Tutorial: Converted wave (2D PS) processing

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ABSTRACT

This tutorial represents an initial attempt at documenting conventional converted wave (PS) processing as practiced at CREWES. It is intended for people who, while already familiar with ProMAX, have never processed a converted-wave data set. The Blackfoot 1997 3C-2D dataset is used as an example, and a series of ProMAX processing flows sufficient to generate a time-migrated radial stack from raw shot gathers are presented.

INTRODUCTION

In these notes, we describe the conventional converted-wave (PS) processing of the 1997 Blackfoot 3C-2D seismic line in ProMAX.

Several assumptions are made:

1. Familiarity with ProMAX, and an understanding of the basic concepts of converted-wave processing.
2. All assumptions required for standard vertical processing are also required for radial processing.
3. One vertical and two horizontal geophones were carefully planted at each station on the seismic line, one of the horizontals parallel to the seismic line (inline), the other perpendicular (crossline). So, all three components have the same field geometry.
4. The vertical component (PP) data are already fully processed, so the final PP root mean square (RMS) and interval velocities are already known.
5. Only converted waves with a down going P wave, a conversion point at a reflector, and an up going S wave are considered to be signal. Multi-mode converted waves are considered to be noise.

PROCESSING

1. Create a new line:

   In the same ProMAX area used for processing the vertical component (PP) data, create a new line directory for processing the radial component (PS) data.

2. View shot gathers:

   Before beginning, it is a good idea to have a look at the raw shot gathers in order to get an initial impression of data quality (Flow 1). We recommend that you name your flows with a number followed by a descriptive name. For example, “(01) View shot gathers.” Descriptive names are also recommended for data sets, tables, and lists.
3. Geometry:

Use Flow 2 to transfer existing geometry information from the radial trace headers to the database. Complete the “2D Land Geometry Spreadsheet*” exactly the same way as for vertical data, including CDP binning. Then use Flow 3 to synchronize the database with the trace headers. Under LINE->datasets, click on “shots with geom” with the middle mouse button. If all has gone well, it should say that your geometry and trace numbers match the database.

Flow 2. Copy existing geometry information from radial trace headers to database.

Flow 3. Load geometry from database to radial trace headers.

An easier way to do the same thing (recommended) is to copy the database from the vertical line to the radial line using, then execute Flow 3. This avoids the need to complete the geometry spreadsheet twice.

4. Trace edits:

Run Flow 1, then from the pull-down menus in ‘Trace Display’ use ‘Picking->Kill Traces…’ to flag bad traces in the shot gathers. Use ‘Picking->Reverse Traces…’ to fix any polarity reversals. In this example we are saving our results in lists called ‘trace kill for radial’ and ‘reverse traces for radial’ (used in Flow 5).

5. PS binning:

While many methods exist for binning PS data, we only discuss asymptotic binning here. Execute Flow 4, then plot common depth point (CDP) fold from the CDP database to check the results. You will find that the PP CDP fold has been replaced with the PS ACP (asymptotic conversion point) fold which depends on the average $V_p/V_s$ ratio, and will look different than the CDP fold.
We use the same bin size for CDP as for ACP binning; however, the natural bin size for ACP binning is smaller than for CDP binning. This can cause extreme variations of fold from one bin to the next if an integer $V_p/V_s$ ratio is used (Figures 3, 4, and 8. Lawton (1994) has some good 3D examples). For land data, $V_p/V_s=2$ is usually a good initial guess, but it is better to use 1.9 or 2.1 in Flow 4 (Figures 1, 2, and 3).

<table>
<thead>
<tr>
<th>P-S Asymptotic Binning*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select input database ............................................................... shots with geom</td>
</tr>
<tr>
<td>Overwrite input dataset headers .......................................................... No</td>
</tr>
<tr>
<td>Select output dataset ................................................................. shots with psbin</td>
</tr>
<tr>
<td>Trace sample format ............................................................... 16 bit</td>
</tr>
<tr>
<td>Skip primary disk storage? ................................................................. No</td>
</tr>
<tr>
<td>$V_p/V_s$ value for binning ............................................................. 2.1</td>
</tr>
<tr>
<td>Pad ACP range? ............................................................... Yes</td>
</tr>
<tr>
<td>Number of bins to pad ends by .......................................................... 10</td>
</tr>
</tbody>
</table>

**Flow 4. PS asymptotic binning.**

6. **Initial guess of PS RMS velocity:**

   Copy the final PP RMS velocity file from the vertical line to the radial line, and execute Flow 5. This will provide an initial guess of the PS RMS velocity for use in Flow 7. Parameters for this step can be obtained by inspection of the PP and PS shot gathers. If the same events can be identified on both components, then time-varying $V_p/V_s$ values can be estimated.

7. **Prestack processing:**

   Prestack processing (Flow 6) is identical to PP processing, with one major exception: traces on one side of the source location in a PS shot gather will have the opposite polarity to traces on the other side (Figure 4). The third “Trace Kill/Reverse” in Flow 6 takes care of this by reversing the polarity of all traces with a negative source-receiver offset (Figure 5).

8. **Refraction statics (shot and receiver):**

   Refraction statics are crucial for converted wave processing, especially since the receiver statics can be as large as 100-200 ms. As mentioned before, converted waves are P-wave down and S-wave up. Practically, this means that shot statics calculated during PP processing (Typically with Hampson-Russell GLI3D at CREWES) can be reused for PS processing. However, shear velocities vary more laterally in the shallow section than compressional velocities, so PS receiver statics are more difficult to compute.

   There are two ways to do receiver refraction statics for the radial component: 1) Identify the S-wave refraction in the shot gathers and use the results to calculate the receiver static, and 2) hand statics (easiest). Four steps are necessary to apply hand statics: 1) Generate a receiver stack (Flow 7), 2) Interpret a horizon (Flow 8), 3) transfer the horizon to the database (Flow 9), 4) apply the hand statics and evaluate the results (Flow 10).
FIG. 1. Asymptotic conversion point (ACP) fold for $V_p/V_s = 1.9$

FIG. 2. Asymptotic conversion point (ACP) fold for $V_p/V_s = 2.0$

FIG. 3. Asymptotic conversion point (ACP) fold for $V_p/V_s = 2.1$
FIG. 4. Example of an unprocessed radial shot gather, after Flow 3.

FIG. 5. Shot gather shown in Figure 1 after reversing the polarity of traces with a negative source-receiver offset (right side, Flow 6).
**Flow 5. Initial guess of PS RMS velocity field.**

<table>
<thead>
<tr>
<th>Construct P-S Velocities* &lt;= P-P final velocities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input P-P Velocity Field</td>
</tr>
<tr>
<td>Type of P-P velocity field.......................... stacking (RMS) velocity</td>
</tr>
<tr>
<td>Get P-P velocities from the database?................Yes</td>
</tr>
<tr>
<td>SELECT P-P input RMS velocity file .................. P-P final velocities</td>
</tr>
<tr>
<td>Input P-S Velocity Field</td>
</tr>
<tr>
<td>Get Vp/Vs ratios from database?........................No</td>
</tr>
<tr>
<td>Vp/Vs values vs. P-P time.........................................1: 0-2.1,1000-2.1,3000-2.1</td>
</tr>
<tr>
<td>Output Velocity field</td>
</tr>
<tr>
<td>Type of output velocity field.........................NMO velocities</td>
</tr>
<tr>
<td>Output RMS or INTERVAL velocities?.....................Stacking (RMS) Velocity</td>
</tr>
<tr>
<td>SELECT output RMS velocity file ....................... P-S initial</td>
</tr>
<tr>
<td>Time step size for the output table...................... 50.</td>
</tr>
</tbody>
</table>

**Flow 6a. Prestack data processing.**

<table>
<thead>
<tr>
<th>Disk Data Input &lt;- shots with psbin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace Kill/Reverse &lt;= trace kill for radial</td>
</tr>
<tr>
<td>Trace editing MODE................................. Kill</td>
</tr>
<tr>
<td>Get edits from the DATABASE?.........................Yes</td>
</tr>
<tr>
<td>SELECT trace kill parameter file.................trace kill for radial</td>
</tr>
<tr>
<td>Trace Kill/Reverse &lt;= reverse trace for radial</td>
</tr>
<tr>
<td>Trace editing MODE................................. Reverse</td>
</tr>
<tr>
<td>Get edits from the DATABASE?.........................Yes</td>
</tr>
<tr>
<td>SELECT trace Reverse parameter file.................reverse trace for radial</td>
</tr>
</tbody>
</table>

### Apply Elevation Statics
- Final datum elevation.................................same as used for vertical component
- Replacement velocity.................................same as used for vertical component
- Database math method.................................Shot Holes Ignoring Uphole Times
- Specify Weathering velocity............................120:610.
- NMO static method.................................Elevations
- Length of smoother..................................51
- Processing DATUM.......................................NMO DATUM

### True Amplitude Recovery <= P-S tar velocity
- Apply spherical divergence corrections?................Yes
- Basis for spherical spreading..........................1/dist
- Apply inelastic attenuation corrections?...............No
- Get TAR velocity function from database?................Yes
- Select velocity parameter file..........................P-S tar velocity
- Apply dB/sec corrections?.................................Yes
- dB/sec correction constant................................4.
- Apply time related to a power corrections?...............No
- APPLY function to data or REMOVE effect of amplitude corrections? Apply
- Maximum application TIME..............................4000.
Figure 6 shows a receiver stack generated by Flow 7 and displayed with Flow 8. Locate a reflection that will be easy to pick, for example at 2200 ms. Go to “Picking -> Pick Other Horizons” and set a new table name “horizon at 2200ms” for this example. Pick the horizon, and be sure to “File -> Save Picks,” before exiting “Trace Display.”

Execute Flow 9, then go to “Database” and find the horizon ***** under SRF. Click on the name of the horizon, go to “math,” “scalar,” ”shift,” and shift your horizon by -2200 (ms, this example only). Go to “Database,” save the edited horizon and exit the database.

Flow 10 makes a new receiver stack which includes the new hand statics. If the statics are good, you should see a flat event at around 2200ms (Figure 7). If not, you should repeat the procedure for picking a horizon until you are satisfied with your results.
### Disk Data Input <- shots preprocessed

- sort by REC_SLOC

### Database/Header Transfer

- Direction of transfer: Load TO trace header FROM database
- Number of parameters: 2
- First database parameter: SIN STATICS GLISTAT
- First header entry: s_ref
- Second database parameter: SRF STATICS GLISTAT
- Second header entry: r_ref

### Trace Header Math

- r_ref = r_ref * 2.1

### Header Statics

- Bulk shift static: 0
- What about previous statics?: Remove previous statics
- Apply how many statics header entries?: 2
- First header word to apply: s_ref
- Second header word to apply: r_ref
- HOW to apply header statics: Add

### Normal Moveout Correction <= P-S initial

- Direction for NMO application: FORWARD
- Stretch mute percentage: 30
- Apply any remaining statics during NMO?: Yes
- Apply partial NMO?: No
- Get velocities from database?: Yes
- Select Velocity parameter file: P-S initial

### Trace Muting

- Re-apply previous mutes: No
- Mute time reference: Time 0
- TYPE of mute: top
- Starting ramp: 30
- EXTRAPOLATE mute times?: Yes
- Get mute file from the database?: No
- SELECT Primary mute header word: receiver index number
- SELECT Secondary mute header word: AOFFSET

### CDP/Ensemble Stack

- Sort order of input ensembles: RECEIVER
- Method for trace summing: Mean
- Root power scalar for stack normalization: 0.5
- Has NMO been applied?: Yes

### Resample/Desample

- Disk Data Output -> receiver stack

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Flow 7. Make a receiver stack.

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### Disk Dataset Input <- receiver stack

- sort by REC_SLOC

### Bandpass Filter

- 5-8-40-50

### Automatic Gain Control

### Trace Display

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Flow 8. Display the receiver stack for horizon picking.

Disk Data Input <- shots preprocessed ................................................................. sort by REC_SLOC
Database/Header Transfer ....................................................................................... same as Flow 7
Header Statics ........................................................................................................... same as Flow 7
Trace Header Math .................................................................................................... same as Flow 7
Database/Header Transfer
  Direction of transfer .............................................................. Load To trace header FROM database
  Number of parameters ........................................................................................................ 1
  First database parameter ................................................................................................. SRF horizon ****
  First header entry ........................................................................................................... r_hand1
Header Statics
  Bulk shift static ........................................................................................................... 0.
  What about previous statics? ......................................................................................... Add to previous statics
  Apply how many statics header entries? ........................................................................... 1
  First header word to apply ............................................................................................. r_hand1
  How to apply header statics ............................................................................................ Subtract
Normal Moveout Correction .......................................................................................... same as Flow 7
Trace Muting .................................................................................................................. same as Flow 7
CDP/Ensemble Stack ..................................................................................................... same as Flow 7
Trace Display

Flow 10. Make and display a new receiver stack with hand statics.

9. Brute stack:

The next step is to create an ACP brute stack so we have something to compare the results of poststack processing to (Flow 11). The initial guess at the PS velocity function from Flow 6 is used for NMO corrections.

10. Velocity analysis:

Velocity analysis is a critical aspect of any seismic processing. Flow 12 will generate and display data for semblance-based velocity picking. Save your picks, and use them in Flow 11 to generate a new version of the brute stack (brute stack1, this example). As you refine your velocity function, the brute stack should improve.

11. Residual statics:

ProMAX provides several residual statics modules. Here, we only describe the procedure for use of the “EMC Autostat: Xcor Sum” module, which requires an external model. First, an enhanced stack must be created for use as the model using any of the signal enhancement techniques available in ProMAX. In addition to normal pre-processing, unwanted high- and low-frequency noise should be removed by band-limiting the input data. An AGC should also be applied to all input traces (Flow 13). Data preparation for input to the residual statics module includes correlation with the external model (Flow 14).
FIG. 6. Portion of initial receiver stack generated by Flow 7.

FIG. 7. Receiver stack with hand statics (Flow 10).
Flow 11. Make a brute stack.

Execute Flow 15 to compute the residual statics. Note that the ID number and maximum source or receiver static must match those specified in Flow 14. Actually, these statics are decomposed into source, receiver, and structure (CDP) statics. The newly computed residual source and receiver statics should now be in the database. Source: SIN STATICS SPEM0001, Receiver: SRF STATICS SPEM0001.

A. Repeat the velocity analysis (Flow 12), but apply residual statics and generate a new velocity function, ‘PS vel2.’

B. Make a new ACP stack (Flow 11), but apply residual statics and use the new velocity function. This stack should be an improvement over the original brute stack.

C. Repeat the steps for calculating residual statics (Flows 13-15), but apply the residual statics from the first round, and use the new velocity function. Also, change the maximum source and receiver static from 36 to 24, and change the ID number from 0001 to 0002.

You should now have new residual source and receiver statics in the database. Source: SIN STATICS SPEM0002, Receiver: SRF STATICS SPEM0002.
**Disk Data Input** <- shots preprocessed ...sort by CDP and OFFSET

**Database/Header Transfer** ...same as Flow 7

**Trace Header Math** ...same as Flow 7

**Header Statics** ...same as Flow 7

**Database/Header Transfer** ...same as Flow 7

**Header Statics** ...same as Flow 10

**Normal Moveout Correction** <= P-S initial
- Direction for NMO application: FORWARD
- Stretch mute percentage: 10.
- Apply any remaining statics during NMO?: Yes
- Apply partial NMO?: No
- Get velocities from database?: Yes
- Select Velocity parameter file: P-S initial

**Trace Muting** ...same as Flow 11

**Automatic Gain Control**

**Bandpass Filter** ...10-14-70-90

**Resample/Desample** ...4.

**Disk Data Output** -> temp for vel analysis

**Supergather Formation** *
- Read data from other lines/surveys?: No
- Select dataset: temp for vel analysis
- Maximum CDP fold: from database
- Minimum center cdp number: from database
- Maximum center cdp number: from database
- Cdp increment: 25
- Cdps to combine: 15

**Velocity Analysis** <= P-S_vel_1
- Select display DEVICE: This Screen
- Table to store velocity picks: P-S_vel_1
- Is the incoming data Precomputed?: No
- Number of CDPs to sum into gather: 15
- Apply partial NMO-to-binning?: No
- Apply differential CDP mean statics?: No
- Absolute offset of first bin center: 5.
- Bin size for vertically summing offsets: 10.
- Maximum offset: 3400.
- Use absolute value of offset for stacking?: Yes
- Number of stack velocity functions: 11
- Method of computing velocity functions: Top/base range
  - Velocity variation at time 0: 200.
  - Velocity variation at maximum time: 1000.
- Interact with other processes using PD?: No
- Get guide function from an existing parameter table?: Yes
- Velocity guide function table name: P-S initial
- Maximum stretch percentage for NMO: 0.
- Interval velocity below last knee: 0.
- Set horizon parameters?: No
- Copy picks to next location?: Yes

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Flow 12. Semblance based velocity analysis on supergathers.

Flow 15. Compute residual statics.


Repeat steps A and B, but change the maximum source and receiver static from 24 to 12, and change the ID number from 0002 to 0003. Now run Flow 16 instead of Flow 15 for step C. You will now find trim statics in the database: TRC STATICS TRIM0003.

12. ACP stack:

Repeat step A to generate an improved PS velocity function (P-S vel3), and repeat step B with the new velocity function and trim statics to make the final ACP stack section.

13. Poststack time migration:

If the final ACP stacked section is satisfactory, you can perform a poststack migration on it. After stacking, the stacked section is at the final datum, but your PS velocity function is at a floating datum (NMO datum). Before Kirchoff time migration, ‘P-S vel3’ must be adjusted to the final datum using velocity manipulation (Flow 17). The adjusted velocity function is then used in Flow 18 to produce a migrated section (Figure 7).
Flow 17. Adjust PS velocity function for use with Kirchoff migration.

14. Depth variant stack:

As mentioned above (section 5), the average \( V_p/V_s \) ratio is used when we do asymptotic binning. This is a very rough estimate, especially for the shallow section, where \( V_p/V_s \) is typically much higher than the average. Now that we have migrated CDP and ACP stacks for the vertical and radial components, we can estimate the \( V_p/V_s \) ratio in different time windows, and at different locations along the line. The first step is to interpret the same horizons on both stacks, possibly with the aid of synthetic seismograms. Once this has been done \( V_p/V_s \) can be estimated from the picked travel times using \( \frac{V_p}{V_s} = \frac{2\Delta T_{PS}}{\Delta T_{PP}} - 1 \), where \( T_{PP} \) is the traveltimes to a horizon on the migrated PP section, and \( T_{PS} \) is the traveltimes to the same horizon on the PS section. Now Flow 19 can be used to make a depth-variant stack.

15. Migrate final stack:

Run Flow 18 again to produce the final migrated stack.
Flow 18. Poststack Kirchoff time migration.
The Blackfoot 1997 3C-2D data set has been used to demonstrate basic converted-wave processing in ProMAX. The reader should be able to use the example processing flows to successfully process their own 2D data sets.

FUTURE WORK

This tutorial needs to be checked for consistency with ProMAX version 2003.3.2, the version in use at CREWES at the time of writing. A discussion of max-power geometric data rotation would be useful and ProMAX modules written at CREWES should be added to the tutorial. The authors welcome any comments or criticism of this document.

REFERENCES


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