REVIEW ARTICLE
*At the recent EAGE meeting in Florence, a workshop entitled '*High-density high-resolution seismic velocity analysis:where are we and for what benefit?*' was organized by Etienne Robein, Ian Jones, and Eric de Bazelaire . In the following article, the co-chairmen review the session, summarizing the salient details.*

High-density high-resolution seismic velocity analysis: where are we and for what benefit?

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Introduction

The most influential factor in any seismic processing sequence is the velocity field. Whether it be for moveout or migration, velocity is the single most damaging factor if we get it wrong. It is also the most time consuming factor to get right!

In addition to obtaining correct estimates of velocity, we also have the issue of statistical reliability related to the density of sampling. If the velocity is sampled too sparsely, we may not get an accurate representation of the parameter.

Many techniques for automated velocity picking have been introduced over the past 35 years, but only recently have been considered acceptably reliable. In part, the success of automatic picking is due to dense sampling of picks, which gives statistical redundancy. Additionally, the possibility of iteratively migrating the data prior to final velocity estimation, ensures that the Fresnel zone has been optimally collapsed, so that a) we can obtain maximum resolution in our estimates, and b) the collapse of diffraction energy permits autotrackers to more reliably find events.

Given that we now have the potential for obtaining dense continuous velocity fields, can we employ 'velocity' for purposes other than just processing? Is the velocity a useful interpretational attribute in itself, and can it help in estimating other petrophysical parameters? It was these and other questions that the following papers set-out to address.

The Workshop

The workshop commenced after a brief introduction by Etienne Robein, explaining how the session was divided into three themes, namely: 'how to get high resolution velocities'; 'measuring in various domains'; and 'applications'. Each of these subsections had three papers.

The first paper, presented by Philippe Julien with co-authors Eric de Bazelaire & Etienne Robein (all from TotalFinaElf), was entitled: '***What is "high density" for velocity analysis?***'. This work really set the stage for what is absolutely necessary in terms of density of picks. Working from Shannon's original theorem on entropy (viz information content) and Gabor's work on communication theory, they showed that the intrinsic limits on resolution (information content) within the data only require a sampling as small as: $\lambda/\tan(\alpha)$, where λ is the vertical wavelength of the carrier frequency, and α is the migration aperture. In other words the lateral extent of the post-migration Fresnel zone limits how much resolution we can obtain. Consequently, there is no point in sampling velocity information more finely than this. They presented several examples of high density velocity volumes and discussed their respective benefits (Figure 1).

Colin Johnson (consultant) with co-authors Randall Carroll & Nick Benfield (PGS) reviewed the basics of '***High resolution velocity analysis'*** showing the mechanics of the underlying techniques in automated stacking velocity analysis. This set the scene for the following paper by David Le Meur & Philippe Herrmann, who looked at '***Optimum stacking from optimum velocities'*** in order to assess the importance of geostatistical filtering of dense velocity fields. Their contention was that by incorporating other geological information or statistical 'rules', we could better separate background 'estimation noise' from the underlying velocity.

The second section started with the question '***Does high density high resolution velocity analysis achieve our purposes?***' posed by Robert Bloor, with co-authors Martin Bayly, Dave Boreham, Dave Burkepile, Dave Hill &

Geoff King (all of WesternGeco). The noted that whilst dense RMS velocities do benefit stacking, interval velocities need not be so dense, as they are ultimately used for migration, which usually requires a smoother velocity field. They also noted that quantity couldn't replace quality in picking. This point is most important for difficult areas, for example, when multiples are dominant and can easily mislead autopickers.

Steffen Bergler (with co-authors Pedro Chira, Jürgen Mann, Kai_Uwe Vieth & Peter Hubral, all of Karlsruhe University) showed applications of '***Stacking velocity analysis with CRS stack attribute***'. The common reflection surface stacking technique has been promoted in various forms recently, and offers a very powerful technique for machine intensive multi-dimensional 'curve fitting' in order to estimate local slopes in various domains of the data, which are then inverted to yield velocity information. In its most general form for 3D pre-stack data, we would need to scan for 13 independent parameters: consequently even the present-day computer power is insufficient for such an approach. However, compute power increases rapidly, and the problem will not go away, so we can expect this class of techniques to gain ascendancy in the coming years.

The second section was concluded with a presentation by Frédéric Billette (with co-authors John Etgen & Walter Rietveld all of bp UT) addressing '***The key practical aspects of 3D tomography: data picking and model representation***'. In this work, the authors emphasized the distinction between the compute intensive parts of dense auto-estimation, and the (human) QC intensive parts. A good liaison between these elements, via easily usable interactive QC tools is required for a speedy completion of the tasks. Based on machine picks following 3D preSDM, they employed tomography to constrain the inversion of the RMO picks to a geologically plausible interval velocity model. They showed several interesting examples of this approach on real data.

Robert Hardy (with co-authors Jaime Stein, Mark Casady, Zheng-Zheng Zhou, & Sampath Gajawada, all of NuTec Energy Services) presented the first of the papers in the applications section, considering '***High resoltion velocity analysis and its applications to pore pressure attribute calculations'.*** Using the ARCO software recently released to the industry by bp, the authors employ Swan's AVO velocity estimation technique to produce dense velocity fields as input to a pressure prediction package. Calibrating with point measurements from wells, using the surface seismic velocity data to extend pressure prediction away from the well offers a powerful tool for increasing the resolution of the pressure estimate.

Andrew Ratcliffe (with co-authors Gareth Williams & Keith Hawkins, all of Veritas DGC) looked at '***A comparison of high density velocity fields obtained from isotropic and anisotropic PSDM as a constraint on amplitude inversion'.*** In using anisotropic parameterisation of the subsurface, one is better able to produce a correctly focused and positioned image. Additionally, in conjunction with dense velocity estimation, here the authors clearly demonstrated improvements in subsequent acoustic impedance inversion. Given the requirements of estimating the low frequency trends (from velocity information) for AI inversion, the velocities found by high resolution estimation stand a better chance of being reliable than those from sparse estimates.

The final paper dealt with '***Continuous high resolution velocity analysis as a 4D attribute***' authored by Ian Jones (GXT) and Per Gunnar Folstad (bp Norge) (Figure 2). Given that previous work has demonstrated the reliability of dense velocity estimation under certain circumstances, the 4D arena was a natural candidate for its application. From elastic modelling studies they showed that fluid related reservoir changes should indeed produce a seismically measurable difference in velocity. Unfortunately in this example, it was azimuthal velocity differences (resulting from the repeat survey being shot orthogonal to the baseline) that dominated the results! However, using dense velocity estimators as a difference tool clearly worked in identifying and helping to understand differences

Discussion

Most of the commentary during the workshop related to the reliability of automated techniques: will they ever completely replace manual picking? How do we best QC autopicked results? Can human intuition (such as in avoiding multiples) be successfully incorporated into autopickers?

From the floor, Shlomo Levy (Data Modeling Inc.) argued that autopickers had already come of age, and that the industry was once again lagging behind in failing to adopt a proven technology. Others were more cautions arguing that autopickers could only be relied upon for the simplest, multiple-free data.

This brings us back to the problem of multiples: a simple autopicker will be unable to distinguish primary from multiple energy, so unless we are confident that an efficient job of multiple suppression has been performed, and/or the autopicker is smart enough to discriminate against multiples, we will obtain unreliable velocities.

Robert Bloor noted that poor quality data, even in abundant quantities, is not as good as sparse high quality data: so autopickers will be doomed to fail if the data are too poor.

It became clear that we must decide what is ‘fit for purpose’ for a given application. Dense stacking velocity estimates clearly improve the stack response. However, given the various implicit smoothing operations that occur in, say, migration, it is questionable whether the migration interval velocity field needs to be equally dense.

Once a dense field of pick is obtained, what is the best way to edit and filter it? How best can we incorporate geological, statistical and geophysical criteria in this process. Geostatistics offers one solution.

Converting from the raw measurements, which are invariably cumulative quantities, how best do we invert to interval quantities: here tomography is the natural solution. However, for a full 3D tomographic resolution of a large number of input values, we need to solve very large matrix inversions, hence we probably need to filter and sub sample the dense information prior to tomography.

Conclusions

The main conclusions of the workshop were that automatic velocity estimation has indeed come of age, and that the applications for such techniques are many and diverse. Constraining autopickers with the criteria behind ‘human intuition’ still remains a challenge, but with the rapid improvement in cost-performance ratios for computing, the task can only get easier.