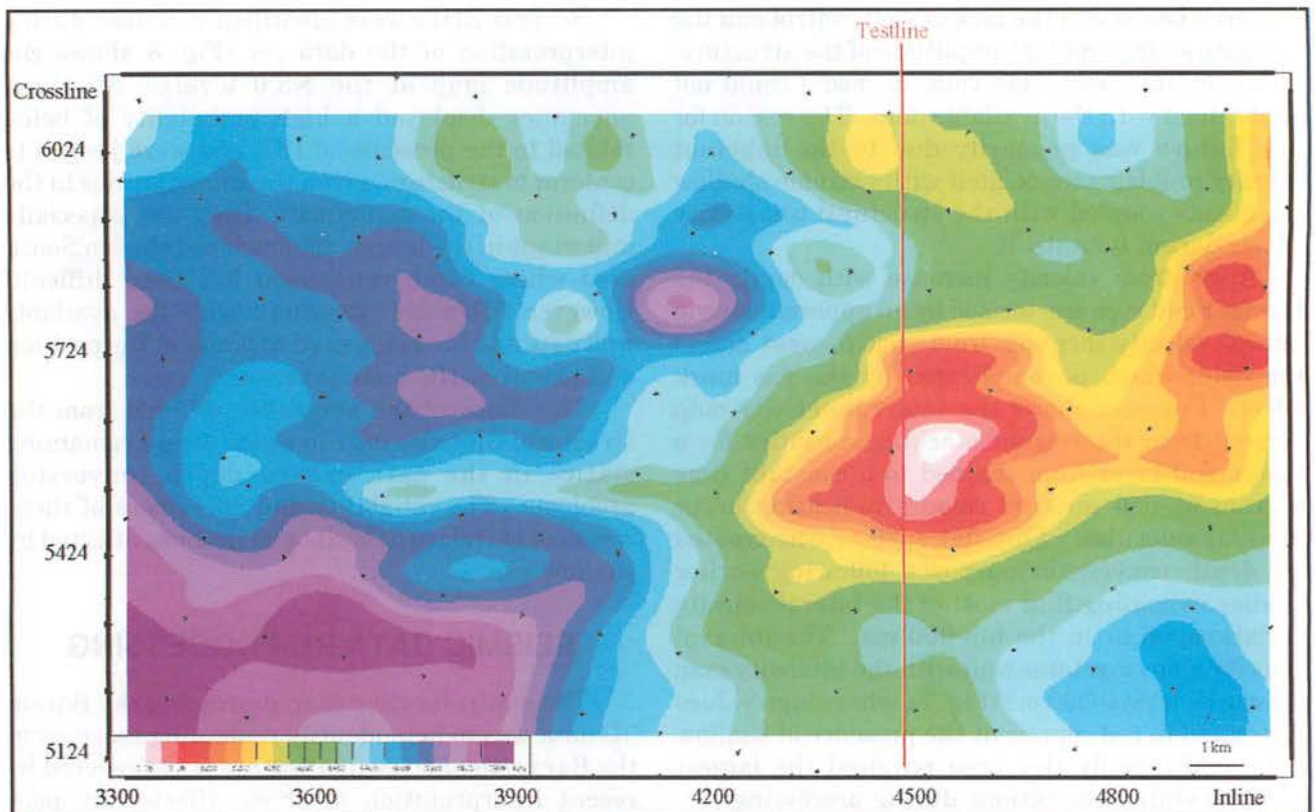


Figure 6. Interval velocity — sea bed to 950 ms.

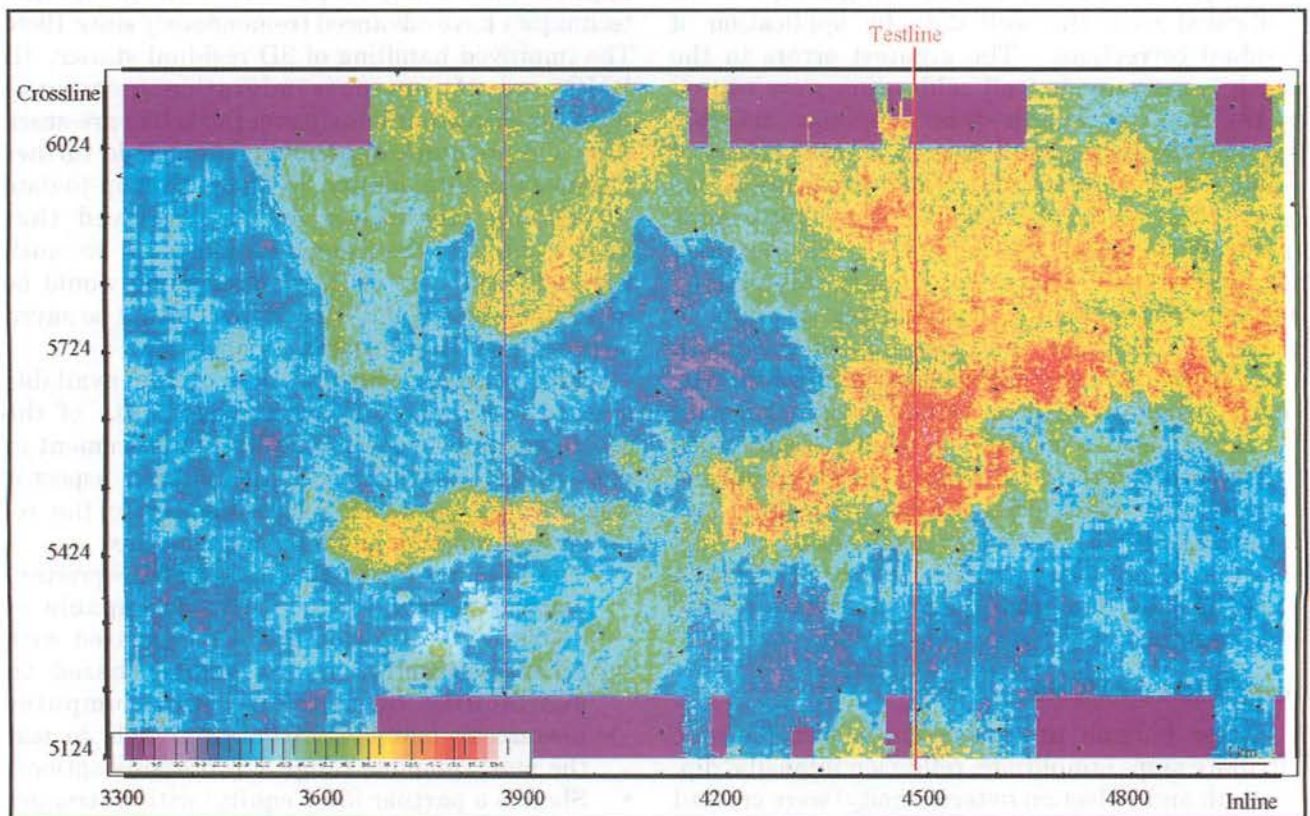


Figure 7. Reflection intensity — 0 to 300 ms.

the work.

- Easy accessibility of data in SSB offices and hence efficiency in data and time management.
- The vicinity of SSB and PETRONAS Carigali offices in Miri helps the close cooperation during the processing project with an active interface and exchange of ideas and skills between SSB processing staff and PETRONAS Carigali interpreters.

It was the first time SSB/SSPC's SIPMAP processing centre processed seismic data from an area operated by PETRONAS Carigali. At the same time, this was the first 3D re-processing project in the region.

A testing phase of 4 months was chosen to determine whether re-processing of the Baram 3D data set could be justified by a sufficient improvement in data quality and in order to establish the optimum re-processing route to achieve a balance between data quality, improvement, cost and delivery time. The selected test area (highlighted in Fig. 3) was centred on inline 4475 and covered the area worst affected by the earlier described effects of gas masking.

Results of the testing phase allowed comparisons between 3D post-stack time migration and 3D pre-stack time migration with results from the original 1989 processing. A complete range of 2D processing tests was performed on one sailline

and compared 2D post-stack time migration with 2D pre-stack time migration and 2D pre-stack *depth* migration.

Comparison of Results

The 1998 re-processed result for inline 3841 is shown in Figures 9a, b together with the result from the 1989 processing. The overall reflection quality is significantly improved after re-processing with SIPMAP. In general, reflections stand out more clearly and the section looks much cleaner compared to the original migration. The improvements in terms of signal-to-noise ratio, fault imaging and continuity of reflectors is obvious.

A significant step in data improvement came with the application of 3D residual statics. The 1998 3D residual statics solution for the binned receiver locations is displayed in Figure 10. Most values are within a range of ± 10 ms. This map shows a strong resemblance to the earlier discussed maps of reflection intensity (Fig. 7) and interval velocity (Fig. 6) also highlighting the anomalies in areas with shallow gas.

Figures 11a, b compare the DMO stacks for crossline 5,680 from the original processing with the SIPMAP re-processing. The remaining jitters on the 1989 stack have been removed by a proper 3D residual statics solution in the new data. In addition to the above improvements, the fault

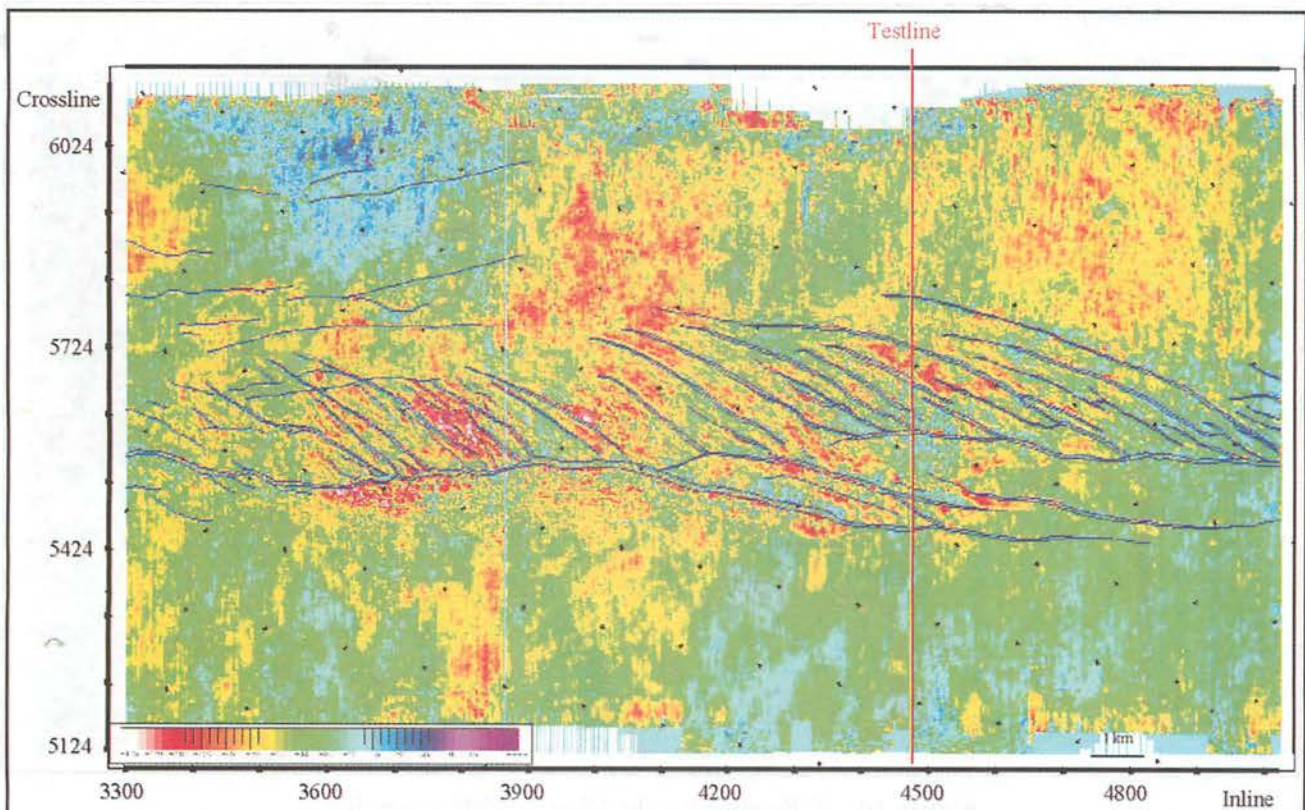


Figure 8. Measured amplitudes — N3.0 Horizon.

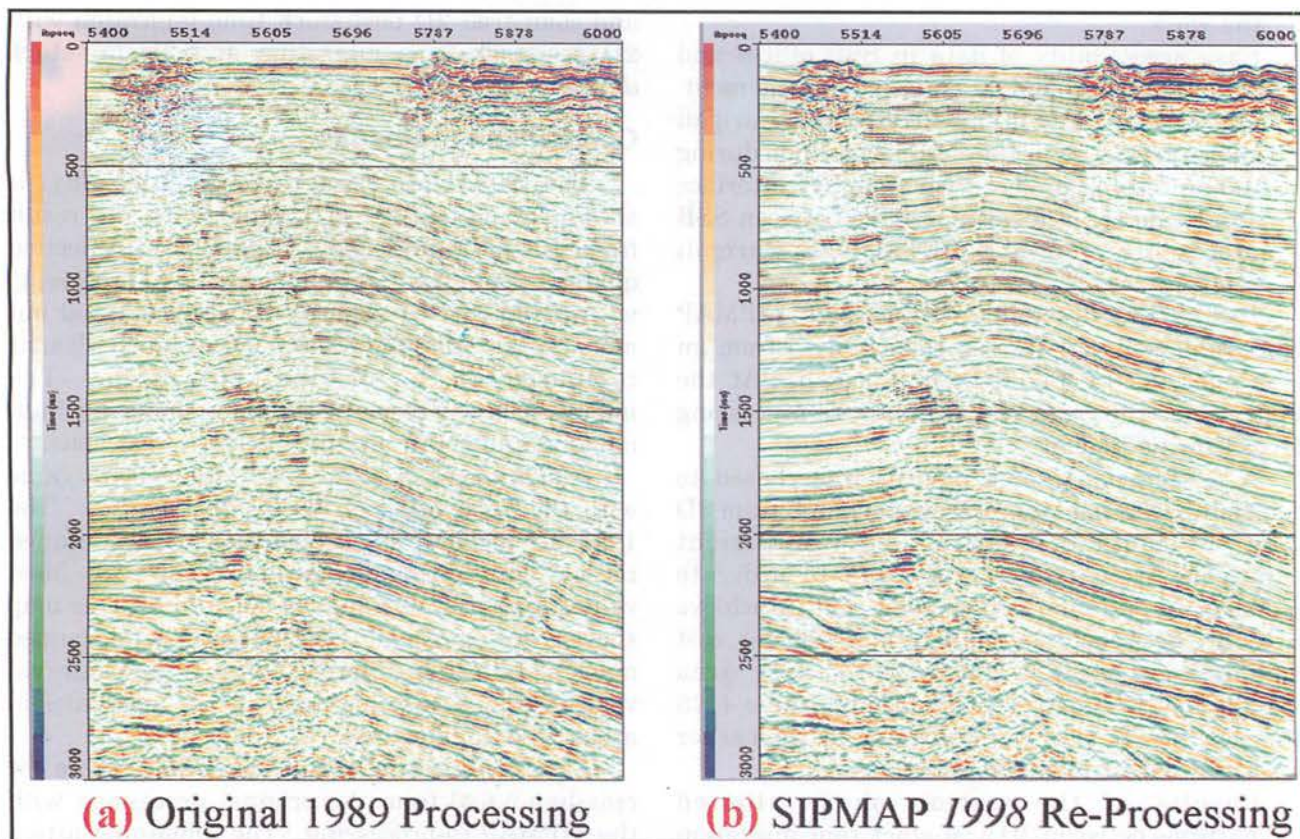


Figure 9a. Inline 3841: Final post-stack time migration, 1989 processing.

Figure 9b. Inline 3841: Final post-stack time migration, 1998 processing.

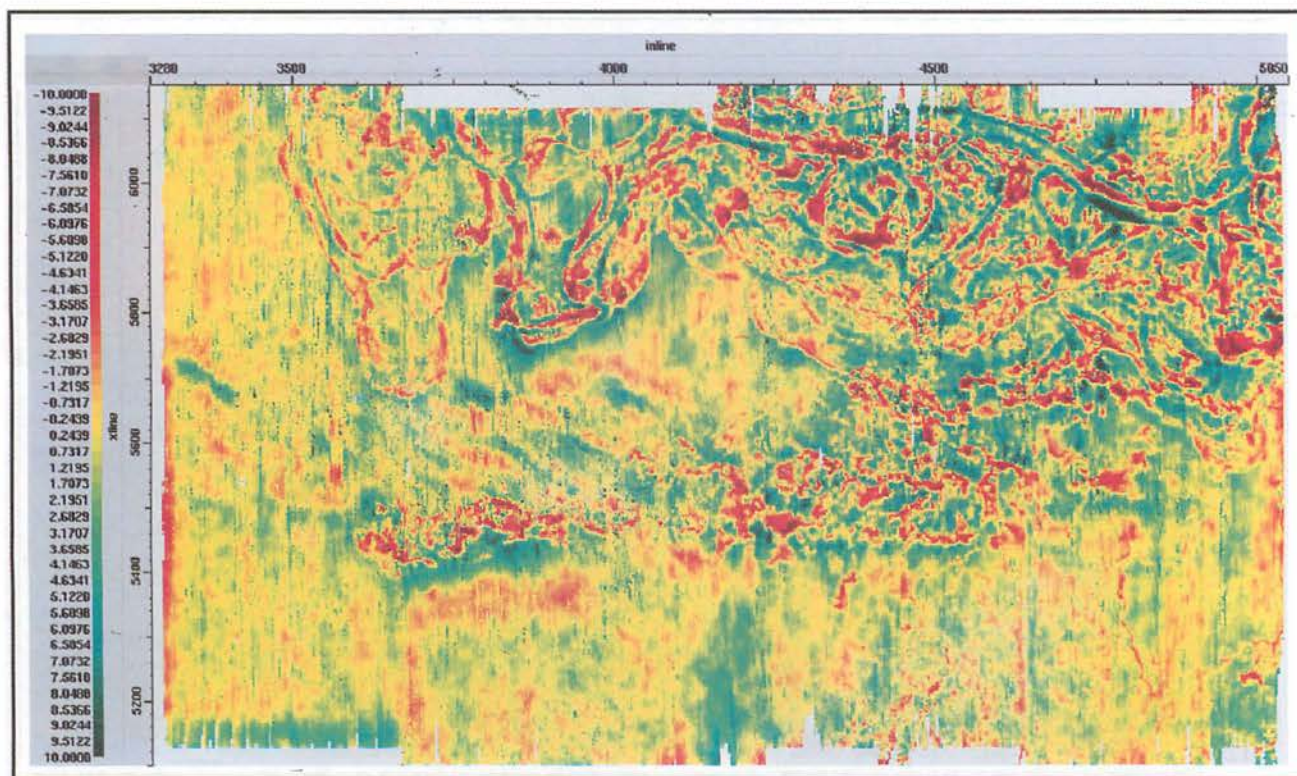


Figure 10. 3D Receiver Residual Statics, 1998 processing.

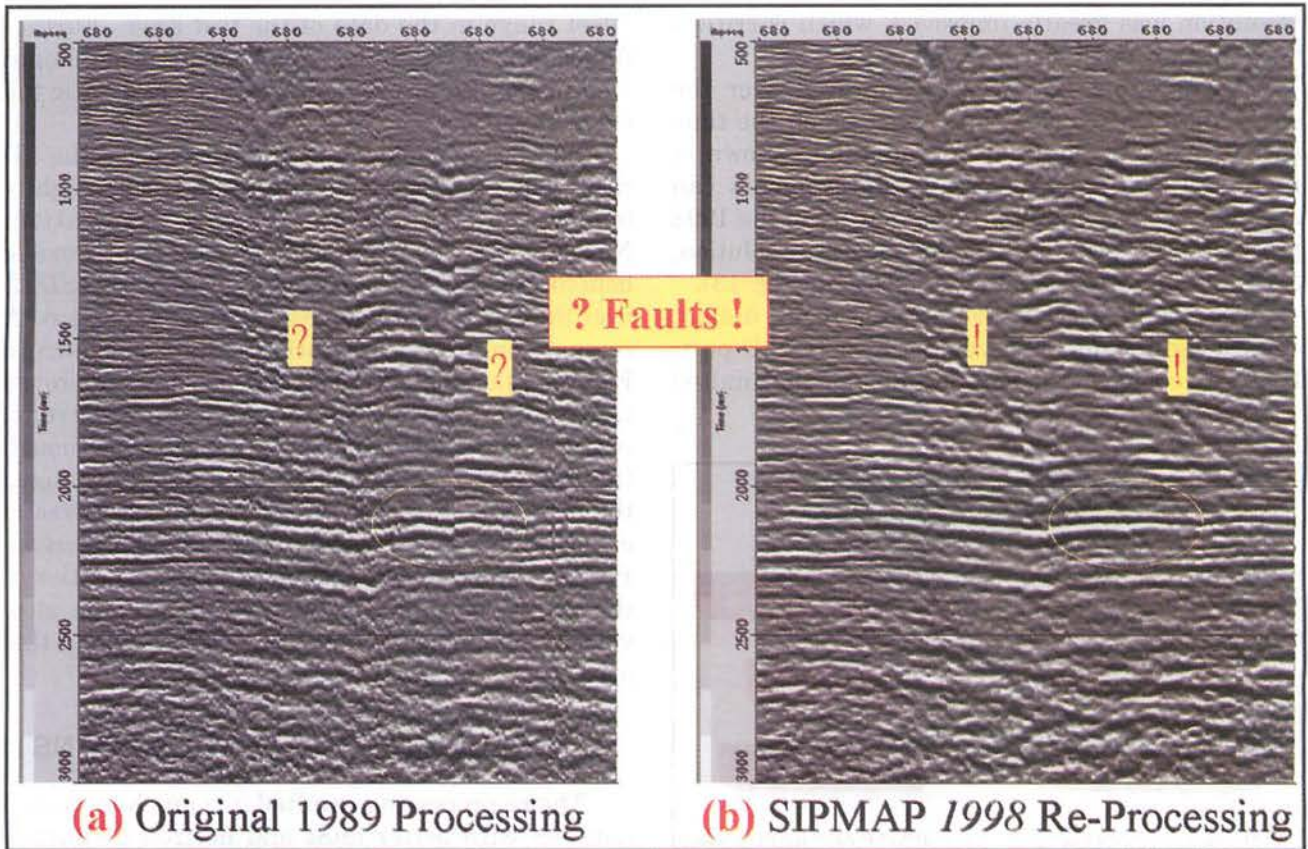


Figure 11a. Crossline 5680: Final DMO stack, 1989 processing.

Figure 11b. Crossline 5680: Final DMO stack, 1998 processing.

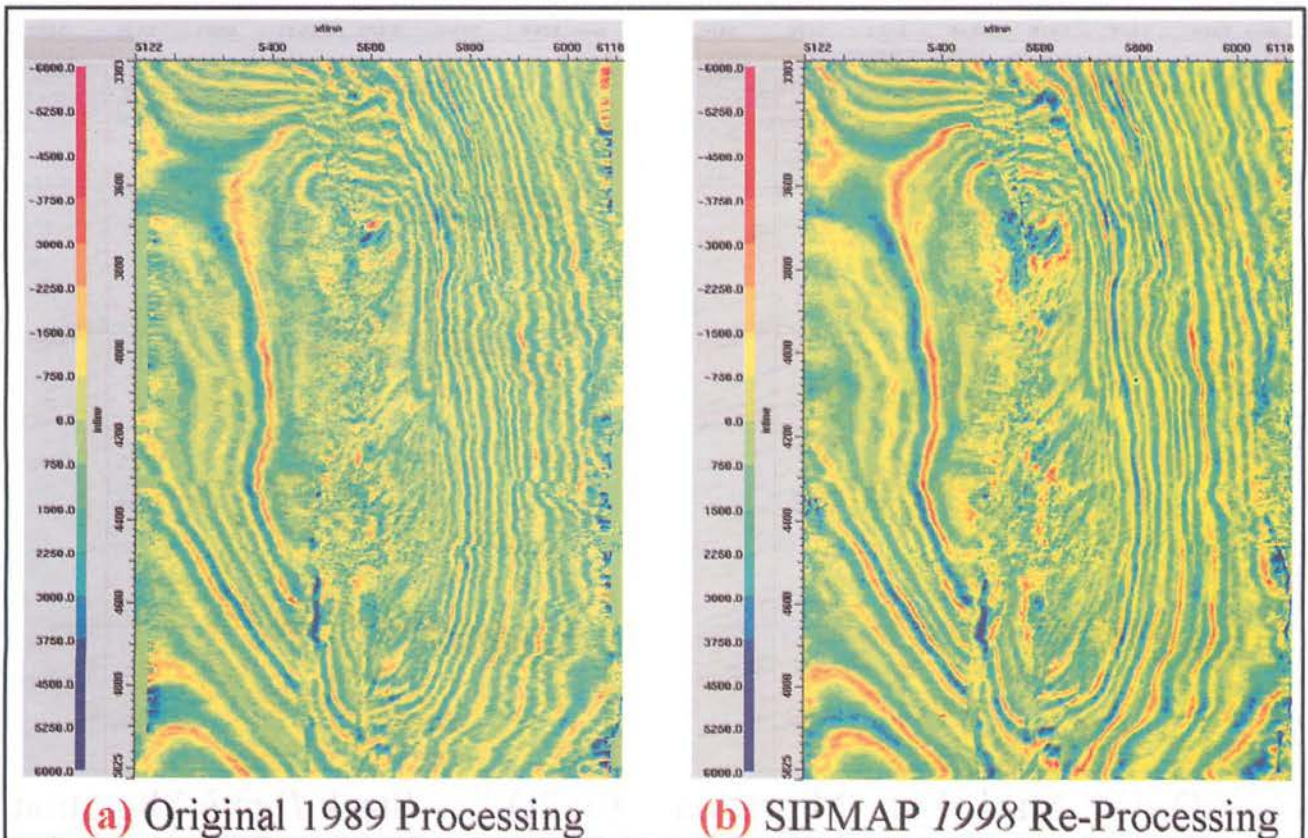


Figure 12a. Time Slice @ 1,800 ms: Final post-stack time migration, 1989 processing.

Figure 12b. Time Slice @ 1,800 ms: Final post-stack time migration, 1998 processing.

resolution was greatly improved, which is critical for determining structures.

The imaging has greatly improved over the entire data set which is most obvious on the time slice displays of the final migrated data shown in Figures 12a, b. The observed improvements can mainly be contributed to the 3D nature of the 1998 processing run stream: 3D residual statics solution, 3D DMO and 3D post-stack migration (Fig. 13).

The 3D pre-stack time migrated result did not show a significant improvement over the 3D post-stack time migration possibly due to the limited

offset range in the data of the test area. Further fine-tuning of the underlying velocity model might lead to small improvements without justifying the extra expense.

Similar conclusions can be drawn for the 2D case. The pre-stack time migration is only slightly better than the post-stack time migration. Nevertheless, the results demonstrate the possible benefits of pre-stack *depth* migration (PreSDM) over the conventional post-stack time migration. A comparison of both migration results is shown in Figures 14a, b. The PreSDM section shows improved fault and horizon imaging in many areas, particularly in deeper parts of the section. Although the PreSDM result has not dramatically changed the overall picture, faults are positioned correctly experiencing up to 100 m lateral shift. The derived PreSDM velocity model showed lower velocities in the centre part of the line resembling the slow velocity phenomena caused by shallow gas in this area.

CONCLUSIONS AND FUTURE PLANS

The re-processing resulted in a much-improved data set with better fault and horizon definition. The coherence and amplitudes of reflections

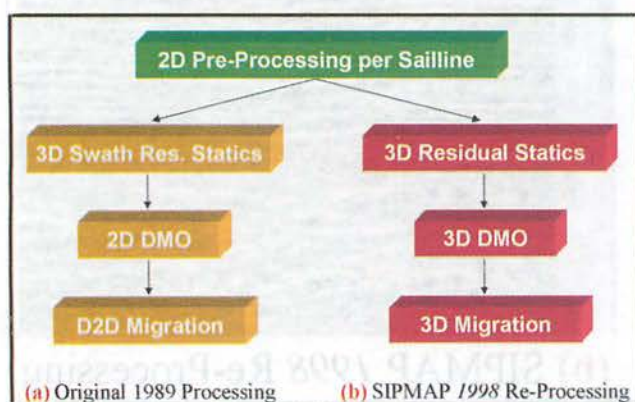
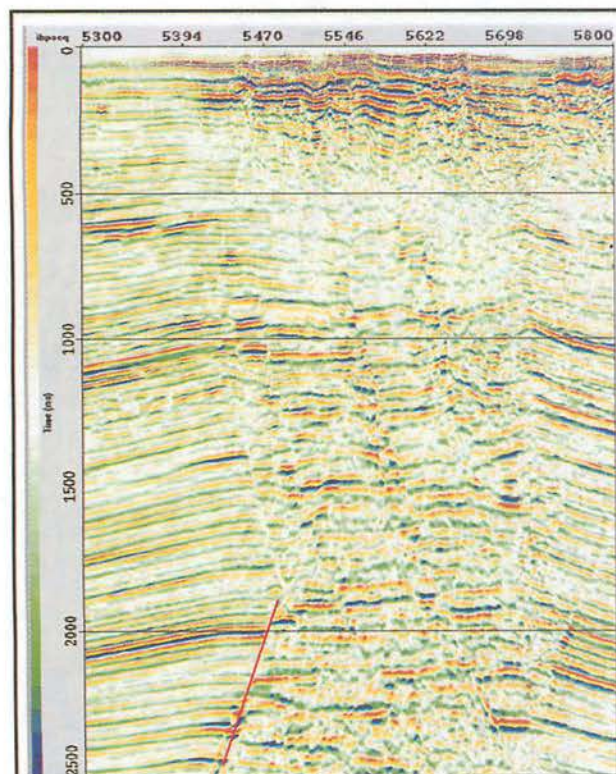
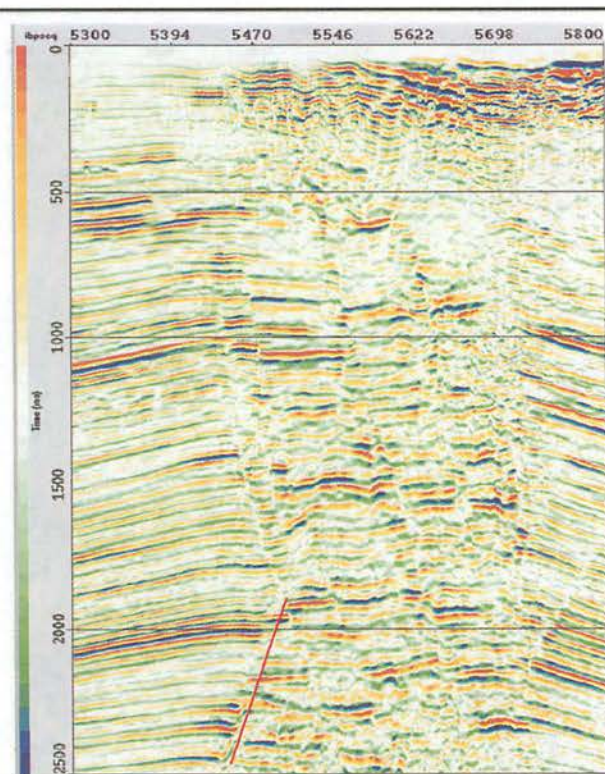


Figure 13. 1989, 1998 seismic data processing sequences.



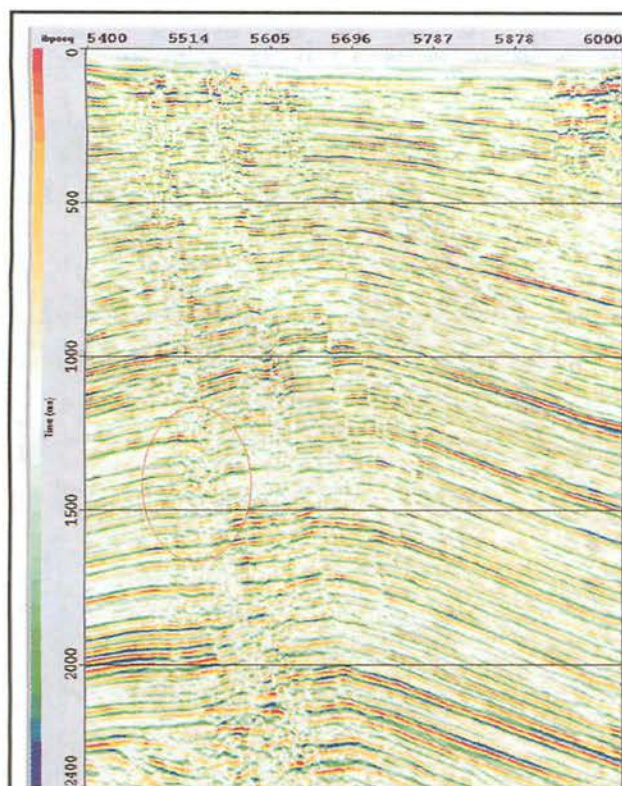
(a) 2D Post-Stack Time Migration

Figure 14a. Sailline 4475: 2D post-stack time migration, 1998 processing.

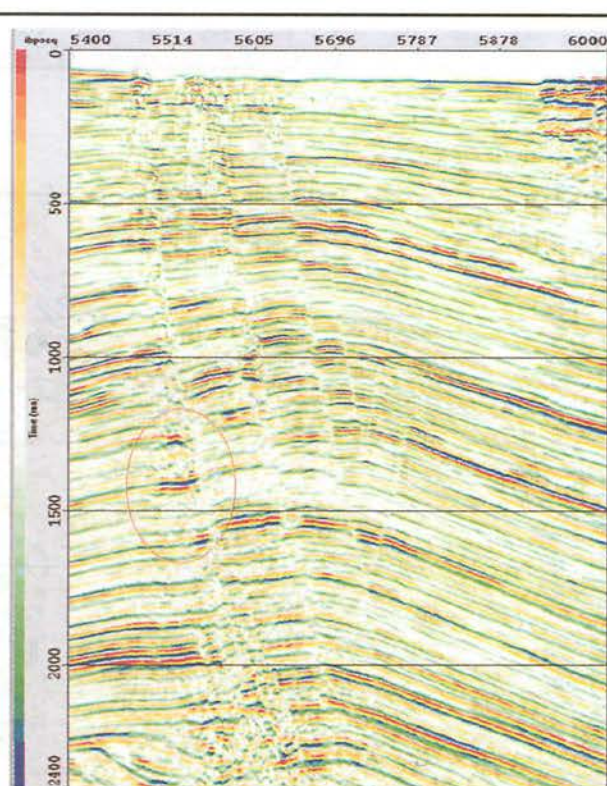


(b) 2D Pre-Stack Depth Migration

Figure 14b. Sailline 4475: 2D pre-stack *depth* migration, 1998 processing.



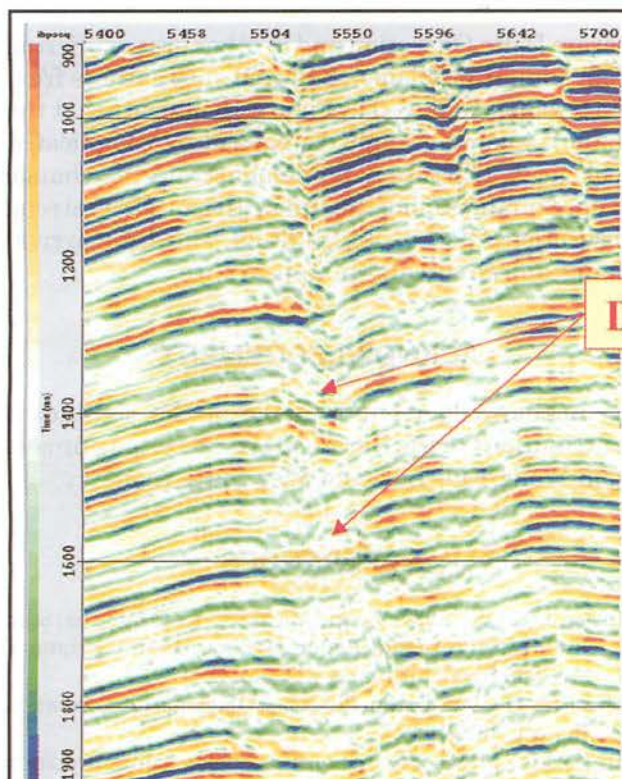
(a) Original 1989 Processing



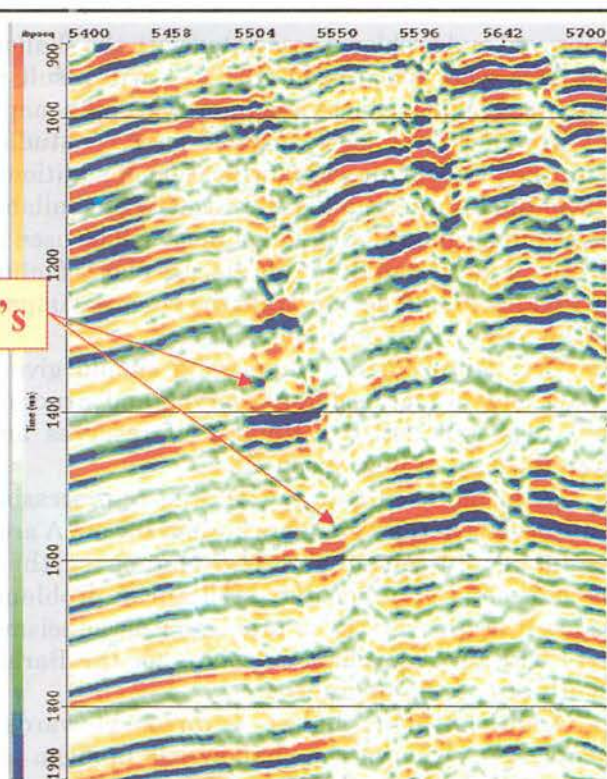
(b) SIPMAP 1998 Re-Processing

Figure 15a. Inline 4075: FINAL post-stack time migration, 1989 processing.

Figure 15b. Inline 4075: FULL post-stack time migration, 1998 processing.



(c) Migrated Near Stack



(d) Migrated Far Stack

Figure 15c. Inline 4075: NEAR post-stack time migration, 1998 processing.

Figure 15d. Inline 4075: FAR post-stack time migration, 1998 processing.

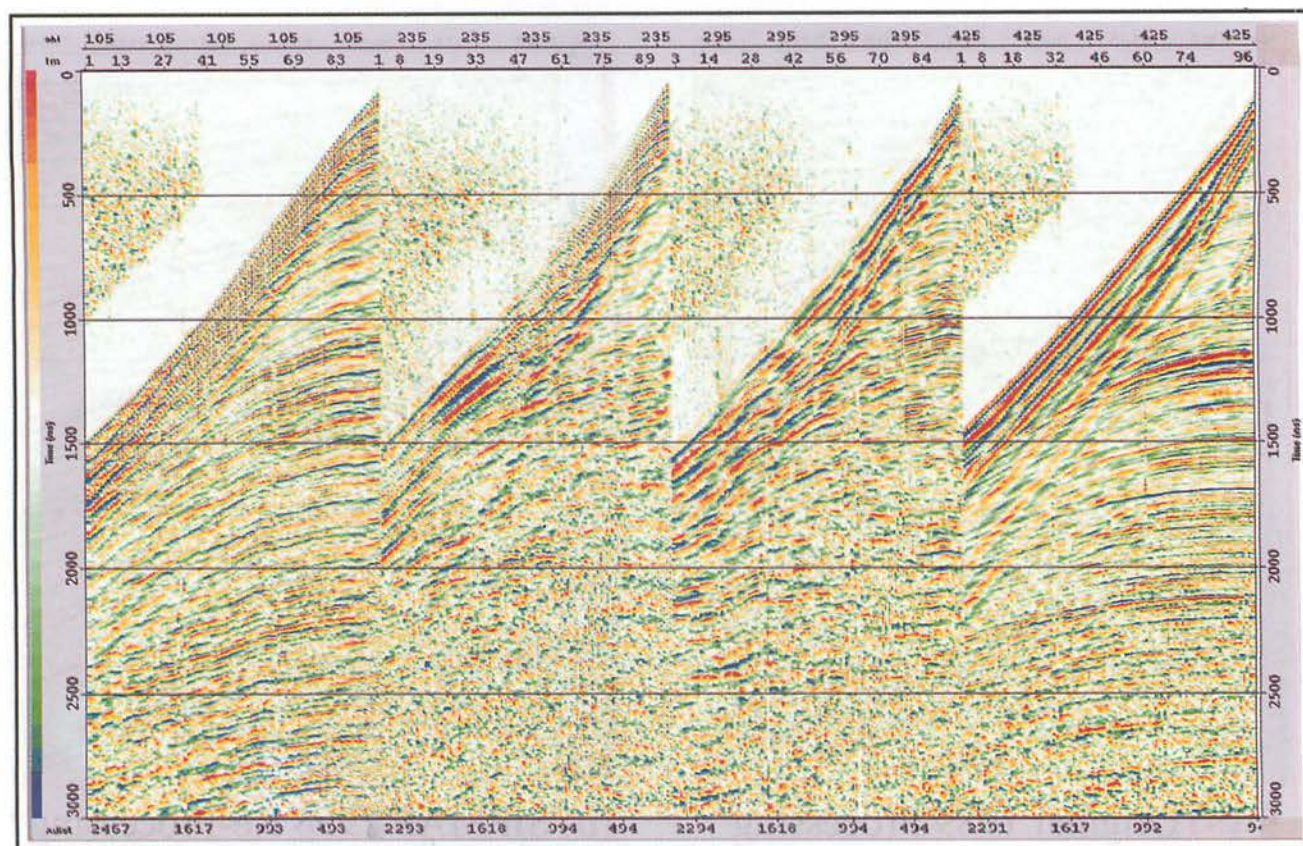


Figure 16. Sailline 4475: Selected raw shot records.

improved and problems associated with the shallow gas area were much reduced. This will result in better seismic time picks and improved depth maps.

The new data set is suitable for AVO studies with the possible direct identification of additional HC in the Baram area. The previously unavailable near and far migrated data volumes will be used to further analyse amplitude effects. Displays of inline 4075 (Figs. 15a-d) demonstrate the potential impact of this newly available information.

The improvements in imaging should give a better understanding of the reservoir and structure and result in better estimates of reserves and identification of new prospects.

With improved results from the re-processing future wells in the complexly faulted Baram A area could be optimised and the chance of them encountering unexpected structural problems reduced. Moreover, the re-processing of the seismic data will allow development plans for the Baram South area to be upgraded.

Additional efforts have to be directed towards a complete solution of the shallow gas problem — this would have a tremendous impact on the entire

Baram Delta Operation and in other areas suffering from similar problems. Selected shot gathers from the testline displayed in Figure 16 indicate that the shallow anomaly might be caused by complicated geological structures and demonstrate the change in data quality along the line with caused by strong absorption effects. In addition, the first arrival changes dramatically in appearance.

ACKNOWLEDGEMENT

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