Title
Frequency-domain visco-acoustic full waveform inversion of laboratory data

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reduced by lithostatic pressure. Thus, we expect low velocities near the surface, increasing with depth up to the values observed in the lab on intact samples, 5.5 - 5.7 km/sec. We use a one-dimensional inversion of P-waves to obtain an "expected" P-wave velocity (Vp) and attenuation (Qp) relation as a function of depth for The Geysers rocks. We then use a three-dimensional Vp and Qp inversion to find anomalous zones within the reservoir. We find portions with "high" Vp and Qp, high Vp and low Qp, and low Vp and low Qp. We interpret the regions with high Vp and Qp to be relatively less fractured, and the regions with low Vp and Qp to be significantly fractured. The high V and Q anomaly is centered on the zone of greatest pressure drop, and is mostly within the shallowest part of the felsite. The anomalous zones within the graywacke reservoir are on either side of the felsite, in areas of more moderate pressure depletion. More work is required to interpret the significance of these observations.

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Frequency-Domain Visco-Acoustic Full Waveform Inversion of Laboratory Data

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The quest to extract rock properties from seismic images has resulted in a growing interest in full-waveform inversion. This study investigates the performance of a frequency-domain full waveform visco-acoustic inversion for imaging velocity and attenuation using synthetic and laboratory data.

Although the frequency domain method is mathematically equivalent to the time-domain method, an efficient implementation can be achieved by performing a series of single-frequency inversions sweeping from a low to a high frequency. In the visco-acoustic inversion, the intrinsic attenuation is incorporated using a complex velocity. The velocity and quality factor (Q) can be imaged either simultaneously or consecutively. Our approach is a cascaded inversion in which the velocity is imaged using phase information first, then the Q-value is imaged using amplitude information.

This method is applied to laboratory data obtained in a water tank with suspended acrylic rods. Broadband 200 kHz data is obtained for a crosshole configuration with a two-axes computer-controlled scanning system and a piezofilm source and detector. The image produced by full waveform inversion has a higher resolution and more precisely defines the location of the acrylic bars compared to the result of the traveltime tomography. Current efforts to image Q are underway and will be reported at the conference.

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Feasibility Study for Monitoring Oil Recovery Using Full Waveform Acoustic Logs in Eastern Venezuela

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Feasibility study for monitoring fluid flow through a reservoir can serve as a tool to understand how changes in fluids saturation, pressures and/or temperatures during production phase alter the elastic parameters of reservoir rocks. Those changes may be detected via seismic records at several production time windows. Previous works on this area involve measuring well cores elastics properties in the lab, limiting the method where core data is available. In this study, full waveform acoustic logs have been used to compute elastic properties of reservoir rocks. The use of this kind of log produces a more abundant set of elastic parameters over a broader depth interval, which better represents real conditions of the reservoir. Those data along with the fluid flow simulation model, were used to construct maps for the elastic properties in saturated media, via Gassman relationships and Biot theory. The methodology has been applied to the Santa Barbara field located at eastern Venezuela. The Santa Barbara field is a gas and oil productive field. The results have been compared favorably to those obtained in a previous work using only well core data

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Improved Subsurface Imaging of Deep Seismic Data in Areas with Rugged Topography and Crooked-line Geometries

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Deep seismic reflection surveying in mountainous areas imposes serious restrictions and compromises on both data processing and acquisition. In addition to complex subsurface structure, rugged acquisition topography, crookedness of seismic lines and irregular distribution of shots often result in poor data quality. High-velocity rocks at the surface can cause shot and receiver coupling problems, and produce misalignments of seismic traces due to improperly-determined statics. Furthermore back-scattered energy from off-line surfaces can get trapped in weathered layers and generate unwanted coherent noise. We have investigated the applicability and limitations of conventional processing to deal with the problems related to acquisition geometries. We evaluated and modified the following options in data processing to improve the deep seismic image: (1) Simultaneous application of Kirchhoff trace mapping and local-datum corrections (wave-equation datuming or static time shift); (2) Kirchhoff imaging to account for the crookedness of shot and receiver lines; (3) Simultaneous application of 3D DMO trace mapping and cross-dip corrections; (4) Accurate estimation of refraction/reflection statics by turning-ray tomography and global-optimization method. The seismic datasets used for this case study are a 2D seismic profile acquired in Hidaka mountains on Hokkaido, northeast Japan, and a 2D seismic profile from the INDEPTH Project in the Himalayas. The result of imaging crustal structure of the Hidaka collision zone has revealed that the Kuril arc lithosphere is delaminated at about 23km deep in the lower crust. Also, we find that the above processing strategy significantly improved imaging of structure in the upper plate of the Himalayan megathrust.

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Improving the Cost Effectiveness of Crustal Reflection Seismology

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Anyone who has visited a Vibroseis crew recording a seismic reflection profile realizes that the vibrators are only vibrating about half the time. This is because a typical program calls for eight sweeps each of 25 to 30s each followed by a listening period of 25 to 30s. Including startup time, the crew spends at least eight minutes on each vibrator point. Considering that seismic crews base their charges on the time it takes to collect the data, a typical charge being $20,000/day, efficiency is a big issue especially on research budgets. Thus, if the amount of time spent on each vibrator point could be reduced by 45% to 50%, without compromising the quality of data, then the cost of collecting crustal reflection data would be reduced by a similar amount or a survey that was thought to be too expensive could be within reach financially.

There are a number of possible ways to reduce the time spent at each vibrator point these include: using modified slip-sweep techniques, using long linear sweeps, or long pseudorandom transmissions. The slip-sweep technique uses multiple vibrator groups in which each vibrator group starts its sweep after the listening period of the previous group. In an exploration mode this requires three or four groups of vibrators, however in a crustal seismic mode this would require only one vibrator group because listening periods are about the same length as the vibrator sweep. In the crustal mode, vibrators would start each sweep immediately after the previous sweep and the listening period would occur at the end of a set of sweeps, while the vibrators are moving to the next point. If eight sweeps are being used, this will eliminate the listening periods of seven of the eight sweeps, a 45% reduction in the time spent on each vibrator point. With the use of long linear sweeps the need to restart the vibrators multiple times at the same vibrator point is eliminated, reducing the time and complexity of generating multiple sweeps. If the vibrator signal is changed from a linear sweep to a pseudorandom signal, the correlated signal becomes a simple sinc function rather than the Klauder wavelet associated with linear sweeps. This reduces side lobes and increases signal-to-noise ratios, possibly further reducing the time needed at each vibrator point. Readily availble technology makes it possible to try the slip-sweep approach, and vibrator controllers for long sweeps exist but are not commonly employed.

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Seismic Imaging Below Basalt

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Sub-basalt seismic images are often of very poor quality. Frequently a bright top basalt is observed with little or no coherent imagery below it. Traditionally it has been assumed that the high impedance of basalt was the primary cause of this poor imagery. Here we show that basalt heterogeneity plays a lead role. Using statistical information from borehole logs and digital imagery of exposed basalts we built highly heterogeneous basalt models. Finite difference wave simulations in these models reveal that, although there is significant transmission through the basalts, wave scattering obscures the sub-basalt image.

We investigate the relative importance of interface and body scattering for basalt of various thicknesses. For 'thick' basalts body scattering is important and velocity control in migration is critical. For 'thin' basalts interface scattering dominates. For the latter case we present a wave equation datuming technique which significantly improves sub-basalt image quality on both synthetic and real seismic data.

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New VSP to 8.5 km Depth at the KTB Super-deep Drillhole - Seismic In Situ Investigation of Deformed Crystalline Crust

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The deepest part of the superdeep borehole of the Continental Deep Drilling Program (KTB), Germany, from 6000 m to 8500 m, has been sampled for the first time by Vertical Seismic Profiling. The VSPs show P-, S- and PS-converted waves. We observed S-wave splitting over the whole depth range. The azimuth of the polarization of the faster S-wave correlates with the azimuth of rock foliation. The velocity-depth profiles are of high spatial resolution due to the narrow geophone spacing of only 12.5 m. High accuracy was achieved by using a reference geophone at 3.8 km depth in the KTB pilot hole. Amphibolite units show an average P-wave velocity of 6500 m/s with 10% variation caused by composition, fractures and anisotropy. In a Gneiss sequence at 8.5 km depth low velocity of only 5500 m/s is observed correlating with changes in the relative orientation of foliation and fractures. To quantify the effect of intrinsic anisotropy and fractures, reference velocities were computed based on laboratory measurements and on the depth function of mineral composition. By analysing the differences between real and simulated velocity depth profiles we could determine that the maximum P-wave anisotropy of the amphibolite rock matrix in situ is about 9%. Also, we could