Chapter 21
The Effects of Geometry on the P-Wave Seismic Response of Massive Mineral Deposits:
Results From Analogue Modelling

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ABSTRACT

Results from analogue seismic modelling aimed to investigate the effect that the geometry of a mineral deposit imposes on its seismic response are presented. 3D Seismic data were acquired on two physical models representing the possible end-member geometries of mineral deposits. The physical modelling involved acquisition of 3D pre-stack data on scale models. The results for the ellipsoidal model comprised closed, continuous, circular diffraction patterns in time slices. For the cylindrical model, the quality of the stack was degraded by the scattering caused by the rugged surface. The diffraction patterns were discontinuous and comprised the diagnostic concentric, circular amplitude peaks and troughs which would allow identification of drill targets in field data. The results show that 3D seismic data are valuable in mineral exploration because they provide (1) enhanced spatial resolution, and (2) slices of time help to identify the seismic response of small seismic targets with complex geometry.

INTRODUCTION

Synthetic seismic models and reflection coefficient analysis based on physical rock properties suggest that massive mineral deposits hosted by hard rocks should cause strong P-wave anomalies because they have high acoustic impedances (Salisbury et al., 1996; Harvey, 1997; Laletsang, 2001). Despite these high acoustic impedances, however, they cause only weak seismic responses in field data (Salisbury et al., 1996). This occurs partly because they are small compared with the wavelengths used in conventional

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seismic surveys and also because of their complex geometries. Analysis of density-driven acoustic impedances using plane wave solutions show that mineral deposits cause strong P-wave but weak S-wave responses near normal incidence in seismic data (Laletsang, 2001). Hence, the results discussed here are restricted to P-waves responses only.

We present results from analogue seismic modelling aimed to investigate the effect that the geometry of a mineral deposit imposes on its seismic response. Seismic data acquired on two physical models representing the possible end-member geometries of mineral deposits are described. The first model is ellipsoidal with a smooth surface, while the second is roughly cylindrical with a rugged surface relief and a complex structure. They were scaled such that the seismic resolution is preserved (Hubbert, 1937). The physical modelling involved acquisition of 3D prestack data on scale models in a water tank, which were processed using CMP-based methods and migrated post-stack with the F-K time migration technique.

The propagation of seismic waves in scale models is identical to that in the actual features because the equations of motion are valid in both situations (Ebrom and McDonald, 1994; White, 1965; Ivakin, 1966). Physical modelling avails an unique opportunity to examine the 3-D seismic response of a complex feature incrementally by adjusting the model complexity (O'Brien and Symes, 1971), hence the choice of the geometries of the models. Breaking a seismic response into simpler components allows better insight into a complex imaging problem. Seismic modelling may also be used to evaluate data acquisition and processing parameters because the parameters can be adjusted inexpensively on a scale model.

We made the models from epoxy resin and measured their physical properties as follows. Cores 2.5 cm wide were cut into pieces, weighed, and their volumes measured by displacement in water. The P-wave velocity of the resin was measured using the pulse transmission method (Birch, 1960a; Harvey, 1997). The physical properties were calculated from the measurements using linear regression, and are, respectively, 1.20 ± 0.01 g/cm^3 and 2.55 ± 0.04 mm/μs (2550 ± 40 m/s).

The modelling apparatus comprised a signal source and receiver, transformer, anti-alias filter, amplifier, 12-bit A/D converter, and a 1.44 m^3 water tank. The source and receiver were commercial P-wave piezo-electric transducers (PZT) mounted to move vertically and horizontally independent of one another to allow the capture of offset 3D shot gathers.

PHYSICAL MODELS

Ellipsoidal Model

An ellipsoidal surface is difficult to map with reflection seismic profiling because it scatters seismic waves at wide angles from the source to an extent dependant on its flattening (Adam et al., 1998). Eaton (1999) has shown that small spherical bodies produce no energy in the normal incidence aperture (0-20°), suggesting that small spherical mineral deposits may not be detected with surface reflection seismic. The ellipsoidal model has a flattening of ½, and is expected to cause a strong amplitude response in the normal incidence aperture.

We use this model to investigate the reflection response of an ellipsoidal volume on the seismic response. The model measures 13 by 24 wavelengths and was located at a scaled depth equivalent to 64 wavelengths in the water tank ($\lambda = 12.5$ m), where it was 1.2 by 2.1 Fresnel zone widths. Nevertheless, its seismic response is expected to consist entirely of diffractions because of the strong surface curvature.