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VELOCITY-STACK PROCESSING

Hız-Yığma İşlemi

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ABSTRACT

A conventional velocity-stack gather consists of constant-velocity CMP-stacked traces. It emphasizes the energy associated with the events that follow hyperbolic travel time trajectories in the CMP gather. Amplitudes along a hyperbola on a CMP gather ideally map onto a point on a velocity-stack gather. Because a CMP gather only includes a cable-length portion of a hyperbolic travel time trajectory, this mapping is not exact. The finite cable length, discrete sampling along the offset axis and the closeness of hyperbolic summation paths at near offsets cause smearing of the stacked amplitude along the velocity axis. Unless this smearing is removed, inverse mapping from velocity space (the plane of stacking velocity versus two-way zero-offset time) back to offset space (the plane of offset versus two-way travel time) does not reproduce the amplitudes in the original CMP gather. The gather resulting from the inverse mapping can be considered as the model CMP gather that contains only the hyperbolic events from the actual CMP gather. A least-squares minimization of the energy contained in the difference between the actual CMP gather and the model CMP gather removes smearing of amplitudes on the velocity-stack gather and increases velocity resolution. A practical application of this procedure is in separation of multiples from primaries.

In this paper, a method is described to obtain proper velocity-stack gathers with reduced amplitude smearing. The method involves a t^2-stretching in the offset space. This stretching maps reflection amplitudes along hyperbolic moveout curves to those along parabolic moveout curves. The CMP gather is Fourier transformed along the stretched axis. Each Fourier component is then used in the least-squares minimization to compute the corresponding Fourier component of the proper velocity-stack gather. Finally inverse transforming and unstretching yield the proper velocity-stack gather which then can be inverse mapped back to the offset space. During this inverse map-

ÖZET

Geleneksel bir hız yığma topluluğu sabit hızla yığılmış OON (ortak orta nokta) izlerinden oluşur. Söz konusu topluluk, yalnızca OON topluluğundaki hiperbolik seyahat zamanı eğrilerini izleyen olaylarla ilgili enerjiyi içerir. Bir OON topluluğundaki bir hiperbol boyunca yer alan genlikler, ideal olarak bir hız-yığma topluluğundaki bir noktayı temsil ederler. Bir OON topluluğu, bir hiperbolik seyahat zamanı eğrisinin ancak bir kablo uzunluğu kadarlık kısmını içerdiğinden, bu temsil etme tam doğru değildir. Sınırlı kablo uzunluğu, açılım ekseni boyunca örneklemedeki süreksizlik ve yakın açılımlardaki hiperbolik toplama yollarının tek olmayışı, hız ekseni boyunca yığılmış genliklerin saçılmasına neden olmaktadır. Bu saçılma giderilmedikçe hız ortamından (yığma hızı düzlemine karşı gidiş-dönüş sıfır açılım zamanı), açılım ortamına (açılım düzlemine karşı gidiş-dönüş seyahat zamanı), tersine haritalama işlemi orjinal OON topluluğundaki genlikleri tam olarak vermez. Tersine haritalama işlemi neticesi elde edilen topluluk, gerçek OON topluluğunun yalnızca hiperbolik olaylarını ihtiva eden model OON topluluğu olarak düşünülebilir. Gerçek OON topluluğu ile model OON topluluğunun içerdikleri enerji farkının, en küçük kareler yöntemiyle en aza indirilmesi, hız-yığma topluluğundaki genliklerin saçılmasını giderir ve hız ayrımlılığını artırır. Bu işlem pratikte birincil yansımaları tekrarlı yansımalardan ayırmada kullanılabilir.

Bu makalede, genlik saçılmaları olmaksızın, uygun hız-yığma toplulukları elde etmek için etkin bir yöntem tanımlanmıştır. Yöntem açılım ortamında t^2-gerilmesini gerektirir. Bu gerilme, hiperbolik normal kayma eğrileri boyunca uzanan yansıma genliklerini, parabolik normal kayma eğrileri boyunca uzananlara dönüştürür. OON topluluğunun gerilmiş eksen boyunca Fourier dönüşümü alınır. Böylelikle elde edilen her Fourier bileşeni, gerekli hız-yığma topluluğunun uygun Fourier bileşenini hesaplamak için en küçük kareler yönteminde kullanılır. Sonuç olarak ters dönüşüm ve gerilmenin kaldırılması uygun hız-yığma toplu-

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ping, multiples, primaries or all of the hyperbolic events can be modeled. An application of velocity-stack processing to multiple suppression is demonstrated with a field data example.

luğunu verir. Söz konusu topluluk ise açılım ortamında yeniden haritalanabilir. Bu tersine haritalama esnasında, tekrarlı yansımalar, birincil yansımalar veya bütün hiperbolik olaylar modellenebilirler. Hız yığma işleminin tekrarlı yansımalara uygulanması bir saha veri örneğiyle gösterilmiştir.

INTRODUCTION

Consider the synthetic common-midpoint (CMP) gather in Figure 1c. This gather is a composite of the CMP gather with three primary reflections shown in Figure 1a and the CMP gather with one primary and its multiples shown in Figure 1b. Note that the three primaries arrive at the same zero-offset times as the multiples,and the moveout between the primaries and multiples is less than 100 ms at the far offset (2350 m).

Traces in the composite CMP gather (Figure 1c) are stacked with a range of constant velocities and the resulting stacked traces are displayed side by side, forming the conventional velocity-stack gather shown in Figure 1d. The highest stacked amplitudes occur with the actual primary and multiple velocities. The lower-amplitude horizontal streaks on this velocity-stack gather are due to the contribution of small offsets, while the large-amplitude regions are due to the contribution of the full range of offsets (Sherwood and Poe, 1972).

Let d (h , t) be the data in the offset space (the plane of offset versus two-way travel time as in Figure 1c) and u (v , τ) be the transformed data in the velocity space (the plane of stacking velocity versus two-way zero-offset time as in Figure 1d). The mapping from the offset space to the velocity space is achieved by summing over offset:

$$u(v, \tau) = \sum_{h} d\left(h, t = \sqrt{\tau^2 + 4h^2 / v^2}\right), \qquad (1a)$$

where t is the two-way travel time, τ is the two-way zero-offset time, h is the half-offset and v is the stacking velocity. The inverse mapping from the velocity space back to the offset space is achieved by summing over velocity:

$$d'(h, t) = \sum_{v} u\left(v, \tau = \sqrt{t^2 - 4h^2 / v^2}\right). \qquad (1b)$$

Figure 1d was obtained by using equation (1a), where the summation is performed over a finite range of offsets. At first, it appears that using equation (1b), where the summation is performed over a finite range of velocities, the original data d (h , t) in Figure 1c can be reconstructed from the data in Figure 1d. The modeled CMP gather d'(h, t) using equation (1b) is shown in Figure 2b. Observe the relative weakening of amplitudes at far offsets, especially along events with large moveout. Repeated transformations using equations (1a) and (1b) from the offset space to velocity space (Figure 2c) and back (Figure 2d) further reduce the amplitudes at far offsets. Results of Figure 2 clearly demonstrate that the discrete transforms given by equations (1a) and (1b) are not exact inverses of each other. The discrete summation in equation (1a) over a finite range of offsets causes mapping of amplitudes along a hyperbolic event in the offset space (Figure 1c) to depart from the ideal point in the velocity space and results in smearing of amplitudes along the velocity axis (Figure 1d). Amplitude smearing means loss of velocity resolution between two events with little moveout difference. The velocity resolution is further reduced with lack of far-offset data (Figures 2b, c).

To reduce the amplitude smearing on conventional velocity-stack gathers, Thorson and Claerbout (1985) proposed a least-squares formulation of the problem. Consider equation (1b) in matrix notation:

$$d' = L\, u, \qquad (2)$$

I call u (v , τ) in equation (2) a proper velocity-stack gather, whereby hyperbolas in offset space are represented by points in velocity space, to distinguish from the conventional velocity-stack gather with amplitude smearing. L is the matrix operator that maps each point in u (v , τ) onto a hyperbola in d' (h , t), the modeled CMP gather. The purpose is to find a u (v , τ) such that the difference e (h , t) between the actual CMP gather d (h , t) and the model CMP gather d' (h , t) is minimum in a least-squares sense. Using the matrix motation and equation (2), e (h , t) is defined as:

$$e = d - L\, u. \qquad (3)$$

The minimum error e (h , t) associated with the least-squares solution u (v , τ) should be interpreted as being the CMP gather that contains only the nonhyperbolic events, such as random or linear noise, that may be present in the original CMP gather d (h , t).

The least-squares solution for u (v , τ) normally requires computing the inverse of the matrix $L^T L$ (T is for transpose), which may have dimensions of 60,000 x 60,000 for a typical field data case. Inverting such a large matrix is quite impractical.

A practical approach to solving equation (3) is given by Hampson (1986). First, the imput CMP gather is NMO corrected; thereby resulting moveouts of the events with originally hyperbolic moveouts are approximately parabolic. Second, the NMO-corrected gather is Fourier transformed in the time direction. Thus, equation (3) can

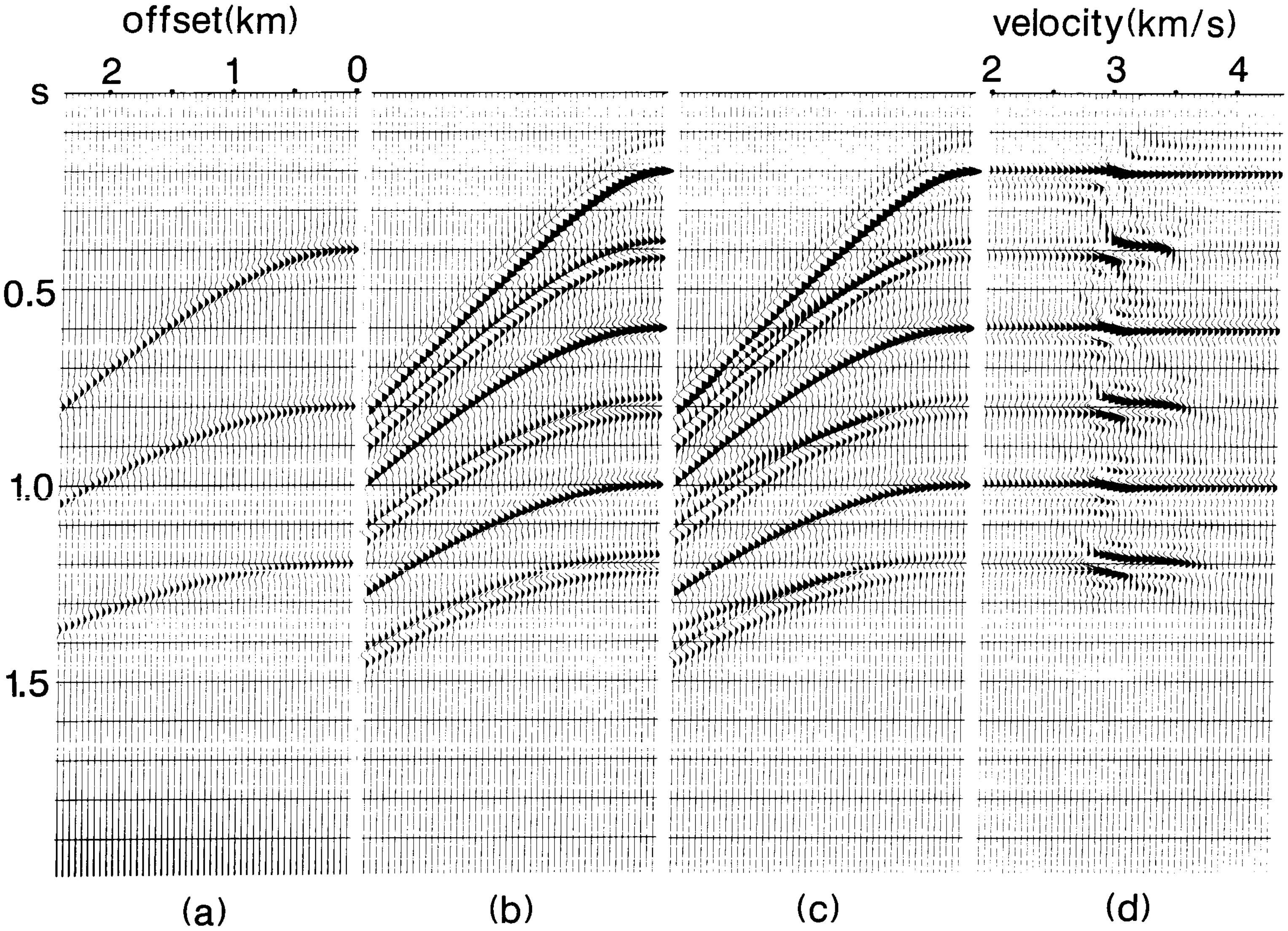

Fig. 1. (a) A synthetic CMP gather with there primary reflections; (b) a synthetic CMP gather with one primary reflection (arrival time at 0.2 s at zero-offset trace) and its multiples; (c) composite CMP gather containing the primaries and multiples in (a) and (b); (d) the conventional velocity-stack gather derived from the composite CMP gather using equation (1a). Note the amplitude smearing along the velocity axis.

Şekil 1. (a) Üç yansıma içeren bir sentetik OON topluluğu; (b) tek bir yansıma (geliş zamanı sıfır açılımlı izde 0.2 sn) ve onun tekrarlı yansımalarını içeren bir sentetik OON topluluğu; (c) (a) ve (b)'deki OON topluluklarının birleştirilmesiyle oluşan OON topluluğu; (d) (1a) eşitliği kullanılarak (c)'deki OON topluluğundan elde edilmiş klasik hız-yığma topluluğu. Hız ekseni boyunca genlik saçılması gözlenmektedir.

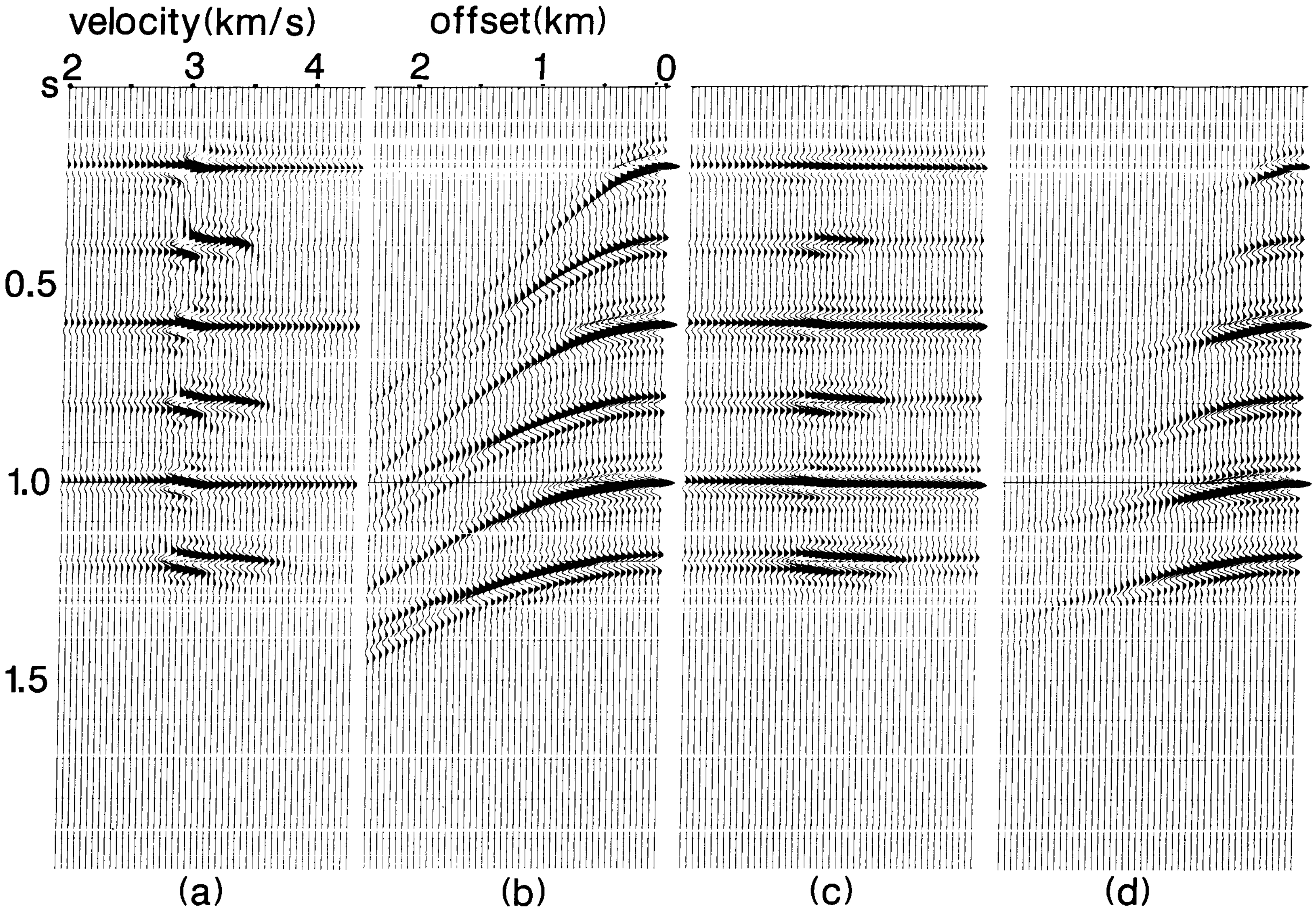

Fig. 2. (a) The same velocity-stack gather as in Figure 1d; (b) the CMP gather reconstructed from the velocity-stack gather in (a) using equation (1b); (c) velocity-stack gather derived from (b) using equation (1a); (d) CMP gather reconstructed from (c) using equation (1b). Note the degradation of velocity resolution on the velocity-stack gather (c) due to reduction of far-offset amplitudes (b).

Şekil 2. (a) Şekil (1d)'deki hız-yığma topluluğu; (b) (1b) eşitliği yardımıyla (a)'daki hız-yığma topluluğundan tekrar elde edilen OON topluluğu; (c) (1a) eşitliğiyle (b)'deki OON topluluğundan elde edilen hız-yığma topluluğu; (d) (1b) eşitliğiyle (c)'den tekrar elde edilen OON topluluğu. (c)'deki hız-yığma topluluğundaki hız ayrımlılığının azalması (b)'deki uzak-açılımların genliklerinin düşmesi nedeniyledir.

be rewritten for each frequency component, independently. For a typical field data case, the new form of the complex matrix L may have dimensions of 60 x 60, which is much easier to handle than the L matrix as defined originally in equation (3). Hampson (1986, 1987) applied his technique for multiple suppression and signal enhancement by random noise suppression.

As events on the NMO-corrected CMP gather deviate from the ideal parabolic form, there can be degradation in the ability to map those events into the velocity space (Hampson, 1986). Moreover, stretch muting that is normally required after NMO correction can significantly remove the far-offset data. In this paper, I modify Hampson's technique to circumvent the parabolic approximation. Specifically, in the present approach, a t^2-stretching of the time axis replaces the NMO correction of the CMP gather. This stretching converts all the hyperbolic events in the original CMP gather to exact parabolas. I also use the singular-value decomposition (SVD) technique to avoid computing the direct inverse of $L^T L$. In the next section, this procedure is described and its application to multiple suppression is demonstrated with a field data example.

DESCRIPTION OF THE METHOD

Start with the synthetic CMP gather shown in Figure 1c. Events on this gather have hyperbolic travel times defined by:

$$t^2 = \tau^2 + 4h^2 / v^2. \qquad (4)$$

Apply stretching in the time direction by setting $t' = t^2$ and $\tau' = \tau^2$. Equation (4) then takes the form:

$$t' = \tau' + 4h^2 / v^2. \qquad (5)$$

In the stretched coordinates, equations (1a) and 1b) become:

$$u(v, \tau') = \sum_h d(h, t' = \tau' + 4h^2 / v^2), \qquad (6a)$$

and

$$d'(h, t') = \sum_v u(v, \tau' = t' - 4h^2 / v^2). \qquad (6b)$$

Figure 3a shows the stretched CMP gather; note the hyperbolas in Figure 1c are replaced with parabolas. Actually, the t^2-transformation causes compression on data before 1 s and stretching on data after 1 s. (A nice property of the parabolic moveout is that it is invariant along the t^2-axis.) The sampling rate along the t^2-axis was set equal to $(t_{max})^2/\underline{n}$, where $\underline{n}$ is the number of samples along the t-axis. There can be a potential problem of aliasing near t = 0; however, this problem should not be a concern when dealing with field data. Applying parabolic moveout and stacking over a range of constant velocities (Equation 6a), we get the stretched velocity-stack gather shown in Figure 3b. Compare with Figure 1d and note that both velocity-stack gathers have amplitude smearing along the velocity axis. Our goal here is to eliminate this smearing and enhance the velocity resolution.

By Fourier transforming equation (6b) with respect to t', we get:

$$d'(h, \omega') = \sum_v u(v, \omega')\, e^{i\omega' 4h^2/v^2} , \qquad (7)$$

where ω' is the Fourier dual ol t'. Equantion (7) can be written in matrix form as equation (2) for each component of d' (h, ω') and u (v, ω'), where L now is a complex matrix:

$$L = \begin{bmatrix} e^{i\omega' 4h_1^2/v_1^2} & e^{i\omega' 4h_1^2/v_2^2} & \cdots & e^{i\omega' 4h_1^2/v_p^2} \\ e^{i\omega' 4h_2^2/v_1^2} & e^{i\omega' 4h_2^2/v_2^2} & \cdots & e^{i\omega' 4h_2^2/v_p^2} \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ e^{i\omega' 4h_m^2/v_1^2} & e^{i\omega' 4h_m^2/v_2^2} & \cdots & e^{i\omega' 4h_m^2/v_p^2} \end{bmatrix}$$

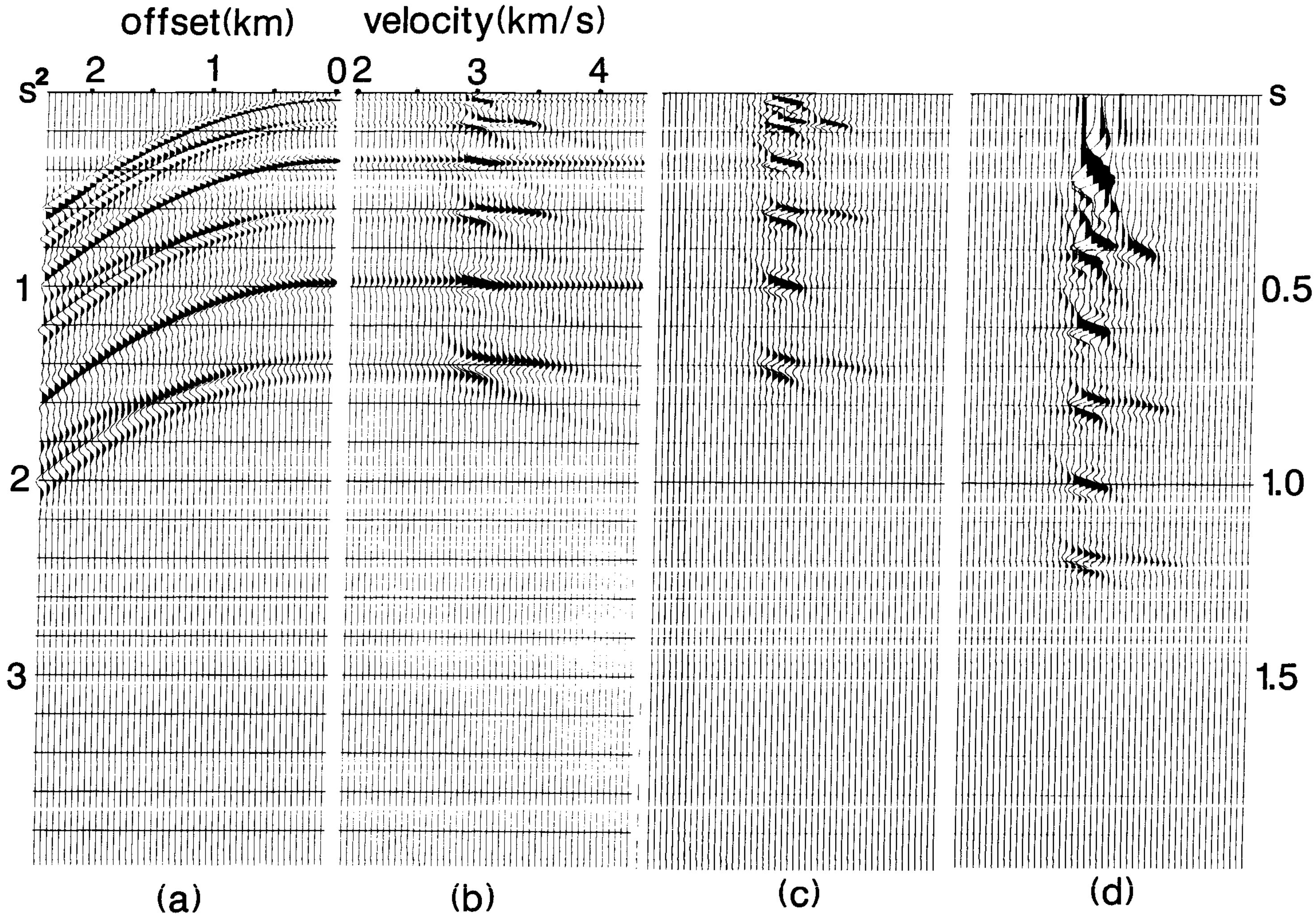

Fig. 3. (a) The CMP gather of Figure 1c after t^2-stretching; note the hyperbolas (Figure 1c) are replaced with parabolas, and the vertical axis is in units of travel time-squared; (b) the conventional velocity-stack gather derived from the CMP gather in (a) using equation (6a); (c) the proper velocity-stack gather using the SVD procedure described in the text; (d) the same velocity-stack gather as in (c) after undoing the t^2-stretching. Note the distinct separation of primaries from multiples on the proper velocity-stack gather (d) compared to the amplitude smearing on the conventional velocity-stack gather in Figure 1d.

Şekil 3. (a) t^2-gerilmesinden sonra Şekil 1c'deki OON topluluğu. Hiporbollerin parabollere ve düşey eksenin seyahat zamanının karesine dönüştüğü gözlenmektedir; (b) (6a) eşitliği kullanılarak (a)'dan elde edilen klasik hız-yığma topluluğu; (c) metinde açıklanan SVD yöntemiyle elde edilmiş uygun hız-yığma topluluğu; (d) t^2-gerilmesi kaldırıldıktan sonra (c)'deki hız-yığma topluluğu. Uygun hız-yığma topluluğundaki (d) yansıma ve tekrarlı yansımaların birbirlerinden ayrılması, Şekil (1d)'deki klasik hız-yığma kesitinde gözlenen genlik saçılmasıyla karşılaştırıldığında açıkça görülmektedir.

Here, $\underline{m}$ is the number of offsets and $\underline{p}$ is the number of velocities. Note that the elements of the L matrix only depend on the geometry of the input CMP gather.

The least-squares procedure can now be reformulated using the new definitions of d', u and L (equation 8) in equation (3), where d (h, ω ') is the actual CMP gather and e (h , ω ') is the error in the transform domain. The constrained least-squares solution u (v , ω ') then is (Lines and Treitel, 1984):

$$u = (L^{T*}L + \beta I)^{-1} L^{T*}d, \tag{9}$$

where the asterisk denotes complex conjugate and β is Marquardt's damping factor.

Normally, this constrained solution would require computing the inverse of ($L^T L + \beta I$). We can avoid the matrix inversion by singular value decomposition (SVD) of the complex matrix L (equation 8). This procedure factors L into a product of three matrices (Lines and Treitel, 1984):

$$L = U \wedge V^{T*} \tag{10}$$

By using this factorized form of the matrix L, the constrained solution given by equation (9) takes the form:

$$u = V [(\wedge^2 + \beta I)^{-1} \wedge] U^{T*} d \tag{11}$$

where

$$(\wedge^2 + \beta I)^{-1} = \begin{bmatrix} \frac{\lambda_1}{\lambda_1^2 + \beta} & & & O \\ & \frac{\lambda_2}{\lambda_2^2 + \beta} & & \\ & & \ddots & \\ O & & & \frac{\lambda_p}{\lambda_p^2 + \beta} \end{bmatrix} \tag{12}$$

and λ_i are the positive square-roots of the eigenvalues λ_i^2 of $L^T L$. Recall that the damping factor is a scalar that prevents the solution (equation 11) from becoming unstable.

We now summarize the method:

(1) Start with a CMP gather, d (h , t) (Figure 1c).
(2) Apply the t^2-stretching, d (h , t ' = t^2) (Figure 3a).
(3) Fourier transform in the t'-direction, d (h , ω ').
(4) For a specific value of ω ' :
   (a) set up the L matrix (equation 8) based on the geometry of the CMP gather.
   (b) set up the d vector by transposing the data set d (h , ω ').
   (c) Apply SVD on L (equation 10), and compute U, ∧, and V^{T*}, hence U^{T*} and V.
   (d) Specify a value for β and set up the diagonal matrix of equation (12). For field data, a value of 1 % of the largest eigenvalue-squared, λ_1^2, often yields adequate results.
   (e) Finally, solve for u (equation 11).
   (f) Repeat (4) for al ω ' values and accumulate the results in u (v , ω ').
(5) Inverse Fourier transform to get u (v , ω ') (Figure 3c).
(6) Undo the t^2-stretching to get u (v , ω ') ; this is the desired result, namely the proper velocity-stack gather (Figure 3d).
(7) If desired, perform inverse mapping back to offset space to get the model CMP gather (equation 1b). At this stage, all or part of the velocity-stack gather that contains primaries or multiples can be included in the modeling defined by equation (1b). (An application of this step for multiple suppression is demonstrated in the next section.)

Compare the proper velocity-stack gather (Figure 3d) with the conventional velocity-stack gather (Figure 1d). Note the significant reduction of amplitude smearing and enhancement of velocity resolution in the proper velocity-stack gather. In particular, multiples and primaries are now clearly distinguishable. Nevertheless, note the frequency distortion of the wavelet, especially in the shallowest event, primarily due to stretching (step 2) and unstretching (step 6).

Using the proper velocity-stack gather (Figure 4a) in equation (1b), the CMP gather can be faithfully reconstructed (Figure 4b). Repeated application of the SVD procedure outlined above always reproduces the CMP gather (Figures 4c, d), with the exception of frequency distortion at the very early times. (Compare the panels in Figure 4 with those in Figure 2.)

Consider the field data example in Figure 5a. This deep-water CMP gather contains little random noise, but strong multiples below 3.5 s. The conventional velocity-stack gather (Figure 5b) shows the familiar amplitude smearing, whereas the proper velocity-stack gather (Figure 5c) shows better focusing of amplitudes. The reconstructed CMP gather (Figure 5d) contains all the hyperbolic events present in the original CMP gather (Figure 5a) and excludes noise. The amplitudes on the reconstructed CMP gather appear to be faithfully restored to their original values.

APPLICATION TO MULTIPLE SUPPRESSION

I now demonstrate an application of velocity-stack processing to multiple suppression. Consider the synthetic CMP gather in Figure 1c and the proper velocity-stack gather (Figure 3d) estimated from it. Using the entire velocity-stack gather in the summation in equation (1b), we get the fully reconstructed CMP gather shown in Figure 6a. Aside from the loss of high-frequency energy at early times, this modeled CMP gather is a close approximation to the original CMP gather (Figure 1c). Instead of including the entire velocity-stack gather (Figure

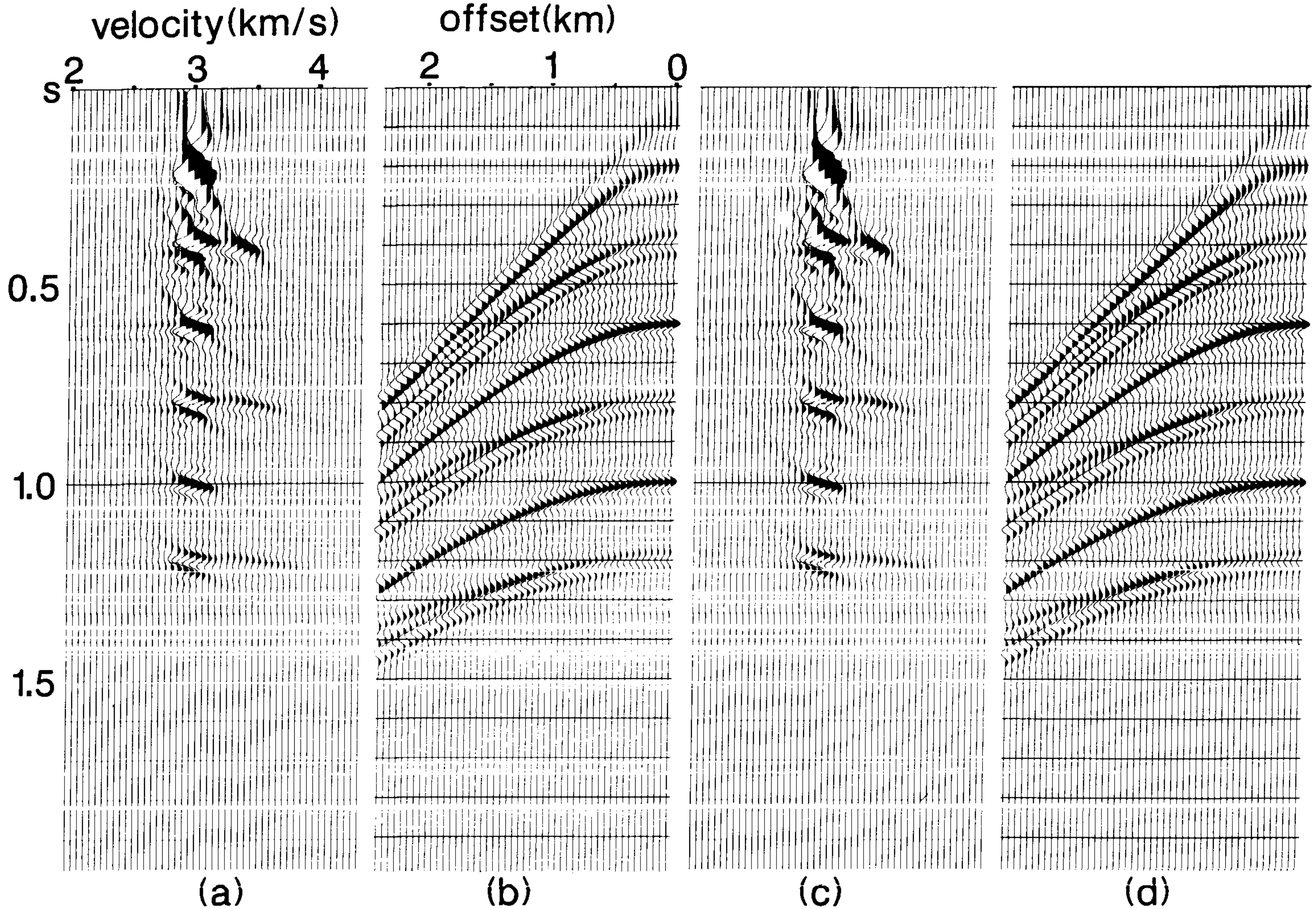

Fig. 4. (a) The same velocity-stack gather as in Figure 3d; (b) the CMP gather reconstructed from the proper velocity-stack gather in (a) using equation (1b); (c) proper velocity-stack gather derived from the CMP gather in (b) using the SVD procedure described in the text; (d) CMP gather reconstructed from (c) using equation (1b). Note the accurate reconstruction of the CMP gather (b) from the proper velocity-stack gather (a) compared to the reduction of far-offset amplitudes on the CMP gather in Figure 2b reconstructed from the conventional velocity-stack gather in Figure 2a.

Şekil 4. (a) (3d)'deki hız-yığma topluluğu; (b) (a)'daki uygun hız-yığma topluluğundan (1b) eşitliği kullanılarak tekrar elde edilmiş OON topluluğu; (c) (b)'deki OON topluluğundan SVD yöntemiyle elde edilen uygun hız-yığma topluluğu; (d) 1b eşitliği kullanılarak (c)'den tekrar elde edilmiş OON topluluğu. Uygun hız-yığma topluluğundan (a) elde edilen OON topluluğunun (b) doğruluğu, Şekil 2a'daki klasik hız-yığma topluluğundan elde edilmiş OON topluluğunda (2b) uzak açılımlardaki genlik kaybı ile karşılaştırıldığında gözlenmektedir.

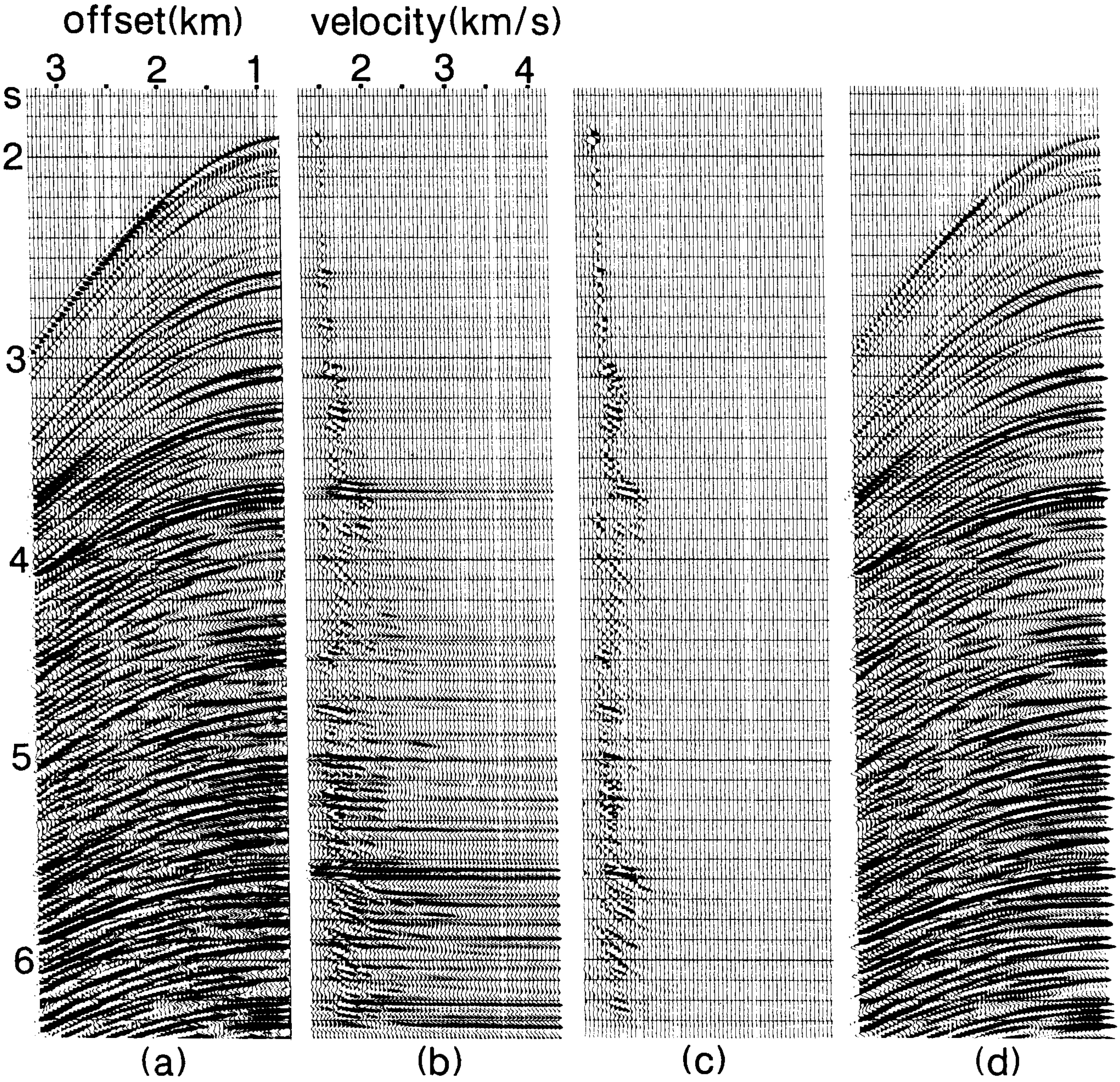

Fig. 5. (a) A deep-water CMP gather with strong multiples; (b) the conventional velocity-stack gather; (c) the proper velocity-stack gather; (d) the CMP gather reconstructed from (c). Compare with (a) and note the preservation of amplitudes along hyperbolic events. (Data courtesy Norwegian Petroleum Directorate.)

Şekil 5. (a) Kuvvetli tekrarlı yansımalar içeren derin deniz OON topluluğu; (b) klasik hız-yığma topluluğu; (c) uygun hız-yığma topluluğu; (d) uygun hız-yığma topluluğundan tekrar elde edilen OON topluluğu. (a) ile karşılaştırıldığında hiperboller boyunca genliklerin korunduğu görülmektedir (Veri Norveç Petrol Direktörlüğüne aittir).

3d) in the summation in equation (1b), only multiples (Figure 6b) or only primaries (Figure 6c) can be reconstructed by simply imposing a suitable pass corridor over the velocity-stack gather. Compare the modeled multiples-only and primaries-only CMP gathers (Figures 6d, c) with the actual CMP gathers shown in Figures 1b, a, respectively. (The modeled shallow primary in Figure 6c corresponds to the primary in Figure 1b). It appears that, although insignificant, the multiples-only gather (Figure 6b) contains some residual primary energy, and the primaries-only gather (Figure 6c) contains some residual multiple energy. In practice, it may sometimes be desirable to model the multiples and subtract the result from the actual CMP gather (Hampson, 1986). One reason for this is the necessity to retain in CMP data some of the nonhyperbolic energy, such as diffractions. In the present example, Figure 6d shows the difference between Figures 1c and 6b. When compared with Figure 6c, the subtraction result (Figure 6d) shows slight differences in the early times.

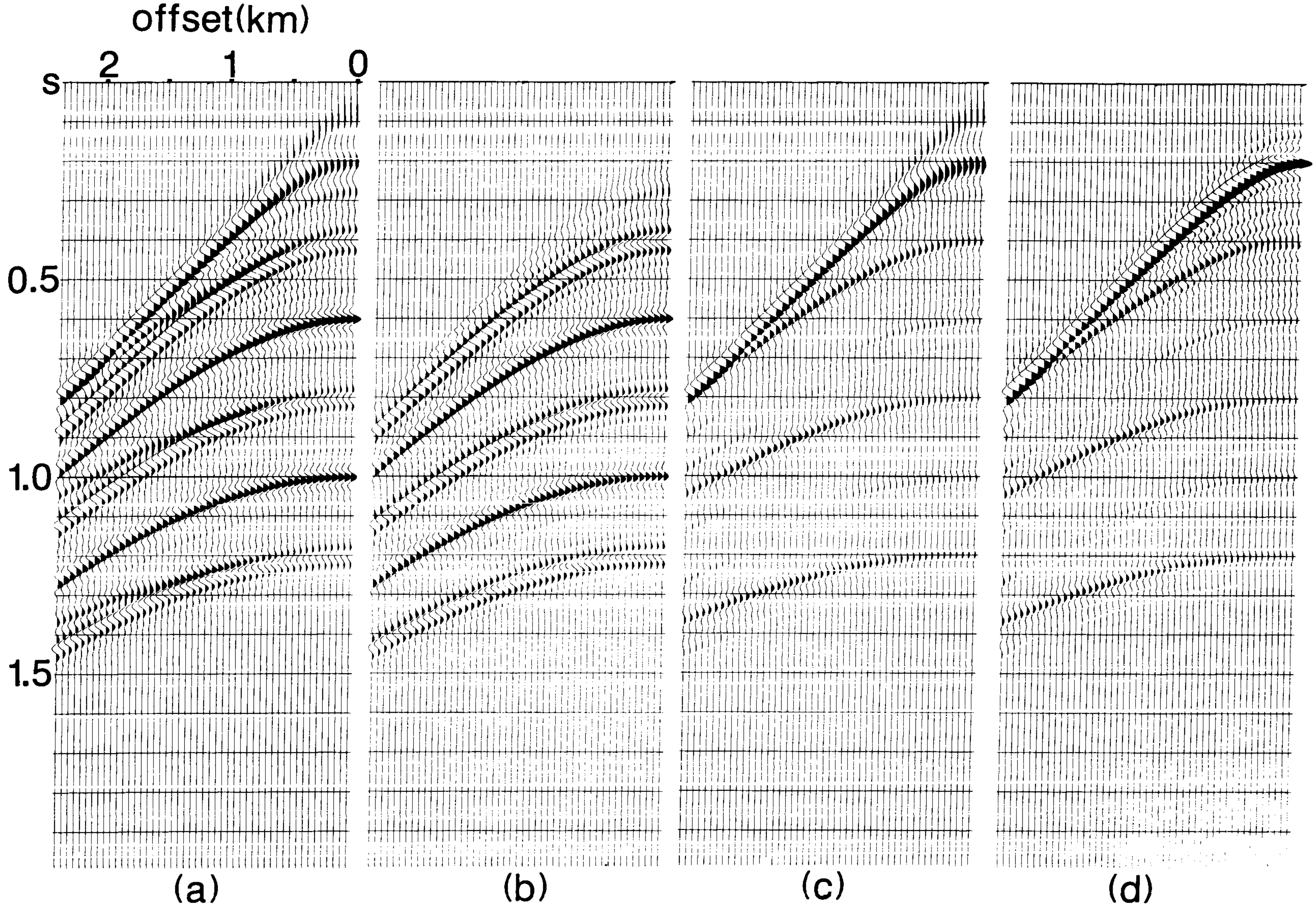

Fig. 6. Reconstruction of the CMP gather in Figure 1c using (a) the entire velocity-stack gather in Figure 3d; (b) allowing only the multiple energy; (c) allowing only the primary energy; (d) subtraction of (b) from Figure 1c.

Şekil 6. (a) 3d'deki bütün hız yığma topluluğu; (b) sadece tekrarlı yansıma enerjisi; (c) sadece yansıma enerjisi; (d) Şekil 1c'den (b)'nin çıkartılması; kullanılarak 1c'deki OON topluluğunun tekrar elde edilmesi.

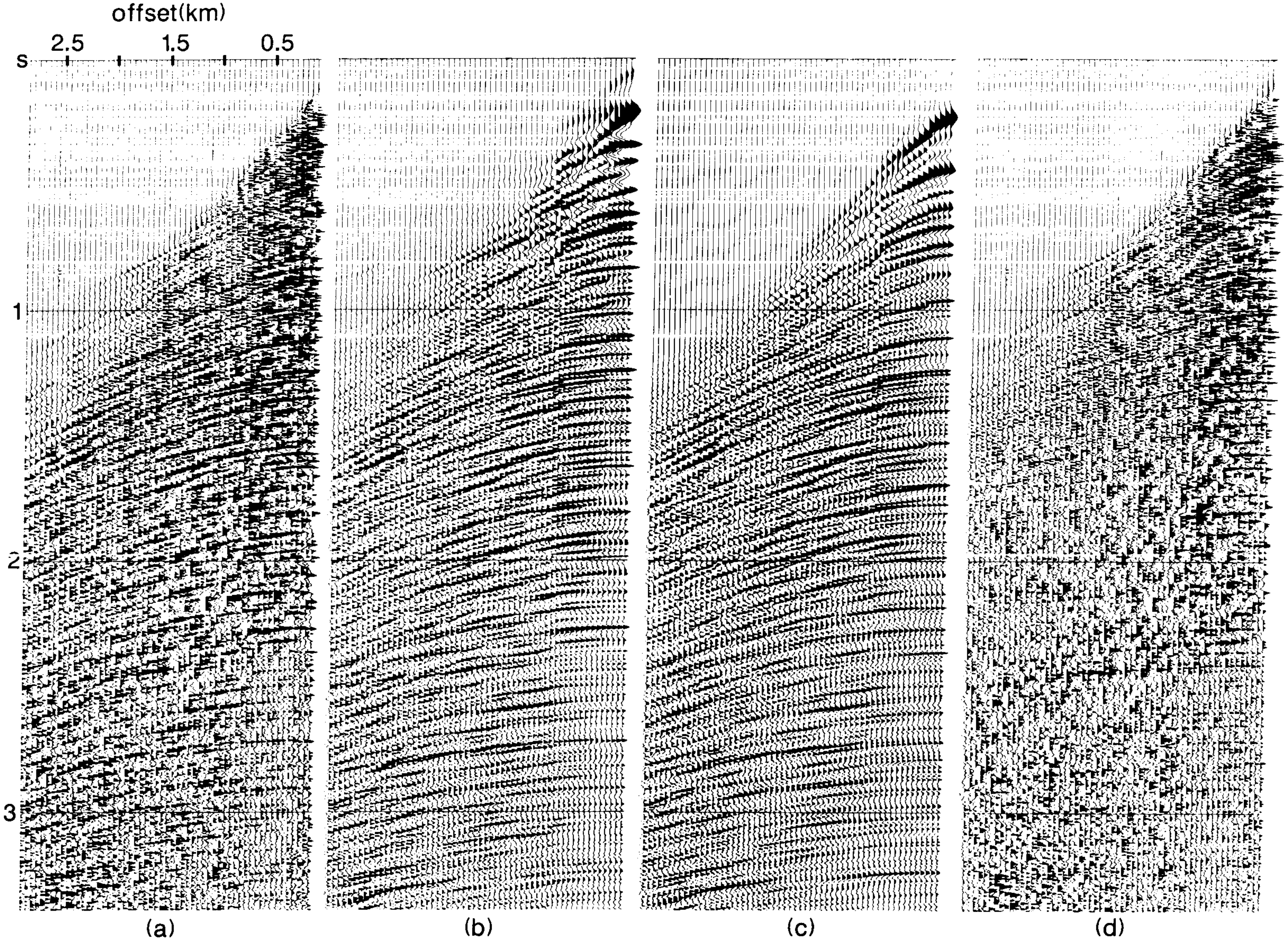

Fig. 7. (a) A shallow-water CMP gather; (b) full reconstruction from the proper velocity-stack gather; (c) multiples-only reconstruction; (d) difference between (a) and (c). (Data courtesy Abu Dhabi National Oil Company.)

Şekil 7. (a) Bir sığ deniz OON topluluğu; (b) uygun hız-yığma topluluğundan tam olarak tekrar eldesi; (c) tekrarlı yansımaların tekrar eldesi; (d) (a) ile (c) arasındaki fark (Veri Abu Dhabi Milli Petrol Şirketine aittir).

A field data example with short-period interbed multiples is shown in Figure 7. The velocity spectra computed from the original CMP gather (Figure 7a) and the gather with multiples removed (Figure 7d) are shown in Figure 8. Detailed portions of CMP stacked sections with and without velocity-stack processing for multiple suppression are shown in Figure 9. An important observation in Figure 9a is the apparent lateral continuity due to the multiples. This continuity is replaced, in Figure 9b, with features that are perhaps geologically more detailed and plausible. Note the presence of a subtle structural closure at 1.5 s in Figure 9b; this feature is completely disguised amongst the multiples in Figure 9a. Unfortunately, because of unavailability of sonic-log information, no definite assessment can be made about the details in the CMP stacked section processed for multiple suppression (Figure 9b).

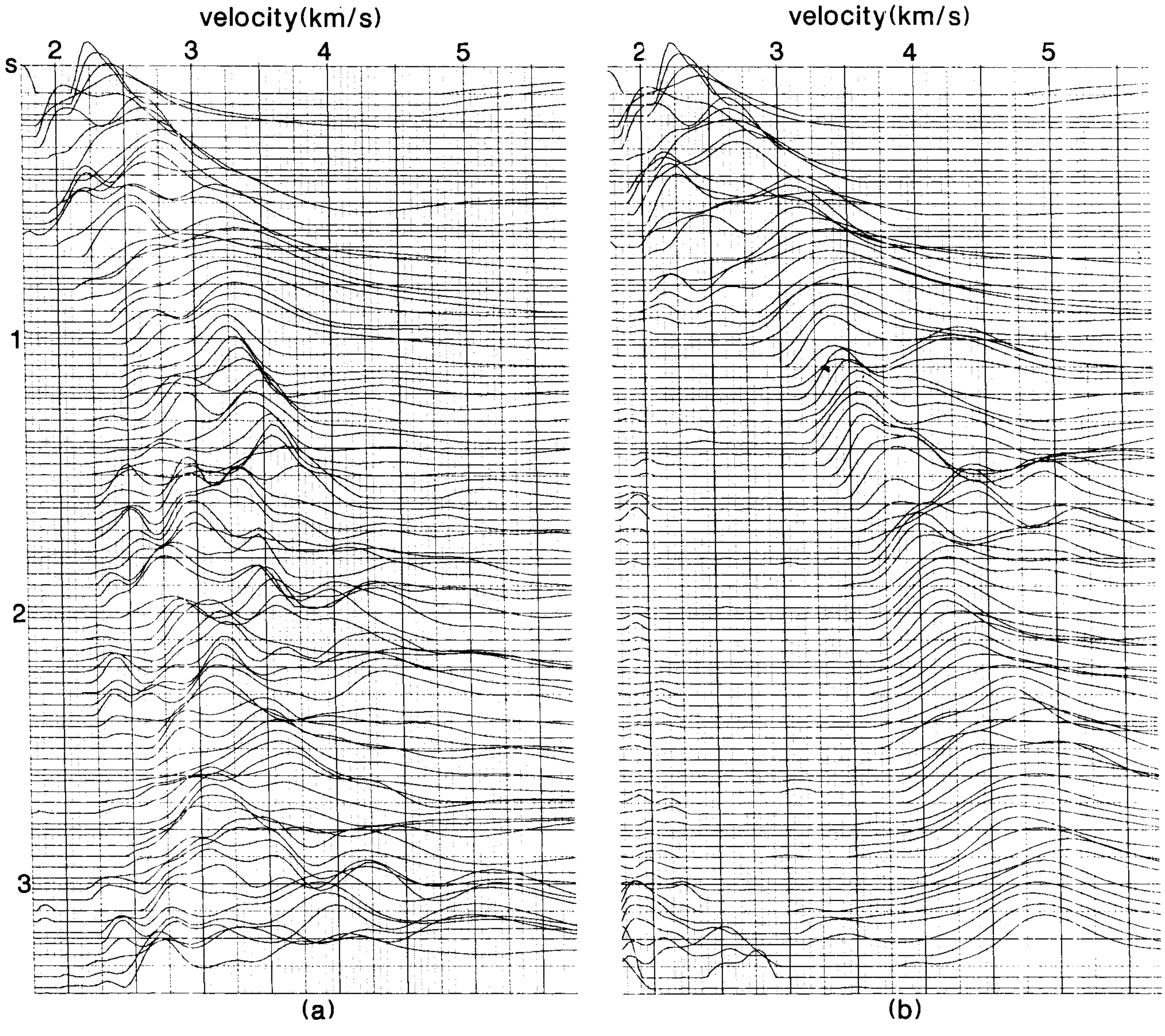

Fig. 8. Velocity spectra associated with (a) the CMP gather in Figure 7a; (b) the CMP gather in Figure 7d.
Şekil 8. (a) Şekil 7a'daki OON topluluğuna ait; (b) Şekil 7d'deki OON topluluğuna ait; hız spektrumları.

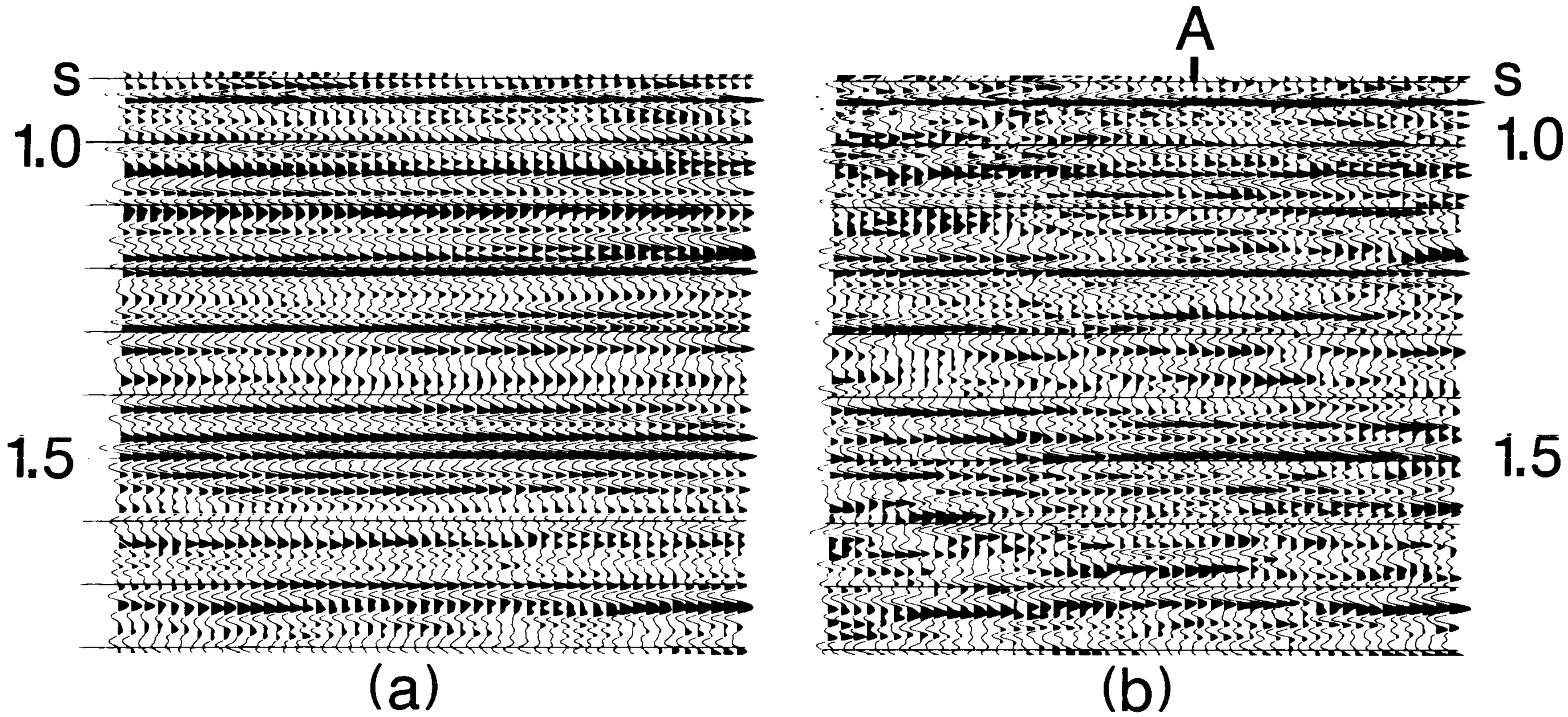

Fig. 9. Detailed portions of (a) CMP stacked sections associated with the CMP gather in Figure 7a with short-period multiples; (b) CMP stacked section associated with the CMP gather in Figure 7d with velocity-stack processing for multiple suppression. Note the apparent lateral continuity caused by the short-period multiples in (a); this false continuity is removed in (b), thereby uncovering a probable subtle structural feature at 1.5 s below midpoint A. (Data courtesy Abu Dhabi Natonal Oil Company.)

Şekil 9. (a) Şekil 7a'daki OON topluluğu ile ilgili kısa tekrarlanmalar içeren yığma kesitinin; (b) Şekil 7d'deki OON topluluğu ile ilgili tekrarlı yansımaları sönümlemeye yönelik veri işlenmesiyle elde edilmiş yığma kesitinin; ayrıntılı sunumu. Kısa peryotlu tekrarlanan yansımalar (a)'da gözlenen ve gerçek olmayan bir devamlılığa neden olmakta, (b)'de ise bu görünüm ortadan kalkmakta, dolayısıyla A noktasının altında 1.5 saniyede, küçük, olası bir yapısal özellik gözlenebilmektedir.

CONCLUSIONS

A method was presented to estimate proper velocity-stack gathers without amplitude smearing seen in conventional velocity-stack gathers. The method involves t^2-stretching of the CMP data in the offset space, followed by Fourier transforming along the stretched axis. Each Fourier component then is used in a least-squares minimization to compute the corresponding Fourier component of the velocity-stack gather.

Removal of amplitude smearing increases velocity resolution, thus allowing better separation of primaries from multiples. This advantage can be put to use to suppress multiples by inverse mapping only the primaries from the velocity space back to the offset space. In practice, however, it may be desirable to inverse map the multiples and subtract the resulting multiples-only CMP gather from the original CMP gather to yield the primaries-only CMP gather. This CMP gather would retain nonhyperbolic components of the data that may be of interest.

A velocity-stack gather emphasizes the energy associated with the events that follow hyperbolic travel time trajectories in a CMP gather. Reflections with nonhyperbolic moveouts, such as those associated with complex structures, are not to velocity space, properly. Random noise uncorrelated from trace to trace and coherent noise with linear moveout on a CMP gather are excluded from the mapping to velocity space; hence, the model CMP gather obtained from the inverse mapping should be free of such noise.

In the least-squares inversion scheme used here, a critical parameter is Marquardt's damping factor β. Choice of this factor depends on the noise content of the data For most field data cases, a value of 1 % seems to be a good choice.

Other practical parameters are the velocity range and velocity increment used in constructing velocity-stack gathers. The velocity range should span the velocities associated with primary and multiple reflections. A good practice for the choice of velocity increment is such that the number of traces in velocity space is set equal to the number of traces in offset space.

Application of velocity-stack processing to multiple suppression was demonstrated with a field data example with short-period multiples. Unfortunately, no sonic-log information was available to assess to what extent the uncovered features are geologically plausible. Nevertheless, the velocity spectrum of the data after velocity-stack processing clearly indicates removal of a large amount of multiple energy. Moreover, the CMP stacked section after multiple suppression shows evidence of a subtle structural closure and some details that may have geological significance and are not at all visible on the conventional CMP stacked section.

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