Abstract

Before embarking on any mining operation, it is advantageous to locate the subsurface orebody in three-dimensions with a high resolution (~1m) ahead of actual mining, because this will increase productivity and efficiency. Borehole radar is such an emerging mapping tool in the mining industry, that can be used to image the subsurface orebody with high resolution.

3-D subsurface imaging using two-dimensional aperture synthesis requires many boreholes and is thus not economically feasible in underground orebody imaging. Therefore, the main objective of this thesis is to develop 3-D imaging techniques, using a limited number of boreholes.

An interferometric synthetic aperture radar (InSAR) is a well established space-borne/air-borne technique for mapping the Earth's surface. A borehole InSAR simulation study was thus carried out, using a sidelooking antenna configuration to image the subsurface orebodies, such as potholes and cylindrical Kimberlite structures, in 3-D. A performance analysis of an interferometric experiment is presented.

In general, borehole radars are a wide-band system, often having bandwidths of 75% of the centre frequency. A 3-D image reconstruction technique was developed by means of correlation-type processing, using magnitude images of multiple boreholes coming from different view angles, which is more suitable for wide-band/ultra wide-band borehole radar signals. The technique was tested by using simulated multiple borehole radar magnitude images, as well as real acoustic images that had been captured in air and water media. The 3-D reconstructed grid spacing derivations are presented for a borehole trajectory fanning outward from the borehole centre. In this thesis, a 40kHz air-based sonar system was used in the laboratory environment to emulate inverse synthetic aperture radar (ISAR) data in the context of a real borehole experiment. A deconvolution processing approach was adopted to range-compress the 40kHz sonar data captured in air. A time domain focusing technique was used to focus the simulated borehole radar as well as the real acoustic data.

In the case of homogeneous, isotropic and non-dispersive media, a straight-line wave propagation is considered to process the data in range and azimuth. In a real borehole environment, however, an accurate electromagnetic (EM) wave propagation model is essential. For the purpose of modelling borehole EM propagation in a conductive medium, 3-D finite difference time domain (FDTD) code was written and implemented in a Cartesian coordinate system by using a uniaxial perfectly matched layer boundary wave absorber. The accuracy of the implemented code was first tested against published results. Thereafter, the code was used to simulate the EM responses from various geological settings, such as cross-well borehole EM wave propagation in a sedimentary layer, reflection from a geological reverse fault, and reflection from a pothole-type orebody structure. Different kinds of imaging modes have been used in the FDTD simulation experiment, such as common offsets, common source and transillumination mode. The radar traces, both transmitted as well as reflected, are affected by the size of the borehole and the electrical properties of borehole mud. It was found that the electrical properties of the borehole mud affect the radar traces more significantly than the size of the borehole. The effect of host rock conductivity on radar traces has also been investigated.

To ensure the accuracy and stability of the FDTD method, the discrete step size of the simulation needs to be set to less than $\frac{1}{10}$th of the minimum significant wavelength. Therefore, for realistic 3-D simulations, there is a requirement for large matrices to be allocated and processed, which easily exceed the limits of a standard desktop PC in terms of memory and speed. In order to overcome these limitations, a parallel version of the 3-D FDTD C code has been implemented using Parallel Virtual Machine (PVM) as *middleware* running on a *Beowulf-type* Linux cluster. A speed up of 2.7 was achieved, which corresponds to a 90% efficiency, where a speed of 3 for three slave processors is considered to be 100% efficient.

The signal processing techniques investigated in this thesis have been verified on simulated borehole radar data, as well as on real sonar data. These techniques can therefore also be applied to real borehole data, in order to construct 3-D images of subsurface orebodies.