Thesis

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High strain rate properties of geological materials

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The dynamic response of various geological materials has been investigated through a series of plate impact experiments. The materials involved were supplied from various mines by De Beers and Rio Tinto and were generically termed: sandstone, scilied siltstone, kimberlite, quartz/feldspathic gneiss, biotite schist, amphibolite, amphibolitic gneiss, basalt and iron ore. Investigations into compressional, shear and tensional behaviour were carried out.

This project was part of a larger international study to develop models for the explosive loading of rock in a mining environment. This model is known as the Hybrid Stress Blasting Model, or HSBM. For this model to be accurate and relevant to the mining process it is essential to have dynamic data on the various rock types concerned. This was the purpose of the current project.

The materials were initially characterised statically both through the measurement of density (utilising a volume method) and sound speeds (using a time of flight method with ultrasonic transducers) and also through the use of mineral analysis equipment at the University of Nottingham (this work was carried out by Dr S. Plint). The materials were found to have a wide range of properties, with a density range of 1.93 - 4.46 g cm^-3 and a range of longitudinal sound speeds of 1.97 - 6.86 km s^-1. Two of the materials were found to be porous, the iron ore and the sandstone. A large number of mineral phases was identified within the specimens.

Dynamic investigations into material properties were carried out at the Cambridge Plate Impact Facility at the Cavendish Laboratory. This facility consists of a well instrumented 50 mm bore single stage light gas gun. The facility has been operating for a number of years and has previously been shown to be suitable for investigations such as the ones presented. The main diagnostic equipment used in the experimental series were commercial manganin stress gauges and a laser interferometer (or VISAR) system. Both of these diagnostics are widely used in the shock physics eld and are reliable in the data they provide. In the region of 120 separate plate impact experiments were performed for this thesis. The use of the facility involves many sophisticated techniques, and the author underwent a signicant training period in order to learn their correct and safe use. The data analysis is also complex and the author made signicant advances with this analysis.

The compressional response of all of the materials was measured. The porous materials demonstrated behaviour dominated by their compaction, with a curved Hugoniot relation for sandstone, and an obvious Hugoniot elastic limit (HEL) at around 3 GPa in the iron ore longitudinal data. Additionally, while not exhibiting porosity, the biotite schist also had a curved Hugoniot. It is postulated that this is due to the presence of clay in the material, something that was shown to be the case in the mineral analysis. The other materials all showed a linear Hugoniot relationship when the data are in sigma - up space. Additional experiments conrmed that this linear relationship implied that the shock velocity did not change signicantly over the pressure regime studied. As well as the compressional response, the unloading behaviour of a number of the materials was also investigated. It was found that in all loading/unloading cycles there was some irretrievable energy loss. In a number of the materials it appears that the energy lost on loading increases with pressure, as more damage is done to the material. The opposite trend was observed in the biotite schist. Basalt consistently showed a higher percentage of energy lost than the other materials, with the exception of sandstone, where substantial energy loss associated with the collapse of pores occurred.

Shear strength and lateral stress were measured using stress gauges for amphibolite, iron ore, sandstone, quartz/feldspathic gneiss, kimberlite, siltstone and basalt. With the exception of sandstone and biotite schist, all of the materials were found to have an obvious HEL. These ranged in value from 1.3 GPa (gneiss) to 5 GPa (siltstone). This HEL was not obvious in many cases from the longitudinal data as it would be in many other materials. It is speculated that the nature of nonelastic deformation in rocks, namely brittle cracking would possibly account for this observation.

Attempts were made to investigate the dynamic tensile properties of a number of the materials, however this was only successful for kimberlite (21 ± 4 MPa), siltstone (55 6 MPa) and biotite schist (one experiment giving 26 MPa). The polycrystalline and inhomogeneous nature of rocks means that fracture is unlikely to occur in the well dened planes that are required for successful plate impact tensile failure experiments. This means that a statistical approach is necessary to determine a spall strength, and a signicant number of unsuccessful shots should be expected.

As the material data are destined for use in a computer modelling programme it was essential to attempt to develop prediction methodologies to avoid the need for expensive dynamic characterisation of any new materials encountered in the mining environment. Much of the static data provided with the materials from De Beers proved of little use in predicting behaviour, although crucially it was not possible to determine sucient dynamic tensile strengths in this investigation to make comparisons with the De Beers data. More success was found in predicting the slope of the Hugoniot with the elastic impedance of the material (for the non-porous linear Hugoniot materials). A fairly strong trend was found, which was backed up with data from the literature. Additionally some eort at further analysis using mineral data was undertaken. Attempts at predicting the HEL were also partially successful. While no specic quantitative prediction method was found, it was noted that the HEL did seem to scale with grain size, in that the large grained materials had a lower value of the HEL (below 2 GPa) compared with the ner grained materials (around 4 GPa and above).