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Characterization of strain-burst rock fragments under a scanning electron microscope – An illustrative study

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ABSTRACT

Fractures around excavations in hard, fine-grained, brittle rock sometimes display unique patterns from which an interpretation of the manner of failure/fracture propagation can be made. Igneous rock fragments from a strain-burst event at a site in Western Australia have been studied under a Scanning Electron Microscope (SEM) in order to characterize their surficial features. SEM image analysis indicates that anisotropy, a contrast in geomechanical properties, geometry and contact patterns present at the micro-scale as they do at the large mine/drive scale. It is proposed that these micro-scale features can lead to anisotropic material behaviour and stress concentrations that manifest as strain-burst events.

1. Introduction

The term 'strain-burst' is used to represent cases in which brittle failure in rock occurs violently and usually involves the creation of new fractures (Keneti and Sainsbury, 2018a). Progressive development of cracks resulting in brittle failure is mainly controlled by the micro-structural and mineralogical properties such as composition, grain size and shape. Hence, an intrinsic interpretation of rock failure mechanism requires study of the grain-scale structures governing the macro-scale response such as strength, deformability and failure pattern (Nicksiar and Martin, 2014; Zhang and Wong, 2018).

Strain-bursting has previously been characterized by events with a Richter Magnitude between −0.2 and 0.0 M_L (Ortlepp, 2005) and is known to occur at low confinement levels (σ_3 = 0 to 5 MPa), and when the maximum principal stress magnitude (σ_1) exceeds the peak rock mass strength envelope (Martin et al., 1999). A strain-burst event (along with any other type of seismic source underground) is only possible when there is stored energy in the rock mass that can be dissipated when a change to the in situ conditions (geometrical and/or stress related) occurs. Mineral composition, grain size, grade of metamorphism and tectonic history all play a role in determining the characteristics of the rock mass and the stored energy (Mitri et al., 1999).

In general, the problem of mine seismicity is stochastic, due to the variability in distribution of geological structures and heterogeneous nature of rock masses (Board, 1994). Strain-bursting is more likely to occur in massive rocks than in significantly jointed and fractured rock masses (Aubertin et al., 1994). As illustrated in Fig. 1, under the same in situ stress conditions, two adjacent lithological units present different behaviours in terms of storing strain energy that is observed through the resulting fracture network that has been generated. The sketch of the fractures depicted from the highlighted area of this figure shows that the dark dolerite has a higher fracture density and majority of the fractures terminate at the contact between the dolerite and massive host rock. These behavioural differences are considered to be a direct result of a significant contrast in geomechanical properties such as stiffness (Bewick et al., 2017; Keneti and Sainsbury, 2018a). As a result of this contrast in behaviour, knowledge of the mineralogical properties is an important requirement for the determination of strain-burst proneness.

To facilitate the study and analysis of the complex processes involved in bursting ground, in the book 'Rock fracture and rockbursts: an illustrative study', Ortlepp (1997) outlined details of the observed damage caused by an event. However, the study was confined to visual observations at a large scale, since photographs and thin section samples prepared were lost before an analysis could be undertaken. From the foreword to this book, Stacey proposed the "*Readers of this remarkable book compare the case studies with their own observations; … and to promote or actually undertake similar studies or research*".

Since this initial publication, complementary research associated with investigating the micro-scale features of rock-burst surfaces has not been conducted. The research contained herein, assists with complementing the micro-mechanical investigation along with providing

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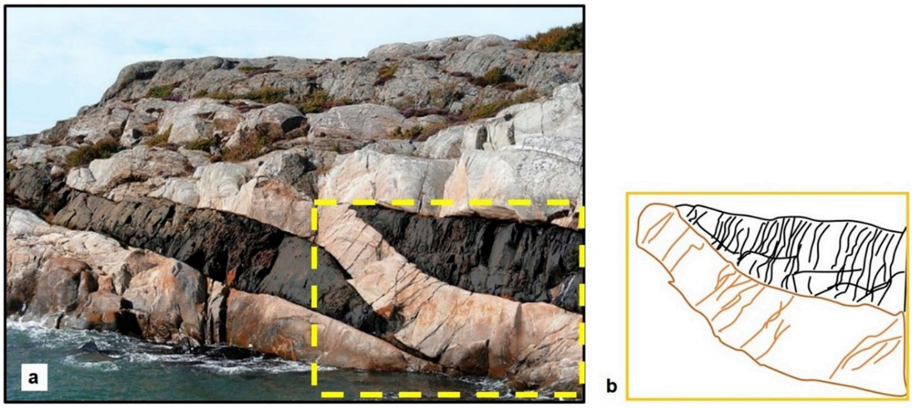

Fig. 1. Branches of dark-coloured dolerite dykes in the Koster Islands, Sweden (retrieved from http://www.geologyin.com on 20/04/2018): a) A rock mass demonstrating domains with contrasting stiffness, b) sketch of fracture density of the highlighted area where fracture initiation and propagation have been affected by the contrasting material and their contact.

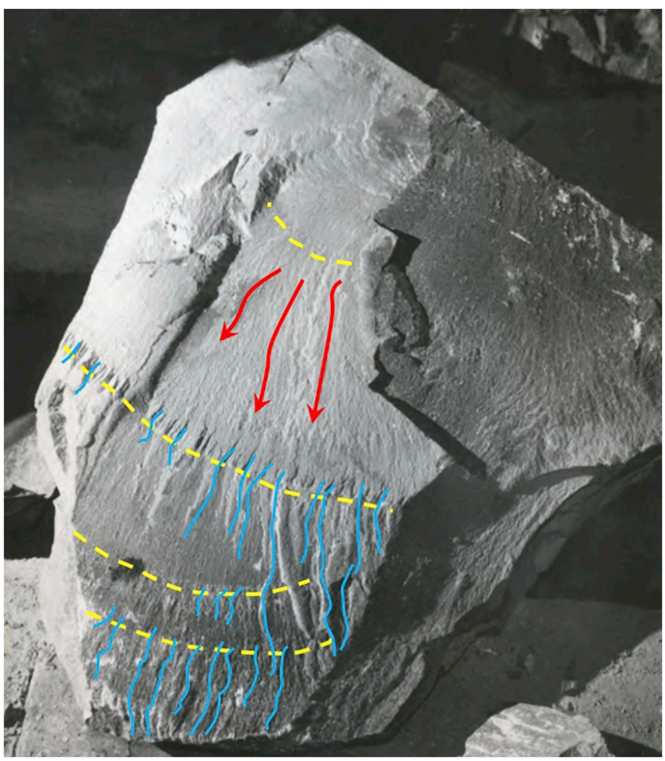

Fig. 2. Mirror zones (yellow arcs) and hackle zones (blue branches perpendicular to the mirror zones) on a large block ejected during a strain-burst event. The red arrows suggests the potential direction of fracture propagation (after Ortlepp, 1997). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

detailed information to assist with the validation of numerical simulations of strain-burst events.

2. Strain-burst fracture mechanics

The fracture process in rock commences at the tip of an existing crack, further growing in the direction of the maximum principal stress. When stress increases slowly, these fractures develop in a stable manner - detected by extreme slenderness of the slabs. Strain-bursting occurs when tangential stress builds up in the immediate skin of the excavation and the rock mass surrounding the fracture creates a relatively ‘soft’ loading environment such that the rock fails locally in an unstable manner (Kaiser and Cai, 2012). This unstable fracture propagation results in violent exfoliation or spalling of the surface which is termed strain-bursting (Ortlepp and Stacey, 1994).

Engelder (1987) has previously characterized a strain-burst failure

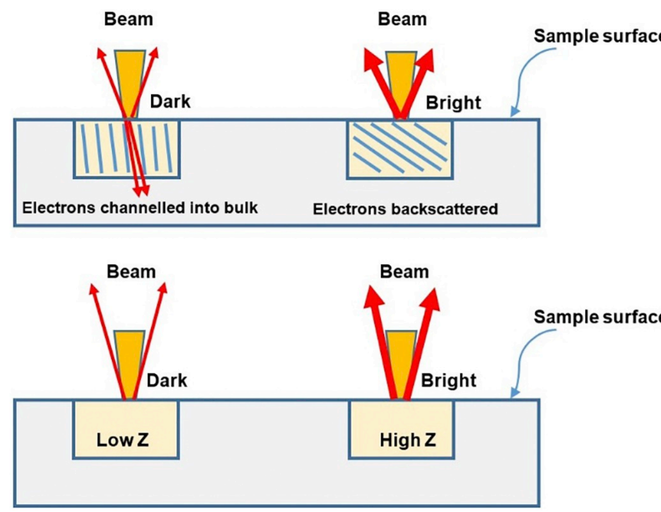

Fig. 3. Dependency of backscattered electrons contrast formation to the material crystallography (top) and composition (bottom).

surface by a ‘mirror zone’ and a ‘hackle zone’: the mirror zone is defined as a flat surface adjacent to the rupture origin. In this zone, the slow but accelerating crack tip reaches a critical velocity beyond which bifurcation occurs forming the hackle zone. The transition from a single crack propagating at the critical velocity to the numerous smaller fractures of a hackle zone ideally occurs along a circular arc as shown in Fig. 2.

3. Investigation of strain-burst fragments

Scanning Electron Microscope (SEM) is a technique used to observe features from the micron-scale to the nano-scale range. A SEM machine uses a focused beam of electrons, scanned over the surface of a sample to reconstruct a magnified image of the sample exposure. Additionally, Electron Backscattered Diffraction (EBSD) can be available within a SEM, allowing phase and orientation related information to be revealed.

In EBSD imaging mode, the backscattering coefficient (i.e. contrast formation) depends on the atomic number (Z) of the sample as well as the orientation of crystallographic (lattice) planes within the material - as presented in Fig. 3. Through this technique, electrons are ‘channelled’ into a material if the beam is close to a major zone axis (dark contrast). Away from this zone, the backscattering coefficient will be higher (bright contrast). Heavy (high atomic number) elements backscatter more strongly than lighter elements, i.e. high atomic number regions are brighter and low atomic number regions are darker.

Fig. 4 presents a 6 mm × 8 mm wide and 3 mm igneous rock