Tri-axial well seismic acquisition: Its application for VSP data enhancement with particular references to case histories

Andrew James and Leslie Nutt

Seismic profiling with shear waves can provide much of the same information as P-wave surveys, with a few useful bonuses thrown in, due to the special properties of shear propagation.

First of all, shear propagation through a porous medium depends mainly upon the structure and lithology of the rock matrix, and is thus relatively unaffected by the nature of the fluid in the pores. Claims are also made that the resolution obtainable with S-waves is sharper than with P-waves because the wavelength is shorter at a given frequency. (However, it seems likely that any advantage may be negated by the greater attenuation of shear waves.)

A major problem impeding the development of shear seismic is the poor time–depth correlation of shear waves. Practical experience shows that it is difficult to correlate S-wave reflectors to P-wave reflectors especially if there are a lot of multiples. One solution to these problems is the development of multi-axis downhole geophone to record and analyse the horizontally polarised shear waves in a VSP regime.

The multi-axis downhole geophone, however, has applications that are more extensive than the acquisition and analysis of S versus P data.

In order to review these applications in more detail let us consider the example of a vertical well with a large source offset (Fig. 1). We will define our co-ordinate system as Z, X, Y where X is the plane of locking arm and tool body and Y is orthogonal to X (that is, coming out of the page).

Let us now consider a spatial array of geophone stations within the well-bore (or 'levels') and follow through the example.

The method works level by level, the main idea being to determine, at each level, an orthogonal three-component reference frame to which the initial data will be referenced, in order to enhance separation of the different kinds of waves: P, SV or SH.

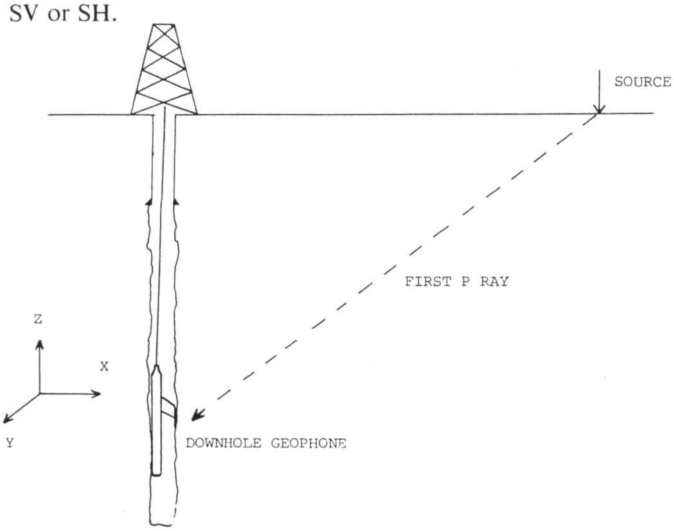


Fig 1 Coordinate system for tri-axial model.

The fundamental goal is to detect upgoing P-waves and upgoing S-waves and to prepare the three component data for the classical one-component offset VSP.

The main steps are two separate axes-rotation in the three-dimensional space:

(1) The first one is performed in the horizontal (X, Y) plane, and aims to compensate for the random tool rotation from level to level. It transforms (X, Y) into (HMX, HMN), where HMX is intended to maximize the horizontal first-arriving energy (P-wave normally), and HMN minimize this energy.

(2) HMX is in the source-well plane and we assume represents in-plane movement.

(3) HMN, under the same hypothesis, is the out-of-plane movement in the direction orthogonal to the source-well plane. In horizontally stratified media, it corresponds to the so-called SH-wave and uncouples from the P and SV in-plane movement.

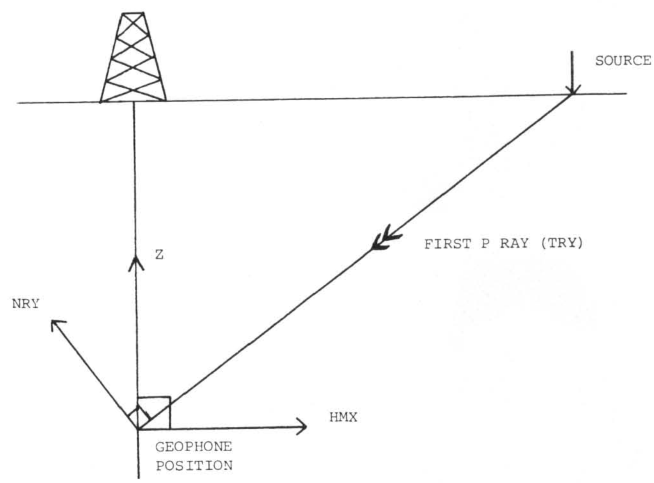


Fig 2 Rotation in the (Z-HMX) vertical plane.

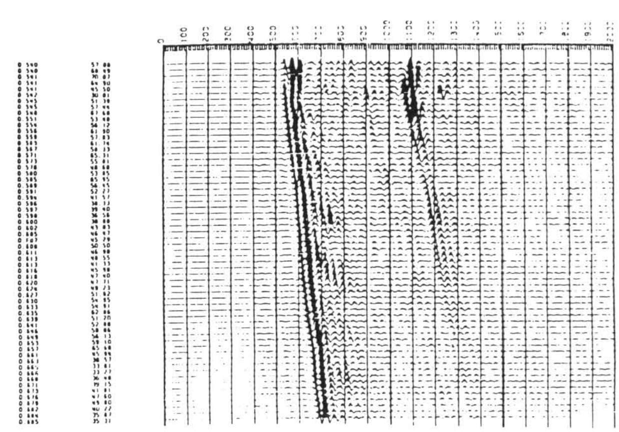


Fig 3 Z stacked data.

(4) The second rotation is performed in the vertical (HMX, Z) plane and aims to enhance separation of P and SV waves. It transforms (HMX, Z) into (TRY, NRY), so that:

(5) TRY enhances 'first Downgoing' P-energy, and, depending on model parameters, Upgoing SV-energy.

(6) NRY enhances Downgoing SV-energy, and, depending on model parameters, Upgoing P-energy (Fig. 2).

Both of these axes-rotations are performed by the holograph technique of defining maximum energy azimuth through vector analysis for wavefields. Velocity filtering of TRY and NRY then yields enhanced Upgoing P, Downgoing P, Upgoing SV and Downgoing SV data sets. This classification is not of course a rigorous separation but just a practical way to enhance such events.

An example of this enhancement is shown in Figs 3 and 4. Figure 3 is the raw Z axis data. Figure 4 is the same data after the projections described previously. Two points should be noted; firstly the fidelity of the data immediately following the first break is increased, and secondly the shear wave corruption evident at 1100–1300 ms in the Z data set has been removed.

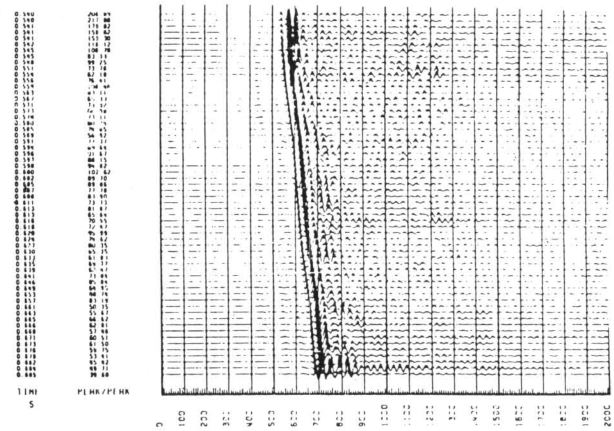
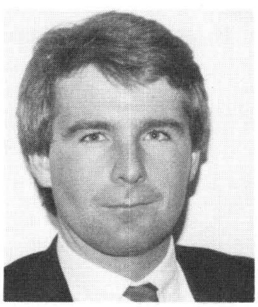
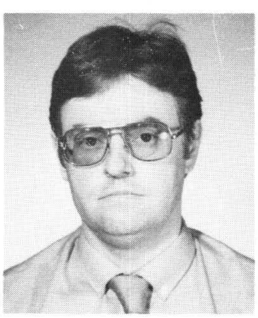


Fig 4 TRX: Component along the first ray.



Andrew James graduated in 1978 with a BSc(hons) in physics with geophysics at the University of Birmingham, England. Upon graduation he joined Schlumberger Overseas SA in Paris and since then has completed assignments in Indonesia, India, Burma and Australia. During the 1983/84 academic year he returned to study postgraduate courses in Geophysical Engineering at the Colorado School of Mines, USA. He is currently Geophysicist with Schlumberger Seaco Inc. in Perth. James lectures graduate classes part time at the West Australian Institute of Technology and is a member of SEG, ASEG, SPWLA and SPE.

A. James, Schlumberger, PO Box 7098, Cloisters, Perth, WA 8000.



Les Nutt received his BSc in pure and applied physics in 1976 and his PhD in physics in 1979 from Queens University, Belfast. From 1979 to 1981 he worked as a geophysicist with GSI in England and Saudi Arabia. He then joined Schlumberger and is currently Unit Geophysicist for Indonesia and Australia based in Jakarta. Main areas of interest are borehole seismic and the integration of borehole and surface seismic data, three component VSP recording and analysis.

L. Nutt, Schlumberger, PO Box 7098, Cloisters, Perth, WA 8000.