Equivalent offset prestack migration for rugged topography

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ABSTRACT

The process of prestack migration using equivalent offset and common scatter point gathers was initially based on input data converted to a horizontal datum (Bancroft et al. 1994). This short paper demonstrates how the process may be adapted for rugged topography, and allow the prestack migration to be from surface. Equivalent offset gathers were created for a model data set with a single scatter point in the subsurface. The results indicate that the algorithm works for both positive and negative datum shifts, although large shifts may move data of a single input trace over a wide range of offsets. An Alberta Foothills data set was prestack migrated using the rugged topography method. The initial results show excellent imaging of subsurface structure.

INTRODUCTION

Equivalent offset migration

Equivalent offset prestack migration (Bancroft 1994 a,b) creates an intermediate step in the Kirchhoff process by creating a gather from all the input traces for each output trace. The input traces that are gathered for a given output location are sorted by an offset that is based on the distances of the scatter point from the source and receiver locations. The collection of input traces is referred to as the common scatter point (CSP) gather, and is similar in function to the common mid point (CMP) gather. Both are defined for an output location, and both contain input traces that are sorted with offset. There is no time shifting of the input samples when they are sorted into the CSP gathers.

When the CSP gathers have been formed, each CSP gather may be scaled and filtered, or processed similarly to CMP gathers. Conventional algorithms such as noise and multiple removal, or velocity analysis, may also be used on the CSP gathers. Velocity analysis performed on the CSP gather will contain a more accurate velocity discrimination than those derived from CMP gathers. The improved discrimination results from using only one CSP gather, the high fold in the offset bins within the CSP gather, and offsets that are much larger than the source-receiver offset. Noise and multiples in the CSP gather now apply to the final prestack migration offsets, and not the offsets of CMP gathers in conventional processing.

Processing datum and the surface elevation

It has been recognized for a long time that migration and normal moveout (NMO) should be performed on time data with a processing datum as close to that actual surface as possible. Time migration and NMO assume that offset data are hyperbolic with offset. Consider Figure 1 which shows the one-way travel times for rays from the surface to a common reflector point (or a possible scatter point).

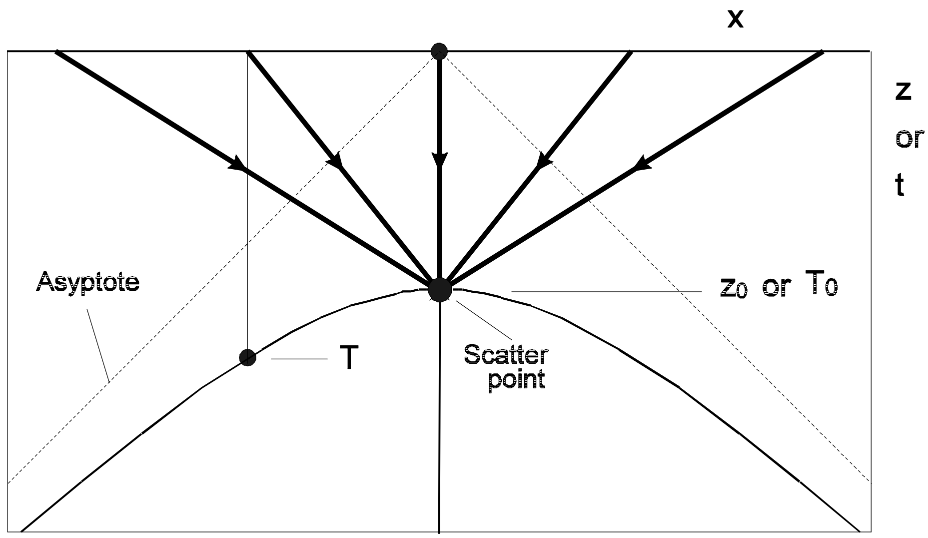


Fig. 1. One-way raypaths defining a hyperbola for NMO or time migration.

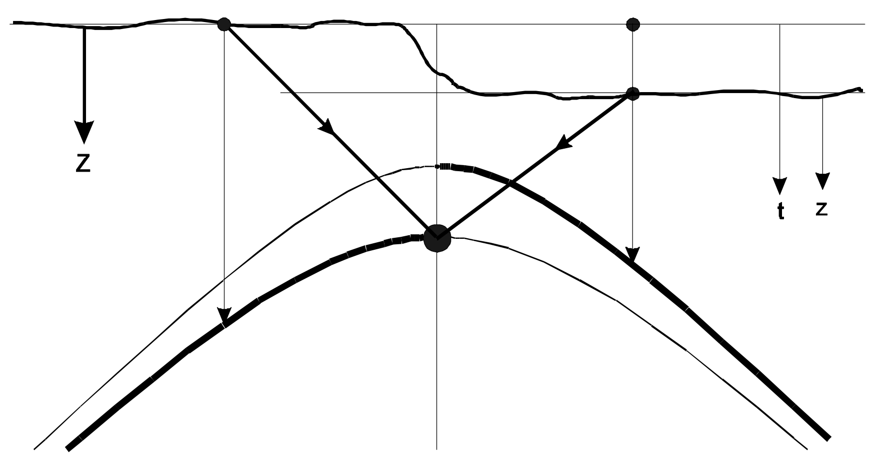
The geological structure in Figure 1 is assumed allow the use of the RMS velocity V_{rms} at the scatter point, to permit the simplification of linear raypaths for NMO and time migrations. Scaling of time allows plotting the time responce on the same figure. The one-way travel time for each ray is plotted below the surface location. The travel times T form a hyperbola for both NMO and time migration, according to

$$T^2 = T_0^2 + \frac{x^2}{V_{rms}^2} \tag{1}$$

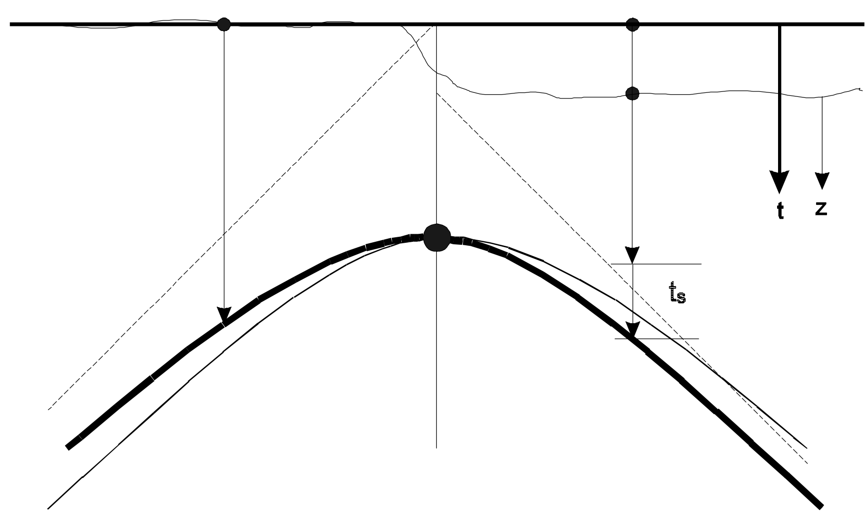
where x is the surface location of the ray relative to the center point, and T_0 is the zero offset travel time . When the offset x becomes large relative to the depth, the T_0 term defines the asymptotes for the hyperbola. The asymptotes are shown as dashed lines in Figure 1, and they intersect at the surface. This intersection point at the surface is a basic assumption for NMO and time migration, and requires the processing datum to be at or near the surface. Elevation and other static corrections may violate this condition (Profeta 1994) and lead to difficulties in evaluating velocities and sections that are not optimally focused.

Rugged topography

Rugged topography is a significant challenge to processing as the asymptotic assumption is violated. Consider Figure 2a which also shows a combination of depth cross section with a lower elevation on the right, and a one-way time section withtime zero defined at the higher elevation. Rays from the left are at a higher elevation and have a deeper recording time shown on the darker portion on the deeper hyperbola. Rays from the right have a shorter ray path and correspondingly shorter travel time as indicated by the shallower hyperbola. Figure 2b illustrates the effect of conventional processing using vertical elevation corrections and shows an increase in time t_s to accommodate the elevation differences. The diffraction portion on the left (and corresponding thin line on the right) are at the appropriate time for correct NMO or migration. The right side however shows the misfit of the shifted hyperbola and its corresponding asymptote (dashed), so that no NMO or migration will be able to focus its energy.



a)



b)

Fig. 2 . Raypath hyperbolas with elevation change, with a) showing the formation of two hyperbola from the same scatter point, and b) the hyperbolas after vertical static shifting.

The datum may be a constant elevation, or allowed to vary smoothly (or float), by filtering the input elevations with a spatial filter of a few spread lengths. This process is adequate when the elevation differences to the datum are less than a few station intervals. When the changes in elevation are much larger, distortion occurs in the processed data, and prestack migrations are required. Data processed to a floating datum should use a wave equation datuming technique (Berryhill 1979 and 1984) to convert the floating datum to a horizontal datum for migration.

Prestack migration by the Kirchhoff method allows the ray paths from the source to scatter point and the scatter point to receiver to be considered independently. The migration travel times are calculated from the surface elevation. This process requires the computation of RMS velocities for a given scatter point that are different for the source and receiver positions. These velocities may be computed from the RMS velocity at the datum of the scatter point, and adjusted to the appropriate source and receiver elevation using interval velocities.

The equivalent offset method of migration may also be performed from surface by computing the equivalent offset at a datum set for each CSP gather. The equivalent offset is found by equating the travel times to the scatter point from a zero offset source and receiver on the datum with the original source-receiver travel times, as illustrated in figure 3.

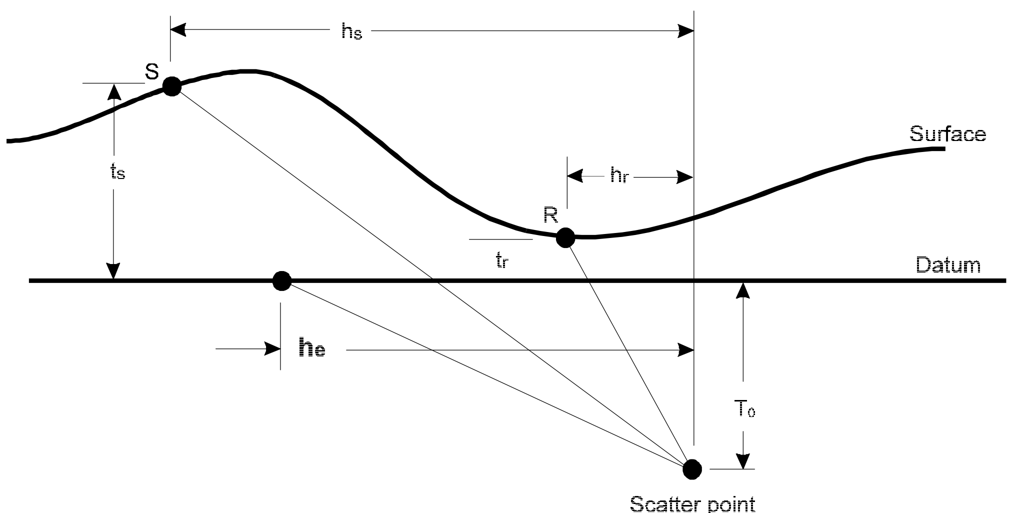


Figure 3. Ray paths, offsets, and travel times for computing the equivalent offset with rugged topography.

The total travel times for the original ray paths are computed from equation (2) using the appropriate offsets (h_s and h_r), the zero offset time for the source $T_0 + t_s$, the zero offset time for the receiver $T_0 + t_r$, and appropriate velocities for the source V_{srs} and receiver V_{rec} defined from the surface, i.e.

$$T = \left(\left(T_0 + t_s\right)^2 + \frac{h_s^2}{V_{srs}^2\left(T_0 + t_s\right)} \right)^{\frac{1}{2}} + \left(\left(T_0 + t_r\right)^2 + \frac{h_r^2}{V_{rec}^2\left(T_0 + t_r\right)} \right)^{\frac{1}{2}}, \qquad (2)$$

where t_s and t_r are the vertical travel times from source and receiver to the datum. The equivalent offset h_e is computed on the datum with velocity V_{sc} by solving,

$$T = 2\left(T_0^2 + \frac{h_e^2}{V_{sc}^2\left(T_0\right)} \right)^{\frac{1}{2}}, \qquad (3)$$

giving

$$h_e = V_{sc}\left(T_0\right)\left(\frac{T^2}{4} - T_0^2 \right)^{\frac{1}{2}}. \qquad (4)$$

IMPLEMENTATION OF RUGGED TOPOGRAPHY EQUIVALENT OFFSET MIGRATION

The implementation of equivalent offset method with rugged topographical data as described above assumes zero statics. Real data provides an additional challenge by including statics to account for velocity variations in the near surface that are not part of the migration velocity model. It is assumed that these statics have negligible wave field effect on the data. A number of approaches may be taken to include these statics.

The first method of including statics is to use regularly processed data and back out the statics attributed to elevation correction. The input trace may then be assumed to be recorded from surface with near surface corrections applied.

An alternate method is to is to model the near surface with some method, such as first breaks, and to add the computed time statics to the trace. A similar method adjusts the elevation of the source or receiver to accommodate the different travel time due to near surface effects.

EXAMPLES

A model of a single scatter point in a constant velocity medium was created to test the ability of the algorithm to handle simple datum shifts. Figure 4 is a perspective view of a portion of Cheops Pyramid, the impulse response of a single scatter point in the space of cmp distance CMP, half source-receiver offset h, and time t. Synthetic shot records of the spike response were created by calculating the travel times from the source to the scatter point to the receiver using the double square-root equation (see paper #23). Each trace contains only one non-zero sample at the calculated arrival time. More complex subsurface models can be created by modelling a series of closely spaced scatter points, including spherical divergence and obliquity effects, and convolving the trace with a suitable source signature.

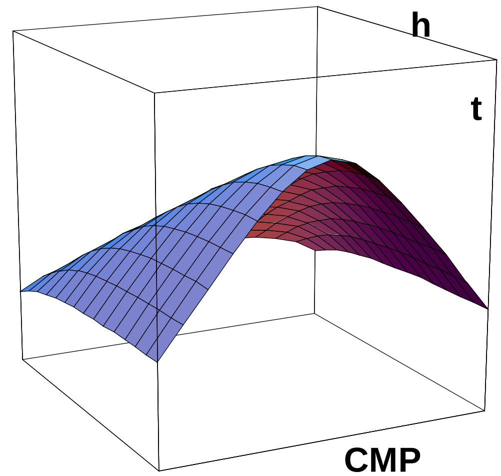
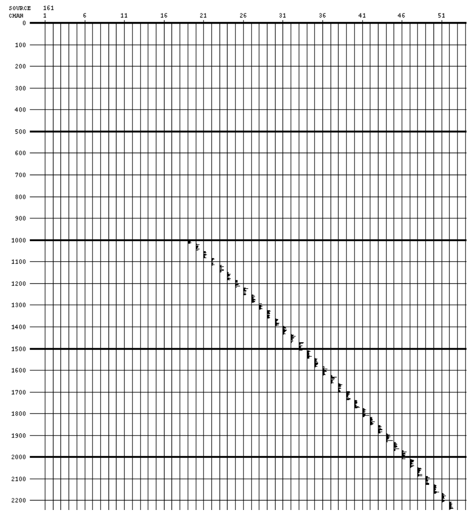


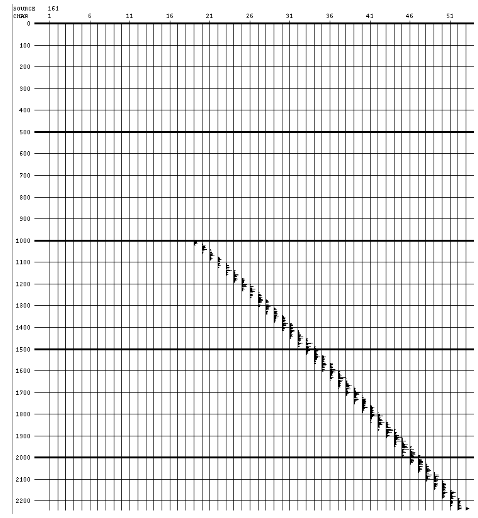
Figure 4. Perspective view of Cheops pyramid for a single scatter point.

The model data set consists of 6461 traces whose samples map out the surface of a full Cheops Pyramid 1000m on each side and 3 seconds deep. Each input trace in the migration aperture will map into each output CSP gathers. The scatter point is located at a depth of 600m in a medium with constant velocity of 1200 ms^{-1}. Figure 5 contains 6 CSP gathers that illustrate the hyperbolic moveout of the samples once mapped into the equivalent offset trace locations. Figure 5c is the CSP gather from surface at an elevation of 0m and velocity 1200 m^{-s}. Figure 5a is the CSP gather from a datum 200m below surface, while Figure 5e is from a datum 200m above surface,both at 1200 ms^{-1}. Note the change in the shape of the hyperbola required by the datum shift and the excellent focusing of the input trace samples. However, movement to a lower datum (below surface) pushes data away from the near offsets Figure 5b and 5f are CSP gathers collected from the lower and higher datums at a surface location 25m away from the true CSP location. Figure 5d is the CSP gathers at surface for a velocity of 1100 ms^{-1}. These CSP gathers show poorer focusing of the hyperbola as expected.

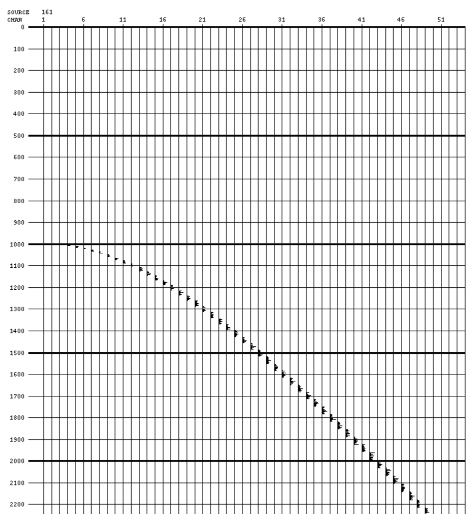
Rugged topography equivalent offset prestack migration was applied to the processing of a 2-D data set from the Alberta Foothills. The data set was the focus of a recent workshop at the SEG in Houston. Conventional processing was applied to determine surface consistent refraction and reflection statics. Near surface weathering statics were applied, with the result that the traces can be considered to lie on the surface over a layer equivalent to the replacement velocity to the base of weathering. Equivalent offset gathers were created at a datum level of 1600m. Two iterations of velocities were picked from semblances and percentage velocity stacks. The final prestack migrated section is shown in Figure 6.



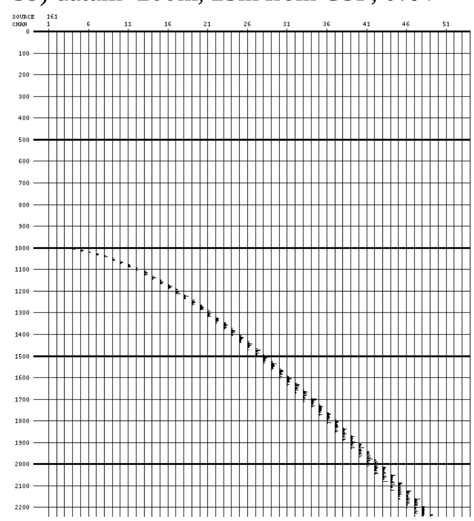
5a) datum -200m (below), 0%V



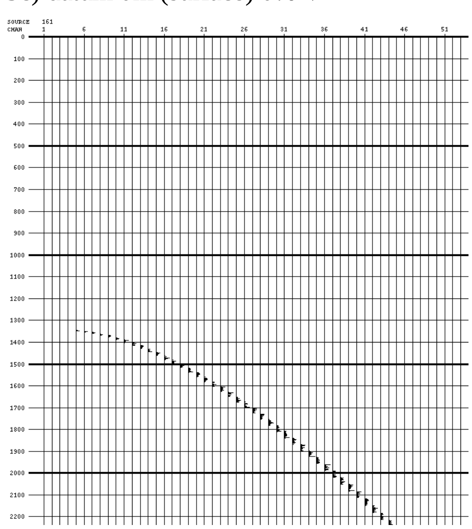
5b) datum -200m, 25m from CSP, 0%V



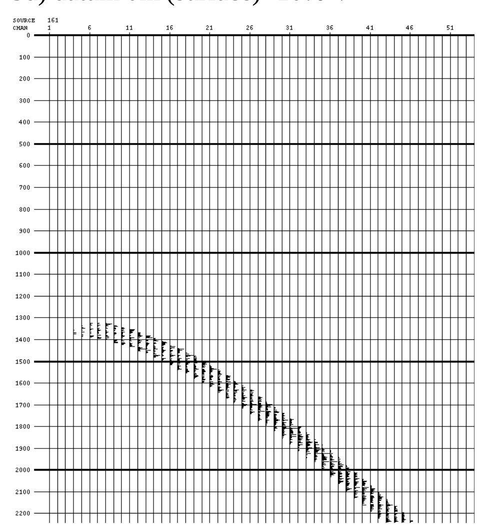
5c) datum 0m (surface) 0% V



5d) datum 0m (surface) -10% V



5e) datum 200m (above) 0% V



5f) datum 200m, 25m from CSP, 0% V

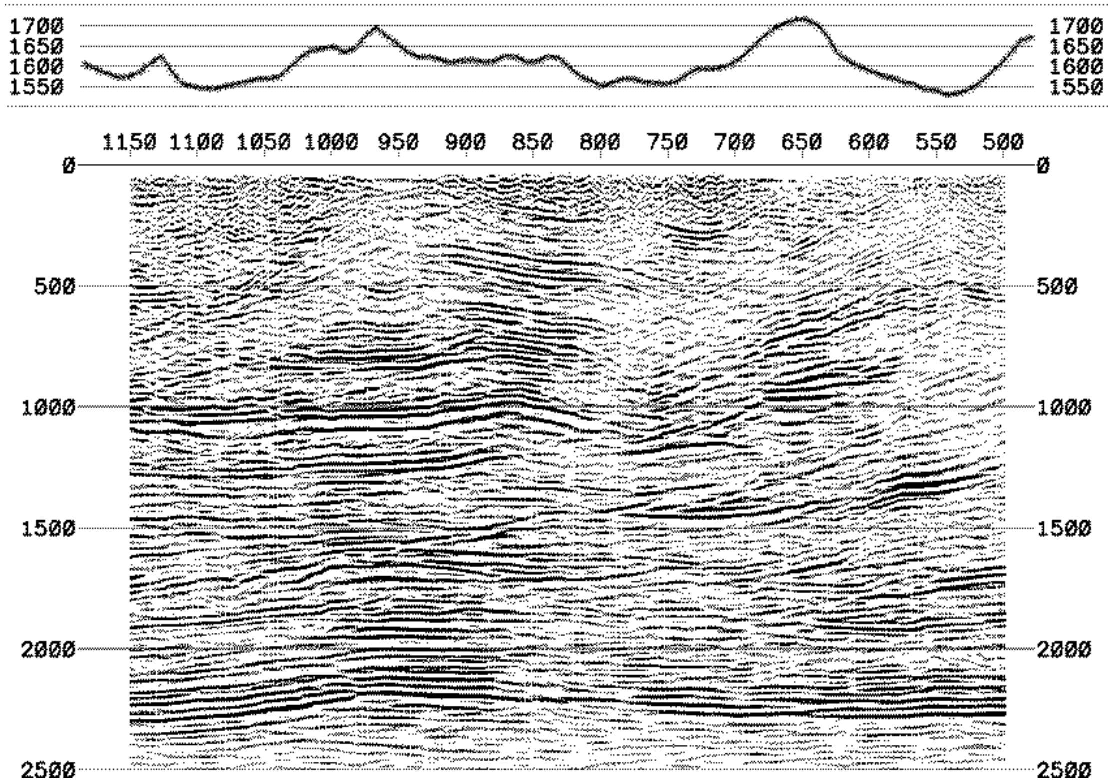


Figure 6: Rugged topography prestack migration of Alberta Foothills 2-D data set

CONCLUSIONS

The equivalent offset method of prestack migration may be simply adapted to migrate rugged topographies from surface. The method uses velocities computed for each source and receiver, and computes the equivalent offset at the datum of the scatter point location.

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