Depth processing: An example

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The objective of velocity analysis procedures *in* depth processing is to construct an interval velocity model as a function of depth and a spatial coordinate. This model, consisting of the major velocity layers, is sometimes called a "macro velocity model." The structure of the model also has geologic meaning; thus, velocity analysis is a highly interpretive process and requires knowledge of the area's geology.

In most cases, velocity analysis procedures start at the surface and progress downward. Generally, we divide the subsurface into two main parts: the overburden (called the "simple geology" region) and the substrata (called the "complex geology" region). In the data used in this study, the top of the salt separates these regions (Figure 1).

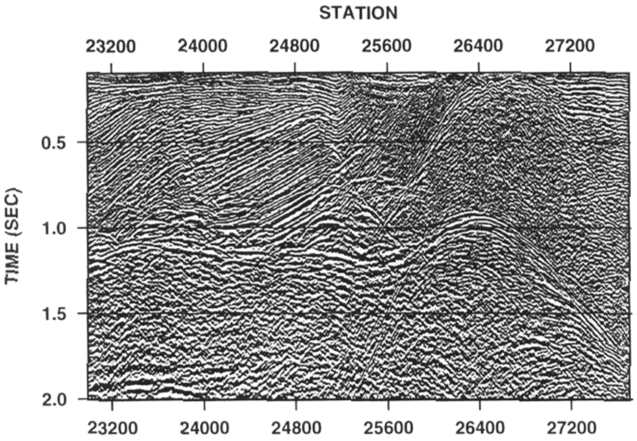

Figure 1. DMO-stack section of the area under investigation. The seismic data were acquired near the Red Sea. The target area is the structural high at the hase of the salt, at station 26 400 and time 0.95 s.

The characteristics of seismic events on a time section distinguish the two regions. In the simple geology area, events are relatively continuous and velocity variations (vertical as well as lateral) are not severe. This means that we can easily identify seismic horizons (on an unmigrated stack section) and use approaches based on ray tracing for building a velocity model.

The boundary between overburden and substrata is usually characterized by a severe velocity change. In the complex geology region. seismic events on a time section are not necessarily continuous and are more difficult to interpret on a conventional stack section. Hence, in this region, we avoid horizon picking and use migration-based velocity analysis techniques.

In the following, we describe and demonstrate application of these procedures using land data acquired near the Red Sea. We also demonstrate the use of residual velocity analysis and generation of a true zero-offset section using forward modeling.

Initial velocity analysis using ray tracing. Our initial interval velocity analysis is a ray-tracing procedure called coherency inversion that was introduced by Landa et al. in "'A method for determination of velocity and depth from seismic data" *(Geophysical Prospecting* 1988). We use this method for velocity determination only; interface location is subsequently determined via poststack depth migration. The core of the algorithm is maximization of a coherency function (semblance, for example) along nonhyperbolic traveltime trajectories on CMP gathers, where traveltimes are obtained from ray-tracing calculations.

The procedure starts with picking major time horizons on an unmigrated stacked section. Next, we choose a number of CMP station locations for velocity analysis. Starting at the surface and proceeding downward, we fix the top n-l layers of the velocity model and solve for the *nth* layer by performing the following three-step procedure (Figure 2):

I) Using a trial velocity, ray migrate the *nth* time horizon to a depth horizon.

2) Using the trial depth horizon, shoot rays for a specific CMP station location using its CMP configuration. This obtains arrival times from the target horizon for each trace which belongs to the CMP gather.

3) Using a time gate around the estimated traveltimes on each CMP gather, calculate a semblance function for the current trial velocity.

Repeating the above steps for a series of trial velocities generates a series of semblance values whose maximum corresponds to the appropriate layer velocity. We now poststack (depth) migrate the stacked section, using velocities found for all analysis locations, to obtain the final location for the *nth* layer interface.

This approach differs from time processing methods in several ways:

1) The velocity analysis is horizon consistent (in depth) and *is* done in a layer-stripping mode.

2) Calculation of traveltimes uses a ray-tracing algorithm, meaning ray paths obey Snell's law when crossing layer boundaries. Thus, calculation of semblance functions on prestack gathers is done along nonhyperbolic moveout.

3) The velocity field is constructed in terms of interval velocity as a function of depth and the horizontal coordinate.

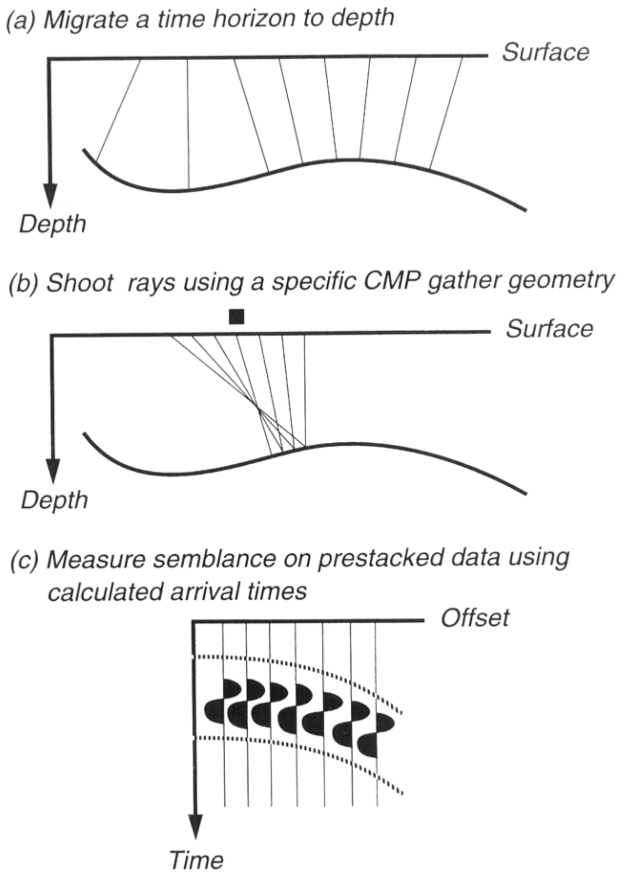

Figure 2. The "Initial velocity analysis" procedure is based on ray-tracing application. This illustration explains the three step procedure.

After applying this ray-tracing technique on the example data set, we found two general trends: Velocity is increasing from east to west and velocity is also increasing in depth. Attributing the increase of velocity in depth to geologic compaction, we utilized gradients in the vertical direction to derive the velocity model for the overburden (Figure 3).

Major velocity analysis procedure using depth migration. In this procedure, a series of prestack depth migrations is performed where the half-space underneath the known portion of the velocity model is incrementally changed before each iteration. We call this method "constant velocity half space" or CVHS analysis.

Using the velocity model for the overburden, we first apply prestack depth migration and obtain a depth section from which we pick the details of the boundary delineating the top of the complex geology region.

Next, we downward continue the data to a level just above the top of the salt (the boundary between the overburden and complex geology in this example). This is the starting point for CVHS analysis.

We start by selecting a number of surface locations for velocity analysis. Then, we fix the top n-l layers of the velocity model and solve for the *nth* layer with the following three-step procedure (Figure 4):

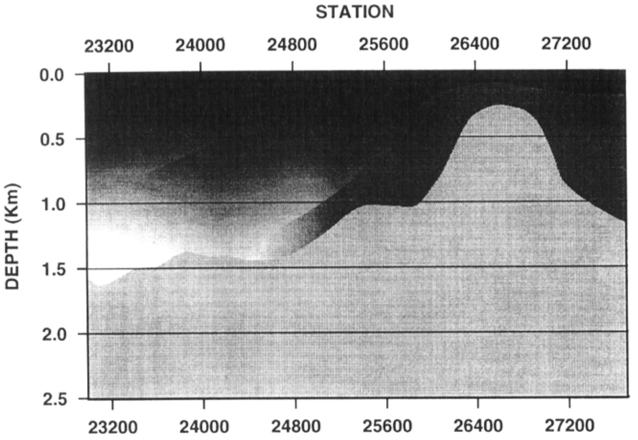

Figure 3. Overburden velocity model constructed by ray-tracing technique. Vertical velocity gradients were utilized. Velocity values range from 2000 m/s to 3500 m/s.

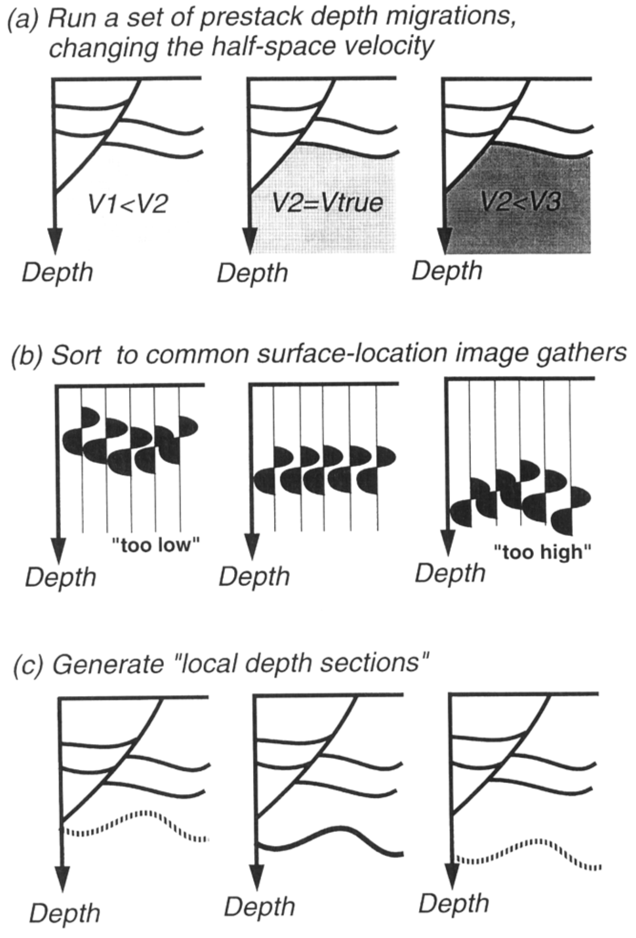

Figure 4. "Major velocity analysis" is based on pre-stack depth migration. This illustration explains the procedure.

1) Using a trial velocity for the underlying half-space, prestack depth migrate the shot gathers which contribute to the image at the selected interface location.

2) Sort the migrated shots by surface-location to obtain common surface-location image gathers. (Please note that, at this stage, a receiver station is meaningful only as a pointer to a surface location.)

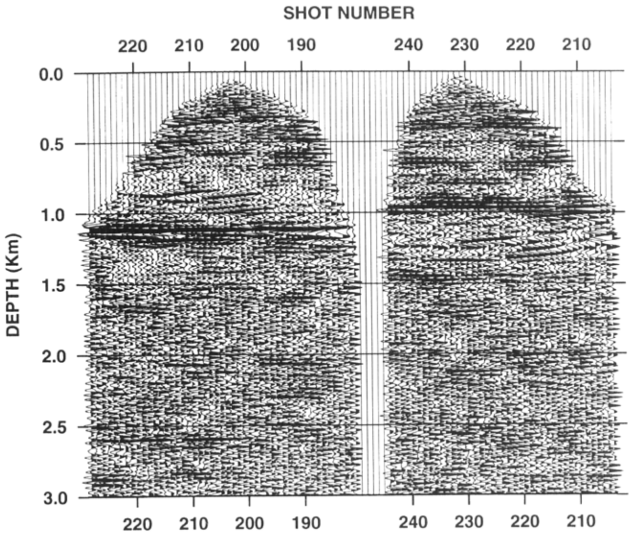

Figure 5. Common surface-location gathers obtained by prestack depth migration, after application of the CVHS analysis. Those gathers belong to stations 25 000 and 26 000, respectively.

3) Stack the common surface location gathers for a short range around the analyzed surface location to obtain "local depth sections."

Repeating this procedure for a series of trial velocities yields a set of common surface-location gathers and local depth sections which are ready for interpretation.

When good signal-to-noise ratio exists after prestack depth migration, the common surface location gathers are used directly in the analysis. This method was introduced by Taner at SEC's 1979 Annual International Meeting in the talk "Common image point stacking system." Since all traces of a common surface location gather belong to the same surface location, events on these gathers align horizontally when the correct migration velocity is used. If the velocity is too low, events curve upward as distance from the shot to the surface location increases and they curve downward when the velocity is too high. In addition, if the reflecting horizon is nearly flat, the curve is symmetric around the middle trace (i.e., the trace contributed by the shot nearest the analysis point). When dip is present, the center of the curve slides away from the central trace.

The velocity of the *nth* layer is that which generates the flattest image for the *nth* interface. (Two common surface-location gathers resulting from CVHS are presented in Figure 5.)

If S/N ratio of the common surface location gathers is poor, we use the local depth sections. In this case, we choose the velocity that generates the most coherent *nrh* reflector. This technique is similar to conventional constant velocity stacks in time processing, and is applied in exactly the same manner.

We were able, using CVHS analysis, to locate the bottom of the salt layer on the example dataset and add it to the velocity model (Figure 6).

Residual velocity analysis. Since both initial and major velocity analysis were performed at a relatively small number of surface locations. we anticipate that some small error in the velocity model will occur away from the control points. Inspection of common surface location gathers often reveals slight curvature (overcorrection or undercorrection) of some imaged events. Analysis of this curvature is the technique that facilitates residual velocity estimation.

Recent articles in *Geophysics* (by Al-Yahya in 1989, and by Lee and Zhang in 1992) describe residual velocity analysis procedures that treat event curvature on common surface location gathers in a manner similar to that of traditional normal moveout in CMP gathers. Assuming that event curvature can be adequately described by a set of straight rays, traced through a medium whose velocity is equal to the average velocity from the surface to the reflecting image, a simple relation between the true average velocity and the average velocity used in migration can be derived. This relationship resembles the usual hyperbolic moveout equation; hence, a

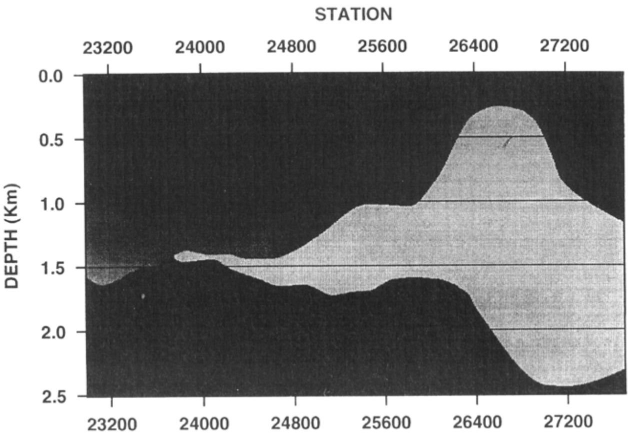

Figure 6. Final velocity model obtained by initial and major velocity analysis procedures. The top of the salt was defined by the initial velocity analysis procedure, and the hase was defined hy the major velocity analysis procedure. Velocity values range from 2000 to 4500 m/s.

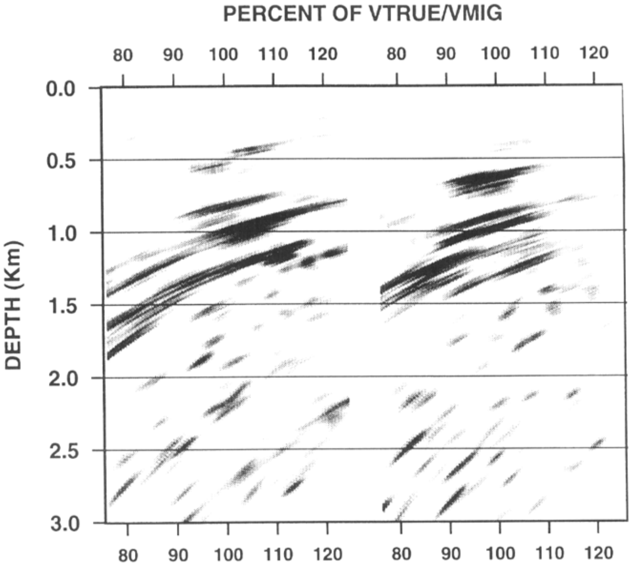

Figure 7. Residual velocity analysis spectrums constructed for stations 24 100 and 24 200, respectively.

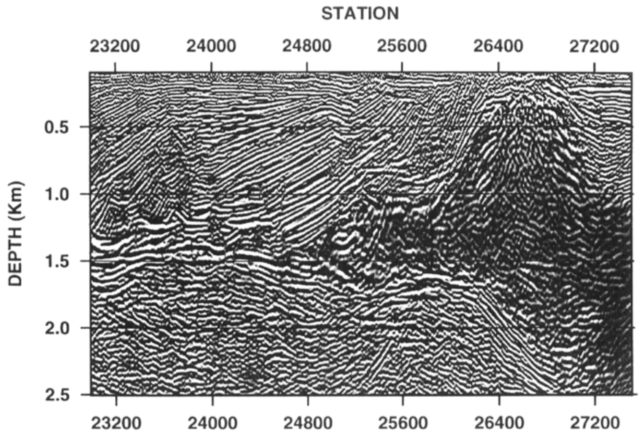

Figure 8. Final depth section obtained by depth processing procedures. Comparing to the section resulted by conventional time processing, the target location was shifted by 1 km to the east.

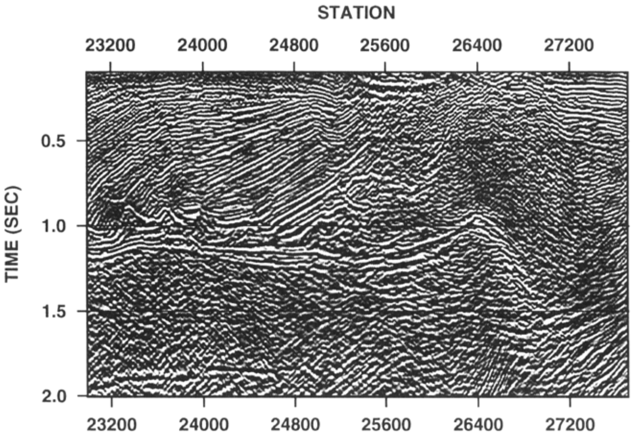

Figure 9. Prestack time migrated section.

small modification of time domain semblance velocity analysis and normal moveout correction algorithms gives us the ability to correct both the velocity field and the associated depth images with simple and efficient operations.

We performed this residual velocity analysis for all selected common surface location gathers, adjusted the velocity model, and performed the final iteration of prestack depth migration. Figure 7 shows residual velocity spectrums. Figure 8 is the resulting final depth section.

Tomographic approaches to analysis and correction of common surface location gathers have also been introduced recently. In these techniques, ray paths obey Snell's law and they are therefore expected to yield reliable results even when the velocity field is quite complex.

Example results. A target area was identified below the high portion of the salt structure in our example data set (.95 s at station 26 400 in Figure 1). This is a structural high at the base of the salt. The primary objective of seismic processing was, therefore, to correctly position the base of the salt and identify its relative high point.

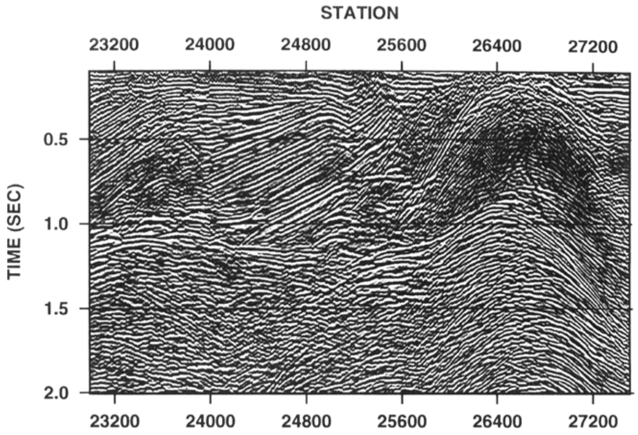

Figure 10. Zero-offset section obtained by modeling the final depth section of Figure 8.

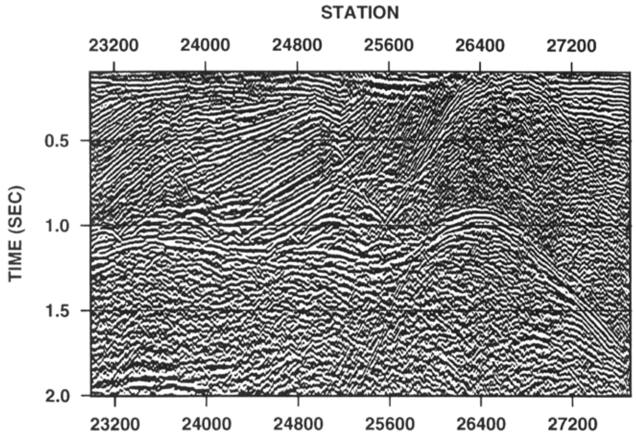

Figure 11. Filtered version of the DMO-stack section presented in Figure 1.

The salt structure and its high velocity give rise to severe distortion of the base of salt on a time section. Prestack time migration (Figure 9) clearly imaged the base of the salt but failed to position the structure to its true lateral position. On the other hand, on the section resulting from depth processing (Figure 8), the base of the structure is located at 1.6 km at station 25 900, about I km to the east of its location on the time section.

A well, located on the basis of this depth section, reached the bottom of the salt as expected and resulted in a successful oil discovery. Note also that, at the modified target location, the amount of salt that had to be penetrated is significantly less than the initial estimate obtained via conventional time processing techniques.

Forward modeling, model validity check. With the final depth section (Figure 8) and the velocity model (Figure 6). we can use forward modeling to generate a zero-offset section. This can serve as a consistency check to validate the depth processing procedures. This sequence of operations was described by Berkhout as "migration of zero-offset data" *(see Seismic migration, imaging of acoustic energy by wave field extrapolation, theoretical aspects,* Elsevier, 1982).

We utilized a reversed poststack depth migration code for the modeling. Using the "exploding reflector" concept, we assume that each point of the depth section represents a reflecting element with strength equal to its seismic amplitude. Upward propagating the depth section in this way results in a true zero-offset section (Figure 10). Naturally, the modeled zero-offset section may contain events which were not captured on a DMO-stack section. However, given a detailed stacking velocity function, we expect good correspondence between the two. Also, since we are using the one-way wave equation, multiples were not modeled.

Comparison of Figure 10 with the filtered DMO-stack section (Figure 11) gives us a way to understand the origin of events. Moreover, analyzing differences between the two sections can guide us to locations where the velocity model is deficient. For example, such deficiencies exist at 1 s near station 25 600. In this case, it did not affect the target zone and, thus, a modified velocity model was not used as input for another iteration of prestack depth migration.

Summary. This article demonstrates a methodology for depth processing which consists of an initial velocity analysis based on ray tracing and a major velocity analysis based on prestack depth migration. Residual velocity analysis is used to tune the velocity model.

The objectives of depth processing procedures are generation of a depth interval velocity model and an accurate depth section. Using a land data set, we showed that those objectives are realizable even with data from complex structural areas. This can minimize exploration risk and cost. We therefore believe that depth processing will become an integral part of data processing, for both 2-D and 3-D data sets. 6

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