Common-Reflection-Point Stacking: A Macro Model-Driven Approach to DMO

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SUMMARY

In this paper a depth oriented approach to DMO - better referred to as "common-reflection-point stacking" - is presented. In this approach, the DMO operator design is based on ray tracing in a macro-model (or velocity-depth model) of the subsurface. To obtain an exact DMO operator for inhomogeneous media, an offset ray tracing for all offsets should be done. We will show that the multi-offset ray tracing can be approximated by merely zero-offset ray tracing, in combination with a simple move out expression. A description of the method will be presented. Some examples of "generalized DMO operators" are shown. Finally examples will be shown of the performance of the CRP stacking algorithm on synthetic data derived from inhomogeneous macro-models. A real data example will be shown as well during the presentation.

INTRODUCTION

In todays seismic data processing three main approaches are available and feasible. They are different branches in a processing scheme depicted in Fig. 1, which starts with the preprocessing of the seismic data and leads to a bandlimited reflectivity image of the subsurface, either in vertical time or in depth.

In order to get a practical view on the different approaches, we consider a dipping reflector in a constant velocity medium, see Fig. 2. The data acquired from this geometry enables us to demonstrate the features of the different processing methods, namely the CMP, the CRP and the CDP method.

The CMP method is the simple conventional processing of single-dip NMO plus common midpoint stacking. The method is robust but dip-selective and the reflection point is smeared. However, as can be observed in Fig. 2, the travel time compensation before stack is correct.

The CDP method is the full pre-stack migration - in this figure -accomplished by shot record migration. The CDP method is the only applicable technique when the hyperbolic moveout assumption is not valid (i.e. when media become arbitrary complicated).

The CRP technique - for homogeneous media also called the DMO method - is visualised in the middle column of Fig. 2. In the CRP method the main disadvantages of the CMP technique (dip-selectivity and the reflection point smearing) are addressed. Data from one shot-receiver pair is now corrected according to the zero-offset ray from the reflection point of that offset ray on the dipping reflector to the surface.

Note, that since the surface point corresponding to this ZO-ray will be different from the shot-receiver midpoint, the offset data will also be shifted in space. In other words, the reflection point smear in CMP processing is replaced by a midpoint smear in CRP processing.

Going from left to right in Fig. 2, we conclude that methods become more sophisticated and are based on less assumptions and/or approximations. However, the methods also become less robust, more complicated and computationally more intensive. In this abstract we will concentrate on the CRP technique.

In recent years DMO techniques have got ample attention in the literature. Although some attempts have been presented to generalize the DMO concept to depth-variable velocity models, the main emphasis has been put on the proper treatment of amplitudes in DMO processing.

We feel, however, that since the earth is far from homogeneous, the primary goal in proper DMO processing - or preferably: CRP processing - should be the proper treatment of travel times, the so called kinematic aspects of CRP. Once these kinematic aspects have been treated satisfactorily, the amplitudes can be addressed as well.

Following, we will present a scheme in which the conventional constant velocity DMO has been generalized to accommodate - within certain limits - data acquired from inhomogeneous media.

CRP STACKING, A MODEL DRIVEN APPROACH TO DMO

The aim of CRP stacking is to gather and process data according to their actual common-reflection-point. CRP processing transforms offset data into a real zero-offset section, while CMP processing transforms offset data into a stacked section, which is an approximation to a zero-offset section.

In order to explain the concept of CRP stacking, we consider the subsurface model depicted in Fig. 3.

Shown are also a shot position S, a geophone position G, a midpoint x_M and the travelpaths to an imaginary local dipping reflector, which does not necessarily exist. The difference between the reflection points R and R_1, belonging to the offset ray and zero-offset ray respectively is known as the reflection point smear. Levin (1971) derived an expression for homogeneous media, which formulates this smear Δx_M in terms of local reflector dip α, half offset h, medium velocity c, and zero-offset time T_{CMP} :

$$\Delta x_M = \frac{2 \sin\alpha}{c\, T_{CMP}} \cdot h^2 \qquad (1)$$

Based on this formula and on the conventional normal moveout equation the expression for the conventional constant velocity DMO operator can be derived easily. However, extension of this procedure to the subsurface model depicted in Fig. 3 is more subtle. Exact CRP stacking would imply application of the following procedure:

(i) define a subsurface - or macro - model.

(ii) for the specified midpoint and offset, perform for a range of dip angles an offset raytracing.

(iii) determine for each raytracing the reflection point and corresponding local dip.

(iv) trace a zero-offset ray from that reflection point to the surface.

(v) determine the traveltimes along the offset ray (T_h) and the ZO ray (T_{CRP}), the dip angle of the ZO ray with the surface and the lateral shift between the midpoint x_M and the position where the ZO ray intersects the surface. This information directly gives us the lateral and temporal shift to be applied by the CRP operator.

Since full offset raytracing has to be performed for each apparent dip angle and all offsets in every CMP gather, this is computationally an impractical procedure.
Fortunately there is a way to come around the offset raytracing when we give up some generality, by using two assumptions.
For each CMP gather we assume that the subsurface macro model is locally built up by a number of constant velocity layers separated by plane dipping interfaces (assumption (I)). The local boundaries are determined by the local dip of the interfaces of the real macro model around the zero-offset travelpath from the common-midpoint. For this type of macro models, the so called normal incidence wavefront approximation is valid (Shah (1973), Hubral and Krey (1980), Wapenaar (1985)). This implies that for small offsets (assumption (II)) the traveltime relation formulated by Shah (1973) is valid:

$$T_h^2 = T_{CMP}^2 + \frac{4h^2}{c_{RMS}^2} \cdot \cos^2 \psi_o \qquad (2)$$

Where T_h is the offset traveltime, T_{CMP} is the zero-offset traveltime from the common-midpoint, h is the half offset, ψ_o is the apparent dip angle and c_{RMS} is the rms-velocity along the zero-offset ray for dip angle ψ_o .

Expression (2) enables us to map traveltime T_h (see Fig. 3) along ray SRG to traveltime T_{CMP} along zero-offset ray R_1X_M. To accomplish complete CRP processing, we have to apply an additional traveltime correction equal to the time difference between T_{CRP} and T_{CMP} in Fig. 3, followed by a lateral shift equal to Δx_M.

It turns out that it is possible to derive approximate expressions for this lateral and temporal shift, based on the same assumptions used sofar. The derivation is quite lengthy. The interested reader is referred to Van der Schoot (1989) for details. The general form of the expressions for the lateral and temporal shift read:

$$\Delta x_M = A(\psi_o, T_{CMP}) \cdot h^2 \qquad (3)$$

and

$$\Delta T = T_{CMP} - T_{CRP} = \frac{2\Delta x_M \cdot \sin\psi_o}{c_1} \qquad (4)$$

in which $A(\psi_o, T_{CMP})$ is a parameter determined by <u>zero-offset</u> raytracing and c_1 is the interval velocity of the first layer.
Notice that,

1. Δx_M is proportional to the square of h, which means that no offset raytracing is needed . From the zero-offset raytracing the lateral shifts corresponding to all offsets are fully determined.
2. For a homogeneous medium it can be proven by simple substitution that expression (3) reduces to expression (1). In other words, the CRP processing as proposed here is fully compatible for homogeneous media with the conventional DMO.
3. The method described here is different - and in fact more accurated - than the CRP processing described by French (1985). French proposed to use expression (1), while using the dip-dependent rms velocity - to be determined via a coherency measurement - instead of the constant velocity c. We generalized however expression (1), thus including the actual reflection point smear per interface in the parameter A (ψ_o , T_{CMP}).

In summary, CRP processing involves the following procedure (see Fig. 3):

(i) define a macro model.

(ii) perform ZO raytracing at each

midpoint for a range of dip angles ψ_0, yielding $C_{RMS}(\psi_0)$ and $A(\psi_0, T_{CMP})$.

(iii) compute for each dip angle ψ_0 for all times the lateral shift ΔX_M and T_{CRP}, using formulas 3 and 4.

(iv) map the input data at T_h for offset h, to time T_{CRP} at position Q.

DISCUSSION

We will now evaluate the proposed CRP stacking scheme, using a synthetic data example. The model is shown in Fig. 4. We consider only reflection energy from the second interface. Note that for this single reflector the conventional CMP processing without constant-velocity DMO will give a better result than processing including DMO. The reason is that CMP processing is dip-selective but can therefore process one dip properly (if the overburden is not too complicated). The conventional DMO processing, however, is applied as being a multi-dip process but the underlying zero-dip NMO correction, based on the zero-dip rms velocity is wrong. Consider the result of conventional DMO processing - the zero-dip rms velocity varies laterally - of a sparse set of CMP gathers, see Fig. 5 (only in the middle of the figure we have full coverage). Note that we see the well known V-patterns associated with multi-offset CMP gathers after DMO processing. The far offsets, however, - which correspond to the maxima of the V-patterns - are entirely mispositioned.

Application of CRP processing on the same sparse set of CMP gathers, see Fig. 6, shows that one branch of the V-patterns aligns with the reflector dip, so that all offsets contribute to the final zero-offset section.

We may conclude that already in this simple case we see that CRP stacking leads to superior results.

During the presentation several synthetic data examples as well as applications to real data will be discussed.

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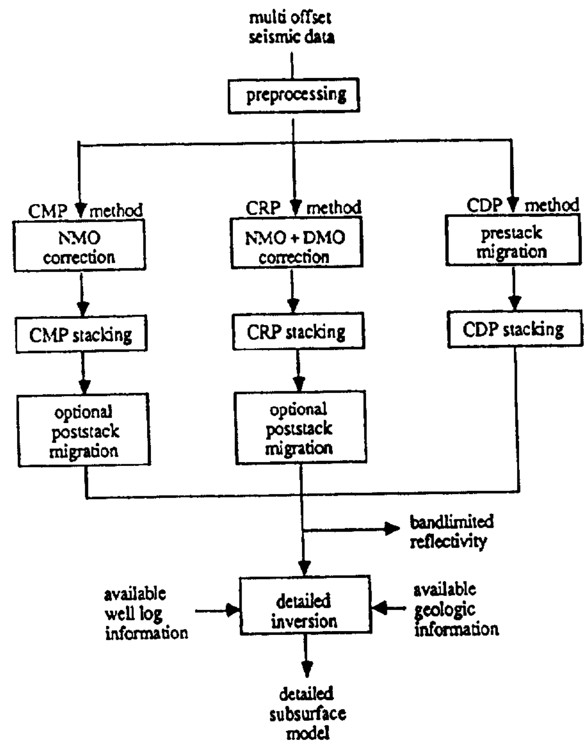

FIG. 1. Processing flow to obtain detailed subsurface model from multioffset seismic data.

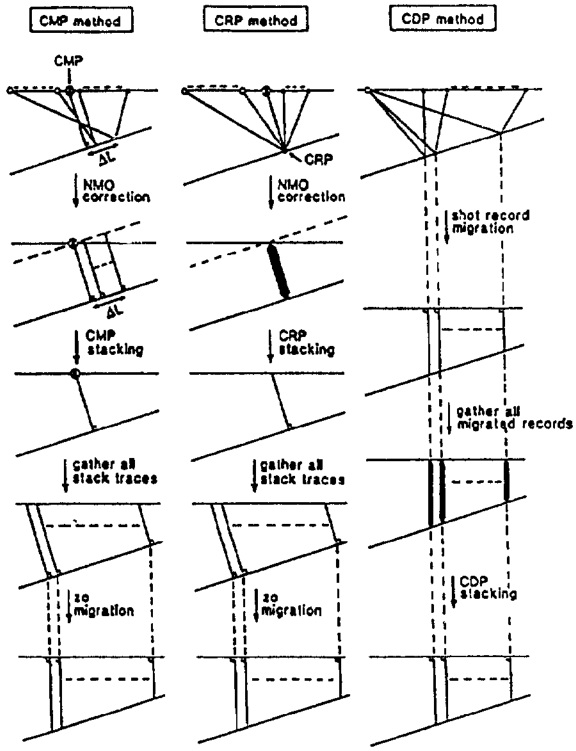

FIG. 2. One dipping reflector in a homogeneous medium, illustrating CMP, CRP, and CDP methods.

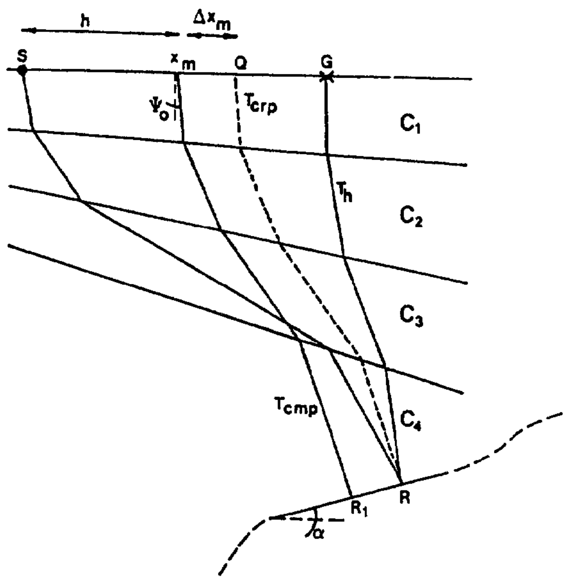

FIG. 3. Inhomogeneous macro model with offset ray tracing for a certain CMP location.

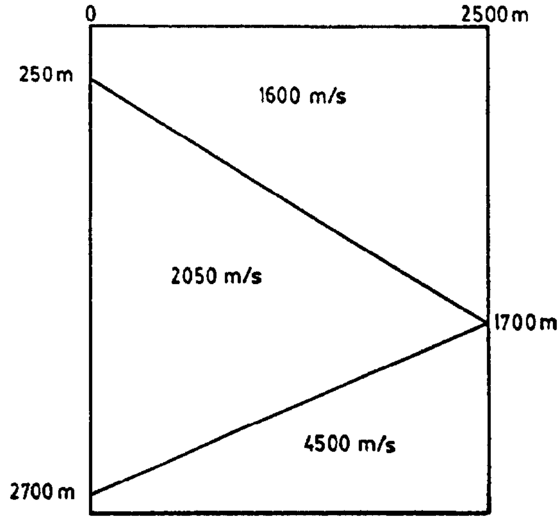

FIG. 4. Macro model. Reflections from second interface are considered.

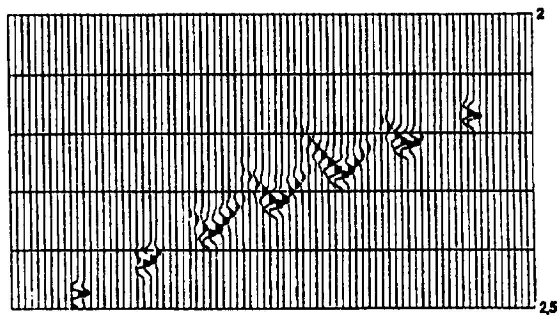

FIG. 5. Result of conventional DMO processing of a sparse set of CMP gathers.

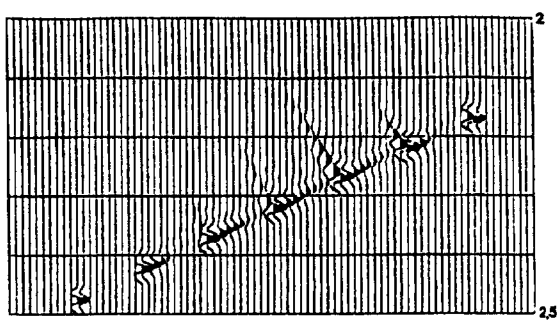

FIG. 6. Result of CRP processing of a sparse set of CMP gathers.