Equivalent offset migration for vertical receiver arrays

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ABSTRACT

The equivalent offset method of prestack migration is extended to include data that is acquired with vertical receiver arrays. Summing of input data directly to the vertical-array common scatterpoint gather (VCSP) is maintained with a single time shift (static) for each input trace.

INTRODUCTION

Seismic reflection energy is usually recorded with horizontal arrays of sources and receivers that tend to be parallel to the earth's surface. An exception has been the vertical seismic profile (VSP) where the receivers are placed at various depths in a borehole (see Wuenschel 1976 for an early review). More recently, vertical arrays of hypdrophones have been used in marine acquisition to acquire high quality seismic data (Hunter and Pullan 1990, Krail 1994). The large elevation difference between the sources and receivers requires special attention.

In surface seismic, small elevation changes are compensated by vertical time shifts of the seismic trace. Large elevation changes may be addressed by some form of wave-equation datuming, or by algorithms that migrate from surface. Kirchhoff migrations are particularly adaptable for this purpose as the travel times for the source and receiver ray paths may be computed to the actual surface locations.

EOM

The equivalent offset method (EOM) is a Kirchhoff prestack migration that initially forms common scatter point (CSP) gathers. Application of Kirchhoff NMO then stacking of these gathers complete the prestack migration. (Kirchhoff NMO is the application of NMO correction that includes the amplitude scaling and filtering of Kirchhoff migrations.) A beneficial feature of the EOM method is the CSP gathers are formed with no time shifting of the input data. This allows rapid copying of each input trace into the CSP gather of each migrated trace. An input trace is copied into bins of a CSP gather at equivalent offsets defined by the surface geometry, recording time and velocity. Only the transition times at which the input trace moves to a new offset bin are computed (Bancroft et al 1998).

An essential feature of the equivalent offset method is the reduction of the double square-root equation into a hyperbolic form of the travel time equation (1).

$$T = \left[\frac{T_0^2}{4} + \frac{(x+h)^2}{V^2} \right]^{1/2} + \left[\frac{T_0^2}{4} + \frac{(x-h)^2}{V^2} \right]^{1/2} = 2\left[\frac{T_0^2}{4} + \frac{h_e^2}{V^2} \right]^{1/2}, \qquad (1)$$

where T_0 is the vertical two-way traveltime from a scatter point to the surface, x the distance between the surface locations of the CSP gather and the source-receiver midpoint, h the half source receiver offset, and V the RMS type velocity. The equivalent offset h_e is the offset of a particular time T for a defined CSP gather.

Fowler (1997) showed that the hyperbolic simplification in equation (1) may contain an infinite number of solutions for various representations of the time T_{0e} and velocity V_e. The EOM solution equates T_{0e} with T_0 and V_e with V to allow the copying of the input trace with no time shifting.

It is the goal of vertical array EOM to maintain the simple copying of an input trace to the CSP gather without a complex time shifting of the input data, i.e. NMO or Kirchhoff time corrections.

RAYPATH ASSUMPTIONS

A number of raypath configurations were considered to define the value of T_{0e} and V_e in equation (1). A method that produces CSP gathers with velocities and times similar to conventional processing is illustrated in Figure 1.

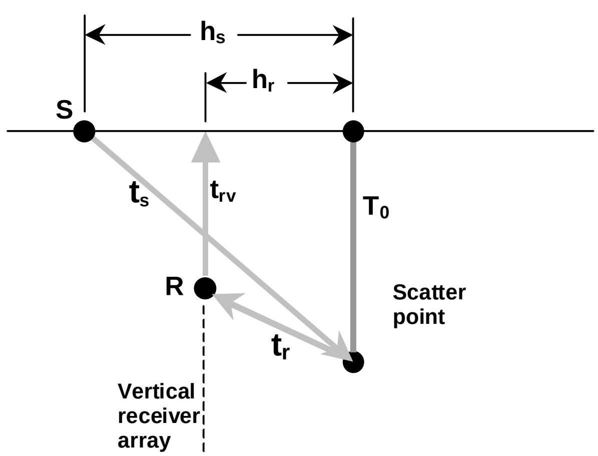

Figure 1 Raypath diagram showing the traveltimes of t_s, t_r, and t_{rv}. The vertical zero-offset time to the scatter point T_0 is also shown.

Figure 1 shows the source and receiver raypaths with travel-times t_s and t_r, which defined the total travel-time T on the corresponding input trace. An additional vertical ray path from the receiver to the surface datum is also shown with travel time t_{rv}. A new total travel time T_{srv} is defined for vertical array EOM as,

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$$T_{srv} = t_s + t_r + t_{rv} = \left[\frac{T_0^2}{4} + \frac{(x+h)^2}{V_s^2}\right]^{1/2} + \left[\frac{(T_0 - t_{rv})^2}{4} + \frac{(x-h)^2}{V_r^2}\right]^{1/2} + t_{rv} . \qquad (2)$$

which now includes the vertical travel-time t_{rv}. This new time is defined equal to the equivalent offset time defined in equation (3), i.e.

$$T_{srv} = 2\left[\frac{T_0^2}{4} + \frac{h_e^2}{V_s^2}\right]^{1/2} , \qquad (3)$$

and illustrated in Figure 2.

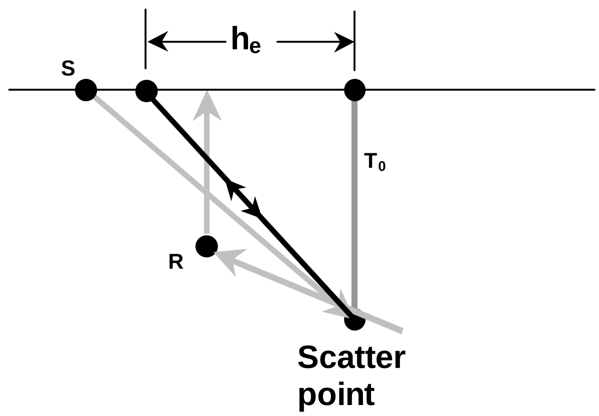


Figure 2 Ray path diagram showing the addition of the equivalent offset ray path.

The inclusion of the vertical time t_{rv} in equation (2) has the same effect of adding a static shift of t_{rv} to the input trace when it is added to the vertical array CSP gather (VCSP).

Note the different velocities of V_s and V_r in equations (2) and (3). V_s is the conventional RMS velocity that is defined at the scatter point for rays that travel to the surface. The receiver ray, however, does not travel to the surface and requires a new RMS velocity to be calculated for the time range from T_0 to t_{rv}, i.e.,

$$V_r^2 = \frac{V_s^2(T_0) \times T_0 - V_s^2(t_{rv}) \times t_{rv}}{T_0 - t_{rv}} , \qquad (4)$$

As in conventional EOM processing, the transition times at bin boundaries are computed. The input trace is then added to the corresponding bins in the VCSP gather. This process is repeated for all input traces and for each VCSP gather. Kirchhoff NMO and stacking completes the prestack migration of the VSP data.

DATA EXAMPLES

The CREWES Blackfoot 3-D VSP data was preprocessed with the sources at a flat datum. VCSP gathers were then formed for a North/South line for comparison with previously published material. A gather at the well location is shown in Figure 3. The resulting VCSP prestack migration is shown in Figure 4.

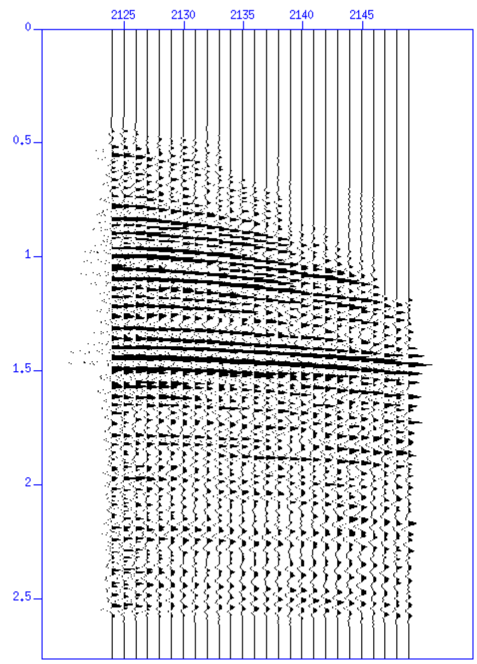


Figure 3 VCSP gather at the well site.

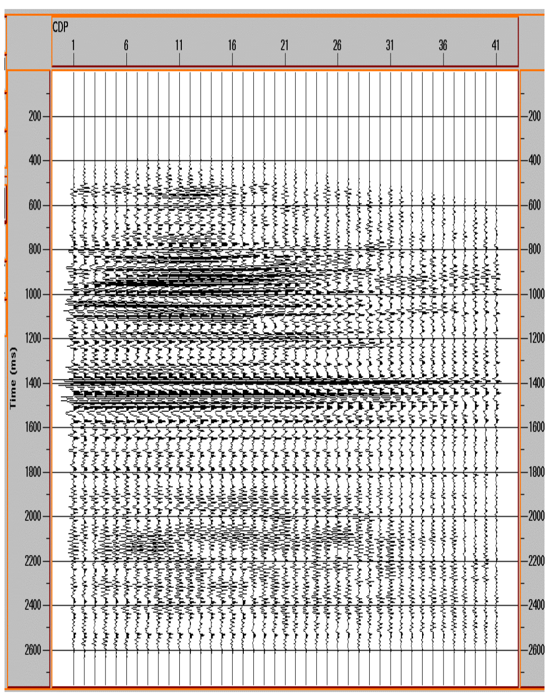
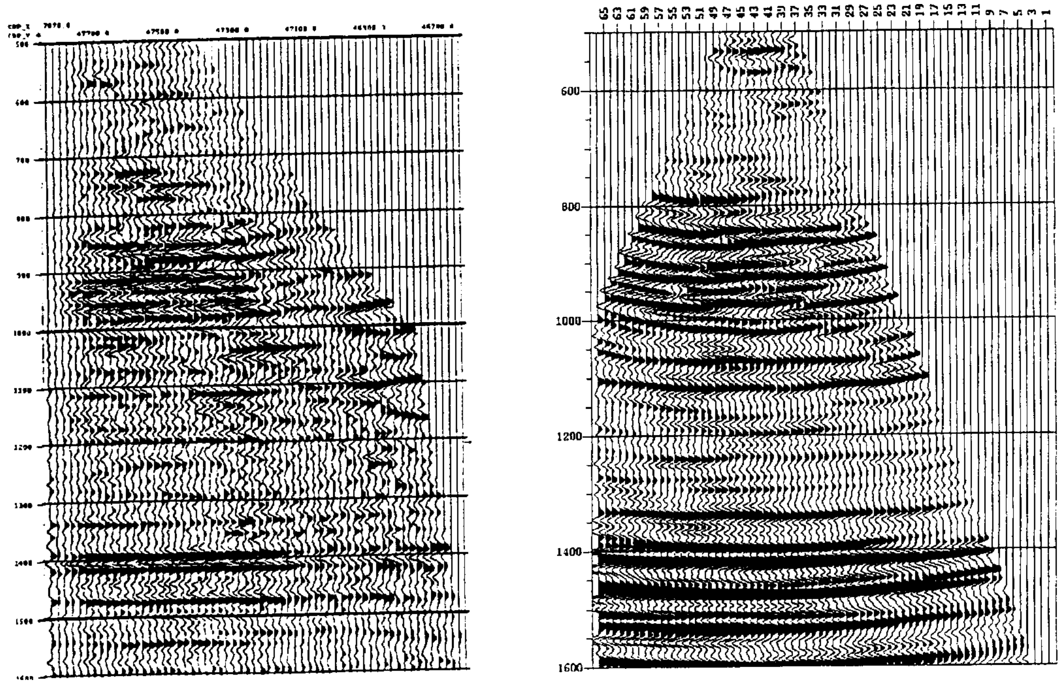


Figure 4 VEOM prestack migration

Figure 5 contains examples of processing by Bicquart (1998). Part (a) shows a stack of the data and (b) shows a prestack migration. A cut and paste comparison of the stack and prestack migration with the VEOM method is shown in Figure 6.



a) b)

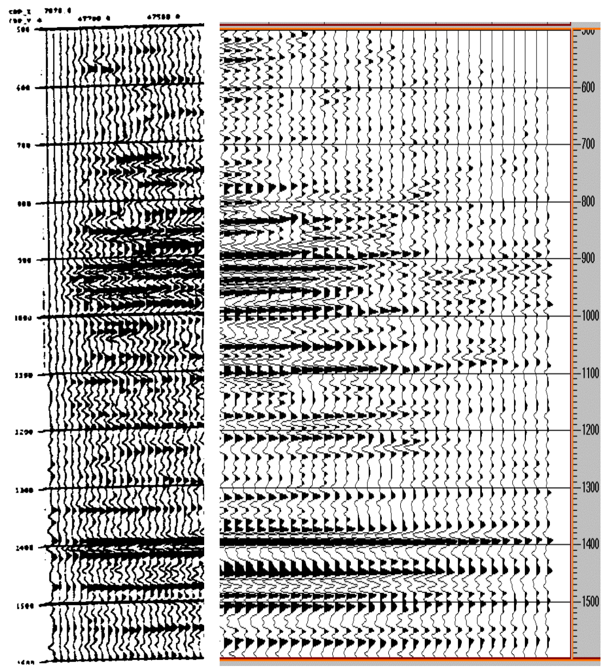
Figure 5 Processing of VSP data by Bicquart (1998) showing a) a stack and b) a prestack migration.

CONCLUSIONS

The EOM method of prestack migration was applied to VCSP data. Prestack migration gathers enable accurate velocities to be estimated.

REFERENCES

Bicquart, P., 1998, Application of Kirchhoff Depth Migration to 3D-VSP, Exp. Abs. SEG Nat. Conv., p 390-392



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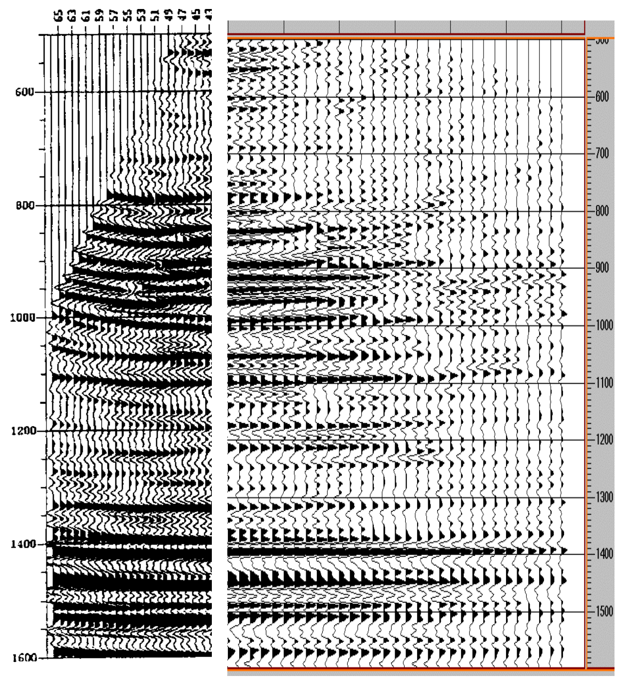

b)

Figure 6 Side by side comparison of VEOM with processing be Bicquart (1998), a) comparing the stack and b) comparing the prestack migration.