Anatomy of common scatterpoint (CSP) gathers formed during equivalent offset prestack migration (EOM)

John C. Bancroft and Hugh D. Geiger

SUMMARY

The equivalent offset method of prestack migration (EOM) is a two step process: the first being a gathering process that forms common scatterpoint (CSP) gathers, and the second a simplified Kirchhoff NMO to zero offset performed on the CSP gathers.

CSP gathers contain a greater amount of information than conventional CMP gathers because they contain all input traces within the prestack migration aperture. These traces are sorted by an equivalent offset into bins in the CSP gather with no time shifting. The energy from these traces, which is typically associated with CMP gathers and poststack migration, is now combined into one CSP gather to produce a compounded distribution of energy. Understanding the distribution of energy on the CSP gather is essential to define parameters for a successful prestack migration.

INTRODUCTION

The formation of common scatterpoint gathers

Common scatterpoint (CSP) gathers are formed at each output trace location similar to CMP gathers. The CSP gathers are composed of all input traces within the prestack migration aperture. The offset of each input trace is uniquely computed for each CSP location, and is based on the distance of the source and receiver relative to the CSP location. Figure 1b shows the ray paths for a given source and receiver travelling to and from a scatterpoint. The source and receiver are collocated at an imaginary surface position that maintains the same time T, thus defining the equivalent offset h_e. Equating travel times gives

$$T = \left(T_0^2 + \frac{(x+h)^2}{V^2}\right)^{1/2} + \left(T_0^2 + \frac{(x-h)^2}{V^2}\right)^{1/2} = 2\left(T_0^2 + \frac{h_e^2}{V^2}\right)^{1/2} \tag{1}$$

where x is the distance from the CSP location to the CMP location, h the half source-receiver offset, T_0 the vertical one-way traveltime, and V the RMS velocity defined at the scatterpoint. Solving for h_e gives

$$h_e^2 = x^2 + h^2 - \frac{4x^2h^2}{T^2V^2}. \tag{2}$$

The reflection point in Figure 1b is observed to lie on a hyperbolic moveout path at the equivalent offset h_e, while still maintaining the original input time T as required by equation (1).

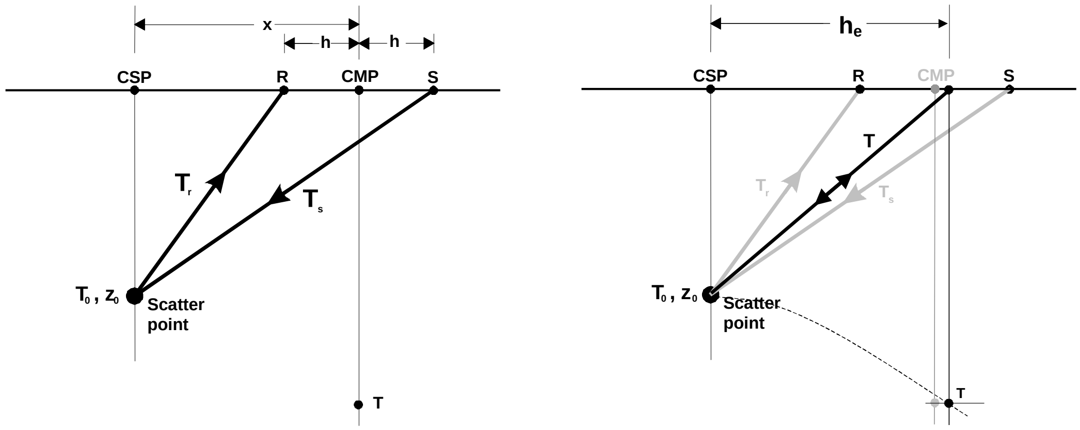


Figure 1. Ray diagram for a) a given source and receiver, and b) a colocated source and receiver that defines the equivalent offset.

The equivalent offset is defined from source and receiver locations to scatterpoints located below a surface position of the migrated output trace (Bancroft et al. 1996). Samples in each input trace, within the prestack migration aperture, are assigned an equivalent offset and then summed into offset bins of the CSP gather. The equivalent offset in equation (2) includes a time and velocity dependence which may spread an input trace across a number of offset bins. Equation (2) is only computed at the transition times where the input trace moves from one input bin to another.

CSP gathers may be formed at any surface position: singularly for velocity analysis, as a 2-D line extracted from a 3-D volume or for complete 2-D or 3-D processing. The formation of CSP gathers is fast because no time shifting, scaling, or filtering is required. Scattered energy lies on hyperbolic paths at the appropriate prestack migration velocity.

Velocity analysis

The movement of input energy to the CSP gathers is slightly dependent on velocity (Bancroft and Geiger 1996). Usually a stacking velocity from previous processing is sufficient to form the CSP gathers. Velocity analysis of the hyperbolic moveout in the CSP gathers (such as conventional semblance plots) can then be applied to estimate more accurate velocities. The improved velocities can be used to image the gather directly by applying Kirchhoff NMO, or as input velocities for creating more accurate CSP gathers.

Kirchhoff NMO and stack

Once the CSP gathers have been formed, the prestack migration is completed with Kirchhoff NMO. Energy from seismic reflections is aligned along hyperbolic paths similar to a CMP gather. Conventional NMO correction (simply referred to as NMO) will flatten the hyperbolic reflection energy which is then stacked to produce the final section. The process however, must also include antialias filtering, phase filtering, and scaling that is part of the Kirchhoff migration process. We refer to this combined process as Kirchhoff NMO. Note that a significant reduction in computational effort is achieved because the scaling and filtering is applied to the binned traces of the CSP gather after they have been formed.

DISTRIBUTION OF ENERGY ON THE CSP GATHER

Horizontal events

Energy from a 2-D horizontal constant amplitude reflector at time T_0 forms a hyperbolic cylinder within the prestack volume (x, h, t) where x is the CMP location, h the half offset, and t the time axis, as illustrated in Figure 2a. A CMP gather is a plane (h, t) at a defined x_{cmp} that intersects the cylinder, and contains energy along a hyperbolic curve as illustrated in Figure 2b. NMO and stacking moves the energy to the apparent reflector position at T_0 on the zero offset plane. Poststack time migration produces no additional change to the horizontal reflectors.

In creating a CSP gather at x_{csp}, all energy from the hyperbolic cylinder (that lies within the migration aperture) will be summed without time shifting into the CSP gather at an appropriate equivalent offset. This includes the CMP hyperbolic data, the zero offset data at time T_0, and all points in between. Thus the CSP gather contains an image of the zero offset section, as illustrated by the horizontal event in Figure 2c.

The lower boundary of energy in Figure 2c is formed by the hyperbolic data close to the x_{csp} plane. The gray area in Figure 2c represents the remaining energy from the prestack hyperbolic cylinder, which will lie between the horizontal event at T_0 and the lower hyperbola. For band-limited seismic wavelets, this energy will destructively interfere. Thus, for a horizontal reflector, all that appears in the CSP gather will be the horizontal event at T_0 and the hyperbolic event, as illustrated in Figure 2d. These two events converge at zero equivalent offset and time T_0 to form a prow (bow of yacht) shape. For horizontal constant amplitude events, the maximum equivalent offset of specular energy is limited by the source-receiver offset. However, scattered or diffuse energy from real data will lie well beyond this limiting offset. The larger equivalent offsets in CSP gathers include this energy and thus enhance the imaging.

The prow shape on a CSP gather, produced by horizontal reflectors, indicates that the formation of the gather combines specular and diffuse energy. As in poststack migration of horizontal events, only the horizontal portion of the prow at zero offset will contribute energy to the output migrated trace. Consequently the zero offset imprinting has no effect on the final migrated image.

A detailed analysis of the prow shape will also reveal different phase changes on the horizontal and hyperbolic boundaries. These phase changes are a necessary part of the process and, after Kirchhoff NMO, will be combined to produce the correct phase of the horizontal reflector.

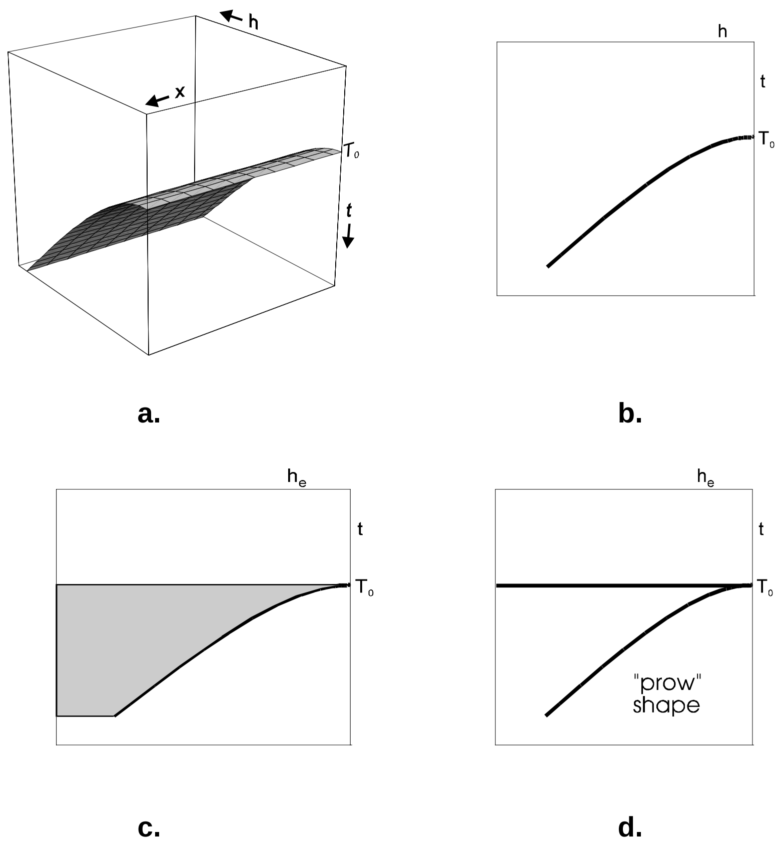


Figure 2. Energy distribution for a horizontal reflector at time T_0 displayed in a) as a surface in a prestack volume *(x, h, t)*, b) a hyperbolic curve in a CMP gather before NMO, c) a CSP gather with a zone of destructive interference shown in gray, and d) with constructive interference showing horizontal and hyperbolic distributions of energy to form a “prow”.

The distribution of energy on the CSP gather is an essential part of the process. Kirchhoff NMO is a very powerful operation that reconstructs the appropriate reflection energy and attenuates all other energy.

Dipping events

The horizontal reflector may be considered as a set of closely spaced scatterpoints along a horizontal line. Energy from each scatterpoint lies on a surface defined by equation (1), often referred to as Cheop’s pyramid, as illustrated in Figure 3a. With the combination of many scatterpoints, this model constructively and destructively interferes to produce a hyperbolic cylinder in the prestack volume, as illustrated in Figure 3b (and in Figure 2a).

Dipping events can also be considered a set of closely spaced scatterpoints lying along the event, as represented by the thick line in Figure 3c. The Cheop’s pyramids from all scatterpoints (one is shown in Figure 3c) will reconstruct the appropriate dipping reflection surface shown in Figure 3d. When considering Cheop’s pyramid as a summation surface for prestack migration, the area of tangency (identified by the highlighted band in Figure 3d), will be summed back to the scatterpoint. When CSP gathers are formed, this energy will reconstruct down the flank of the hyperbolas in the CSP gathers (Bancroft and Geiger 1996). This dipping energy may extend well past the maximum source-receiver offsets as indicated in Figure 3d. Care must be taken to include this energy in the migration.

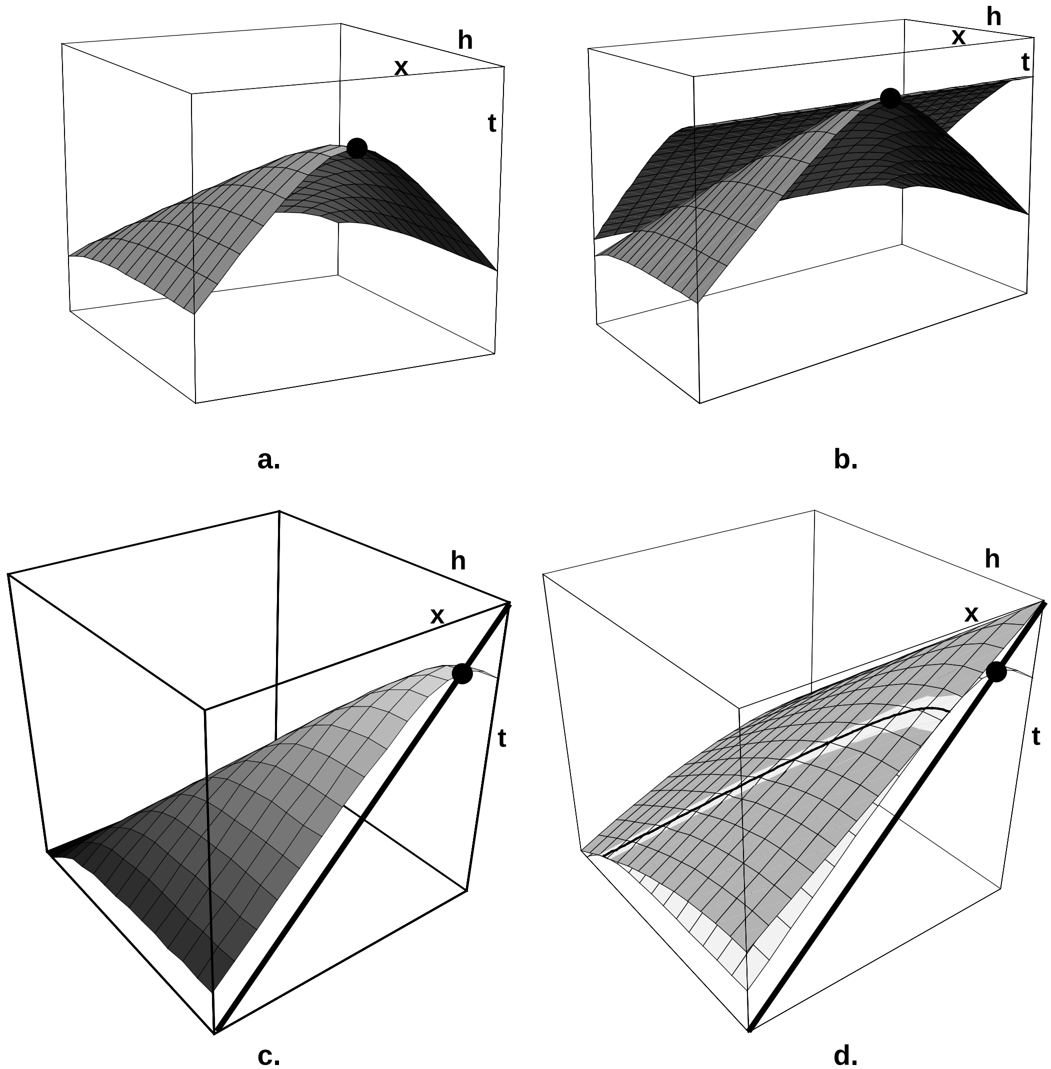


Figure 3. The formation of reflection event using Cheop's pyramid, a) Cheop's pyramid, b) the formation of the hyperbolic cylinder for flat events, c) a Cheop's pyramid from a scatterpoint on a dipping (diagonal) event, and d) the surface from dipping reflector energy (dark gray).

DATA EXAMPLES

Modelled data

A very simple constant velocity model was constructed with a scatterpoint, horizontal reflector and a dipping event, as shown in Figure 4a. Rays were traced to create 101 shots. All reflection amplitudes were assumed constant, and the data bandpass filtered to create seismic wavelets. Only the scatterpoint include diffracted energy, i.e. there is no diffracted energy off the edges of the reflectors. An example of one shot record is shown in Figure 4b.

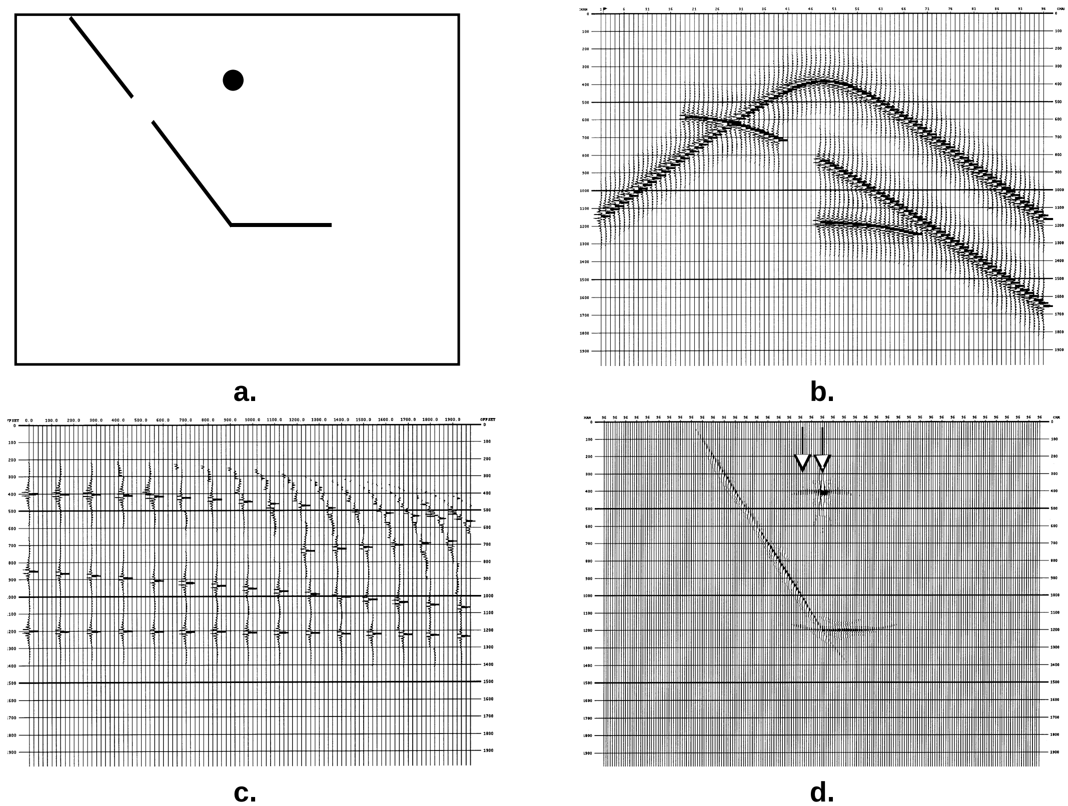


Figure 4. Model for forming CSP gathers, a) the input structure, and b) an example of a source record, c) a close up of a CSP gather with only one shot record as input showing trace movement across bins, and d) the full processed prestack migration.

In Figure 4c, traces from only one shot gather have been mapped into the CSP gather. On the right side of the gather (large equivalent offset), individual samples from a single trace clearly span a number of offsets, illustrating the effect of the offset dependent cross term in equation (2). Figure 4d is the fully processed prestack time migrated section. The arrows at the top of Figure 4d show the locations of CSP gathers in Figure 5.

Figure 5 contains examples of two CSP gathers, before and after NMO. The first CSP gather in Figures 5a-b is located exactly at the scatterpoint, while the other CSP gather in Figures 5c-d are located ten traces to the left of the scatterpoint, as identified by the arrows in Figure 4d. Both CSP gathers contain all the input data without amplitude scaling.

The CSP gather in Figure 5a has collected all the energy from the scatterpoint and aligned it on a hyperbolic path.   After NMO (Figure 5b), all the scatterpoint energy has been corrected to zero offset time and is ready for stacking. This CSP gather happens to be located where the horizontal event meets the dipping event. The prow effect of the horizontal event can be seen on the left side of Figure 5a.

Energy from the dipping event is distributed over much of the CSP gather, but does form coherently towards the maximum equivalent offset. After NMO, the dipping energy is visible as stronger amplitudes at the right side of Figure 5b.

When the CSP gather is located away from the scatterpoint, as in Figures 5c-d, the scatterpoint energy is spread throughout the gather with no coherent formation. After NMO and stack, this energy cancels (as it should), as evident in the final migrated image of Figure 4d. Energy from the horizontal event does not align with the moveout hyperbolas and does not stack. The dipping event is the only image on the output migrated trace in Figure 4d, and forms from coherent energy as identified in Figure 5d. The dipping energy again forms tangentially at a large offset, and at a shallower time than the dipping energy in Figure 5b (again as it should).

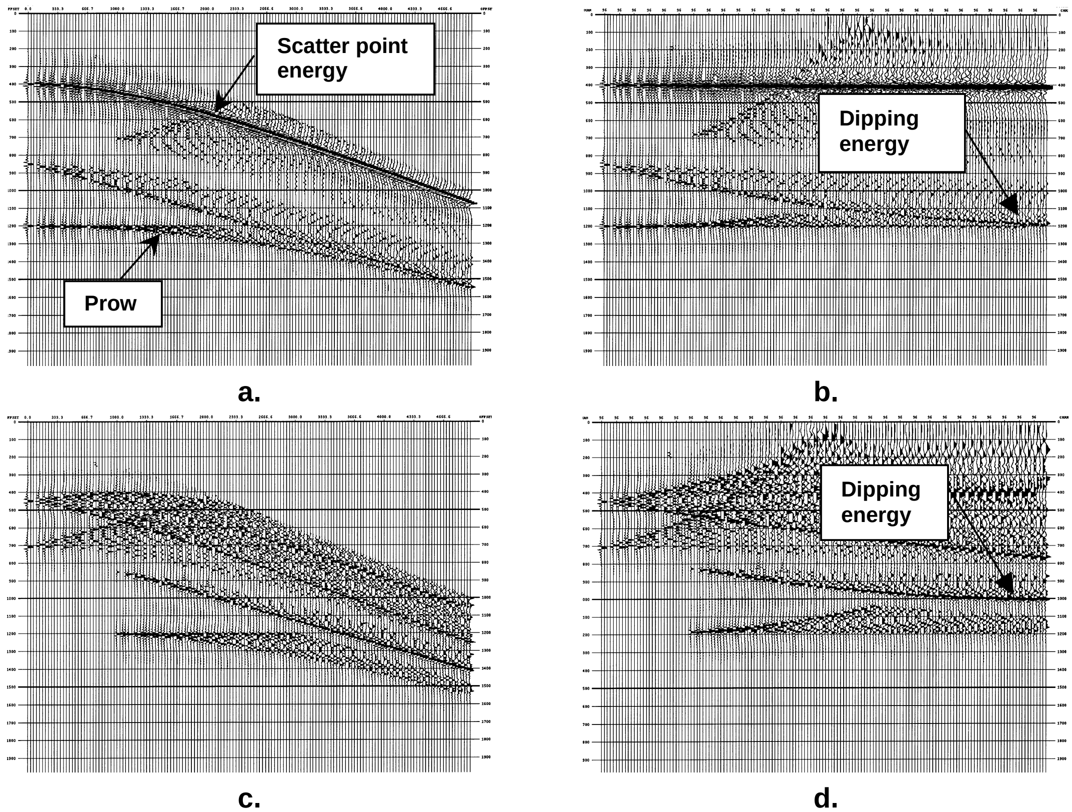


Figure 5 Examples of CSP gathers, a) at the scatterpoint location, b) is (a) with NMO removal, c) ten traces from the scatterpoint, and d) is (c) with NMO.

REAL DATA EXAMPLES

Figure 6 contains an example of a CSP gather formed from an Alberta data set. The gather contains energy from horizontal reflectors that form the prow effects identified by the arrows.

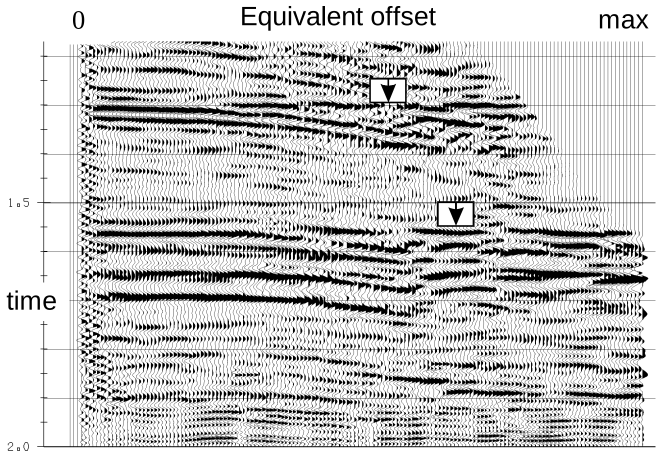


Figure 6. An example of a CSP gather illustrating the prow effect.

Figure 7 contains a CMP gather, a CMP gather with the traces located at their true offset, and a CSP gather, all from the same data set shown in Figure 6. On the CSP gather, note the larger offsets, and full coverage of all offset traces. The reconstruction of energy on the CSP gather comes from all input traces within the migration aperture, with energy positioned at an offset relative to the migrated trace location. Note the hyperbolic energy with zero offset time of 1.25s. This diffraction energy comes from the edge of a channel at the same location as the CSP gather. Amplitudes in this CSP gather have been scaled for viewing purposes and shows some uneven patterns that may be due to gaps in acquisition geometry.

A conventional migration is compared with an equivalent offset prestack migration (EOM) in Figure 8. The data is also from the same Alberta data set and incorporates the CSP gather containing the channel edge. Note the superior signal to noise ratio in the EOM example which illustrates that additional energy in CSP gathers does not degrade the prestack migration.

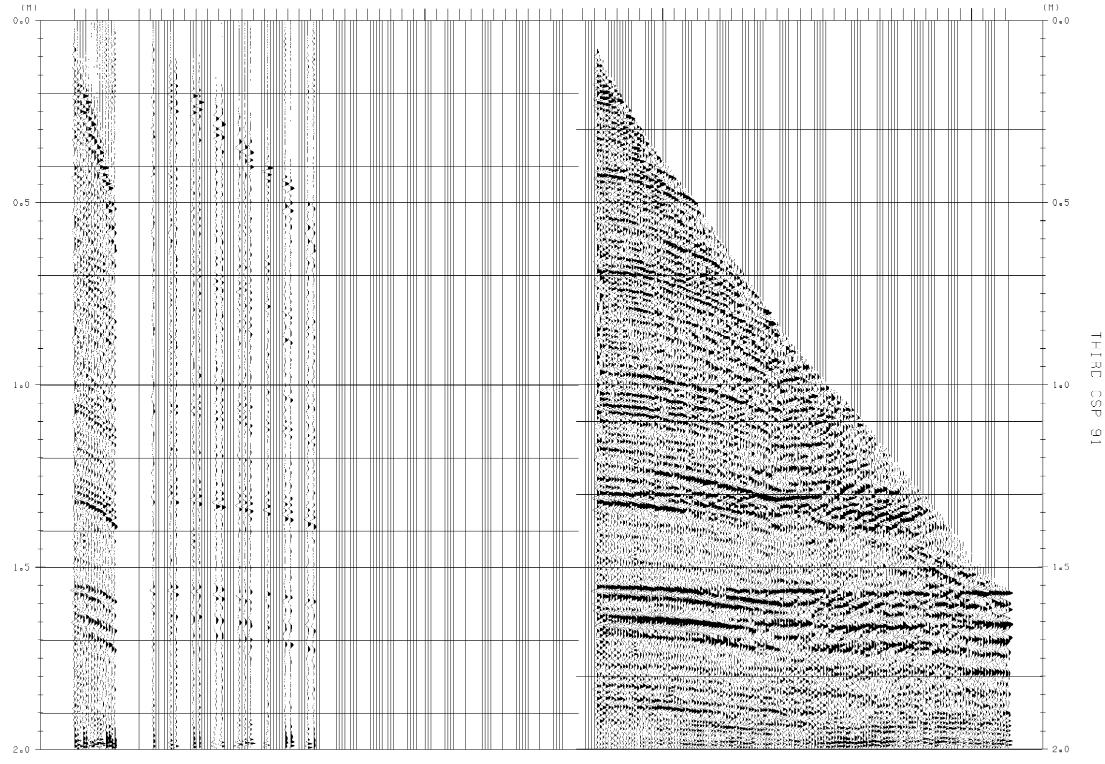
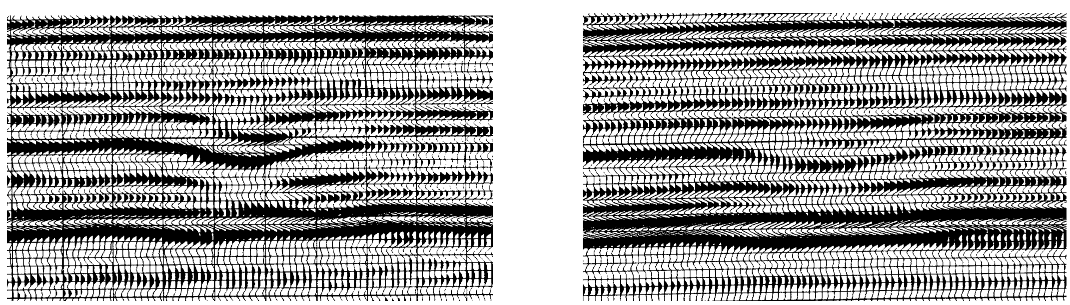


Figure 7. Comparison of a CMP gather, a CMP gather with traces at their true offset, and a CSP gather.



a. b.

Figure 8. Comparison of a) a traditional migration, and b) an EOM migration that incorporates the CSP gather of Figure 7.

Figure 9 contains a comparison of a super-CMP gather and a two-sided CSP gather. This example is taken from a marine line where the water bottom is at approximately 3.0s. The CSP gather was formed with a fixed equivalent offset applied to the entire trace. Consequently the entire input trace is summed into the gather. This approach captures a more complete zero offset image as is evident from the image of the sloping water bottom and its multiple at approximately 6 seconds. The CSP gather has a much greater offset than the CMP gather, and contains hyperbolic energy that extends to these large offsets. Reflections from dipping events are evident as maximums on the flank of the hyperbolas. An arrow in Figure 9 identifies one such example.

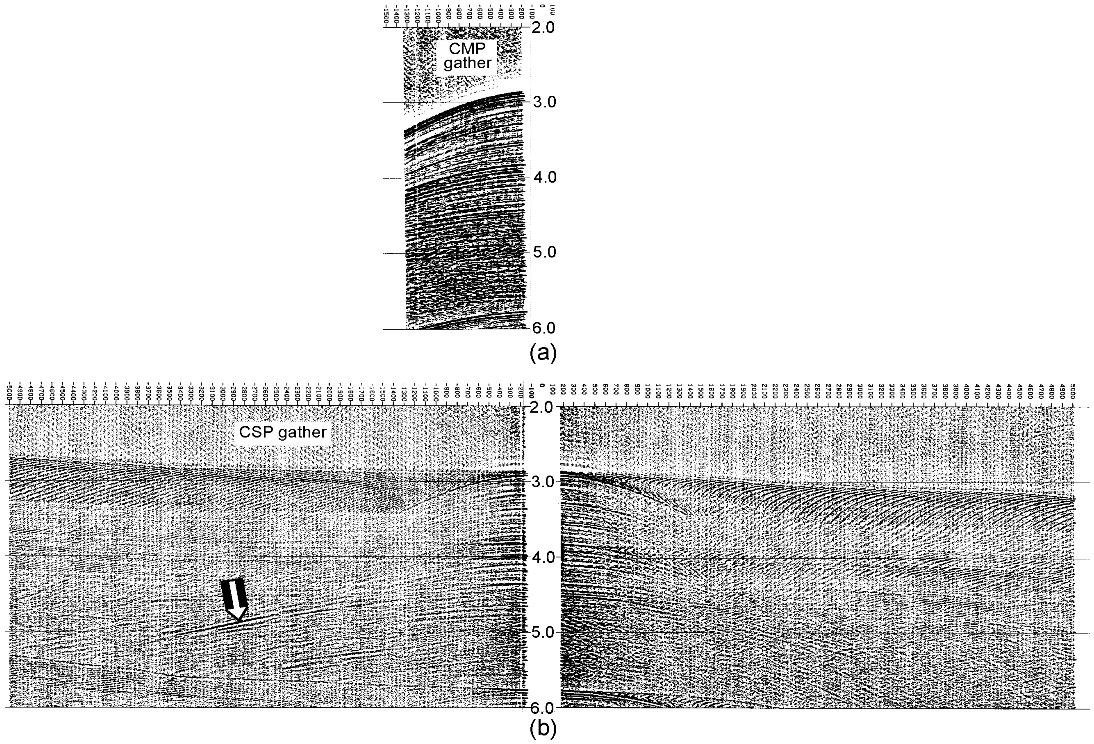


Figure 9. A CMP and CSP gather example taken from a marine line.

CONCLUSIONS

Energy from all traces within the migration aperture is included in each CSP gather. Thus, a CSP gather includes energy from the CMP gather at the same location as well as energy from all adjacent CMP gathers, including their zero-offset traces. The resulting zero offset imprint is a necessary part of the CSP gather formation, and is required for appropriate amplitude and phase on the final prestack migrated section. As with the familiar poststack migration case, the zero offset imprint has no detrimental effect on the migration.

Features on the CSP gather, such as the prow effect, are a necessary part of energy reconstruction. The prow effect is a combination of specular and diffuse energy, which is included in all prestack migrations and only becomes visible when CSP gathers are displayed. Energy from dipping reflections will form on the flank of the moveout hyperbolas. This energy is optimally positioned relative to scatterpoints and reflectors located at the migrated position and will reconstruct on the appropriate hyperbolas and cancel elsewhere.

REFERENCES

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