A Review of 3D PreSDM Model Building Techniques

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FOREWORD
In this review article, we outline the development of model building techniques over the past decade, with specific emphasis on the limitations of the techniques, and some of the pitfalls that open themselves to the unwary model-builder.

To give this article a broader perspective, we have included contributions from several colleagues throughout the industry, so as to represent the diverse approaches in use. The contributing organisations include: BP, CGG, Delft, ENSMP, GXT, IFP, Paradigm, SEP, Shell, TFE, Veritas & WesternGeco.

Any comments and conclusions reflect the views of the author and not necessarily the contributors.

Introduction
Here we review several of the model building techniques introduced over the past decade or so, with emphasis on the assumptions and limitations of each technique.

Model building techniques are generally divided into two phases: ‘picking’, and, ‘inverting’. The errors and assumptions in these two phases are quite distinct.

Picking may take place on a single offset (or the stack) for various horizons, or for a series of offsets in the gathers. Picking may also be performed before or after an initial migration.

If picking takes place before migration, then the picking error may be large, as for complex environments it is difficult to track or distinguish the various arrival branches of diffraction hyperboloids.

Given that manual picking can be tedious; various schemes have been developed for automating this part of the process. In addition, various data reduction schemes can be employed, such as stacking, so that the picking need only be done on one data volume (the zero offset cube, for example) instead of on many finite-offset volumes.

For example, the trade-off of picking on stacked data, constitutes a speed-up in the overall inversion process, but by stacking, we loose information: the complexity we are trying to recover in a complex model will often manifest itself in the non-hyperbolicity of the moveout in the pre-stack data. In stacking, we assume hyperbolicity, thus stacking destroys useful information in this case.

Migration Scanning Techniques
Some techniques employ picking performed on gathers or images produced by migrating with a suite of perturbed models, and picking of the ‘best’ member of the scan (i.e the sharpest image or flattest gather in the scan).

Data-Fitting and Tomographic Techniques
All tomographic inversion techniques involve the definition of some objective criterion of ‘error’ in the estimate of a model, and proceed to perturb the model so as to minimize this error.

The trade-off between speed (and robustness) and accuracy is the key element in an inversion scheme: we make some assumptions about the physical process involved, and try to represent some aspect of the process with a tractable set of equations which can allow us to relate some measurements to the model.

We minimize the differences between the observed data, and data computed (in light of our assumptions) in association with the present rendition of the model.

Thus tomographic inversion has two basic steps:
- forward model & compute differences between calculated and observed ‘data’
- perturb model so as to reduce the magnitude of the differences, and iterate until satisfied.

The relationship between model and observations can be simplified with a linearization, or the tomography can be more complex, dealing with non-linear associations.

For some schemes, the update is not tomographic, (e.g. a simple vertical Dix inversion of the picked errors). In this case, the updated information is not being ascribed to its correct spatial location.

Figure 1 outlines the general flow of most model building techniques: starting from initial information (stack times Ts, velocity Vrms) we build a starting depth model (e.g. by map migration). This feeds into some iterative loop for velocity update and layer geometry definition (if layered), ending with the final high fidelity migration run.

Tomographic schemes themselves can be described as in figure 2, where the model representation is iteratively perturbed so as to minimize differences between modelled and observed ‘data’.

Layer Based versus Gridded Models
Models themselves also fall into two major categories, reflecting the underlying geological environments: layer-based, and non- layer-based.

Layer-based models are typical of say, the North Sea, where the velocity (and vertical compaction gradient) are bounded by sedimentary interfaces. Here, it is sufficient to pick seismic reflection events as the partitions to the velocity regions in the model.

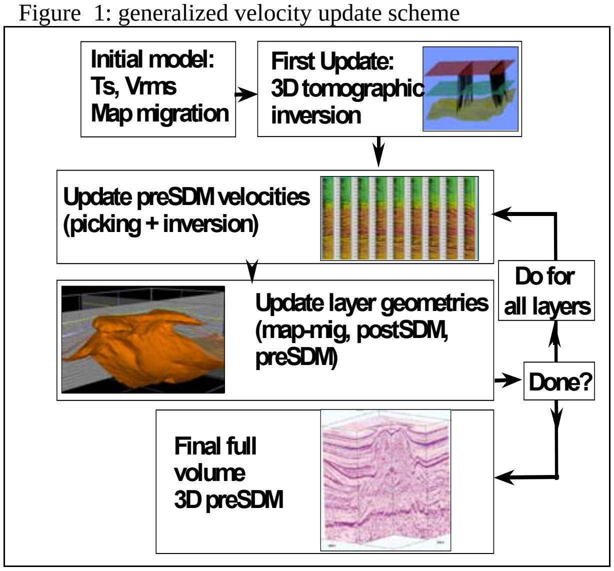
Non-layer-based models (as found for example in the Gulf of Mexico) have velocity regimes dominated by compaction gradients that sub-parallel the sea bed. In the case of salt or shale tectonics, the scenario is complicated by the presence of these irregular bodies set within the background compaction gradient driven velocity field. In overthrust tectonic regimes such as found in the Canadian Foothills & Rockies, the problem is further complicated by anisotropy with a tilted axis. In this case it can be difficult to represent the axis of anisotropy, as a gridded model has no inherent layering to define surface normals.

Both geological environments present difficult challenges in model building, and in addition present challenges in the design of model updating software, as the assumptions for each case are quite different.

Picking can be quite simple in a layer based medium when continuous coherent reflectors are visible as the update information can simply be picked or autotracked along reflector boundaries. The situation is less evident when the velocity field does not follow visible reflectors. In this case, we need an a-priori assumption of how the velocity field behaves. For example, we may need to estimate a compaction gradient, which commences from a given depth (usually the sea bed). The compaction gradient and the starting velocity are in general spatially variant.

In order to update a gridded velocity field, we still need to pick information associated with reflectors, but the understanding is now that the update derived from a pick is not constrained to follow an horizon. Thus a scatter of picks is made, and the resulting 'cloud' of values input to the inversion scheme.

Figure 1: generalized velocity update scheme



The Techniques

Examples produced by various organizations are shown throughout this paper demonstrating a range of techniques from the simplest through to the most complex.

However, it must be noted that all major imaging groups, including all contributors to this article, nowadays have available one or more of the most advanced techniques, even if a simple example was provided by them for this article.

In figure 3, we outline the various schemes reviewed. The general clutter of this figure is indicative of the diversity of approaches available!

One of the fist questions to ask, is what measurements are we 'inverting' against? (figure 4) If we are making picks on unmigrated data, then the picking phase will suffer from considerable errors. This is worse for complex areas, where diffraction branches from various arrivals will be difficult to distinguish, and especially difficult to pick with auto-trackers.

Figure 2: generalized tomography and model update mechanism

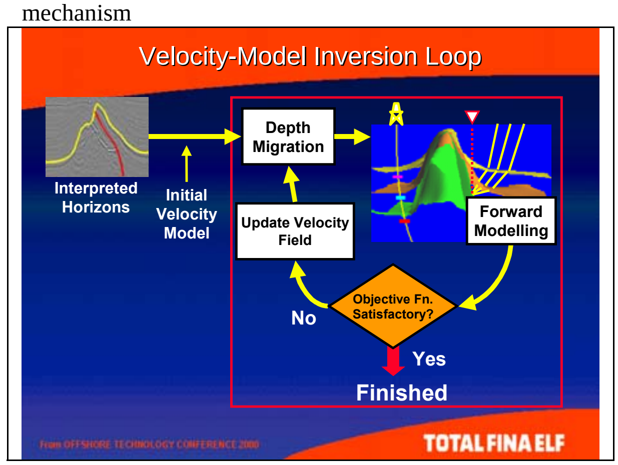


Figure 3: Schemes Reviewed

Inversion of picks on single offset

- **Coherency Inversion**
- **'Manual tomography'**
- **Deregowski loop**
- **CRP-scan & (Z_0, V_z)**
- **CRP-scan & (Z_0, V_z) tomography**
- **(T_s, V_{rms}) tomography**
- **(T_m, V_{dmo}) tomography**
- **Common focal point update**

Inversion of picks on several offsets

- **(T_{xi}, V_{rms}) tomography**
- **($T_{m,xi}$, V_{mig}) tomography**
- **(Z_{xi}, V_z) tomography**
- **Stereotomography**

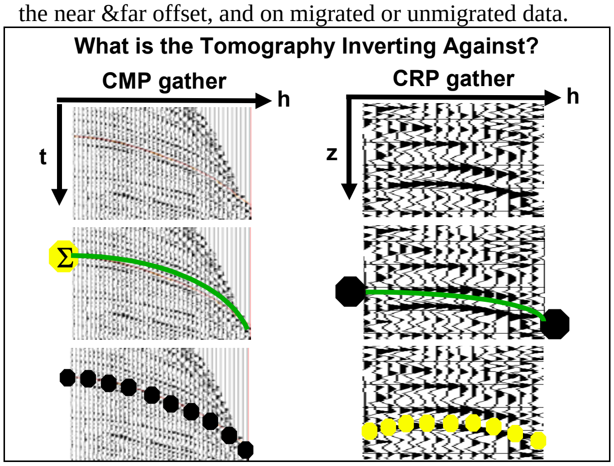
For data that have undergone an initial migration, the picking will be significantly easier. However, tomography often needs unmigated times for the inversion, consequently the algorithm may first need to demigrate the picks in some way. Hence, tomography based on migrated picks could be working with data that have been modified, and are thus in some way less accurate.

This limitation can be reduced by incorporating the initial migration techniques within the forward modelling step, we would be, for example, comparing migrated data measurements with modelled migrated arrival times.

So we see that we have a trade-off between accuracy in picking and algorithmic ease of inversion.

To achieve maximum reliability in tomography, we need dense input information, thus need to rely on auto-pickers, especially for pre-stack data. Thus picking on migrated data is beneficial.

Figure 4. Picks can be made on stacks, individual offsets, the near &far offset, and on migrated or unmigrated data.



Density of Picks and Automation

Regardless of the technique employed, another limitation to date has been the spatial sampling of the information used to perform the velocity estimation. Typically, pre-stack migrated velocity information (usually in the form of CRP gathers) is output on a coarse grid, often 500m by 500m.

In order to improve on the limitation of spatial sampling, automated techniques for increasing the statistical reliability of the velocity information to be input to the chosen velocity update scheme have been introduced. The automated nature of these techniques addresses the problem of unreasonably high manpower time needed to pick very dense velocity grids. It is this high manpower time that has really limited us in the past in obtaining dense velocity grids.

Much work on autopicking of kinematic attributes has been conducted in recent years by Hubral's group at the university of Karlsruhe (e.g. Muller at al 1998).

With automation, we do not in any way improve on the limitations of the underlying techniques, (whether that be Deregowski-loop or CRP-scan), we merely make the best possible use of the information already available, by looking at a very dense sampling of information.

In other words, when we estimate the velocity with many values, we only improve the precision of that estimate, but *not* the accuracy. Thus, if the values coming out from our velocity estimator were all erroneous, but consistently erroneous, then we would simply have a very precise estimate of that inaccurate result.

In figure 5a wee see an example of manual picking of CRP scan percentage perturbation updates on a 500m by 500m grid, compared with the autopicked percentages on a 25m by 500m grid (Jones, et al 2000). Following normal ray inversion the derived interval velocity fields are quite different (figure 5b). These differences result solely from the density of picking, and would lead to very different migrated results.

Figure 5a. picked model perturbation values from CRP scanning are very different if dense picking is used

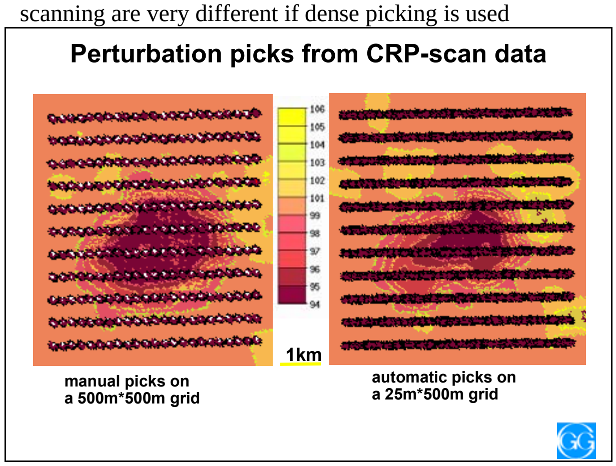
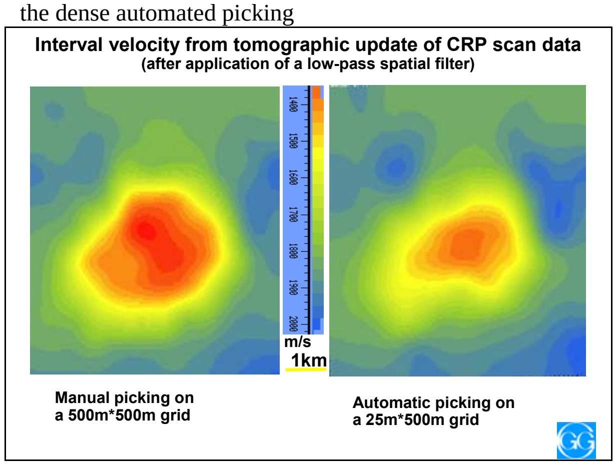


Figure 5b the interval velocity field resulting from inversion of the perturbation picks is radically different for the dense automated picking



Inversion of Picks made on a Single Offset.

Coherency Inversion:
This quasi-1D scanning technique was originally based on ray-tracing through an initial model, so as to compute the move-out corridor for computing the coherency (semblance) in a velocity analysis window centred on the obtained trajectory corridor.

The velocity in the layer under investigation was then perturbed, and the (3D) ray-tracing repeated so as to yield a new semblance corridor for the subsequent velocity analysis element. By scanning over ray-traced corridors for a range of perturbed velocities, the maximum semblance could be chosen by picking, and the interval velocity updated at this CMP location by simple vertical Dix inversion update (figure 6).

This technique is fast, but not very accurate for complex structures, as there is no actual 3D migration of data involved, but merely a 1D perturbation of the local velocity field. Hence, we are assuming that we can accept a constant velocity perturbation within the ray bundle, and update the model point by point vertically.

Due to its speed and ease of use (especially when using horizon consistent velocity analysis) this technique is often used for initial model construction. It involves no picking of seismic data, so avoids the pitfalls related to interpretation.

A well known application of this approach is shown from GeoDepth™ in figure 7, courtesy of Paradigm Geophysical (Reshef, 1994).

Manual Tomogrphy
This is a variation on coherency inversion (Murphy & Gray, 1999) where the velocity is fixed in the overburden, and only perturbed in the layer under investigation. In addition, the subsequent inversion of picks is tomographic, and the data being picked have undergone an initial migration.

The Deregowski Loop
This is the most basic technique for simple post-migration update of a model. The data are migrated, and the resulting gathers subjected to a residual moveout analysis. The results from this analysis (a new RMS velocity value) are used to update the interval velocity model via vertical Dix inversion.

It suffers from two inherent problems. Firstly, the fact that residual moveout exists in the migrated gathers indicates that the event being picked is located at the wrong spatial location. Secondly, the RMS error picked is then inverted vertically using the Dix equation.

To correctly update the model, we should pick the velocity error in its correct spatial location, and then update the velocity model by inverting along the normal to the reflector being updated. Figure 8 shows this: a vertical update inverts to a location vertically above the picked horizon, whereas to correctly update the model, we should invert back along the normal ray.

Figure 6 this technique is essentially an anhyperbolic velocity analysis: Instead of the usual hyperbolae used in conventional time processing, individual ray-traced corridors are constructed to make the spectrum.

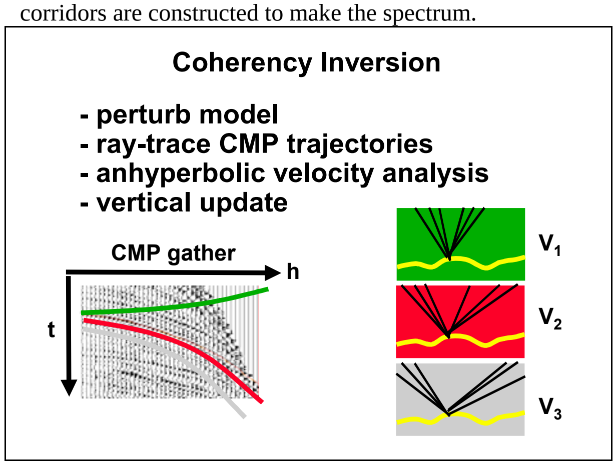


Figure 7 GeoDepth™ graphical interface example

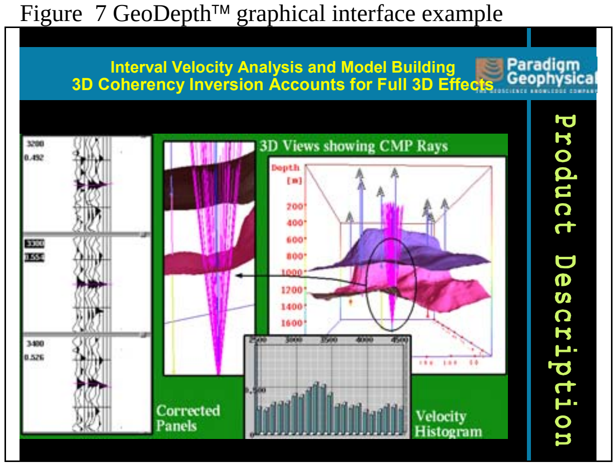
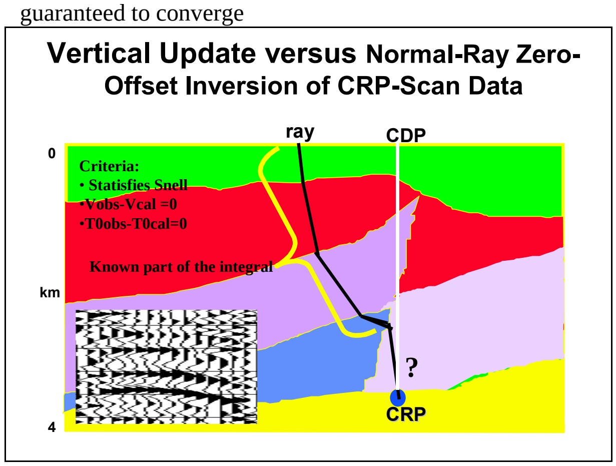


Figure 8. Error measured from migrated data is accumulated along the normal ray (for zero offset inversion). Vertical updates ignore this fact, and are not guaranteed to converge



Furthermore, inverting vertically can be shown to diverge, even for a simple model. Audebert et al (1997) demonstrate this in figures 9-11. Synthetic data were generated for a model with a dipping interface below a lateral velocity gradient, overlying a flat deep horizon. Performing model update using simple vertical 'Deregowski loop' updating cannot converge on the correct model, whereas a more general technique (in this case CRP scanning followed by 3D normal-ray update) gives a more satisfactory result.

The CRP-Scan

In this technique, a unique migration is performed for each of a suite of models, and the resulting scan of CRP gathers inspected to select the flattest (for the current horizon). In this way, we pick the error in its correct spatial location: the error here being the percentage perturbation value used to produce the flattest gather,figure 12 (Audebert, et al 1997, Jones, et al, 1998).

The perturbation can be performed either for the last layer only, or from the surface of the model. It is approximately valid to perturb from the surface, given that the ray parameter is conserved (both sides of Snell's law scaled equally) at each interface, as long as normal ray update is then used to invert the picks.

Once the error has been determined, it is then updated either vertically for simple geometries, or along the normal from the subsurface event. When the update is computed back along the normal from the subsurface picking point, we can usually update more than one layer at a time. Figure 13 shows initial and final gathers after using three iterations of this technique.

3D Tomographic inversion of picked zero-offset stack times and stacking velocities:

In this technique, a 3D model is globally perturbed (in say a Marquart-Levenberg scheme), and for each perturbation, the multi-offset ray traced CMP arrival times are fitted with an hyperbola. This hyperbola is used to determine a computed 'stack' time and stacking velocity associated with the current model perturbation. The model is iteratively perturbed so as to minimize the differences between observed and calculated stack times and stacking velocities. An example of this technique is shown in figure 14, courtesy of CGG (Rakotoarisoa, et al, 1995).

This scheme is well suited for first arrivals, where the picks from the stack are reliable. However, when the stack is questionable, as it often is for complex geometries, then the input data to the inversion is suspect.

Because the scheme relies on picking from a stack, we have a much-reduced data volume involved in the picking (compared to pre-stack picking), but here the trade-off relates to accepting the corruption caused by the stacking process itself.

The technique can also be used for multi-arrivals by breaking the data into overlapping patches (Lanfranchi, et al 1996).

Figure 9. Model with a lateral velocity gradient above a dipping reflector and flat deep reflector

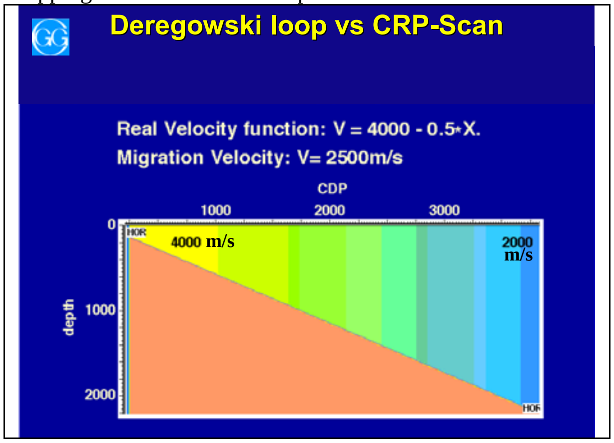


Figure 10. velocity update for the first layer using an iterative vertical 'Deregowski' approach does not recover the velocity field, and thus poorly images the dipping reflector after subsequent re-migration

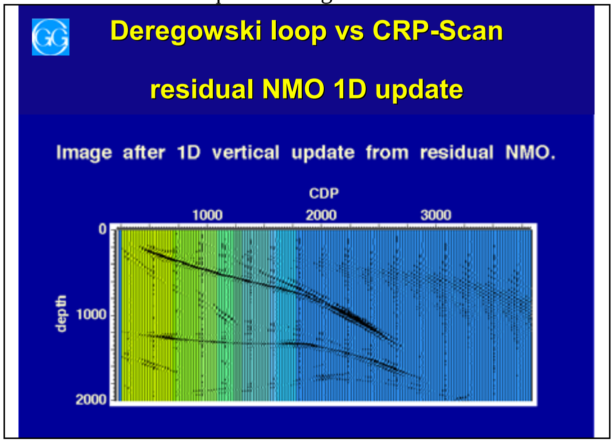


Figure 11 velocity update for the first layer using an iterative CRP scanning approach with normal ray inversion does better, imaging the dipping reflector more accurately.

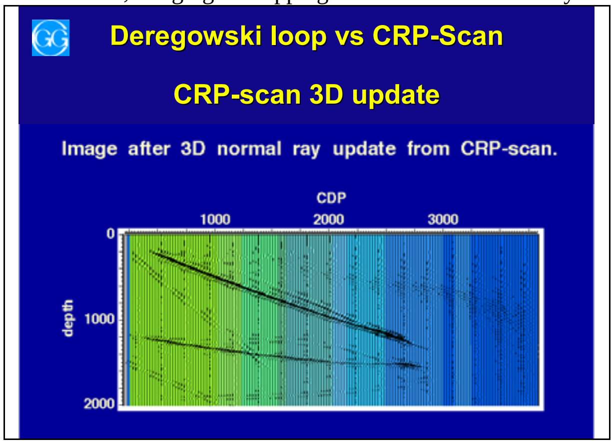


Figure 12 a single CRP is migrated with a suite of trial models, and the flattest member of the scan picked for the update

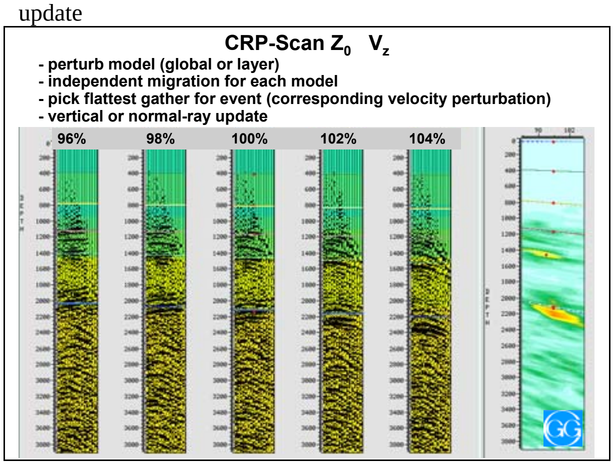
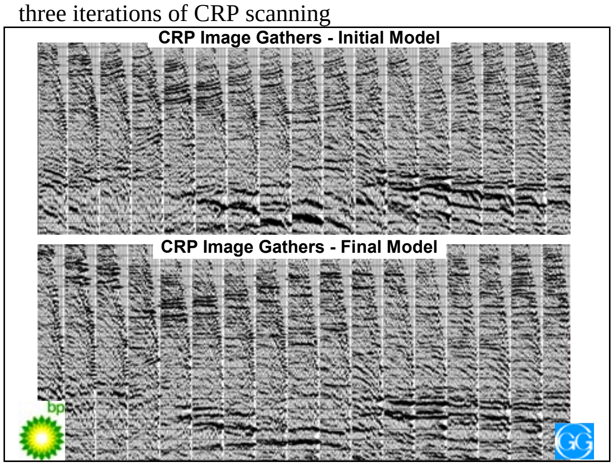


Figure 13. Gathers are flattened (from the top down) after three iterations of CRP scanning



To a large extent, these techniques are limited to providing an initial model, as the imposed hyperbolic assumption (as the input data were picked from a stack) does not permit the resolution of velocity changes giving rise to anhyperbolicity.

We saw this in one example, where during an iterative preSDM update scheme we obtained progressively flatter gathers, but a run of this zero-offset tomography using each model could not distinguish between them on the basis of the zero-offset tomographic objective function. In other words the differences in the models that compensated for non-hyperbolic effects lay within the null-space of the zero-offset inversion.

Figure 15a shows a 3D depth image of data with a complex chalk overburden, obtained using the initial zero-offset tomographic model. Figure 15b shows the corresponding image after model update using iterative CRP scanning. The objective functions produced by the zero-offset tomography, for the initial and final models were equally 'good'. Thus differences in the models (which clearly result in improved depth imaging) lie in the 'null-space' of the zero-offset inversion technique, and are not resolvable.

Figure 14 In zero-offset tomographic inversion, travel times from multi offset ray tracing are used to compute a stack time and stacking velocity for comparison with real measurements

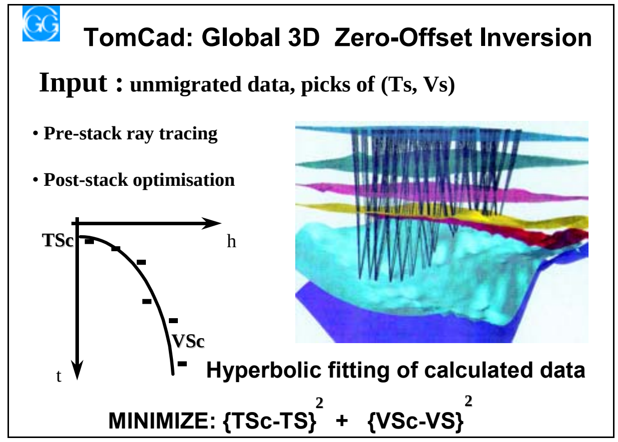
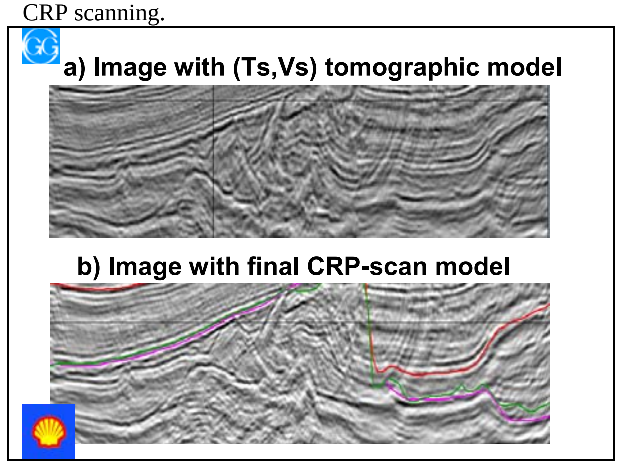


Figure 15 Depth imaging using original zero-offset tomographic model is inferior to that after 3D preSDM CRP scanning.



Tomographic inversion of picked zero-offset time-migrated times and DMO velocities:
As above, but with the benefit of using observables picked from migrated data: thus the input data are more reliable for complex geometries. However, if the scheme requires de-migration of the picks and backing-out DMO effects from the velocities, then we will suffer restrictions. A more accurate rendition is to use iterative forward modelling of rays through a perturbed model including the geometric effects of time migration and DMO, until the observed data are matched. An example of this application is the SuperDix™ package developed by Elf (Sexton, 1998). Incorporating anisotropy and well control in the scheme, as in SuperDix, also leads to more robust models.

CFP analysis
The theory of the CFP-method was developed by Berkhout in the early nineties (Berkhout, 1997a,b; Berkhout and Verschuur, 2001). The essence of this theory is that parameterization of the subsurface (with velocities for

example) needs to be delayed as much as possible in seismic processing to avoid a bias in the subsurface model. Instead, we estimate the wavefield operators from seismic data first. In Berkhout's theory these operators are the one-way propagation operators (W) and reflection operators (R). Together, they define the response of the subsurface (WRW).

Thus CFP velocity model building is carried out in two phases. Firstly, the W-operators (often referred to as CFP-operators) are estimated in an iterative way from the data. Secondly, all CFP-operators are inverted to a velocity model by one-way tomography. It is important to realize that in the CFP-method, operator estimation is data driven and does not require a velocity model. In other words, the velocity model is not in the iteration loop.

Figure 16: a) creation of a CFP gather, and b) the analysis panel for operator updating.

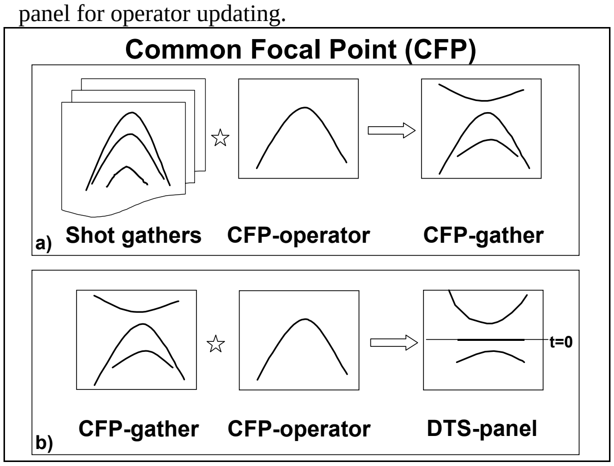


Figure 17 Example of CFP-operator updating on a real dataset: the reflector of interest is picked in a time section (a), and initial CFP-operators are chosen based on NMO velocities. The reflection events in the DTS-panels (b) are picked, and half of the travel time errors are used to update the initial operators. After a few iterations, the result is a set of DTS-panels with flat events at zero time (c).

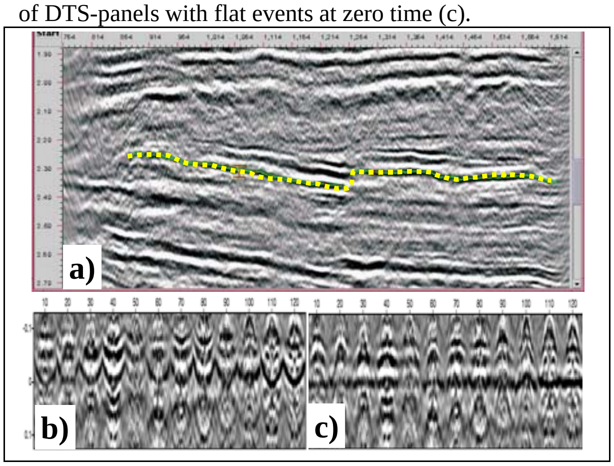


Figure 16 illustrates the principles of the CFP method. A CFP-gather represents a half-redatuming of the seismic sources to a new position at a boundary location (focus point). This is achieved by taking the CFP-operator (containing the one-way travel times from the focus point towards the surface), correlating it with all traces within a shot record along the time axis and adding the results per shot.

To check the validity of this CFP-operator, the resulting CFP-gather is corrected with the operator times (DTS-panel). A correct operator will display a reflection event at zero time for all CFP offsets, meaning that operator and response have the same travel times ('principle of equal travel time').

Inversion of Picks made on Several Offsets.

Tomographic Inversion of pre-stack multi-offset arrival times.
In conjunction with automated picking of horizons in the pre-stack data volumes, this technique can yield a rapid starting model to precede subsequent iterative updates. However, it faces the problem common to all picking of unmigrated data that the picking in complex area is very difficult. Thus it perhaps best suited to regions with low structural relief, but with significant lateral velocity changes. An example using such a technique applied to non-structured data with significant lateral velocity change is shown in figure 18a (preSDM with initial model) and 18b (preSDM after model update), courtesy of Veritas.

Tomographic Inversion of pre-stack time migrated migrated multi-offset arrival times.
Here we avoid the problems of attempting to pick on unmigrated data in order to obtain the pre-stack multi offset input for the tomographic inversion scheme. Some schemes permit either cross-line migrated or fully 3D migrated data as input, and the migration used would usually be a full Kirchhoff multi-offset pre-stack time migration.

Outputting offset gathers continuously along a grid of in-lines and cross-lines after 3D Kirchhoff preSTM and autopicking layers provides input to the tomography.

Tomographic Inversion of pre-stack depth migrated multi-offset arrival depths.
As above, we avoid the problems of attempting to pick on unmigrated data. Picks of residual depth error are made for all offsets on an event, and these picks fed to the inversion scheme so as to minimize these residual errors. As part of the inversion process, 3D ray-tracing occurs from the subsurface point where the residual errors were picked.

It can also be used in conjunction with the CRP scanning technique, such that the input to the inversion can be picked from the flattest gathers resulting from a preSDM with a suite of perturbed velocity models.

Figure 18a non-structured data with significant lateral velocity changes after preSDM with initial model

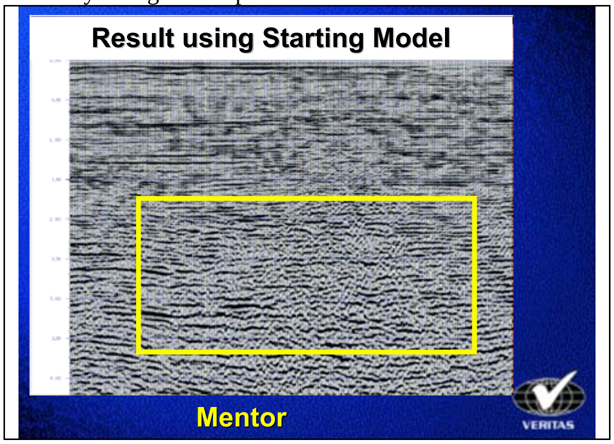
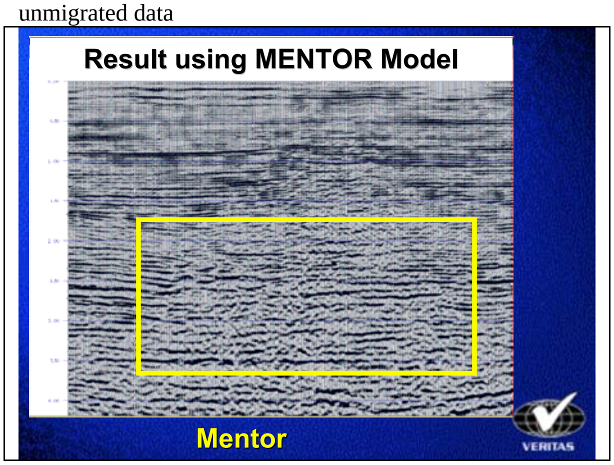
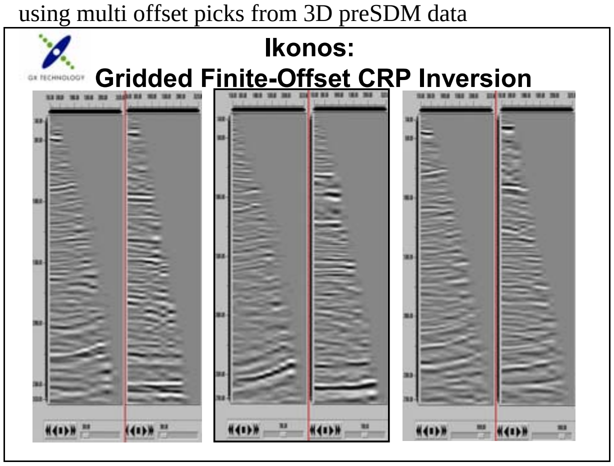


Figure 18b non-structured data with significant lateral velocity changes after preSDM with model updated via tomography using multi offset travel time picks from unmigrated data



Examples of this technology can be found amongst most of the major contractors and oil companies. In figure 19, we see three pairs of preSDM CRPs before and after gridded tomographic update, taken from GXT's Ikonos™ routine.

Figure 19 gathers before and after gridded tomography using multi offset picks from 3D preSDM data



In figures 20 & 21 we see a comparison of layer based versus gridded tomographic update on a 2D section from a gas charged channel. Away from the channel, where good picks of events can act as a geological constraint, the layer based tomographic update can yield better results, but were pick quality is unreliable (below the channel), the gridded approach can be better. In production, the gridded result could be further updated using additional iterations of tomography or CRP scans.

Some techniques work iteratively using layer stripping, but some, such as TFE's Figaro (Sexton & Williamson, 1998) attempt to solve the inverse problem for all residuals globally in one pass.

Figure 20a model derived from layered tomography

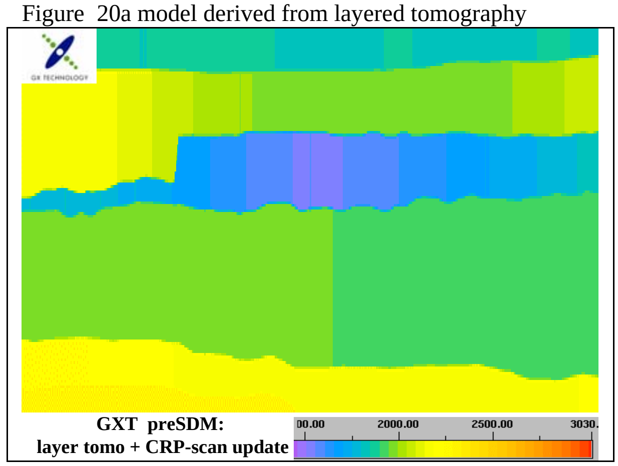
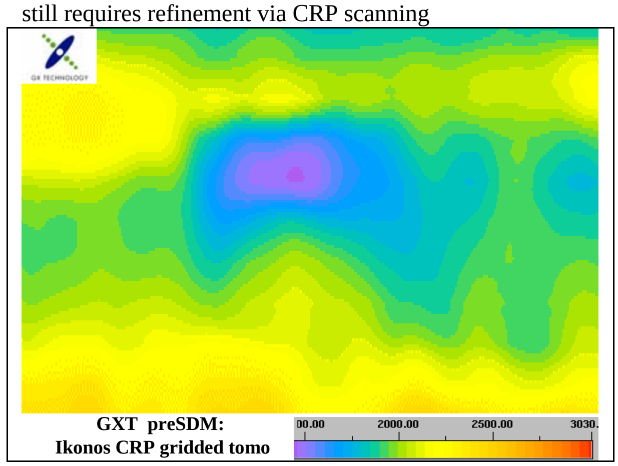


Figure 20b model derived from gridded tomography. This still requires refinement via CRP scanning

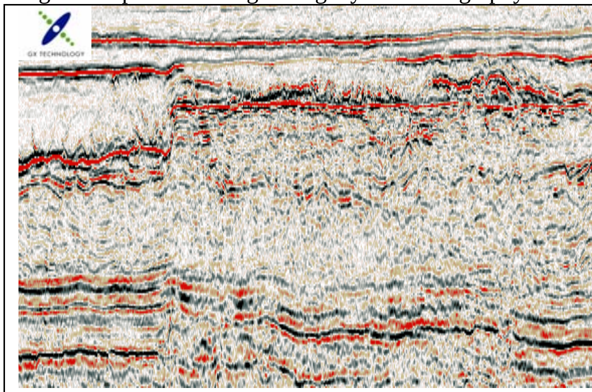


Stereo Tomography.

In this pre-stack technique, two 'dips' are picked. In 2D, the dips could be the geological dip picked on an offset section, plus the time dip (gradient to the local tangent) seen for the event at the corresponding offset on a shot gather. In 3D, the 'dips' could be the gradients seen in shot and receiver gathers for the same event (figure 22).

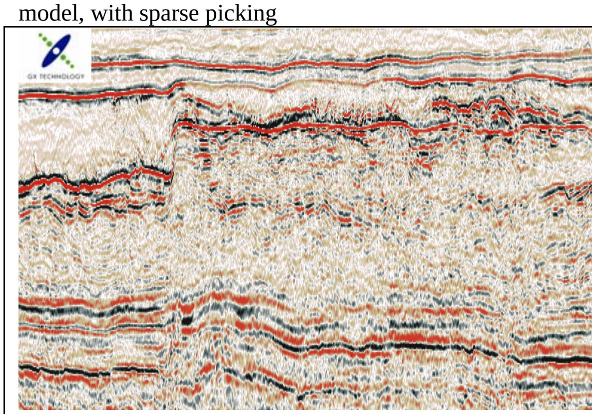
Inversion of the dip information yields model update. This technique was first introduced in the Soviet literature (Riabinkin, 1962), and more recently by Billette & Lambaré (1998) at the Paris School of Mines..

Figure21a preSDM image using layered tomography model



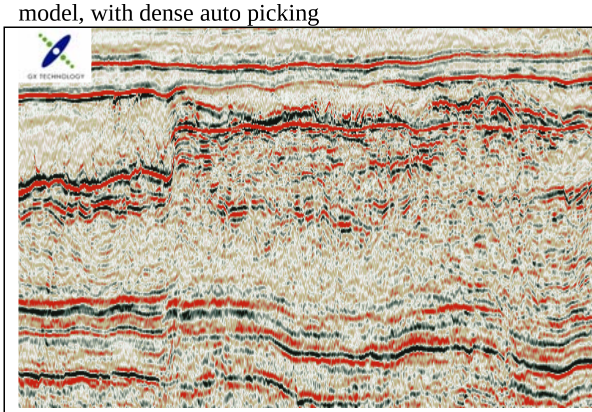
preSDM using layer tomo + iterative CRP-scan

Figure 21b preSDM image using gridded tomography model, with sparse picking



preSDM using 'Ikonos' gridded tomo, with sparse picking

Figure 21c preSDM image using gridded tomography model, with dense auto picking

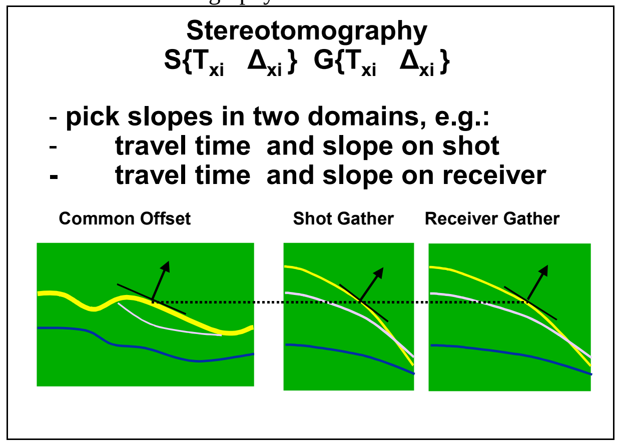


preSDM using 'Ikonos' gridded tomo, with dense auto picking

Wavefield Extrapolation (non-Kirchhoff) techniques

The bulk of the model updating schemes mentioned here are tied to migrated data produced with ray-based integral techniques such as Kirchhoff migration. The travel times used in the subsequent tomography are thus similar to those used in the travel time computation for the migration (or should be), and are most often associated with a single arrival.

Figure 22. Picking dips in two domains provides the input data for stereotomography



However, we are now seeing the emergence of Wavefield Extrapolation (WE) techniques which for multi-pathing problems offer a more complete solution than single arrival Kirchhoff. The problem with WE migration (from a model building standpoint) is the availability of gathers after migration. Common shot migrations do not inherently produce prestack data as the offsets are collapsed to zero offset during imaging.

Various common azimuth techniques have been introduced which can produce gathers and do have associated model updating schemes (e.g. tau-p domain, Duquet, 2001; txy domain Clapp et al 1998), but these migrations have restrictive assumptions. However, despite these restrictions, some interesting model updating results have been presented by Clapp et al, (1998).

Anisotropic Parameter Estimation

In this work we have primarily reviewed techniques for estimating isotropic P-wave velocities. However, much interest has been shown recently in anisotropic migration with the associated problem of anisotropic parameter estimation (e.g. Armstrong, et al, 2002). For time imaging, one additional parameter (η) is required (Alkhalifa, 1997). For depth imaging, two additional parameters (ε and δ) are required (Thompsen, 1986).

In Thomson's notation, the vertical and horizontal velocities are related to the surface seismic near-offset moveout velocity (V_{nmo}) by:

$$V_h = V_v \sqrt{(1+2\varepsilon)}$$
$$V_{nmo} = V_v \sqrt{(1+2\delta)}, \text{ or } = V_v (1+\delta) \text{ for small } \delta$$

Where:

V_{nmo} is the near offset velocity estimated from stacking velocity analysis,
V_v is the vertical velocity seen in well logs, and
V_h is the horizontal component of velocity
(which we do not usually have access to)

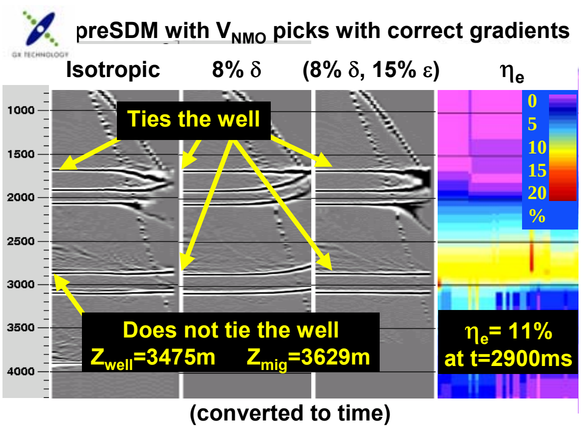
Alkhalifah's η parameter can be related to Thomsen's ε and δ formulation via:

$$\eta = (\varepsilon - \delta)/(1+2\delta)$$

Unless we have first obtained a reliable estimate of the vertical velocity compaction gradients, the anisotropy parameter estimates will be in error (Jones, et al, 2002). However, assuming this has been done, then we usually estimate δ from well ties and determine η from higher order moveout estimates or during tomographic inversion incorporating long offset data. No reliable inversion scheme based on surface seismic measurements has yet been demonstrated for obtaining δ, though some methods have been discussed (e.g. Isaacs, 2002), A serious restriction on anisotropic parameter estimation from surface seismic data is the availability of long offset information (offsets>depth).
In analysing long-offset data, we actually measure a cumulative η_e, which has to be inverted to yield the interval values of η (in an analogous way to RMS inversion to obtain interval velocity). Once the interval η values are obtained, then ε can be determined for use in depth migration.

Figure 23 shows a various steps in anisotropic parameter estimation for simple synthetic data (Jones et al, 2002). Depth mis-ties yield δ and subsequent migration with this δ value followed by automated continuous η_e estimation yields values for inversion to obtain η and thence ε.

Figure 23. A single CRP gather after various migrations, and (far right) the η_e estimate for several adjacent CRPs. Including correct vertical compaction gradients in the velocity model facilitates accurate estimation of the anisotropy parameters. Ignoring the gradients leads to an incorrect estimate of ε



Discussion
Most techniques can yield an adequate starting model for depth imaging. However, for geology with moderate to complex structure, or for rapidly changing velocities, tomographic techniques are beneficial.

Tomography can produce consistent updates during iterative inversions, but we should be aware of:

- is it grid or layer based?
- what is being inverted?
- how reliable are the picks?
- is the inversion tomographic?
- what is the spatial resolution of velocity?

Spatial resolution of the velocity is a function of the number of rays that the inversion uses to sample each element of the subsurface. Thus, in order of increasing resolving power, we would have:

Vertical Dix update, zero-offset normal ray update, two point parametric tomographic inversion, multi offset tomographic inversion. Naturally, increasing the spatial sampling of any of these techniques would improve its precision (but not accuracy).

Most of the tomographic solutions available can be formulated fror either gridded or layered models. Both model representations have strengths and weaknesses, and ideally a flexible model builder should permit use of both representations.

Converted Mode and S-Wave Velocity Update
This paper has restricted itself to P-wave velocity model building. However, as multi-component data processing becomes more widespread, more development will be required for updating the converted wavefield velocities, perhaps also via joint inversion of the vector field (e.g. Brown, et al, 2002).

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