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Summaries

Pitfalls Revisited* (Keynote Address)

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It has been over a decade since *'Pitfalls in Seismic Interpretation'* (November 1971) was first presented by Paul Tucker and Howard Yorston (1973). Since then direct contact with over 3000 explorationists, through the school 'Seismic Interpretation for Geologists', has been made. They have represented the full spectrum of companies, large and small.

These contacts have shown that the new generation of seismic interpreters (geophysicists and geologists) is unaware of the pitfalls in their data. These pitfalls include both the original list, and new ones that are a spin-off from our newer technology.

Of equal concern is that now there is an added group of nontechnical pitfalls. These may perhaps be called 'mental pitfalls': those which are within the minds of individuals, effectively blocking out the proper use and emphasis of the seismograph in our exploration effort.

'Pitfalls Revisited' should logically have followed the very successful format of the original publication, with a seismic example for each pitfall. Unfortunately, for many reasons this was impossible. The original was unique and is not reproducible today. But perhaps the cartoon examples of this presentation will serve the same purpose, being a gentle reminder of what to avoid. The original categories of 'Velocity', 'Geometry' and 'Recording and Processing' are followed, to which are added 'Stratigraphic Mapping' and 'General'.

Reference

Tucker, P. M. & Yorston, H. J. (1973), *'Pitfalls in Seismic Interpretation'*, Soc. Explor. Geophys. Mono. Ser. No. 2.

**'Pitfalls Revisited'*, by P. M. Tucker, is available as a booklet from the Society of Exploration Geophysicists, PO Box 3098, Tulsa, Oklahoma 74101, USA.

Horizontal resolution — the key to petroleum (Keynote Address)

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The traditional picture of the earth used for developing seismic reflection theory is one-dimensional, 'layer-cake' geology, where the physical properties of the earth vary only with depth, and the horizontal direction exists only for the purpose of considering an offset between source and receiver.

Unfortunately, layer-cake geology holds no oil or gas. It is only where it is interrupted by a dip reversal, a fault, a pinchout or a facies change that there is a potential trap. So it is in exactly our areas of interest that the theory (on which we base data acquisition and processing) breaks down.

The seismic reflection method was first applied successfully in areas where simple anticlines or domes often held oil or gas, and where the lateral dimensions of fields were large. In such cases, where dips are small and geology is simple, the theory used in reflection seismology is close to reality. But in most parts of the world, all such structures have been investigated. The remaining prospects are ones in which the resolution of lateral changes in the geology is important, and as the size of an economic prospect decreases, the limits to this resolution become critical.

What limits the lateral resolution? There are three basic limitations: (a) temporal frequency content of the recorded data; (b) spatial frequency content of the recorded data; (c) processing approximations and inaccuracies which cause loss of resolution.

The temporal (time) frequency content of the recorded data is limited by seven factors:
(1) frequency content of the source wave;
(2) losses in the Low Velocity Layer (LVL) (downgoing);
(3) transmission losses in the earth;
(4) losses in the LVL (upcoming);
(5) losses in the geophone array;
(6) frequency response of the recording system;
(7) dynamic resolution of the recording system.

The spatial frequency content is limited by:
(8) geophone and source array response;
(9) spatial sampling.

In processing, we can lose high frequencies in:
(10) deconvolution;
(11) filtering;
(12) stacking;
(13) migration.

The only processes which affect the spatial frequency content are those which process several traces together. Each of these can reduce the maximum spatial frequency content of the data:
(14) velocity filtering;
(15) stacking;
(16) migration.

Of these 16 factors which limit the lateral resolution of seismic data, only one (3) is totally beyond the control of the geophysicist. All the others can be varied to some extent, although there is always a trade-off. Almost any measure to improve resolution costs money; for example, it may be necessary to reduce the frequency response of the recording system, in order to record, at a practical price, enough channels to achieve a desired spatial sampling.

In current practice, the highest spatial frequency content of the field record is usually two to three octaves lower than the depth equivalent of the highest temporal component of the same data, so the important areas for improving lateral resolution are the geophone and source arrays and the spatial sampling. Once we have improved these, we will find that the multi-trace processes need careful attention.

Theoretically the horizontal resolution is related to the time resolution by the expression:

$$\Delta H = V\Delta t/2 \sin \alpha,$$

where ΔH is the minimum lateral interval which can be resolved, V is the velocity at the target depth, Δt is the minimum time interval which can be resolved and α is the migration angle. A necessary first condition for this is:

$$\lambda_{min} = V/(2f_{max} \sin \alpha),$$

where λ_{min} is the shortest wavelength recorded, and f_{max} is the highest frequency component in the target reflection.

For a typical survey, f_{max} might be 50 Hz, and V might be 3000 m s^{-1}, α is typically 45°. λ_{min} should therefore be about 42 m. To record such a wavelength, we would need a group interval of less than 42 m (note that with multi-trace recording, the subsurface sample interval is half the surface sample interval) and an effective array length of no more than 21 m.

Even if we were to record such data we would find that the lateral resolution would be reduced in processing. This mainly occurs in the stack and in migration.

In the stack, we have the following effects:
(1) inaccurate static corrections;
(2) inaccurate dynamic corrections;
(3) inaccurate theory at wide reflection angles, especially for dipping events.

In migration, there are four major effects:
(1) inaccurate velocities;
(2) approximation in computation;
(3) inaccurate theory especially in velocity assumptions and in the two-dimensional assumption;
(4) the 'end effect' with short lines.

The net result of all these factors is to reduce the resolution of steeply dipping events — precisely those features which define horizontal changes in the geology. All of them can be minimised with careful processing, but they are impossible to eliminate.

In summary, to produce data with the maximum possible lateral resolution, we must:
(1) record with a significantly shorter group interval;
(2) use shorter geophone and source arrays;
(3) use techniques which maximise the temporal resolution;
(4) use the best possible velocities for stacking and migration;
(5) reduce the reflection angles used to the minimum consistent with adequate multiple attenuation;
(6) use a migration algorithm which accurately approximates the local geology and which is accurate to at least 45°;
(7) shoot lines in the dip direction, and long enough for proper migration.

A fatherly view of asymmetrical floating point array processors

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I doubt if anyone in the audience is not familiar with the class of machines termed array processors. After all, they have been an integral part of digital seismic processing for more than a decade.

In the time allotted me, I am going to give you a brief, one-sided history of the development and evolution of array processors and have a look at the future. If I do a reasonably good job of this, I won't have to elaborate on my conclusion as it should be obvious by then.

During the 1950s, several research organisations produced some startling conclusions in regard to digital manipulation of time series data. The application involved was reflection seismic and, during the early 1960s, a joint development between two energy companies and a geophysical contractor produced the first commercially available special purpose digital seismic processing capability.

Initially, the main attraction of digital seismic processing was in regard to filtering. Yet, the inability of hardware vendors to provide satisfactory hardware to solve (what was then) computationally daunting multiply-add requirements delayed the so-called 'Digital Revolution' for a number of years.

IBM's initial attempt at a solution was pretty good in concept, but inadequate in practice. It was a hard-wired instruction that computed the 'inner kernel' of convolution and correlation operations in fixed point at (about) five times the speed of the involved computer's standard arithmetic unit. It was first installed in 1964. In terms of equivalent instructions per second, it rated (about) 500 000*.

IBM's next attempt at a solution indicated a better understanding of the problem. This was an independent machine operating under asymmetrical control of a host computer.

*A product-sum was the equivalent of load halfword, multiply halfword, add register, add register (one index) and branch on index low or equal (other index and loop control).