# Ray tracing computations in the smoothed SEG/EAGE Salt Model

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## Summary

Two-point rays of refracted and reflected P-waves in the smoothed SEG/EAGE Salt Model are calculated. The source-receiver configuration is derived from the original Phase A Acquisition. Map of reflection points at the bottom interface is displayed. One profile is used for generation of the ray-theory seismograms. The results show that the smoothed SEG/EAGE Salt Model is suitable for two-point ray tracing.


## Introduction

The greatest advantages of ray tracing in comparison with precise methods, e.g., finite differences or finite elements, are the speed of computation, the small memory requirements and the possibility to separate elementary seismic waves.

The original 3-D SEG/EAGE Salt Model (Aminzadeh *et al*. 1997) is very complex model and cannot be directly used for ray tracing, because ray tracing computations need smooth velocity macro models (Bucha, Bulant & Klimes 2003). Is the smoothed SEG/EAGE Salt Model suitable for two-point ray tracing computations?

## Smoothed SEG/EAGE Salt Model

The Salt Model selected for ray tracing computations was smoothed by Bulant (2001, 2002, 2003). It is the best model obtained as a result of many test smoothing computations. The model is parameterized by B-splines and was smoothed using the Sobolev scalar products. There are two versions of the smoothed model, the one-block version and the version with the most important interfaces. Ray tracing calculations described in this paper are performed in the version with the most important interfaces that correspond to the highest discontinuities in the velocity field. These interfaces are the ocean bottom, the interfaces limiting the salt body, the geopressure horizon and the bottom flat interface (see Figure 1).

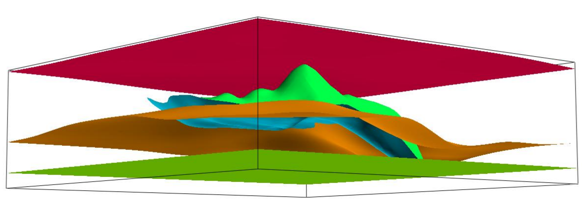

Figure 1: Smoothed Salt Model with the most important interfaces. Interfaces are coloured according to the indices of surfaces.

## Receivers and shots

The position of the shots and receivers is derived from the original Phase A Acquisition SEG/EAGE (Aminzadeh *et al*. 1997). The square of 21 x 21 receivers is located above the salt body (see Figure 2). The receivers are located in the depth of 0m and the grid step is 320m. The receiver grid step in Phase A Acquisition was 20m. An attempt to compute one elementary wave for the grid of 329x329 receivers with step 20m was successfull, but the sizes of output files make the visualization of rays difficult. The red point profile (see Figure 2) was selected for generation of synthetic seismograms.

Three shots are used for computation of rays and seismograms. One shot is located at the centre of the square of 21 x 21 receivers above the salt crest in the depth of 20m. Two other shots are located in the well (see Figure 2), one shot above the salt in the depth of 900m and one shot below the salt in the depth of 2300m. Map of amplitudes of reflection points at the bottom flat interface is computed for 17 shots located in the depth of 20m (see Figure 3).

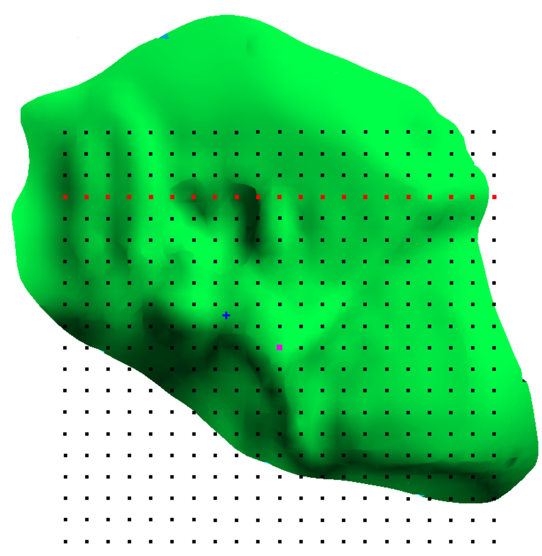

Figure 2: Top view of the salt body, shot point, well and receiver points. Violet point in the centre of configuration is source in the depth of 20m. Blue cross represents the well with two shots in the depth of 900m and 2300m. Red point profile is used for synthetic seismogram computation.

# Ray tracing computations

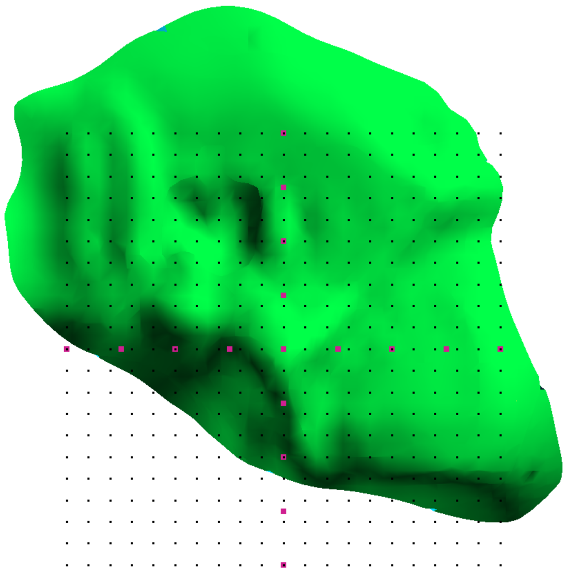

Figure 3: Top view of the salt body, shot points and receiver points. Violet points are 17 shots in the depth of 20m used for computation of reflection map at the bottom interface.

### Ray tracing computations

Two-point rays of refracted and reflected P-waves are determined by means of two-parametric shooting method using MODEL, CRT and FORMS subroutine packages (Cerveny, Klimes & Psencik 1988, Bulant 1996). The computations are performed on a PC with Linux. Figures 4, 5, 6 and 7 show examples of two-point rays for various locations of shots. The figures are GOCAD screen snapshots.

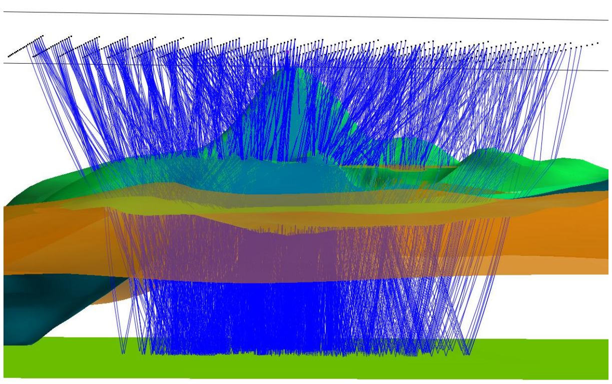

Figure 4: Rays of P-wave reflected from the bottom flat interface. The geopressure horizon and the top of the salt body are partially transparent. Shot is located at the centre of the square of 21x21 receivers above the salt crest in the depth of 20m.

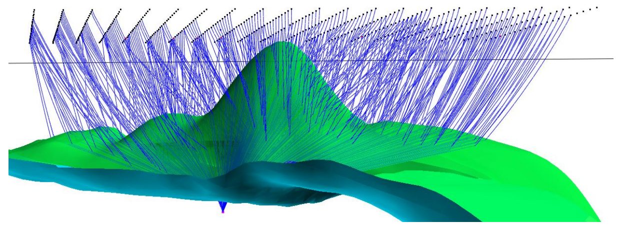

Figure 5: Rays of the refracted P-wave. Shot is located in the well below the salt in the depth of 2300m.

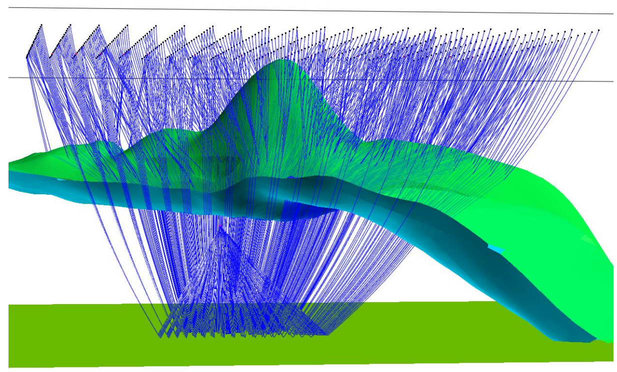

Figure 6: Rays of P-wave reflected from the bottom flat interface. Shot is located in the well below the salt in the depth of 2300m.

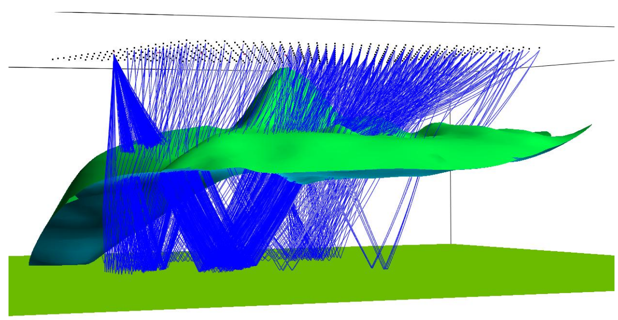

Figure 7: Rays of P-wave reflected from the bottom flat interface. Shot is located at the edge of the square of receivers.

### Map of reflections

Two-point rays of P-waves reflected from the bottom flat interface for 17 shots are computed (see Figure 3). Figures 8 and 9 show reflection points colour coded according to reflection amplitude. The distribution and amplitudes of reflection points are affected mainly by salt body shape, velocity properties and shot-receiver configuration. Displaying of reflection points and two-point rays for each shot and each elementary wave separately is recommended for detailed study of subsalt reflections.

## Ray tracing computations

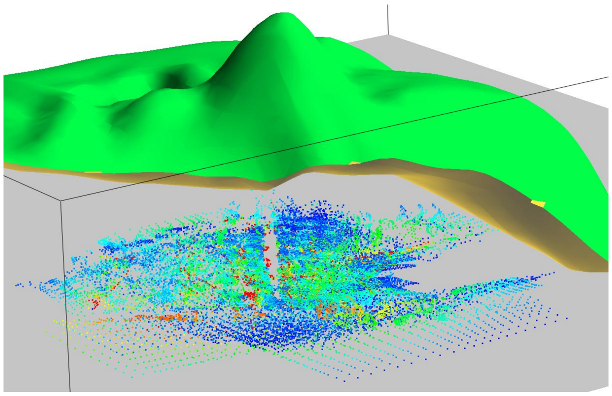

Figure 8: Reflection points at the bottom interface colour coded according to amplitudes of reflections (blue is for low amplitude to red for high amplitude).

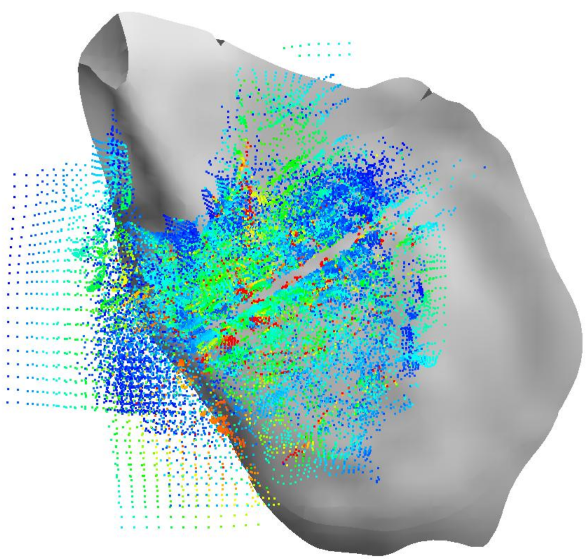

Figure 9: Bottom view of the salt body and reflection points at the bottom interface colour coded according to amplitudes of reflections (blue is for low amplitude to red for high amplitude).

**Synthetic seismograms**

One profile, selected of the square grid of 21 x 21 receivers, was used for generation of the ray-theory seismograms. The selected profile is marked by red points in Figure 2. The source time function is defined by the Gabor signal of prevailing frequency 30Hz. The source is an isotropic explosion.

Figure 10a shows the seismograms generated from all the computed elementary waves: one refracted and three reflected P-waves. The shot is located at the centre of the square of 21 x 21 receivers in the depth of 20m. The maximum amplitude at each trace is scaled to a given constant. Figure 10b shows traces of individual elementary waves distinguished by colours. The maximum amplitude of each elementary wave is scaled to a given constant. The arrivals of individual waves may be compared with Figure 10a. For example, the amplitudes of the reflections from the bottom interface are very small in comparison with other waves and are hardly visible in Figure 10a, but they are visible clearly in Figure 10b (black colour amplitudes). Simultaneous visualization of the model interfaces, rays, sources and receivers helps to interpret the computed seismograms.

**Conclusions**

Results of the calculations show that the smoothed SEG/EAGE Salt Model is suitable for two-point ray tracing. Computation and visualization of rays, maps of reflection points and seismograms of individual elementary waves is a great advantage of ray tracing method and should help to study problems in subsalt areas. A comparison of similar computations performed with some precise method will be checked in future.

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The author thanks to Petr Bulant and Ludek Klimes for valuable comments and recommendations concerning this paper. The research has been supported by the Grant Agency of the Czech Republic under Contracts 205/01/0927, 205/01/D097 and 205/04/1104, by the Grant Agency of the Charles University under Contracts 237/2001/B-GEO/MFF and 229/2002/B-GEO/MFF, by the Ministry of Education of the Czech Republic within Research Project MSM113200004, and by the members of the consortium "Seismic Waves in Complex 3-D Structures" (see "http://sw3d.mff.cuni.cz").

**References**

Aminzadeh, F., Brac, J., Kunz, T., 3-D Salt and Overthrust Models, SEG/EAGE 3-D Modeling Series No.1. Soc. Explor. Geophysicists, Tulsa 1997.

Bucha, V., Bulant, P. & Klimes, L., Velocity macro models. In: Extended Abstracts Book, EAGE/SEG Summer Research Workshop on 'Processing and imaging of seismic data' Using explicit or implicit velocity model information? (Trieste), Eur. Assoc. Geoscientists & Engr., Houten, T32 (4 pp.), 2003.

Bulant, P., Two-point ray tracing in 3-D. PAGEOPH, 148 (1996), 421-447.

## Ray tracing computations


Bulant, P., Sobolev scalar products in the construction of velocity models - application to model Hess, to SEG/EAGE Salt Model, and to model Pluto 1.5. In: Seismic Waves in Complex 3-D Structures, Report 11, pp. 133-159, Dep. Geophys., Charles Univ., Prague 2001.

Bulant, P., Sobolev scalar products in the construction of velocity models: Application to model Hess and to SEG/EAGE Salt Model. Pure appl. Geophys., 159, 1487-1506, 2002.

Bulant, P., Constructing the SEG/EAGE 3-D Salt Model for ray tracing using Sobolev scalar products. In: Seismic Waves in Complex 3-D Structures, Report 13, pp. 17-33, Dep. Geophys., Charles Univ., Prague 2003.

Cerveny, V., Klimes, L. & Psencik, I., Complete seismic-ray tracing in three-dimensional structures. In: Doornbos, D.J.(ed.), Seismological Algorithms, pp. 89-168. Academic Press, New York 1988.


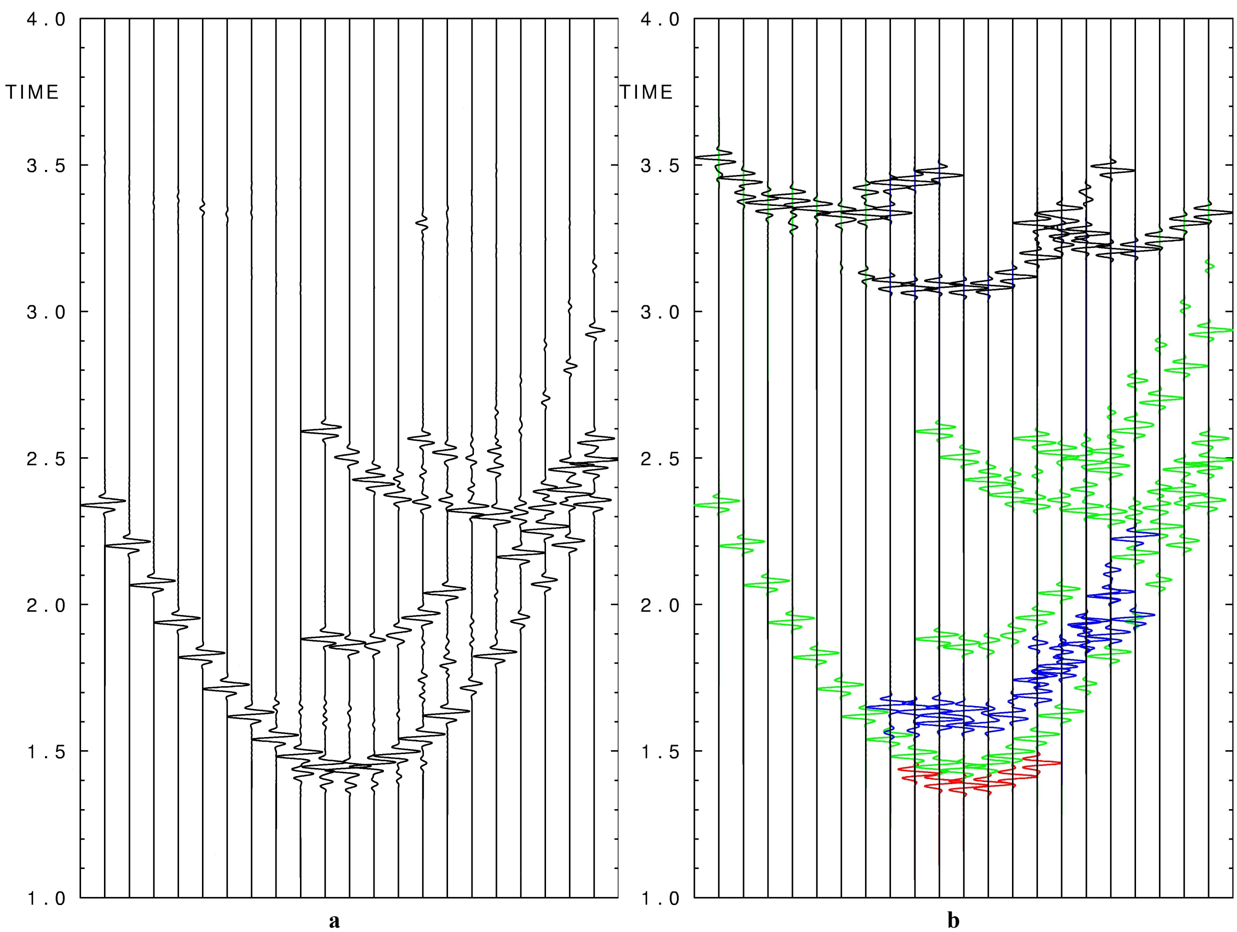


Figure 10: Seismograms computed for the shot located at the centre of the square of 21 x 21 receivers in the depth of 20m and for the selected receiver profile shown on Figure 2. a: Vertical components of synthetic seismograms of all computed elementary waves. The amplitudes at each trace are scaled according to the maximum amplitude at each trace. b: Vertical components of seismograms of individual elementary waves, with maximum amplitude of each elementary wave scaled separately. The red colour denotes the refracted wave, green denotes the reflections from the top of salt, blue denotes the reflections from the bottom of salt and black denotes the reflections from the bottom interface.