Application of acoustic scanner data in determining end wall stability

A case study from an operating coal mine in the Hunter Valley, New South Wales

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INTRODUCTION

Background

Multiple small-scale failures were occurring along the western endwall of the main pit at an operating open-cut mine in the Hunter Valley, NSW. A 15 m wide catch bench had to be added to the haul road under the endwall, sterilising approximately 1 million tonnes of reserves. Investigations by the site geotechnical engineer and senior mine geologist identified a joint set subparallel to the strike of and with a shallower dip than the endwall (named the D joint set). This set was apparently related to a thrust fault west located of the endwall and was causing small wedge failures. McElroy Bryan Geological Services (MBGS) reviewed acoustic scanner drill hole data in areas of future mining, where the orientation of both mining direction and the thrust fault changes, to determine the orientation of the D joint set and aid mine planning.

Geology

Structural geology at the mine site is complex with multiple synclines, anticlines and thrust faults present (Figure 1). Major structural features including faults, folds and dykes traverse the area and seams have been subjected to a number of post-depositional tectonic phases with structural complexity decreasing from north to south.

Along the western edge of the current mining operation is Thrust B. This is a major northeast dipping thrust fault extending several kilometres north of the mine site. Deformation structures associated with Thrust B in the project area accommodate displacement at depth. Deformation at the surface resembles a monocline with small scale, localised thrust faults (typically <2 m displacement).

Future mining will pass through Thrust B where deformation presents as a monocline, and into an area affected by a syncline. Thrust B and the syncline trend southeast through the north of the project area, then turn east-southeast in the central portion before turning south in the southern portion of the project area.

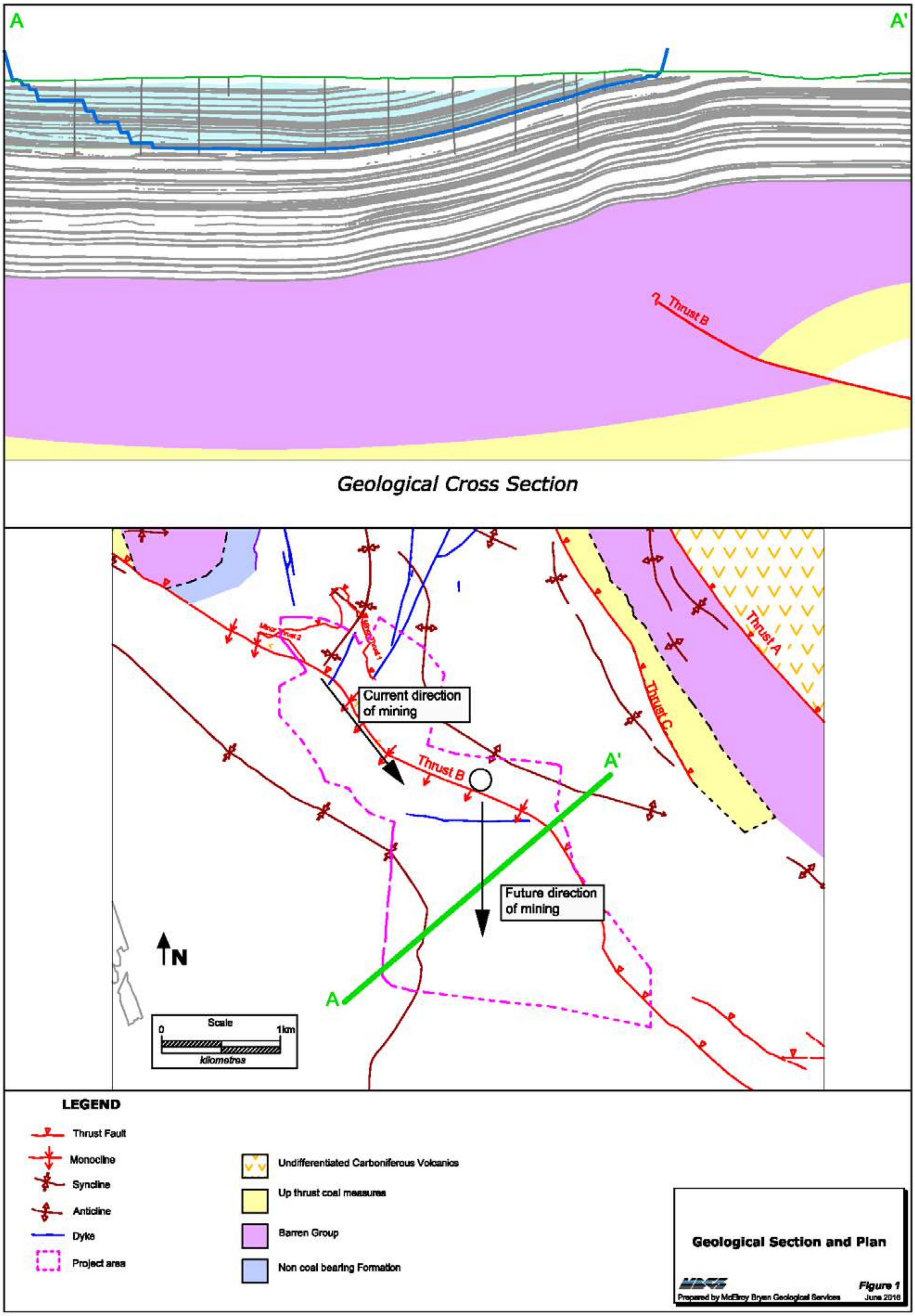


Figure 1 – Project area geology and geological section

The site geotechnical engineer and senior mine geologist investigated the endwall instability with in-pit and photogrammetry mapping. They identified conjugate joint sets J1 and J2, generally orthogonal and related to bedding. A third set, the D joint set was present within 200 m of the endwall (that is, near Thrust B), decreased in frequency away from the wall and rotated slightly with depth. The strike of the D joint set is similar to J2, with a shallower dip. The combination of joint sets, with D and J2 striking subparallel to the orientation of the endwall, creates small wedge failures, particularly in the more competent sandstone units.

METHODOLOGY

The acoustic scanner

This case study used acoustic scanner data for 60 drill holes, drilled from 2002 to 2012. The acoustic scanner is a geophysical downhole logging tool that generates a high resolution image of a drill hole wall by transmitting ultrasonic pulses and recording the reflected signal. The amplitude and travel time of the reflected signal are a function of the rock properties of the wall and the nature of the geological discontinuities such as bedding, joints and fault planes that are intersected by the drill hole. The acoustic scanner tool provides an accurate and cost effective means of determining the orientation of such geological features, and has the advantage over oriented-core methods of being able to use vertical holes. It is important to note that:

- The quality of the drill hole wall and water saturation of strata at the time of data collection can have a significant impact on data quality.
- The absence of evidence of a joint in acoustic scanner data interpretation does not necessarily indicate that the joint is not present in the strata.
- Drill hole orientation and deviation due to dipping strata may result in joints of particular orientation (e.g. sub-parallel to drill hole orientation) not being intersected in the drill hole.

Interpretation of acoustic scanner drill hole data

The acoustic scanner logs were reviewed and, where necessary, the interpretation was refined. Only joint data with high confidence was presented and all other features (such as faults and borehole breakout) were removed to reduce noise. The joint sets of interest occurred mainly in interburden strata, so jointing within coal seams was disregarded. Additional bedding, the strike of which is variable throughout the deposit, was also analysed in each hole to aid identification of the J1 and J2 joint sets and differentiation from the D joint set. Joint sets and bedding were presented as stereonet plots for the total hole (Figure 2) and in depth increments of 100 m.

The stereonet plots were analysed by an experienced geologist, aided by core photographs and geotechnical logs (where available) to determine the presence of specific joint sets within each hole. Approximately 15 holes within the mined area were analysed to provide a benchmark against the joint sets identified by site personnel using photogrammetry data. Once a benchmark was established, holes were analysed moving progressively south, into that area in advance of mining, and reviewed to identify trends and relationships in joint sets.

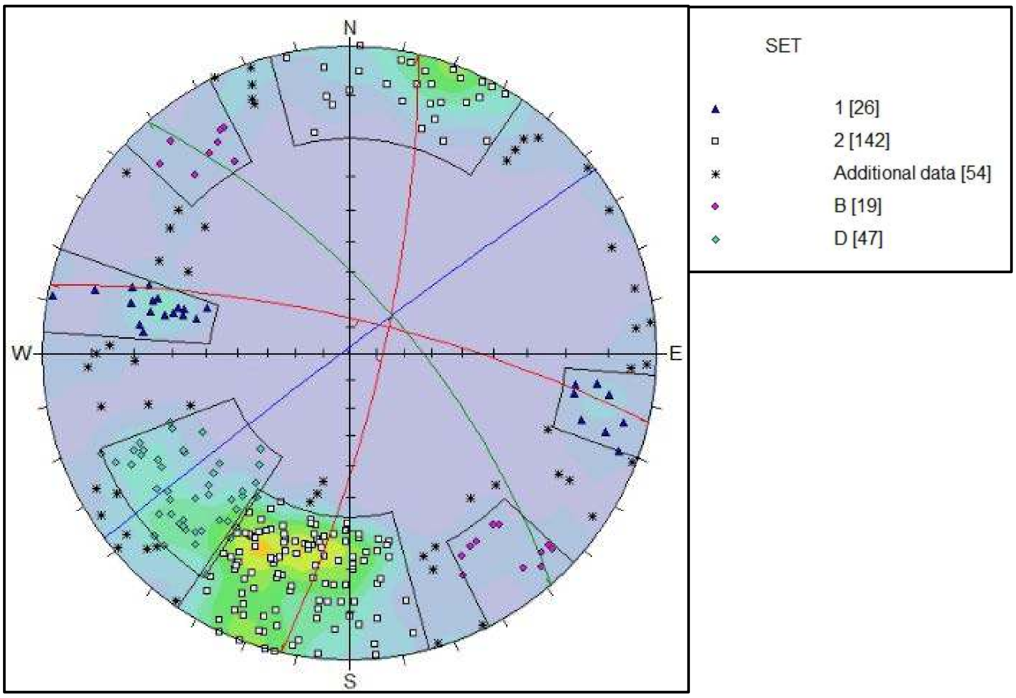


Figure 2 – Example stereonet showing the dominant joint sets in a drill hole

After analysing the data from the historical drill holes, six main joint sets were identified within current workings and in the future mining area. These joint sets were assigned identification codes in order to be traced throughout the deposit on stereonet plots. Drill holes in the southern portion of the lease were limited to a depth of approximately 200 m. This is significantly shallower than the majority of holes which reduces the effective sample size of these holes when interpreting joint sets.

Joint sets identified are described below:

- J1 and J2: conjugate joints apparently related to bedding which rotate clockwise over 90 degrees south through the project area with the folding of strata. J2 is readily identified in most drill holes, while J1 is less common. This is likely because J1 joints are often subparallel to drill hole orientation. Both appear approximately perpendicular to bedding prior to any deformation and as a result rotate predictably with changing bedding orientation. Dip angles for both joint sets typically range ±15-20 degrees. Strike of J1 and J2 commonly ranges ±10-15 degrees; J2 can range up to ±20 degrees.
- D: a joint set dipping either side of the vertical axis, these joints may be associated with east-west compression. In close proximity to the current western endwall, they are sometimes not able to be differentiated from J2 joints. D joints decrease in frequency moving east away from Thrust B, consistent with in-pit observations, and disappear entirely towards the centre of the project area. The strike of the D joints rotates with the orientation of Thrust B throughout the project area. When viewed in depth increments of 100 m, D joints rotate slightly towards the north with depth. Dip angle is typically ±10 degrees (up to ±25 degrees) and dip direction varies ±15 degrees (up to ±20 degrees). D joint orientation has stabilised in the south of the project area, typically dipping towards 065 to 085 degrees with dip varying from 55 to 90 degrees.
- R: the R joint set dips either side of the vertical axis and may be associated with north-south compression; they appear to be related to the syncline in the south of the project

area and are not present in the central or northern parts of the project area. Like D joints, they have a similar, often the same, dip and dip direction as J2 as J2 rotates with bedding. Often not more than a few joints presenting (which may be partly a function of the shallower drill holes in this area and therefore reduced sample size), dip angle typically varies by ±10 degrees and dip direction by ±15 degrees.

- A and B: conjugate joints which may be associated with north-south compression. Strike does not appear to rotate with the change in orientation of Thrust B. Both joint sets show evidence of dips rotating through the vertical. Strike ranges ±10 degrees and dips range from ±10-15 degrees. Strike has not rotated with the change in orientation of Thrust B. Joint set A typically appears in 4 particular interburdens usually made up of competent sandstone, though this may be a function of drill hole stability and the ability of the acoustic scanner to discern joints in strata, rather than the absence of these joints in other strata.

The D joint set is of most significance in relation to the current endwall failures. This set consists of low to moderate angle joints in close proximity to Thrust B. It strikes subparallel to, and dips slightly shallower than, the endwall, creating small wedge failures. This set was initially identified by site personnel using photogrammetry.

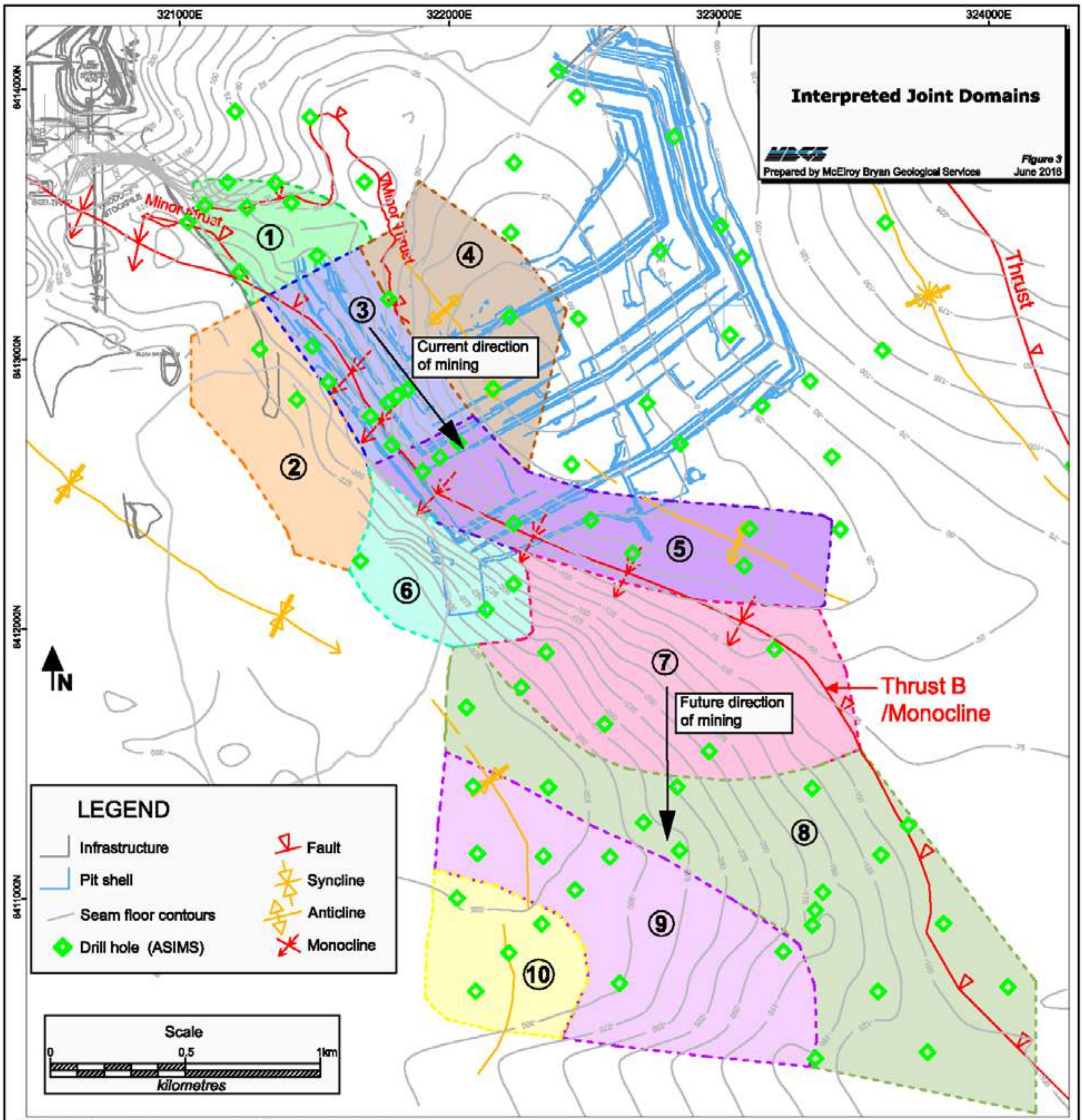
The J1 and J2 joints, associated with bedding and rotating through the deposit as the bedding rotates, predate the deformation events. A relationship was established between bedding orientation and joint orientation as they were traced throughout the project area.

The R, A and B joint sets develop in the areas of future mining, where the orientation of Thrust B has changed. They are not present in the current mining operations. The identification of these joint sets, similar to those currently causing instability, will aid in medium- to long-term planning and pit design. Several holes exhibit a second bedding set with different orientation to the main bedding set. In some holes one bedding set occurs above a fault (identified in interpreted acoustic scanner data, core logging or in-pit mapping) and the other below a fault. This rotation of bedding above and below a fault has also resulted in rotation in joint sets (seen in data presented in depth increments) and been used to identify those sets which have rotated with faulting.

Several drill holes which exhibit two bedding sets are not apparently faulted. The secondary bedding features occur at depths throughout the hole interspersed with identified horizons of the main bedding set and have been interpreted as a sedimentary feature. A review of core photos for cored holes which exhibit these secondary bedding sets indicate they may be associated with erosional coal seam contacts. In these instances, the second bedding set has not been taken into account when interpreting joint sets as it is not believed to have influenced jointing.

Joint Domains

Once all drill holes had been interpreted and reviewed, the project area was divided into ten domains based on similar joint orientations and characteristics. These are shown in Figure 3. These joint domains will aid in medium to long term planning of the development of the pit to minimise geotechnical instability.



DOMAIN LEGEND (Domain boundaries inferred)

Domain 1: Joint sets variable. No discernable joint pattern. Minor Thrusts 1 and 2 present generating variable strata dip.

Domain 2: J2 sets present. Strata dip 10-15° to southwest.

Domain 3: J1 and J2 joint sets present. J2 and De joint sets similar in dip direction; East: De dip angle is shallower than J2 dip angle; West: De dip angle is equal to or steeper than J2 dip angle; From west to east: De dip angle rotates towards the vertical. A and B joints becoming common. Southern end of zone J2 and De dip directions diverge by 20-40°. Strata dipping 25-35° towards southwest.

Domain 4: J1 and J2 joint sets present. Strata dipping towards the west with variable dip.

Domain 5: J1 and J2 joint sets present. De joints less common; where present, dip angle steeper than J2 and diverge by 40°. B joints more common in south. Rn may be developing in south. Bedding dip direction is rotating towards the south in the south. Dip is variable.

Domain 6: J1 and J2 joint sets present. De dipping shallower than J2. De, Dw, A and B all common.

Domain 7: J1 and J2 joint sets present. Rn becoming common in south, often with similar dip and dip direction to J2. Few occurences of D and A joints. Strata dipping southwest.

Domain 8: J1 and J2 present. A common near the eastern endwall. De and J2 have similar dip and dip direction in strata dipping towards 255-265 and often not separable. West-southwest dipping strata and southern portion of domain shows De, J2 and Rn as distinct sets with similar dip and varying dip direction. Strata varies from west-southwest to west.

Domain 9: J1 and J2 joint sets present. Few other joints near western endwall. A present in centre and south of domain. De and Dw joints present, however typically not common. Strata dipping west-northwest to west.

Domain 10: J1 and J2 joint sets present. De and B may be present. Strata dipping north to north-northwest.

Figure 3 – Joint domains identified using acoustic scanner interpretation results

CONCLUSIONS

By reviewing acoustic scanner data in conjunction with endwall photogrammetry data acquired by the mine site it was possible to identify joints identified in photogrammetry data and endwall mapping (J1, J2 and De) in acoustic scanner data from drill holes. Sixty drill holes in the project area were reviewed to identify bedding, joints and faults present and determine any relationships or trends in their orientation. The availability of acoustic scanner data and core photographs for holes in the project area, collected throughout the early stages of exploration and the photogrammetry data collected by the mine site allowed a close collaboration of "exploration" and "operational" data and expertise to aid in pit design orientation to minimise the risk of wall failures or further sterilisation of reserves.

Some limitations were the quality of data collected; the acoustic scanner works best in smooth holed walls (ideally fully cored) with high water tables. The population of data, allowing identification of a joint set, is also reduced by shallow drill holes. Also, where joints occur sub-parallel to the orientation of the drill hole, they may not be intersected in the hole. Fully cored angled holes with acoustic scanner logs may provide data in these data shadows.

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