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Migration Velocity Analysis by Fourier Transform in Seismic Data Processing

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Abstract

Migration is the transformation of apparent reflecting positions to true positions. The information obtained from the field cannot be explained easily due to unwanted signal. Velocity estimation, common-midpoint (CMP) stacking and migration generally are considered independent processes. They all have a common theoretical base: the scalar wave equation. This method operates in the Fourier transform domain using the exact form of the double-square-root (DSR) operator. The theory of migration velocity analysis based on wave field extrapolation was discussed. A constant velocity of 3000m/s was used for extrapolation. In this work we apply migration technique to provide an adequate approximation to the structure known as resolved-time method. The technique of the migration could be extended to prestack processes such as dip moveout (DMO), short- and receiver-gather downward extrapolation and thus suggests a unified approach to processing data from irregular surfaces. When the information from the field are fully processed, geological interpretation could easily be facilitated. The various procedures and figures are clearly shown. The velocity analysis described does not handle lateral variations in velocity. It is based on a Fourier-transform domain formulation with only vertically varying velocity used in extrapolation.

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1.0 Introduction

The basic objective of all seismic processing is to convert the information recorded in the field into a form that most greatly facilitates geological interpretation. One object of the processing is to eliminate or at least suppress all noise.

Data processing covers filtering, trace correction, stacking, compositing, velocity analysis, true-amplitude registration, migration, and plotting.

Migration is the transformation of apparent reflecting positions to true positions. In the initial recording of seismic reflections, it is almost impossible to explain from the information on a single trace where the reflecting point is actually located in space. One field records and on conventionally plotted record sections, each event will appear to be directly below the receiving point along a channel representing arrivals at that receiver. The change in reflection time between adjacent traces makes it possible to determine the actual position along the profile of the reflecting surface.

Migration using surfaces of maximum convexity was introduced by Hagedoorn (1954), although it was based on some interesting new concepts, it did not then appear to be a very convenient approach for the routine migration of reflection data.

If a constant velocity can be assumed for the reflection path, migration becomes quite simple to carry out with readily accessible drafting aids such as a straight edge and protractor. In areas where the velocity-depth function is not known, a migration technique devised by Rice (1955) may provide an adequate approximation to the true structure. This is known as resolved-time method. This involves plotting reflections in time and presenting horizontal distances along the section in equivalent time units obtained by dividing the surface distance by the velocity below the base of the weathered zone.

The automatic computer migration, like other migration, requires a knowledge of the velocity-depth relation if it is to be useful. Programs written for such migration is such that all dipping events are tangent to some curve of maximum convexity constructed with this velocity function and that such events when migrated will appear at the vertex of the curve.

Figure 1 compares a record section before migration with one plotted from the same field data after migration.

Velocity estimation, CMP stacking, and migration generally are considered independent processes. However, they all have a common theoretical base: the scalar wave equation. Solution of this equation allows downward extrapolation of a seismic wave field recorded at the earth's surface. In turn, downward extrapolation provides a basis for CMP stacking and migration (Clayton, 1978; Yilmaz and Claerbout, 1980). Velocity estimate could be obtained from the processes of CMP stacking and migration requires velocity information (Taner and Koehler, 1969; Gardner et al, 1974).

There exists no distinct difference between migration and stacking velocity when the subsurface medium is horizontally layered. However, for dipping reflectors, the two types of velocity differ. Stacking velocity is sensitive to the dip of the reflecting interface (Levin, 1971), while, in theory, migration is independent of dip (Hubral and Krey, 1980). For velocity migration, we must use a velocity field that is corrected for dips present in the data. As a result, any procedure that obtains velocities suitable for migration must use data from a number of neighbouring CMP gathers.

The idea of a velocity analysis that is based on differential solutions of the scalar wave equation first was introduced by Doherty and Claerbout (1974). They use the 15-degree finite-difference migration algorithm and worked with single CMP gathers. Gonzalez-Serrano and Claerbout (1979) later extended the wave equation velocity analysis to slant-midpoint coordinates and worked with linearly moveout-corrected CMP gathers. This method operates in the Fourier transform domain using the exact form of the double-square-root (DSR) operator (Yilmaz and Claerbout, 1980).

2.0 Location

The Trans-Atala 3-D prospect spans a large area of OMLS (Omission Lines) 35 and 46. The total surface area of the prospect is approximately 256 square kilometers. The area is swampy and low-lying with surface elevation gradually rising from 2.28m in the south to 1.98m up north.

The prospect covers Burigbene and Ogbotobo fields. The adjoining communities are Ekurugbene, Bassan, Lobia and so on. These are all in Western Ijaw Local Government Area of River State.

3.0 Theory

The theory of migration velocity analysis based on wave field extrapolation is described as shown. Consider seismic data in midpoint-(half) offset (y, h) coordinates. Let us obtain a volume of focused energy at zero offset in (y, ν, τ) coordinates. For a midpoint location y, migration velocity function can be picked from the corresponding (ν, τ) plane.

If a 3-D Fourier transformation is applied to the upcoming wave field P(y, h, τ = O, t), which is recorded at the surface.

$$P(k_y, k_h, \tau=0, w) = \iiint P(y, h, \tau=0, t)\ .\exp(ik_y y + ik_h h - iwt)\,dk_y\,dk_h\,dw \tag{3.1}$$

where t is the two-way travel time and

$$\tau = 2\int \frac{dz}{V(Z)} \tag{3.2}$$

is the two-way vertical time equivalent of downward continuation depth z in a medium with velocity V(Z). The variables (k_y, k_h, w) are the Fourier duals of (y,h,t). The surface wave field given by eqn. 1 is extrapolated down to depth τ by

$$P(k_y, K_h, \tau, w) = P(k_y, K_h, \tau=0, w)\exp(-i\tfrac{w}{2}\tau DSR) \tag{3.3}$$

where

$$DSR \equiv \left[1-(Y+H)^2\right]^{1/2} + \left[1-(Y-H)^2\right]^{1/2} - 2 \tag{3.4}$$

and Y and H are the normalized midpoint and offset wave numbers respectively given by

$$Y = {vk_y}/{w}, \quad H = {vk_h}/{w}$$

The −2 term puts the expression in retarded time form. Equation (3.3) is used recursively to extrapolate the wave field from one depth to another in steps of Δτ.

We next, transform the extrapolated wave field $P(k_y, k_h, \tau, w)$ into the space-time domain. To do this, we only need to obtain the zero-offset information ($h = 0$). If we sum equation (3.3) over k_h, we obtain the wave field at zero offset, $P(k, h = 0, \tau, w)$. By solving the 2-d inverse transform over (ky, w), we get

$$P(y,h=0,\tau,t)= \iint P(k_y,h=0,\tau,w).\exp(-ik_y y+iwt)dk_y dw \tag{3.5}$$

$P(y, h = 0, \tau, t)$ is the zero-offset section at various depth levels from which we want to extract velocity information.

If velocity V_e were used to extrapolate the surface wave field down to depth τ, equation 3 could be written with V_e and τ as:

$$P(k_y,k_h,\tau,w) = P(k_y,k_h,0,w).\exp\left[-i\tfrac{w}{2}\tau DSR(V_e)\right] \tag{3.6}$$

If the true medium velocity V were used to extrapolate the surface wave field down to depth $\tau = t$. Rewriting equation (3.3) with v and t we obtain

$$P(k_y,k_h,t,w) = P(k_y,k_h,\tau=0,w).\exp\left[-i\tfrac{w}{2}tDSR(V)\right] \tag{3.7}$$

If we match the two extrapolated wave fields in equations (3.6) and (3.7) to obtain a relationship between V_e, τ, v and t:

$$\tau\, DSR(V_e) = tDSR(v) \tag{3.8}$$

Equation (3.8) does not provide an explicit expression for v in terms of τ, t and Ve. To get an approximate expression by expanding the square roots in Taylor series, the first-order expansion of equation 4 yields.

$$DSR \approx -Y^2 - H^2 \tag{3.9}$$

Substituting equation (3.9) into equation (3.8) and considering that $Y = vk_y/w$ and $H = vk_h/w$, then simplifying, we obtain the approximate relationship.

$$\tau V_e^2 = tV^2 \tag{3.10}$$

Equation (3.10) suggests that downward continuation with the correct (medium) velocity to a wrong depth in equivalent to downward continuation to the correct depth with the wrong velocity (Doherty and Claerbout, 1974).

In equation (3.10), V_e is assumed to be constant. If V_e is depth-variable, then equation 10, still holds because equation 3 is valid for a stratified earth model. If V_e is replaced by the rms velocity.

$$V_{rms}^2 = \frac{1}{\tau}\sum_k \Delta\tau V_e^2(k\Delta\tau) \tag{3.11}$$

The approximation (equation 3.9) is best for small ratios of offset-to-reflector depth, the accuracy of the mapping procedure based on equation (3.10) degrades at very shallow depths.

4.0 Field Data Example and Discussion

The unprocessed data got from the field operations are fed into automatic computer whose program is written in line with the theory above. Figure 2 summarizes the main computational steps involved in this migration velocity analysis based on wave field extrapolation.

4.1 Procedure

Recorded Data	:	$P(y, h, \tau = 0, t$
3-D FFT	:	↓ $P(k_y, k_h, \tau = 0, w)$
Operator	:	x ↓ $\exp(-i\frac{w}{2}DSR\tau)$
Extrapolated Wavefield	:	↓ $P(k_y, k_h, \tau, w)$
Zero Offset	:	↓ $\sum_{K_H} P$ ↓

2-D FFT^{-1}	:	$P(y, h = 0, \tau, t)$
Mapping	:	$\{\tau \rightarrow v\}$
Velocity Information	:	$Env[P(y, h = 0, \tau = t, v)]$

Figure 2: Computational steps involved in the migration velocity analysis.

The procedure above could be demonstrated using the DSR operator. Figure 3 shows two common-offset sections over a number of point buried in a constant-velocity earth, where v = 3000m/s. If a constant velocity is used for extrapolation, Ve = 3000m/s, the image planes is shown in each midpoint. Two planes corresponding to midpoints 1 and 5 in Fig. 3 are shown in Figure 4. The (v, τ) planes (Figure 5) were generated from the image planes by the mapping process. In Figure 4, almost all the energy is in the image plane which corresponds to midpoint 1, five midpoints away. At midpoint 5, the migrated energy is very low. Fig. 6 shows common-offset data based on a horizontally layered earth model containing three point scatterers located beneath midpoint 1 on the boundaries between constant-velocity layers, where (a) is zero-offset and (b) is far offset. Figure 7 shows image planes corresponding to midpoint 1 and 5 as indicated in Figure 6, where (a) is CMP 5 and (b) is CMP 1.

Figure 8 shows CMP stack of the field data of Atala Prospect while Figudre 9 is a close-up of the conventional migration of the datum-corrected field data in Figure 8. The velocity in the layer between the surface and datum was that used in calculating elevation-static corrections (3000m/s). Figure 10 shows migration of the datum corrected field data using the zero-velocity-layer method. The steep events under location B in Figure 9 are now positioned under location A, a lateral charge of about 400m.

Snell's law is obeyed at the interface between the zero and non-zero velocity layers. For a flat-layered medium, Snell's law describes refraction at the interface between two layers of velocity V_1 and V_2 as

$$V_1 \sin\theta_2 = V_2 \sin\theta_1$$

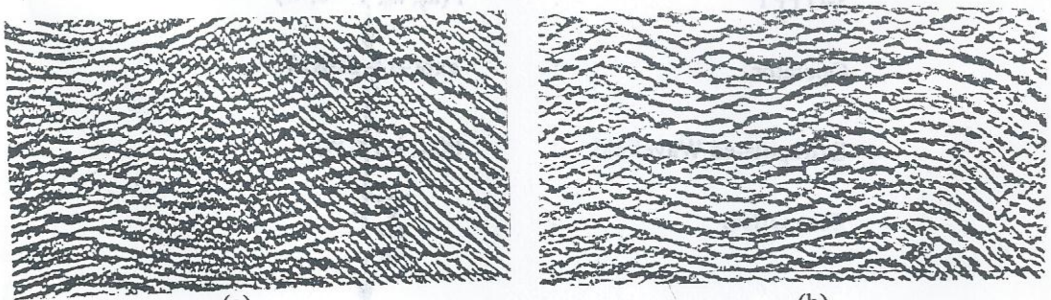
where θ_i is the angle of propagation measured relative to vertical in the *i*th layer.

Snell's law is accounted for in migration by both the diffraction and thin-lens term. The diffraction term honours Snell's law assuming horizontal interfaces while the thin-lens term corrects for dipping velocity interfaces (Hatton et al, 1981).

5.0 Conclusion

The velocity analysis described does not handle lateral variations in velocity. It is based on a Fourier-transform domain formulation with only vertically varying velocity used in extrapolation. The method is efficient for the dip-corrected velocity estimate needed for time migration.

The migration velocity analysis technique is based on wave field extrapolation. Velocity estimation is carried out from unstacked seismic data in mid point offset coordinates. The techniques enable us to incorporate dip information that is essential for migration velocity estimation. It enabled us to convert the information recorded in the field into a form that most greatly facilitates geological interpretation.



(a) (b)

Figure 1: Migration by computer: (a) unmigrated time section showing great number of diffraction patterns; (b) migrated section showing synclinal and anti-clinal features

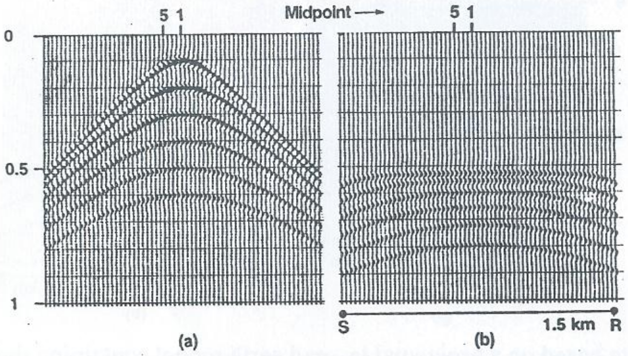


Figure 3: Two common-offset data over a number of point buried in a constant velocity earth. (a) is zero-offset and (b) is far offset.

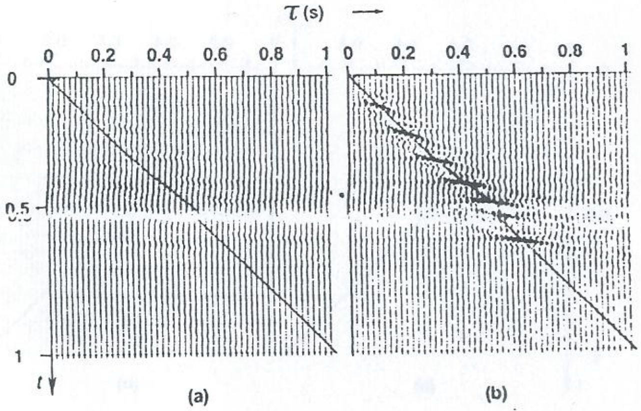


Figure 4: Images planes corresponding to midpoints 1 and 5 as shown in Figure 3, (a) is CMP 5 and (b) is CMKP 1

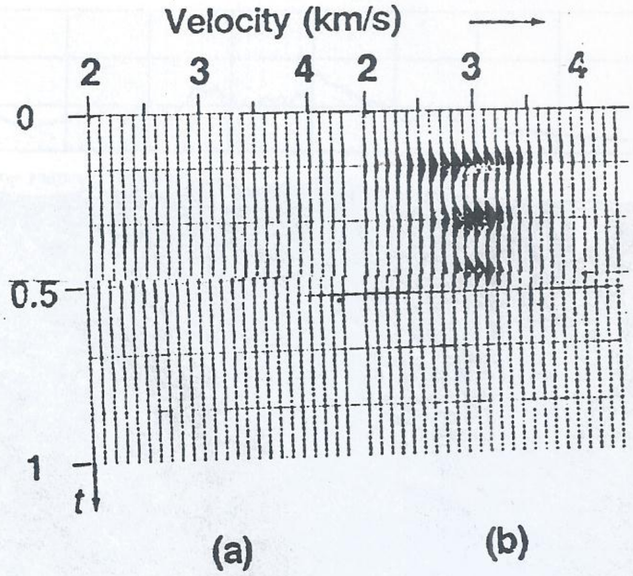


Figure 5: The (V,τ) planes corresponding to mid points 1 and 5 derived from images planes in Figure 4, (a) is CMP and (b) CMP 1.

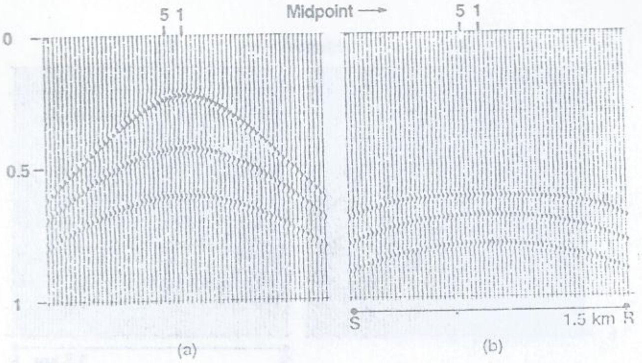


Figure 6: Common-offset data based on a horizontal layered earth model containing three point scatterers. (a) is zero-offset and (b) is far offset.

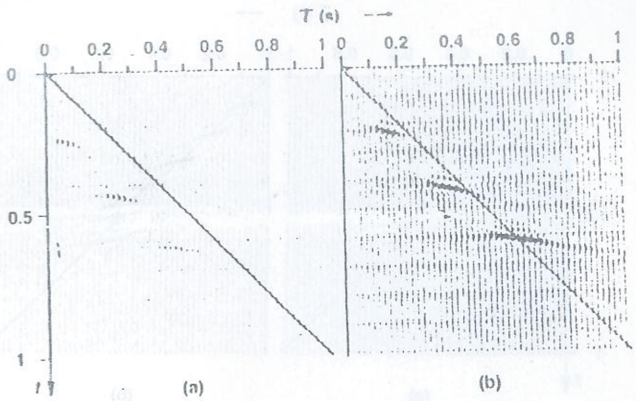


Figure 7: Image planes corresponding to mid points 1 and 5 as shown in Figure 6: (a) is CMP 5, and (b) CMP 1

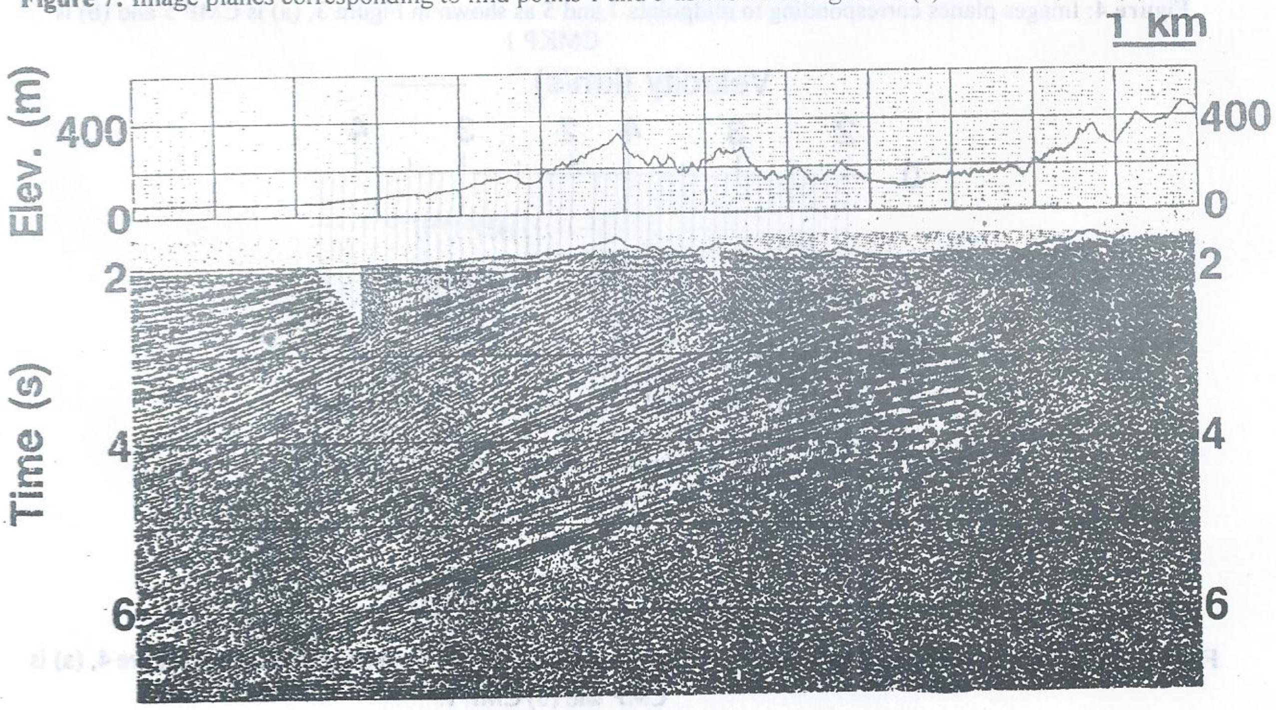


Figure 8:CMP stack (after DMO) of field data

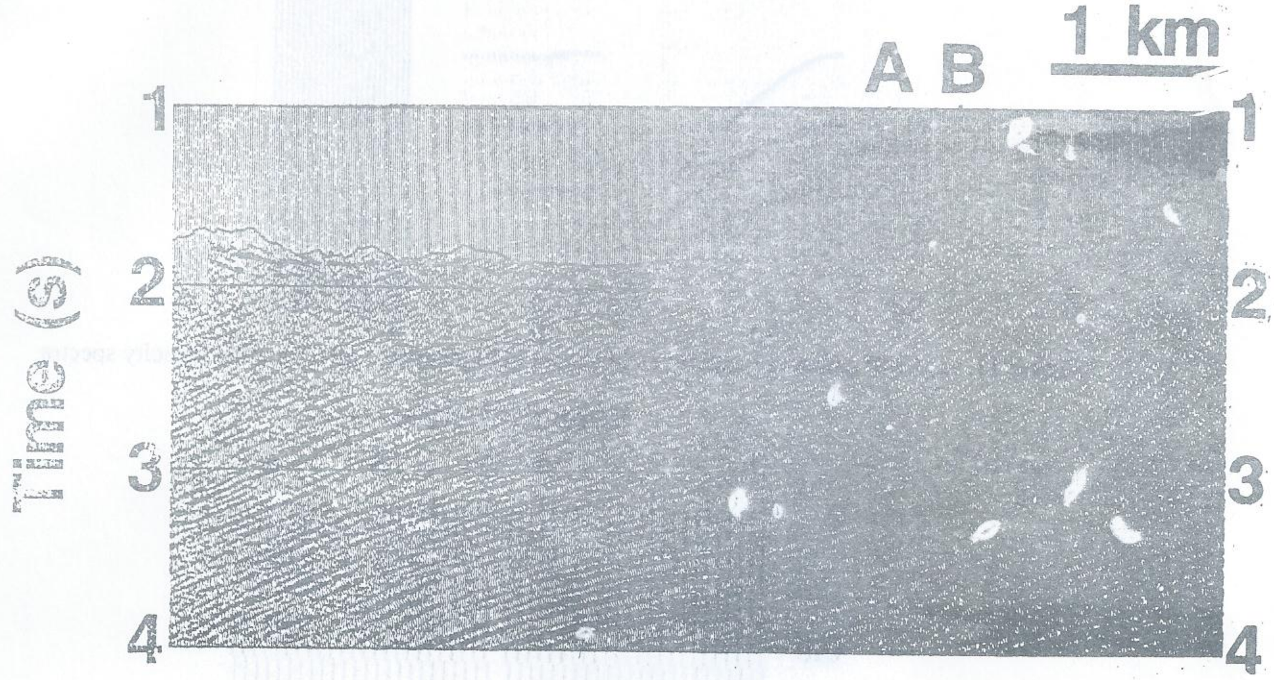


Figure 9: Close-up (right-hand side) of the datum-corrected field data in Figure 8

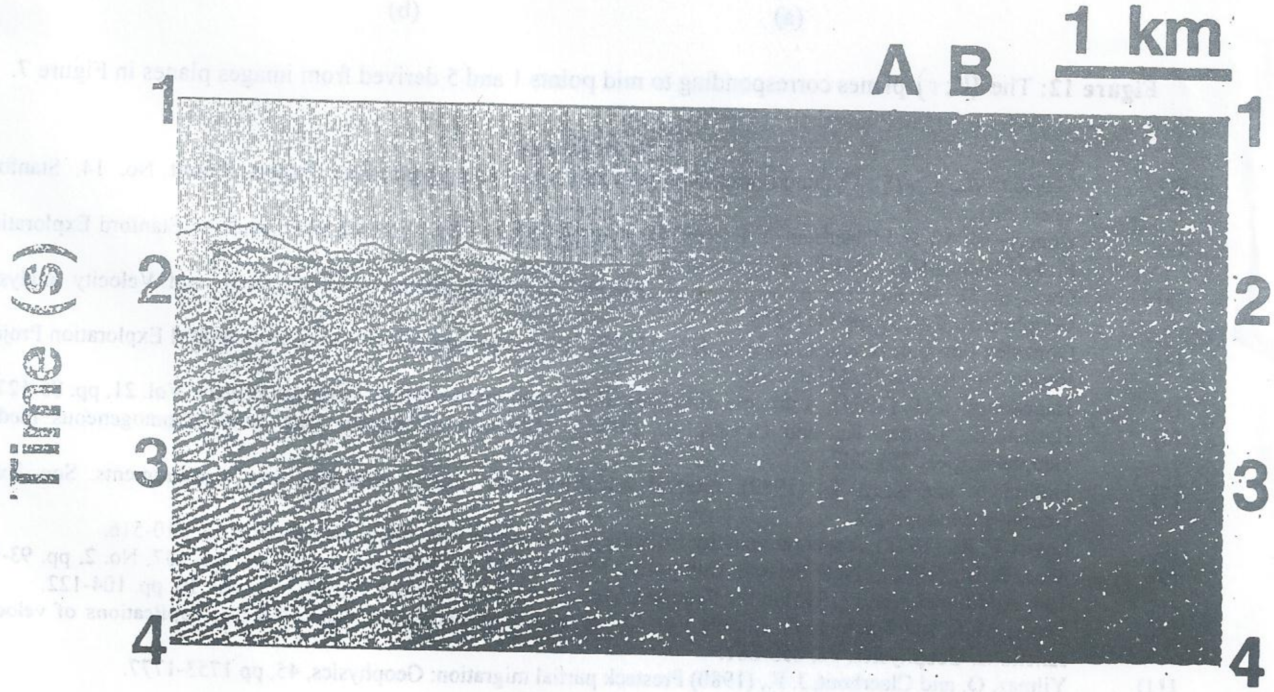


Figure 10: Migration of datum-corrected field data using the zero-velocity-layer method.
Note that the steep events under location B in Figure 9 are now positioned under location A, a lateral change of about 400 m

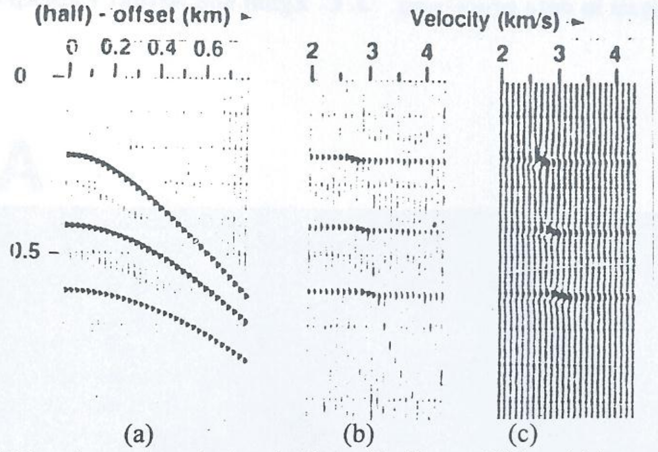


Figure 11: (a) CMP gather at location! as indicated in Figure 6(b) and (c) are the velocity spectra

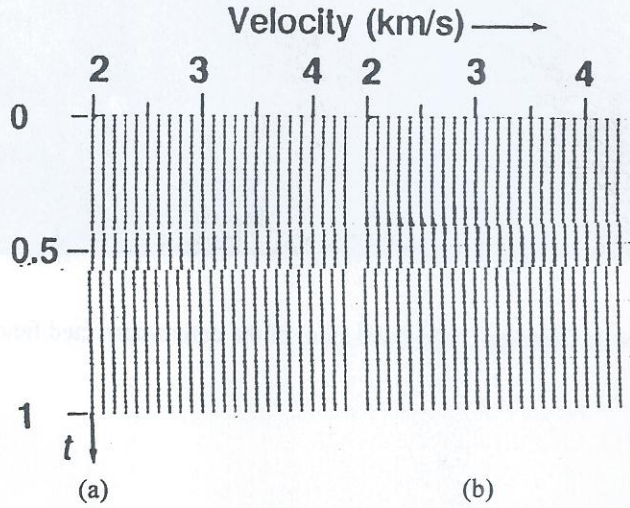


Figure 12: The (V,τ) planes corresponding to mid points 1 and 5 derived from images planes in Figure 7.

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