Wave Inversion Technology, Report No. 3, pages 183-188

Full Wave Form Modeling In Time-Lapse Studies

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keywords: *seismic modeling feasibility fluid time-lapse*

ABSTRACT

In reservoir rocks physical quantities, such as p-wave and s-wave velocities, depend on porosity and fluid content. Observing the influence of fluid flow properties on seismic wave propagation enables us to estimate the feasibility of seismic imaging of fluid related quantities in reservoir rocks. Often only full wave form modeling can capture the essence of the reservoir response. Preliminary time-lapse tests in an elastic 3D SEG/EAEG salt model are computed numerically.

INTRODUCTION

A major aim of applying full wave form modeling techniques for time-lapse studies is to produce realistic feasibility studies, which are either generic in a typical average setting or are specific cases based on a very particular reservoir situation. Asymptotic modeling, although fast, cannot in many cases capture the essence of the total reservoir response. Full wave form modeling can help in cost effectively design acquisition and monitoring programs for specific targets and can help decide which type of recording geometry, surface, OBC, VSP, cross-well, vertical cable, multi-component recordings are most likely to produce unique quantitative images of the reservoir change. From fluid flow simulations reservoir changes over time can be obtained. In a companion paper Kaselow et al. (1999) describe a methodology that can be used in order to compute variable fluid content and type in a typical reservoir.

In order to use full wave form modeling as a tool, it needs to allow quick computation of the initial 3D seismic wave field. In a companion paper in this report (Karrenbach, 1999) a combination of Eikonal solution and high-order finite difference method produces a hybrid scheme, that depending on the model geometry and properties can compute the response more quickly than standard FD techniques. In another companion paper (Pohl, 1999) we show another way to reduce the computational cost by using a variable grid. This method has another advantage of reducing numerical artifacts since grid lines are chosen such that they follow major model boundaries (such

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as salt body).

To use full wave form modeling for time-lapse studies residual modeling techniques need to be used in order to compute quickly the effect of changing the target properties of the model. The effort can be greatly reduced by precomputing Green's functions up to an area surrounding the target zone (this can be done in the initial modeling run). The residual modeling of a single time lapse response can then be produced by using a full wave form modeling technique in the target region and recording seismic response where the previous Green's functions were recorded. Upward continuing the solution to the surface concludes the residual modeling step. For further time-lapse responses additional full wave form computation is limited to the target region only, thus the computational effort is greatly reduced.

Using full wave form modeling described above allows the realistic testing and calibration of processing and imaging algorithms, such as the following:

- Multiple Attenuation, Subsalt and Multi-component Imaging
- AVO/AVAZ Analysis and Fracture Detection
- Near Surface and Topography Influences
- Seismic Tracking of Target Property Changes

A NEW SEG/EAEG 3D MODELING EFFORT ?

Currently SEG is contemplating to renew its modeling activities. A workshop has been held at the SEG meeting 1999 to poll the interest among academia, industry and national laboratories. So far the computational burden for a realistic 3D elastic model seems overwhelming. However, a next SEG 3D modeling could be extremely useful if carried out acoustic, elastic, as well as viscous and anisotropic. To maximize usefulness for a variety of purposes a future model should accommodate exploration as well as production problems. Since the effort of constructing such a comprehensive 3D model is considerable, it should be made sure that it is possible to easily extend it in the future. In contrast to previous SEG/EAEG modeling activities, a future model should be designed cooperatively with Petroleum Engineers. To create a model as realistic as possible, it needs to incorporate the temporal change in the subsurface parameters due to subsurface fluid flow. Not one single 3D prestack data set should be generated, but a variety of related (smaller) 3D prestack data sets, such as with and without free surface multiples, target replacements, overburden replacements, with acoustic, elastic, viscous and anisotropic material should be produced. It would allow to objectively test and calibrate elastic seismic processing and imaging methods. In order to carry out 3D elastic numerical modeling, high performance computing in form of MPP, VPP, clusters need likely to be used on the hardware side as well as optimized and hybrid Finite

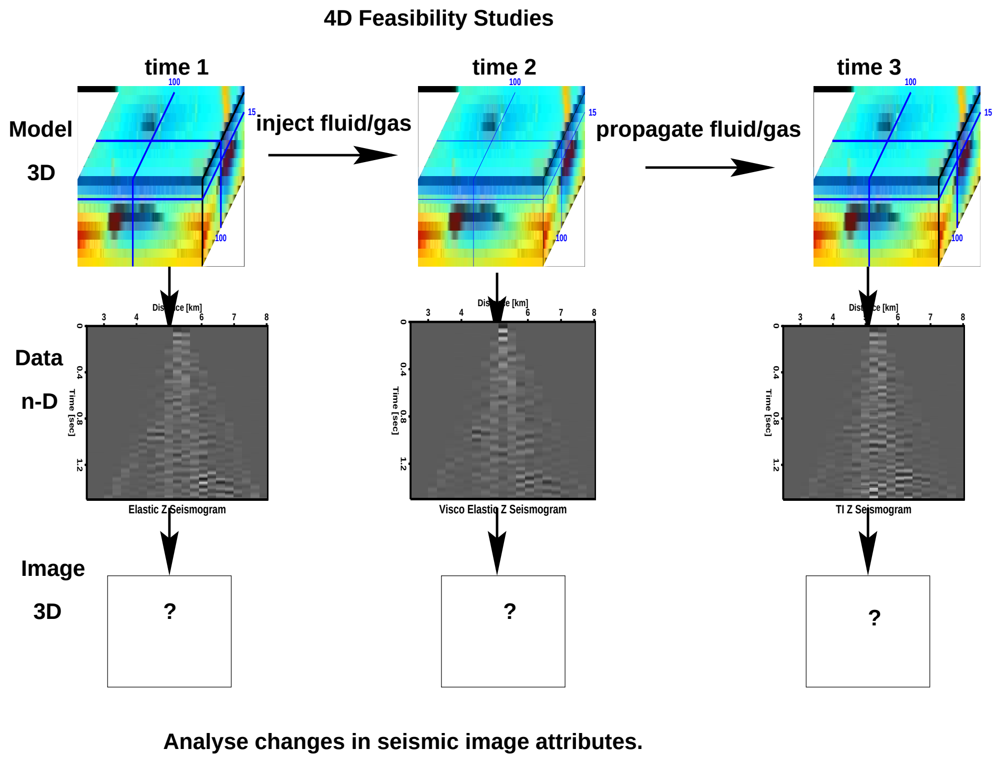
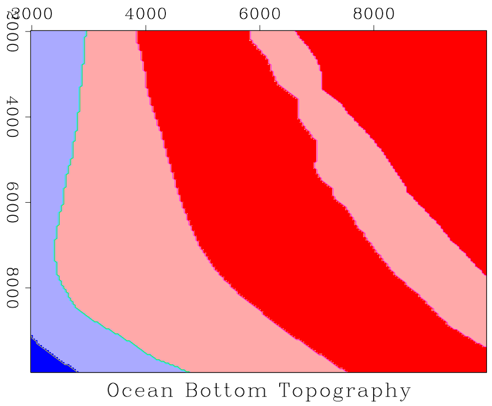


Figure 1: Seismic responses due to changes in the 3D reservoir.

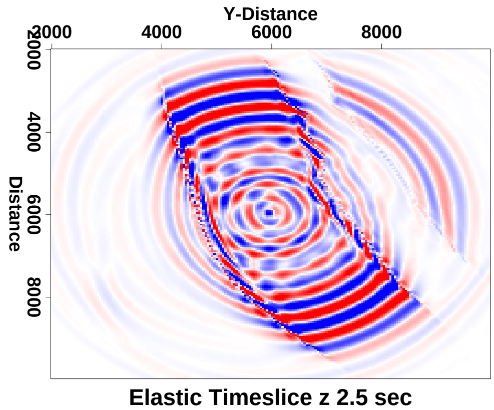
Difference type methods on the software side (Karrenbach, 1999). Elastic modeling is memory and compute bound on most present day hardware, however, massively parallel and cluster computer hardware is becoming rapidly economical. Seismic data storage, access and distribution is a practical issue and will determine how effectively data will be used. The use of compression technology is likely to be necessary.

PRELIMINARY TESTS IN THE SEG/EAEG SALT MODEL

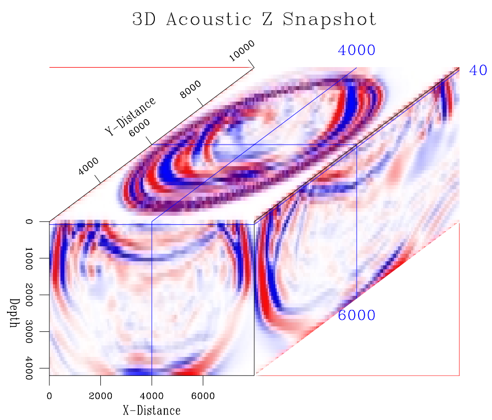
In the previous years I have used this 3D model extensively. Being familiar with this model allows the construction of a useful generic extensible 3D model with various features of a production within a exploration model. I include small-scale property variations in target zones or overburden. The direct embedding of fluid properties in the 3D model allows to carry out fluid flow simulations concurrently and to couple it with the seismic response. Seismic data was generated for such a smallish production model in various incarnations: acoustic, elastic, viscous, transverse isotropic, with and without certain multiples. Figure 1 shows the 2D surface recording in a 3D model that changes its subsurface properties target-oriented over time. We can observe slight changes in the target region of the seismic recording, clearly demonstrating a characteristic change in subsurface properties. The numerical data acquisition can be very flexible, be it pressure or multi-component, OBC, VSP, VC, Cross-well acquistion geometries. Figures 2 show the ocean bottom topography in the model, a time slice in a surface shot recording, and the comparison of an acoustically versus an elastically computed 3D snapshot. Figures 3 demonstrate the capability of recording arbitrary 3D VSPs. Figure 3 a) shows recording in a vertical well in the center of the model, b) and c) show deviated well recordings where the lower part of the well extends in the direction towards the target in the center of the model.



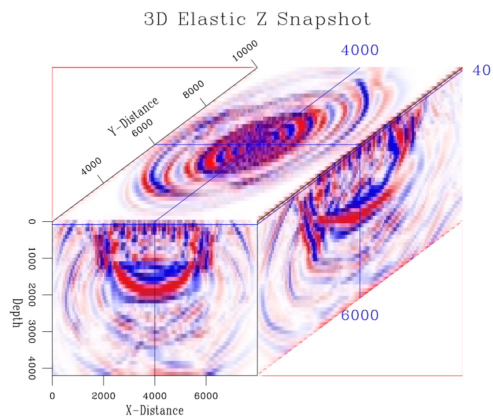
(a)



(b)

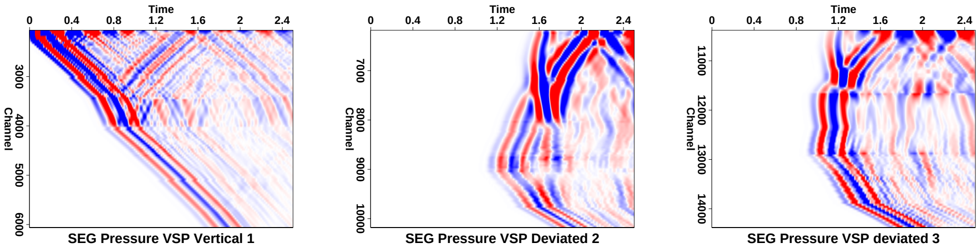


(c)



(d)

Figure 2: Acoustic / Elastic snapshot comparison for the SEG/EAEG 3D Salt Model.Figure a) show the ocean bottom topography, b) shows a time slice of shot recording, c) shows a acoustic snapshot and d) an elastic snapshot of a single 3D surface shot.



(a) (b) (c)

Figure 3: 3D VSP recording in the SEG/EAEG salt model. Figure a) shows vertical well in the center of the model , b) and c) show deviated well recordings where the lower part of the well follows the direction towards the target in the center of the model.

CONCLUSION

Several numerical techniques can be combined that allow to perform full wave form modeling fast for initial as well as repeat modeling runs. Initial tests have been carried out in the 3D SEG/EAEG salt model and some typical seismic data have been calculated and recorded in several geometries. Full wave form modeling, although numerically intensive, is sometimes the only way to capture a realistic reservoir reservoir response and to evaluate a 4D feasibility study confidently.

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