The Petrographic and Geotechnical Properties of a Dolerite Intrusion in the Assessment of Its Blasting Performance at the Magdalena Colliery, Dundee, South Africa

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Abstract

The presence of dolerite intrusions in underground collieries often causes damage to mining equipment, delays in mining schedules and loss in production. This is often exacerbated by inadequate pull from the blasting operations along the intrusion. Thus, the proficient removal of dolerite intrusions through efficient blasting techniques play a vital role in the economic output of a colliery. This study is focused on one such intrusion within the Magdalena Colliery, wherein a 13.88 m dolerite dyke resulted in the replacement and displacement of the Alfred seam. Selected sampling was conducted along the length of the intrusion in order to determine the petrographic and geotechnical properties influencing the blasting performance of the dyke. A detailed petrographic analysis was done by analyzing thin sections of the dolerite in order to identify the major minerals present. X-ray diffraction (XRD) analysis was also conducted to determine the percentage composition of minerals along the intrusion. Geotechnical tests were also conducted in order to assess the technical properties of the dolerite. The geotechnical tests conducted included point load test, sound velocity test, uniaxial compressive strength test and Brazilian disc strength test. The study conducted demonstrates that a strong correlation exists between the blasting performance and geotechnical and petrographic properties of the dyke.

Keywords

Alfred seam • Blasting • Dolerite intrusion • Pull

1 Introduction

South Africa is one of the largest coal producers in the world, where coal mining has been going on a commercial basis since 1857. Whilst in-roads are being made into clean energy, coal remains the primary energy source in South Africa for domestic power generation, and is set to dominate energy demands for the foreseeable future (Hancox and Götz 2014). Buffalo Coal currently operates two collieries in Dundee, South Africa; the Magdalena Colliery and the Aviemore Colliery, which are hosted within the Klip River coalfield. The Aviemore Colliery extracts high-grade anthracite coal while the Magdalena Colliery extracts high-grade bituminous coal (Muller et al. 2013). The focus of this study was the Magdalena Colliery, which has been mining bituminous coal since 2005.

Two coal seams, which are referred to as the Alfred seam and the Gus seam of the Vryheid Formation, are currently being mined at the Magdalena Colliery. Mining is by the bord and pillar method, also referred to as the room and pillar method, whereby a continuous miner is used to extract bituminous coal from the Alfred seam and the Gus seam. The bord and pillar mining method involves the extraction of coal from relatively flat-lying deposits, whereby the excavation is carried out to produce a network of rooms between pillars of coal that are left behind to support the overlying strata (Brady and Brown 2006; Esterhuizen et al. 2013; Clemente et al. 2013). The rooms that are produced as a result of excavation of the coal seams act as access openings, haul roads, and ventilation paths.

It is well known that igneous intrusions, mostly dolerite dykes and sills, are ubiquitous within the coal bearing formation (Roberts 1987). These intrusions within the coal, result in damage to mining equipment and significant loss in production. This study is focused on one such occurrence within Panel 417, Section 1 of the Magdalena Colliery, wherein a dolerite intrusion spanning a length of 13.88 m was encountered, resulting in both replacement and

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displacement of the coal seam. This caused a significant delay in the mining schedule and was exacerbated by inadequate pull from the blasting operations along the intrusion. The proficient removal of dolerite intrusions through efficient blasting techniques thus play a vital role in the economic output of the colliery.

The main aim of this study was to assess the influence of the petrographic and geotechnical properties of the dolerite on its blasting performance. A detailed petrographic analysis of the intrusion was conducted in order to determine the primary minerals present as well as the nature of minerals present. X-ray diffraction (XRD) analysis was also conducted to determine the percentage composition of minerals along the intrusion. Laboratory tests were conducted on selected samples obtained along the intrusion in order to determine the geotechnical properties along the course of the dolerite intrusion. The geotechnical properties determined were the density, porosity, point load strength, uniaxial compressive strength and Brazilian disc test. Assessment of the blasting advance was done using a laser distometer.

2 Location of the Study Area

The study area is located within the Magdalena Colliery, which is approximately 22 km north of the central town of Dundee, in the KwaZulu-Natal Province (27° 58′ 24″ S and 30° 11′ 51″ E), South Africa (Fig. 1). The towns of Hattingspruit, Normandien, and Fort Mistake lie to the south, west-southwest, and southwest respectively of the Magdalena Colliery.

3 Geology of the Study Area

The study area lies within the Vryheid Formation of the Ecca Group, a subdivision of the Karoo Supergroup, which is of Carboniferous age (320–180 Ma) (Johnson et al. 1997). The Vryheid Formation comprises feldspathic sandstone, grey micaceous shale, and mudstone (Fig. 2) (Muller et al. 2013). The Vryheid Formation contains five coal seams that persist throughout the Formation (Venter 1994). The coal seams currently located at the collieries belong to the Klip River coalfield. These represent the two most economically minable seams, the upper Alfred seam and the lower Gus seam (Muller et al. 2013). The Alfred seam is more developed than the Gus seam, as it ranges in thickness from 1.5 m in the south to 3.3 m in the north, whereas the less developed Gus seam ranges in thickness from 0.5 m in the south to 2 m in the north (Muller et al. 2013).

It is well known that mostly dolerite dykes and sills of Jurassic to early Cretaceous age, are ubiquitous within the early Permian Vryheid Formation (Roberts 1987). In South Africa, difficulties with intrusions in coal were recognized as early as 1899 and approximately 90% of the Natal coalfields are affected by intrusions (Heslop 1924). Blignaut (1952) estimated that 40% of KwaZulu-Natal's coal has been destroyed in this manner, and concluded that the limiting factor in the life of every colliery is the presence of intrusions.

A series of dolerite intrusions is present in the Magdalena area, represented by the Ingogo dolerite sill as well as a network of widely spaced dolerite dykes, (Clemente et al. 2013; Muller et al. 2013). The Ingogo dolerite sill extends

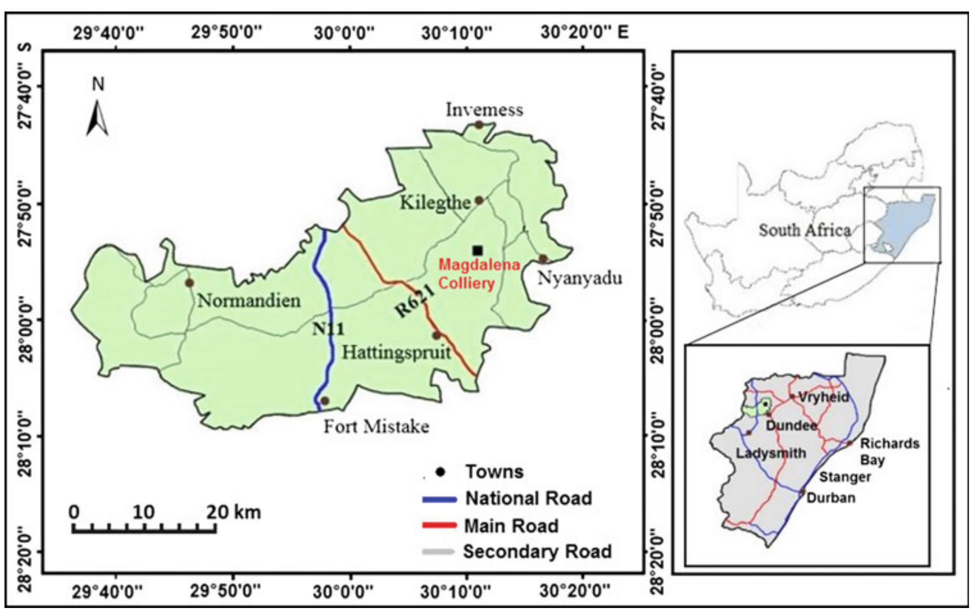

Fig. 1 Location map of Magdalena Colliery

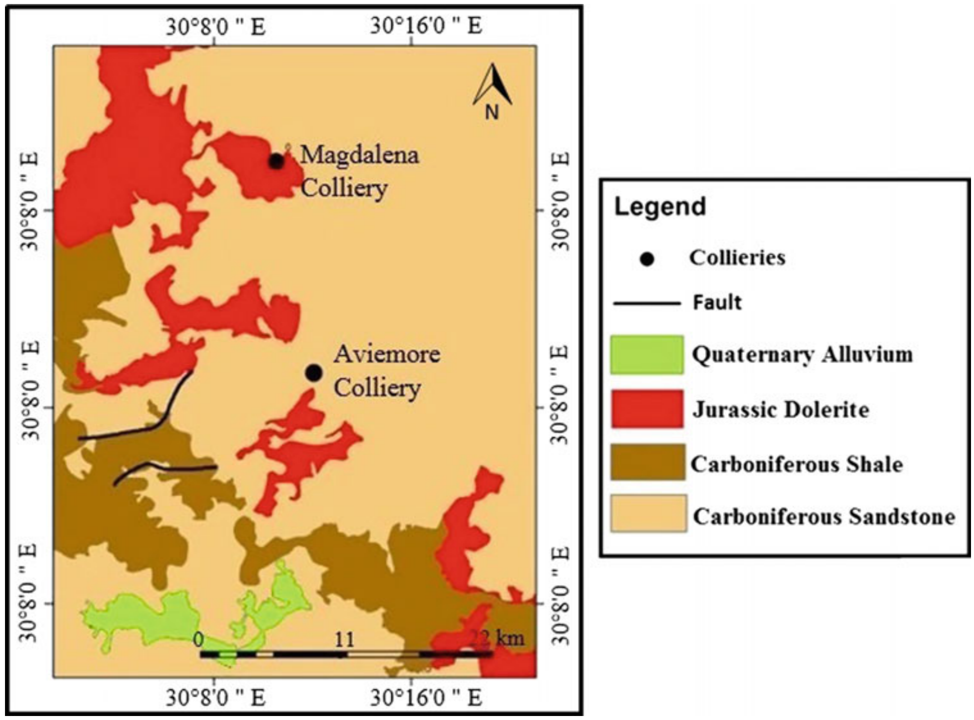

Fig. 2 Local geology of the Magdalena colliery (modified after Council for Geoscience 1997)

over a large area, with a transgressive spilt from the base of the sill. In certain regions of the area, the sill has been removed by erosion. Within the eastern region of the Magdalena area, a phenomenal change in the sill's characteristics is observed, where the sill transgresses into a dyke, cross-cutting the lithology and then returns to its sill-like habit, lying concordantly with the lithology. This change in placement relative to the coal seams has caused a displacement in the seams pushing the seams by a distance equal to the thickness of the sill. As a result of exposure, the coal seams in this region have been eroded away (Clemente et al. 2013).

Within Section 1, Panel 417 at the Magdalena Colliery, a dolerite intrusion spanning 13.88 m caused both replacement and a 13.3 m displacement of the Alfred seam (Fig. 3). The unexpected occurrence of the dyke during the mining operation caused a significant delay in the mining operation and considerable loss in production. As a result of the intrusion, the involvement of a specialist team was required in order to remove the dyke by blasting. The blasting method employed involved the use of a wedge cut solid blasting technique, which utilizes synchronized delay intervals between blastholes. Due to the sensitive environment and associated dangers within a coal mining environment, such as the presence of methane and highly combustible coal dust, the blasting operations have limited flexibility. Therefore, a total permitted amount of 1000 g of Seamex® water gel explosives was used in the blasting operations. Other controllable blasting parameters such as the drill hole diameter (38 mm), stemming material (clay), stemming length (200 mm), drill hole depth (1.8–2.2 m) and explosive delay intervals (0–400 ms) were kept constant throughout the blasting operation of the dolerite.

4 Methodology

Selected sampling was conducted along the length of the intrusion and three sampling points; A_2, A_6, A_9, were chosen at strategic locations of the dolerite as shown in Fig. 3.

Detailed petrographic analysis of thin sections, using an Olympus BX41 microscope, was done on seven samples taken from the dolerite. XRD analysis was conducted on five samples, three of which were taken from the geotechnical sampling points. Sample preparation was carried out as prescribed by Jenkins and Snyder (1996) and Darling (2011). The analysis was done using a PANalytical Empyrean diffractometer, with data interpretation using the High Score Plus software.

The preparation and assessment of all samples used for geotechnical analysis were completed in accordance with the ISRM (1981) procedures. The geotechnical properties determined were the dry density, porosity, Brazilian disc strength, uniaxial compressive strength (UCS) test, point load test and sound velocity.

In order to quantify the blasting performance, measurements were taken from a known point of reference after each blast advance, using a laser distometer. In order to ensure the

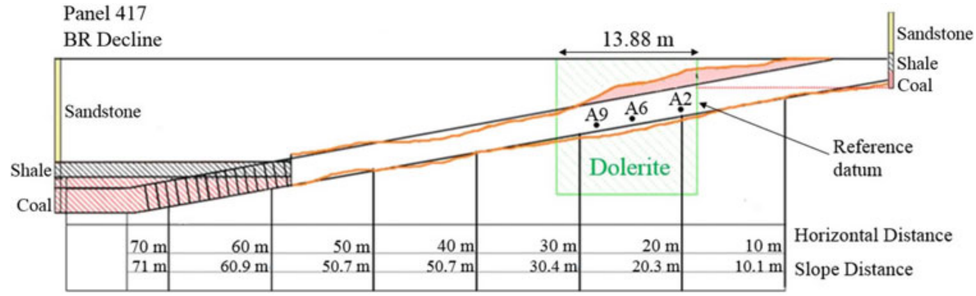

Fig. 3 Cross section along BR decline, Section 1, Panel 417

accuracy of each measurement, three measurements were taken along the face, with the average value used as a representation of the blast advance.

5 Results and Discussion

5.1 Petrographic Analysis of the Dolerite

Results obtained from thin section analysis, indicate that the dolerite comprises anorthite (65–80%), augite (10%) and enstatite (5%) as the essential minerals, and accessories of calcite, devitrified glass and opaque minerals (5%).

Plagioclase feldspar being the main constitute, occur as subhedral tabular crystals with pyroxene, glass and opaque minerals occupying the spaces between the plagioclase laths giving rise to an interstitial texture. The samples at the contacts were much finer grained with an average grain size of 0.25 mm than at the centre of the intrusion with average grain size of 0.75 mm (Fig. 4).

A notable difference in the thin sections prepared from samples taken along the contact of the intrusions from those taken at the centre, was the presence of calcite infillings (Fig. 5). It was observed that the percentage of calcite reduces from the contact to the centre of the intrusion with little or no calcite present at the centre. This was also confirmed by XRD analysis (Fig. 6).

According to research conducted on dolerite intrusions within the Klip River coalfields, Roberts (1987) indicated a similar observation stating that the intrusions within the coalfields exhibited evidence of late stage reaction with a mobile fluid phase along intrusive contacts with coal. This resulted in many of the intrusions being altered to carbonate and other secondary minerals by endometamorphism. At the dolerite-coal contacts, the intrusions were described as being brecciated and penetrated by a series of calcite veins (Roberts 1987).

5.2 Geotechnical Properties of the Dolerite

A summary of the geotechnical properties obtained from the various tests conducted on the dolerite intrusion are shown in Table 1. The UCS and Brazilian disc strength values show that the dolerite is stronger at the centre than at the margins. The relatively low strength values at the margins

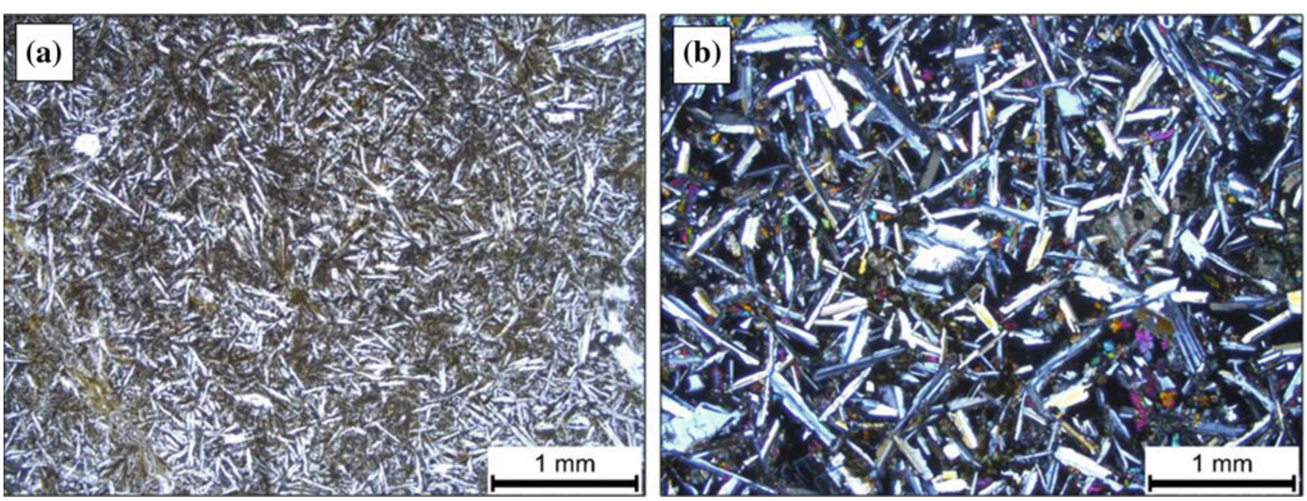

Fig. 4 **a** Photomicrograph of sample taken along contact, magnification 2× under cross-polarized light showing interstitial texture; **b** Sample A_6 Photomicrograph of sample taken at the centre, magnification 2× under cross-polarized light showing interstitial texture

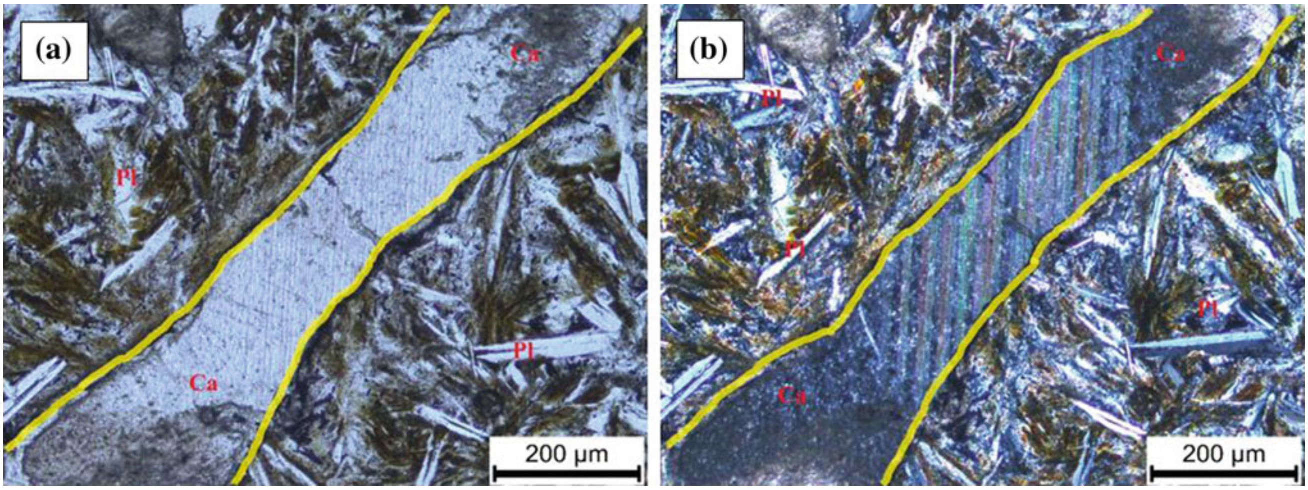

Fig. 5 **a** Sample A_2 photomicrograph magnification 10× under plane polarized light showing calcite infilling (yellow); **b** Sample A_2 photomicrograph magnification 10× cross polarized light showing calcite infilling (yellow)

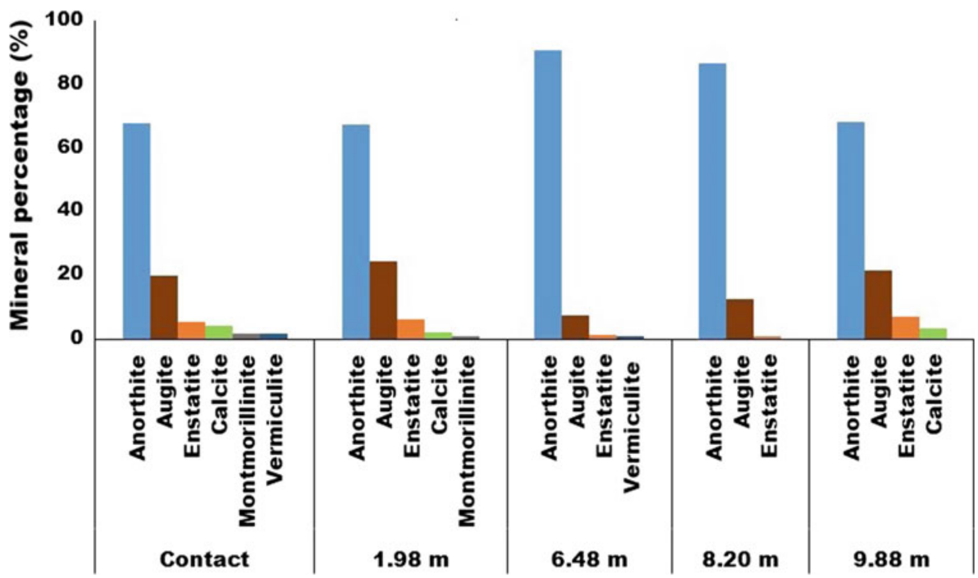

Fig. 6 Modal mineral percentages for samples taken along length of intrusion

could be attributed to the presence of calcite infillings, which compromise the strength of the rock. Based on the average UCS and Brazilian disc strength values, the blastability index, which is the ratio of the UCS to tensile strength, was obtained for the dolerite at the sampling points. The values obtained show that the blastability indices at the margins were found to be higher than at the centre which suggests a higher expected advance at the margins than at the centre of the intrusion.

5.3 Blasting Analysis

Blasting advance recorded along the length of the intrusion indicate a distinctive trend in the amount of pull received during excavation of the intrusion (Fig. 7). According to the empirically calculated planned blasting advancement (i.e. 1.5 m), actual advances recorded indicate a decrease from the margin towards the centre of the intrusion. Thus, the blasting performance was shown to be greatest at the margins of the intrusion and progressively decrease towards the centre. It is evident that although the dolerite was subjected to identical energy input from explosives throughout, different results were obtained in the advance. This is indicative of different resistance of the dolerite to blasting along its length due to its variability in mineralogy, grain size and geotechnical properties along the length of the intrusion.

Several authors (e.g. Hino 1959; Jimeno et al. 1995; Bhandari 1997; Olofsson 1999) have pointed out that the ease of fragmentation of a rock can be indicated by its

Table 1 Geotechnical properties of the dolerite intrusion

Sample		A_2	A_6	A_9
Density (g/cm^3)	Average	2.72	2.64	2.69
	Range	2.72–2.73	2.61–2.65	2.65–2.72
	No. of samples	3	3	5
Porosity (%)	Average	0.79	0.96	0.98
	Range	0.78–0.81	0.93–1.02	0.87–1.28
	No. of samples	3	3	5
Sound velocity P-wave (m/s)	Average	5211	5344	5668
	Range	–	5336–5352	–
	No. of samples	1	2	1
UCS (MPa)	Average	143.49	160.89	156.86
	Range	–	159–162	–
	No. of samples	1	2	1
Point load index Is_{50} (MPa)	Average	6.46	7.88	7.48
	Range	5.34–7.34	6.32–9.51	5.34–8.71
	No. of samples	5	7	5
Correlated UCS by Broch and Franklin (1972) (MPa)	Average	155.04	189.12	179.52
	Range	128–176	151–228	128–209
	No. of samples	5	7	5
Brazilian disc strength (MPa)	Average	13.38	20.91	19.13
	Range	11.60–16.78	20.28–21.59	18.29–20.38
	No. of samples	3	3	5
Blastability index	Average	11.58	9.04	9.38

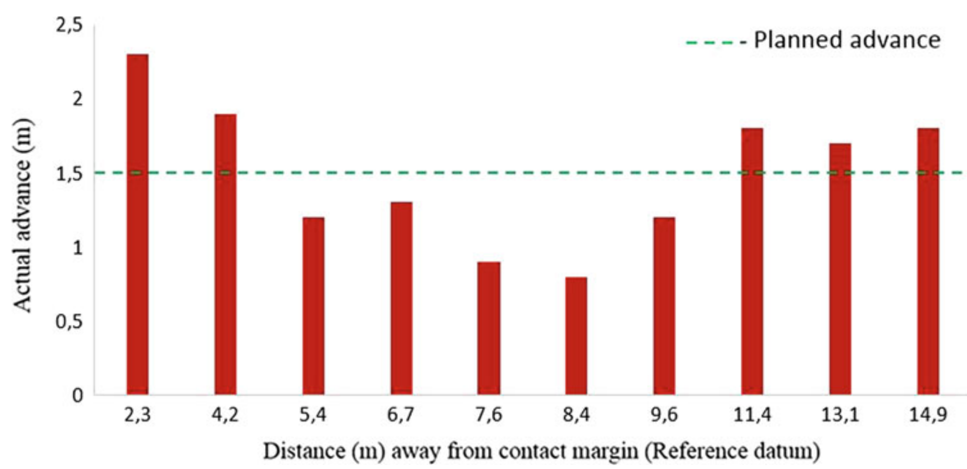

Fig. 7 Blasting advance measurements taken along Panel 417, Section 1

blastability index, which is defined as the ratio of the uniaxial compressive strength to the tensile strength. According to the blastability index calculated for the sampling points along the length of the intrusion, a higher than the planned advance along the intrusion contact was found to correspond to a higher blastability index in comparison to the centre of the intrusion.

6 Conclusion

A dolerite intrusion within Panel 417, Section 1 of the Magdalena Colliery resulted in both replacement and displacement of the Alfred seam. The intrusion resulted in a delay in the mining schedule. This was further exacerbated by inadequate pull from the blasting operations along the intrusion. Thus, the study was focused on investigating the influence of petrographic and geotechnical properties in the assessment of its blasting performance. Petrographic analysis revealed that the main minerals in the dolerite comprises anorthite, augite and enstatite, with accessories of calcite, devitrified glass and opaque minerals. A notable difference was observed in thin sections prepared from the margins of the intrusion, which revealed the presence of calcite infillings due to endometamorphism. According to the geotechnical analysis conducted, the results indicate that the mechanical strength of the intrusion was compromised along the margins of the intrusion. This was shown to have a significant effect on the blasting performance, whereby greater pull was obtained along the margin of the intrusion margin as compared to the centre. Thus, the investigation demonstrates that a strong relationship exists between the blasting performance and the geotechnical and petrographic properties of the dolerite. Thus, the variation in pull from the blasting operations of the dolerite can be attributed to the influence of its geotechnical and petrographic properties.

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