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TPR
OR-376

Amplitude Versus Offset Study Report
Permit T22P Bass Basin
Line TNK4-79

for

SAGASCO Resources Limited,
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ADELAIDE. S.A. 5001.

by

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May 1990

HGS

Halliburton Geophysical Services, Inc.

A Halliburton Company

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SECTION 1

INTRODUCTION

This report details an Amplitude Versus Offset (AVO) study performed by Halliburton Geophysical Services (HGS) for SAGASCO Resources Limited in Permit T22P. This permit is situated in the Bass Basin in Bass Strait between Victoria and Tasmania. The location of the permit is shown in Figure 1.

Line TNK4-79 from a survey shot in late 1984 was chosen for the study. This line was shot by GSI's M/V Eugene McDermott II in a northeast to southwest direction. The survey was conducted with a 240 trace digital streamer giving 60 fold data and an offset range from 386 to 3971 metres. This offset range is more than adequate to enable an AVO study to be performed. Full details of the recording parameters are given in Table 1.

The processing sequence used for AVO must be a true amplitude one and carefully applied so as to preserve the true offset variations of the recorded amplitudes. Details of the processing applied are given in Section 2.

The main technique used in the AVO study was HGS's AVOSCAN program. This program is based on the linear fitting of amplitudes versus angle of incidence (at each offset) to input NMO corrected CDP gathers. The AVOSCAN technique is discussed in detail in Appendix A. In addition, three horizons had their amplitudes tracked at several locations along the line. The resultant amplitudes were then plotted against offset. The results of the AVOSCAN processing and the amplitude plots are discussed in Section 3.

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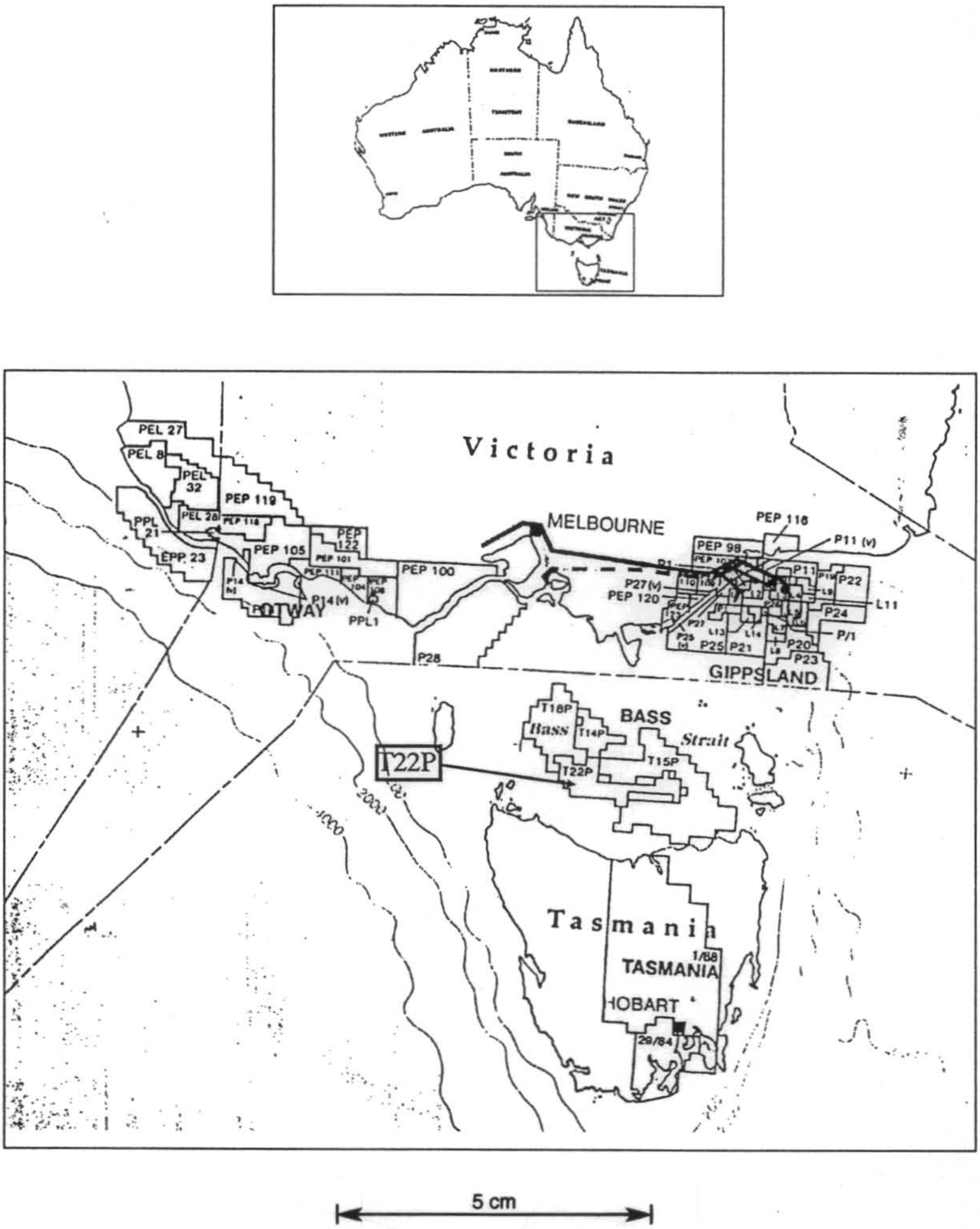
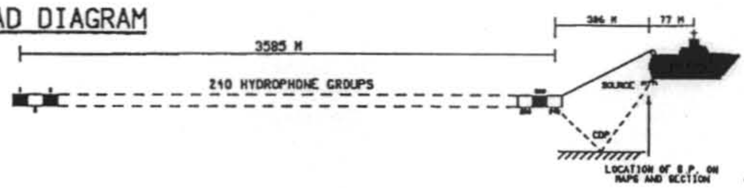


Figure 1. T22P Prospect Location Map.

TABLE 1. TNK4-79 FIELD RECORDING PARAMETERS.

Data Shot By	: GSI M.V. Eugene McDermott II
Date Shot	: November 1984
Recording Instruments	: TSR 001
Digital Tape Format	: SEG D, 6250 BPI
Record Length	: 6.0 seconds
Sample Rate	: 2 milliseconds
Recording Filters	: High: 128 Hz @ 72 dB/octave Low: 8 Hz @ 18 dB/octave
Recoding Polarity	: An increase in pressure on the hydrophone produces a postive number on tape (**SEG Reverse**)
Energy Source	: Pnu-Con tuned airgun array
Source Volume	: 4075 cu.in.
Source Pressure	: 1900 P.S.I.
Source Delay	: 51.2 milliseconds
Source Depth	: 10 metres
Source to Antenna Distance	: 77 metres
Shotpoint Interval	: 30 metres
Near Trace Offset	: 386 metres
Streamer Type	: GSI Multiplexor
Streamer Length	: 3600 metres
Streamer Depth	: 13 metres
Number of Groups	: 240
Group Interval	: 15 metres
Coverage	: 60 Fold
Navigation System	: Primary : ARGO Secondary : Syledis
Shotpoint Annotation	: Source Position

SPREAD DIAGRAM



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SECTION 2

PROCESSING PARAMETERS

The processing sequence required for AVO work must preserve any true amplitude variations with offset. Any processes applied must be trace/offset independent. For example, conventional pre-stack deconvolution should not be applied as it designs a different operator on every trace and, thus, modifies the amplitude variations with offset. The processing sequence applied for this study is shown in Figure 2. Details of the process applied may be found in Appendix B. Key features of the sequence include:

- The polarity of the data was reversed as the data was originally recorded SEG reverese.

- A notch type F-K velocity filter was applied to attenuate coherent noise. This type of velocity filter is more mild than the conventional "fan" type and thus results in less smearing of the amplitudes across the input shot records.

- Standard designature was used as this is a shot consistent deconvolution method. Only one wavelet per shot record is designed and applied to the data. The resultant wavelet on the data is zero phase which gives maximum resolution.

- True amplitude dip moveout was applied in order correct for CDP "smear" and to remove the dip-dependence on the velocities, enabling RMS (zero dip) velocities to be interpreted.

- Velocity scaled amplitude recovery (for spherical divergence) was used in order that the data be as true amplitude as possible.

- No scaling of data was performed.

The shotpoint range from 565 to 1000 and the time range from 1.2 to 2.4 seconds was processed through AVOSCAN. In addition to this the VSCALE'd data for the entire line from 0 to 4 seconds had Demultiple applied and was stacked and migrated. Both raw and filtered/scaled versions of the stack were displayed.

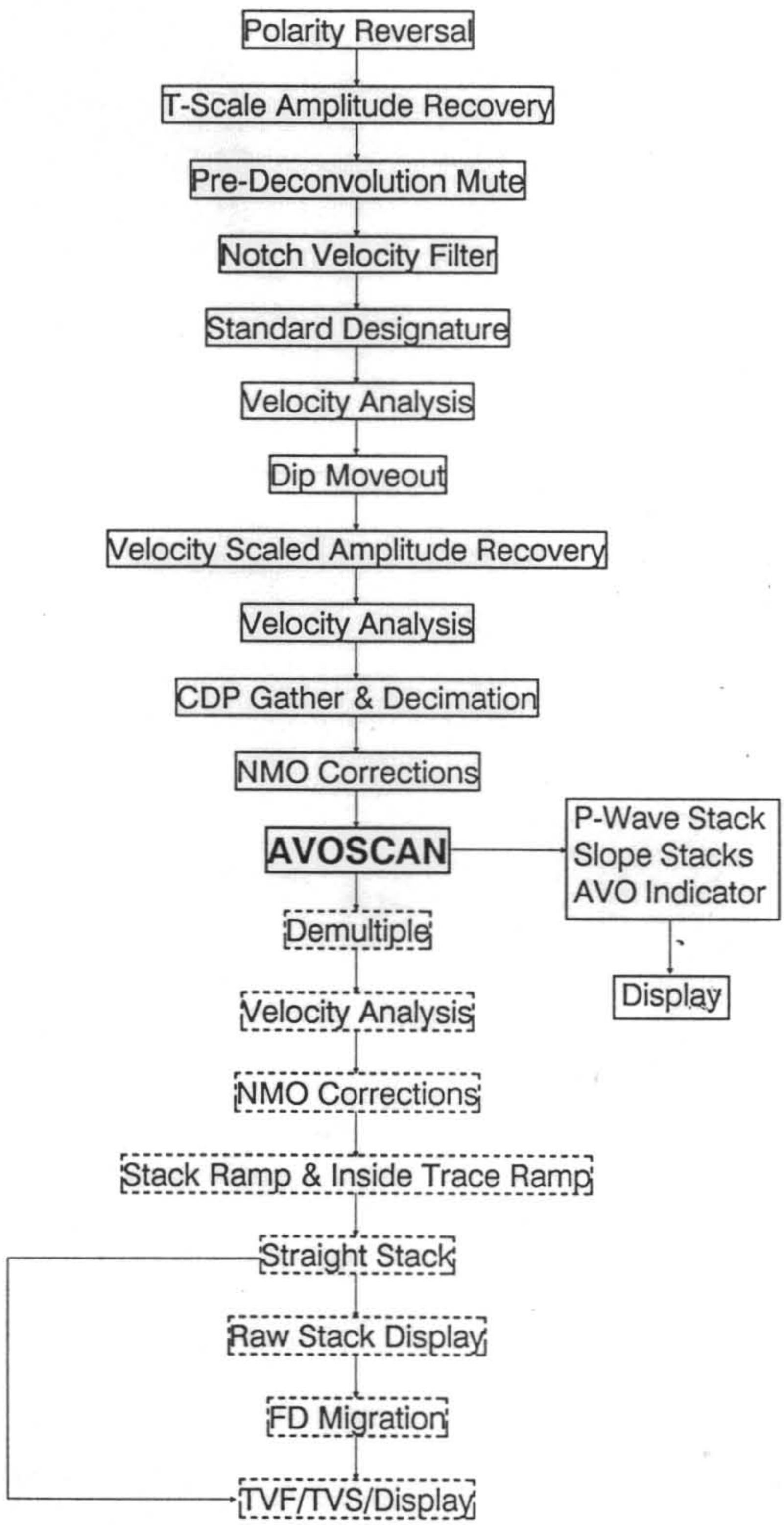

Figure 2. Processing Sequence.

Details of the individual processes are as follows:

• Polarity Reversal	- All traces reversed.
• Amplitude Recovery	- T-scaled recovery only.
• Pre-Deconvolutiion Mute	- Ramp Length: 100 msec Offsets(m) : 386, 806, 1856, 3971 Start(msec): 0, 600, 1400, 2800
• Velocity Filter	- Using a notch cut of +5 to +20 msec/tr in the shot domain with cosine ramping
• Designature	- Using a standard wavelet.
• Velocity Analysis	- Using 21 depth point Velscan anlyses located every 2.0 km.
• Dip Moveout	- Kirchhoff algorithm applied to NMO corrected common offset planes. True amplitude option used. Dip Limit: 9 msec/trace
• VSCALE	- Velocity scaled amplitude recovery.
• Velocity Analysis	- Using 21 depth point Velscan anlyses located every 2.0 km.
• CDP Gather	- 60 fold CDP gathers. Note: Only every 2nd CDP processed from this point.

THIS DATA INPUT TO AVOSCAN AFTER NMO CORRECTIONS

• Demultiple	- F-K domain multiple attenuation. Negative cut-off velocity 67056 m/sec. Demult velocities computed from primary velocities allowing 25% attenuation.
• Velocity Analysis	- Using 21 depth point Velscan anlyses located every 2.0 km.
• NMO Corrections	- Applied using velocities interpreted from demulted Velscans.
• Stack	- 60 Fold straight stack.
• Inside Trace Mute	- Ramp Length: 48 msec Offsets(m) : 386, 1286, 1287 End(msec) : 600, 2800, 4000
• Stack Ramp	- Ramp Length: 96 msec Offsets(m) : 386, 806, 1856, 3971 Start(msec): 0, 600, 1300, 2600
• Migration	- 45 Degree Finite Difference algorithm. Timesetp: 20 msec Fidelity: Medium
• Time Variant Filter	- Frequency(Hz) Time(msec)

Frequency(Hz)	Time(msec)
7-60	0
6-45	2000
4-30	4000

• Time Variant Scaling	- Using 500 msec DGCS scalars. Start Time: 0 msec

SECTION 3

AVO PROCESSING

Every second CDP from shotpoint 565 to 1000 over the time range from 1.2 to 2.4 seconds was input to the AVOSCAN process. (See Appendix A for a description of AVOSCAN.) The inputs were NMO corrected CDP gathers with processing applied as described in Section 2. The resultant output sections were as follows:

- P-Wave Stack
- Raw Slope Stack
- Absolute Slope Stack
- AVO Indicator Stack

A conventional stack of the data input to AVOSCAN is shown in Figure 3. The P-Wave stack is shown in Figure 4. A comparison of these two stacks shows that the P-wave stack has a generally higher amplitude level than the conventional stack and reveals more detail, particularly in low amplitude zones. This higher amplitude character tends to point to the fact that the amplitude decreases with offset as the zero intercept amplitude (the amplitude of the P-wave stack) is greater than the average amplitude (the amplitude on the conventional stack).

The raw slope stack is shown in Figure 5 and the absolute slope stack in Figure 6. In comparing the raw slope stack with the P-wave stack, it can be seen that where the P-wave stack is positive the slope is negative, and where the P-wave stack is negative the slope is positive. This is indicative of data in which the amplitudes decrease with offset. This is further confirmed by the absolute slope stack which is generally negative, showing that the amplitudes are decreasing with offset. The only positive areas on the absolute slope stack correspond to very low amplitude areas or close to zero-crossings on the P-wave stack. Both these types of zones are very sensitive to the straight line fitting used and prone to erroneous results.

The AVO indicator stack is shown in Figure 7. This stack was generated with a Poisson's ratio of 0.25 and B equal to 0.8 (see Figure A2). This stack does provide much additional information in this case. As no AVO anomalies exist the change in Poisson's ratio tends to be the opposite of the P-wave amplitude. This is because when the P-wave stack amplitude is positive, the raw slope is negative and thus, by the defining equation, the delta poisson's ratio will also be negative. Similarly, when the P-wave amplitude is negative, both the raw slope and the delta Poisson's ratio will be positive.

In addition to the AVOSCAN processing, the amplitudes of three horizons were manually tracked at several shotpoint locations along the line. The horizons and locations are shown in Figure 8. The resultant amplitude plots are shown in Figures 9, 10, 11, and 12. On each of the amplitude plots a linear least squares line has been fitted to the raw amplitude values.

These plots tend to confirm the general amplitude decreasing with offset nature of the data. However, the amplitudes on the P2 horizon at shotpoints 775, 710 and 665 appear to either remain fairly constant or show a slight increase with offset over the first 25 to 30 traces and then drop off at longer offsets. This character is particularly apparent at shotpoint 775. The P1 and P3 horizons also show similar amplitude variations at this shotpoint. The P1 and P3 amplitudes at the other shotpoints are clearly decreasing with offset.

In conclusion, it was found that there were no apparent AVO anomalies over the line segment studied. However, there were signs of amplitude increases on some tracked horizons, particularly at shotpoint 775, over the near 25 to 30 traces with the amplitude then decreasing at longer offsets.

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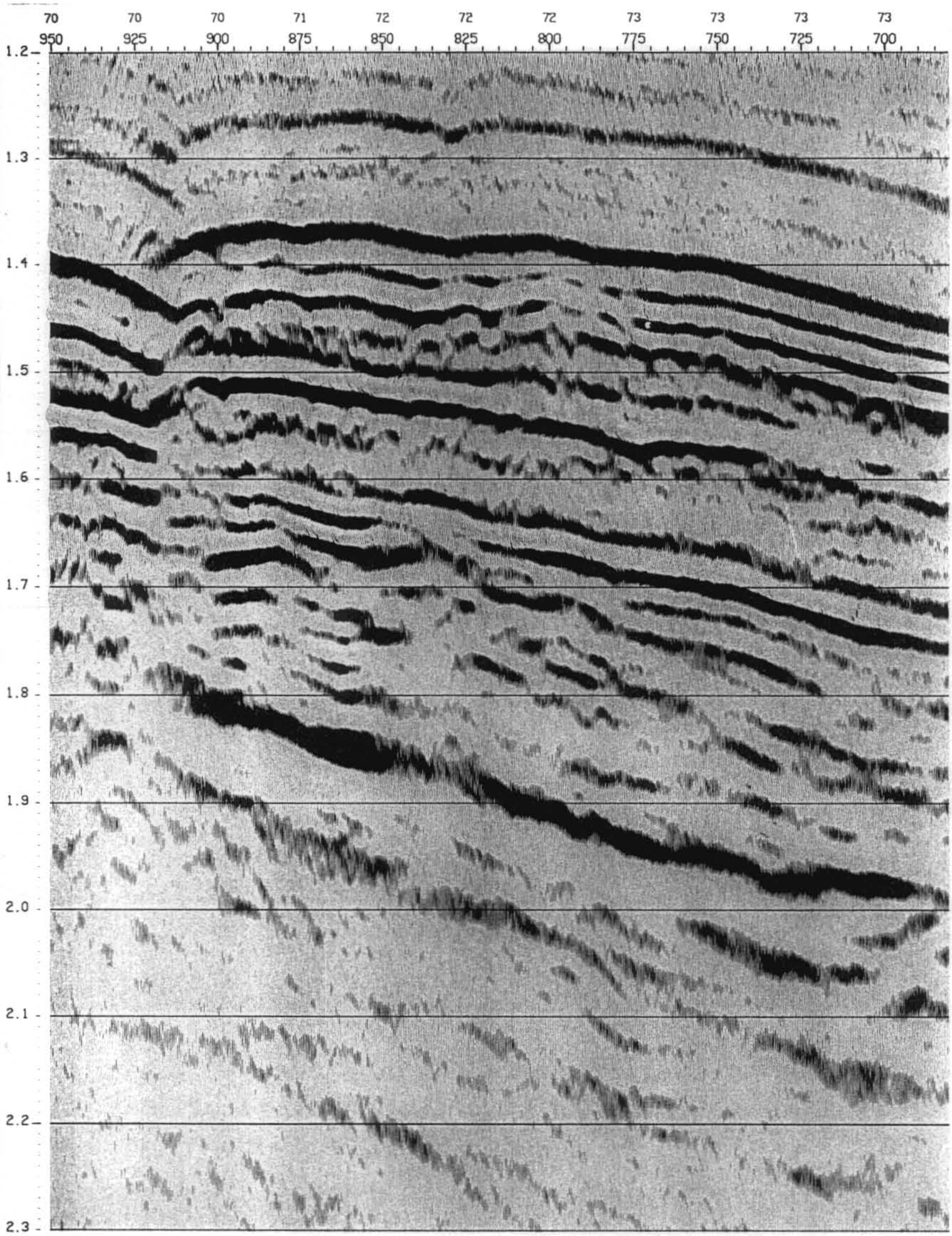

Figure 3. Conventional Stack.

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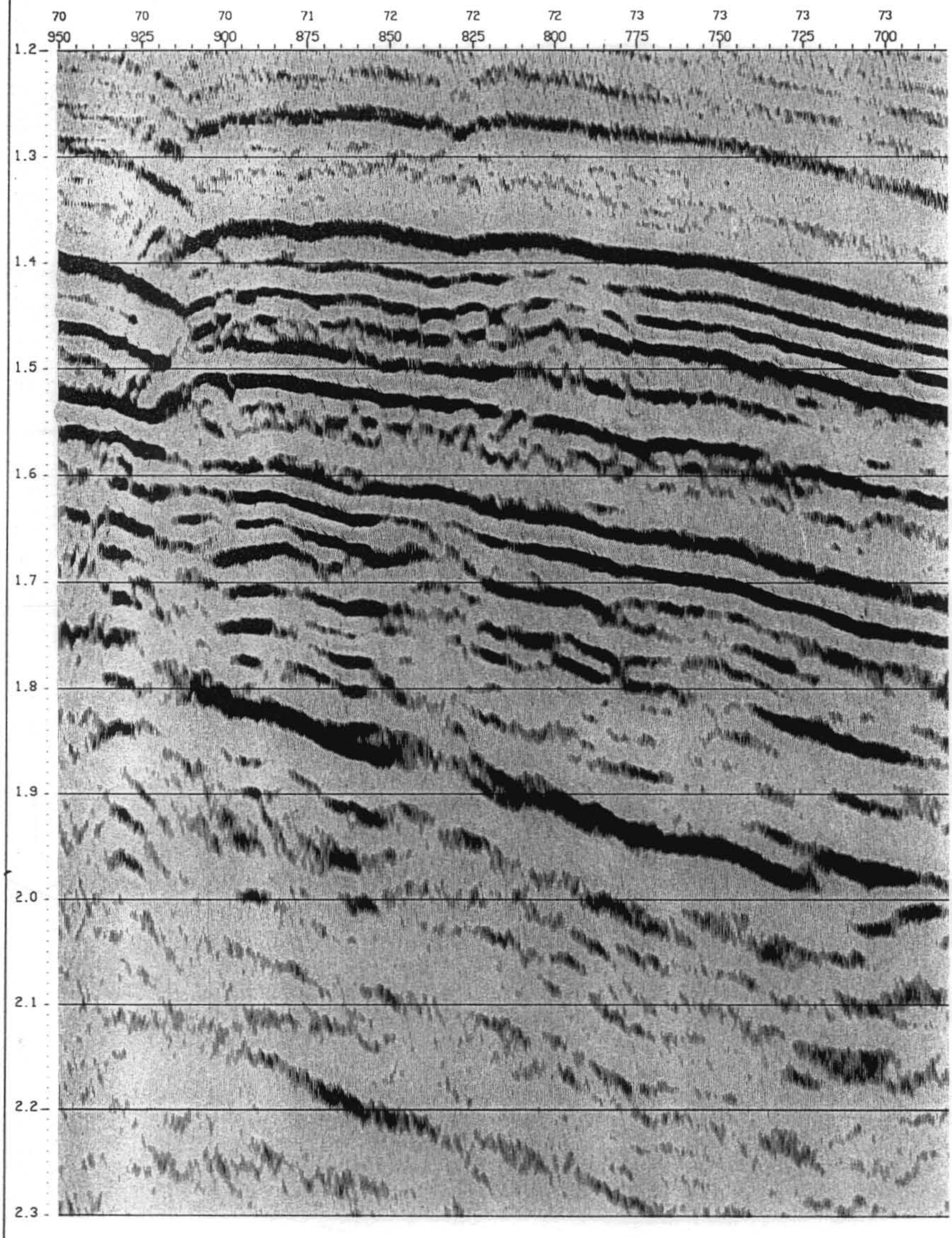

Figure 4. P-Wave Stack.

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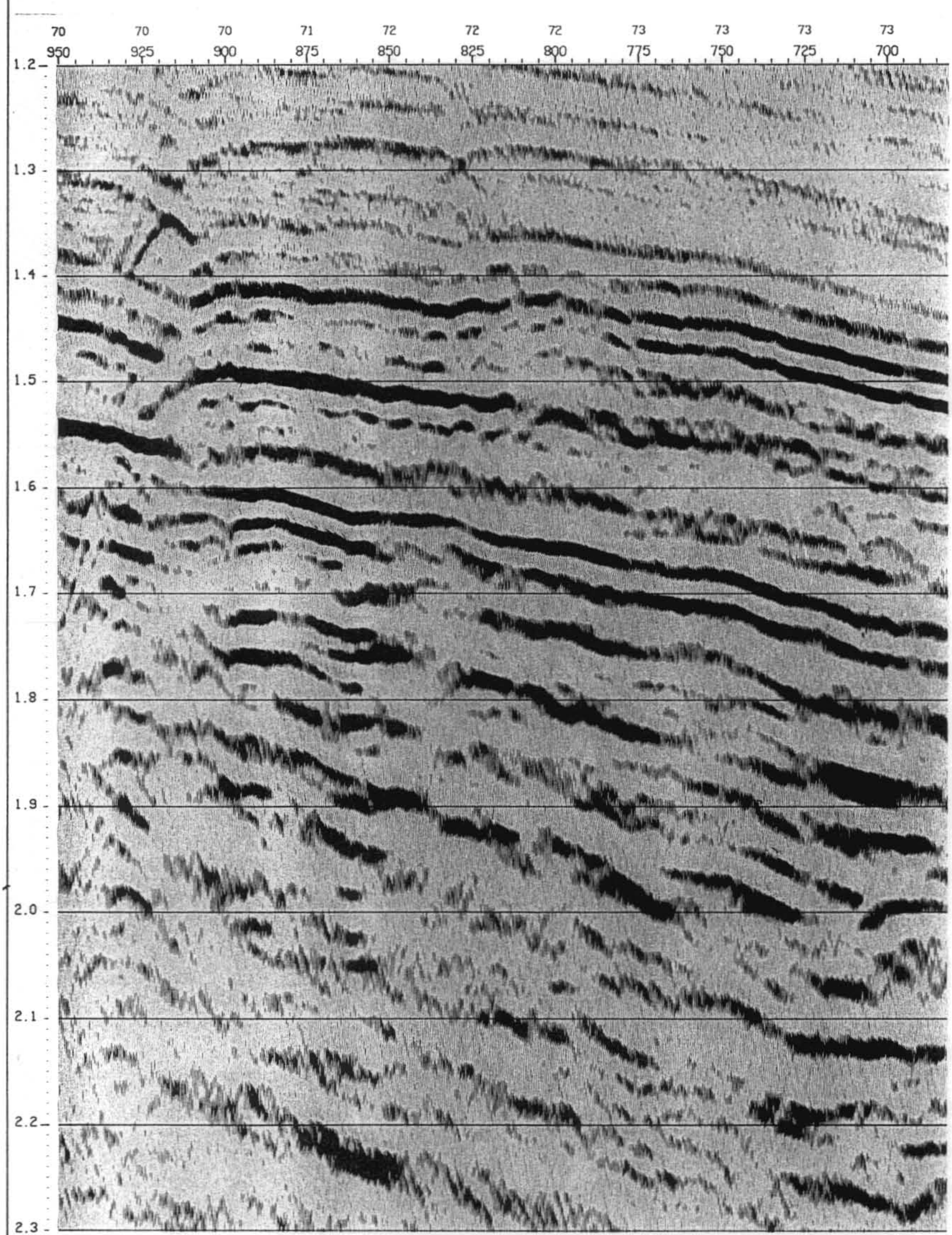

Figure 5. Raw Slope Stack.

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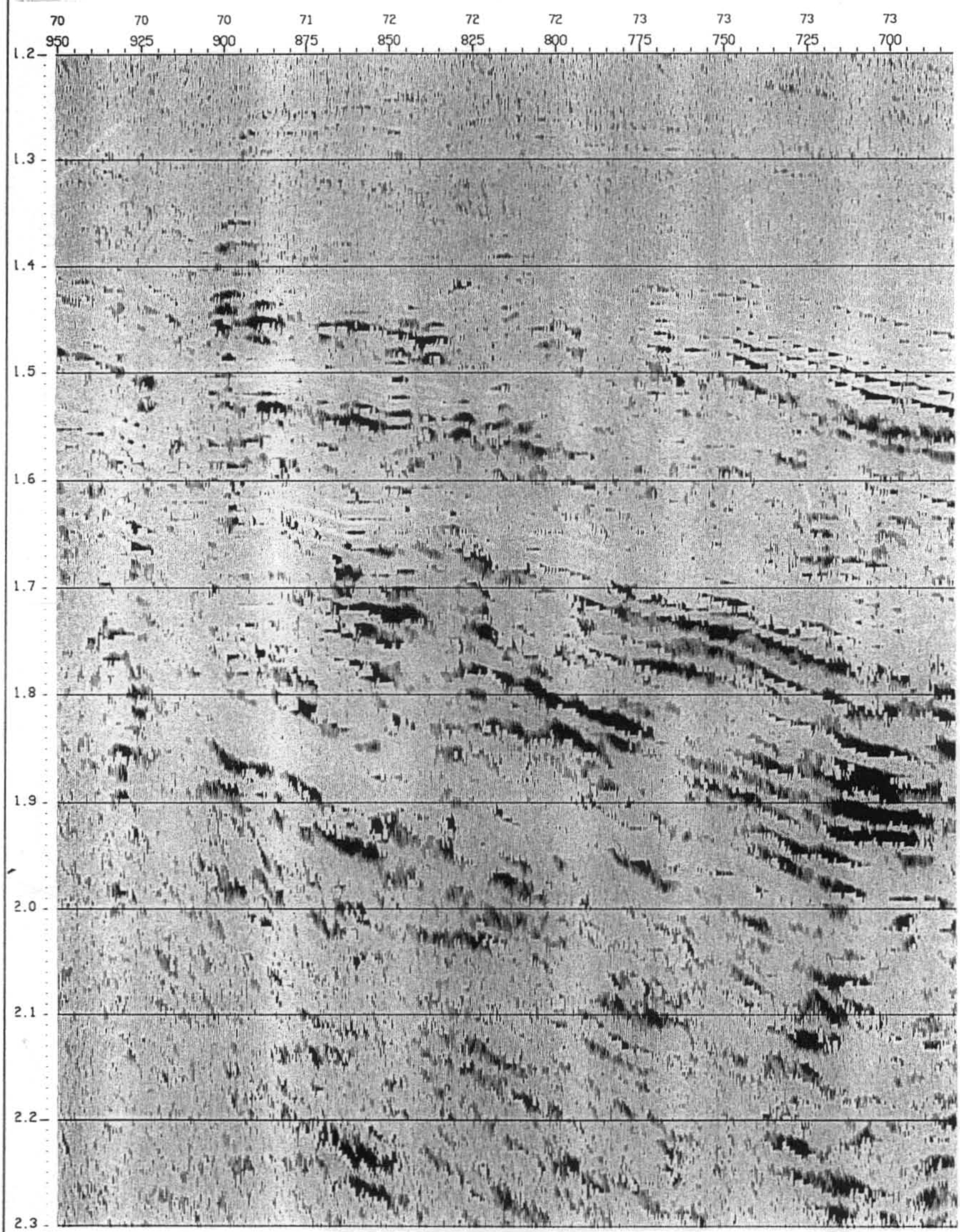

Figure 6. Absolute Slope Stack.

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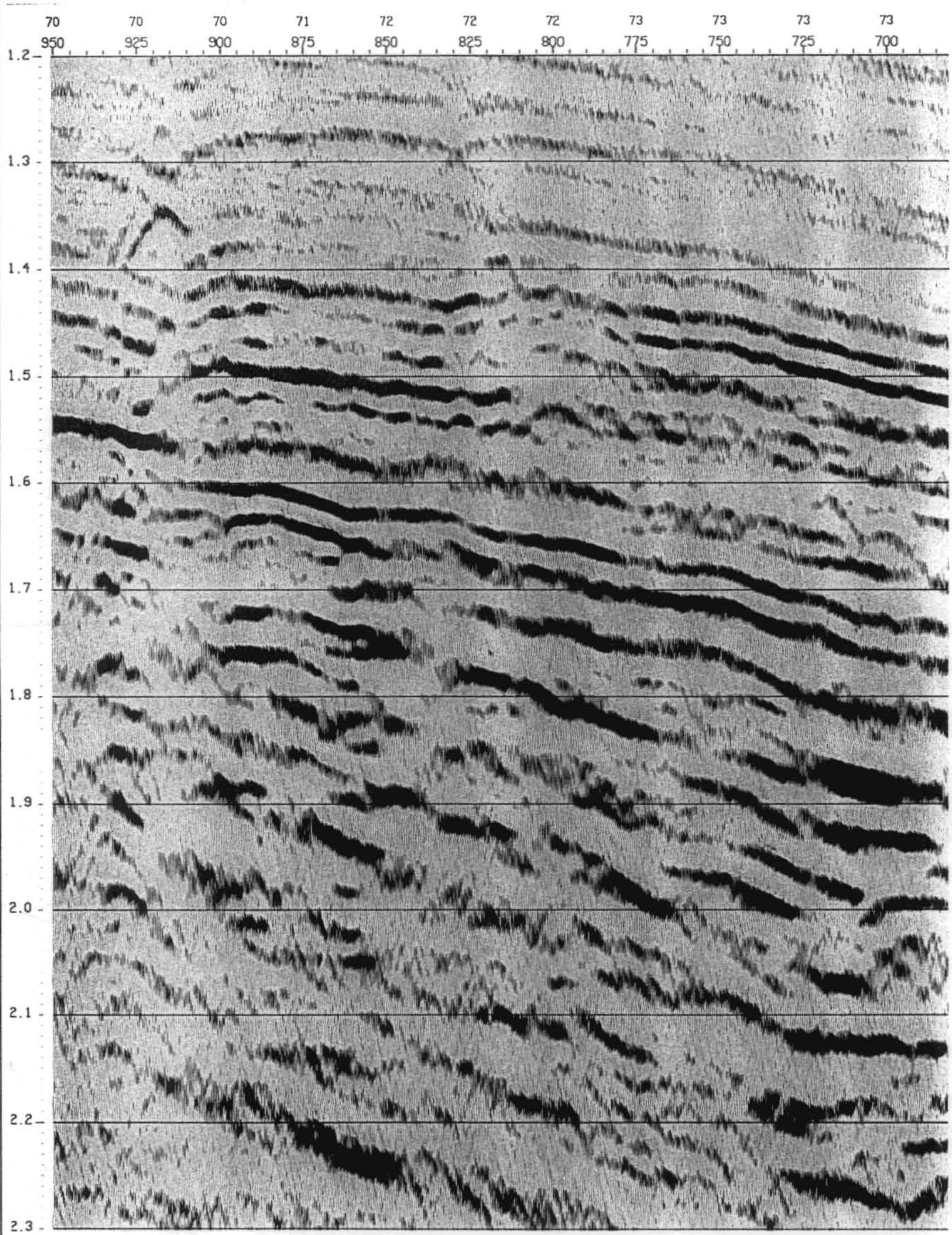

Figure 7. AVO Indicator Stack.

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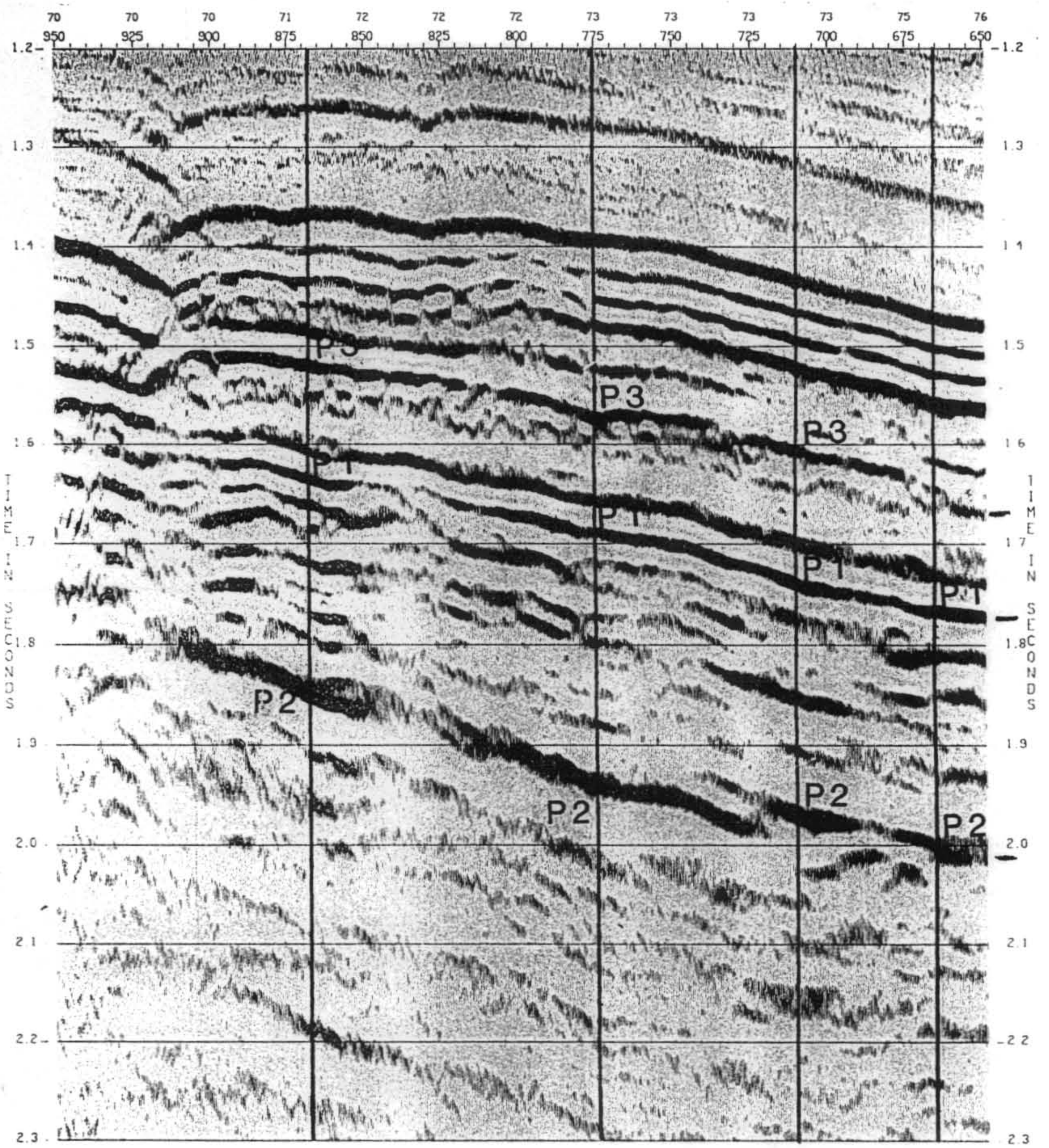

Figure 8. Location of horizons manually tracked.

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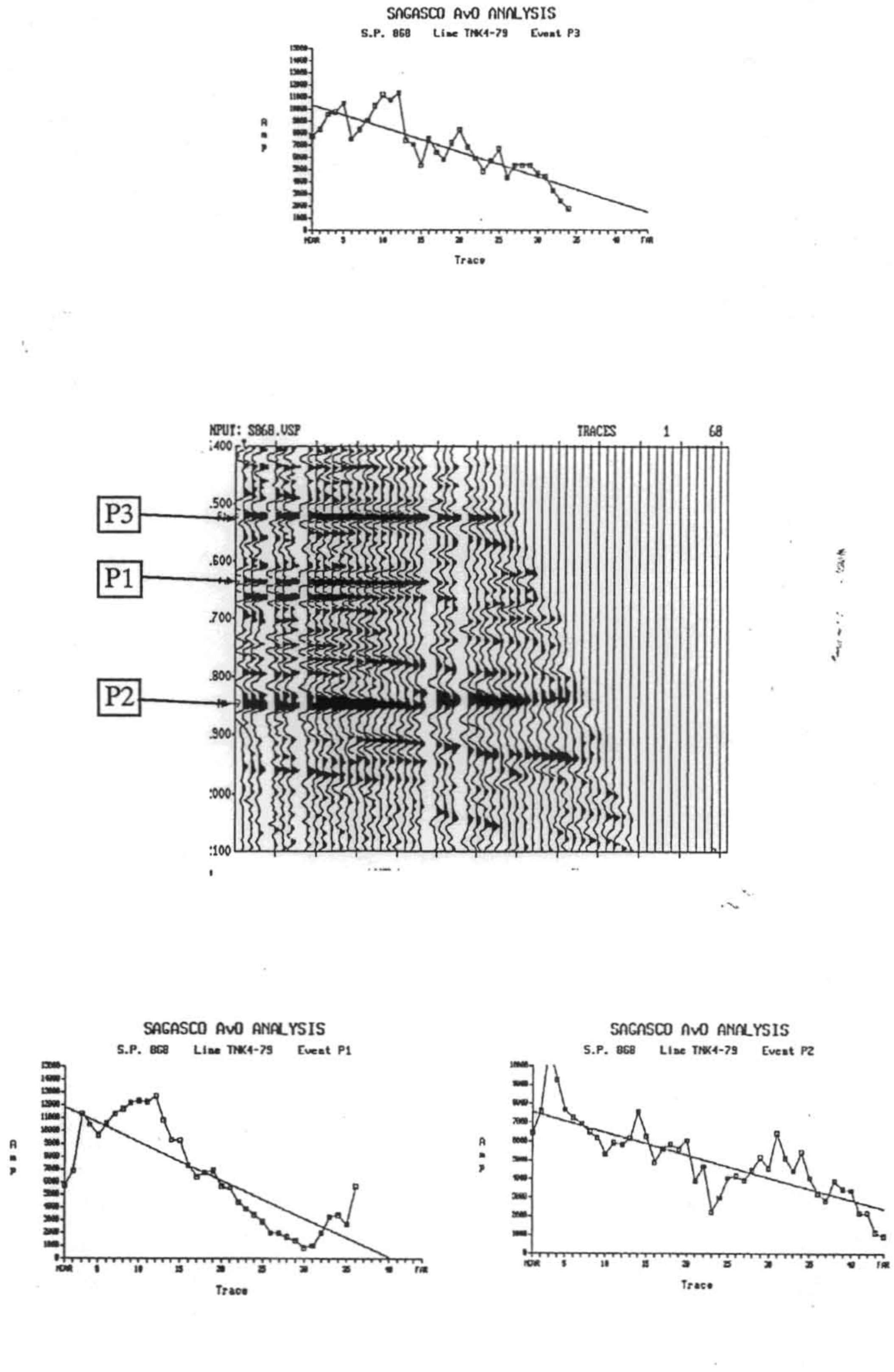

Figure 9. Amplitude plots at S.P. 868.

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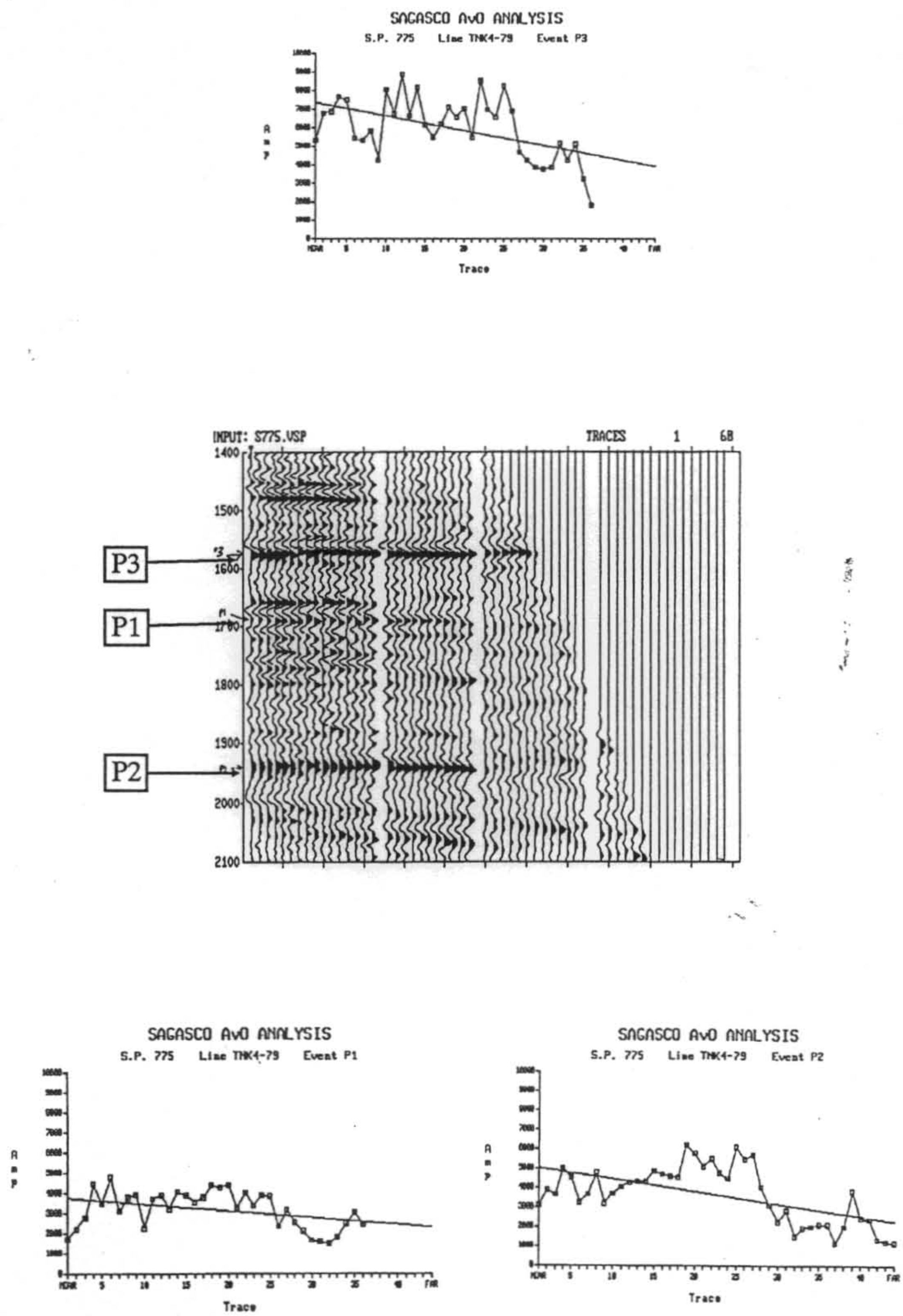

Figure 10. Amplitude plots at S.P. 775.

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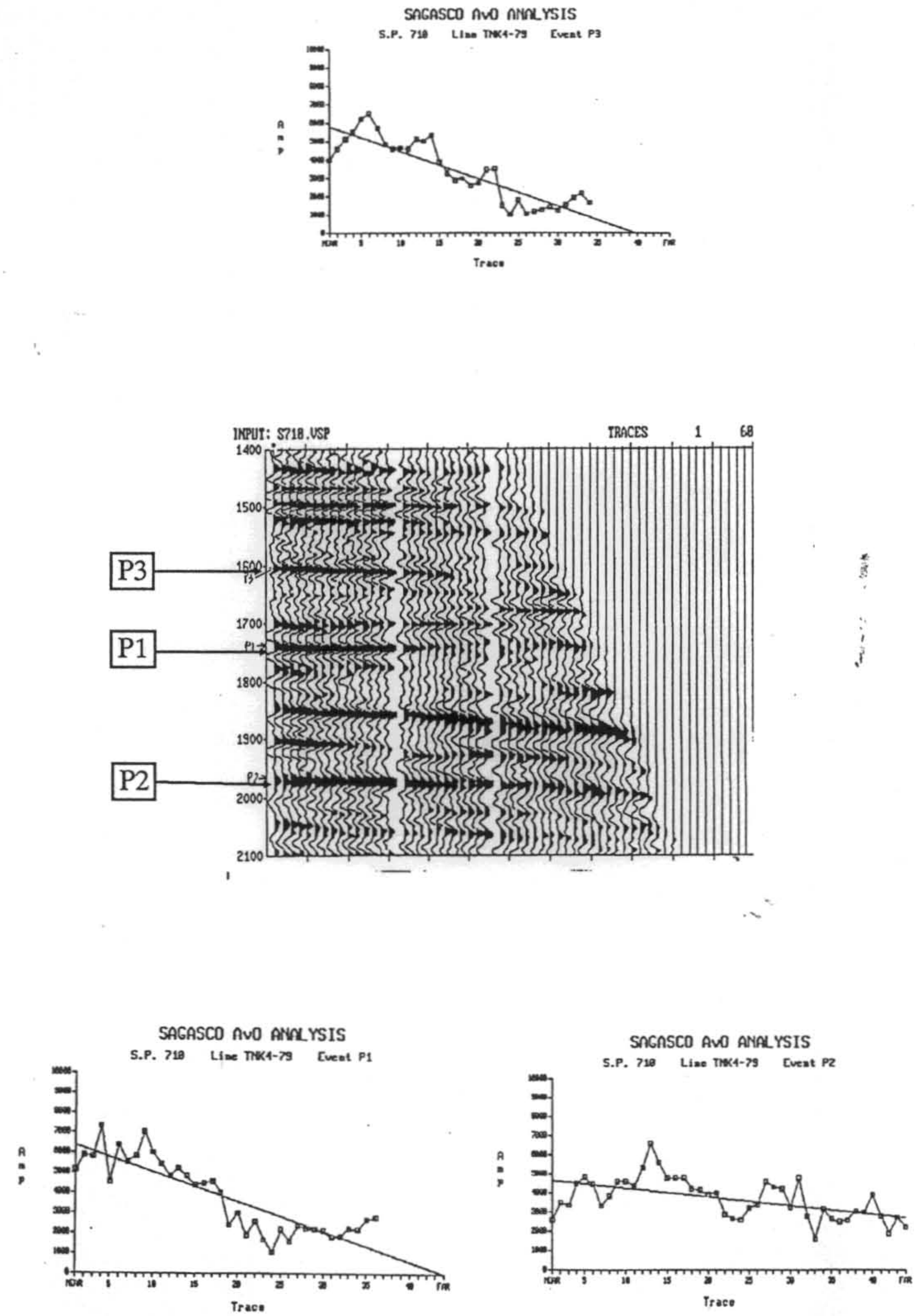

Figure 11. Amplitude plots at S.P. 710.

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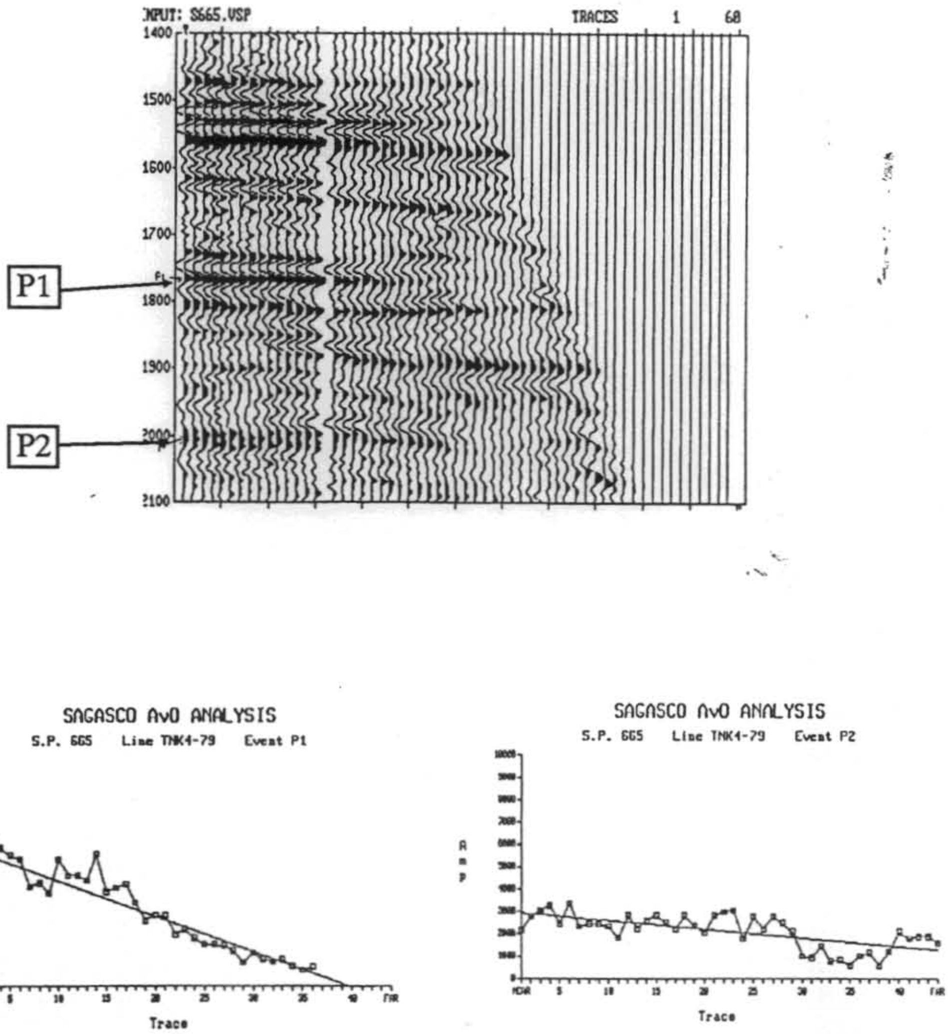

Figure 12. Amplitude plots at S.P. 665.

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Respectfully submitted
for and on behalf of
HALLIBURTON GEOPHYSICAL SERVICES

GEOFF MANSFIELD
Area Geophysicist
Sydney Processing Centre

APPENDIX A

AVOSCAN TECHNICAL DESCRIPTION

AVOSCAN is a program that can reveal amplitude versus offset (AVO) anomalies across 2-D seismic profiles or 3-D seismic data volumes. This technique is based on the linear fitting of amplitudes versus angle of incidence (at each offset) provided the P-wave velocity field is known. The concept of AVOSCAN is illustrated in Figure A1.

The parameters that characterize the linear fitting are the intercept amplitude and the slope of the straight line fitted to the amplitudes. The formulae used for the straight line fitting are shown in Figure A2. These parameters are computed for each CDP and are displayed as traces for further analysis. AVOSCAN takes into account structural complexities by making dip corrections to each angle of incidence. For quality control, errors associated with the fittings (both intercept amplitude and slope) are quantified and output at each time sample of each CDP and may be displayed like the stack sections. The errors are related to standard deviations from the fittings.

The intercept amplitudes are by definition the P-wave section. This section does not contain amplitude effects due to shear modulus. The P-wave section is theoretically a better section than the conventional stack since it more closely represents a "zero offset stack". Migration and post-stack inversion techniques (P-wave acoustic impedance estimation) may be performed on this attribute for conventional interpretation.

The slope information is of particular importance because of it's relationship to Poisson's ratio contrasts which in turn help identify lithology and pore fluid variations. A positive slope means that amplitudes are increasing with offset, a negative slope means that amplitudes are decreasing with offset.. The slope attribute may be displayed either in black and white or in colour to give a pictorial representation of the amplitude anomalies, if any.

The slope measurement and the intercept amplitude may be combined to help isolate the apparent Poisson's ratio contrasts between layers. This section is called the RELATIVE DELTA POISSON'S RATIO section or AVO INDICATOR section. Approximations for background Poisson's ratio and acoustic impedance ratios are input to AVOSCAN and a section is output to represent the relative Poisson's Ratio effects. This means that a trough at the zone of interest indicates that there is a decrease in Poisson's ratio relative to the layer above.

As an aid to the interpreter large scale displays of the zone of interest are created. If the slope attribute is noisey, DIPCON may be applied to help attenuate random noise. The slope attribute by design is far more unstable than the intercept attribute. Errors in the fittings at zero crossings and in areas with excessive noise will be noticed. Any processing done to the input to AVOSCAN must be True Amplitude processing. Any technique that attenuates noise should be carefully applied so as to perserve the true offset variations of the recorded amplitudes.

It is important to note that anomalies observed in the zone of interest should be validated by displaying the NMO corrected gathers input to AVOSCAN. An anomaly by itself does not indicate the presence of hydrocarbons nor does it identify lithology. The observed AVO response can be due to a very complex set of circumstances, ie. multiple-layer AVO interference, impedance contrasts, Poisson's ratio contrasts, seismic data collection and processing pitfalls, and earth and structural effects. For the correct interpretation, pre-stack synthetic seismograms should be created from information obtained about the lithology of the area under study. Well log information if available should aid in the generation of synthetics for AVO data callibration and interpretation.

The three products, the P-WAVE section, SLOPE section, and the AVO INDICATOR section should be used simultaneously to help the interpreter predict zones that show large changes in acoustic impedance (P-WAVE section) and to help predict various pore fluids in potential hydrocarbon bearing reservoirs with the SLOPE and AVO INDICATOR sections.

The following are helpful hints for interpretation:

1) Understand the lithology of area under study.

- What pore fluids are expected, gas, oil, water? What saturation levels are present in nearby rocks? Is the zone in geopressure?
- What kind of porosities are expected in the target lithology?
- Do you see bright spots or dim spots in the conventional stacked sections?
- Can rock properties be predicted from well log data nearby?
- Will structural dip affect the AVO analysis?
- What is the magnitude of overlying velocity contrasts?
- Is the target thick enough for the interpretor to see the AVO response?
- Are there lateral thickness changes in target zone?

- Are there shallow amplitude anomalies above the target? These can produce false anomalies below.

2) Tie the seismic to synthetics generated from well data to understand phase problems, multiples, etc. Calibrate the seismic. Determine the expected AVO response from pre-stack models.

- Does the target event show positive or negative AVO? Is there a polarity change on the event over the range of offsets recorded in the nmo corrected gather?
- If logs intersect the line being analyzed, does the modelled response correlate with the seismic gather?
- Is there some uniqueness of the AVO response at the target?
- Does the P-wave section show improvement over the conventionally stacked section. Are dim spots less dim, bright spots less bright? Is there increased or decreased bandwidth, continuity?
- Are slope section anomalies valid? Did they came from residual moveout, zero-crossings, spikes?
- Are there interference effects? These may be direct hydrocarbon indicators if validated from pre-stack modeling. When the target reservoir is thin, positive and negative AVO events close together in time may produce unique AVO responses. Normally this is a gas-oil, gas-water, or oil-water contact.. These look like residual NMO, but they are not.

Reference

Shuey, R. T., 1985, A simplification of the Zoeppritz equations: Geophysics, 50,609-614.

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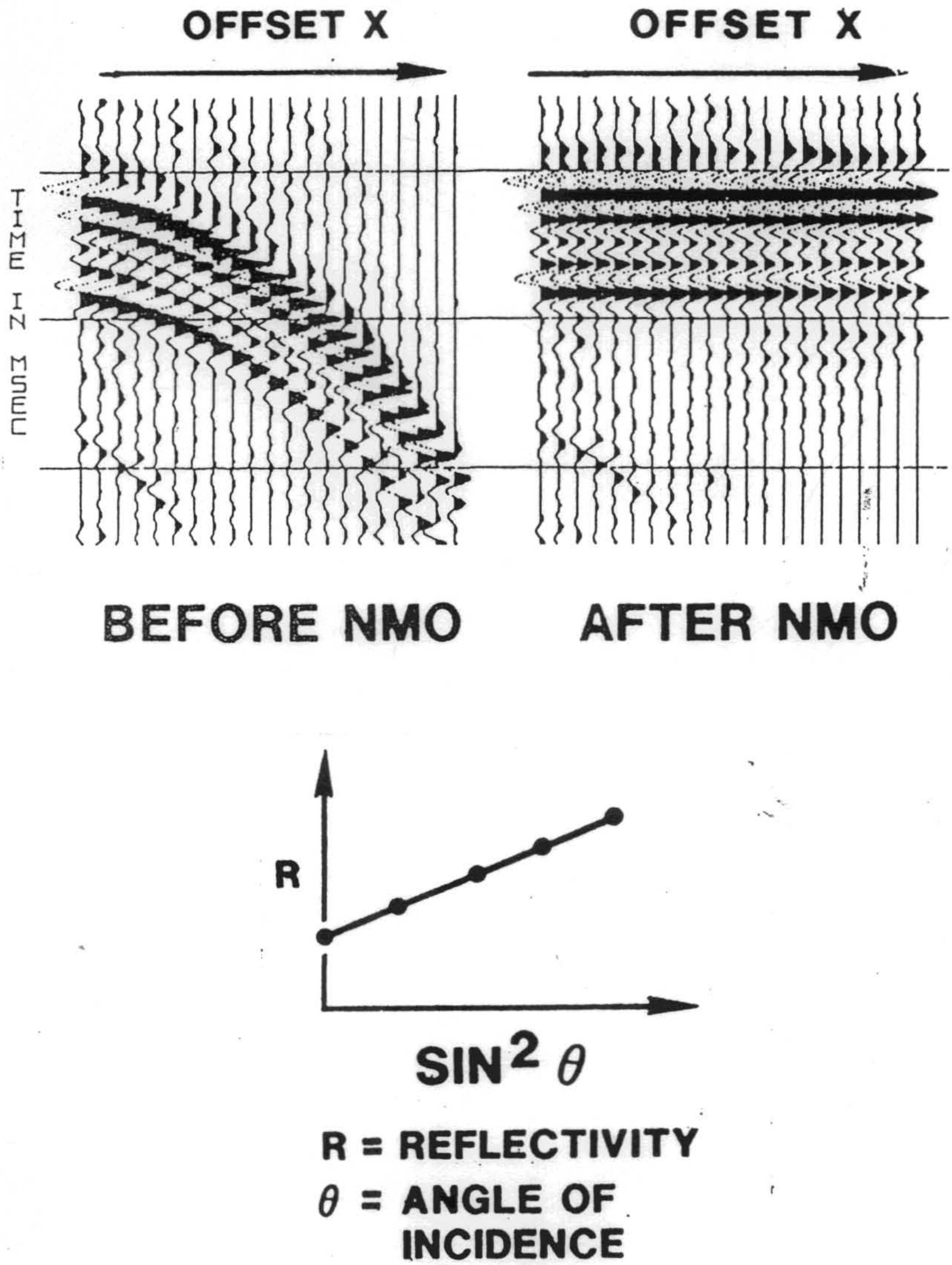

Figure A1. Concept of AVOSCAN.

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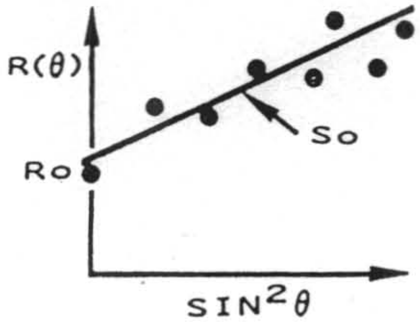

• $R(\theta) = Ro + So \cdot SIN^2\theta$

R = AMPLITUDE VARYING WITH ANGLE OF INCIDENCE

Ro = INTERCEPT AMPLITUDE (P-WAVE AMPLITUDE)

So = SLOPE

θ = ANGLE OF INCIDENCE

• $\Delta\sigma = (So - AoRo) \cdot (1-\sigma)^2$

$\Delta\sigma$ = AVO INDICATOR

$$R(\theta) \cong \underbrace{Ro}_{\text{INTERCEPT}} + \underbrace{\left[AoRo + \Delta\sigma/(1-\sigma)^2\right]}_{\text{SLOPE}} \sin^2\theta$$

$$Ao = B - 2(1+B)(1-2\sigma)/(1-\sigma)$$

$$B = \Delta Vp/Vp/(\Delta Vp/Vp + \Delta\rho/\rho)$$

(SHUEY, 1985)

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Figure A2. Formulae used in AVOSCAN.

APPENDIX B

PROCESS DESCRIPTIONS

PCMODEL REFRACTION STATICS

This system uses refraction breaks to derive a broadband near surface model. Use of the method for Vibrator data should be decided on a prospect by prospect basis after inspection of the field records. The method is applicable for split-spread data or off-end data with non-dipping refractors.

Field recording and geometry attributes together with time-trapped first-break trace data are transferred from the IBM mainframe to desk-top computers for statics estimation by Interactive Refraction Modelling. Trace data picked using a correlation process on linearly moved-out refractors. These picks are overplotted on the trace data and displayed on the VDU for editing and QC. When editing is complete, trace to trace residual statics may be estimated; a low-cut spatial filter is then applied to these residuals to obtain the short wavelength portion of the static profile. Time-Distance (T-X) plots of the picks (with optional residual statics applied) are plotted so that refractor segments can be identified. It is from these that the near surface model is derived.

Depths and velocities are interpolated to every station and a high-cut spatial filter is applied to give the long wavelength model from which static profiles are computed.

Displays of T-X plots with statics and linear moveout are useful in highlighting unresolved delays and directional problems. Stacks of the refractors in shot, receiver, or CDP domains can also be generated and displayed.

Statics derived by Refraction Modelling are not absolute values, hence a shift is needed to tie the computed statics to the uphole information collected by the field crew.

SCALCOMP COUPLING COMPENSATION

Interpretation of lithologic effects such as bright spots, and associated amplitude versus offset variations, requires careful "true amplitude" processing of seismic data. An essential component of this processing is compensation for the data collection system "coupling effects", i.e., amplitude variations caused by factors other than subsurface reflection and geometry.

SCALCOMP is a process that calculates scalers to compensate for these coupling effects. Some are surface consistent variations due to near surface absorption, and to physical source and receiver coupling to the earth. On marine data, receiver hardware is associated with a common offset, rather than with a common surface location as on land. Thus for marine data, SCALCOMP includes an offset dependent "hardware"coupling scaler.

Good signal-to-noise ratio is also important in conjunction with maintaining true amplitudes. In this regard, SCALCOMP is an essential process, giving correct reflection amplitude scaling, prior to AUTOEDIT for the detection of noisy traces, and to
DIVERSITY STACK which can then provide the correct scaling for maximum signal-to-noise ratio improvement in CDP stack, while maintaining true signal amplitudes.

SCALCOMP works on a time gated average amplitude measure from each trace in a line of data. This can either be a gate over the reflection data, or where there is a suitably consistent refractor, it can be over the first breaks, since these will show the same near surface coupling effects as the reflection data. The amplitude variations are then sorted into their respective domains (i.e. source, receiver, and offset) by statistical analysis. The technique is very similar to the "beamsteer" process used for residual static analysis to sort residual time measurements into surface consistent source and receiver statics and an offset dependent residual moveout effect.

The SCALCOMP analysis first estimates and removes the effect with the most statistics, namely the average offset dependent amplitude variation. The common source variations are estimated and removed next, followed by the common receiver location effects. These three steps can be iterated to improve the scaler estimates. Following them, for marine data only, the common offset dependent "hardware" effects are estimated as the "high frequency" component of the overall offset dependent variations.

Listings and displays of the amplitudes and scalers can be output for quality control, and then the source and receiver scalers (and the marine offset scaler) can be applied to the data.

TRUE AMPLITUDE RECOVERY

The TAR process is applied to digital field records to produce output records on which the relative amplitudes of reflections, on each trace are approximately true. The first step of this process consists of removing the gain imposed on the field records by the recording system, and then correcting for inelastic attenuation and spherical divergence losses.

Correction for inelastic attenuation is controlled by specifying a gain increase in dB/second to be applied to the trace amplitudes. The gain increase value is called the exponent or alpha value.

Spherical divergence is corrected for by a simple algorithm which scales trace amplitudes in proportion to their reflection time.

PRE DECONVOLUTION MUTE (PDR)

Refraction and first break energy is removed from shot records, prior to the design of deconvolution or Designature filters, by a pre deconvolution ramp (PDR).

The PDR is affected by the application of velocity filtering, because the velocity filter will remove noise from the front end of the shots which may otherwise have to be ramped off. Therefore, if velocity filtering is being applied a less severe PDR is often required. For this reason the PDR is often chosen, in conjunction with the velocity filter, by examining F-K contour displays with and without velocity filtering.

BEAMSTEER

BEAMSTEER is a form of horizontal mix designed to attenuate coherent noise on shot records. The process simulates a receiver array effect by mixing traces in the shot domain. NMO is applied before a weighted horizontal mix is applied. The NMO is removed (NMI) before any further processing commences. A shot array simulation is achieved by a horizontal weighted mix, of the data, in the receiver domain.

The running mixes performed in BEAMSTEER are high-cut K filters formed by the application of the weights to the group interval. BEAMSTEER has the advantage of being able to attack aliased noise components without affecting the signal. The "array length" simulated by BEAMSTEER needs to be at least one wavelength for an equally weighted array, and 1.5 wavelengths for a "triangular" weighted array. Edge affects are minimised by applying "triangular" weighted arrays.

VELOCITY FILTERING (VELFILT)

Velocity filtering is a frequency-wavenumber operation that can be used to discriminate against specified horizontal velocities on pre-stacked data.

The data is transformed from the space-time (X-T) domain to the frequency-wavenumber (F-K) domain where the filter is applied. After filter application the data is transformed back to the X-T domain for further conventional process applications.

A linear event in the X-T domain (implying a constant velocity) appears as a linear event in the F-K domain, where lines of constant velocity all pass thought the origin. Thus, a multitude of noise events, with the same velocity, at various times on the input record join on the F-K plane into a single event. If the velocity of the noise is adequately separated from the primary signal velocities the noise will transform into a different part of the F-K plane than the signal. A window of primary dips can be specified and dips outside this window are rejected.

Examples of noise alignment that can be removed are direct arrivals, hard bottom refraction, mud roll and cable jerk. These types of noise alignments have a velocity slower than primary signal or have a dip opposite to the primary.

As well as removing certain types of coherent noise, velocity filtering also reduces random noise, since some noise will be transformed into the part of the F-K plane that is zeroed.

Since "Version 5", HGS's F-K domain velocity filter process has had the option of using "cosine" cut-off ramps, as opposed to the linear ramps of previous versions. The cosine ramps are also wider, and the net effect of these changes is to reduce the "edge effects" on the output records. These edge effects showed up on data as energy alignments parallel to the cut-off dips used in the process. The result of using a cosine taper, is a cleaner record in comparison to earlier versions. (See Figure B1.)

The latest versions of HGS's velocity filtering allow either a conventional "fan" type cut, or a "notch" type cut to be specified (see Figure B2). The "notch" cut is a milder form of velocity filter and may be used to attenuate specific noise trains such as direct arrival energy or air blasts.

Aliasing both in the frequency and wavenumber axes can be predicted from the time sampling period and the spatial sampling (or group interval) of the input data. Spatial sampling determines, to a large extent, the effectiveness of the process. Velocity filtering attenuates some portions of aliased events. However, when aliased noise overlays signal, velocity filtering loses its discriminating power.

RADMULT and RADVELF

RADMULT and RADVELF are F-X domain processes which utilise the generalised Radon Transform. RADMULT uses a Radon Transform which sums along parabolic trajectories and RADVELF uses a Radon Transform which sums along linear trajectories (cf. tau-p or slant stack transforms).

RADMULT may be used as a multiple attenuator, a random noise attenuator, and as a signal enhancer. NMO corrected CMP gathers are input to the process. A window of data is defined by the user specifying a range of delta moveouts at the far offset over which parabolic modelling is performed. A portion of the modelled data may then either be kept or cut, and the result inverse transformed to produce the output data. The NMO corrections may be removed subsequently to allow further processing and velocity analysis.

RADVELF may be used to attenuate both coherent and random noise. Shot or receiver records may be input. These are generally not NMO corrected but, for some classes of noise, a linear moveout may be applied to the input and removed after RADVELF application. As with RADMULT a window of data is defined by specifying a range of delta moveouts at the far offset. Linear modelling is performed over this window and and a portion of the resultant model data either retained or cut and the result inverse transformed to produce the output.

A general reference on the generalised Radon Transform and its uses is "Inverse velocity stacking for multiple elimination" by Don Hampson (Journal of the Candian SEG, Vol. 22, No. 1, Dec 1986, 44-45).

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477033

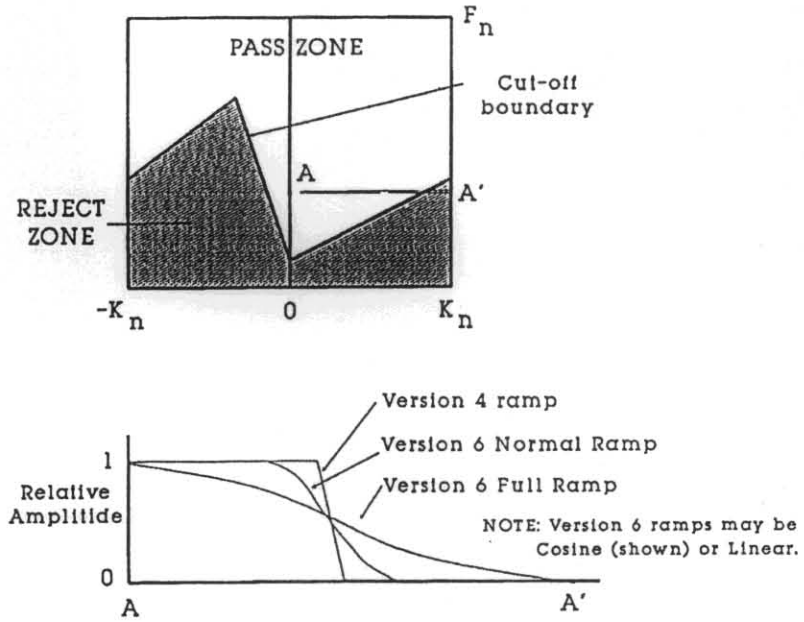

Figure B1. VELFILT Ramps

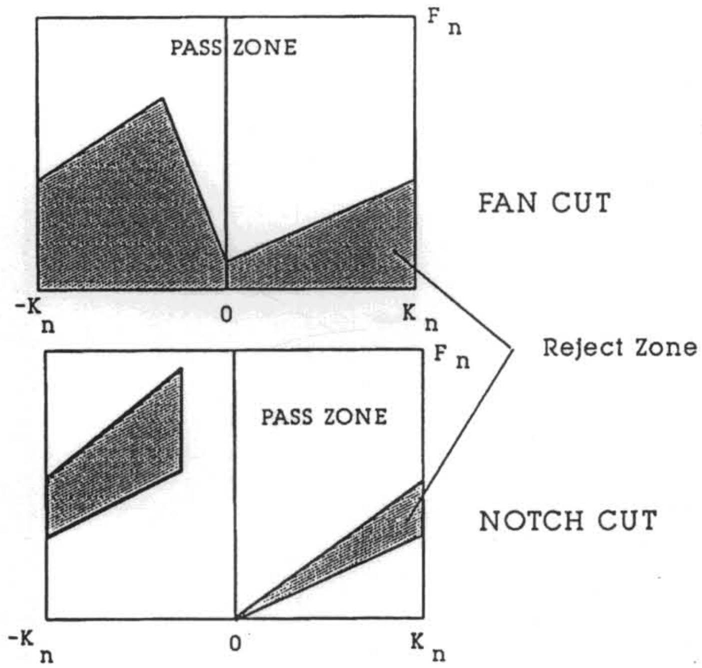

Figure B2. VELFILT Cut Types

DESIGNATURE (DESIG)

Designature is a generic name for processes which attempt to replace an arbitrary source wavelet, convolved with the reflection sequence, with a shorter wavelet of improved resolving capability.

DESIG V6 is the current designature program and provides an alternative to conventional pre-stack deconvolution (TVD). DESIG V6 is a multi-channel process, that can use the entire record to estimate the wavelet, whereas TVD is a single channel process that only uses a portion of a trace to design an operator. The increased statistical power of DESIG enables the process to better estimate the stationary wavelet from the seismic data than conventional deconvolution (TVD).

While TVD is time and offset-variant, DESIG V6 is not time-variant. It can, however, be offset-variant by specifying the OFFSET-DEPENDENT option. In this case the shot record is divided into four sets of traces. Designature is applied separately to each set of traces as though they were separate shot records. In areas where streamer depth and/or water depths vary along the streamer, gradual and progressive variations in the receiver ghost period and reverberation period occur. Offset-dependent Designature is better able to compensate for these variations than STANDARD Designature, which operates on the entire record.

DECONVOLUTION

When the pulse from a seismic energy source travels through the earth, it is convolved with the earth's reflection sequence, and also with various earth and recording instrument filtering effects which distort the shape of the original pulse in various ways, before the reflected energy is finally recorded on tape. Deconvolution is a time-domain, single-channel process which aims at shortening the reflection wavelet to increase resolution, and attenuating short-period reverberations.

The source wavelet is estimated from the seismic traces and the assumption is made that the wavelet to be removed is minimum phase and the reflection sequence is random. An inverse filter (the deconvolution filter) is first designed from a trace and then convolved with the same trace, giving an output which is minimum phase. This is done for each trace on each record. If the deconvolution is time-variant, the trace is divided into gates, and a deconvolution filter is designed on each gate. The deconvolution filters are then applied in time-variant fashion. The filter points are weighted by unity at gate centres and are linearly tapered to zero at the centre of the adjacent gate(s). Between gate centres, the two weighted filters are added together. The filter remains constant before the first and after the last gate centre. In order to minimize any distortion halfway between gate centres where both filters may be non-typical, gates are overlapped so that part of each gate is used in the design of adjacent filters. The amount of overlap in filter design can be different from the amount of overlap in filter application.

Two types of deconvolution in common use are whitening deconvolution and predictive (or gapped) deconvolution.

Whitening Deconvolution

In the design of a whitening deconvolution filter, the amplitude spectrum of the specified portion of trace is obtained. In the time domain design this is done, in effect, by taking the auto-correlation of the portion of trace. Before the autocorrelation is used in a matrix equation, its zero lag value (zero time sample) is usually increased by a small amount. This effectively adds a small amount of white noise to the amplitude spectrum. Firstly, the added white noise prevents zero amplitude values at any frequency on the spectrum, and consequent division by zero when the spectrum is in effect inverted; and secondly, it limits the flattening of the amplitude spectrum of the output trace. The amount of white noise needed for the first reason is generally no more than 1% of the average power of the trace, but much greater percentages may be added if the second reason is important. Filter lengths may either be a constant or they may be based on the water depth. For whitening deconvolution, the ZW1 and ZW2 options are defined as:

ZW1 filter length = 1.2 x two-way water layer travel time
ZW2 filter length = 2.2 x two-way water layer travel time.

Predictive, or Gapped Deconvolution

Predictive deconvolution has the same general aims as whitening deconvolution and DESIG, namely wavelet shortening and de-reverberation; but it approaches the deconvolution filter design from a rather different point of view. In spite of this, the arithmetic processes in its design have some similarity to those in whitening deconvolution; and in one limiting situation the results are identical. Predictive deconvolution gives greater control over the degree of spectral flattening than whitening deconvolution, and handles the longer period reverberations better than either the latter process or DESIG. In gapped form, it does not need to assume that the input reflection wavelets are minimum phase, hence its compatibility with DESIG. Its filter is one-sided, however, and so it cannot convert a minimum phase wavelet, or any other one-sided wavelet, to zero phase.

A predictive deconvolution filter is designed and applied in the time domain in a generally similar manner to a whitening deconvolution filter. The autocorrelation of a specified portion of trace is taken and used in a matrix equation that gives the predictive deconvolution filter directly. The filter is then convolved with the trace, or portion of trace if it is a time-variant application. The length of autocorrelation used, from one side only, is equal to the total length of the predictive deconvolution filter (gap length plus live portion length). White noise is not added in the design of a gapped operator; it is not needed to limit spectral whitening, which is controlled by the gap length instead. The gap can either be a constant or it can be based on the water depth, ZW. The Gap = ZW option is defined as:

ZW gap = 0.9 x two-way water layer travel time.

Filter lengths may also be either a constant or they may be based on the water depth. For gapped deconvolution, the ZW1 and ZW2 are defined as:

ZW1 filter length = 0.3 x two-way water layer travel time
ZW2 filter length = 1.3 x two-way water layer travel time.

KIRCHHOFF DIP MOVEOUT (DMO)

Seismic data with locally conflicting dips often suffer from fault definition and imaging problems. For a dipping event, reflection points for nonzero offsets are positioned up-dip from the zero offset ray with the same midpoint. This is called reflection point "smear". A second imaging problem is that stacking velocities are dip-dependent. Thus two events which appear at the same time and location will generally require different stacking velocities. Dip moveout (DMO) has become widely accepted as a method of addressing these two problems. DMO comes closer to producing a zero offset sections than does conventional NMO.

Several methods are known to apply DMO. HGS has implemented a Kirchhoff algorithm. This algorithm is a pre-stack process which moves each amplitude to the appropriate zero offset location for all possible dips. DMO is applied after NMO. The DMO correction is only weakly influenced by the velocity used for NMO. Generally the NMO correction is removed from the data after DMO is applied and velocity analyses are run and interpreted before stacking the data. DMO is applied to common offset sections so that when the data moves to correct for the reflection point "smear", the offset remains fixed and NMI can be applied to the data.

DMO is a computer intensive algorithm. The Kirchhoff algorithm was selected as the most efficient implementation possible for pre-stack data processing. Nevertheless, for some high fold data sets it may be necessary to sub-stack the data prior to applying DMO to keep the computer costs and run time at a reasonable level.

DEMULTIPLE (DEMULT)

Demultiple is an F-K domain filtering technique used to attenuate water-layer, pegleg, and interbed multiples. It is based on the difference in normal moveout between primary energy and slower velocity multiples.

The demult filter is applied independently to each CDP set of traces and consists of five main steps:

- Normal moveout correction (NMO) is applied to the CDP gather using the velocity function of the multiples to be attenuated. In the normal case where multiples have a slower velocity than the primaries, the chosen multiples will be flattened across the CDP and the primary will be overcorrected.

- The NMO corrected gather is then transformed into the F-K domain and a velocity filter is applied. Since the chosen multiple energy has been flattened by the NMO correction, and thus has zero dip, it will be concentrated along the K=0 axis; any slower multiples will be undercorrected and will transform into the positive side. The primary energy, and any faster multiples, will be overcorrected and will transform into the negative side of the F-K plane.

- A velocity filter is then applied in the F-K domain. The filter is specified as a negative velocity, called the cut-off velocity, and is chosen to fall between the primary and multiple energy. Any energy at the cut-off velocity or slower is zeroed. Any energy with a faster velocity will be kept. This includes the primary energy and any faster multiples.

- The final two steps consist of transforming the data back into the time-distance domain, and then applying a reverse NMO correction (NMI). The result is a CDP gather record that has no NMO correction applied and on which the multiples are strongly attenuated.

A side effect of DEMULT is that some attenuation of the primary energy cannot be avoided. This is because, on the shorter offset traces, there is little moveout difference between the primaries and multiples. As a result the primary energy on these traces transforms into that part of the F-K plane that is zeroed. Not only is this energy attenuated, but a false event, or "artifact" can be introduced where the primary energy has been attenuated. This is because the shorter offset end of the remaining primary energy is smeared out across the shorter offset traces as a linear event; parallel to the velocity cut-off slope. After the reverse NMO correction is applied, the artifact becomes a curved extension of the real primary and can "roll over" to have reverse dip on the shortest offset traces.

The roll-over artifacts can make the velocities of the primary events appear too fast, and can also distort the signal on the stacked traces. Therefore, they are usually removed by an inside trace mute before the CDP gather traces are input to any other process.

The success of the DEMULT technique depends on the accuracy of the multiple function used; if the function is too slow the multiples will be overcorrected and not zeroed, but if the function is too fast primary energy will be flattened and rejected by the filter. This is also linked to the cut-off velocity; as the multiple function becomes faster (closer to the primary function) so the primaries are less overcorrected and transformed closer to the K=0 axis. Therefore, a cut-off velocity closer to the K-axis (higher velocity) must be chosen to avoid attenuation of the primary. A higher cut-off velocity has the advantage of reducing the number of traces affected by the "roll-over". It has the disadvantage of reducing the margin for velocity errors; resulting in a multiple being easily missed, or a primary attenuated.

The final choice between these is often a compromise, whereby a certain amount of primary attenuation is accepted in order to attenuate the faster multiples; while still using a fairly low cut-off velocity. The method used by HGS to derive the multiple velocity function is to produce a set of velocity analyses on each line, and interpret a primary velocity function. The multiple function is then derived by specifying an acceptable primary attenuation percentage and cut-off velocity and calculating the multiple function.

ENHANCE

ENHANCE is F-X domain process which attenuates random noise. ENHANCE may be performed on either pre- or post-stack data. For pre-stack applications data in the shot, receiver, CMP, or common offset domains may be input.

ENHANCE is implemented in the F-X domain in the following manner. First, all traces in the input record are Fourier transformed from the time domain to the frequency domain. Following the transform, complex prediction filters are designed and applied in the X-direction across the data at each frequency. The filtered F-X data are then inverse-transformed to the time domain to produce the output record.

ENHANCE may be applied in a time- and space-variant manner. In addition, a variable amount of original data may be "added back" to produce the output. ENHANCE may be run successively in different domains for additional noise removal.

VELOCITY ANALYSIS

HGS's VELSCAN Velocity Module is a high technology program designed to enable stacking velocities to be picked on the basis of the stack response of individual event wavelets. It makes use of advanced picking logic to pick events as functions of time, amplitude, moveout and dip. These attributes are plotted on a scattergram display, with a listing of the attribute values and a display of the associated trace data. The latter comprises a suite of stacked traces, and a CDP gather with different NMO corrections applied. The CDP gather displayed is the central gather of the set of stacked traces.

The event picking proceeds in the following manner:

- Nmo corrections corresponding to a series of moveout functions are applied to each set of CDP traces. For each moveout function, the NMO-corrected traces are stacked. The set of moveout functions is automatically computed such that there is only a small difference in stack response between adjacent functions. Therefore, the stack response will increase gradually toward the correct moveout for stack and then die off gradually as the moveout becomes excessive. This enables the program to interpolate maximum stack amplitude for each event versus moveout, and arrive at the optimum velocity for the event.

- The next step is to apply a dip scan to the suite of stacked traces to further improve the signal to noise ratio and determine a localised dip value of the event. Small increments of dip are used, as were small moveout increments in the moveout scan described above. A maximum amplitude for the event should be found when the correct dip is applied. Dips either side of the correct dip will give a reduced amplitude.

- The result of the moveout and dip scan processes is a set of event amplitudes as functions of time, moveout and dip. An event is located by searching for an amplitude extremum in the time, moveout and dip domains. An extremum may be either a maximum or minimum; that is, both peaks and troughs are picked. The event attributes of time, amplitude moveout and dip are assigned to the centre depth point.

- The picked events are then plotted on a scattergram, with different symbols being used to classify the amplitudes of the events. The highest amplitude symbol in each 50 msec is circled to distinguish it. The velocity, amplitude and dip attributes of each circled event are also listed with the scattergram. The scattergram and event listing is usually displayed with trace data in the form of CDP gathers, and stacks with moveout correction using the different velocity functions.

As part of the velocity analysis routine, static corrections to compensate for shot and cable depth, and multiplexor delays are applied.

The testing involved with velocity analysis consists mainly of obtaining a suitable centre velocity function for the trace data displays. With information about the dominant data frequency, stack fold, and trace offsets, the program will compute functions for a range of velocities above and below the central velocity function.

For second pass (DEMULT) velscans, the primary function picked from the first pass velscans is used as the central function.

RESIDUAL STATIC COMPUTATION

Residual statics are computed to be surface consistent. The method makes use of cross correlations to measure the relative time shifts for each trace within a common depth point set. Each of the traces within a CDP set is correlated with a model trace formed by stacking together several adjacent common depth points. The location of the peak value of the cross-correlation function gives an estimate of the time shift of that trace. This time shift is the sum of several components, namely:

- Residual shot static
- Residual Receiver static
- Residual moveout
- Noise

The correlation functions are computed over gates selected so that the signal to noise ratio is high and little or no residual moveout is present. The time shifts obtained are placed in tables of common source and common receiver positions and a statistical analysis carried out to determine a unique residual static for each position to achieve surface consistency.

The process is iterative and several rounds are applied to upgrade the estimate of residual statics to apply to the data in subsequent processing. To assist in evaluation of results, plots are made of the computed residual statics and displays made of part of the section with residuals applied.

APPLICATION OF DATUM STATICS

Prior to application of normal moveout corrections a "relative" datum static is applied to each trace and after moveout corrections a mean datum static is applied for each depthpoint. The mead datum static is the mean of all the statics computed for that depth point. The relative static is simply the difference between the mean datum static and the individual trace datum statics. A consequence of this method of datum static application is that velocity functions are expressed relative to the surface and not to the datum plane. At this stage, if they have not been applied earlier in the sequence, corrections are made for delays caused by the field multiplexor.

TIPEX DATUMS

Static corrections correct data to a client determined reference plane or datum. The static of a trace is the sum of its shot and receiver statics.

In the TIPEX system the terms are used differently. DATUM means the correction necessary to bring the field trace to the surface and the term REFDAT is used for the correction from surface to the reference datum. Correction times are stored as attributes against each trace and are accessible at all times during processing. This different meaning of datums is entirely internal to the TIPEX system and does not effect data shifts defined by the seismic datum statics which are input. At the commencement of processing for each line details of all recording parameters and statics are supplied to the system. These are stored in a Spatial Attributes file for use during the processing sequence. This file contains not only the parameters supplied but also derivatives from them that may be required during the processing sequence. Thus, not only are the field statics stored, but also the mean and relative statics as described above; these are stored as attributes referred to as STADATUM and STBDATUM.

NORMAL MOVEOUT CORRECTIONS (NMO)

Reflection arrival times at the surface, from a horizontal reflecting interface, increase with offset from seismic source in a predictable manner known as the normal moveout effect. NMO, at a given location, is a function of offset, depth to the reflector, and the velocity of the medium between the reflector and the surface.

NMO corrections remove the NMO increase in reflection times with offset, and reduce all reflection times to the value they would have if source and receiver were coincident.

NMO corrections involve some stretching of the data. This is greatest at early record times but decreases with increasing record time. In order to avoid gross distortion at early record time, ramps are applied to zero out the early part of the traces where NMO is excessive.

For marine data, in conjunction with the NMO process, static corrections to compensate for shot and streamer depth are applied. These average about 12 milliseconds.

COMMON DEPTH POINT STACK (CDP STACK)

The common depth point stack is the summation of all the traces, of a common depth point, into one stacked output trace for each depth point. This summation is performed, after the application of NMO and static corrections, to each individual trace. If these corrections are appropriate then trace signals will reinforce whilst random noise will tend to cancel out. The improvement in signal-to-noise (S/N) ratio of a stacked trace compared to the input traces is theoretically equal to the square root of N, where N is the number of traces summed together. Thus, a stack fold of 60 would give a S/N ratio improvement of approximately 8 over a single fold stack.

In addition to improving the S/N ratio, stacking can also attenuate or suppress undesired reflection events such as multiple reflections.

A ramp is applied to the input traces before summation to remove the stretched data, as described in the previous section on NMO, and the first break noise not removed by the pre deconvolution ramp.

When Demult is applied to the data an inside trace ramp is also applied before summation (see the section on Demult for further details). Because of the application of these ramps there will be time-variant changes in the number of traces being summed to form the stacked trace. As a result the sums will have different amplitude values as a function of the number of line contributors. So they must be normalized before output, a process known as Recovery Scaling. The number of contributing traces vs time is counted and the scaler computed as follows:

$$RSc(t) = 1 / N(t)$$

where RSc(t) is the recovery scaler at time t
N(t) is the number of contributing traces at time t

Diversity Stack

Diversity Stack is a form of weighted stack. Power is measured in short time gates on the gather traces. Then one of two scaling options can be used: Diversity Power (DIVPWR) or Diversity Amplitude (DIVAMP). Scalers for each gate are computed from

$$\text{DIVPWR } Sc(i,j) = 1 / P(i,j)$$

$$\text{DIVAMP } Sc(i,j) = 1 / \sqrt{P(i,j)}$$

where Sc(i,j) is the scaler for gate i on trace j

P(i,j) is the power of the gate.

The DIVPWR option will handle random, high-level noise bursts, and is very useful in suppressing spikes not previously edited or machine generated. The assumption is made that signal levels are approximately constant from trace to trace and that noise difference are responsible for power changes. Provided that this assumption is met then DIVPWR is a true amplitude process.

DIVAMP scaling can be compared to applying short-gate scaling to traces before stacking. The difference is that amplitudes on the stack trace will be the average amplitude of the input traces, not an arbitrary amplitude level that scaling achieves. It can preserve spatial amplitude variations on reflections but compensate for changing amplitudes due to shot and receiver coupling differences.

TRANSMISSION COMPENSATION (TCOMP)

TCOMP is a post-stack, time-variant ,frequency domain deconvolution. It is designed to remove short period , minimum phase reverberation and transmission effects. These effects, caused by interbed and short period multiples, act as a time-variant high-cut filter. Ideally, the input data will have been processed through DESIG which will have collapsed the time-invariant, geology independent, shot wavelet to a zero phase band-limited pulse.

The operation of TCOMP is as follows:

- One or more time gates are picked on the section. The gates may overlap.

- The power spectrum of each trace in each gate is obtained. The power spectra for a span of traces are laterally averaged, and this average spectrum is assigned to the centre trace. This process continues to "roll along", for all traces on a seismic line. The averaging process increases the statistics used to design the inverse filter. The assumption is that the primary energy spectrum is white. The averaged power spectrum for each gate of each trace is then divided by a model spectrum, which may be either a flat "white" spectrum or some user input spectrum, to give the power spectrum of the transmission filter for that gate.

- The TCOMP filter is then transformed into the quefrency (cepstral) domain in which the data is displayed as power versus quefrency. The advantage of this power cepstrum display is that multiple energy will appear as peaks at quefrency values equal to the multiple periods.

- The cepstrum is then windowed so that the desired range of multiple periods fall within the window (the window is controlled by the Taumin and Taumax parameters). This window is then transformed to the frequency domain where it gives the power spectrum of the multiple energy.

- The amplitude spectrum of the multiple reflection sequence is then derived. Since, the multiple sequence has minimum phase characteristics, its phase spectrum can be derived from its amplitude spectrum. Given both spectra the appropriate inverse filters can be designed and applied to the trace.

Q COMPENSATION (QCOMP)

QCOMP is designed to correct for the absorption, or "inelastic attenuation", effects of the earth, which result in high-frequency energy losses.

A user supplied Q-model, which may be time and space variant, is used to determine the absorption characteristics of the earth. A time variant (if the Q-model is time variant) inverse filter is designed for each trace to compensate for the absorption induced high frequency losses in the deeper section. The process can optionally correct for the time delays produced by absorption, but this is only recommended where the Q-model is very reliable, and can be confirmed by well log comparisons.

NMP DECONVOLUTION

NMP (Non-Minimum Phase) is a deconvolution technique which takes advantage of the improved signal-to-noise ratio after stack to finally adjust the reflective wavelet to a zero phase spectrum. NMP is part of the TRANSCOMP post-stack deconvolution "package"and, as such, is compatible with HGS's wavelet processing sequence.

NMP is based on the complex amplitude "envelope" of the trace. A "spike" synthetic trace is derived which represents the stronger reflection events on the trace. A correlation between the trace and the synthetic gives an estimate of the reflection wavelet, from which an inverse operator is designed to adjust the wavelet to zero phase. The process is effective for phase errors within about 45 degrees of zero phase. The process can be applied interactively to give a better wavelet estimate, and can be time gated to handle a time variant wavelet spectrum, as well as allowing good signal-to-noise ratio portions of the trace to be used.

TIME VARIANT FILTERING (TVF)

Bandpass filtering is applied to limit the data displayed to the range of frequencies with a good signal-to-noise ratio. This usually results in the application of a time-variant filter, because the earth's filtering effect results in a progressive loss of the higher frequencies with depth. Therefore, any high frequencies present on the data at depth are usually random noise, not signal, and can be filtered off the data. There are several filtering options available. The most commonly used is a zero phase bandpass filtering option. However, any filter that the client supplies can be applied. In addition a bandpass Kaisel-Bessel filter can be chosen to be applied to the seismic data.

TIME VARIANT SCALING (TVS)

Time variant scaling (TVS) is the last process to be applied. The reason for using a scaling function is the inability of conventional displays to adequately show the large amplitude differences that occur between reflection events. The solution to this is to apply TVS to the data to equalise the range of reflection amplitudes enough to be displayed. The high amplitude events are scaled down and the low amplitude events scaled up.

HGS's scaling process can operate in any of the following modes:

DGCS
FLATTVS
EQ
FITLNTVS

DGCS - Digital Gain Control Scaling

DGCS scaling produces amplitude equalization in a time variant manner down the seismic trace, as well as from trace to trace. A "sliding" time gate is used to compute time variant scalers for each trace.

- **Scaler Derivation.** A scaling gate length, and initial start time are specified and the program goes through the following sequence:

- Amplitudes at all samples in the first gate (i.e. beginning at gate start time, finishing gate length msec later) are examined and their rms value determined. A predetermined number (representing typically half system dynamic range) is then divided by the rms value to give the scaler for the first gate. The second gate starts and finishes one sample later than the first. The third and fourth gates etc. overlap earlier gates, sliding down the trace by one sample at a time. Scalers for these gates are derived in the same manner as described earlier for gate one.

- **Scaler Application.** Scalers derived for each gate are applied only to the sample at the gate centre time. For all times prior to the first gate centre, and after the last gate centre, the scaler derived for the first gate and the scaler derived for the last gate, respectively, are used. The scaling operation is simply a multiplication of amplitude values on tape with the appropriate scaler value.

FLATTVS - Time Variant Scaling

In this mode, a first gate start time and scaling gate length is supplied similar to DGCS, described above. However, the gate structure differs in the following respect: all design gates are contiguous, i.e. non-overlapping. The second gate begins where the first gate finishes, and so on for subsequent gates. Having identified the time gates concerned, trace amplitudes are examined and scalers derived in the same manner as outlined earlier.

Scalers derived for each gate are again applied at the gate centre times. For times between gate centres there is a linear interpolation of derived scaler values prior to application. Scalers are extrapolated backwards and forwards from the last gate centre times respectively.

EQ - Equalization

This is similar to FLATTVS, except that the scaler is derived from only one gate, whose start time and gate length can be specified, and applied to the whole trace.

FITLNTVS - Fit Line Logarithmic Scaling

This scaling option derives the rms amplitude within a given time gate, computes the natural logarithm, and then fits a least-mean-squares line through all the natural logs of all gates. Any value that exceeds the fit line is modified so as to fall on the fit line. Inverse logs are then calculated from the new values, and scalers calculated by dividing 1000 by the gate value. Scalers are interpolated from gate centre to gate centre. Gates with less than 50% of the samples live will not be used in the calculations, and scalers will be extrapolated to those samples.

FITLNTVS was specifically designed to help the problem of very high amplitude events falling into the same gate as a low amplitude area. Normal FLATTVS scaling often gives "dimout" zones around the high amplitude events. FITLNTVS does not have these zones above or below the high amplitude events.

WAVE EQUATION MIGRATION IN THE FK DOMAIN

HGS's F-K domain migration routine uses the Kirchhoff integral solution to the scaler wave equation. This method will migrate data more accurately in the presence of a laterally variant velocity field than many other finite difference techniques. It has a practical dip limit approaching 90 degrees. On sections with events with "true" structural dips less than this it is recommended to dip limit the migration aperture. This helps to prevent excessive wave front noise on low S/N ratio data. There is the provision to limit the migration aperture in degrees, e.g. 10, 20, 55 etc. This dip-control technique will suppress spurious wavefronts by attenuating them with a dip-dependent energy-dispersion algorithm. The rms velocity field, in CDP space, is used to migrate the data. This velocity field is usually obtained from HGS's inverse ray-tracing program SPACEVELS.

WAVE EQUATION MIGRATION BY FINITE DIFFERENCE

HGS's F-D time migration is based on the Claerbout technique for recursive finite-difference migration. There is support for "15 degree", "45 degree", and "65 degree" implementations. The names "15", "45", and "65" are only rough guidelines. However, the algorithms are only accurate up to these dip limits. Finite difference migration does tend to give a better signal-to-noise ratio section than does F-K migration. Finite difference cannot position the migrated output data in the correct time and space position in the presence of a lateral velocity gradient. The F-D migration program requires velocities in migrated space. These are usually obtained with an inverse ray-tracing program such as HGS's SPACEVELS.

KIRCHHOFF TIME MIGRATION

Kirchhoff is the traditional standard for time migration. When Hubral wrote his classic paper on time and depth migration, he used Kirchhoff migration to define what he meant by "time mugration". Thus Kirchhoff migration has a predictable response to velocity variations. This means that image-ray corrections can be applied with confidence after Kirchhoff migration. The other advantage of Kirchhoff migration is its capability to accurately image very steep dips, which is very important in these days of prevalent DMO usage. In contrast to Finite Difference migration, Kirchhoff migration suffers no wavelet dispersion and no mispositioning of dipping events. In contrast to phase shift migration, Kirchhoff migration can handle lateral velocity variations in the manner of a time migration.

INVERSE RAY-TRACING (SPACEVELS)

SPACEVELS is the velocity modelling program used to derive migration velocities. Stacking velocity functions and unmigrated horizon times are the input, and SPACEVELS then uses an inverse ray-tracing technique to build a migrated depth-interval velocity model. This model is then smoothed and the RMS velocity calculated. In the 2D mode SPACEVELS is run separately on each line.

Horizon times are selected; these horizons define major changes in the slope of the stacking velocity functions, and are interpreted to follow the regional geologic dips present in the survey area. Therefore, the selected horizons do not necessarily represent either a structural or geologic interpretation of specific reflectors.

SPACEVELS has the option to scale the interval velocity model which results in a scaling of the calculated rms velocities used for migration. Migration tests are often run, speeding up and slowing down the velocity field.