Simultaneous anisotropic prestack depth migration of P-S VSP and surface seismic data

M. Graziella Kirtland Grech and Don C. Lawton

ABSTRACT

A general prestack depth migration algorithm has been developed to investigate combined depth imaging of VSP and surface seismic data. The migration, which can handle vertical and tilted transverse isotropy, as well as pure P- and S-modes and converted-waves, has been tested on synthetic data from a flat reflector. The results show that the integration of the VSP migrated section with the surface seismic one yields a better image than that from VSP migration alone – it images a larger portion of the reflector and shows enhanced reflection continuity and focusing. Similar imaging improvements were observed when the integrated P-P VSP and surface seismic depth-migrated section was added to the corresponding P-S VSP and surface seismic depth-migrated section.

INTRODUCTION

Multioffset VSPs make use of a number of surface sources and several receivers down the well. Since the Fresnel zone is smaller and the bandwidth larger (due to less absorption of the higher frequencies as a result of shorter travel paths in the subsurface) VSPs generally yield higher resolution data sets (Payne et al., 1994). VSP data may also produce better images in areas of salt domes and volcanics, as the seismic energy travels through the image-degrading zone only once (Payne et al., 1984). The combination of sources and receivers used, together with the structural style and velocity structure of the subsurface, will determine which portion of part of the reflectors will be illuminated and imaged (Köhler and Köenig, 1986; Hartes, 1990). Since only a limited number of sources are used in multioffset VSP surveys, the resulting migrated sections generally have poorer signal to noise ratios due to the inadequate cancellation of migration "smiles".

Several examples exist in the literature on how migration of VSP data sets can yield good quality, high frequency images (e.g. Zhu and Lines, 1994) that tie very well with reflectors on surface seismic migrated sections when the VSP migrated section is spliced in the surface seismic migrated section (e.g. Payne et al. 1984; Dillon et al., 1988). An improvement in lateral resolution obtained by combining surface and borehole data is illustrated in Miller et al. (1987). Daures et al. (1999) show how 3C-VSP data can be used to guide the processing of surface multi-component data, and also how a better understanding of the reservoir zone is obtained by examining both P-P and P-S sections.

In this work we have developed a new approach to the integration of VSP and surface seismic migrated sections. Instead of splicing the VSP result in the surface seismic migrated section, we migrated both data sets simultaneously using a new migration algorithm specifically designed to handle VSP and surface seismic data sets, and created a single output depth migrated image. The migrated image is based on a Kirchhoff approach.

MIGRATION CODE DEVELOPMENT

The general anisotropic ray tracer described in Kirtland Grech and Lawton (1999) has been modified to calculate traveltime tables for source and receiver positions. Both sources and receivers can be either on the surface or in a borehole, making it possible to calculate traveltime tables to be used for surface seismic and VSP migration. Since the raytracer is interface based, traveltimes are collected each time a ray crosses an interface or reaches the model boundaries. This irregular grid of traveltimes is then re-gridded to provide regular sampling in the x- and z-directions. The program then interrogates each trace sample by sample and spreads the corresponding amplitudes along the appropriate aplanatic surfaces. The migrated events are a result of the constructive and destructive interference of all the aplanatic surfaces. No amplitude weighting or filtering has been applied at this point.

THE NUMERICAL MODEL

A simple two-layer model (Figure 1) was developed using GX2 numerical modeling software to test the migration algorithm. The VSP well was located at 550 m and was 400 m deep. For the surface seismic experiment, there was a total of 7 surface shots between 250 m and 850 m, with a source interval of 100m. Receivers were placed every 50 m over the same horizontal extent. In the VSP experiment, the surface shots were kept at the same location as for the surface seismic experiment. However, the shot at the wellhead (550 m) was not used in this case. There was a total of 16 receivers in the well, between 50 m and 250 m, spaced at an interval of 15m. P-P and P-S reflections were simulated. Figures 2 and 3 show the different raypaths for the P-S surface seismic and VSP experiment. Modeling was done twice – first assuming that both layers are isotropic and then adding anisotropy to the first layer. The *P*- and *S*-wave velocities, densities and anisotropy parameters (Thomsen, 1986) for each layer are given in Table 1.

	Vp (m/s)	Vs (m/s)	Density (kg/m^3)	ε	δ
Layer 1	2745	1585	2240	0.1	0.05
Layer 2	3100	1780	2310	0	0

Table 1. Material properties for the model shown in Figure 1.

No down-going waves were captured in the VSP case and all the data were recorded using a vertical geophone. No attenuation mechanisms were included. The traces were then convolved with a zero-phase Ricker wavelet with a peak frequency of 30 Hz and exported as a seg-y file for migration. The polarity of the P-S traces has been reversed for comparison with the P-P traces. The data sets from the P-S surface seismic surveys and P-S VSP surveys, using the isotropic model, are shown in Figures 4 and 5 respectively.

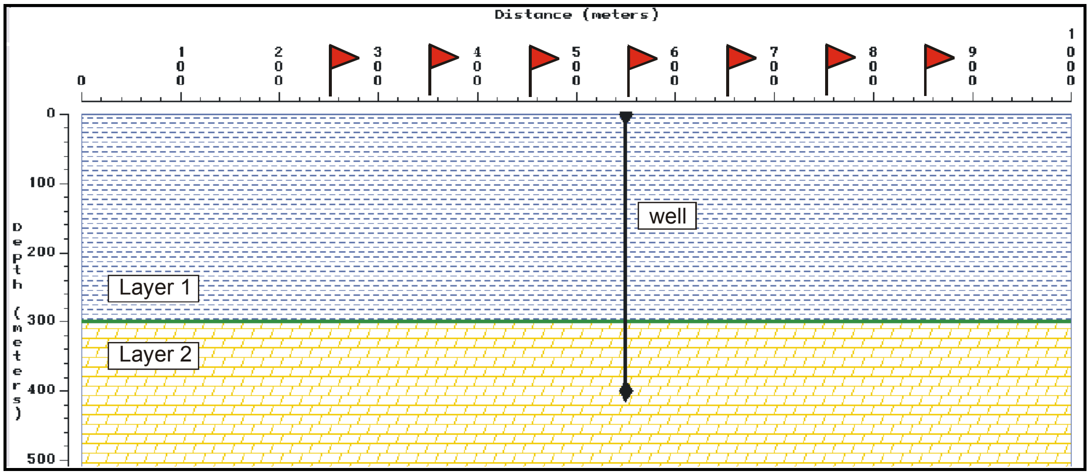

Figure 1. The two-layer model that was used to generate synthetic VSP and surface seismic data sets.

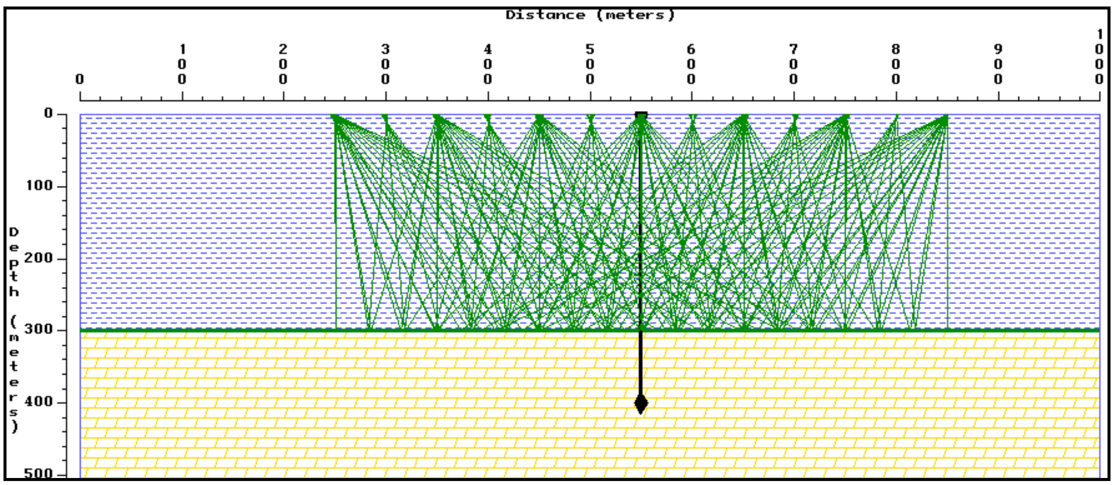

Figure 2. P-S raypaths for the surface seismic experiment (isotropic case).

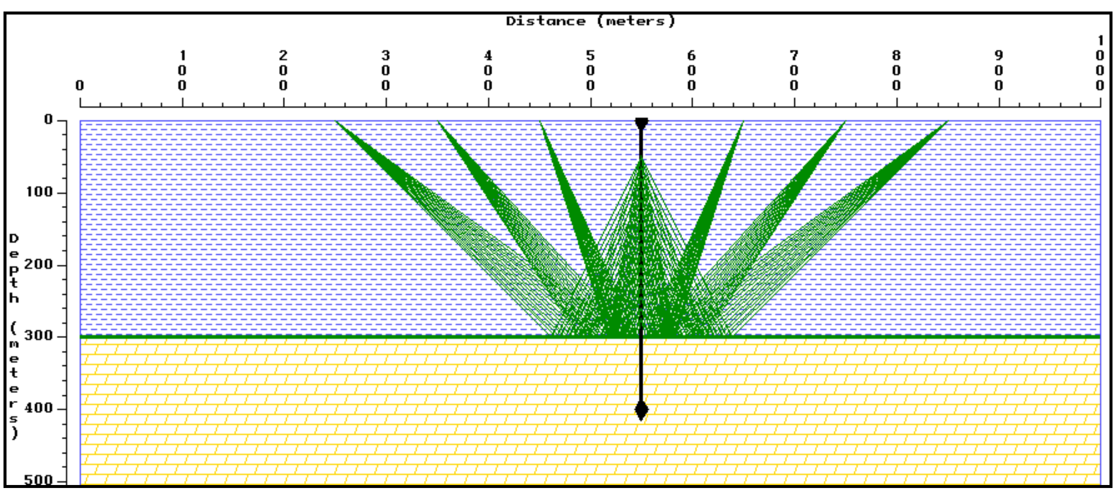

Figure 3. P-S raypaths for the VSP experiment (isotropic case).

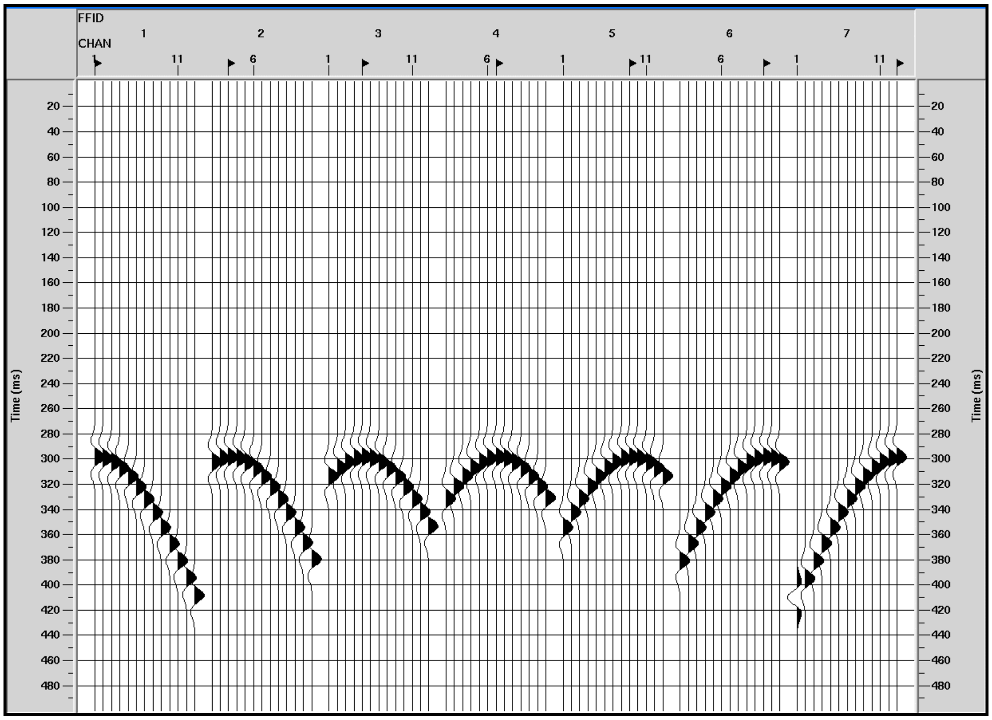

Figure 4. P-S reflections for the surface seismic data set (isotropic model).

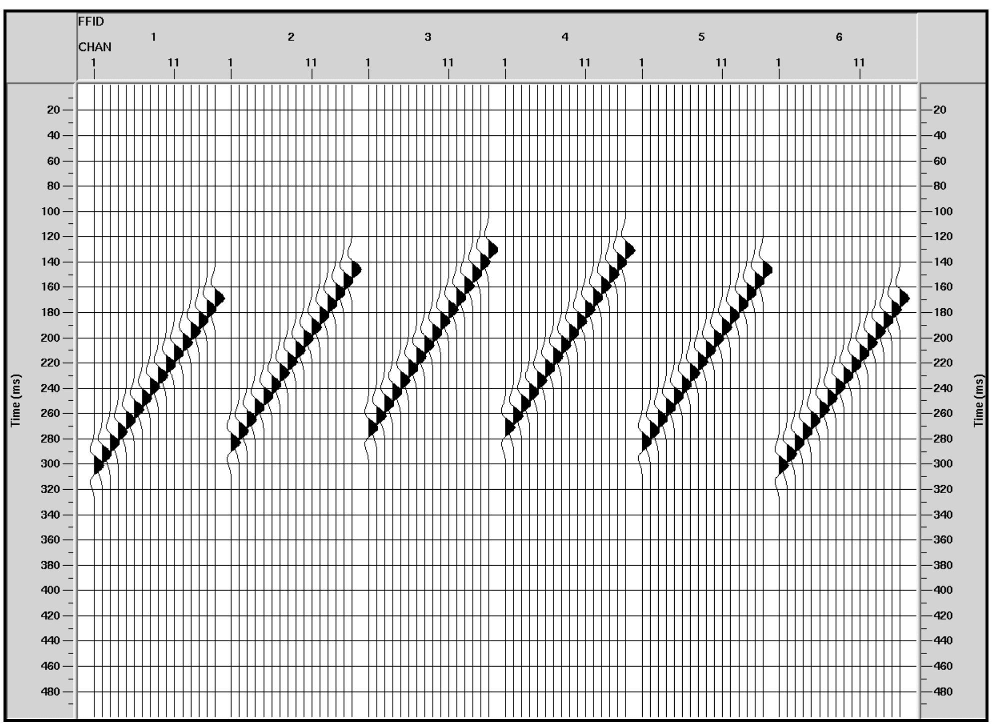

Figure 5. P-S shot gathers showing the up-coming reflections for the VSP data set.

RESULTS

The migrated sections for the converted wave (P-S) data sets are shown in Figure 6 (isotropic case) and Figure 7 (anisotropic case). Figures 6a and 7a show the surface seismic migration results, Figures 6b and 7b the VSP migration results and the combined VSP and surface seismic migrated sections are given in Figures 6c and 7c. The amplitudes after migration have been normalized in each case (except for Figure 8) for comparison purposes and the migration aperture was not restricted.

The migration of the surface seismic data sets (Figures 6a and 7a) images about 250 m of the reflector on either side of the well, whereas the VSP migration (Figures 6b and 7b) images a smaller portion of the reflector, extending to about 100 m on either side of the well. Also the reflection continuity on the VSP migrated sections (Figures 6b and 7b) is not as good as that on the surface seismic migrated section and the amplitude build-up in the center of the event is attributed to the increased reflection fold around the well and zero-fold immediately next to the well (Figure 3). In contrast, the reflection fold for the surface seismic survey (Figure 2) is more regularly distributed, and there is no amplitude build-up on the migrated section. Combining the VSP and surface seismic migrated images (Figure 6c and 7c) attenuates the uneven distribution of amplitudes and shows a strong continuous event, with a lateral extent slightly greater than that on the VSP migration alone. The combined VSP and surface seismic migrated section (Figures 6c and 7c) yield an image superior to that produced by the VSP migration alone (Figures 6b and 7b), in the case of noisy data.

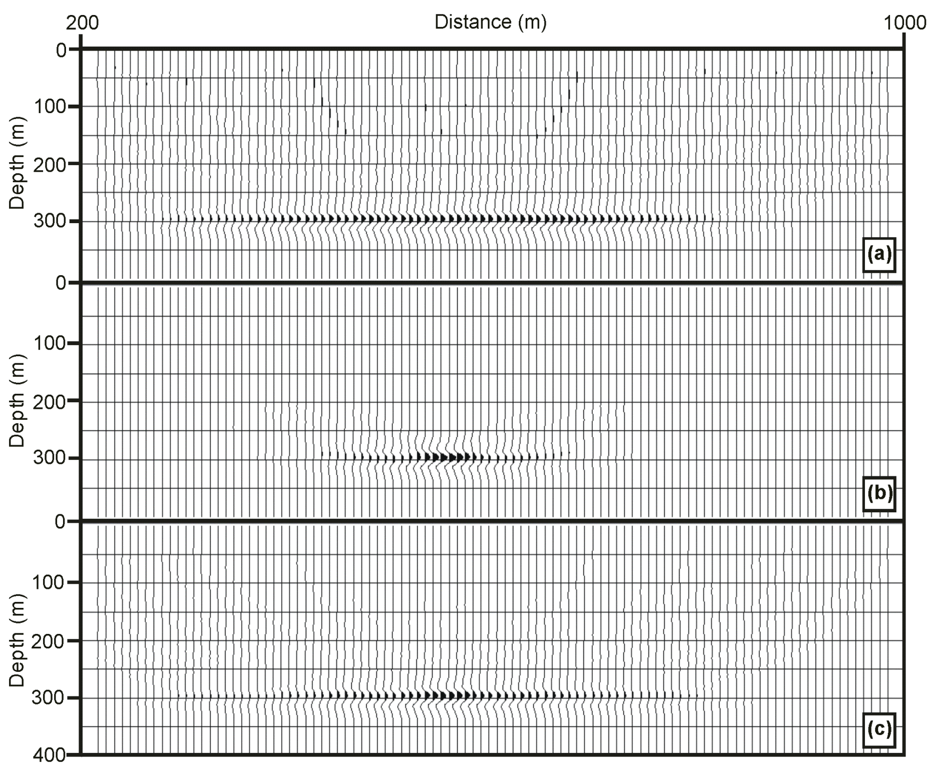

Figure 6. Isotropic prestack depth-migrated sections for the P-S data sets: (a) the surface seismic migrated section, (b) VSP migrated section, and (c) integrated VSP and surface seismic migration.

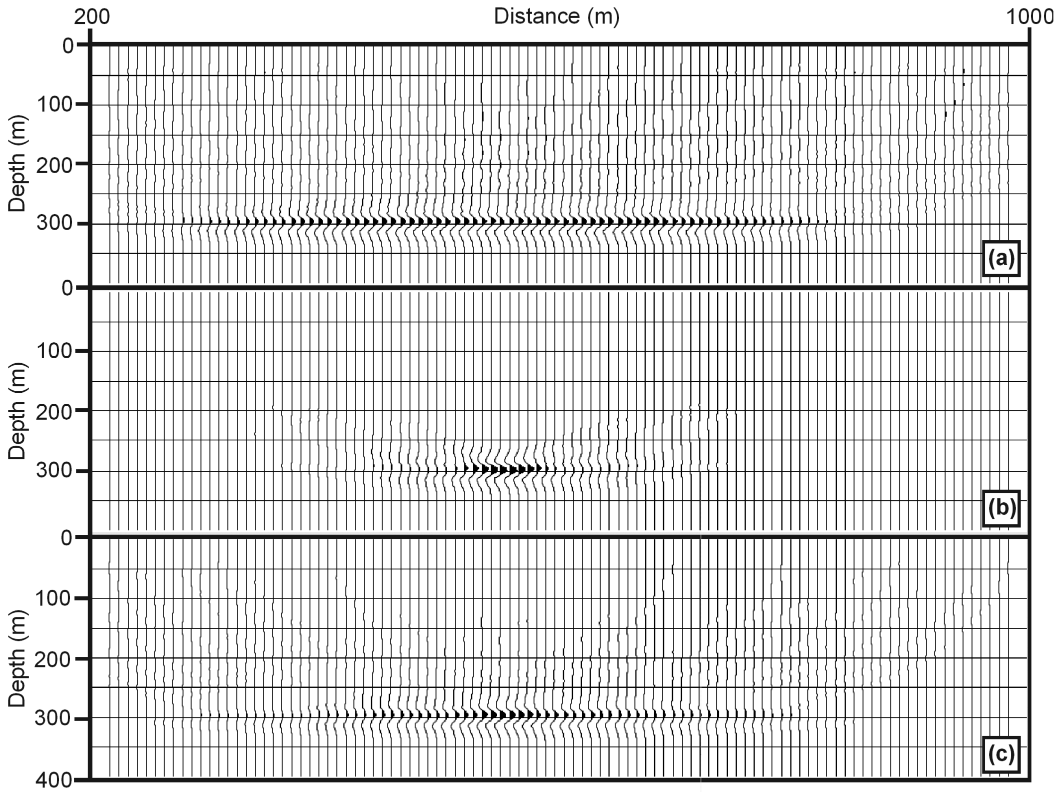

Figure 7. Anisotropic prestack depth-migrated sections for the P-S data sets: (a) the surface seismic migrated section, (b) VSP migrated section, and (c) integrated VSP and surface seismic migration.

Data Scaling

A question arises on how the different data sets should be scaled after migration before summing into the output section. Figure 8 shows the same migrated sections as Figure 7, but in this case no amplitude normalization was performed. This results in weaker amplitude on the surface seismic migrated section (Figure 8a) when compared to the VSP migrated section (Figure 8b). The higher amplitudes on the latter are attributed to the increased reflection fold as discussed in the previous section. When the two data sets are combined (Figure 8c), the event is no longer as well focused and continuous as that shown in Figure 7c, when the amplitudes were normalized, but is dominated by the high amplitude pattern of the VSP migrated section.

Another development consideration will be phase and bandwidth balancing between the VSP and surface seismic data for actual field data.

Potential benefit of combining VSP and surface seismic migration

The integrated VSP and surface seismic migrated section may be used for improved migration velocity analysis. This concept is illustrated in the flowchart in Figure 10. Initially, the VSP and surface seismic data sets are migrated separately using the same migration algorithm and depth-velocity model. As a first attempt, the velocity model may be one derived from migration velocity analysis on the surface seismic data set. The two migrated sections are then integrated to yield one combined depth image, which may contain more information and better resolution than either section alone. This integrated migration can then be used for a new pass of migration velocity analysis to determine a better depth-velocity model for re-migration of both datasets. This procedure may be repeated iteratively until a satisfactory image is obtained.

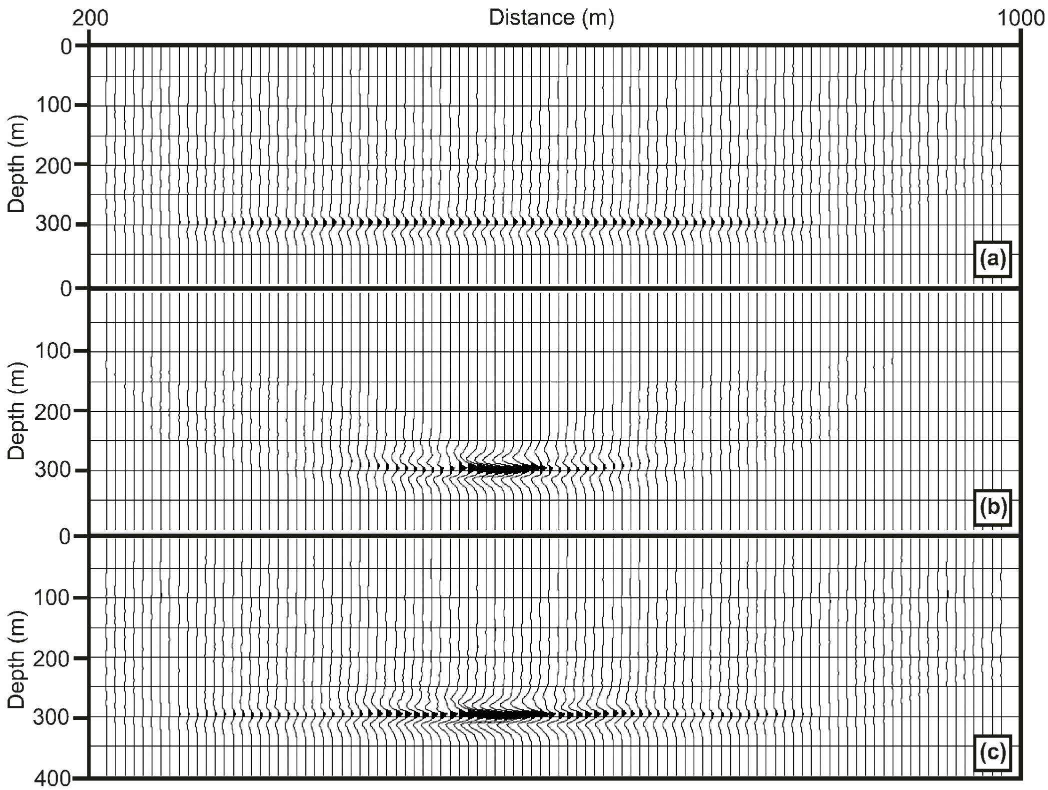

Figure 8. Anisotropic prestack depth-migrated sections for the P-S data sets – no amplitude normalization applied to the sections: (a) the surface seismic migrated section, (b) VSP migrated section, and (c) integrated VSP and surface seismic migration.

Integrating P-P and P-S migrated sections

To investigate the effect of combining P-P and P-S depth-migrated data, we integrated the P-P surface seismic and VSP migrated section (Figure 9a), with the corresponding P-S migrated section (Figure 9b). The resulting section (Figure 9c) shows that the integrated P-P and P-S image is superior to that obtained from the P-P and P-S data sets alone - it has better reflection continuity and improved focussing.

Such integration of P-P and P-S depth-migrated sections may be particularly useful where P-S data images part of a line better than P-P data, for example in the presence of a gas chimney. A combined section may enhance overall reflection continuity and improve imaging through the gas chimney.

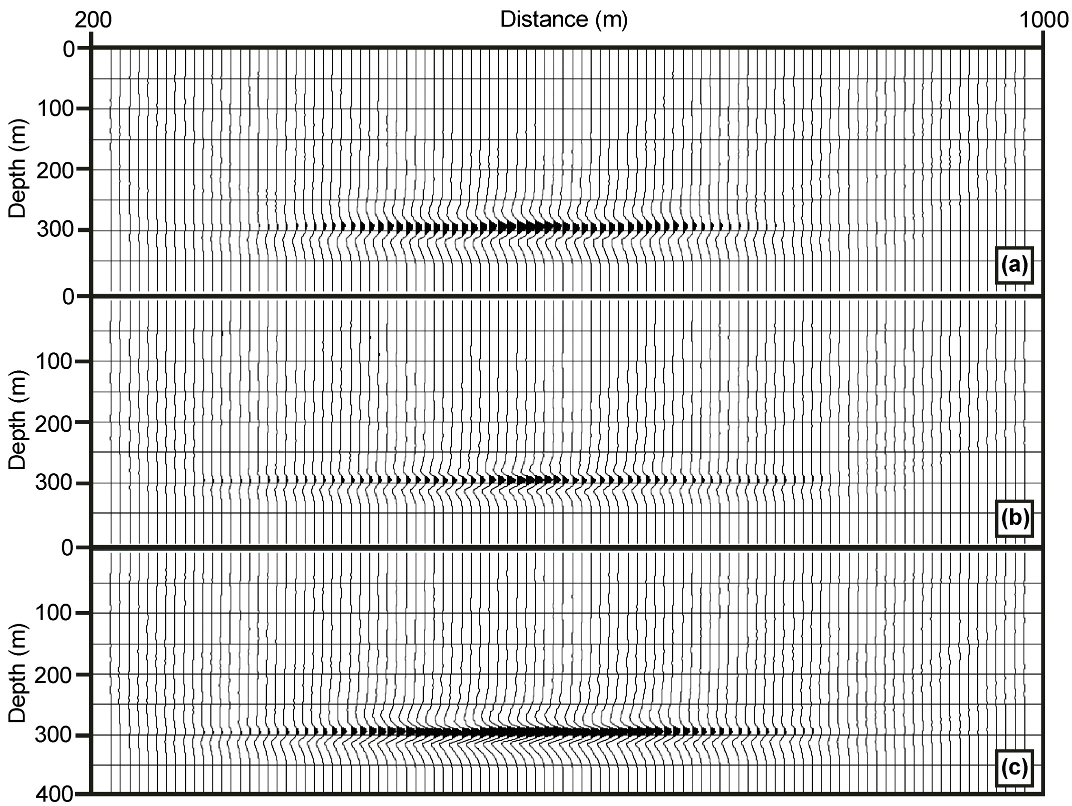

Figure 9. (a) Combined P-P surface seismic and VSP migration, (b) combined P-S surface seismic and VSP migration, and (c) the integrated P-P and P-S image of the sections shown in (a) and (b).

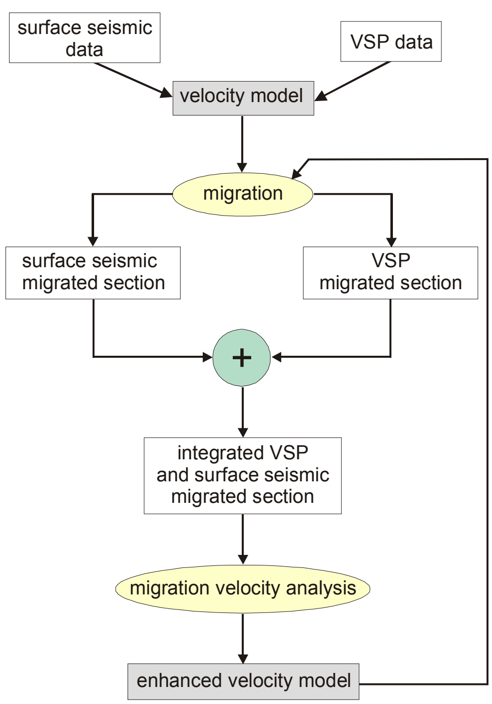

Figure 10. Processing flow for the combined depth imaging of VSP and surface seismic data.

CONCLUSIONS

A new Kirchhoff migration algorithm has been developed and successfully tested for simultaneous depth migration of VSP and surface seismic synthetic data sets. Integration of the VSP and surface seismic migrated sections yielded a better image than that obtained from the migration of the VSP data set alone. Image quality was also improved when P-P and P-S migrated sections were integrated. This may prove to be especially useful now that combined 3C-3D VSP and 3D-surface seismic acquisition is becoming more popular.

FURTHER WORK

More work will be done on the migration algorithm to improve the speed and take account of such factors as amplitude scaling and bandwidth matching. A processing methodology for the combined depth imaging of VSP and surface seismic using this new migration algorithm, will be developed and tested on real data sets.

ACKNOWLEDGEMENTS

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