3–D modelling of a reef–fault block structure

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ABSTRACT

The study presented here revolves around a 3–D zero-offset survey shot over a reef-fault block model using the physical modelling facilities at The University of Calgary. Dimensions and velocities for the model are taken from Keg River patch reefs or bioherms flanking the eastern Peace River Arch, northwestern Alberta. These reefs developed typically on or above prominent basement structures, which are thought to be fault-controlled in this area. 2–D seismic data from the Panny Field are available for interpretation, and a schematic 'reef-fault block (horst)' geological cross-section is presented here. Direct identification of such faulting on 2–D data is shown to be difficult. Erosion of such uplifted fault blocks produced basal clastic (Granite Wash) fault-scarp deposits in adjacent margins. The main objective of the Panny model is to image such a clastic layer beneath the reef. In real data, identification of any regular trends of these deposits and correlation with overlying bioherms would substantiate any theory on the tectonic control of such build-ups.

Such a scenario is used as the geological template for the physical model construction. Physical modelling is described in terms of 3–D zero-offset acquisition, processing and interpretation. A number of vertical and horizontal sections are displayed. Timeslice investigation shows that the areal extent of the basal clastic fault block is particularly well imaged, even beneath a large part of the reef. 3–D numerical modelling of a similar structure has also successfully delineated the regular margins of this layer, thereby identifying fault positions.

Another aim of the model is to uncover interpretation pitfalls with 2–D data. Through numerical modelling it can be shown that certain anomalies observed on physical-model seismic sections are sideswipe reflections. Therefore, this study shows that, in dealing with 2–D data reefs may be inferred along lines shot away from the actual reef. This may frequently result in false imaging on 2–D data.

INTRODUCTION

The Alberta Basin contains one of the best known Palaeozoic reef provinces in the world, with the subsurface distribution of these carbonate formations mapped fairly extensively. However, the mechanisms behind the initiation and development of such reefs are still unclear. In other sedimentary basins, such as the Grand Banks, Newfoundland (Tankard & Welsink, 1987), a close correlation has been observed between basement structure and depositional patterns. A similar relationship between carbonate build-up and basement elements in the Alberta Basin has been postulated by numerous investigators (Sikabonyi & Rodgers, 1959; Mountjoy, 1980; and others). Clearly, knowledge of the basement structure and identification of possible associated faulting are major factors in determining whether any such relationship may be postulated.

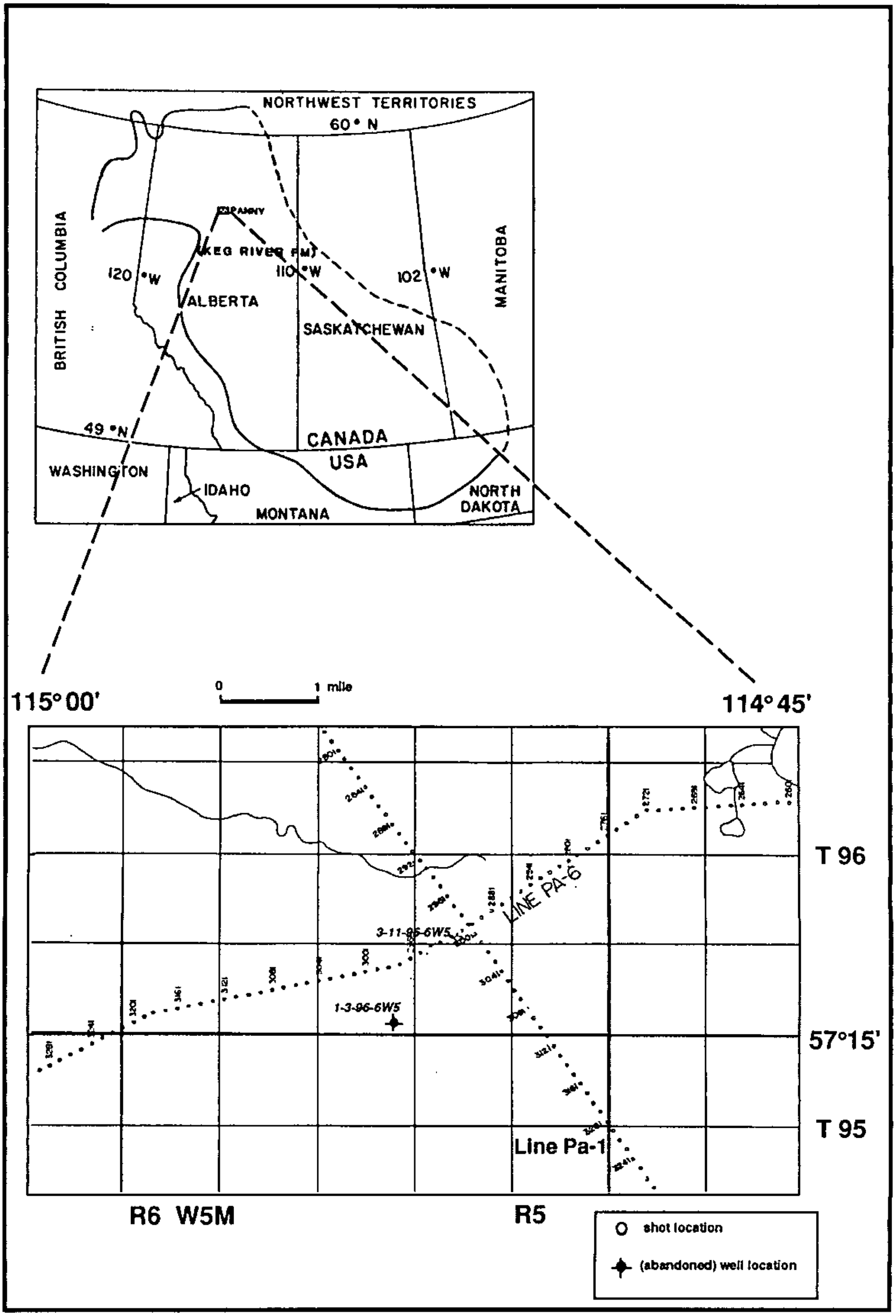


FIG. 1. Location of Panny (River) area wih 2–D seismic sections used in study.

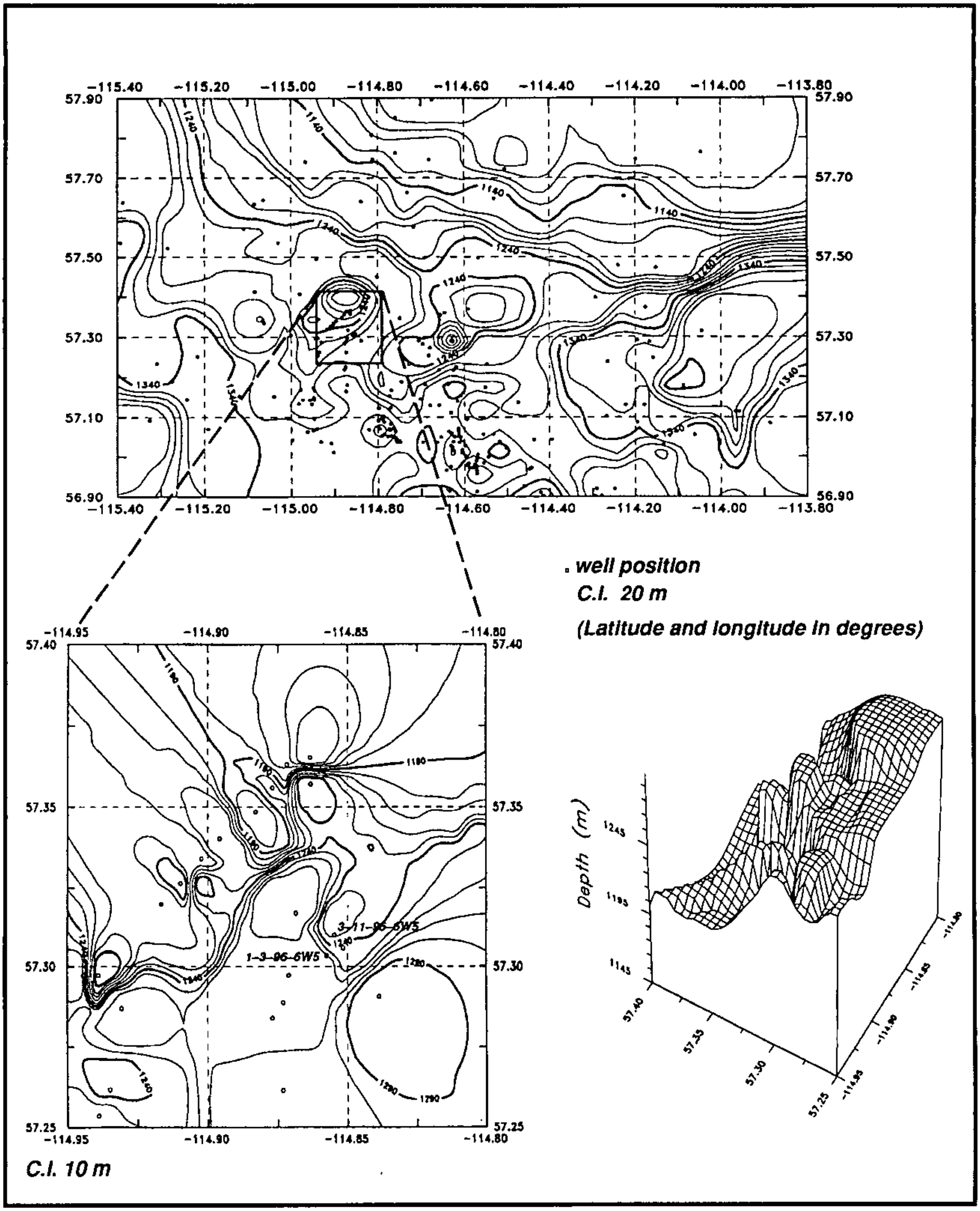
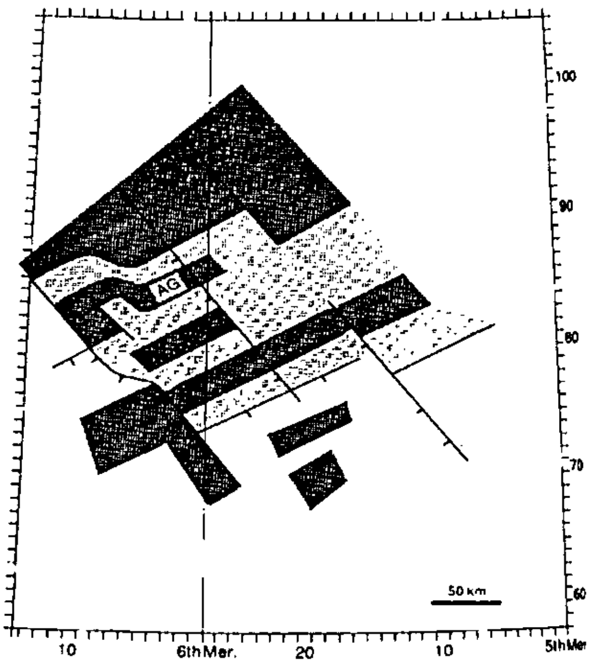
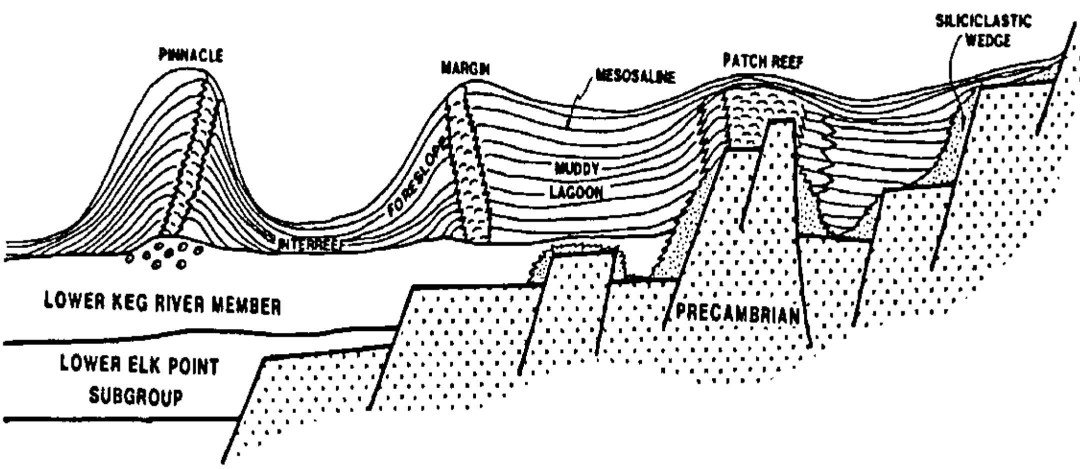


FIG. 2. KB depth to Precambrian in the eastern Peace River Arch

(using available well data)



Precambrian structure map (after Cant, 1988); note 90 degree 'block' faulting (throws>40m) AG=axial graben



Cross-section of the Keg River to Precambrian interval in the Peace River Arch area as viewed from the northwest (Campbell., 1987). Note location of Upper Keg River reefs over Precambrian horst.

FIG. 3. Geological setting for physical model: eastern Peace River Arch area

The study presented here revolves around a 3–D seismic model constructed using the geology of the east Peace River Arch, northern Alberta as a template. Velocities and depths from the Panny (River) Field were used from Anderson et al. (1988). The Keg River Formation, where structurally draped or closed across underlying Precambrian highs, is the principal reservoir facies in this area. Keg River Formation patch reefs or bioherms developed typically on or above prominent basement structures (Campbell, 1987). Basal clastic or Granite Wash deposits are frequently associated with these Precambrian highs. Erosion of Peace River Arch uplifted faulted blocks produced the coarse-grained clastic deposits in adjacent fault-bounded margins.

The primary purpose of the Panny River Model was to analyze the seismic response of lower-velocity basal clastic deposits underlying Keg River patch reefs in an attempt to delineate any basement faulting. Identification of regular trends or orientations through detailed mapping of these deposits by timeslice investigation, and correlation with overlying carbonate bioherms would substantiate the theory behind tectonic development of such build-ups. Direct detection of such faulting on 2–D seismic data is normally difficult because of the limited offset and vertical or sub-vertical nature of the basement displacement. Furthermore, this faulting is also thought to have a strong horizontal, strike-slip component to it. Mitchell (1987) concludes (from an oral presentation) that "3–D seismic has been an effective tool in locating Precambrian highs and their trends (in this area), even when their seismic expression is subtle". The model's secondary purpose was to uncover interpretation pitfalls in 2–D data (particularly those associated with sideswipe), and to illustrate the advantages of 3–D seismic data.

The first section of this paper describes the field acquisition, processing and interpretation of two 2–D seismic sections shot over part of the Panny Field. The two sections intersect at a well drilled into the flank of a patch reef draped over one such Precambrian high. The second section outlines the 3–D physical seismic modelling of a 'reef-fault block' at The University of Calgary in terms of model construction, 3–D data acquisition, processing and interpretation. Finally, 3–D numerical modelling of a corresponding structure is discussed, with particular attention given to the effects of sideswipe.

GEOLOGICAL FIELD SETTING

Since the discovery of oil at Amoco's 2/3–11–96–6W5 test well at Panny in 1983, the eastern Peace River Arch in northern Alberta (Figure 1) has been an active exploration area. An estimated 55 million bbl (8.7 x 10^6 m^3) of recoverable oil has already been discovered. The Keg River Formation is the principal reservoir facies and is typically productive where structurally closed across Precambrian highs. It is commonly considered to be a structural trap as these sediments are productive only where draped across underlying basement structures and the Upper Keg River Reef Member, respectively. Although porosity and permeability within these latter two units are stratigraphically controlled, the off-structure facies generally being tighter, these effects are considered as secondary to the drape resulting from differential compaction. The reservoir facies is capped by the basal anhydrite unit of the Muskeg Formation.

The Precambrian surface consists of anomalous structural highs prevalent throughout the area, with relief typically ranging from 10 to 100m. Generally, such structures have been mapped from the available seismic and well data as being areally closed, a pattern consistent with the idea of a surface fractured by conjugate pairsets of faults oriented in NW–SE and SW–NE directions. There is evidence, both geological and geophysical (Anderson et al., 1988; Cant, 1988), of renewed faulting since Keg River time, either on new surfaces or as reactivations of former faults. The first documented episode of reactivated normal faulting affecting the Arch occurred during deposition of the Elk Point Group in the mid-Devonian. Conglomeratic Granite Wash detritus or basal clastics (and related clastics such as the Gilwood Formation) are eroded from upfaulted blocks and interbedded with Elk Point sediments indicating episodes of tectonism. It is thought that basement relief influenced the locations of bioherms in onlapping carbonate units (Cant, 1988). The Slave Point and Keg River reefs occur on upfaulted blocks near the eastern edge of the Arch, for example at Slave Field (Dunham et al., 1983). A schematic cross-section of the east Peace River Arch area is displayed in figure 3.

Panny River example: 2–D seismic sections

The Keg River Formation is the principal reservoir facies of the Panny Field, the basal Palaeozoic clastics being a secondary target. Figure 1 shows part of the Panny Field with the approximate orientation of the two 2–D seismic lines, PA–1 and PA–6, and wells used in this study. Wells 1–3–96–6W5 and 3–11–96–6W5 both produce from the Keg River Formation.

The seismic data were acquired by Enertec Geophysical Services Ltd. in March 1984 using a 1000m – 60m * 60m – 1000m, 96–trace, spread, with source and receiver intervals of 40m and 20m respectively. A hydrapulse source with 18 pops per source point was used. Data acquired using hydrapulse sources typically have poor penetration below 800–1000ms with an abundancy of lower frequencies. This would seem to present a problem since it is the aim of this paper to image basement faulting, and its subsequent effects.

The data were processed up to stack by Geo–X Systems Ltd. using the following processing parameters:

Demultiplex

Amplitude Recovery

Phase Compensation

Spiking Deconvolution *(80 ms operator, 1% prewhitening)*

Elevation and Refraction Statics

Initial Velocity Analysis

Statics *(Surface Stack Residual)*

Velocity Analysis

Normal Moveout

Mean Scaling *(400–1200ms)*

Mute

Trace Gather *(24 fold)*

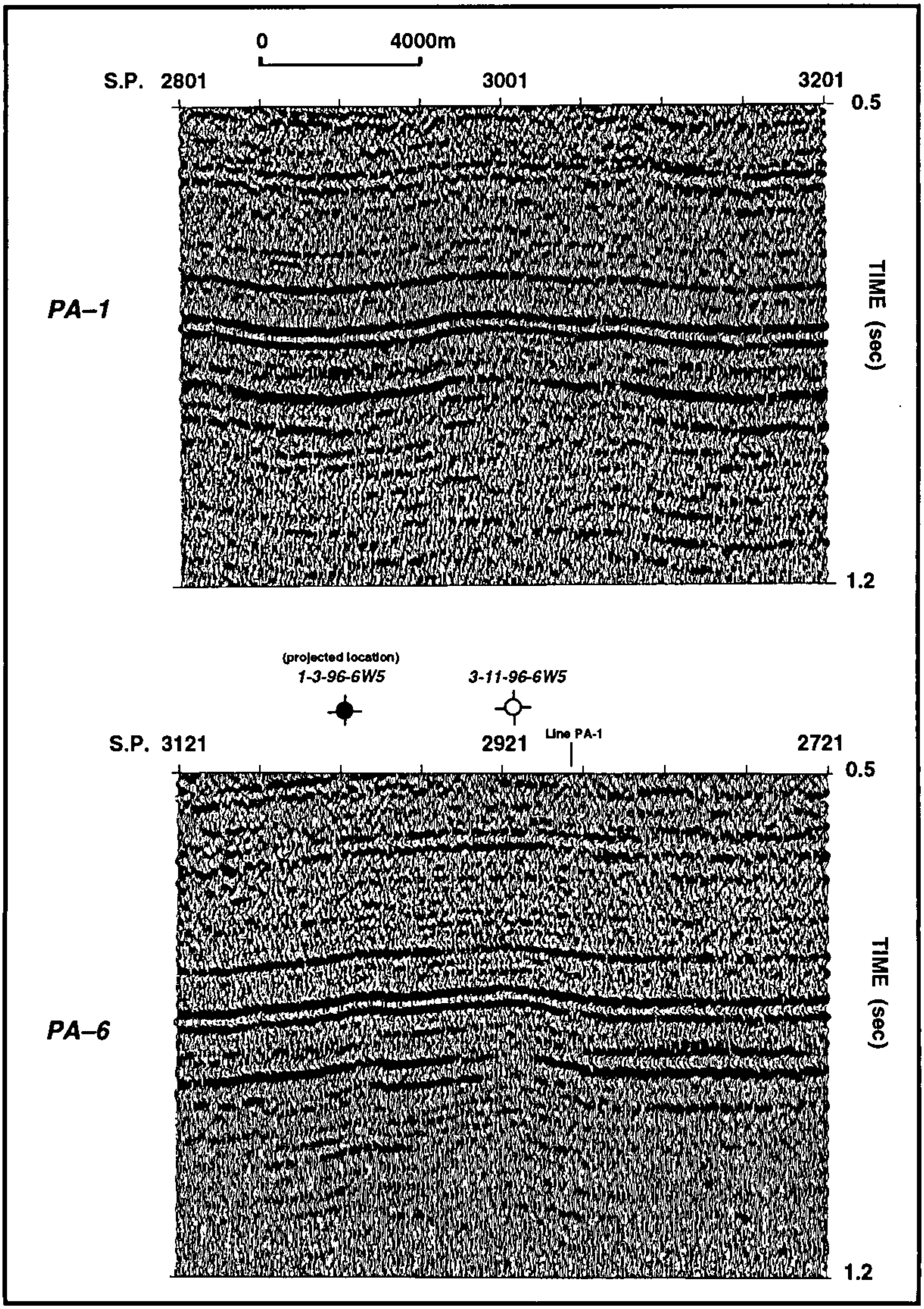


FIG. 4. Condensed scale displays of lines PA–1 and PA–6

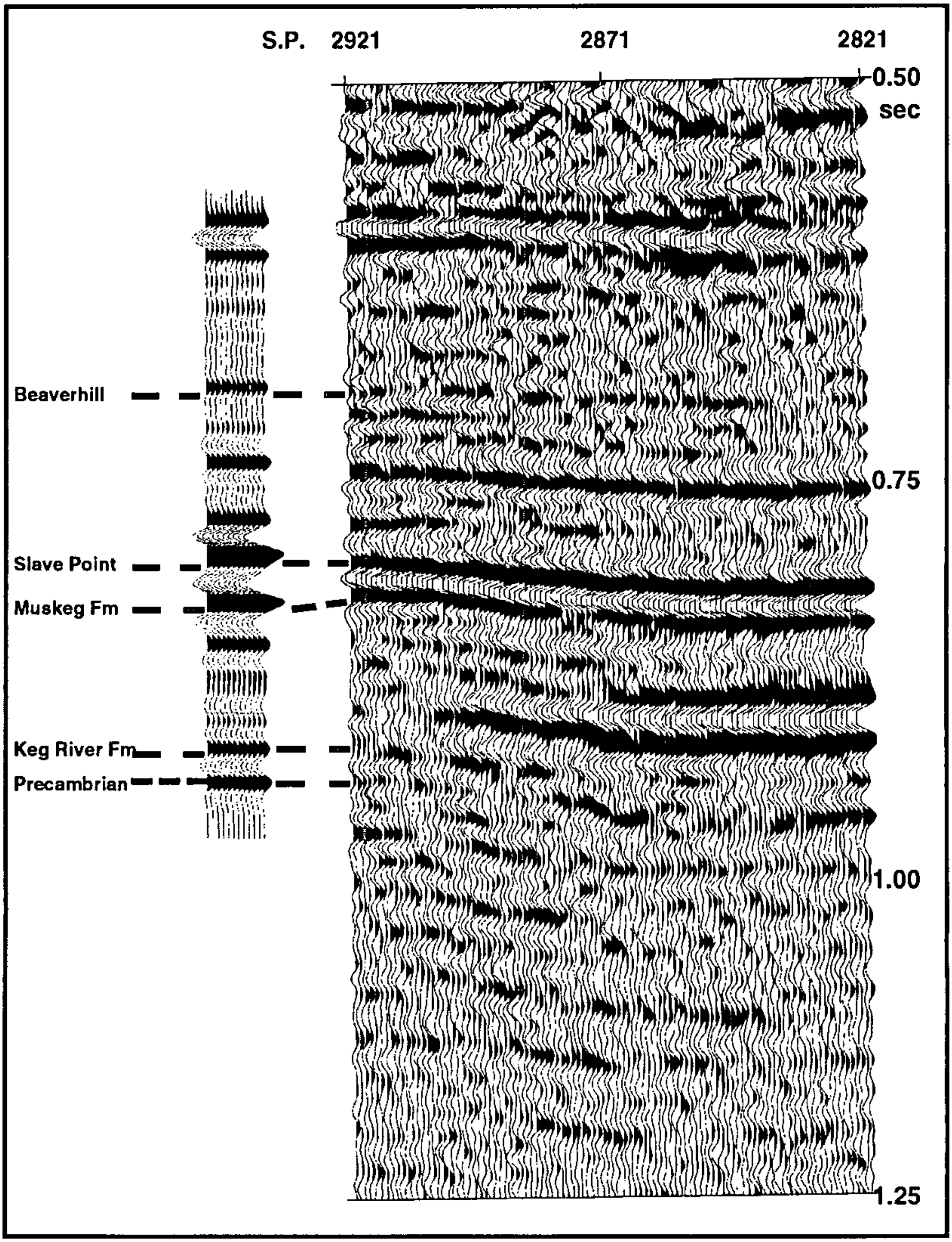


FIG. 5. WELL 03–11–096–06–W5

Synthetic Seismogram tie with line Pa-6

CDP Cross-correlation

Stack

Post-stack processing was undertaken on ITA's *INSIGHT* software using the following modules:

Karhunen–Loeve Stack *(SNR enhancement)*

FK Filter *(20–80 Hz)*

Gapped/Predictive Deconvolution *(operator 100ms, gap 50ms)*

2–D interpretation

Figure 4 consists of condensed scale seismic displays of lines PA–1 and PA–6 in order to illustrate the subtle undulatory nature of the Precambrian basement on such sections, together with the draping of overlying formations over topographic highs. Well 3–11–96–5W5 is found at the point of intersection of these two lines and is used to tie well depths to the seismic data. The synthetic and field data directly correlate at the Precambrian, Keg River, Muskeg, Slave Point, and Beaverhill Lake events (Figure 5). Throughout this paper, such expressions as 'the Keg River reflection event' refer to the top of the named unit.

Well 1–3–96–6W5 is found approximately 0.5 km to the south of line PA–6 but well depths may be projected to intersect it. The synthetic seismogram produced from this well corresponds well with the events interpreted from the previous well. Campbell (1987) describes the core from well 1–3–96–6W5 at depths of 1224m to 1260m. The Keg River in this cored sequence consists of a high-energy bioherm rooted directly on top of Precambrian granite gneiss basement. Overlying the basement rock are a series of siliciclastic sands, conglomerates and carbonate interbeds. Bioclastic gravel-stromatoporoid sequences appear to form the bulk of the deposits associated with the bioherm facies. Figures 6 and 7 show the seismic and schematic geological cross-sections surrounding the well. The bioherm or patch reef is interpreted as overlying a Precambrian basement high and adjacent basal clastic deposits. The Keg River Formation is draped across these structural highs, as a result of differential compaction of lower Palaeozoic sediments, producing a reservoir where structurally closed against the flank of the underlying high. Vertical or near-vertical faulting has been interpreted in the Precambrian but with limited confidence. It would appear these die out below 1 sec (possibly due to the poor resolution of the data). Nevertheless, faults have been identified where the basal clastic unit, thought to be a fault-scarp deposit, is known to exist through well data.

Such a 'reef-fault block (horst)' scenario is used as the geological template for the physical model construction. However, this situation is simplified in the model by the fact that the Keg River interval is only represented by an elongate patch reef with sloping flanks; whereas in reality the reefal facies and adjacent off-reef sediment are normally of similar velocity. Indeed, sometimes the reefal facies is of slightly lower velocity. Hence, the patch reef top and flanks are frequently difficult to image on seismic data shot this area.

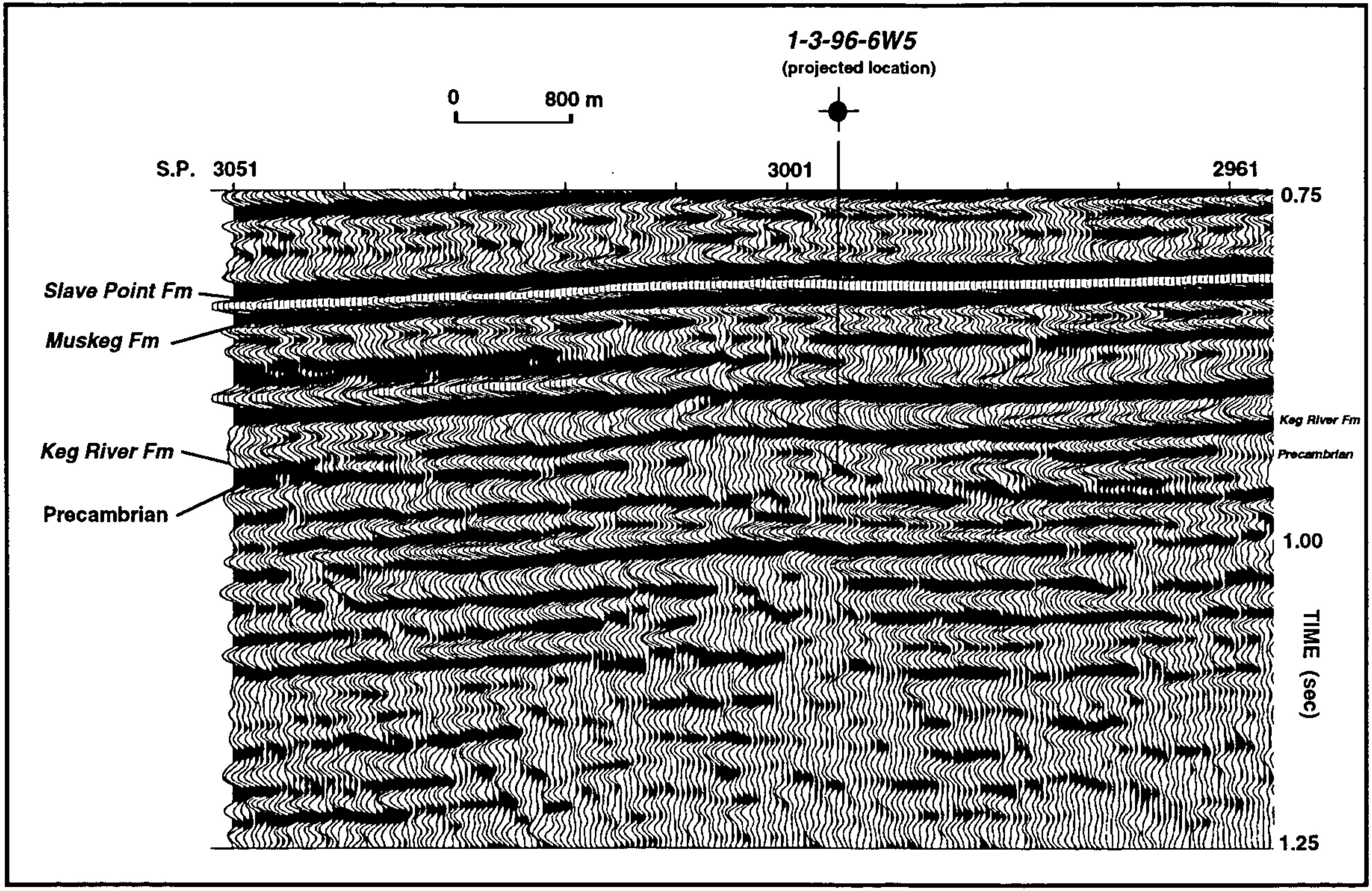


FIG. 6. Enlarged seismic section of line PA–6 around well 1–3–96–6W5

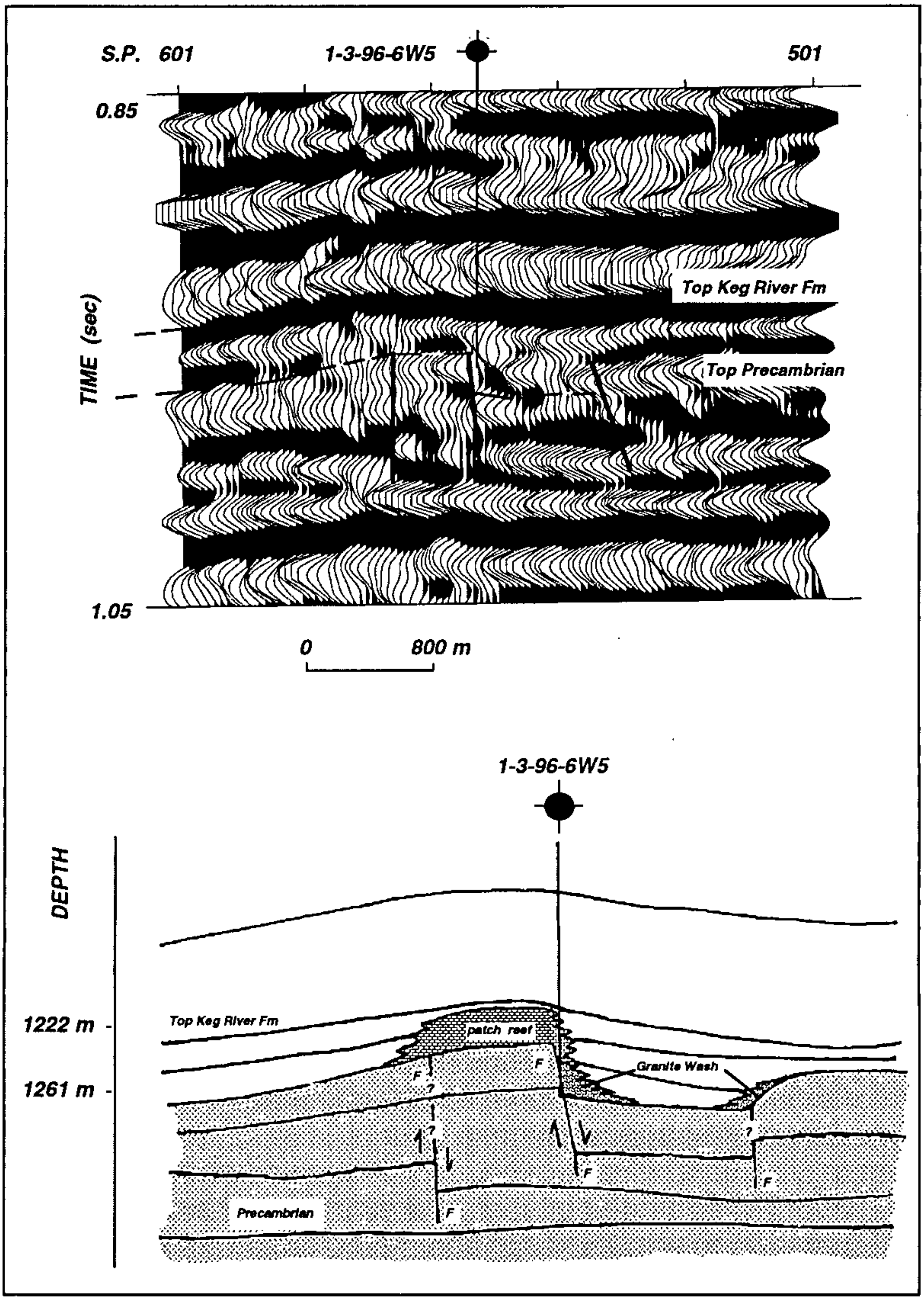


FIG. 7. Geological interpretation of patch reef around well 1–3–96–6W5

PHYSICAL MODELLING

Physical seismic modelling involves the generation of seismic responses over scaled geological models in the laboratory. The success of physical modelling is directly dependent on the choice of modelling materials and scaling factors used for the simulation. The materials used must have acoustic velocities appropriate for scaling and must be readily formable into complex shapes. Scale factors are chosen for the model experiments such that the value of a model parameter multiplied by the appropriate scale factor results in the dimensions of the field prototype. In this study, the physical seismic modelling method was employed to study the seismic response of an reef partially overlying a set of vertical faults.

Reef–fault block (horst) physical model

The geometry of the model is shown in plan view, cross-section, and perspective 3–D outline in figures 8 and 9 respectively. Scaling factors for velocity of 1:2, for depth and distance of 1:10,000, and for time of 1:5,000 were all used such that the model parameters multiplied by the scale factor resulted in the dimensions of the field prototype. The dimensions for the Keg River reef were taken from Anderson et al. (1988) and are typically elongate, around 1000 m by 500 m and 50 m thick (10 cm x 5 cm x 0.5 cm scaled). Such reef are found at a depth of 1200m (12cm scaled) within the Panny and Trout Fields associated with the eastern Peace River Arch. A characteristic maximum throw for the observed normal faulting can be estimated from the contoured Precambrian surface (Figure 2) at approximately 100 m (1cm scaled).

The materials used for model construction were those that had velocities appropriate for scaling with respect to the field velocities observed in the Peace River Arch area. The stratigraphy and velocity structure is contained in Table 1. Using a velocity scaling factor of 1:2, a suitable model substance for the reefs was found to be Canadian Tire Plastic resin with 50 micron diameter glass beads (at a volume of 1:1) with a model *P*–wave velocity of 2840 m/s, giving an unscaled velocity of 5680 m/s (compared to 5600 m/s field value). The basal clastic or Granite Wash unit was constructed from only the Canadian Tire plastic resin, having a *P*–wave velocity of 2452 m/s scaled (4904 m/s unscaled, compared to the field prototype of 5000 m/s). Finally, the base (Precambrian) was cut out of a Plexiglas sheet with an unscaled model value of 2750 m/s (both unscaled and field *P*–wave velocities are 5000m/s).

Physical modelling system

The physical modelling system at the University of Calgary was developed by Cheadle et al. (1985). The major components of the system are: a water-filled tank (3 m wide, 4 m long, and 2 m high); two perpendicular beams containing motorized carriages; two spherical ITC-1089C ultrasonic piezoelectric transducers; a pre-amplifier; a pulse generator; an IBM-XT PC; and a digital storage oscilloscope.

During operation, the reef-fault block model is submerged in the tank on a levelled platform for the experiment. The two transducers act as source and receiver and are moved across the model on the motorized carriages. The acquisition geometry of the survey is programmed using a PB 386/25 which controls the positions of the transducers. A zero-phase signal is obtained by the summation of three wave trains generated from the pulse generator. The received signal is digitized by a high speed storage oscilloscope. A direct link between the oscilloscope and a Perkin-Elmer allows the transfer of the seismic trace, containing a maximum of 4096 samples plus the trace

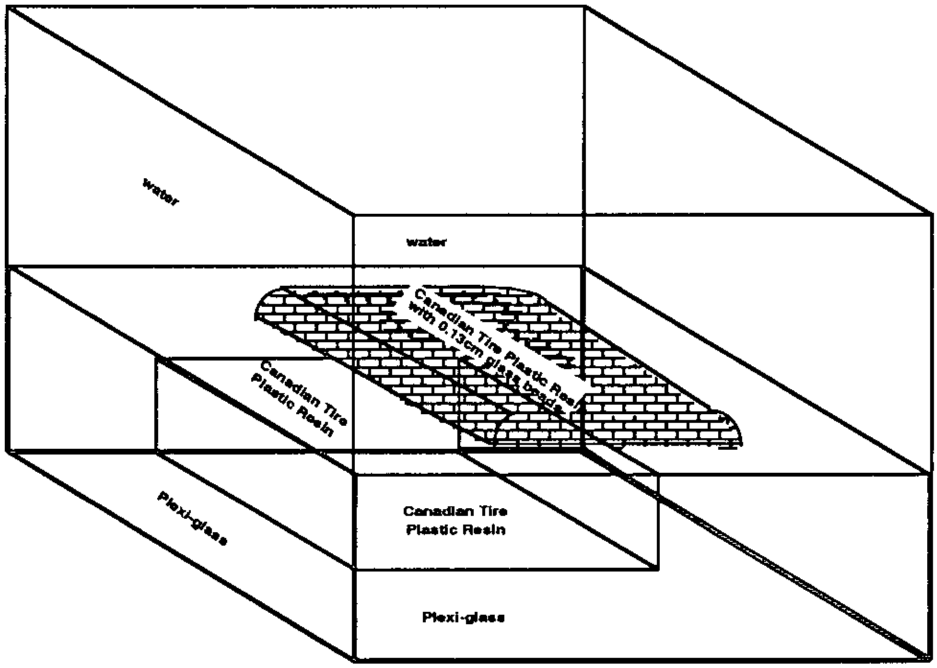


FIG. 9. 3–D perspective view of physical model

SEISMIC DATA (PEACE RIVER ARCH AREA)			PHYSICAL 3-D MODELLING SCALED PARAMETERS				
Formation	desired field velocity (P-wave; m/s)	thickness (m)	material	model P-wave vel(m/s)	model S-wave vel(m/s)	model Vp/Vs	thickness (cm)
'cover'		1200	'water'	1480			12
reef	5600	50	Canadian Tire plastic resin with 0.13cm glass beads; vol 1:1	≈2840 (x2=5680)	≈1480	1.92	0.5
basal clastics	5000	100	Canadian Tire plastic resin	≈2452 (x2=4904)	≈1182	2.07	1.0
Precambrian	5500		plexi–glass	2750 (x2=5500)	1375	1.19	2.0

Scaling parameters ***: time 1:5000 ; distance/depth 1:10000 ; velocity 1:2***

Table 1. Modelling parameters

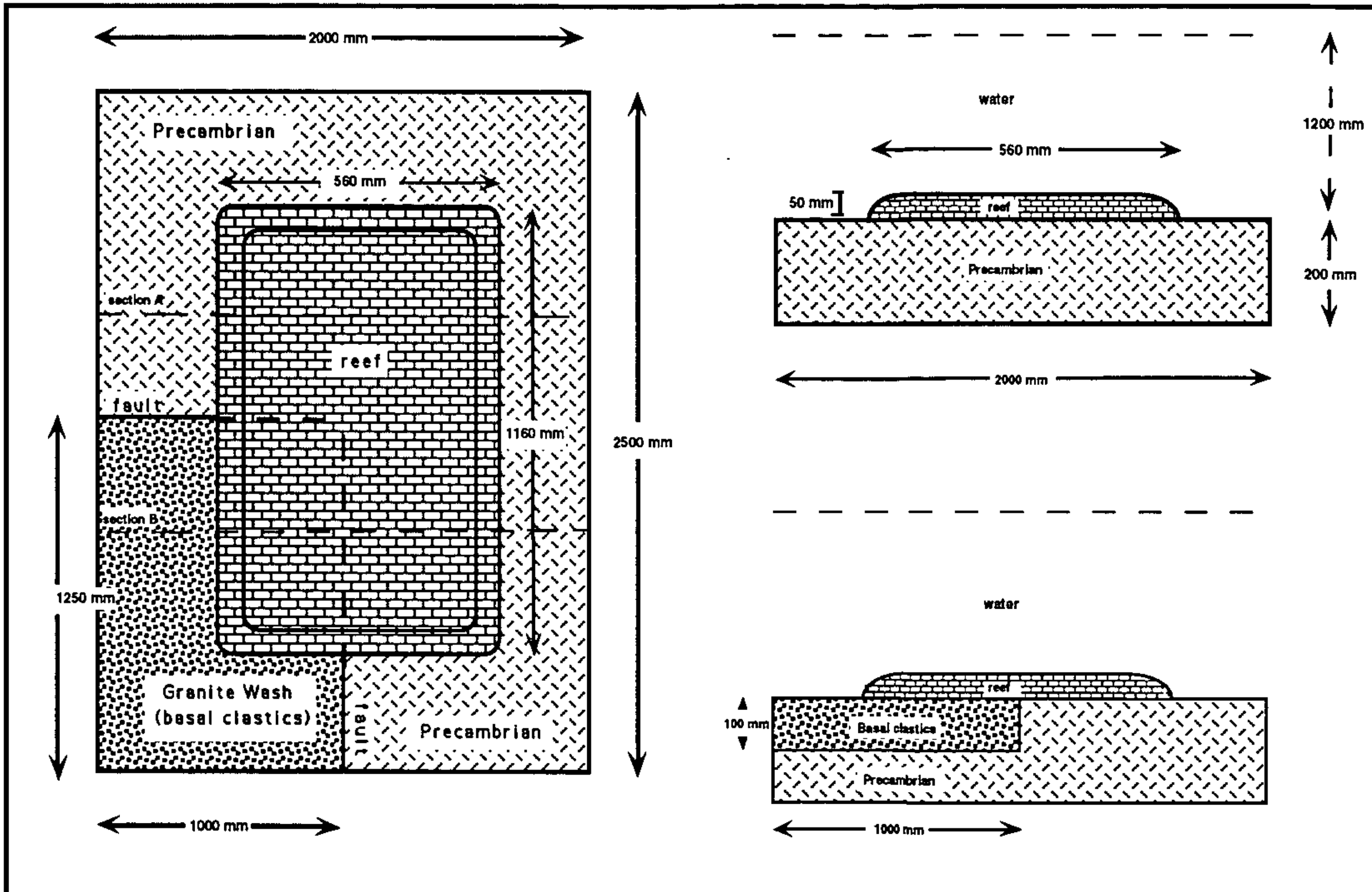


FIG. 9. Schematic plan- and cross-section of reef-fault block physical model

header, onto magnetic tape in SEG–Y format. At this stage, the raw data can be processed using ITA's Insight 3–D software.

Acquisition parameters

A 3–D zero-offset survey was carried out over a scaled area of 25 cm by 20 cm (2500 m x 2000 m unscaled). 3–D zero-offset surveys have a 'stacked' trace at the centre of every bin, and for this survey 5 stacks per trace were used. The survey consisted of 100 lines and 80 shots per line (100 inlines, 80 crosslines). The scaled bin spacing used was 0.25 cm or 25 m unscaled (line, shot, and receiver spacing consistent). The inlines were shot parallel to the short side of the reef (shooting direction). The nearest offset possible was 100 m because of the spatial nature of the source and receiver transducers. A sample rate of 1ms was used over a record length of 2 seconds.

3–D processing

Following acquisition, the raw 3–D zero-offset data is loaded onto ITA's *INSIGHT* system for 3–D processing. The 3–D zero-offset processing flow for the reef-fault block model is summarized in figure 10. 3–D geometry in the form of observer and survey note files are then generated and the dataset is updated. The data were muted from 0 to 700 ms in order to remove the direct arrivals which are of a very high amplitude nature. This is directly related to the small source-receiver offset of 100 m. Effects due to water reverberations are also removed.

The 3–D data volume is sorted on the basis of full 3–D composite CDP number (combined line and station number). This sort map is used to pad the 3–D dataset to a full regular 3–D cube. Data records corresponding to either inline or crossline (station) data segments can then be easily extracted from the data cube.

Inline 50 (reef and fault block) was extracted from the padded 3–D dataset for 2–D migration testing. A frequency band range of 15 to 100 Hz was obtained for input into the migration from analysis of the Fourier spectra (Figure 11). RMS velocities needed for the migration were computed from the known interval velocities of the model using the following equation:

$$V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} V_i^2 t_i}{\sum_{i=1}^{n} t_i}}$$

where V_i and t_i are the known velocity and travel time through the *i*th layer.

Confirmation of these velocities was provided through migration, with the interval velocities recalculated from the RMS velocities using the Dix equation. Figures 11 and 12 illustrate the unmigrated and 2–D migrated inline 50 respectively.

A one-pass 3–D phase-shift depth migration was applied to the entire 3–D dataset, using downward continuation with the two-way wave equation. Time-RMS velocity pairs input into the migration correspond to known interval velocities over the central part of the reef model, since the main aim of the migration is to collapse the

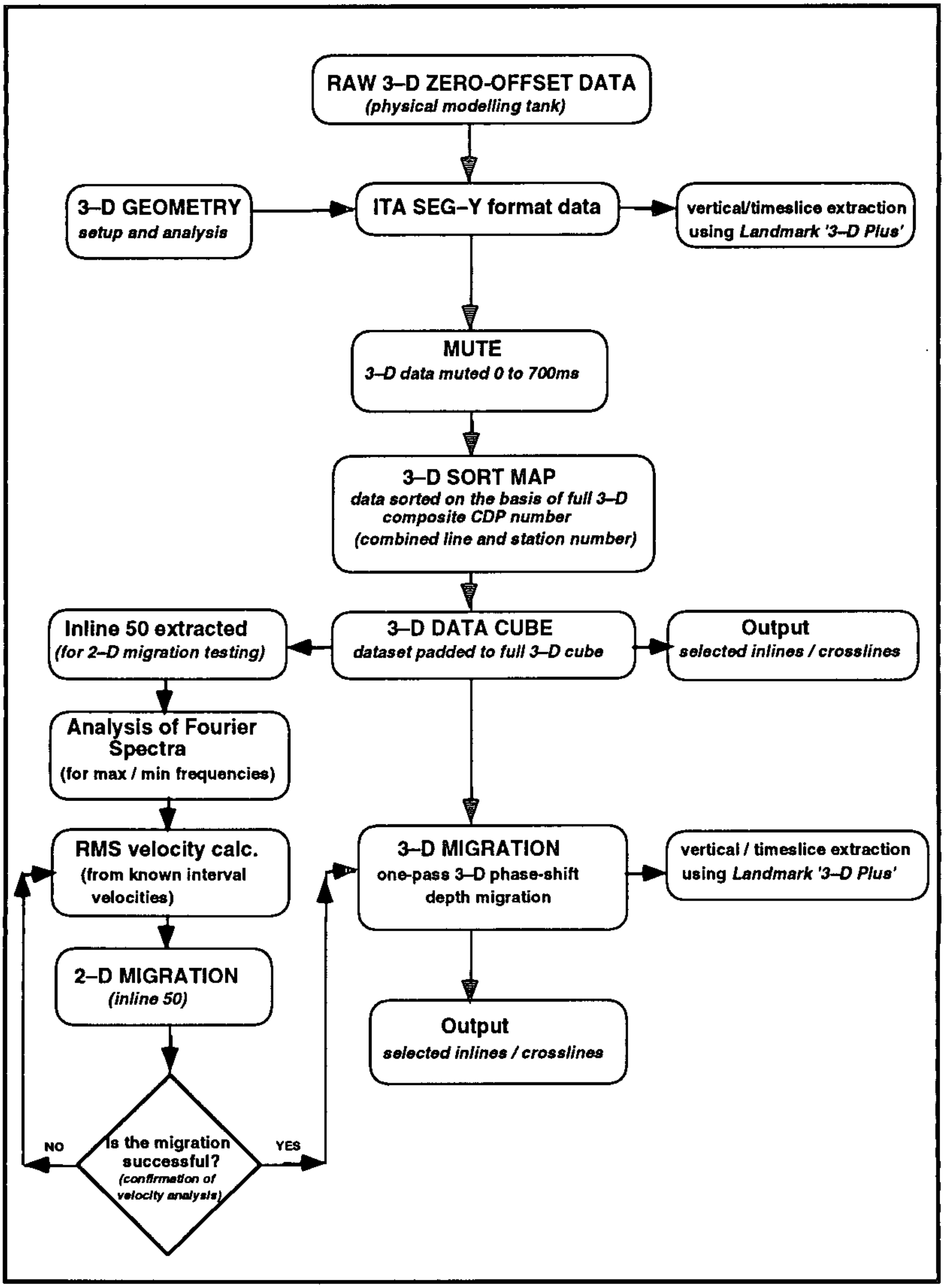


FIG. 10. 3–D zero-offset processing flow for reef-fault block model

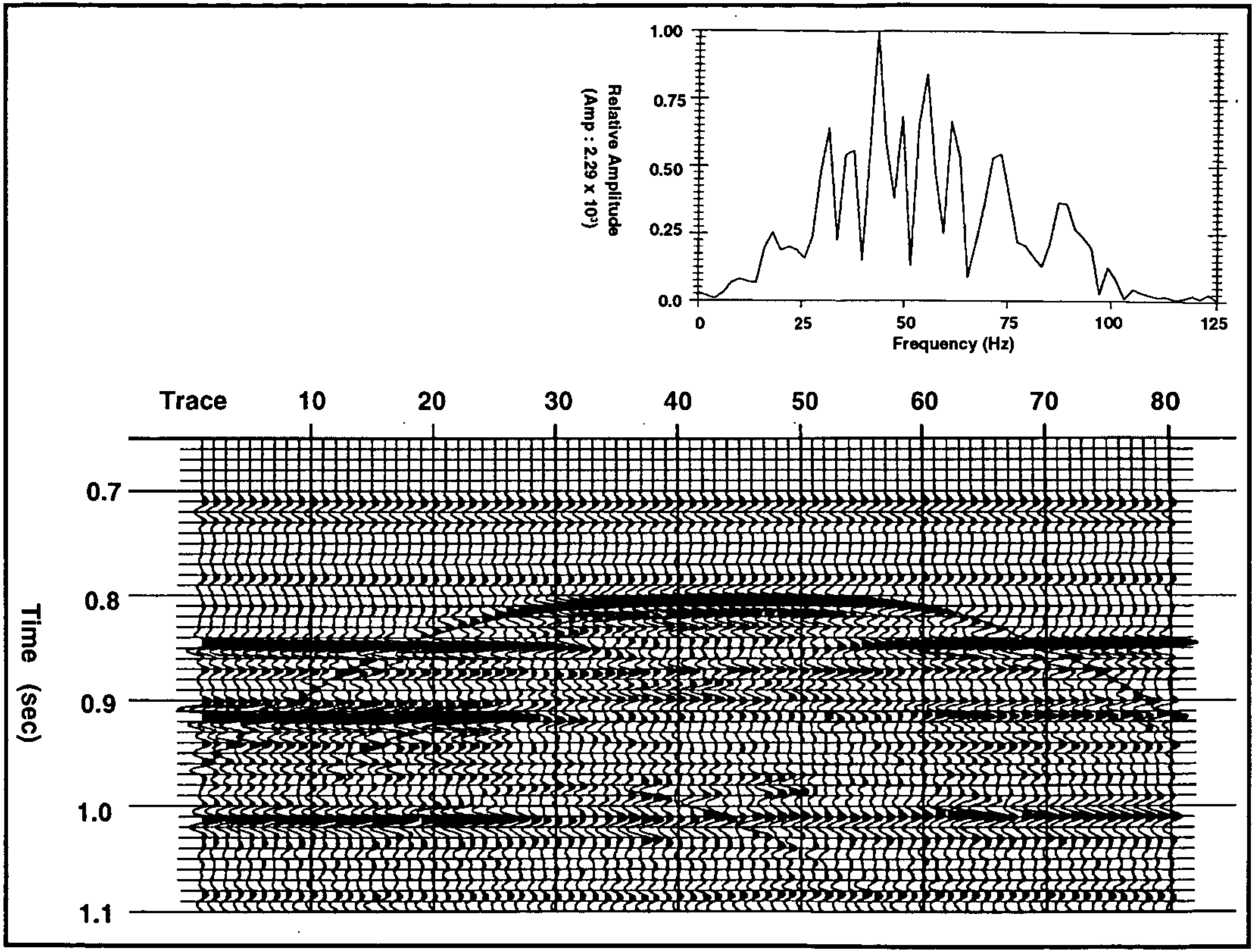


FIG. 11. Inline 50 with frequency range for 2-D migration testing

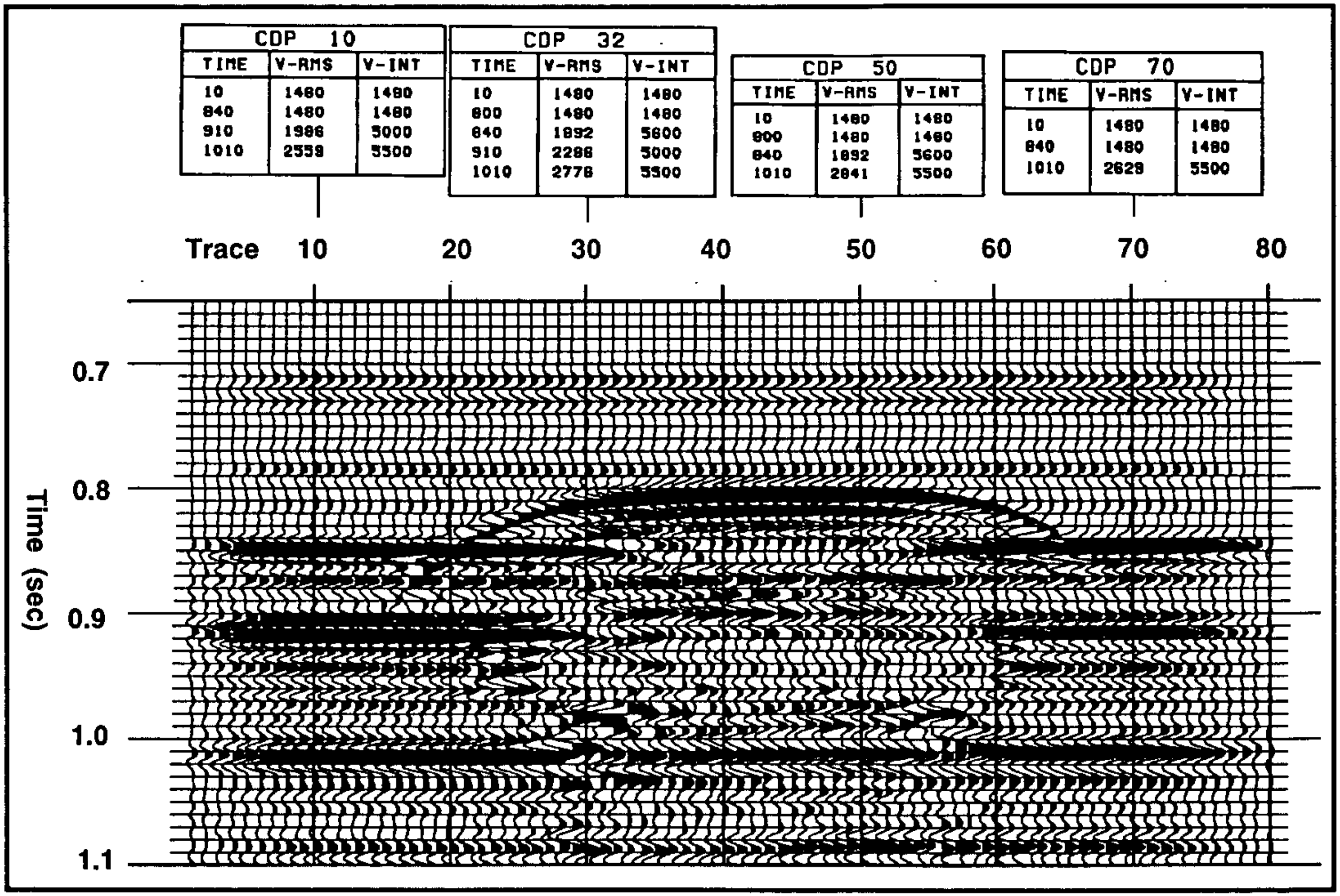


FIG. 12. Test 2–D migration of inline 50 (with RMS velocities used)

diffractions associated with the reef flanks and vertical faults. This is because only one set of velocities can be input into this 'fast' depth-migration process. The time-frequency band definition used for the 2–D migration is also included in this 3–D version.

3–D INTERPRETATION

Both the raw and migrated 3–D zero-offset datasets were interpreted using output from ITA's Insight system and '*3–D Plus*' on the Landmark workstation. Two types of seismic display were produced on both systems: vertical sections; and horizontal or timeslice sections.

Vertical seismic sections

Figures 13 and 14 illustrate representative inline sections from the unmigrated and migrated datasets respectively. They represent situations where :

- only the faulted platform is present
- both the reef and faulted platform are evident
- the reef overlying a simple platform
- a simple unfaulted platform.

A number of events can be picked on the recorded data in a quantitative manner because we know the model geometry and velocity. Top of the reef, platform and basal clastic unit reflectors can all be readily identified due to their high amplitude, continuous nature. The base of the model is also evident, just below 1000 ms. The highest amplitude visible appears to correspond with the top reef event at 810 ms, which is to be expected since the velocity and density contrast between the two media is greatest (water 1480 m/s and reef 5680 m/s – unscaled velocities). On sections such as inline 70, the platform is imaged beneath the reef. Slight pull-up can be identified due to the high- velocity nature of the Canadian Tire plastic resin/glass bead material (reef) with respect to the surrounding water. The reflections from the platform under the reef body arrive earlier than those to the side. A basal clastic event is distinguishable at around 900ms from traces 1 to 40 on lines where the fault block is present (inlines 10 and 40). At first glance it may be possible to correlate this with an adjacent lower-amplitude event at the same time. This is particularly evident on inline 10 where a continuous event could be interpreted. This lower-amplitude arrival is thought to be the result of a bond in the Plexiglas (platform) layer. The reflector that represents the model base appears to vary in amplitude and arrival time. On lines where the reef is present (inlines 40, 70), it is possible that pull-up can be identified for this arrival. Where the fault block is present (inlines 10, 40), a push- or pull-down effect can be recognised beneath the lower-velocity basal clastic unit with respect to the platform. The reflections from this part of the model base therefore arrive later than those adjacent.

On the unmigrated sections, a number of diffractions may be inferred: those associated with the edge of the reef (with a variation in diffraction curvature); and less prominent curves delineating the vertical fault. The later would appear to have phase reversals from branch to branch of the curve. However, no phase reversal is apparent

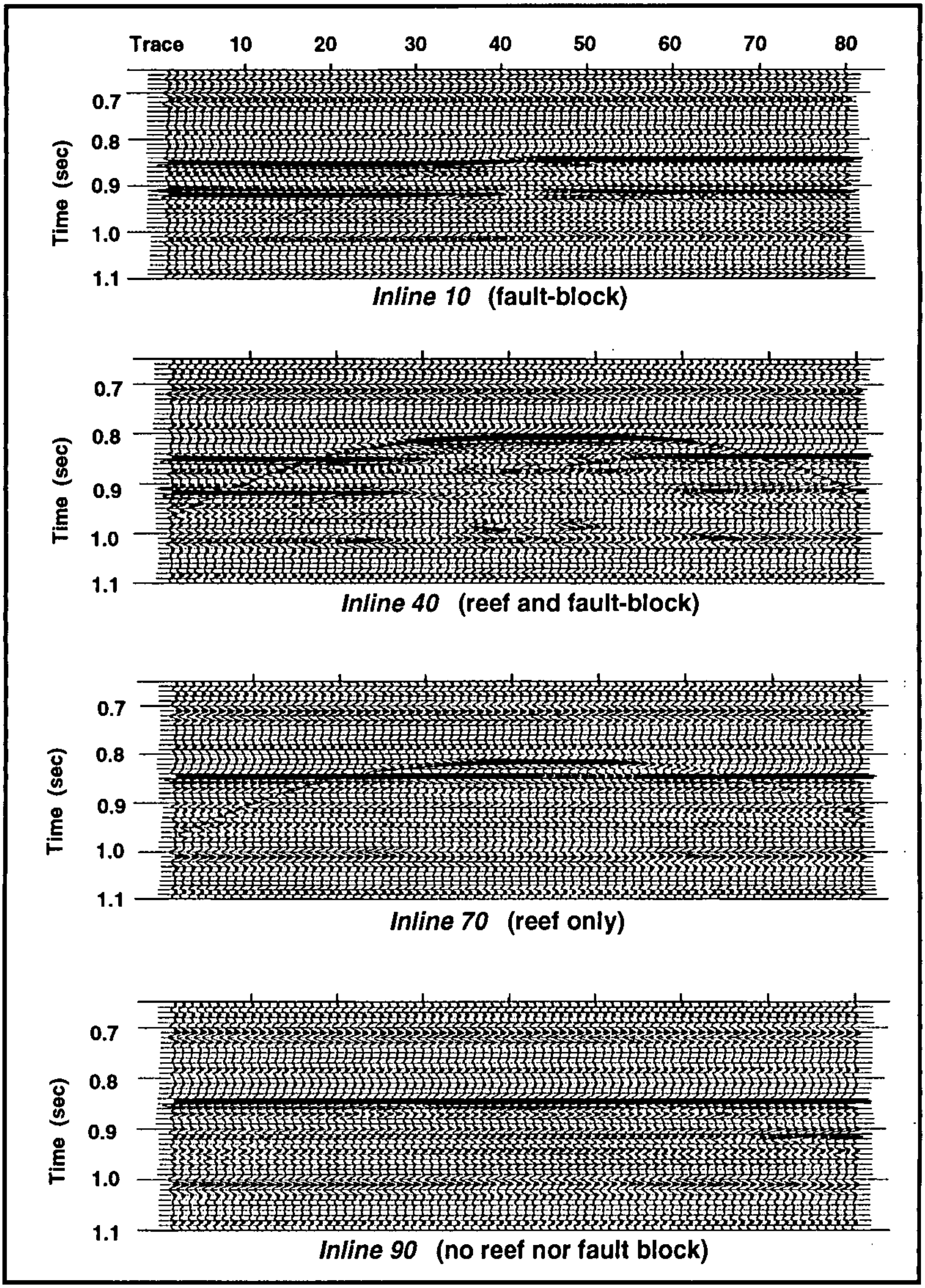


FIG. 13. Representative unmigrated sections

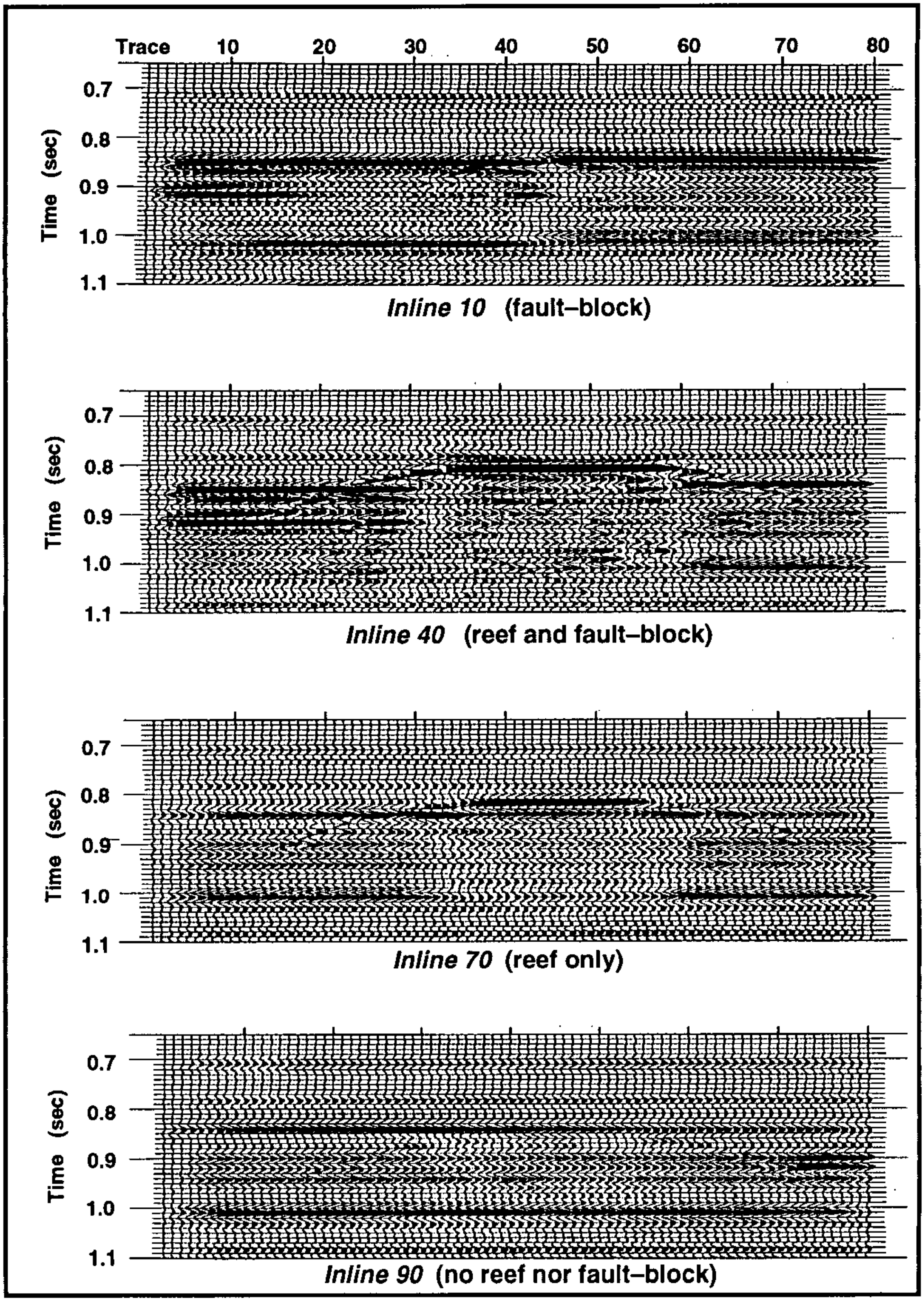


FIG. 14. Representative migrated sections

on the reef edge diffraction with the steeper, narrower curvature and shorter 'tail'. Such diffraction curves should be removed by migration. The migrated sections (Figure 14) illustrate that those associated with the fault and the diffraction with the wider curvature both disappear; but the so-called 'diffractor' with the shorter tail and no evidence of phase reversal still remains. This feature is not a diffraction but is a reflection from the flank of the reef, probably because of the zero-offset nature of the survey. The reflection has a steeper dip than the diffraction. This can be further illustrated by numerical modelling of such a reef, using the *Sierra* modelling system, which does not compute diffractions. Yet, after *Sierra* modelling, this feature is still present – indicating its origin as a reflection. Unmigrated and migrated timeslices further illustrate the areal extent of these distinct diffractions and reflections

An apparent 'diffraction' may also be inferred on unmigrated inline 90 (Figure 13) with the curve apex at, or just below, the platform event. Here, no irregularity nor diffraction source is present. This feature can be interpreted to be a sideswipe reflection from the flank of the reef. A sideswipe reflection is one whose reflection points lie outside the plane of the seismic section. It may be shown through numerical modelling that this is an out-of-plane reflection (Figure 21). If a reflector has a component of dip (reef flank) in the direction normal to the plane of the seismic section, the dip will give rise to sideswipe. Without this understanding, it would not be possible to properly correlate a reflection through a 2–D grid and produce a correct interpretation.

Timeslice displays

One aim of this paper has been to test the usefulness of timeslice sections in interpreting the reef-fault block model. Four characteristic pairs of unmigrated and migrated timeslices are presented in this paper (Figures 15 to 19), illustrating particularly well the nature of the fault-block arrival amplitudes and propagation of diffraction curves and reef-flank reflections with time and distance.

Above the platform, the extent of the reef outline is well imaged on the timeslice for time 820 ms (Figure 15), with surrounding water having a zero amplitude. The focussing effects seen on the reef flank corners of the unmigrated data are not present when migrated.

Timeslice 860 ms (Figure 16) provides a good example of the areal extent of the basal clastic fault block. The regularity if the fault block margin is particularly well imaged in the migrated timeslice. The Canadian Tire plastic resin (basal clastics)–Plexiglas (platform) interface shows up as a marked positive amplitude anomaly. The amplitude decreases significantly toward the centre of the reef where it becomes masked by transmission losses due to the high amplitude top reef event. Also on this timeslice, a small amount of pull-up may be inferred by the presence of anomalous amplitude values around the projected position of the reef, whilst elsewhere values are essentially negligible.

In the 900 ms and 1000 ms timeslices (Figures 17 and 18 respectively), both pull-up and push-down are encountered. As mentioned earlier, pull-up is located beneath the reef and push-down effects are associated with the lower velocity faulted layer. The effect of the push-down is again to successfully delineate the faulted margins.

On timeslices beneath the top-platform event, the diffraction wavefront from the reef flank can be observed to propagate laterally away with time. These diffraction curves are removed when migrated, leaving a (zero-offset) flank reflection which has

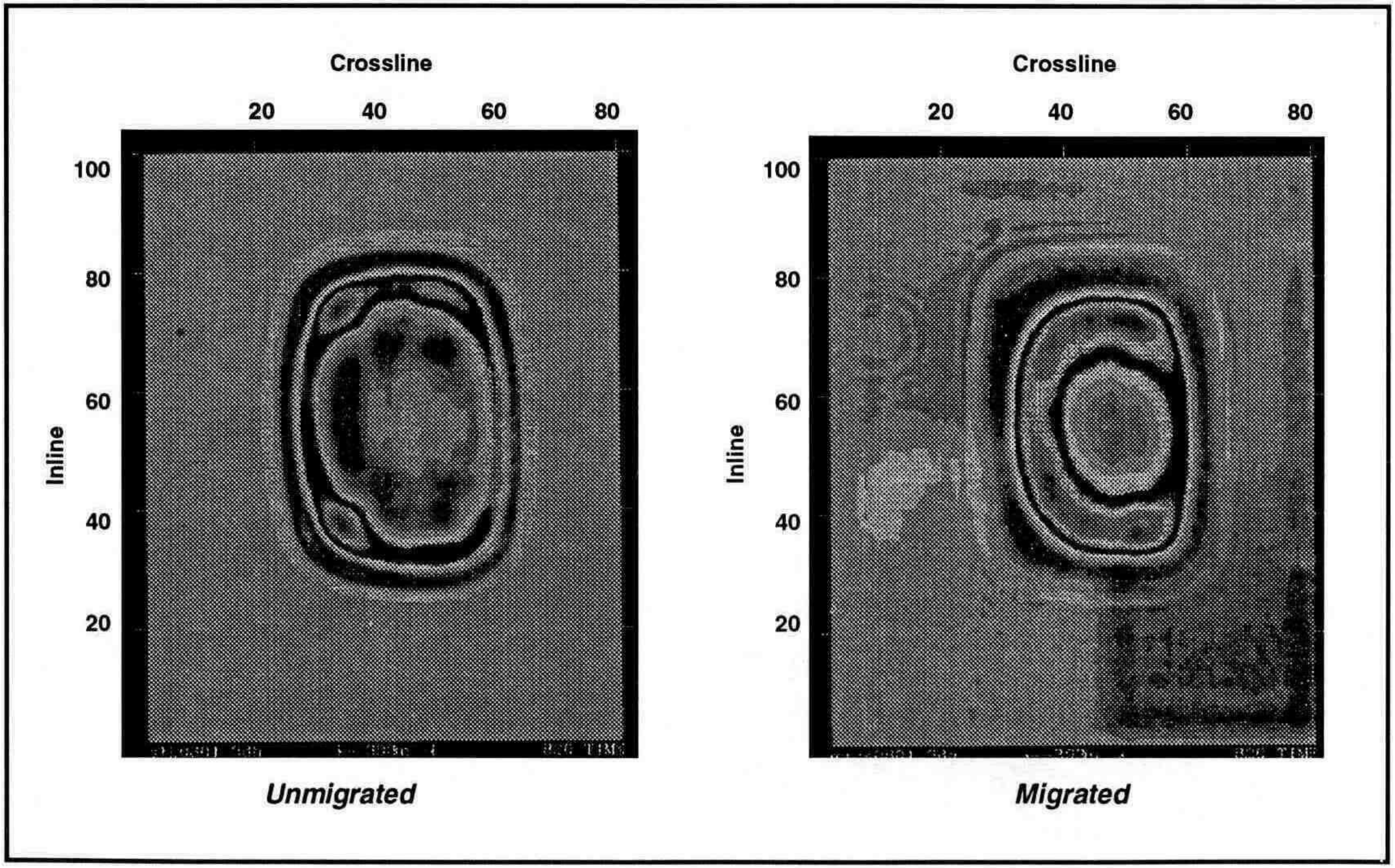


FIG. 15. Unmigrated and migrated timeslices for time 820ms, imaging the reef outline

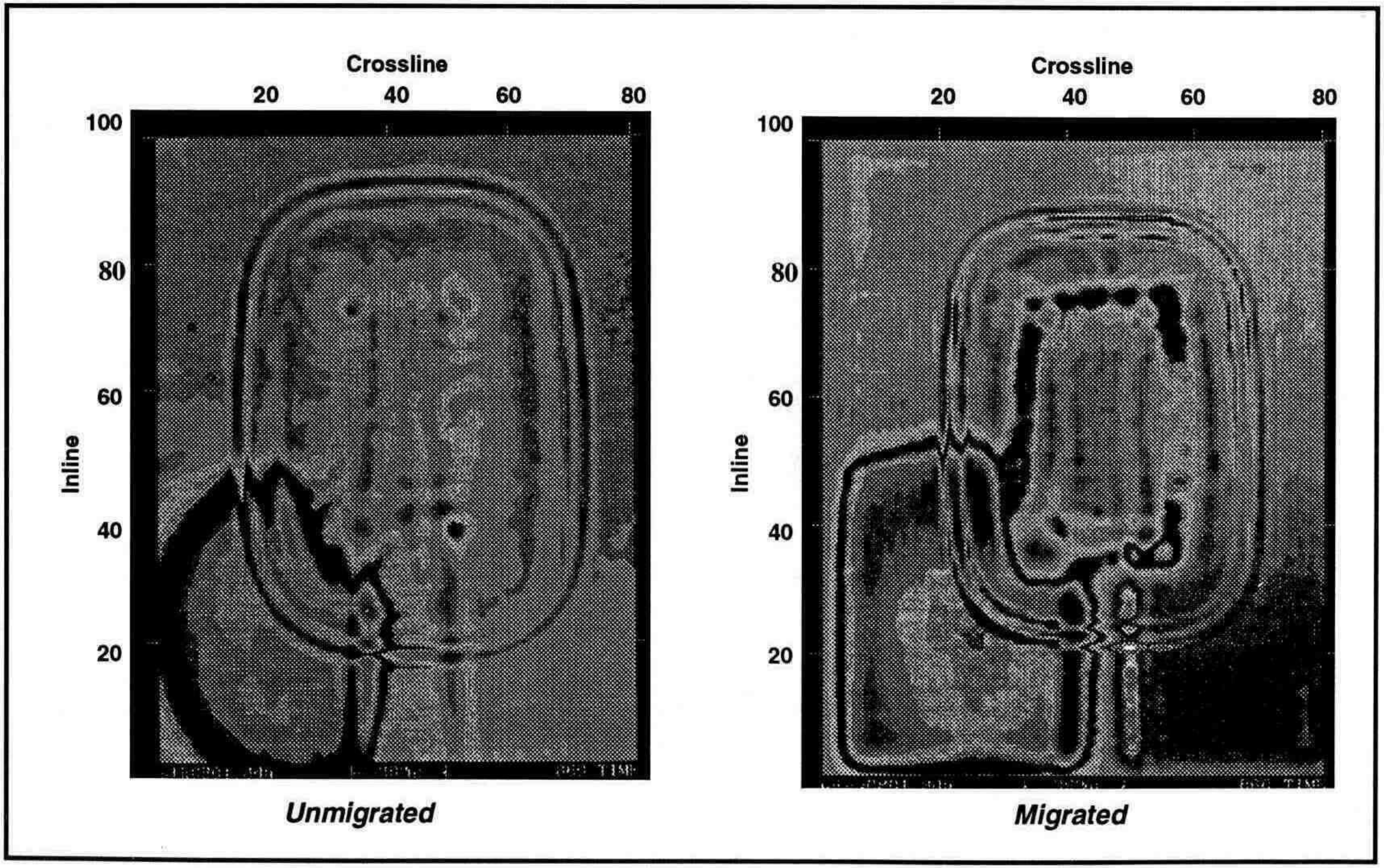


FIG. 16. Unmigrated and migrated 860ms timeslices

(note imaging of reef-fault block)

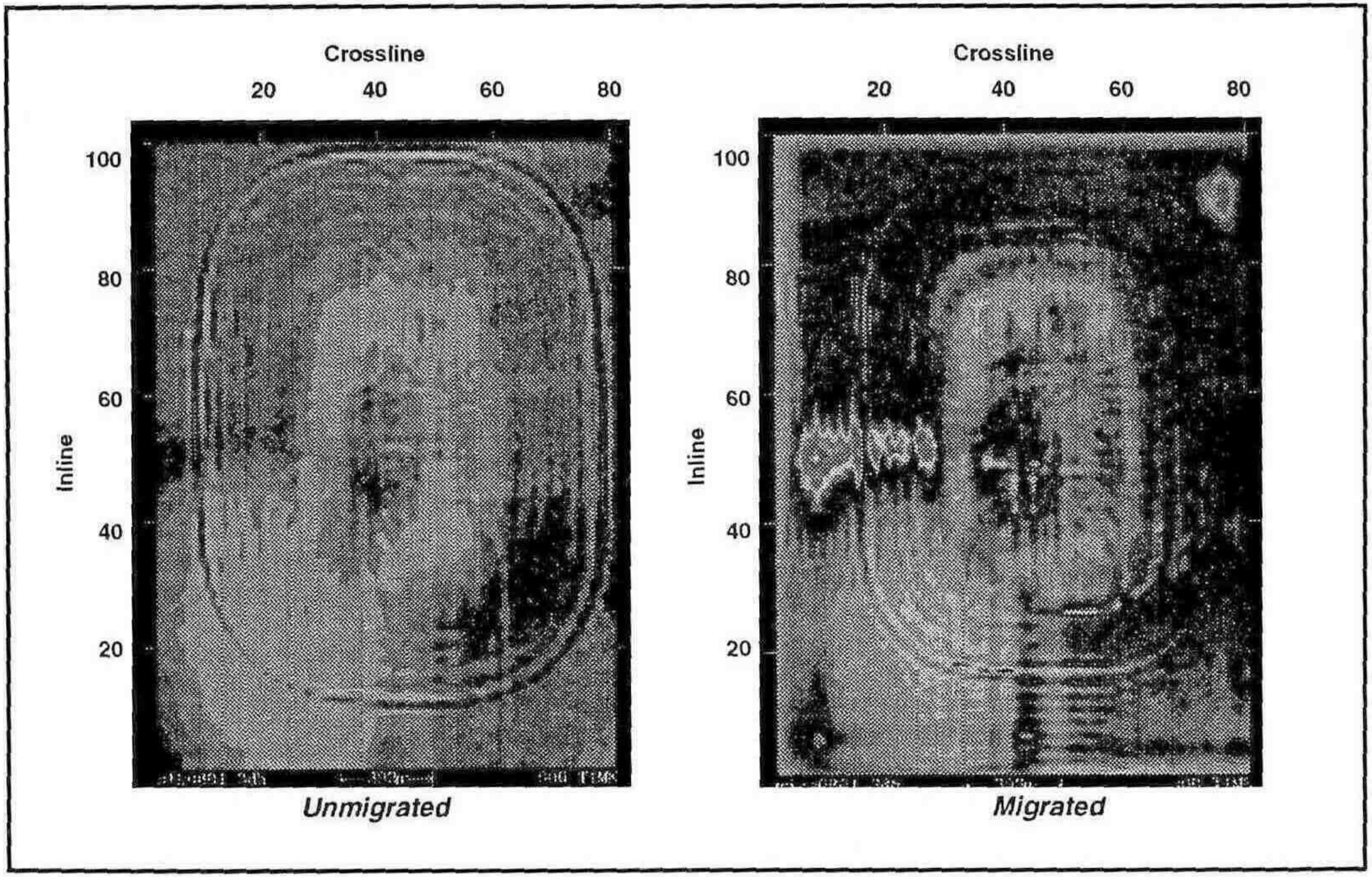


FIG. 17. Unmigrated and migrated 900ms timeslices

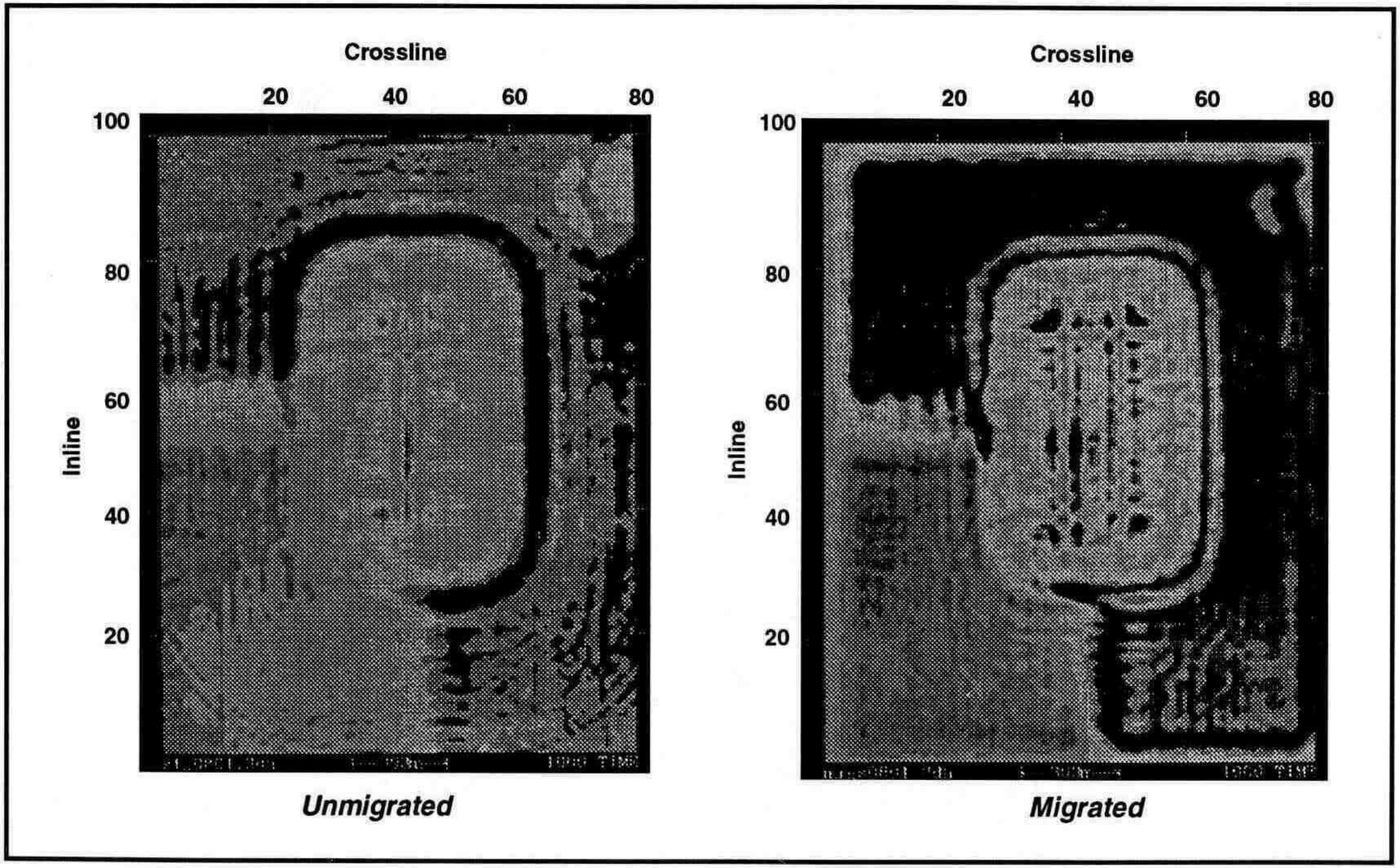


FIG. 18. Unmigrated and migrated 1000ms timeslices

similar concentric pattern but is of less width (reflection has steeper dip than diffraction).

NUMERICAL MODELLING

Sierra's 3–D ray-tracing software was used to shoot a similar 3–D zero-offset survey over a reef-fault block. The only difference in model design is that vertical faults are not allowed in the *Sierra* software. However, the spread length is sufficiently small for any effect to be negligible. An example of an inline and perspective 3–D view of the reef-fault block model is shown in figure 19. By using 3–D ray tracing seismic modelling, it is possible to confirm theories established during physical modelling. Diffraction computation is not possible using this software, thereby confirming the zero-offset reflection origin of the reef flank anomalies imaged beneath the platform in selected inlines (Figure 20). Timeslices (Figure 21) were produced through numerical modelling showing the areal extent of these reef-edge reflections. Timeslices below the platform event again successfully delineate the regular margins of the basal clastic layer, thus identifying the fault.

By examination of such timeslices, it is evident that a line located away from the reef is going to contain these reef edge reflections – constituting sideswipe or out-of-plane reflections. Figure 22 illustrates this with the raypaths for crossline 15 superimposed on a contour map and 3–D perspective plot. Due to sideswipe, an anomaly is present on the unmigrated seismic section . Therefore, 3–D ray-trace modelling also shows that reefs are detected by seismic sections shot off the buildup. In such cases, 2–D migration may then result in the false imaging of a buildup along a line where none occurs.

CONCLUSIONS

In this study, a 3–D zero-offset survey shot over a reef-fault block model was carried out using the physical modelling system at The University of Calgary. Dimensions and velocities for the model were taken from Keg River patch reefs or bioherms flanking the eastern Peace River Arch, northwest Alberta. These reefs developed typically on or above prominent basement structures (Campbell, 1987). Such Precambrian relief is thought to be controlled by normal block faulting. However, the vertical and limited offset associated with such faulting makes their direct identification on 2-D seismic sections somewhat difficult. The situation may also be complicated by pull-up or push-down effects associated with the reefal facies and off-reef sediment. Erosion of uplifted, faulted blocks produced basal clastic (Granite Wash) or fault-scarp deposits in adjacent margins. The base of such a lower-velocity basal clastic layer can be interpreted to a certain degree on the inline sections of the 3–D zero-offset physical model survey. Nevertheless, identifying the layer directly beneath the reef still remains a problem.

Investigation of timeslices through the 3–D physical model dataset show that the areal extent of the basal clastic fault block is particularly well imaged, even beneath most of the overlying higher velocity reef. 3–D numerical modelling of a similar reef-fault block also successfully delineated the regular margins of the basal clastic layer,

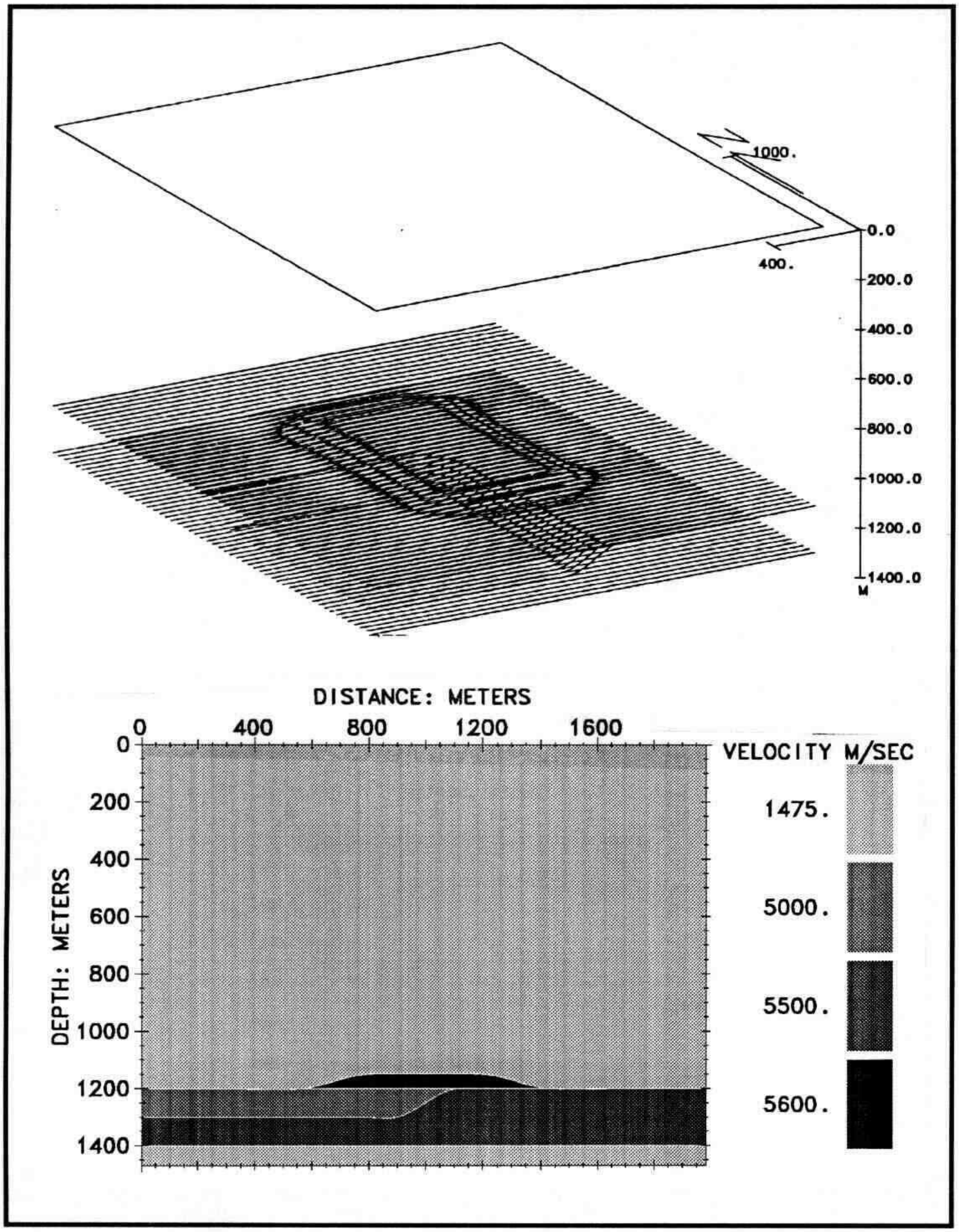


FIG. 19. 3–d perspective view and cross-section of input to numerical modelling

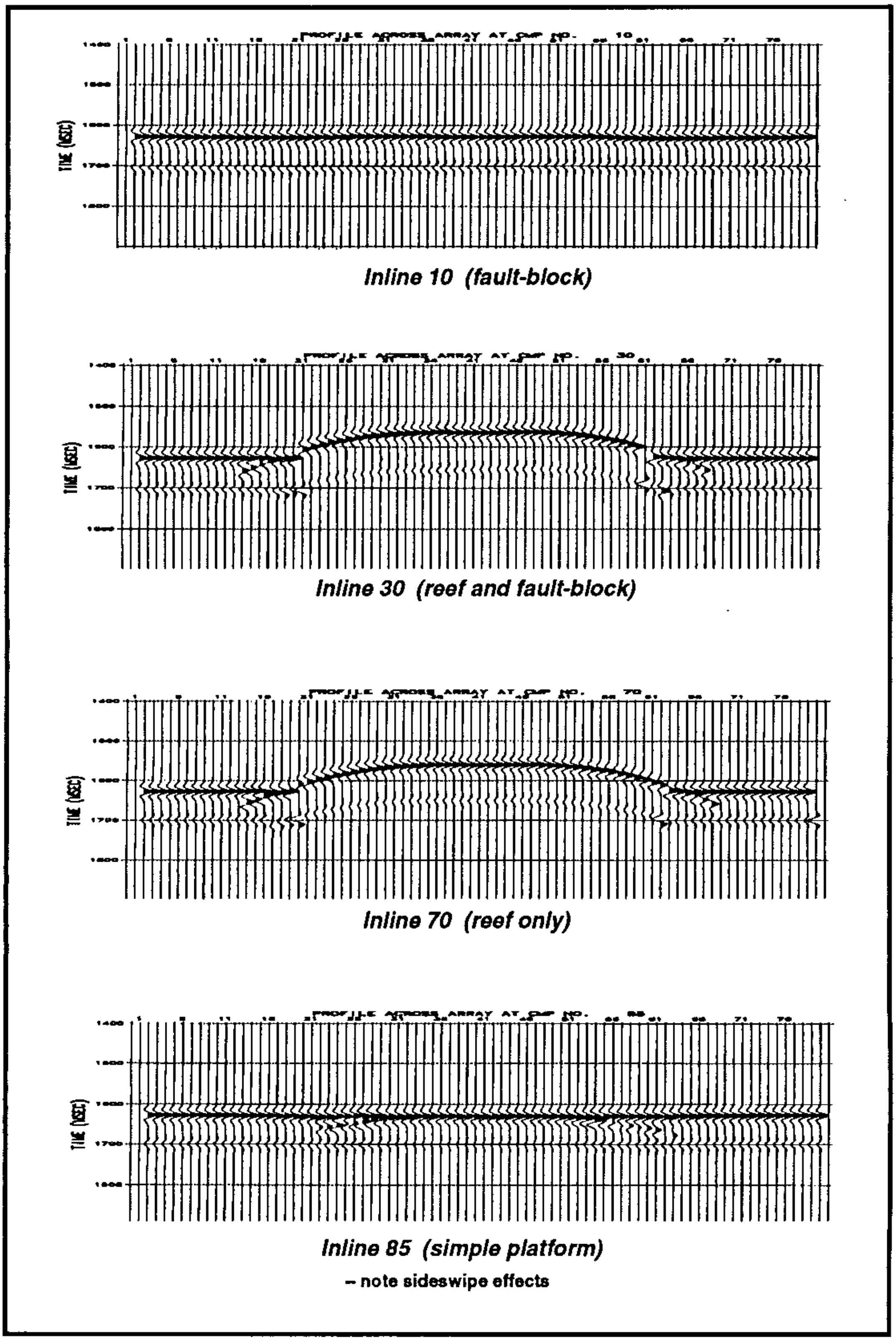
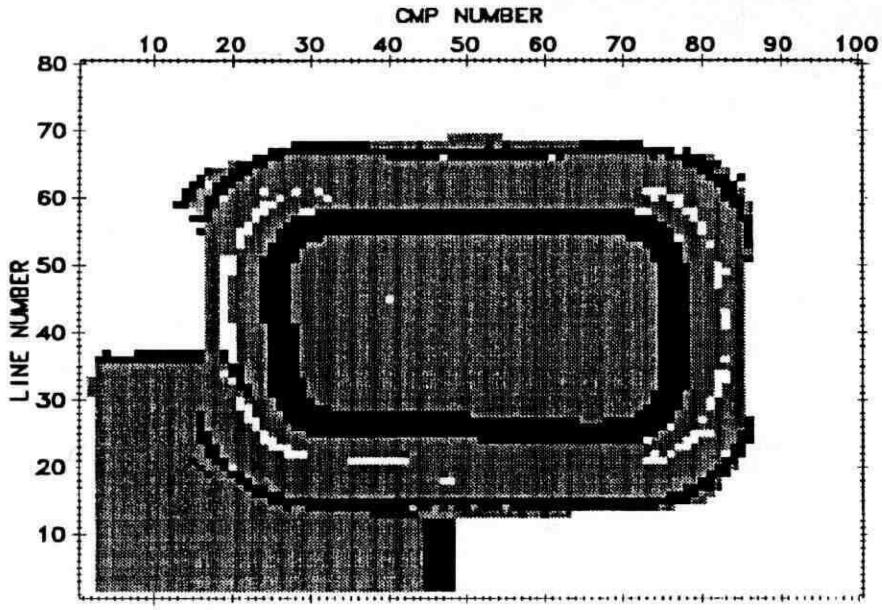
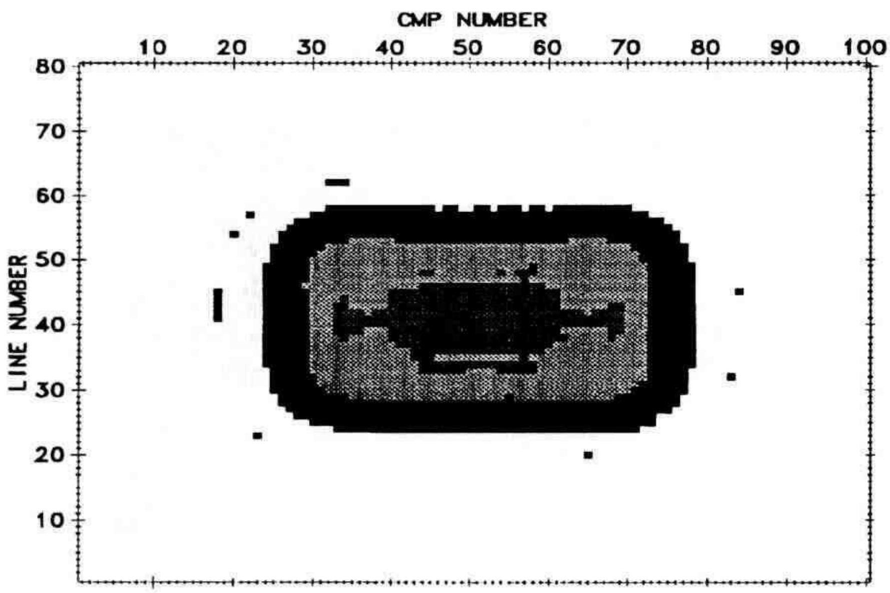


FIG. 20. Selected inlines from the numerical modelling of reef-fault block



Timeslice at 1650ms (unscaled)

- note imaging of basal clastic layer



Timeslice at 1580ms (unscaled)

– note imaging of reef outline

FIG. 21. Selected timeslices from the numerical modelling of reef-fault block model

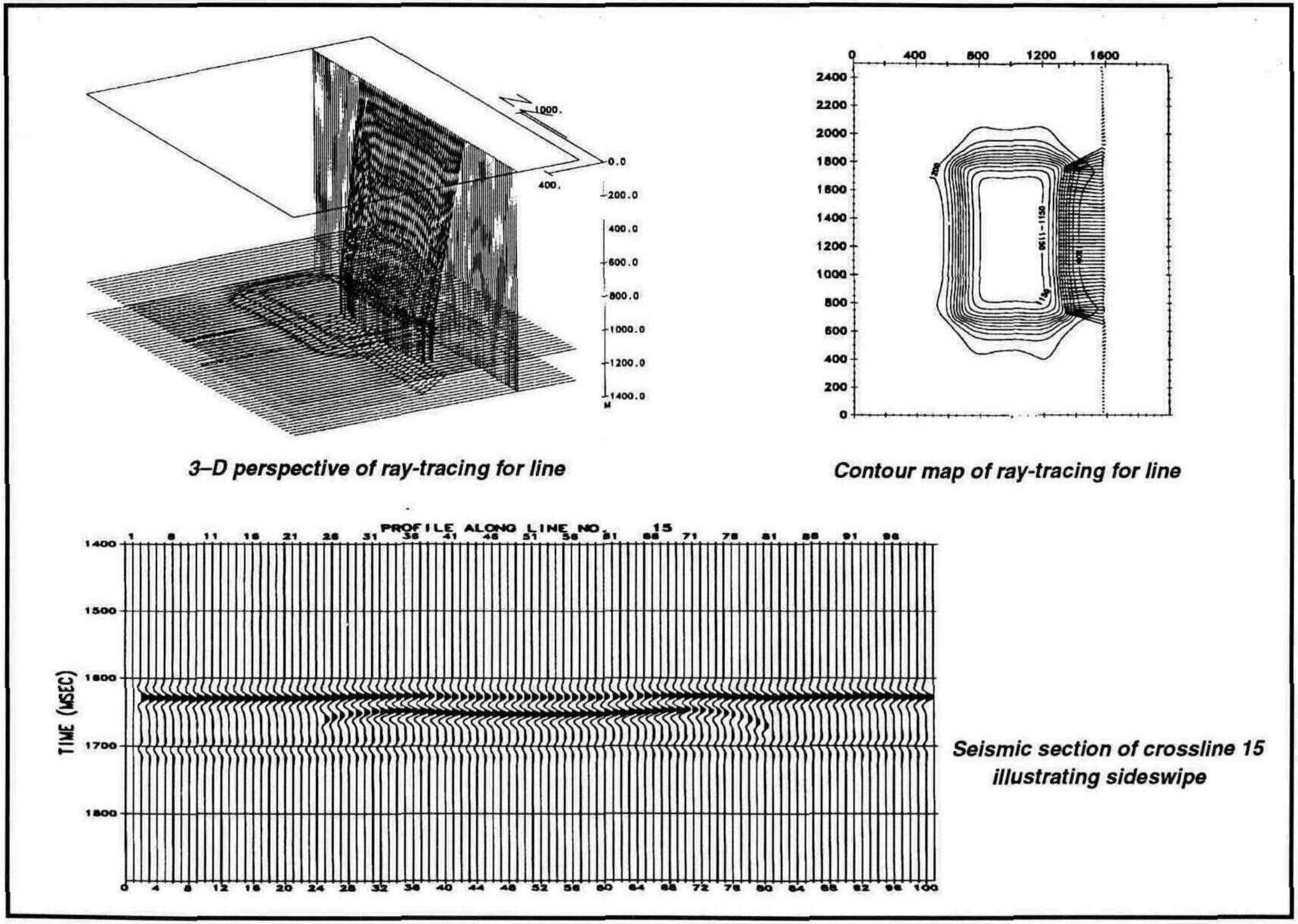


FIG. 22. Numerical modelling of crossline 15 illustrating sideswipe effects

thus identifying the approximate fault positions. It is therefore possible to infer the presence of a fault bounded layer (basal clastics) beneath a patch reef. This has significant implications for real data around the Peace River Arch area in terms of the possible tectonic development of Keg River patch reefs.

The model's secondary purpose was to uncover possible interpretation pitfalls in 2–D data and to illustrate the advantages of 3–D seismic data. 3–D ray-trace modelling confirmed that certain anomalies identified on the physical-model vertical sections and timeslices constituted sideswipe or out-of-plane reflections. It became apparent that lines located off-reef contained reef-edge or flank reflections. Therefore, numerical modelling shows that in dealing with 2–D data such reefs may be inferred along lines shot away from the actual reef. This may frequently result in the false imaging of a reef on 2–D seismic sections.

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FUTURE WORK

In continuing the study of determing whether tectonic control on carbonate morphology is viable, a next step would be to look at both regional and local structural elements in reefal facies areas. Lithoprobe has recently acquired deep seismic profiles (down to 22 seconds) across the Rimbey-Leduc trend of central Alberta, as part of the Alberta Basement Transect program. It is anticipated that this data, together with data to be shot in the Peace River Arch area will be reprocessed and interpreted with this basement control objective in mind. Deep seismic data across the nearby Swan Hills area are also available for this study..

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