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Investigation of DMO algorithms during test-line processing: some recommendations

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Abstract: The Dip Movement processor in seismic data processing, or partial migration before stack is an auxiliary data processing correction that attempts to improve the quality of a seismic stack in the presence of reflection point smearing and conflicting dips. Performed correctly, velocity analysis after DMO is supposedly independent of dips and thus would allow an easier decision in, and perhaps more "correct" velocity pick. DMO algorithms available sometime back in this region are essentially Fourier transform methods, usually with some logarithmic stretch formulation or Integral/Summation (Kirchhoff-style) methods with provisions for spatial aliasing and dip constraints. Fourier transform methods are efficient and best applied to seismic data that are uniformly sampled in space. Kirchhoff-style methods are implemented instead with one input and one output trace at a time and are well suited for irregular survey geometries, missing shots, wide swaths, large variations in source-receiver distances and azimuths, large cable feathering angles, etc.

We recommend during test-line evaluation to compare the velocity spectrum at a preselected CDP location without DMO from the same location with DMO. A "better" velocity pick should be evident in the latter. We recommend next to subtract (a) the stacked section and (b) migrated section without DMO from the same with DMO. Assuming all non-DMO processing are identical, the difference sections should contain **no** horizontal reflections i.e. DMO should not in any way **alter** horizontal reflections. Diffraction hyperbolas will be better preserved with DMO in (a). Fault definitions are enhanced after migration with DMO in (b) because of this preservation. Lastly DMO should **not** be used solely for suppressing high velocity linear noise and lessening back scattered energy. Other filtering options are available.

INTRODUCTION

The seismic method plays an important role in upstream exploration activities in Malaysia. Seismic exploration is carried out in three main stages: data acquisition, processing and interpretation. This study is concerned with an aspect of seismic data processing.

A well established sequence of reduction steps is laid out for standard seismic data processing. The foundation of routine processing are deconvolution, stacking, and migration. There are also some auxiliary processes that help improve the effectiveness of these principle processes. This study examines one particular auxiliary process that enhances the stack quality in the presence of dipping beds, i.e. dip movement processing or DMO for short.

It has been acclaimed that DMO is an industrial standard for processing requirements. By that is thought to imply it should be specified in all routine processing jobs and seismic interpreters would be lost without it. This study investigates the efficiency and effectiveness of this 'accepted' industrial standard. We work on the premise that the old way is not wrong, but that there may be a better way for an effective evaluation of purported enhanced stack sections after DMO.

The primary objective of specifying the auxiliary DMO processor is to correct for reflection point smearing when dipping reflections are stacked. Implemented correctly, and in the right circumstances, the normal moveout for reflectors from a dipping bed will now stack independent of the dip angle. A very large number of algorithms, see for example Black *et al.* (1993), Cabrera and Levy (1989), Deregowski (1985), Hale (1984), Hale and Artley (1993), Jacubowicz (1990), Liner (1990) and Notfors and Godfrey (1987), have been developed to implement this correction. The most desired choice of algorithms is now in question.

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In this paper we:

1. review the underlying reasons for requesting for DMO processing;
2. examine the effects and behaviour of the DMO algorithm on seismic data; and
3. formulate a procedure for selecting and specifying DMO processing.

REASON FOR DMO PROCESSING

For completeness of description we show below that DMO is a processing correction unlike the classical meaning of the effect of dip on arrival times. Poor quality stacks arising from the method of CMP gathers due to reflection point smearing and the presence of conflicting dips are explained next. That DMO correction has no effect on zero-offset data is derived from a simple analysis of the DMO equation for dipping reflectors. An interesting property that arises from this is that the DMO correction or action is more pronounced for shallow structures.

The acronym DMO — Past and Present

The acronym DMO in present day geophysical vernacular stands for dip moveout processing or dip moveout (DMO) for short. It is a process within a seismic data processing sequence with the function such that after DMO, events with various dips stack with the same velocity. By this is meant that the section obtained after stack preserves all reflected and diffracted zero-offset energy such that after migration all structures would be properly focussed. Implicit within the DMO function would be such that horizontal reflectors are not affected, amplitudes of other reflection patterns if present, for example onlap, downlap, oblique, sigmoidal, etc., are not discriminated against, and all diffraction hyperbolas are preserved for the subsequent migration pass.

DMO as discussed here is different from the classical definition of dip moveout which is simply the effect of dip on arrival times. Telford *et al.* (1976), page 266 explains very concisely the diagrammatic relationship between normal moveout and classical dip moveout. Here (A) represents a reflection from a dipping bed; the alignment is curved and unsymmetrical about the shotpoint. (B) shows what would have been observed if the bed had been horizontal; the alignment is curved symmetrically about the shotpoint position owing to the normal moveout. (C) was obtained by subtracting the normal moveouts shown in (B) from the arrival times in (A). The resulting alignment shows the effect of dip alone; it is a straight line and has a time difference between the outside curves of 10 msec. Sheriff (1991), page 246 summarises the relationship between an asymmetric reflection travel-time hyperbola and the ray-paths traced due to a dipping bed in a constant velocity medium. Here the time displacement $\Delta\ t_d$ and the apparent velocities v_u and v_d can be measured directly from the travel-time curve. Dip moveout as used here in the classical sense is given by $\Delta\ t_d/\Delta\ _x$.

Reflection point dispersal

A basic fundamental strength of the reflection method in oil and gas exploration is the ability to form a stacked section from multiple common-midpoint gathers. It is true only for the instance of horizontal reflectors where the ray paths thus traced are symmetric about the midpoint. Where the reflector is dipping there is no longer a common reflection point.

Figure 1 illustrates diagrammatically the common-midpoint ray path relationship in a one layer dipping model. Notice that there is no longer a common reflecting point. Instead, reflection points associated with the common-midpoint traces are now spread out (or dispersed) over a distance. The length of this reflection point dispersal increases as the square of the offset and inversely proportional to the perpendicular depth from surface midpoint to the assumed common-reflection point or $\Delta\ L = h^2 \cos\theta \sin\theta/D$. As a consequence, stacking the traces from this gather will produce a reflection point smear because it is erroneously assumed that they contain only one reflection point. Industrial practise recommends DMO processing to precede stacking for lines acquired with dipping reflectors.

Recapitulating, DMO can now be defined as a process that creates apparent common-reflection point gathers from common-midpoint gathers such that the normal moveout (for reflectors from a dipping bed) need no longer depend on the dip angle. The process corrects for reflection point smear. After DMO, events with various dips will now stack with the same apparent velocity thus giving rise to a better stack.

Conflicting dips

Structural trends and depositional characteristics in basin environments are recognised on seismic sections as giving rise to distinct reflection patterns. Where two beds with different velocities or dips cross or overlap, it is often difficult to pick a velocity that will stack at that reflection point without undue discrimination of one against another. A subjective choice of one particular velocity might lead to undesired suppression of an adjacent reflector and subsequent reduction in stack quality of the reflector image.

Conflicting dips are often seen during the

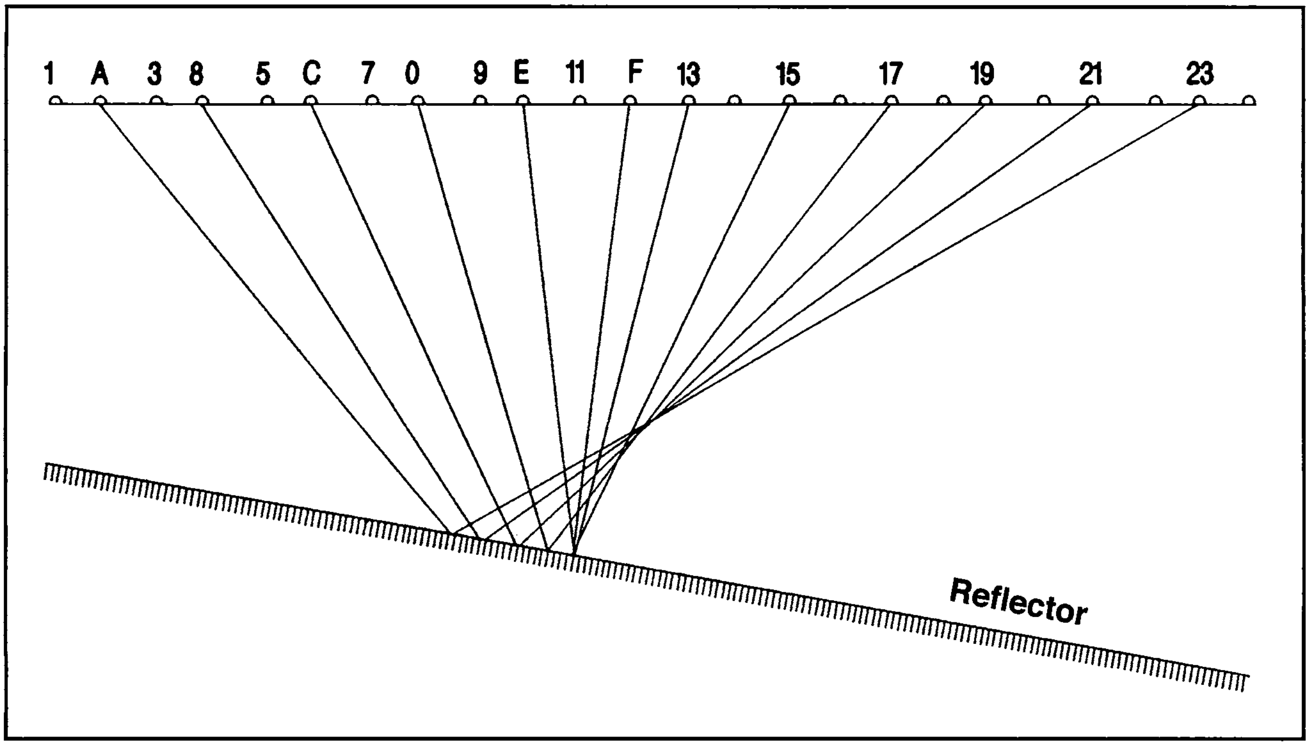

Figure 1. Reflection point dispersal in a one layer dipping model.

tedious and often subjective task of velocity picks for stacking purposes. Here velocity scatter is very commonly encountered. After DMO correction a more consistent trend is observed allowing a less subjective velocity pick and hence might give rise to a better stack after normal moveout.

Summarising, the DMO correction is a seismic data processing function which aims at providing

a) for reflection point smears arising from dipping beds (remember, we want a common-reflection point for a good CMP stack); and
b) a better velocity estimate in the presence of reflections from conflicting dips.

It is apparent thus that areas with large scale dipping features or conflicting dips or both (structural or depositional) would benefit with this correction incorporated into the seismic processing operations. We do not know at what scale of dips would it be necessary to do a DMO correction. This is complicated further by the presence of structural variations within the same data set, for example horizontal sequences broken up by structural changes in the same line.

NMO and DMO

It can be shown (see for example Levin, 1971; Yilmaz, 1987) that the travel time t(x) for a one-layer dipping reflector with dip θ is

$$t^2(x) = t^2(0) + x^2 \cos \theta^2/v^2 \qquad (1)$$

where x is the source-receiver separation and v the velocity of the medium. Rewriting

$$t^2(x) = t^2(0) + x^2/v^2 - x^2 \sin \theta^2/v^2 \qquad (2)$$

or

$$t^2(x) - t^2(0) = x^2/v^2 - x^2 \sin \theta^2/v^2 \qquad (3)$$

The first term on the RHS of (equation 3) is associated with normal moveout (NMO) and the second term with dip moveout (DMO) since it is related with the reflector dip angle θ. The above suggests that the DMO process is a two-stage correction viz: NMO followed by DMO (see Yilmaz, 1987). From (3) the DMO term has the following properties:

(a) no effect on zero-offset data (put x = 0)
(b) the steeper the dip, the larger the correction (sin 0 = 0, sin 90 = 1)
(c) the lower the velocity, v, the larger the correction (inversely proportional to v^2).

The above implies that the DMO process should have no effect on zero-offset data (x = 0) or horizontal reflectors (sin 0 = 0); increasing importance and significance for increasing dips (sin 90 = 1); and most noticeable for shallower events as lower velocities are found there. The last factor also suggests that a more noticeable DMO correction can be seen at the shallower parts of the seismic data which is often the zone of greater interest. Conversely should attention be only at greater depths, it might be perceived that the DMO correction becomes less significant.

RESULTS

We requested several service companies to provide us with eight panels displaying our intermediate test-line results. There are, in order of our preference for panel analysis:

(a) Stacked section with **no** DMO;
(b) Stacked section **with** DMO;
(c) Section (b) **minus** (–) section (a);
(d) Migrated section from (a) i.e. from **no** DMO stacked section;
(e) Migrated section from (b) i.e. from DMO stacked section;
(f) Section (e) **minus** (–) section (d);
(g) Velocity spectrum at a preselected location with **no** DMO; and
(h) Velocity spectrum at the same location **with** DMO processor inserted;

Non-DMO processing are to be the same as to facilitate comparison. Test-line results returned by the service companies are examined visually for 'geophysical' evidences of improvement as laid down earlier. These test-line results were taken from jobs carried out by the various companies at that time and not specifically for the purposes of testing the efficiency of the DMO processors. A more rigorous test might be perhaps to send the same line to various processing centres.

For ease of reference, the figures in these test-line examples are numbered 2(a) to 2(h) following the order given as in above. The geophysical effects are evident in the sequence 2(a) to 2(c); diffraction hyperbolas are better preserved with DMO and linear noise trains are reduced. The difference section 2(c) is instructive. Assuming that all processing parameters, with and without, DMO are identical, this particular algorithm was not able to preserve amplitudes; a lot of residual energy is evident in the ideally non-affected horizontal reflections. Next we expect a better stack to give a more focussed subsurface image after migration. This can only be achieved if all necessary diffracted energy is present in the stacked section. The sections 2(d) to 2(f) illustrate a better migrated section after DMO. The difference section 2(f) should be used to cross-check any 'real' improvement. A better constrained velocity trend is evident in the velocity spectrum after DMO. Figures 2(g) and 2(h) illustrate this effect and reinforces the stacking principle that poor velocity definitions inevitably cannot produce a 'good' stack.

CONCLUSIONS AND RECOMMENDATIONS

We summarise:

1. DMO or partial migration before stack is an auxiliary data processing correction that improves the quality of a seismic stack in the presence of
   (a) reflection point smearing; and
   (b) conflicting dips.
2. Performed correctly, velocity analysis after DMO is independent of dips and allows an easier or 'correct' velocity pick.
3. DMO should not in anyway **alter** horizontal reflections.
4. DMO is implemented using either
   (a) Fourier transform methods, usually with some logarithmic stretch formulation; or
   (b) Integral or summation (Kirchhoff-style) methods with provisions for spatial aliasing and dip constraints.
5. Fourier transform methods are efficient and best applied to seismic data that are uniformly sampled in space.
6. Kirchhoff-style methods are implemented with one input and one output trace at a time and are easily adapted to irregular survey geometries, missing shots, wide swaths, large variations in source-receiver distances and azimuths, large cable feathering angles, etc.

We formulate next a more rigorous test-line procedure for specifying the DMO processor.

We recommend:

1. Compare the velocity spectrum at a preselected critical CDP location without DMO from the same location with DMO. A 'better' velocity pick should be evident in the latter.
2. (a) Subtract the stacked section without DMO from the same section with DMO; and
   (b) Subtract the migrated section without DMO from the same with DMO.

   Assuming all non-DMO processing in (a) and (b) are identical, the difference sections should contain **no** horizontal reflections. Diffraction hyperbolas will be better preserve with DMO in (a). Fault definitions are enhanced after migration with DMO in (b) because of this preservation. Take some extra time also to compare the migrated sections with and without DMO to see whether there is any 'real' improvement.
3. DMO should **not** be used solely for suppressing high velocity linear noise and lessening back scattered energy. Other filtering processes are available.

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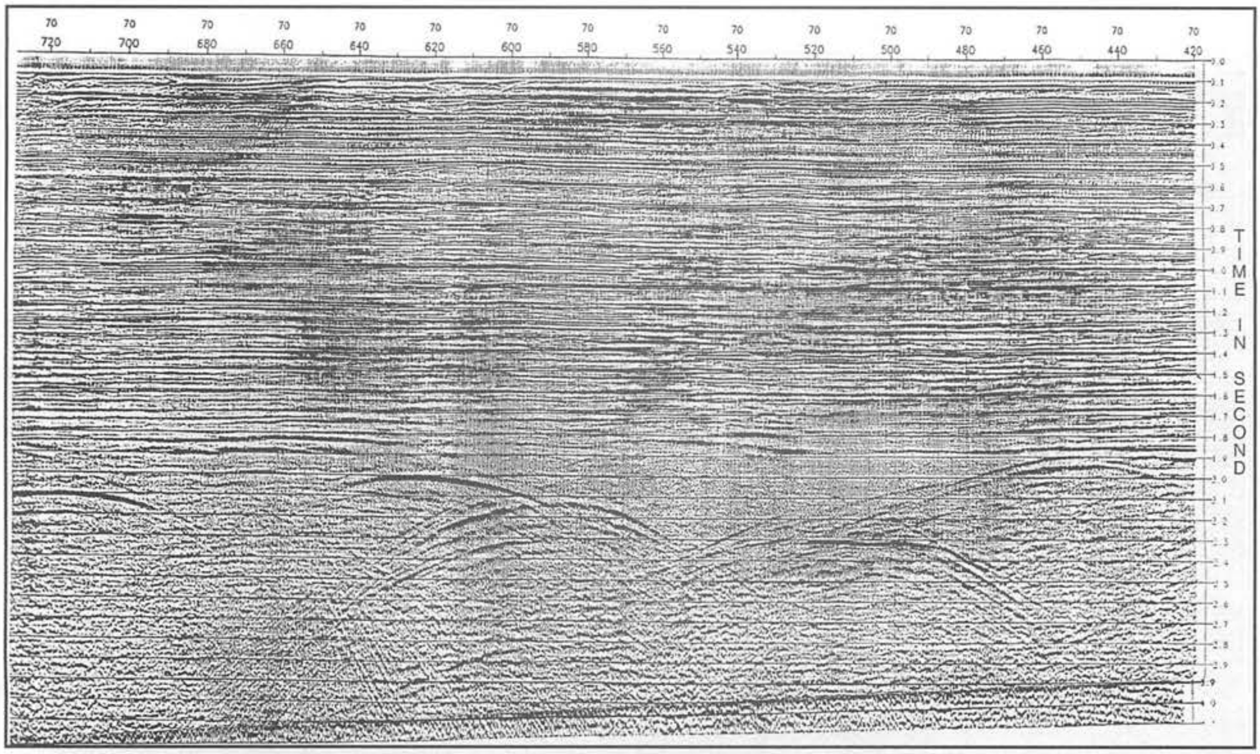

Figure 2a. No DMO stack.

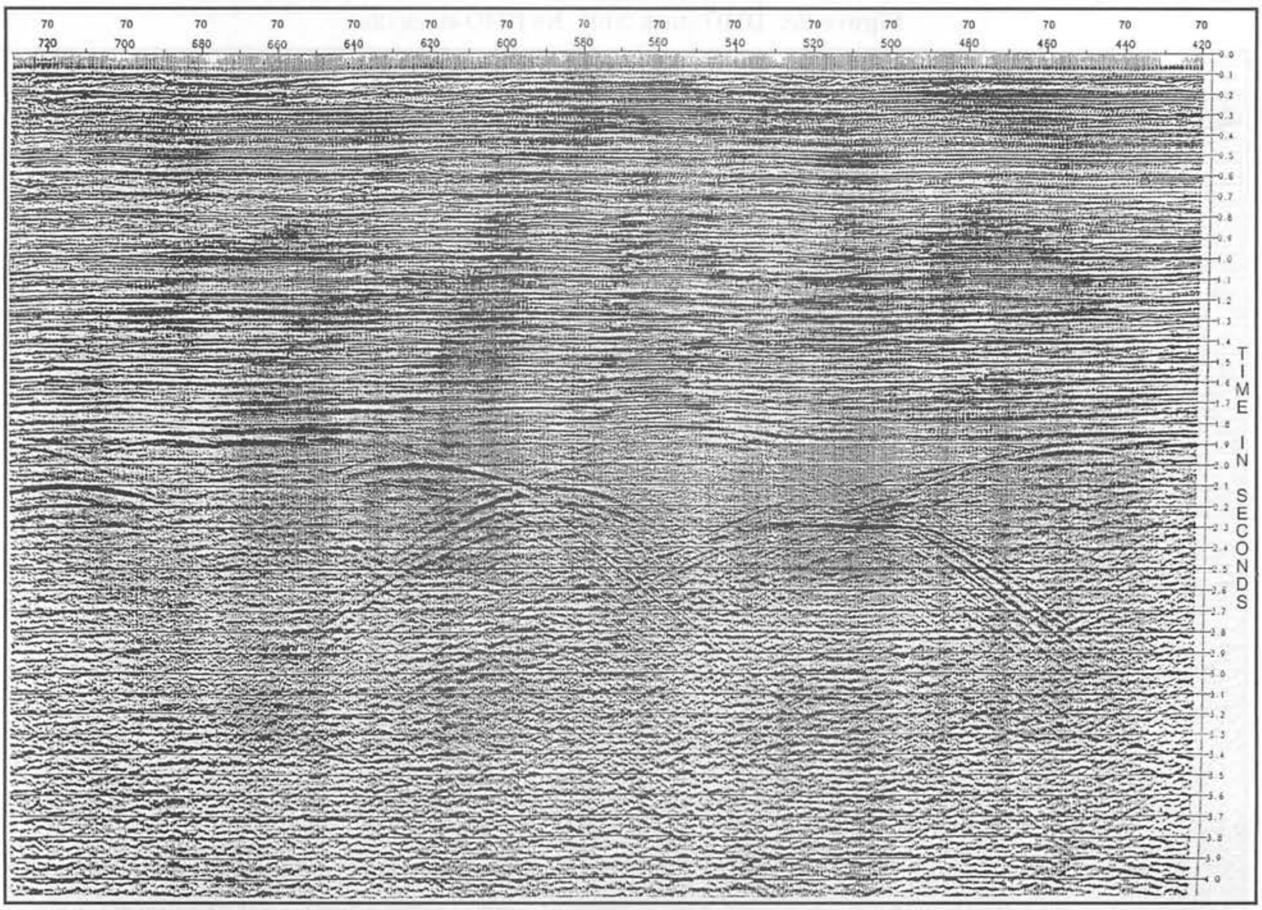

Figure 2b. DMO stack.

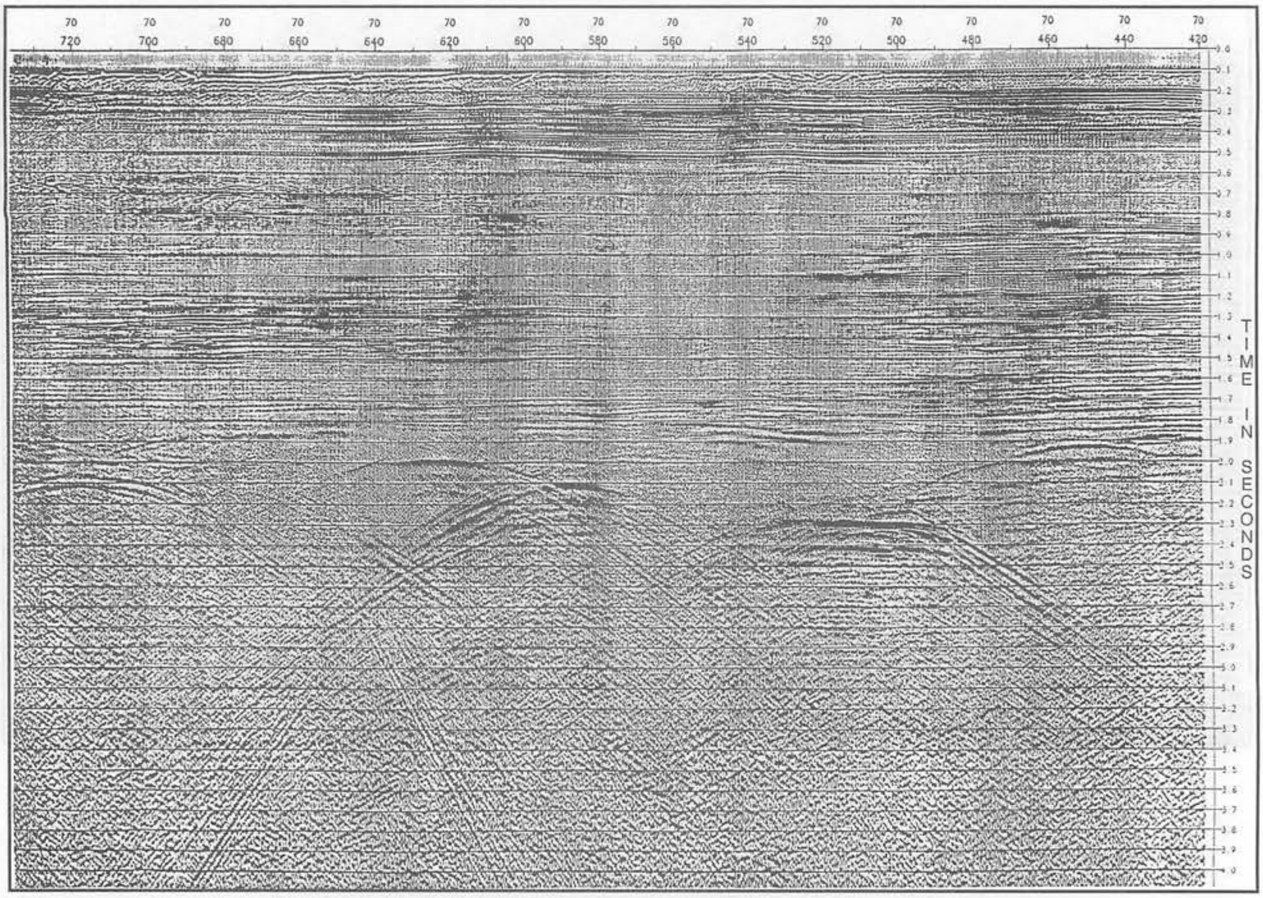

Figure 2c. DMO stack 2(b) – No DMO stack (2a).

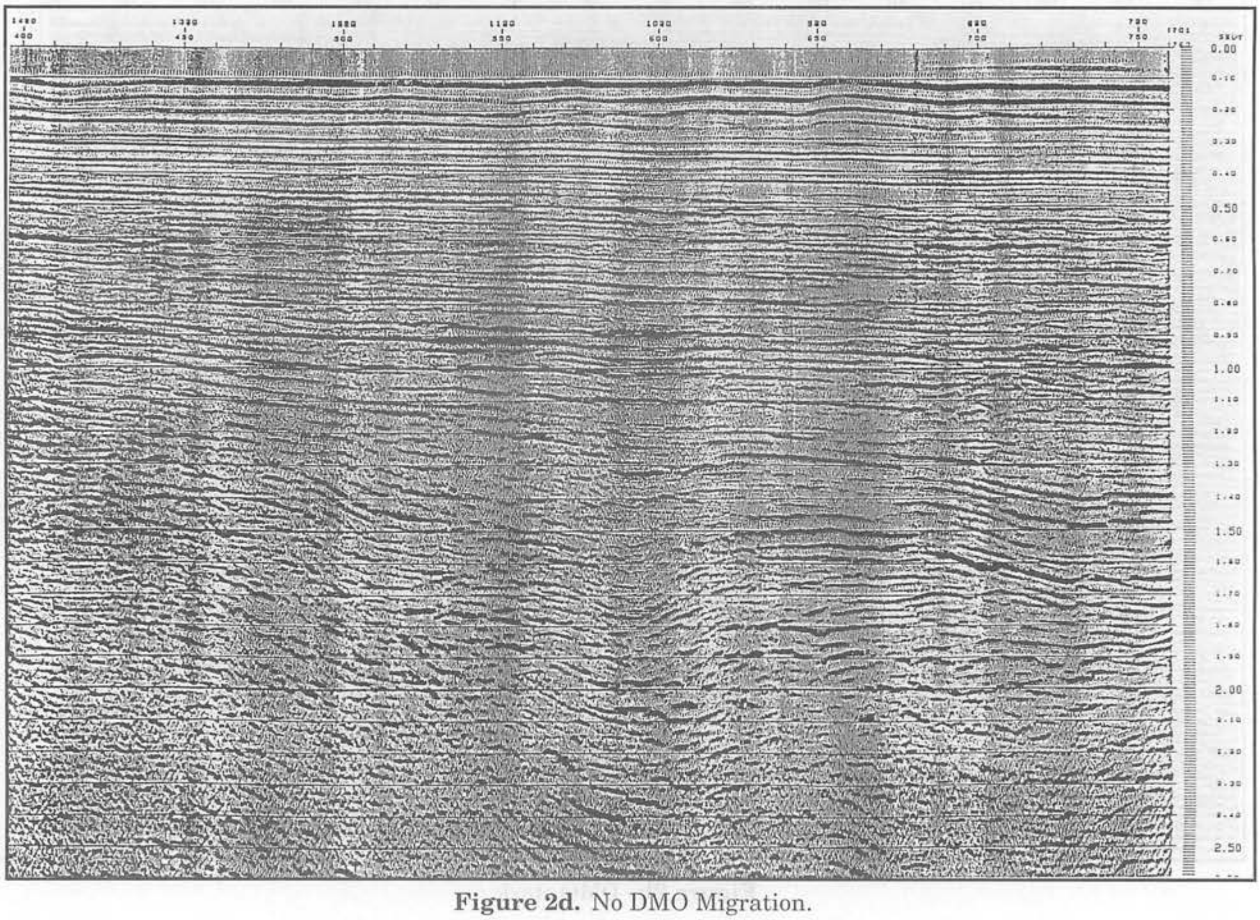

Figure 2d. No DMO Migration.

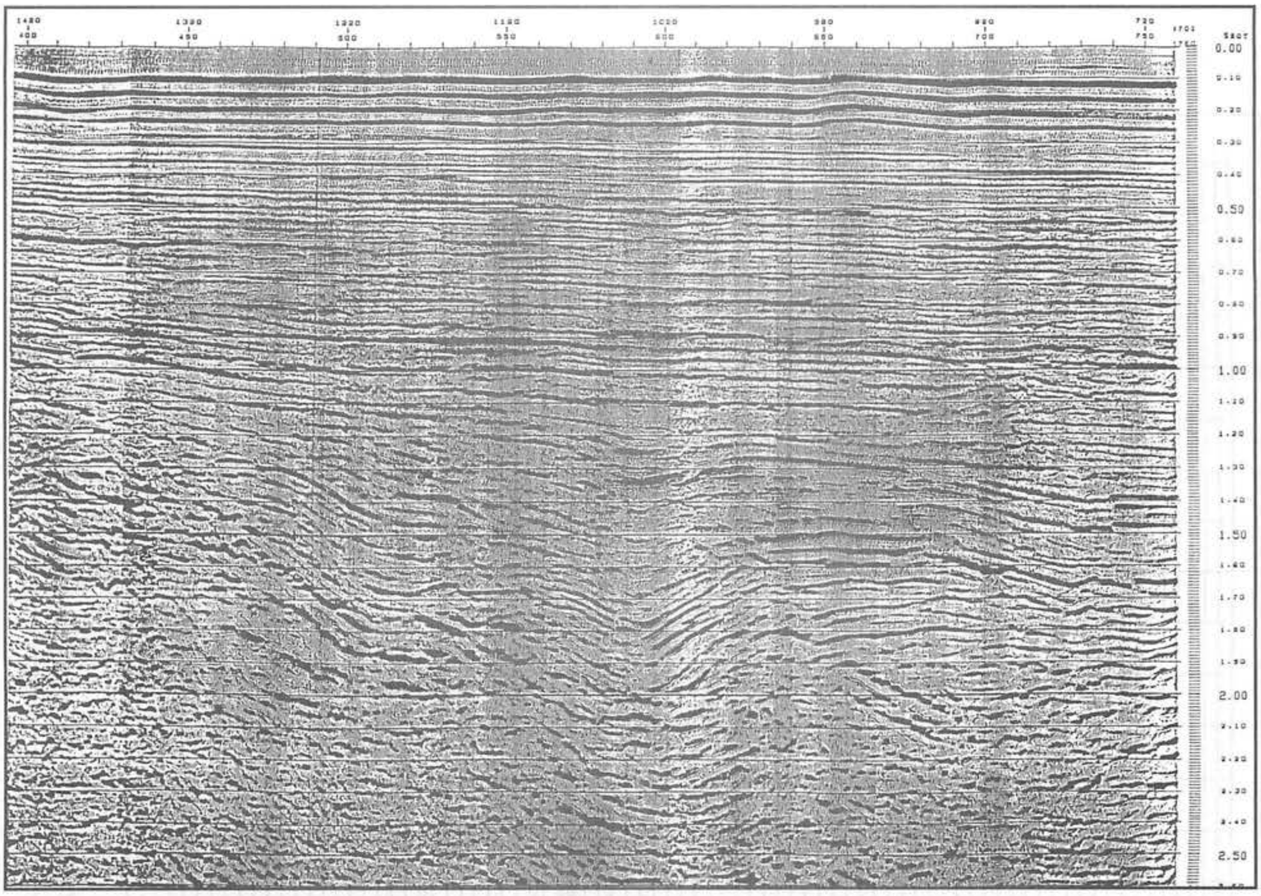

Figure 2e. DMO Migration.

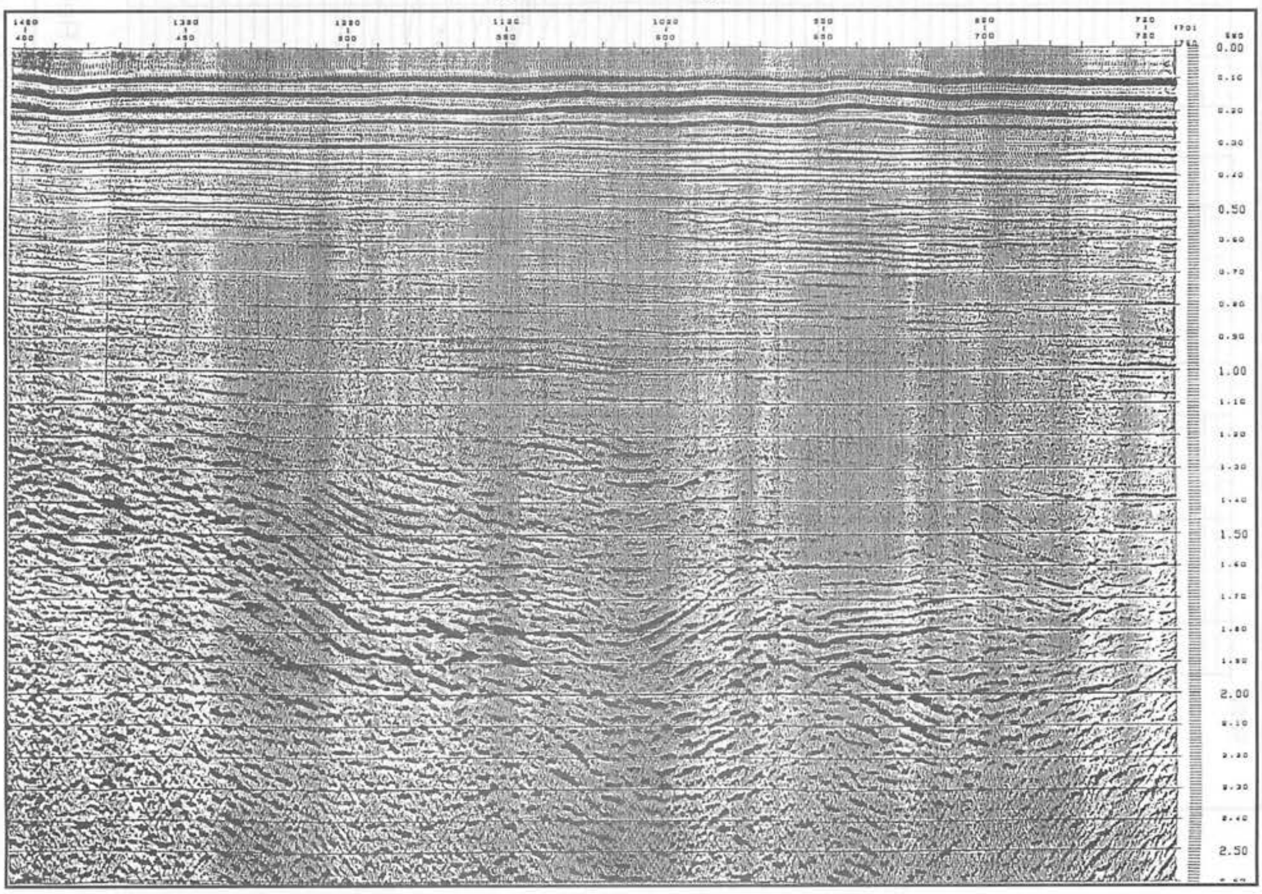

Figure 2f. DMO Migration – No DMO Migration.

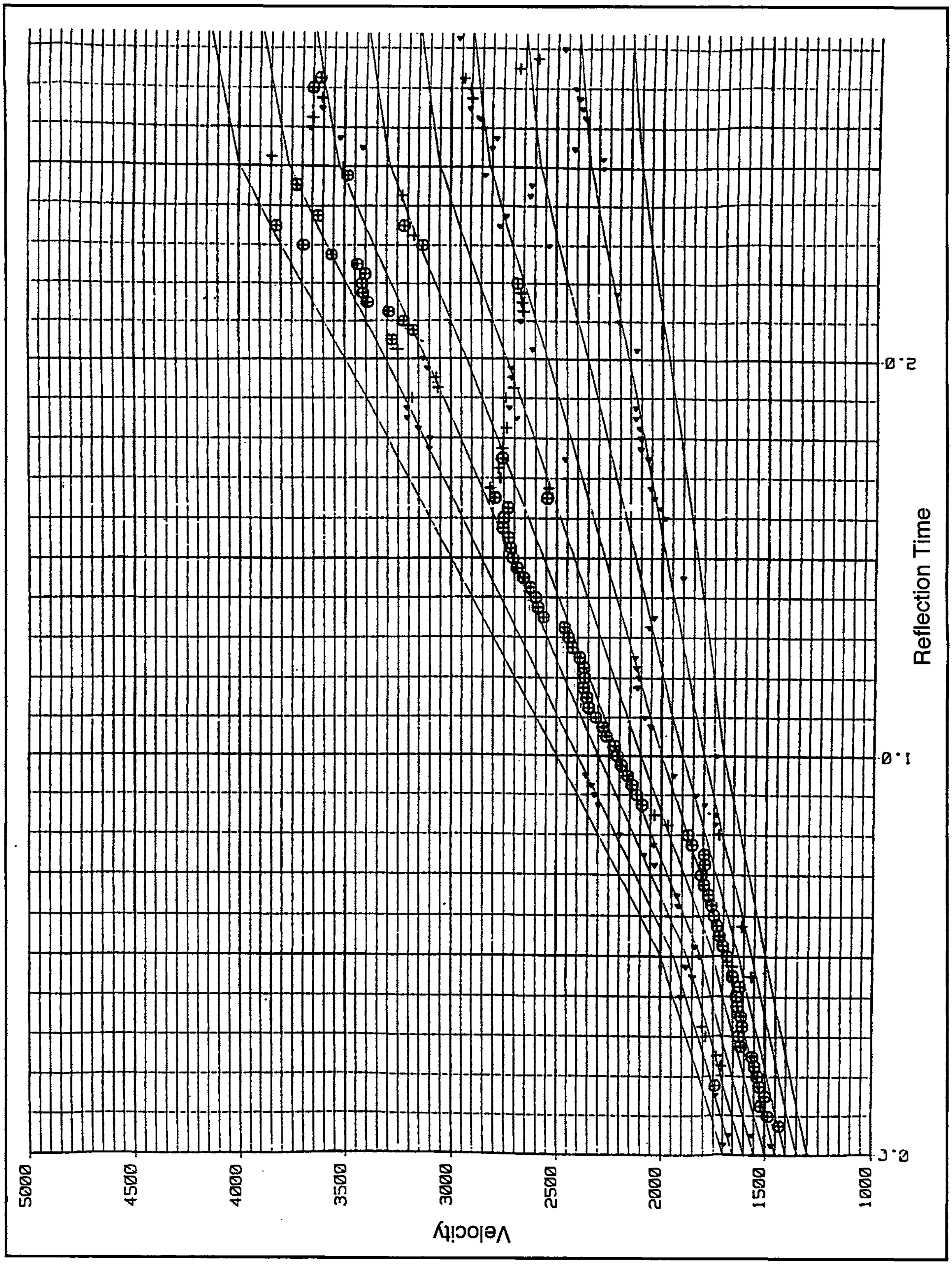

Figure 2g. Velocity spectrum with no DMO.

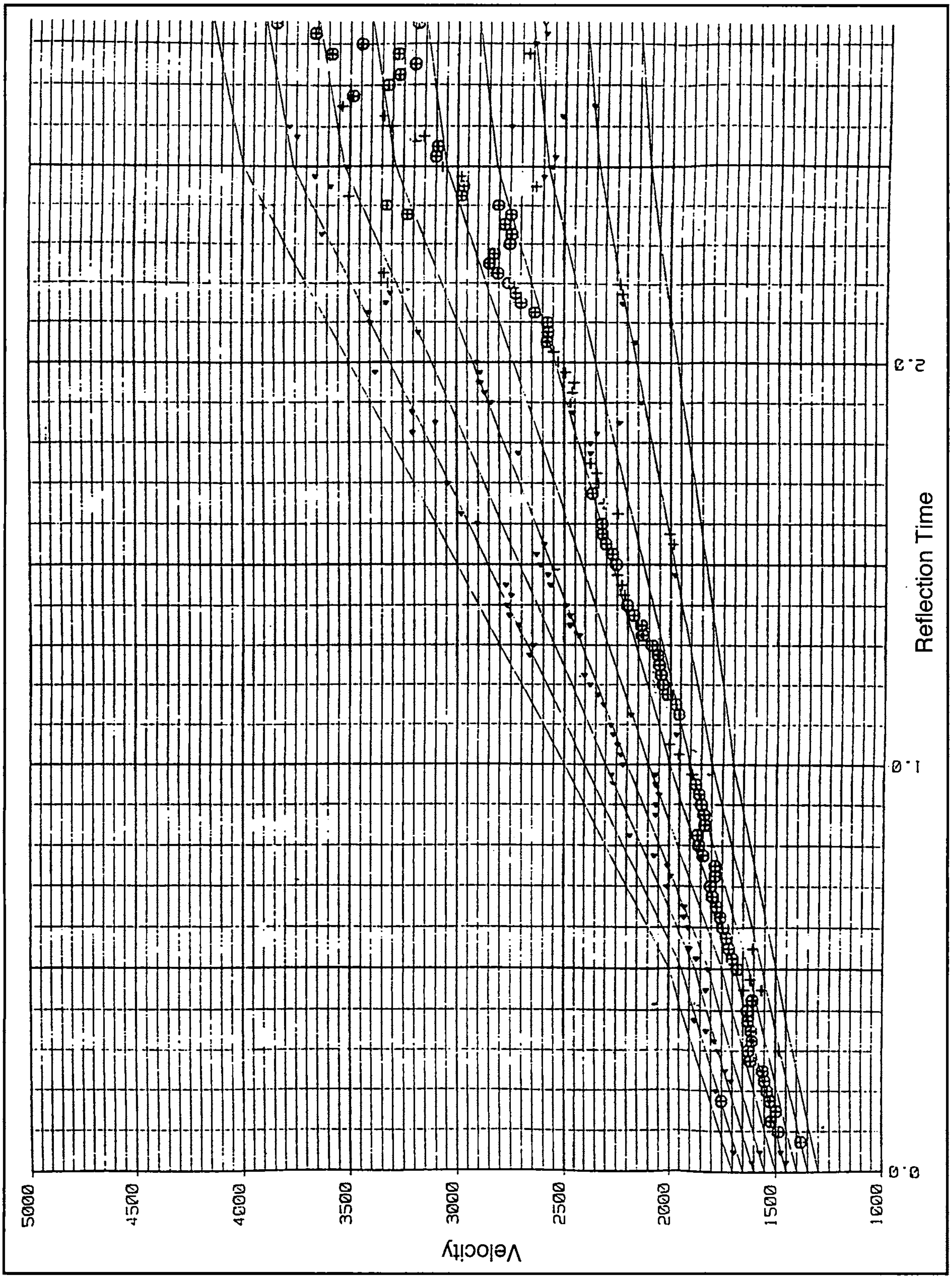

Figure 2h. Velocity spectrum with DMO.

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