SOME ASPECTS OF TWO-COMPONENT IN-SEAM SEISMOLOGY

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ABSTRACT

In-seam seismic methods for geophysical surveys in coal mines have been considerably improved using digital recording techniques, a geophone system with two horizontal components, and digital processing methods.

In this paper we discuss special techniques for velocity analysis and migration which utilize both horizontal components and take the vector properties of the recorded wavefield into account. A novel migration scheme is compared to a conventional Huygens-Kirchhoff summation procedure. These methods assist in a more reliable analysis and interpretation of in-seam seismic data.

INTRODUCTION

In-seam seismology has experienced considerable development since the fundamental work of Krey in 1962 (Krey, 1963). Only in 1977 when a digital recording unit became available for use within mines (Klar and Arnetzl, 1978) could the great advantages of digital techniques and digital processing methods be exploited for in-seam surveys. Since then substantial improvement was achieved with the new digital recording system and with a new geophone system comprising two horizontal components.

In this contribution we focus our attention on two areas of processing which are of the utmost importance for the analysis and interpretation of seismic data: velocity analysis and migration. The described methods make use of both horizontal components and therefore take the vector properties of the recorded wavefield into account.

In the first part of this paper a technique for velocity analysis which combines a simple stacking procedure and an imaging principle is discussed. This technique lends itself to a quantitative description of the recorded channel waves.

In the second part we develop a novel approach to migration of in-seam waves and compare it to a method described by Mason et al (1980).

VELOCITY ANALYSIS WITH TWO COMPONENTS

A reliable determination of velocities is an important step in the processing of seismic data. Here it is the Airy-phase group velocity of the fundamental Love mode of guided channel waves which has to be determined. From transmission data this velocity can be obtained using a method which is illustrated in figure 1.

The shot is recorded by geophones 1 to N set up along a line. The orientation of the X- and Y-components is indicated. For the analysis the components are rotated in order to separate compressional and shear arrivals: Y* points towards the shot and mainly records compressional arrivals, X* is oriented perpendicular to Y* and therefore predominantly contains shear waves. The distance R_i between shot and receiver

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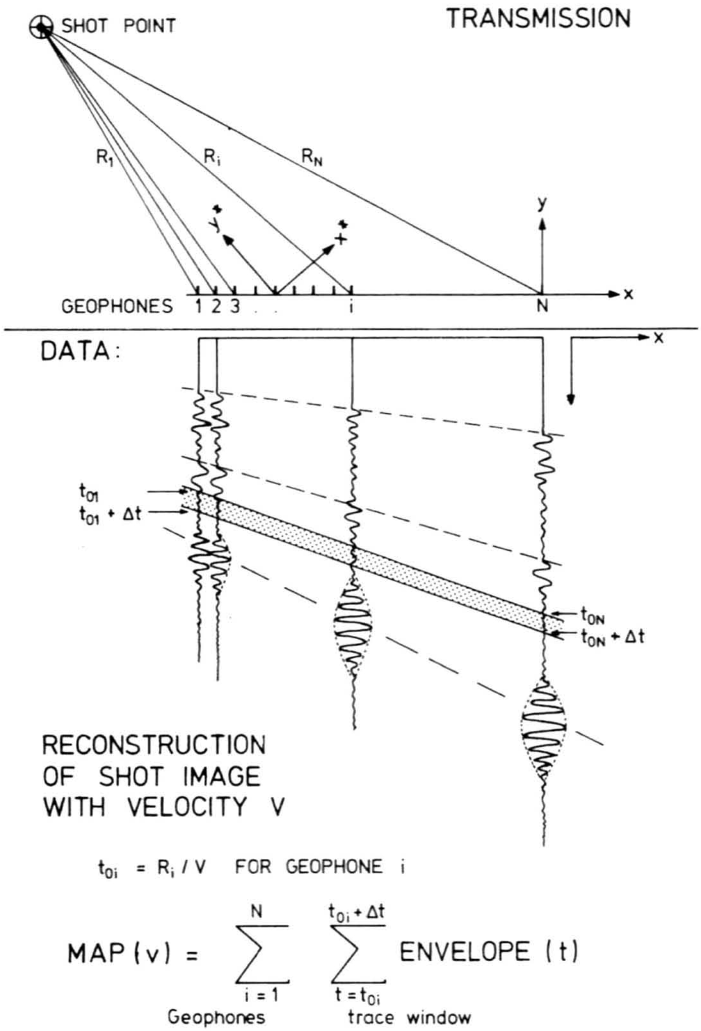

Figure 1 Velocity analysis of two component transmission data

number i can be easily computed from the geometry of the experiment. For a given velocity v, the arrival time t_{0i} is computed at which a hypothetical wave travelling at this velocity would reach the i^{th} geophone. The amplitude of the envelope of the rotated traces is summed over a specific time window starting at t_{0i}. This sum is then stacked for all geophones and yields a number: MAP (v). This summation is formed independently over envelopes of X*-traces and of Y*-traces. The procedure is repeated for a range of velocities. The MAP-function obtained from the X*-traces gives the S-image, the summation over the Y*-traces gives the P-image. The term "image" is chosen as we are attempting to reconstruct the shotpoint with different velocities and with different types of waves: maxima in this MAP-function indicate that a coherent

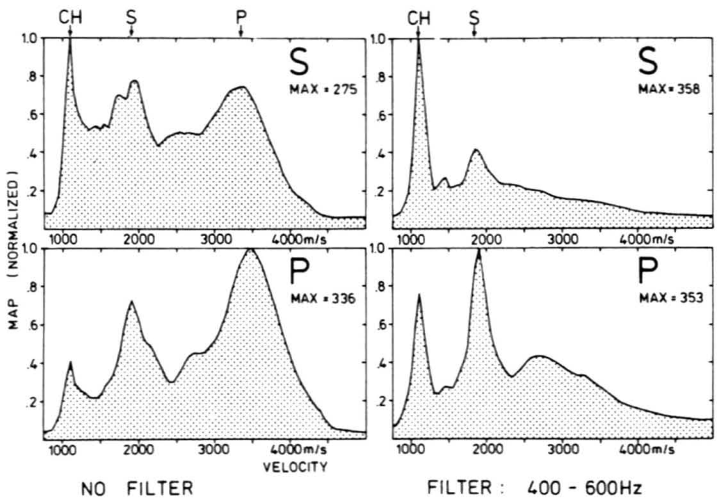

Figure 2 Example of velocity analysis:
24 traces, range 177–310 m

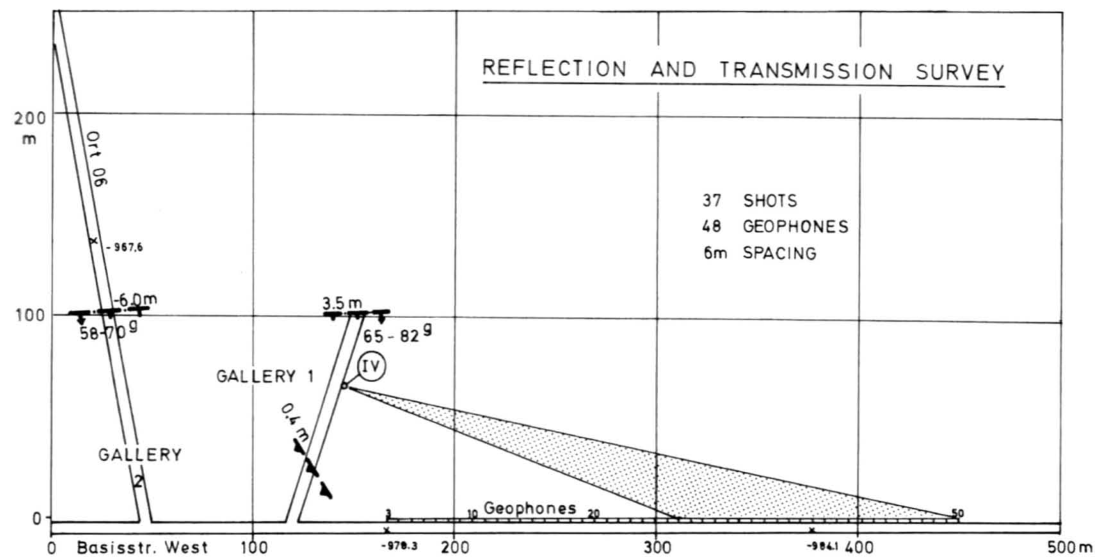

Figure 3 Plan view of in-seam seismic survey
Transmission shot IV recorded at geophone positions 27 to 50. Reflection survey along the geophone line.

image is formed. The procedure can be described as a signal stack as we are attempting to stack arrivals along the geophone line: the MAP-function is used as a measure of coherency.

An example is shown in figure 2; the plan in figure 3 depicts the geometry. Here the traces recorded at the geophone positions 27 to 50 from shot IV were analyzed using velocities from 800 to 5000 m/s (in constant steps of 50 m/s). The left part of figure 1 shows the S- and P-image obtained from unfiltered traces. Three maxima stand out clearly. The maximum at 1100 m/s (CH) is produced by the Airy-phase, the channel phase which is of foremost interest in in-seam seismics. The maximum marked by S represents the shear-wave arrival. The P-maximum is caused by the direct compressional wave. The velocity at this last maximum does not give the velocity of compressional waves in the surrounding rock as this method uses the group velocity. The phase velocity of P-waves in the rock might be defined at the point where the MAP-functions start to rise (here around 4400 m/s). The relative heights of the CH- and P-peaks indicate that a separation of shear-waves and compressional waves has to some degree been achieved.

The right part of figure 2 shows the S- and P-image obtained from filtered traces. The frequency band ranges from 400 to 600 Hz and encloses the band of the Airy-phase. It apparently excludes the band of the P-wave.

The MAP-functions contain more information than just velocity. They can be used to analyze filter tests in order to define the frequency band of the Airy-phase. The ratio of the S-image at the velocity of the Airy-phase to the P-image at the velocity of the maximum of the P-group was found to represent a measure well suited for a quantitative analysis. Table 1 contains this ratio for a number of pass bands. The frequency band 400–600 Hz was given preference over 400–800 Hz not only because the ratio is slightly larger, but also because the average noise level (the value of the MAP-function for velocities greater than 4500 m/s and smaller than 1000 m/s) was lower.

Filter (Hz)	I	Ratio
none	I	0.818
100–800	I	0.808
200–800	I	0.772
300–800	I	0.653
400–800	I	2.563
100–600	I	0.871
200–600	I	0.825
300–600	I	0.726
400–600	I	2.674

Table 1: Ratio SMAP (Airy-phase)/PMAP (P-group)

The ratio of these two values of the MAP-functions can be used as a quantitative measure of the Airy-phase. As this phase contains information of change in the seam properties and other disturbances (minor faults, washouts etc.) encountered along the path, a numerical comparison of the Airy-phase to the P-wave should aid in estimating the magnitude of such disturbances. Such an application is presently being investigated.

The good results obtained from polarization analysis of in-seam data (Millahn and Arnetzl, 1979) performed in the time domain with a method described by Montalbetti and Kanasewich (1970), prompted the development of a simple migration procedure which utilizes the output from polarization analysis.

The analysis of the two horizontal components yields two time functions: the rectilinearity and the angle function. Rectilinearity represents a measure of the degree of linear polarization of the recorded motion. The angle function gives the angle between the direction defined by the X-component and the axis of preferential orientation of the data points in a specific time window and, in most cases, is a reliable indicator of the direction of arrival.

It is the angle function which is exploited in the described method. Its inherent ambiguity – one cannot discern between a compressional arrival from direction φ and a shear arrival from $\varphi \pm \pi/2$ – cannot be overcome without additional information or assumptions. As we are interested in mapping reflected channel waves, we usually assume that the angle function represents shear-waves within the time window chosen for migration.

The basic steps are illustrated in figure 4. One backpropagates straight rays into the direction they arrived from, i.e. a ray is constructed which starts at the position of the recording geophone and leaves under the angle φ, prescribed by

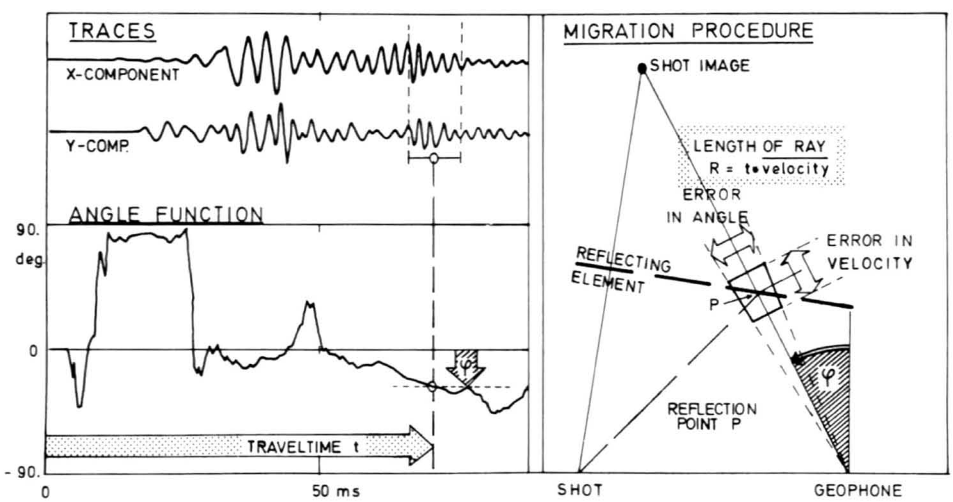

Figure 4 Migration with two components after polarization analysis (for a description see text)

the angle function; its length R being given by the product of the travel time t, at which the angle is picked, and an average velocity (here the velocity is determined in the analysis previously discussed). The endpoint of the ray defines the shot image (or the shotpoint if transmission data are to be migrated).

Assuming that the reflecting element runs rectilinearly within the triangle defined by the shot, geophone and shot image, one can easily construct the reflection point where this particular ray was reflected. A suitably averaged measure ot trace amplitudes at travel time t is assigned to the grid cell which contains the reflection point. This procedure is repeated for all samples within a specified time window, the result being a distribution of amplitudes which can be interpreted as a probability density of the presence of reflectors or scatterers in the coal panel. Maps of different shot-geophone pairs can be stacked.

Errors in the determination of the imaging velocity and in the angle function can easily be taken into account by assigning the amplitude not only to the reflection point, but also to all points within a trapezium, the centre of which is formed by the reflection point. Its extension along the ray is determined by the error in velocity (transformed to error in distance) and its width perpendicular to the ray is defined by the error in angle. Other definitions could be invented, but the one chosen has the advantage of being computationally very simple.

Errors in velocity Δv of 5% and errors in angle $\Delta \varphi$ of 3 to 5 degrees have been found to yield sufficient and physically reasonable smoothing of the amplitude map. Several measures of trace amplitudes were compared: absolute or squared amplitudes, envelopes with different averaging widths. All of these yielded nearly the same result; no specific improvement in resolution or map quality could be found.

LAG-SUM PROCESSING

Another method for migrating in-seam seismic data has been discussed by Mason et al (1980a). Their method called "elliptical lag and sum processing" (ELS) is a Huygens-Kirchhoff summation procedure. Into a given grid cell we map a measure of trace amplitudes picked at the time which a hypothetical wave would need to travel with velocity v from the shot to the grid cell, and thence to the geophone. Amplitudes are distributed along elliptical curves of constant travel time. Mason et al (1980b) give a more detailed description of the procedure. The method was adapted for two components by a slight modification: the components can be rotated towards each particular grid cell. Once again, the directional ambiguity of the two-component system has to be taken into account.

Smoothing was introduced by choosing the time window for averaging amplitudes in such a way that the rays from the shot to every point in the grid element, and thence to the geophone, are considered.

COMPARISON OF THE TWO METHODS

The migration procedures described in the previous section were compared using part of the reflection survey shown in figure 3. The aim of the survey was to find out whether the fault encountered in gallery 2 and at the end of gallery 1 continued to the right.

For migration 50 traces from the left part of the line were taken. Figure 5 shows the result of migration after polarization analysis. Migration velocity and bandpass filter were determined in the velocity analysis already discussed.

From the 50 processed traces 50 individual maps resulted. These maps were normalized and stacked to form the map shown in figure 5. The final stack was again normalized to a value of 100 and contoured. For a proper evaluation of the quality of the maps the amplitudes are inspected before normalization.

Two conspicuous features of the map will now be analyzed: the anomaly to the left of gallery 1 and the elongated anomaly which parallels the roadway at a distance of about 70 m. The anomaly to the left of gallery 1 is caused by the reflection of channel waves from the gallery. The position of the amplitude maximum does not coincide with the right-hand wall of the gallery, as the propagation velocity in coal weakened by mining activities is different from the velocity in undisturbed coal, i.e. this anomaly was mapped with an incorrect velocity.

The elongated anomaly does not coincide with the continuation of the fault encountered at the end of gallery 1 (see fig. 3). Apparently we mapped a reflection

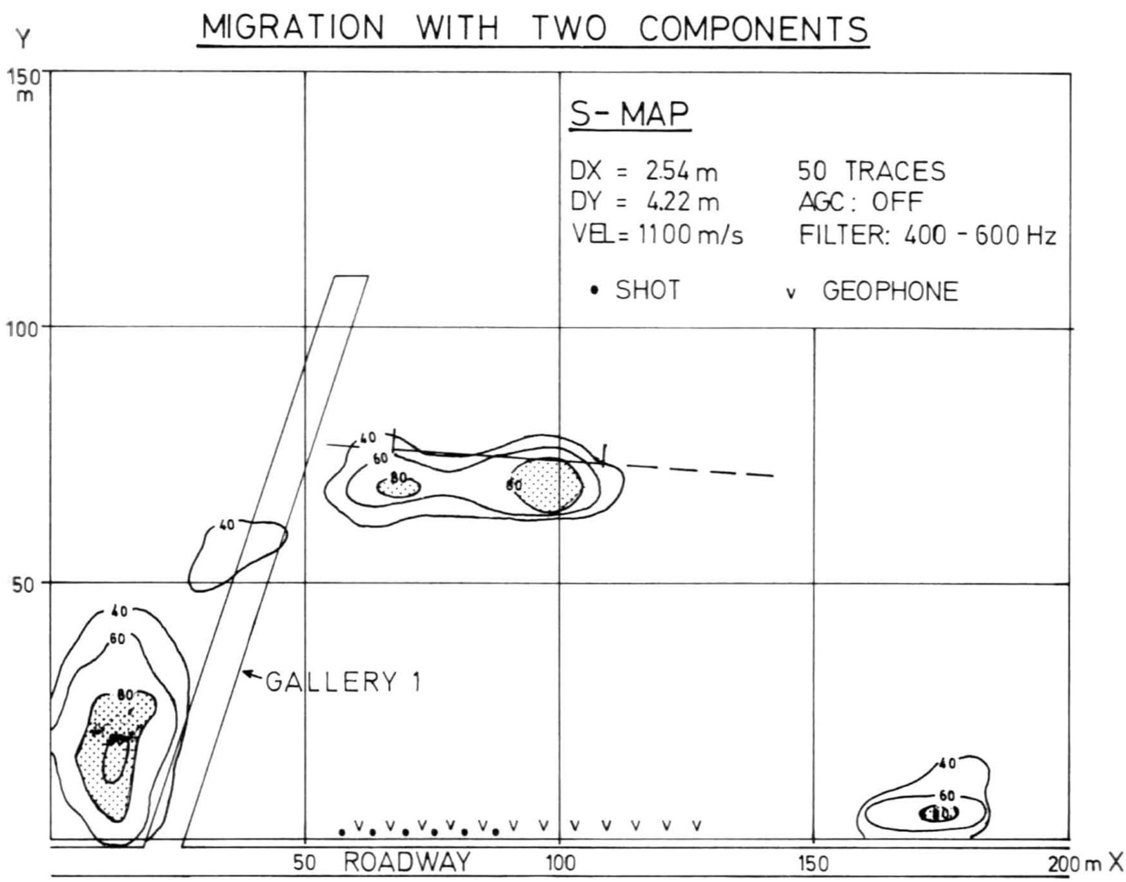

Figure 5 Result of migration after polarization analysis. Only 50 traces from the left part of the reflection survey were used.

from a fault which is 40 m nearer to the roadway and which screens off the fault continuation, if it does continue. The shape of the anomaly coincides very well with a reflecting element which was reconstructed from a CDP-stack of envelopes. This reflector is drawn in figure 5 as a broken line. That part which can be "seen" with the used traces is shown as a heavy line.

The small anomaly occurring near the roadway at 175 m can be interpreted as an event which was mapped in the wrong direction. Whenever the compressional component of the reflected channel wave has a larger amplitude than the shear component, the angle derived in polarization analysis will give the direction of the compressional part. In the migration procedure this angle will be interpreted as representing shear and the event will be mapped in a direction which deviates 90 degrees from the correct direction.

Figure 6 shows the result of rotated lag-sum processing. The shape of the contour lines demonstrates that the basic principle of this method is to distribute amplitudes along ellipses. In those areas where amplitudes do not stack con-

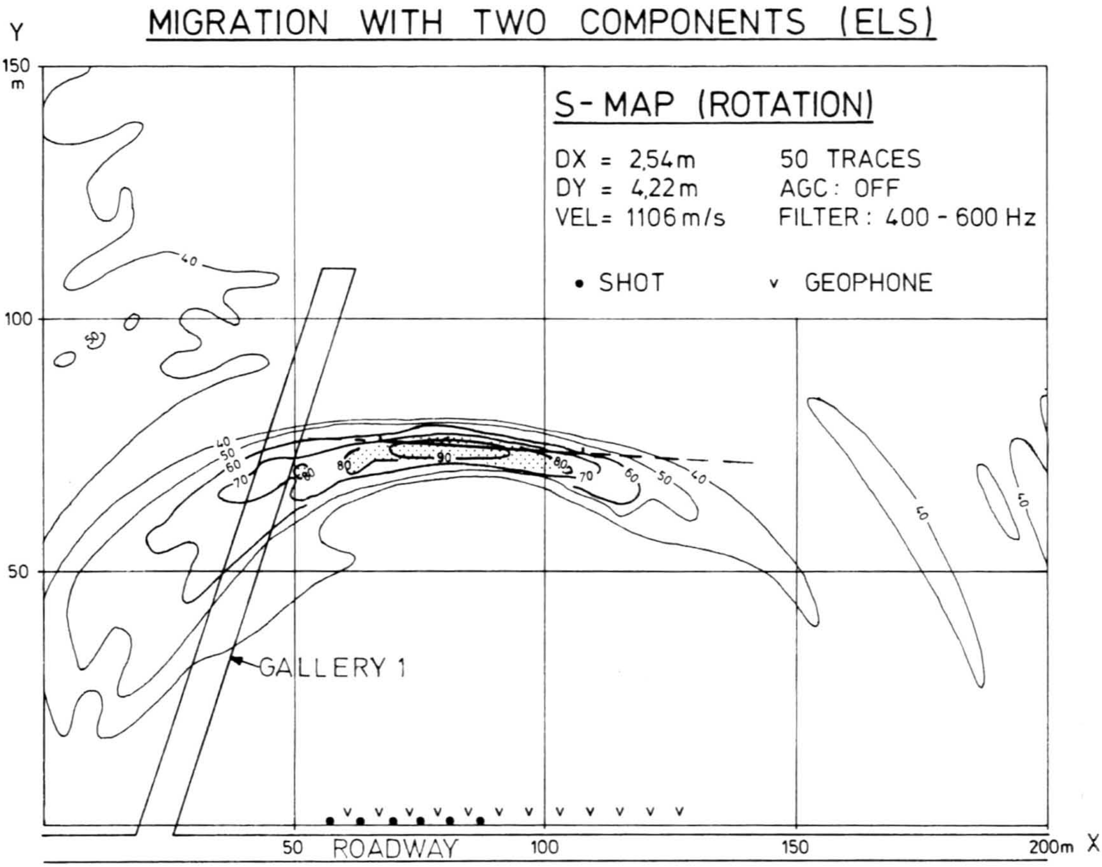

Figure 6 Result of rotated lag-sum processing. The same 50 traces as in fig. 5 were used.

structively the ellipses are visible as migration noise. The reflecting element parallel to the roadway is focused better here than in figure 5. The width of the 80% contour here amounts to only about 5 m (that is approximately one grid spacing in the Y-direction), whereas the contours are up to 20 m wide in figure 5. The reflection from gallery 1, which can be seen in figure 5, is possibly indicated by the asymmetry of the 50% contour line around gallery 1 as compared to the right-hand part of the anomaly.

DISCUSSION

With both migration schemes the reflector parallel to the roadway is found and correctly positioned. In both cases the 80% contour line can be identified as the central part of the reflector. This contour is more continuous and better focused in the ELS-map than in the map obtained using migration after polarization analysis. The latter method retrieves the reflection from gallery 1. This reflection is but vaguely indicated in the ELS-map.

From this experiment alone it is difficult to give one method preference over the other. Migration after polarization analysis is based on information derived from the data and it depends completely on the reliability of this information. Its principle may be called "back-propagation", whereas ELS may be called "back-distribution".

Further tests on several data sets are being performed in order to evaluate the merits and shortcomings of these migration procedures.

CONCLUSION

We have discussed methods of velocity analysis and of migration of in-seam seismic data. These methods are tailored to the special requirements of seismic surveys in coal seams and assist in making a more reliable analysis and interpretation of the data.

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