19th Australasian Tunnelling Conference – Acosta-Martínez, Stewart and Hudson-Smith (Eds.)
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Dyke encounters in the Sydney basin: Insights from 30 km of mined tunnel excavations

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ABSTRACT: This paper presents observations from 66 intersections of dykes encountered across more than 30 km of mined tunnels in the Sydney Basin, primarily within Hawkesbury Sandstone. The data, collected from six major tunnelling projects including WestConnex and NorthConnex, focus on dyke geometry, material and mass characteristics, host rock mass condition, and groundwater behavior.

Dykes were found to be generally steeply dipping and aligned with regional joint sets, with two-thirds being less than 2 m thick and half less than 1 m. Intact strength estimates suggest a real trend of increasing strength with depth, attributed to reduced weathering and stress relief in deeper settings. While most dykes had good rock mass conditions, a small subset had significant clay seams and jointing. Host rock mass conditions reverted to background conditions typically within 5 m of the dyke margin and was generally greater at shallow depths. Groundwater seepage from dykes or the surrounding host rock was observed in under half the cases, with notable inflows limited to depths less than 50 m.

The findings suggest commonly a localized and occasionally significant impact of dykes on the host rock mass.

1 INTRODUCTION

This paper presents observations and geotechnical characteristics of volcanic dykes and adjacent rock mass conditions encountered during recent tunnelling projects across the Sydney metropolitan area. The study is based on data from six mined tunnel projects: all stages of the WestConnex development (including the M8, M4-M5 Link, M4 East, Rozelle Interchange, and Western Harbour Tunnel) and the NorthConnex project. Collectively, these projects represent over 30 km of tunnel excavation, predominantly within Hawkesbury Sandstone. Excavation was primarily undertaken using roadheaders, in either full-face or split-face configurations, with typical ground support comprising rock bolts and shotcrete in drained conditions.

Across these projects, 66 volcanic dyke intersections were mapped, some at depths of cover of up to 90 m. The focus of this paper is on characterizing the dykes and their immediate host rock in terms of material and mass properties. Mapping was undertaken during the excavation cycle, prior to shotcrete application, and from safe working distances. As a result, tactile field tests were generally not possible, and the data are largely qualitative. It also relies on visual interpretation by multiple mappers of varying backgrounds and experience.

1.1 Background

Sydney Basin is generally considered to have uniform geological conditions particularly for tunnelling, dominated by the Hawkesbury Sandstone, Mittagong Formation, and Ashfield Shale. These units have been extensively studied and are well understood in the context of tunnel design and performance (e.g. Pells et. al., 1998; Bertuzzi, 2014). In contrast, volcanic dykes represent discrete zones of geological heterogeneity and introduce local complexity into an otherwise mostly predictable stratigraphy. These intrusions must be explicitly considered in tunnel design and construction due to their variable geometry, material strength, and hydrogeological behavior.

Doleritic and basaltic dykes typically occur as steeply dipping to vertical, sheet-like bodies that intruded along pre-existing discontinuities such as joints, faults, and shears within the sedimentary sequence. It remains uncertain to what extent the host rock conditions we observe today are a result of pre-existing weaknesses, the intrusion process itself, or subsequent weathering and stress relief. In some cases, the rock mass adjacent to dykes shows pronounced fracturing and degradation; in others, there appears to be little to no departure from background conditions.

Thermal alteration effects are occasionally observed at dyke margins, likely caused by the high emplacement temperatures of the intrusive material. In rare cases, this has resulted in localised contact metamorphism of sandstone to quartzite (e.g., the Bondi columnar sandstones; Morrison, 1904). Observations from the tunnel mapping show a spectrum of host rock responses from unaltered to highly fractured and weathered depending on lithology, proximity to the dyke, and depth.

2 DYKE OCCURRENCES

Of the 66 dyke intersections, 12 were mapped in tunnels comprising Ashfield Shale and 54 were mapped in tunnels in sandstone. This equates to a dyke intersected roughly every 500 m of tunnel excavation.

The orientation of the dykes intersected is presented in Figure 1. This shows the dykes follow the broad and well-established basin wide joint patterns of sub vertical dip (i.e. > 70°) with two or more set orientations being approximately northwest-southeast and northeast-southwest.

From the mapping data, eight key characteristics have been inferred as detailed in Table 1.

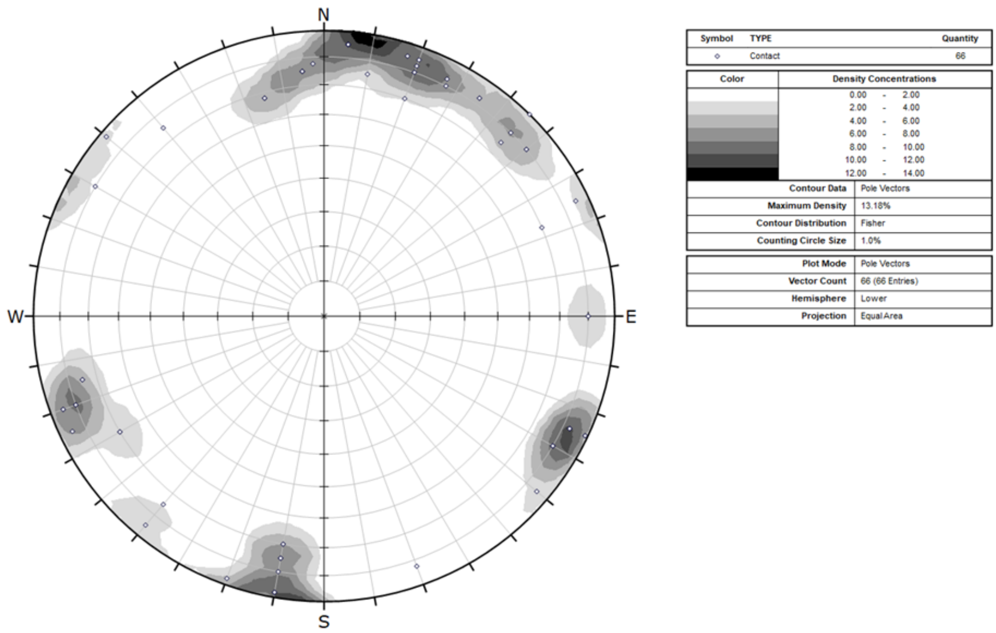

Figure 1: Stereonet Plot showing 66 dyke intersections mapped and their orientations

Table 1: Key physical characteristics recorded in the database

Characteristics	Detail
Host lithology	Rock type that the dyke has intruded into. Mittagong Formation has been grouped with Ashfield Shale
Depth of cover	Distance between tunnel crown and the ground surface at the dyke contact
Dyke rock material and mass conditions	Inferred intact and mass characteristics of the dyke intrusion itself including GSI estimates
Dyke thickness	The true thickness of the dyke
Contact between dyke and host rock	Inferred nature and characteristics of the contact between dyke and host rock
Host lithology rock mass and material conditions	Inferred conditions of the host rock including substance strength, jointing, faulting or infilling of discontinuities adjacent to the dyke
Zone of disturbance in host rock	The distance from the dyke where the host rock mass and material conditions revert to background conditions
Groundwater ingress at dykes	Estimation of the groundwater inflow in the tunnel adjacent to the dyke at the time of mapping

3 RESULTS

Figure 2 presents the data on dyke thickness and Figure 3 shows this as a function of depth of cover.

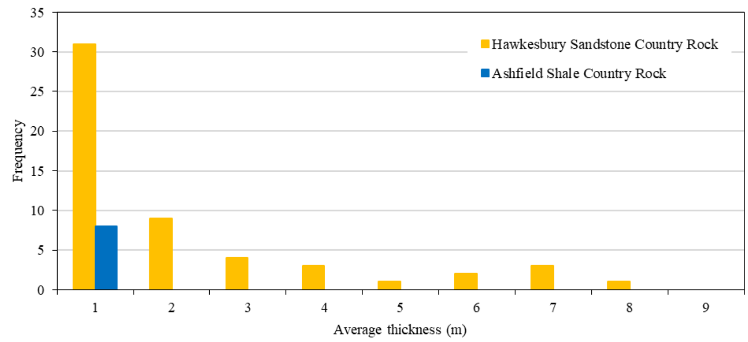

Figure 2: Dyke thicknesses

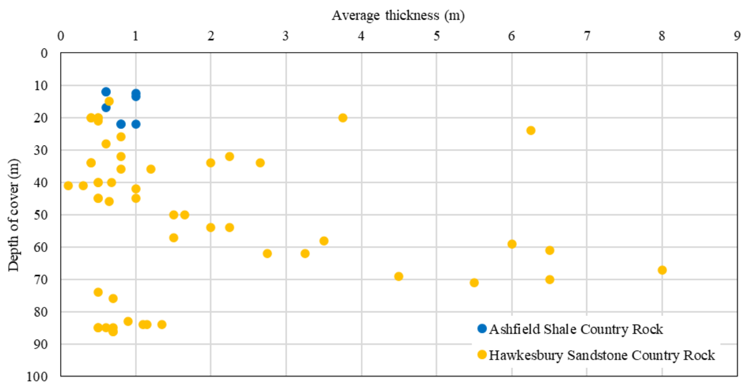

Figure 3: Dyke thickness as a function of depth of cover.

Table 2 presents data for dyke field estimated intact strength and GSI from mapping for each host rock lithology.

Figure 4 shows dyke field estimated intact UCS versus depth of cover.

Table 2: Dyke characteristics

	Dyke characteristics							
	Ashfield Shale Country Rock				Hawkesbury Sandstone Country Rock			
	Count	Av.	Range	SD	Count	Av.	Range	SD
UCS (MPa)	11	13	2-40	10	19	26	7-40	10
GSI	5	62	40-90	26	27	89	70-92	6

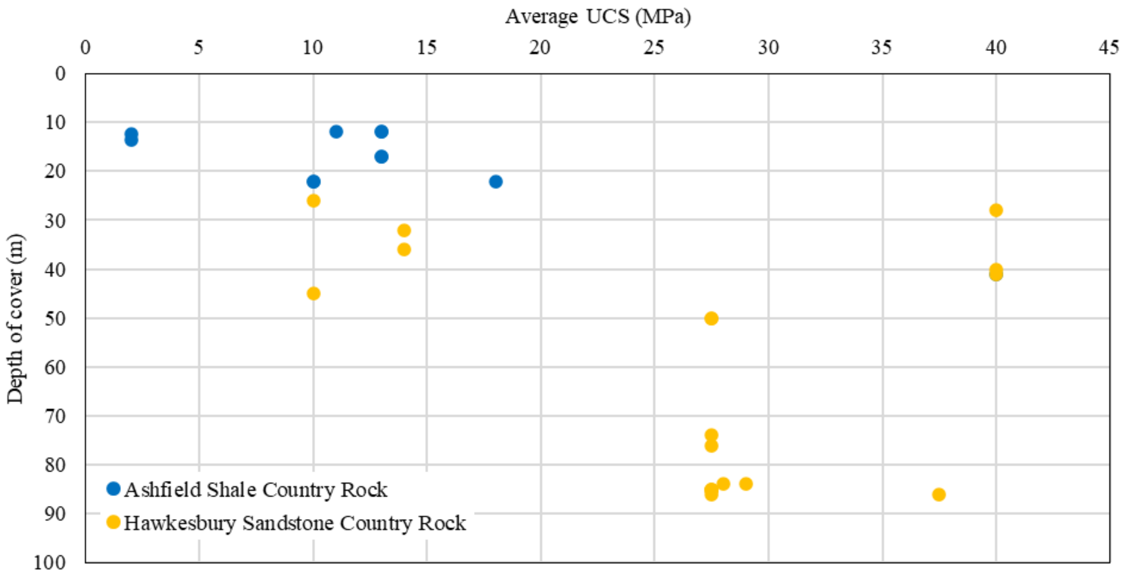

Figure 4: Dyke intact strength as a function of depth of cover.

Descriptions of the general rock mass conditions of the dykes and country rock have been categorized into fields to represent the observations, Figures 5 to 8. Groundwater inflow observations from the dykes or country rock are shown in Figure 9.

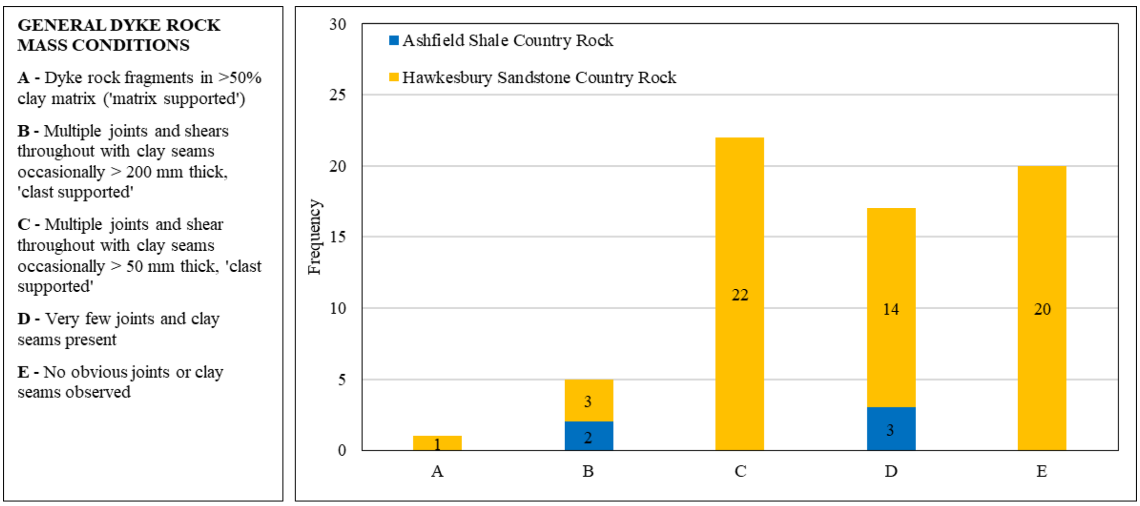

Figure 5: General dyke rock mass conditions in different country rock.

CONTACT BETWEEN DYKE AND COUNTRY ROCK

A - Multiple contacts infilled with clay and/or rock fragments >100 mm thick

B - Multiple contacts infilled with clay and/or rock fragments between 20 mm and 100 mm thick

C - Single contact infilled with clay or rock fragments <20 mm thick

D - Single tight contact with no evidence of infill

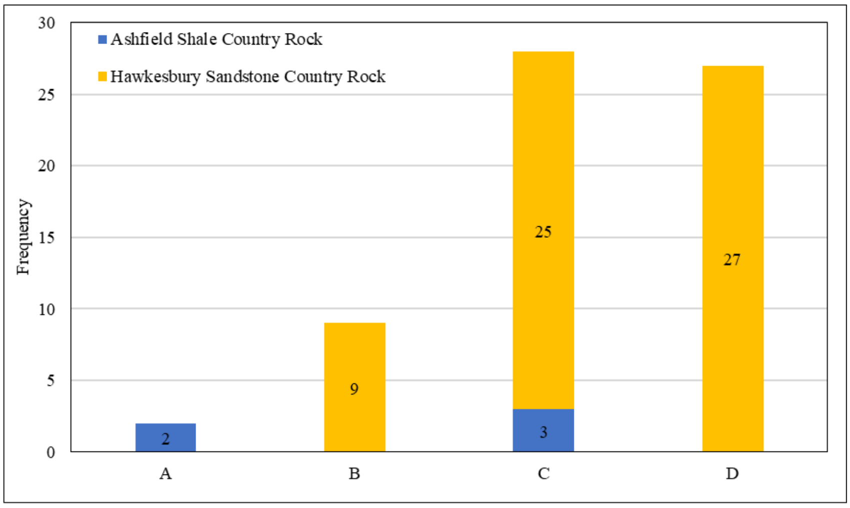

Figure 6: Contact between dyke and country rock condition.

HOST ROCK GENERAL MATERIAL AND MASS CONDITIONS

A - Highly fractured rock with obvious clay infilling or open defects

B - Highly fractured rock, multiple open defect orientations, some with occasional clay infilling observed

C - Multiple closely spaced tight to open defects (0-10 mm aperture), some clay filled parallel to dyke and inclined bedding partings

D - Single to multiple, wide spaced defects either parallel to dyke, inclined or horizontal (bedding partings) with aperture tight to 10 mm.

E - Single tight discontinuity parallel to dyke.

F - Rock mass appears unchanged from background conditions

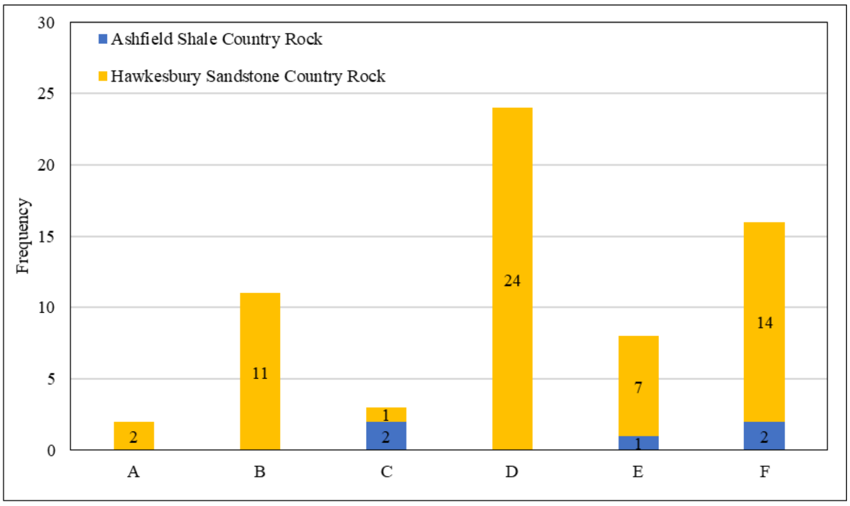

Figure 7: Host rock general material and mass condition.

ZONE OF DISTURBANCE IN HOST ROCK

A - >10 m

B - 5-10 m

C - 3-5 m

D - 1-3 m

E - <1 m

F - 0 m

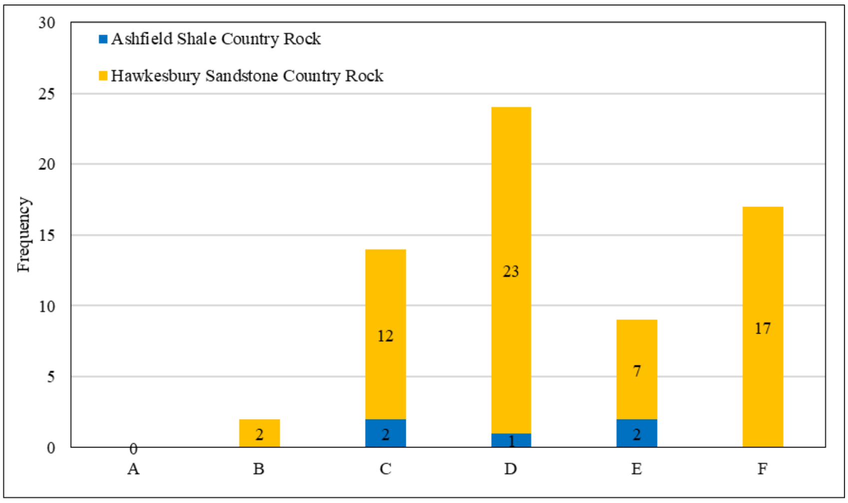

Figure 8: Zone of disturbance in host rock.

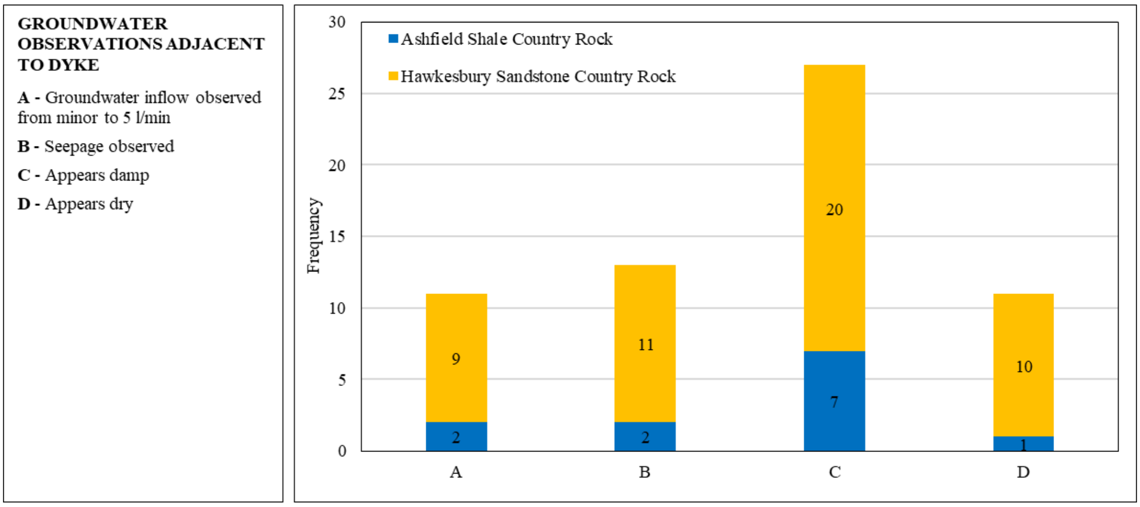

Figure 9: Groundwater observations adjacent to dykes.

These general dyke rock mass conditions and groundwater observations for all lithologies are plotted with depth of cover in Figure 10.

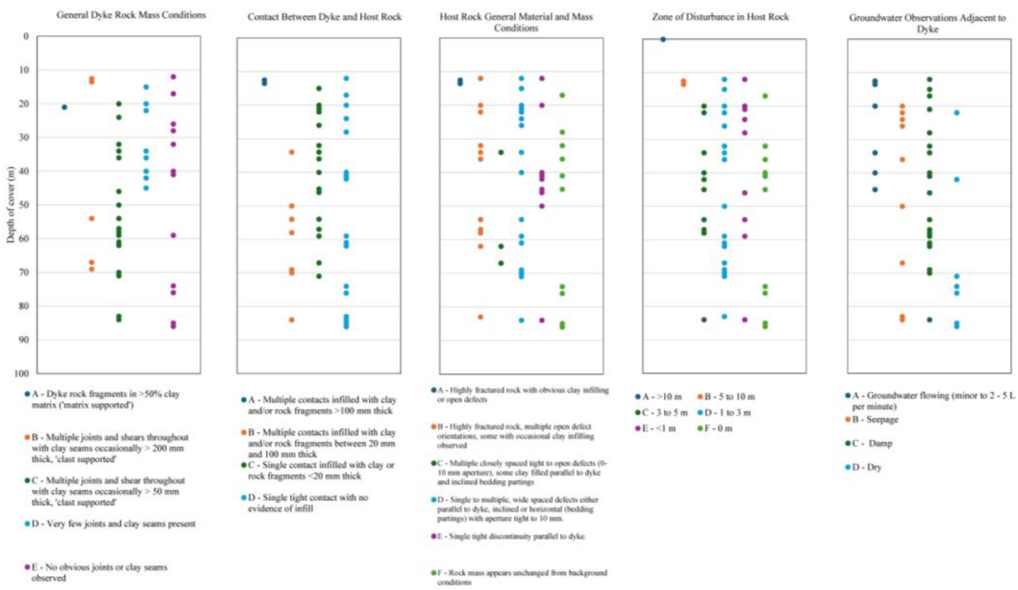

Figure 10: Summary characteristics plotted with depth of cover.

4 DISCUSSION

4.1 *Dyke termination, orientation and thickness*

There is limited evidence regarding the termination of dykes on geological features such as bedding planes, lithological boundaries, or other structural discontinuities. However, the authors have observed one instance where a dyke in the Hawkesbury Sandstone terminated in the overlying Ashfield Shale. This suggests that structures into which the dykes were emplaced are regional or at least persistent enough to extend across multiple lithologies.

Dyke orientations in this study closely reflect the regional joint set patterns described by Bertuzzi (2014), with dominant trends sub-vertical towards approximately NE–SW and NW–SE. This alignment supports the hypothesis that dykes were emplaced along pre-existing joint sets or structural weaknesses.

In terms of thickness, two-thirds of all dykes recorded had thicknesses less than 2 m, with half of them being less than 1 m. Notably, all dykes observed within Ashfield Shale were less than 1 m thick, although this is likely due to the limited sample size.

Two third of the dykes recorded had a thickness of < 2 m, with 50% being < 1 m thick. All dykes emplaced in shale had a thickness < 1 m, but this is likely to be due to the small sample size. The data suggests a general trend of increasing dyke thickness with depth in Hawkesbury Sandstone. However, thin dykes are also observed at all depths, and the apparent correlation between thickness and depth lacks a clear geological basis for the Sydney Basin. The trend is therefore considered coincidental.

4.2 *Dyke intact and mass characteristics*

Dyke intact strength estimates show a trend of increasing with depth. Below approximately 30–40 m from surface, uniaxial compressive strengths (UCS) are typically high (>20 MPa). At depths less than this, dykes are typically medium strength (UCS 6–20 MPa). This is likely due to reduced weathering and alteration at greater depths, where dykes retain more of their original mechanical properties. In contrast, shallower dykes appear more susceptible to degradation through stress relief and weathering processes.

Approximately half of the dykes had very few to no joints or seams and about one-third showed multiple joints or shears, some with clay infill up to 50 mm thick. This means that nearly 90% of mapped dykes could be classified as having ‘reasonably good’ rock mass conditions. The remaining 10% were assessed as poor, with pervasive clay seams and shearing. No consistent correlation was found between rock mass quality and depth of cover.

Dyke-host rock contacts were either tight and clean (40%) or had minor infill with clay or rock fragments (40%). These conditions were observed across the full depth range from 10 m to 90 m. The remaining 20% of cases had infill thicknesses up to or exceeding 100 mm, again with no clear depth dependence.

4.3 *Host lithology rock mass characteristics*

Poor host rock mass conditions characterized by highly jointed or faulted ground with clay-infilled defects were only recorded at shallow depths (<20 m cover). In contrast, more competent host rock masses (Categories D to F: from widely spaced defects to no observable change from background) made up approximately 75% of the dataset and occurred across the entire depth range.

For the zone of disturbance in the host rock, 95% of records showed a return to background conditions within 5 m, and a quarter of all cases showed no noticeable disturbance at all. Only two instances showed zones of disturbance extending beyond 5 m, both of which occurred at cover depths <20 m. This suggests that the influence of dykes on the surrounding rock mass is typically localised.

4.4 *Groundwater*

Groundwater seepage from dyke contacts or adjacent host rock defects was observed in just under half of the records. Category A inflows (2–5 L/min) were only documented at shallow depths (<50 m), supporting the findings of Hewitt (2004) and others that dykes can influence groundwater storage and movement, particularly in shallower, stress-relieved rock masses dykes. These findings also suggested the likely increase the permeability of the Hawkesbury Sandstone because dyke features are typically accompanied by defects (bedding plane shears and joints) dipping towards the dykes which often create transmissive zones.

Despite this, many observations recorded dry or damp conditions in both the dyke and host rock suggesting that they are not consistent sources of groundwater inflow across all conditions or depths.

4.5 *Sandstone versus shale host rock*

It is hard to draw many conclusions for dykes in shale owing to the small number of them encountered in tunnels. There are a few reasons for the smaller dataset, the main one being most tunnelling targets the sandstone as it is a better tunnelling medium. If there was shale overlying sandstone along an alignment, the ramp and mainline tunnels vertical alignments were designed to dive through the shale as much as the gradient allowed thus limiting exposure. Notwithstanding, there are no records of no influence (category F, Figure 8) of a dyke on the rock mass when in shale, this could potentially suggest that dykes have the potential to have a more severe influence of Shale rock mass characteristics rather than sandstone.

5 CONCLUSIONS

A review of the mapping data of 66 dyke intersections across six Sydney tunnel projects provides some insights into the rock and groundwater characteristics:

- Dyke orientation aligns closely with regional joint sets, supporting the interpretation that dykes exploit pre-existing structural weaknesses.
- Two-thirds of dykes had a thicknesses < 2 m, the maximum recorded was 8 m. An apparent trend of increasing thickness with depth was not considered geologically valid.
- Dyke substance strength has a consistent trend of increasing with depth. This is likely due to reduced weathering and stress relief effects in deeper zones.
- Rock mass conditions within dykes were generally considered good, with only a small proportion showing extensive jointing or clay seams. No clear depth dependency was observed.
- Host rock response was typically localised, with most disturbance zones reverting to background conditions within 5 m of the dyke.
- Groundwater inflows were observed in fewer than half the cases, with higher inflow rates restricted to depths <50 m, perhaps consistent with the stress relief patterns in the Sydney Basin.

Overall, while volcanic dykes introduce geological complexity into an otherwise uniform sedimentary rock sequence, their influence on tunnelling is often localised. Recognising their likley presence and understanding their variability should be a consideration for tunnel design and construction.

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