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SOPHISTICATED AUTOMATED TECHNIQUES IN SEISMIC EXPLORATION

(Presented by Helmut Rist - PRAKLA-SEISMOS)

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SOPHISTICATED AUTOMATED TECHNIQUES IN SEISMIC EXPLORATION

by

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presented by

PRAKLA-SEISMOS

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1. Introduction

PRAKLA-SEISMOS offers a newly developed program for the comprehensive analysis of seismic recordings. The program, developed by R. Bortfeld, has been designated the "ASP-system" (Advanced Seismic Program System).

The program is a statistical one which processes every recorded (evenly spaced) sample. The seismogram traces are analysed coherently by means of an up-dating technique. These characteristic features make the ASP-program particularly suited to the processing of seismic survey data.

2. Mathematical Fundamentals

The basis of ASP-analysis is an equation by Gauss and Kalman of the form:

$$\hat{X}_n = \hat{X}_{n-1} + P \cdot (X_n - \hat{X}_{n-1})$$

where X_n (n = 1, 2, ..., z) means a quantity which is repeatedly recorded.

It is desired to determine the optimal estimated value $\hat{X}_n$ after the n^{th} recording.

Any estimated value $\hat{X}_n$ equals the preceding estimated value $\hat{X}_{n-1}$ improved by the weighted difference of the recorded value X_n from the preceding estimated value $\hat{X}_{n-1}$. The weighting factor P includes data about the reliability.

If one increases or decreases this factor P, one reduces the influence of the past at a faster or slower rate, thus being able to equalize the sequence of the estimated values.

In this method, termed "up-dating", recorded values X_n are considered to be functions of time F_n (t) represented by discrete amplitudes at intervals equal to the sampling rate (usually 2 or 4 ms). A trace of the seismic field recording is such a function. Velocities and dips are similarly considered as time functions or "traces". ASP analysis will process successively all traces of a seismic section.

3. Working Principle

The ASP-program assumes pre-processed but dynamically uncorrected seismic traces as shown in fig. 1.

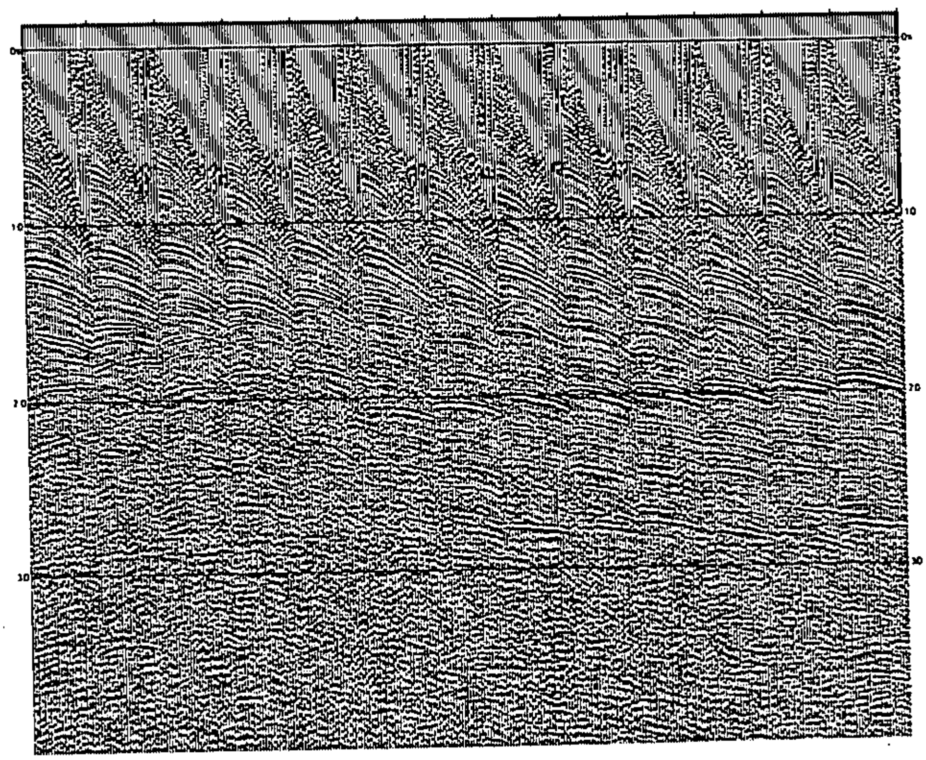

fig. 1 Sample input traces without dynamic corrections

The ASP process entails a continuous analysis of velocities and dips. An appropriate value for the stacking velocity and the dip is determined for each sample of each seismic trace, which takes account of the coherence of one recorded seismic trace with its neighbouring traces and indicates in this way the reflection quality.

The expected shape of the trace to be processed is predicted from the results of the analysis of the preceding seismic traces. The recorded trace is then compared by cross-correlation with this predicted trace, i.e. reference trace. The magnitude of the maximum value of the cross-correlation function, which is calculated for each sample of the trace by means of a selected time gate, yields, after standardization, the value of coherence. The time-shift of the maximum in relation to the expected maximum is also stored. This shift may be due to a change in the dip, to a change in move-out (caused by a velocity change which differs from the predicted value) or, the maximum may have been shifted by superimposed noise.

The recorded shift is subdivided into a change in dip Δ D, a change in move-out Δ MO and a noise factor by means of an algorithm, which takes into account the dependency of the travel time and the shotpoint-geophone spacing.

The calculated values Δ D are used to up-date the dips, those for Δ MO are used, after appropriate re-calculation, to up-date the stacking velocities, coherence being taken into account by the reliability factor P of the Gauss-Kalman equation. Optimal values estimated for dips and velocities are achieved in this way. Coherence is also up-dated. The seismic trace, being automatically corrected by the up-dated stacking velocities is used to up-date the reference trace.

The up-dated reference trace is then extrapolated in the direction of the known dip, thus giving a prediction of the subsequent trace. This process is applied along every trace of the section, thus making available the reference trace, coherence trace, stacking velocity trace as well as the dip trace for each subsurface point. These are shown as an example in figures 2 to 5 for the same line as in fig. 1.

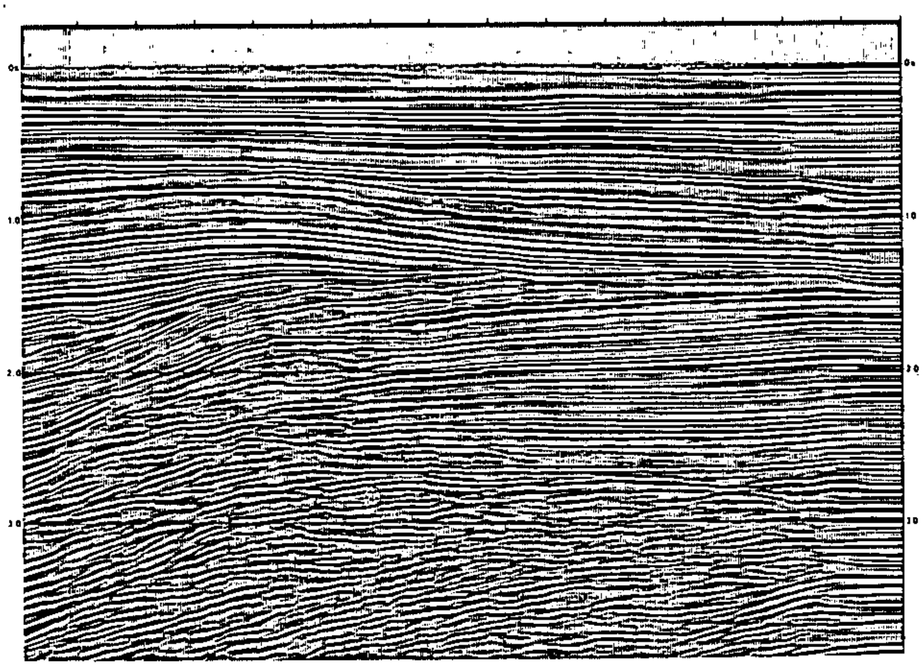

fig. 2 Reference trace section of the same line as in fig. 1

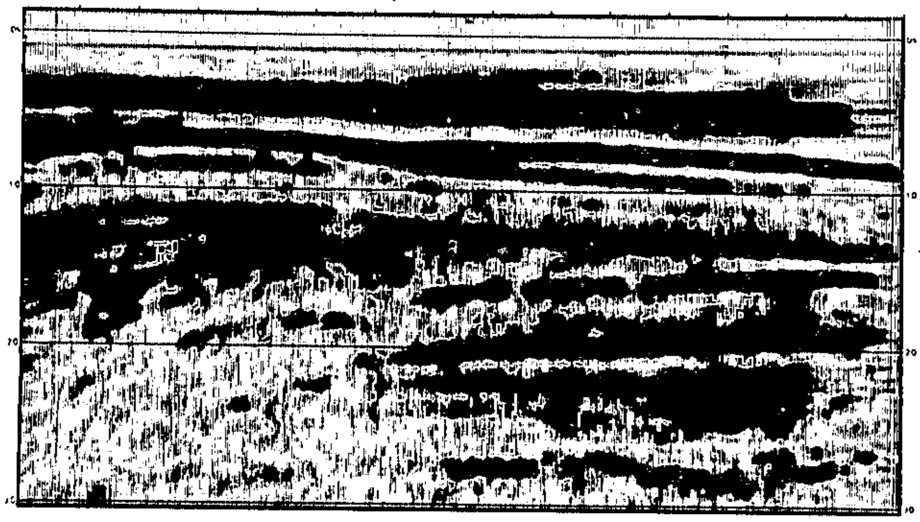

fig. 3 Coherence section of the same line as in fig. 1

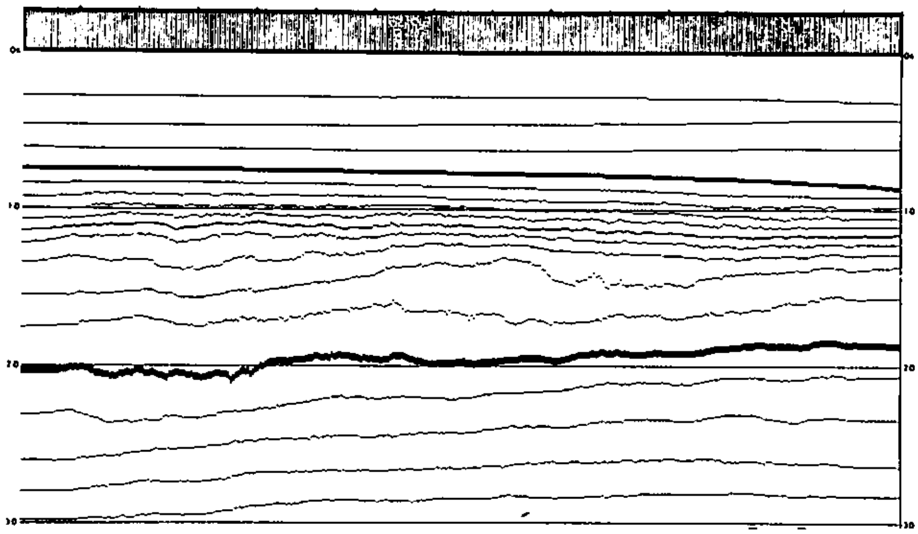

fig. 4 Isoline presentation of stacking velocities automatically calculated from field traces

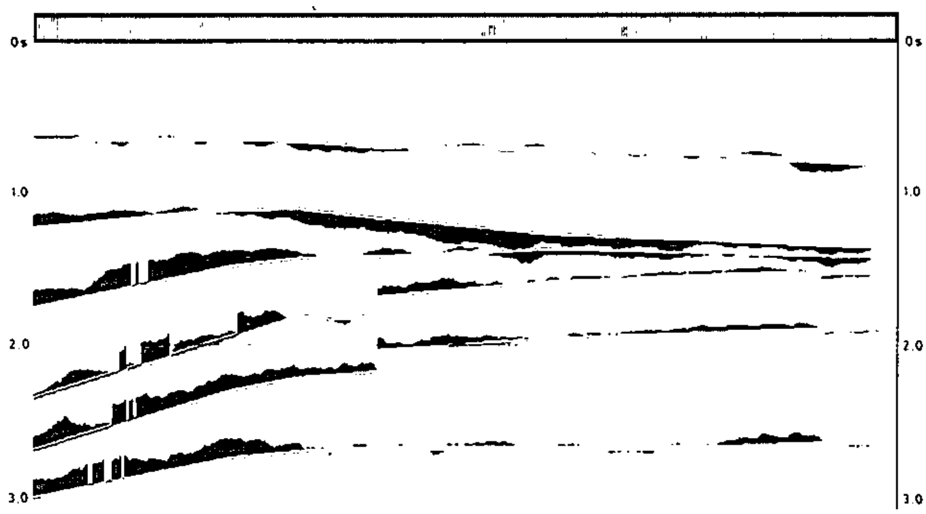

fig. 5 Dip section of the same line represented in ms per geophone group distance following discrete seismic horizons

4. Stacking

The up-dated stacking velocities, obtained in the ASP-analysis, find an immediate use in the program for automatic dynamic correction of the seismic traces. Then stacking is performed to the degree of coverage.

Traces can be weighted according to their coherences, to improve the signal to noise ratio. It is possible by means of appropriate parameters to suit this weighting to the special requirements of the seismic section being processed.

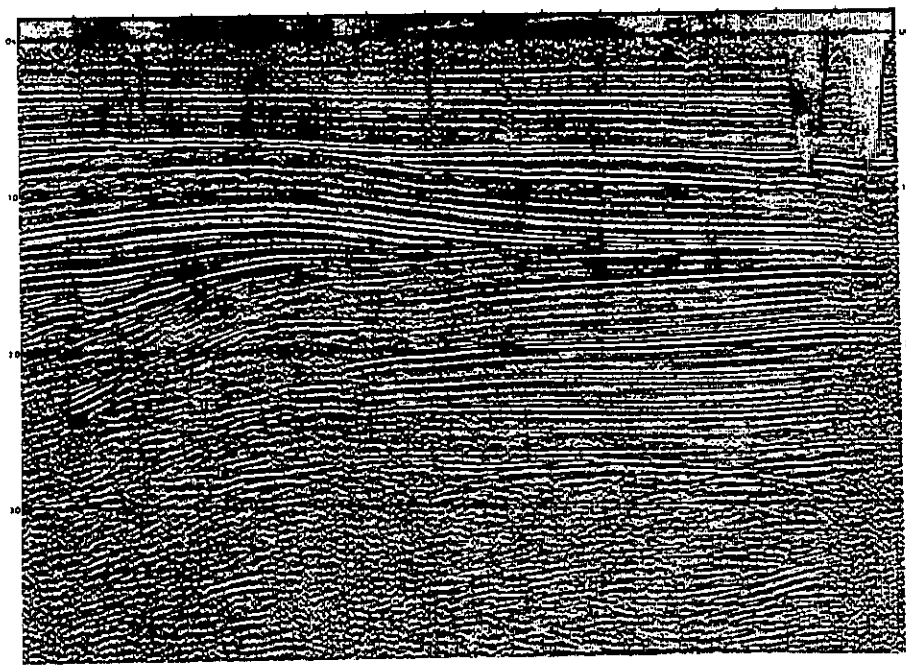

fig. 6 Onshore line after conventional processing

A single coverage is obtained at the same time as the stack. It serves to control the dynamic corrections and the fader employed in the stacking.

It has been found that stacking with automatic dynamic correction is comparable to stacking by conventional methods, as is evident in figures 6 and 7. Improvement over the conventional methods is unlikely.

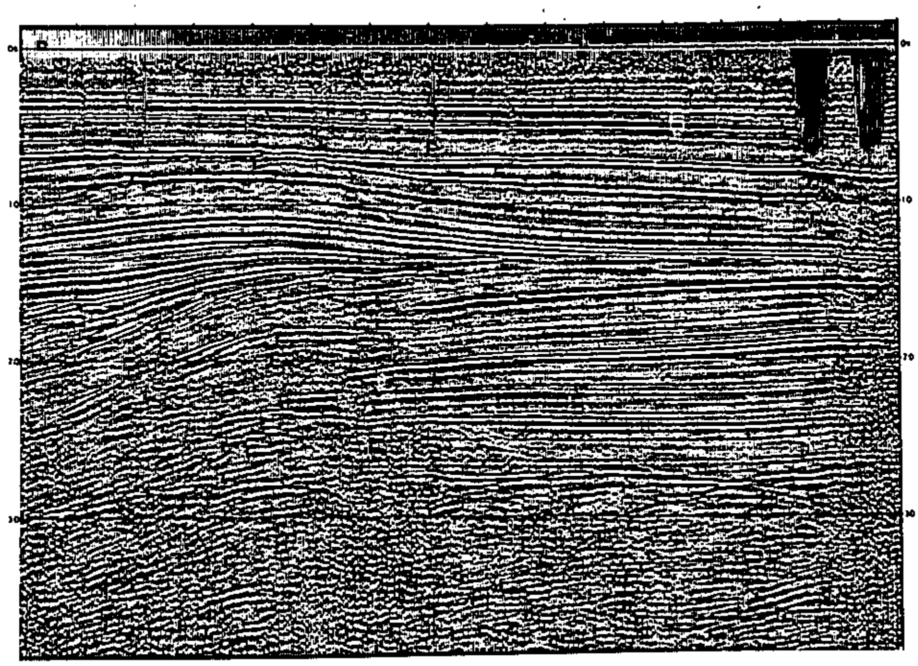

fig. 7 The same line with automatic dynamic correction

5. Kinds of Velocities Derived

The particular advantage of the ASP-system lies in its continuous automatic determination of seismic velocities directly from the recorded data and in the method of presenting the results, as will be described.

At the start of the section a velocity distribution is inserted into the program as an initial value. Experience has shown that reliable values of the stacking velocities are achieved after approximately 24 traces, even when the initial velocity value differs by 10 % or more from the correct velocities. The accuracy of these calculated results depends, of course, to a certain degree on the reflection quality of the records to be processed.

The stacking velocities, calculated in the ASP-analysis from the move-out, can be used in depth calculations only when the strata are horizontal, as they are influenced by the dip of the horizon and by the curvature and refraction of the hanging wall. Knowledge of the dip allows consideration of this influence in the computer program and RMS velocities are obtained which are of reasonable accuracy.

Local, or instantaneous, velocities are derived from the RMS velocities by means of the program as follows. Over a small time gate (e.g. 200 ms) the interval velocity is determined according to the equation of Dix and Krey, taking into account the influence of refraction. The result calculated is assigned to the time-gate centre. The time-gate traverses the length of the velocity trace, so that a value of the instantaneous velocity is obtained for

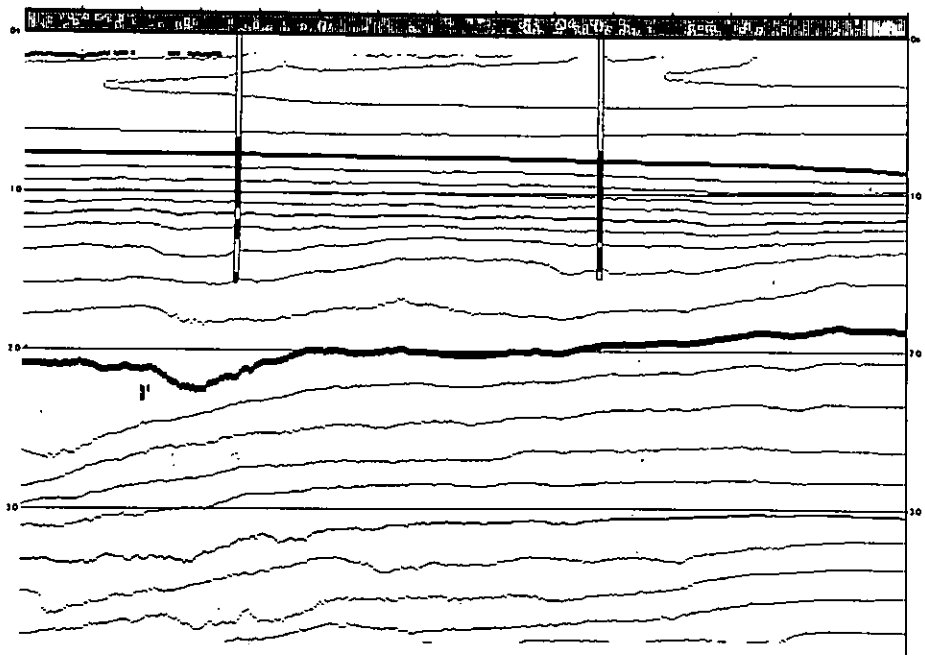

fig. 8 Isoline presentation of RMS velocities

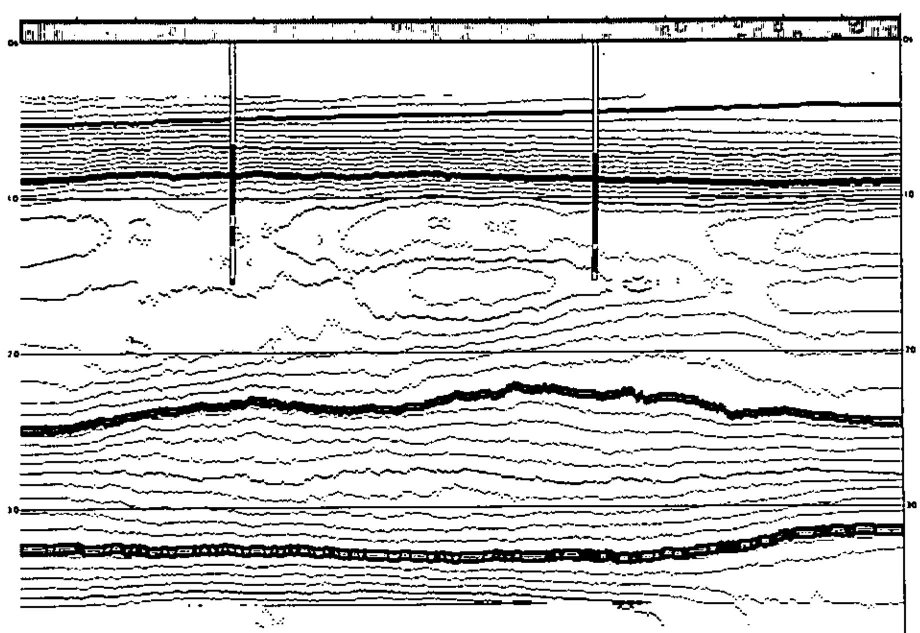

fig. 9 Isoline presentation of instantaneous velocities

every sample. The computed values for any one trace corresponds to a velocity log from a deep well in a compensated state.

It is intended, in future, to compute the geological average velocities from the instantaneous velocities by integration.

The stacking velocities, RMS velocities and instantaneous velocities are presented as sections with isolines, on the same scale as the stacked sections. They are to be interpretated like measured functional values. A dense congregation of isolines indicates a marked gradient of velocity function. Rising isolines indicate increasing velocities, because of the velocity increase with depth.

The interval between isolines is 100 m/s. Integral multiples of 1000 m/s are emphasized by multiple lines (e.g. 3000 m/s by 3 heavy lines). Heavier lines at intervals of 500 m/s are provided for ease of interpretation.

The stacking velocities, RMS velocities and instantaneous velocities for the same section are shown in figures 4, 8 and 9 respectively. Velocity inversions can be seen in figure 9. Fine structure in the isolines indicates the noise level and the reading accuracy.

6. Interval Velocities

Starting from RMS velocities, the program calculates the geological interval velocities by the same algorithm as was used for the instantaneous velocities. But instead of using gliding time-gates, fixed intervals are specified corresponding to the boundaries of geological strata as indicated by the trend of reflections. The interval boundaries can be chosen at any number of arbitrarily selected points. At faults and unconformities these boundaries can be re-set as required.

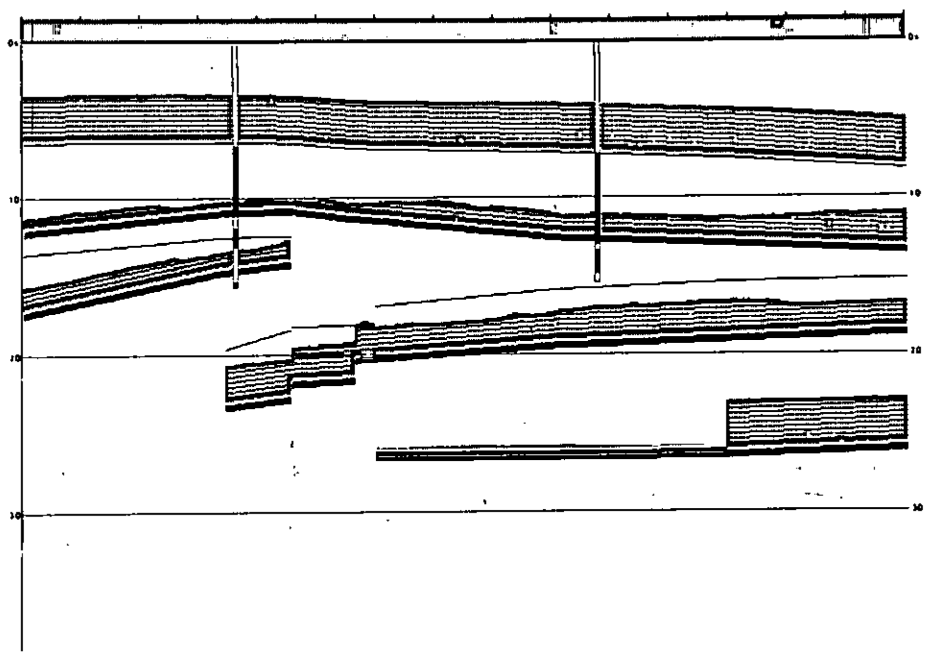

fig. 10 Graphical presentation of interval velocities. Arbitrary intervals may be specified

A section with interval velocities is presented in figure 10, (from the example previously considered). The upper and lower boundary is marked for each interval. At various places the lower boundary coincides with the upper boundary of the adjoining interval. The value of the computed interval velocity is graphically denoted above the lower boundary.

The integral multiples of 1000 m/s are defined by a corresponding number of lines of heavy stroke which follow the lower boundary of the interval. The remainder are denoted by a vertical dash of appropriate size. The thin horizontal lines indicate the multiples of 100 m/s. Resolution is 25 m/s.

A comparison with the geological section, presented in fig. 11 shows which characteristic interval velocities belong to which formations.

A knowledge of the interval velocities is of great interest in the interpretation of seismic surveys, for example, when classifying seismic horizons or when correlating such horizons across fault zones where no deep wells exist.

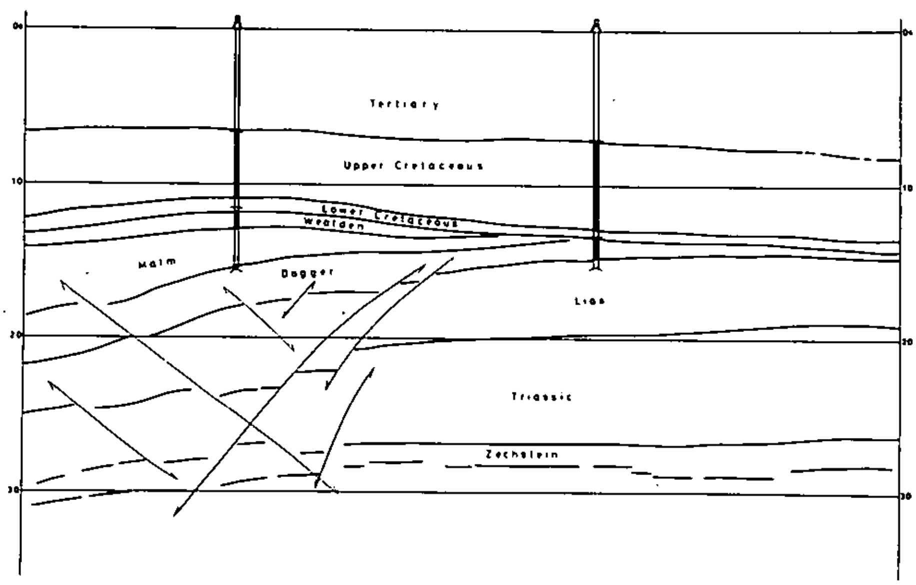

fig. 11 Geological time section

7. Forthcoming Processes

The possible uses of the ASP-program are not limited to the computation and presentation of reliable velocities, although this is seen as the main aim of the process at present. It is feasible, for example, to perform quite easily and precisely a migration on a stacked section, with the aid of tape-recorded RMS velocities. Figure 12 shows a migration performed with velocities obtained in the ASP-analysis. It is intended in the nearest future to use the knowledge of the dip of horizons to improve, by corresponding weighting, the quality of the migration.

A time-depth conversion employing the instantaneous velocities may be accomplished as a further step. This provides a true-to-scale section of the geological structure from which depths can be read-off very accurately. An example showing this is presented in figure 13.

8. Summary

This description of one of the most advanced methods in the processing of seismic survey results indicates the present state of automation in this field. Some of the many possibilities arising from a recently developed program, the ASP-system, have been described. An extension of the ASP-system is at present being developed for 3-dimensional processing. Progress in digital data processing has made seismic exploration an increasingly more reliable method in the exploration of mineral resources.

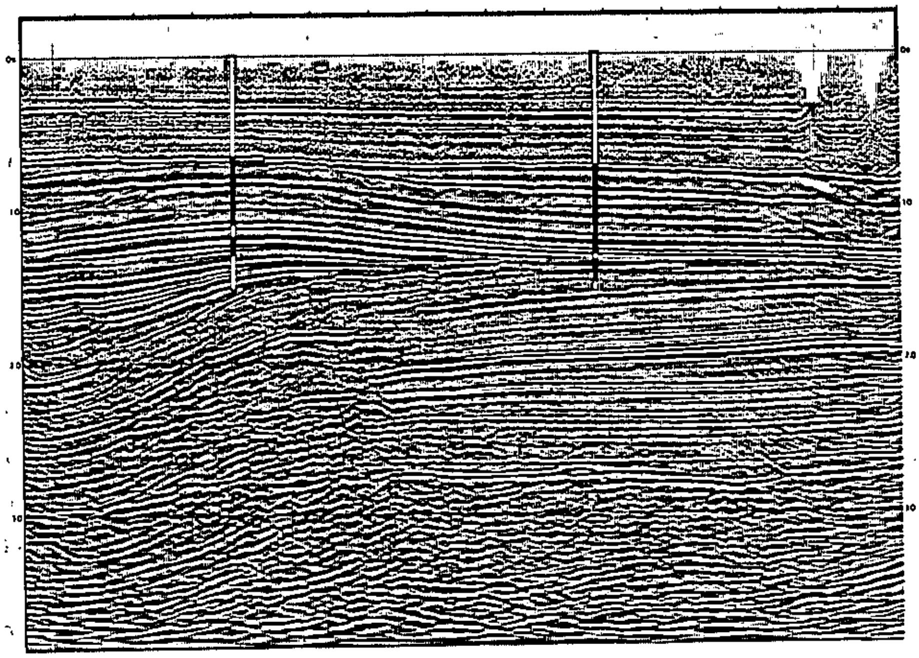

fig. 12 Migrated time section

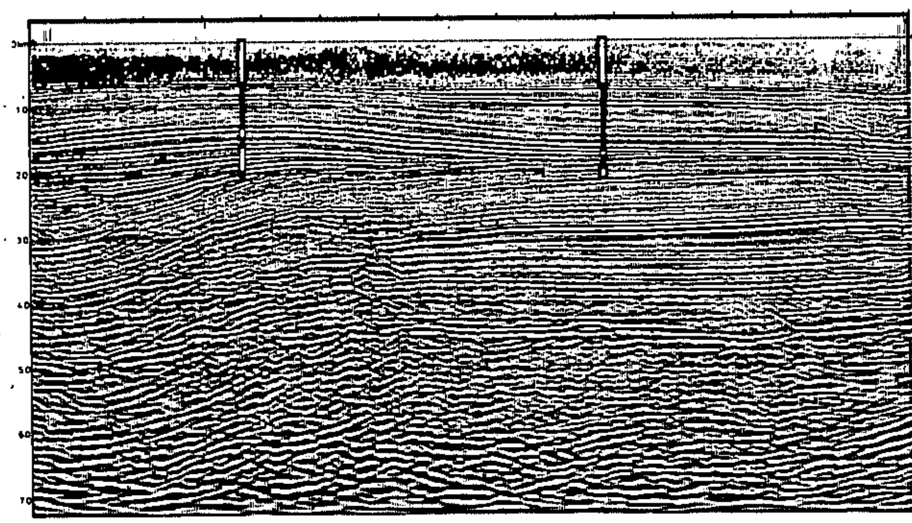

fig. 13 Migrated depth section

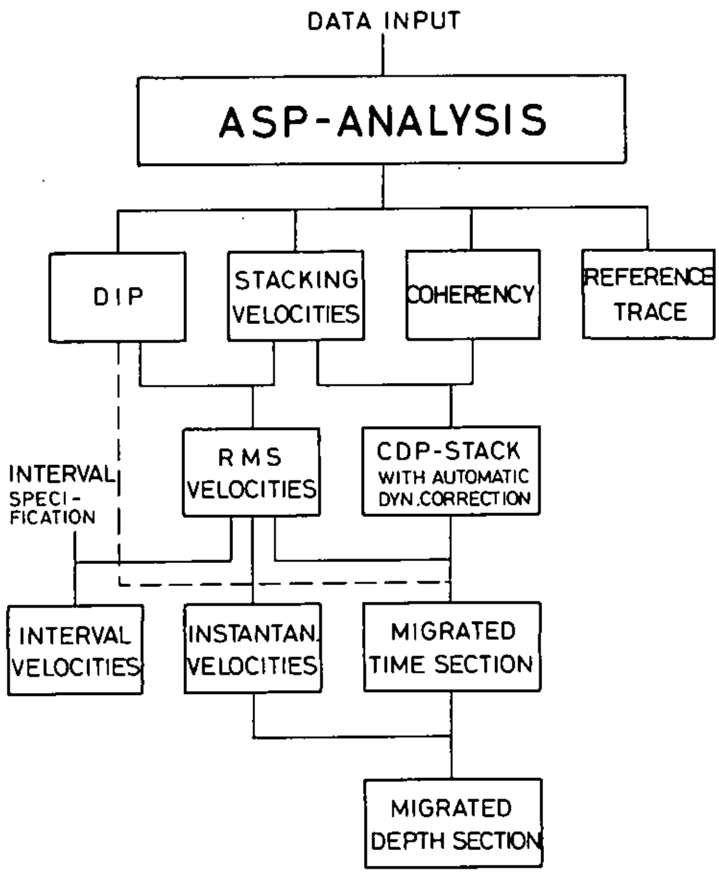

fig. 14 Block diagram of the procedure