Geological Sciences Research (GEOL490.3)

School year: 2006/2007, Term 1

Topic: **Study of geometrical-spreading and near-surface effects on reflection Amplitude Variations with Offset (AVO)**

Problem

Variations of reflection amplitudes with source-receiver offsets (the so-called AVO effects) are the key seismic indicators allowing identification of gas- and petroleum-bearing reservoirs. Numerous techniques have been developed for inverting the seismic AVO responses and their interpretation in terms of anomalies in seismic velocities or elastic properties of reservoir rock which are, in their turn, can be related to porosity and fluid/gas content.

Despite its paramount importance for modern seismic interpretation, the commonly used AVO analysis still relies on plane-wave reflection assumptions (e.g., represented by the Zoeppritz equations). However, in real reflection data acquisition, at least three physical phenomena make these assumptions unrealistic: 1) geometrical spreading of the waves from the source, 2) downward reflection from the free surface, and 3) near-surface P- to S-wave mode conversions. Each of these effects should have a pronounced AVO signature that could potentially mask the desired reflection AVO from the reservoir. The objective of this research is to evaluate the effects of factors 1) and 2) above by numerical modeling, evaluate the ensuing interpretation errors, and possibly make recommendations for improving reflection AVO techniques.

Method

The method used in this project will consist in numerical simulations of seismic wavefields in several standard reservoir models using the program called *reflectivity*. The program computes wavefields in complex layered models and allows accounting for all three factors above. For each reservoir model, the reflection amplitudes will be picked (for example, using ProMAX) and compared to those predicted by plane-wave AVO. To calculate plane-wave reflection amplitudes and also for further data analysis and plotting, Matlab or Octave software could be used.

The work will be conducted using the Linux and Windows computers in Geology Room 111. If needed, one of the Linux clusters could be utilized in numerical simulations. Thus, the project will rely on a part of the IT support normally provided to the Geophysics group.

Expected results

A research paper and presentation summarizing the results will be prepared. The results of this research will provide estimates of the potential bias in AVO interpretations caused by wave propagation effects that are commonly disregarded. Potentially, these results could lead to a publication in a professional journal, such as *Geophysics*, and lead to further studies.

Evaluation

Recommended examining committee

1) Zoltan Hajnal
2) Jim Merriam
3) Igor Morozov

Grading:

Paper:	50%
Oral presentation:	30%
Computer scripts, plots, and test examples in electronic formats:	20%

Recommended reading

Aki, K., and P. G. Richards, 2002. Quantitative Seismology, Second Edition, University Science Books, Sausalito, CA

In this text, note in particular:
Chapter 5: plane-wave reflection coefficients;
Section 9.2: the reflectivity method (this is what you will be using for modeling); see also the paper by Fuchs and Muller below.

Castagna, J. P. 1997. Principles of AVO crossplotting. The Leading Edge, 16, 337-344.

Castagna, J., Swan, H., and Foster, D., 1998. Framework for AVO gradient and intercept interpretation, Geophysics, 63, 948-956.

These two papers explain (and many other you can easily find) the idea of AVO interpretation in industry seismics.

Fuchs, K., and G. Müller, (1971), Computation of synthetic seismograms with the reflectivity method and comparison with observations, J. R. Astronom. Soc., 23, 417-433.

Classical paper on 1D synthetic modeling approach found in many academic and industry programs.

Telford, W.M., L. P. Geldart, R. E. Sheriff. Applied Geophysics, Cambridge University Press.

Yilmaz, O., Seismic Data Analysis, SEG, Tulsa, OK, v. 2.

Classical text on seismic processing and data analysis, recently greatly expanded. I am not sure whether the library has the new edition… If you cannot find it, no problem.

Work plan

(Note that this is also roughly an outline of your expected report).

Work will be conducted using Linux computers in Rm. 111. Octave can replace Matlab very well under Linux.

1) Study the recommended and other literature and compile information for the report. Look for answers to the following questions:
   a. What is AVO? What is its role and use in seismic interpretation?
   b. What are the assumptions for AVO prediction (plane waves, interface shape, frequency dependence)?
   c. What are the Zoeppritz equations and how they are related to the scattering-matrix approach (see Aki and Richards text)?
   d. How different is the ideal case of Zoeppritz AVO from real situations?
   e. What are the methods for synthetic waveform modeling (Aki and Richards, Chapter 9)
2) Write a Matlab script to predict and plot the plane-wave AVO:
   a. Use it for three provided sand reservoir models (water, oil, and gas sand encased in shale);
   b. Apply (in your Matlab script) a simple spherical-divergence correction (1/R, where R is the ray length). Compare the results.
3) Write a Matlab script (modify the one above) to model the dependence of recorded vertical displacement amplitude on the incidence angle (free-surface reflection; se Aki and Richards, Chapter 5)
   a. Apply the free-surface correction to the AVO results for the three reservoirs. Do the results change substantially?
4) Perform modeling of the same reservoirs using SIA version of *reflectivity* program. Modify and execute the provided SIA script.
   a. Pick the travel times of the reflections from the top of reservoir (you might need to export the data into SEGY and use Promax for this).

b. Pick the reflected amplitudes. Note that they, by virtue of *reflectivity* modeling, should include all effects and should represent the best approximation to reality.

c. Plot the resulting amplitudes using GMT (preferably) or Matlab. Compare them to the three you found from approximate modeling above.

5) Discuss the results. Answer the following questions (or raise other?):

   a. Are the differences significant (e.g., could they lead to confusing oil with water or gas?)

   b. Are the simple spherical-divergence and free-surface corrections you id in Matlab sufficient or we need to always use *reflectivity* or similar approaches?