Identification of a fine 'tuff' lamination in the Rouse Hill Siltstone Member of the Ashfield Shale, Sydney Basin, Australia and its implications

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ABSTRACT: Sydney Metro is Australia's largest public transport project, and historical and recent ground data is being collected and used at an unprecedented scale to create robust rock models for the proposed tunnel alignments. Geotechnical investigations target the Triassic Wianamatta Group, Mittagong Formation and Hawkesbury Sandstone of the Sydney Basin. Despite these geological units being well documented, new knowledge gained during the Sydney Metro projects is enabling a better understanding of the Wianamatta Group. In particularly, the Rouse Hill Siltstone Member is typically described as a homogenous siltstone unit at the base of the Wianamatta Group. However, this unit often includes a distinctive white "tuff layer" lamination, which is typically ignored in geological models. Data from 100+ historical and recent boreholes across Sydney indicates that, where present, this lamination is remarkably uniform across the central Sydney region and sits horizontally at approximately 3 m above the base of the Rouse Hill Siltstone Member. This marker horizon assisted in identifying vertical offsets in the strata caused by faulting. The characterisation and identification of this layer will greatly improve our understanding of the geology across Sydney and allow for efficient targeting of geological structure for future tunnelling projects in these units.

KEYWORDS: Tunnelling, Ashfield Shale, Ash-fall tuff layer, Sydney Basin, Metro, Site investigation, Geological model, Marker horizon

1. INTRODUCTION

Sydney Metro is Australia's largest public transport project, and historical and recent ground data is being collected and used at an unprecedented scale to create robust rock models for the proposed tunnel alignments. Over the past decade, several hundred geotechnical investigation boreholes were drilled to assess geological conditions at the proposed tunnel depths. The geology encountered during these investigations comprise the upper Triassic formations of the Sydney Basin, namely the Wianamatta Group (Ashfield Shale), Mittagong Formation and Hawkesbury Sandstone (Figure 1).

This paper defines outcomes of an expanded study on findings from previous geotechnical investigations that span 100 km across the Sydney Basin. The knowledge gained from this study provides valuable insights for future infrastructure projects and geological sciences in general.

2. PREVIOUS STUDIES

Previous studies on the "Wianamatta Shales" extend back to the historic work of Tenison Woods (1884) and Etheridge (1888). The first understanding on the stratigraphic nature of the whole Wianamatta Group published by Lovering (1954a) (Figure 2) was based on geochemistry and palaeontology to characterise the Ashfield Shale. Lovering (1954a) indicated that future studies were needed to define "marker horizons".

Historically, as Sydney developed, resources were required for brick manufacturing and further studies based on investigatory exploration and site assessments were carried out by the Geological Survey of New South Wales. Herbert (1973) and Byrnes (1975) identified thin layers in the Wianamatta Group defined as tuff layers. Herbert's work was in the lower Bringelly Shale (B1 horizon), and along with Byrnes' work sampled a layer across the St Peters Brick Pit site which was related to the Kellyville Laminite Member (A2 horizon) of the Ashfield Shale (Figure 2). However, these marker beds lack continuity due to being relatively shallow across Sydney and having eroded, or having a deep weathering profile.

Recent work on the Sydney Metro North West (Parker, 2012) identified a ubiquitous white lamination 2 to 5 mm thick that gave the Sydney Metro North West Line (North West Rail Link) design team confidence in the stratigraphic correlation between boreholes of the lower Ashfield Shale subgroup (Rouse Hill Siltstone Member). This same distinct white lamination has been observed in several tunnel projects and deep basement excavations across Sydney (Pers. Comms. John Braybrooke, Hugh Burbridge, Tim Nash, David Oliveira and Max Foweraker).

3. REGIONAL GEOLOGY

The rock units encountered across the Sydney Metro projects in the central Sydney Region are the formations of the Wianamatta Group, especially the lower portions of the Ashfield Shale. The upper units, the Bringelly Shale and Minchinbury Sandstone are encountered to the southwest and western region of Sydney that have not featured in extensive tunnel works to date. The Ashfield Shale is underlain by the variably thick Mittagong Formation and distinctive Hawkesbury Sandstone (Figures 1 and 2).

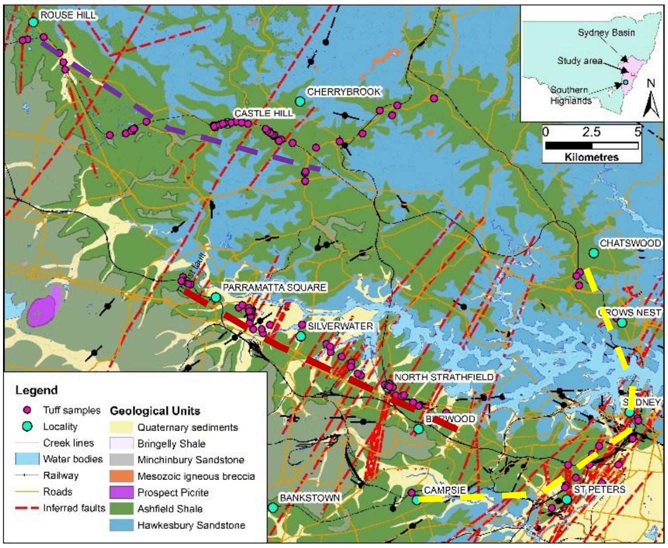

Figure 1 Geological map of the Sydney Region (Och *et al.*, 2009, after Herbert, 1983 and Mauger *et al.*, 1984a & b). Purple dashed line – Sydney Northwest section; dark red dashed line - Sydney Western section; and yellow dashed line - Sydney North to Southwest section highlight simplified geological section in Figure 6.

This paper will focus on the basal Rouse Hill Siltstone Member of the Ashfield Shale. This homogeneous siltstone formation is easily separated from the overlying Kellyville Laminite Member in investigation core, along with laterally extensive white lamination. These two members are described in the next paragraphs.

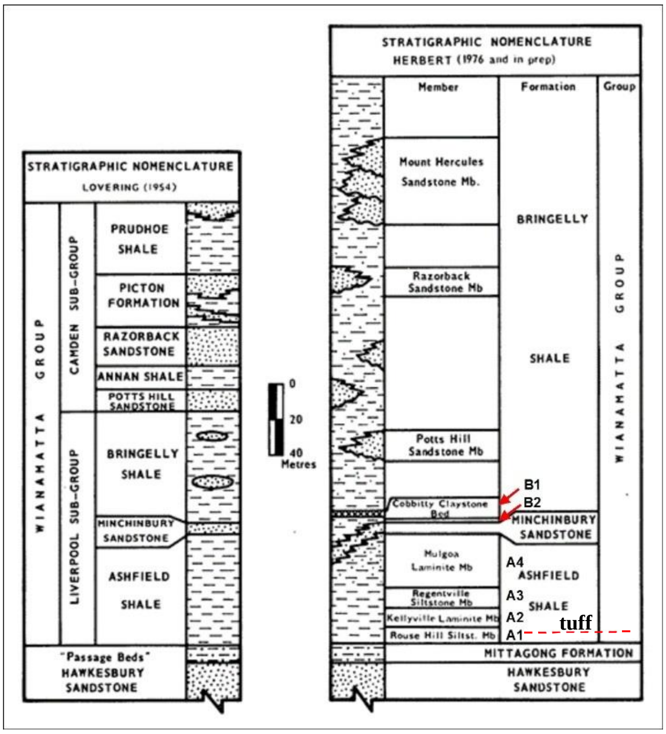

Figure 2 Stratigraphy of the Wianamatta Group as defined by (Lovering, 1954a and modified after Herbert, 1973)

3.1 Kellyville Laminite Member (A2)

The Kellyville Laminite Member easily distinguishable across the Sydney Basin due to its distinctive regularly spaced laminations, comprising dark grey siltstone and light grey fine-grained sandstone. The unit ranges in thickness from to be between 0.7 to 5.8 m (Herbert and Helby, 1980). The unit was deposited in shallow marine conditions (Figure 2 and 3).

3.2 Rouse Hill Siltstone Member (A1)

The basal member of the Ashfield Shale is a homogenous black siltstone unit ranging in thickness from 5.6 to 15.1 m (Herbert and Helby, 1980) that unconformably overlies the Mittagong Formation or Hawkesbury Sandstone in some cases (Figures 2 and 3). This member is inferred to have formed in an expansive freshwater lake environment based on the occurrence of vertebrate and invertebrate fossils (Etheridge 1888; Woodward, 1908; Chilton, 1917; Tillyard, 1918; Watson, 1958; and Pickett, 1971).

3.3 Geological structure

Sydney geology is dominated by NNE striking fault systems (Mauger *et al.*, 1984a & b; Branagan *et al.*, 1988; Och *et al.*, 2009) and regional gentle folds (Herbert, 1983). Stratigraphic offset due to faults is very difficult to assess across Sydney due to the relatively homogenous nature of these formations unless observed in excavations and/or compiled from mapping to define where these faults trends (Pells, *et al.*, 2004; Och *et al.*, 2009) occur then faults are difficult to predict.

4. METHODOLOGY

4.1 Study of Historical Core Photos

The strategy of this study was to assess historical core photos from a wide area of Sydney from major infrastructure projects, specifically targeting locations where the Ashfield Shale was identified (Figure 1). The core sampled a good proportion of the Ashfield Shale across the Sydney region defining an interesting relationship with these thin white laminations.

The study identified a distinct white lamination at 106 locations out of several hundred boreholes from across the Sydney region.

This lamination could not be identified in all boreholes. The absence, or apparent absence, of the tuff lamination was due to deep weathering, zones of intense fracturing (fault and drilling-related), bored length, drilling method and typical limitations associated with historical ground data such as poor quality core photos (Thorin *et al.*, 2017). In some cases, the lamination could not be identified as the lamination may be too thin to observe in photographs, which could be due to post-sedimentation processes or compaction during lithification.

The current phases of Sydney Metro geotechnical investigations have enabled visual inspection of the rock structure during drilling. A geotechnical investigation in the Southern Highlands, 100 km south of Sydney also intersected the Kellyville Laminite Member, the Rouse Hill Siltstone Member and the white lamination (Figure 5). However, the nature of the latter has yet to be ascertained and awaits further investigation.

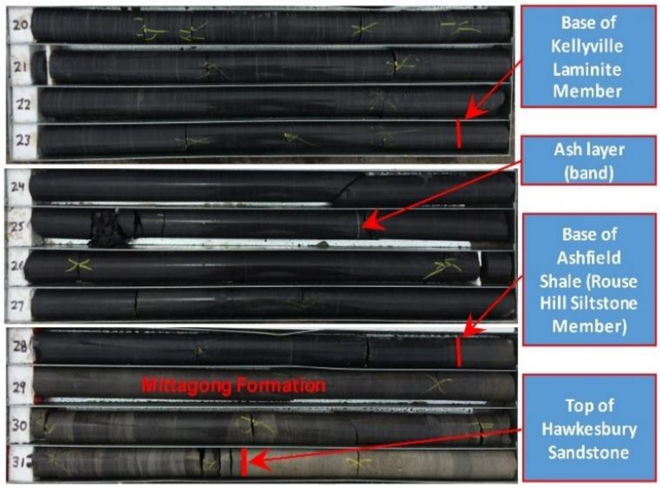

Figure 3 Core box (SRT_BH708 - Campsie) photos of typical stratigraphical representation of the lower Ashfield Shale rock types: lower portion of the Kellyville Laminite Member (20.0 m – 23.9 m) conformably overlying the Rouse Hill Siltstone Member (23.9 m – 28.9 m), note the presence of the white lamination at 25.7 m. The Mittagong Formation between 28.9 m and 31.4 m transitioning into the Hawkesbury Sandstone.

4.2 Results

The white lamination observed in the core is distinctive from the pale grey fine-grained sandstone laminations observed in the laminite members which lie above. The sandstone lamination is characterised by sedimentary features such as grading, apparent ripples, finer cross-cutting interlamination and possible bioturbation. The white lamination also has load casts when thick, but is very distinct, finer grained and unique.

Preliminary microscopic studies indicate detritus that is distinctive of ash-fall tuffs (i.e. alpha quartz, distinctive angular shard-like quartz and kaolinite pseudomorphs after former K-feldspar grains). The contacts often define sub-horizontal unconformable surfaces, some observed to be angular defined by a joint plane. A lithological angular contact defined by a slickenside shear was observed in one location (SMW_BH124), indicating faulting and hence shortening in this interval (1.97 m). Many other boundaries are intensely fractured with a high degree of weathering; commonly observed at the Ashfield Shale – Mittagong Formation Boundary.

The assessment of the 106 locations suggest that the thickness of the white laminations is remarkably uniform at 2.4 mm ± 1.5 mm and that the laminations were found at 2.93 m ± 0.42 m above the base of the Rouse Hill Siltstone Member, which is the base of the Ashfield

Shale (Figure 4). Figure 4 below shows the number of boreholes that were sampled and the distribution of these white laminations above the base of the formation.

The outlier samples shown on the histogram (Figure 4) defines a level that potentially indicates shortening or thickening due to faulting in the strata relative to the other population of measurements. What is also observed in the core photos (Figure 5) is that a high proportion of these layers are subhorizontal. Where the gentle regional dips are observed (e.g. in the central part of the Sydney Basin), the layers have a slight dip (2-5°); a similar trend was observed in recent downhole televiewer imaging of boreholes.

The data assessed also suggested a uniform thickness of the Rouse Hill Siltstone Member across the Sydney region, which is contrary to that range noted earlier by Herbert and Helby (1980). An assessment of core photos at 80 locations (Figure 1) that intersect the entire Rouse Hill Siltstone Member found that the latter has an average thickness of 5.05 m ± 0.51 m, which also provides another "marker horizon" that can be relied upon if the core extends from the upper Kellyville Laminite Member to the lower Mittagong Formation/Hawkesbury Sandstone boundary (Figure 3).

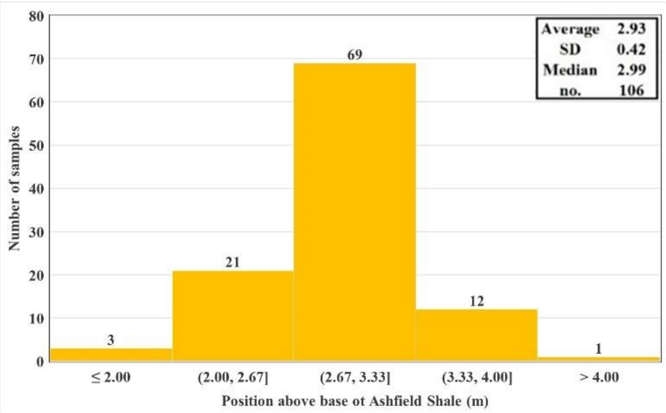

Figure 4 Histogram of depth ranges for the white lamination above the base of the Ashfield Shale.

5. DISCUSSION

The new knowledge gained from geotechnical investigations during Sydney Metro projects along with other data sourced from the WSP CREATE geotechnical database used by the Transport for New South Wales - Sydney Metro (Och, 2018) is enabling a better definition of the Ashfield Shale for use as a geotechnical and geological "marker horizon" across the Sydney Basin.

The persistence of the identified horizontal tuff lamination in the Rouse Hill Siltstone Member has been beneficial in recent tunnel and infrastructure projects in defining proximity to faults from lateral correlation of depth variations of this layer from borehole to borehole and then targeting locations with targeted boreholes to intersect these dominant geological structures. Figure 6 (see Figure 1 for corresponding section locations) shows vertical variations in strata and the tuff "marker horizon" along the 3 corridors.

Figure 6a shows a simplified section of the Sydney Northwest. Most of the core photos observed suggest that the lamination is subhorizontal (e.g. Figure 5 – 22 to 26 m), indicating that these substantial vertical depth variations at each borehole are likely to be associated with fault offsets rather than related to the southward dipping gentle folding across this region (Lovering 1954b). Some major NNE structural linear features are illustrated in Figure 1, but others can only be inferred in the long section of Figure 6a, as residential areas in this north-western area mask any structural linear relief at the surface. The significant offset noted between Cherrybrook and Castle Hill is most likely associated with the NNE striking Coastal Lineament; a significant crustal linear feature across the western Sydney region (Mauger *et al.*, 1984b; Scheibner, 1976).

Figure 5 Core box photographs from different geographical areas of the Sydney Basin that define the continuity of the distinctive white lamination with some slightly angled and others perpendicular to the core axis. All boreholes vertical.

Figure 6b shows a simplified geological section of Western Sydney. The tuff lamination is dominantly perpendicular to the core axis, indicating that these substantial vertical depth variations represent fault offsets and are not fold-related, with exception of Rosehill. At this location, the tuff lamination indicates a slight dip (2 – 3°) to the south, corresponding to downhole televiewer imaging. The Sydney Olympic Park to Haslams Creek (Figure 6b - 8000 m to 10000 m) marker horizon offset reflects a horst and graben structure associated with the NNE striking Homebush Bay Fault Zone (Och *et al.*, 2009), forming swampy marshlands. This structure was confirmed with recent drilling intersections showing down-faulted Hawkesbury Sandstone at depth (Figure 6b - 7895 m).

Figure 6c shows a simplified geological section from Chatswood in the north to Campsie in the southwest illustrating considerable depth variations either side of Sydney Harbour (Figure 6c – 6000 m). The core photos assessed show the tuff lamination is mostly subhorizontal. This section is known to be intersected by major NNE fault structures (Och *et al.*, 2009). Marine geotechnical and geophysical investigations (including cross-hole tomography) for Sydney Metro City & Southwest identified a low-angle thrust fault dipping to the north associated with an approximately 60 m offset (Och *et al.*, 2017), called Sydney Harbour Thrust Fault on Figure 6c. The section to the south around St Peters (Figure 6c – 14000 m) is observed to have multiple offsets, suggesting a "positive flower structure" associated with the possible splaying of the dominant NNE-striking GPO and Woolloomooloo Fault Zones across this region of Sydney (Figure 1, Figure 6 – 12000 to 15000 m).

It is observed in figure 6c that the lack of Ashfield Shale until Campsie is indicative of major regional faulting with major block elevation towards the Cooks River (Figure 6c – 17000 m to 21000 m). Evidence of this can be observed by a distinct dip to the west of bedding in the Hawkesbury Sandstone on the eastern approach to the Cooks River (Figure 6c – 20000 m to 20500 m). East of this location (Figure 6c – 20000 m) a dyke has been emplaced at a boundary between the inclined and horizontally bed sandstone indicative of block rotation due to faulting.

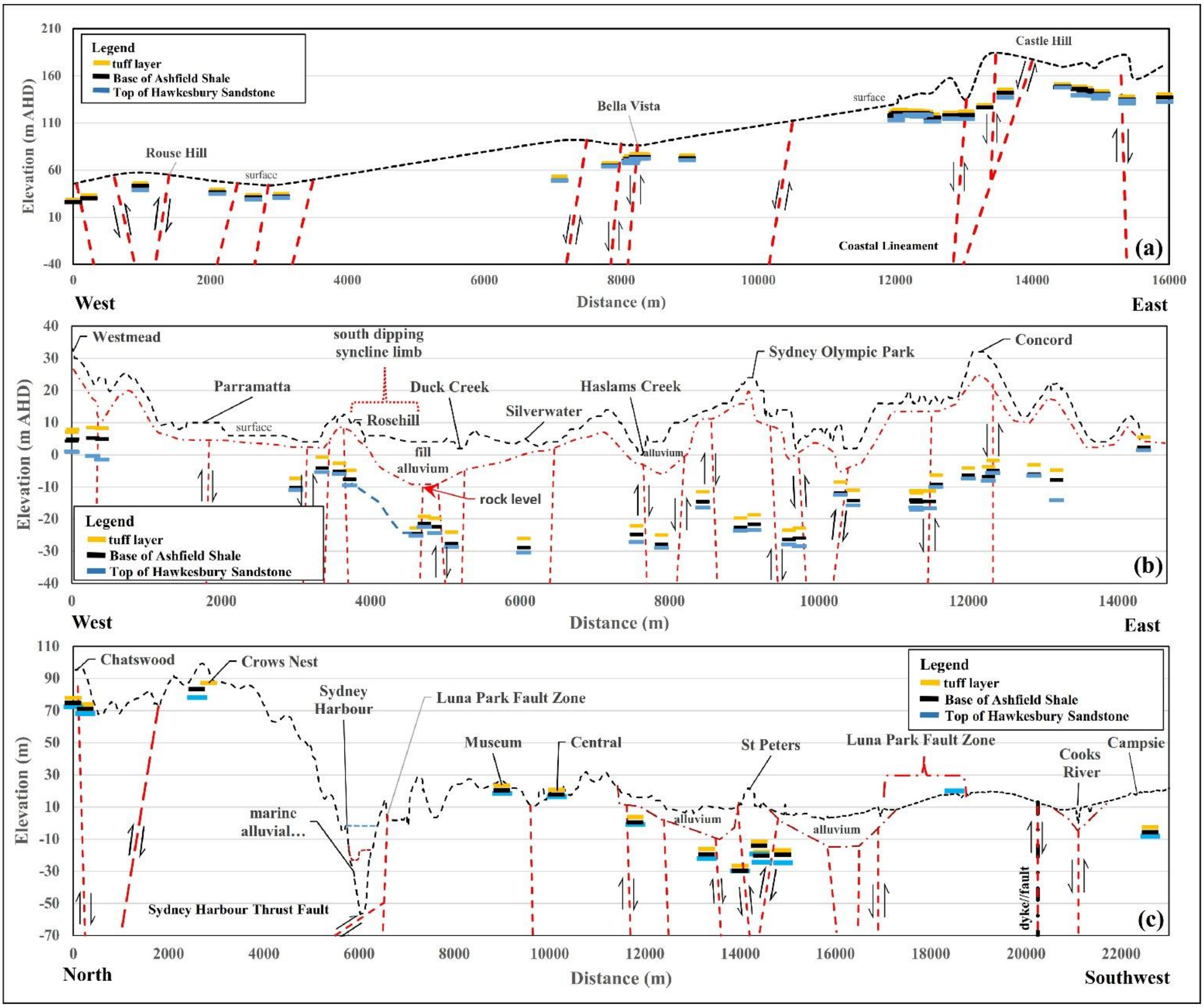

Figure 6 Simplified geological long section profiling the tuff layer in association with the base of the Ashfield Shale and Hawkesbury Sandstone across three regions of Sydney. (a) Sydney - Northwest; (b) Sydney - West; and (c) Sydney – North to Southwest. Sections defined in Figure 1.

Preliminary petrographic studies indicate that the distinct tuff lamination identified in core across the central Sydney Basin is of ash-fall origin (Figure 7). This lamination defines a continuous layer hypothesised to be deposited from a pyroclastic eruption that ejected an extensive ash-fall cloud that was deposited across a relatively level and expansive freshwater lake system of the Sydney Basin with the eruption possibly from a waning Triassic volcanic system in the adjacent north-eastern New England Orogen. Similar ash-fall layers exist in the Permian Newcastle Coal Measures of the Sydney Basin and geochemistry indicates provenance from the New England Orogen (Kramer *et al.*, 2001; Metcalfe *et al.*, 2015).

Due to the geological significance of this discovery, further scientific studies will be carried-out on this and other potential tuff layers in the Sydney Basin in other formations to establish geochemical signature correlations from major and trace element analysis to determine possible provenance. Overseas testing is scheduled to extract any zircons or pollen spores that may exist in these layers that will allow for geochronological and palynological analyses to better define the age of deposition.

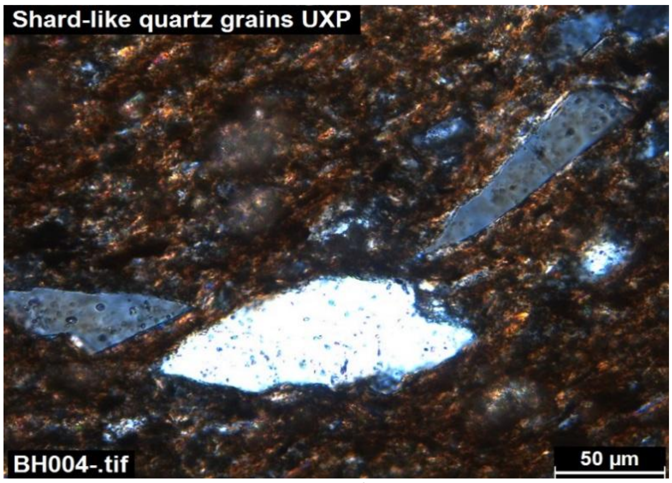

Figure 7 Shard-like quartz grains of volcanic origin observed in a cross-polar photomicrograph from borehole SRT_BH004 (Sydney Metro Sydney & Southwest). The small size attests to a distal ash-fall deposition.

6. CONCLUSIONS

The knowledge gained from this study provides confidence that a "marker horizon" exists in the lower Ashfield Shale member across the Sydney region, offering a valuable interpretive stratigraphic correlation tool for the ground engineering profession in large infrastructure and tunnelling projects around Sydney.

These correlations help reducing project risk by identifying faults (and offsets), which usually are associated with poor geotechnical and hydrogeological conditions.

Findings from the preliminary assessment of more than a hundred boreholes across the Sydney region where a characteristic white lamination was identified are presented with the following conclusions:

- The tuff lamination in the Rouse Hill Siltstone Member is a distinct lamination which is remarkably uniform. This white lamination contrasts greatly with the surrounding bedrock, is unique and easily differentiable from the sandstone laminations found in the overlying Kellyville Laminite Member. Across 106 locations where the lamination was identified, it was found to have an average thickness of 2.4 mm ± 1.5 mm and be located at 2.93 m ± 0.42 m above the base of the Ashfield Shale. This uniformity and continuity enables its use on infrastructure projects as a "marker horizon".
- The vertical depth variations of the subhorizontal tuff lamination can be used to assess proximity to regional fault zones. Folding or faulting can be reasonably inferred if these laminations are not subhorizontal.
- Preliminary petrographic studies suggest that the lamination is of ash-fall origin. It is suggested that this tuff could be derived from a pyroclastic eruption episode from the adjacent north-eastern new England Orogen.
- The Rouse Hill Siltstone Member is a uniformly thick and homogenous siltstone layer that has an average thickness of 5.05 m ± 0.51 m, suggesting less variation than the thickness discussed by Herbert and Helby (1980). For regional stratigraphic studies, when crossed entirely this thickness can also be used as a "marker horizon", rather than the more variably thick underlying Mittagong Formation.
- A mapping of the tuff lamination across various proposed tunnel alignments emphasises the zonal tectonic complexities in the upper rock formations of the Sydney Basin.

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