# Blast design and analysis from aerial imagery

*A. Gaich & M. Pötsch*
*3GSM GmbH, Graz, Austria*

**ABSTRACT:**
Remote-controlled camera drones have reached a level of maturity which allow their routine application in mining and quarry for acquiring aerial imagery at high quality and resolution. Further developments in computer vision science allows for the rapid and consistent processing of a large set of highly overlapping pictures to registered 3D images. With 3D images several surveying and assessment tasks in surface mining are addressed. The use of aerial imagery from drones increases these possibilities and allow for the determination of several parameters (key performance indicators) that are utilised to benchmark and audit the results of drill and blast works in mining in surface operations.

## 1. INTRODUCTION

Drones (so-called unmanned aerial vehicles) have experienced a rapid development and maturity and are applied today by a broader user base. Remote-controlled and GPS-tracked devices are frequently used not only by consumers but also surveyors and related professionalists. In particular the attachment of cameras to drones (fixed or with gimbal) enhances their use for 3D imaging technology from aerial imagery. Nowadays, 3D imaging from drones has found its way to surveying tasks in surface mining and quarrying.

3D images have been used in the past for specific task related to surface mining and quarrying, mainly originating from terrestrial imagery. The tasks included 3D bench face profiling and designing of blasts, and also geometric rock mass characterisation. This article reviews and addresses the various possibilities utilising aerial 3D images in surface mining showcasing that a single data set is useful for several applications such as:

- Blast design and analysis
- Volumetric measurements
- Excavation planning
- Stability assessment
- Fragmentation analysis
- Updating mine maps
- General documentation purposes

In the following section a brief overview on 3D image generation is given as well as the application of 3D images for surface mining which is addressed by various examples.

## 2. 3D IMAGE GENERATION

Photogrammetric reconstruction of surfaces recover 3D information using at least two photos from different angles where the photos show the same part of a "scene", e.g. a rock surface. The technology behind is called photogrammetry and dates back to 1850 (cf. Slama 1980).

In the 1990's upcoming digital imaging and availability of computing power brought new algorithms and new applications to image based stereoscopic measurement and led to the introduction of the term Computer Vision (cf. Faugeras 1993). This technique has been used mainly in robotics but also for geometric rock mass characterisation (Gaich et al. 2003).

A more recent approach handles multiple photographs simultaneously in order to perform a fully automatic 3D reconstruction. This technique is known as Structure from Motion (Snavely et al. 2008). Structure from Motion has reached maturity in the Computer Vision domain but the number of applications using the technique remained rather low.

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Although the geometrical principles have been developed in the 1990's it took till the 2010's where an application to high resolution input photos has been realised mainly for the reconstruction of objects from unordered image collections obtained from Internet user photo galleries (Snavely et al. 2008). Photogrammetry and Structure from Motion have merged then which brought Structure from Motion also to measuring and surveying tasks (cf. Pollefeys et. al. 2001, Hoppe et al. 2012).

In parallel to the evolvement of photogrammetry the availability of small lightweight drones highly rose. The broad utilisation of drones increased the abilities of photogrammetry especially in surface mining. The better angle of the camera to the areas of interest overcame potential occlusions that often occurred in sole terrestrial imaging. Terrestrial imaging, however, is still beneficial for vertical walls and high image resolutions and might be nicely combined with aerial imagery.

An important requisite for comprehensive and accurate 3D models in this context is redundancy in form of having the same part of the surface visible in several images. This redundancy allows to close gaps that pure stereoscopic photogrammetry may deliver and it has the potential to increase the accuracy of single 3D surface points. It furthermore enables the determination of the camera distortions on the fly, i.e. it allows to calibrate the camera while doing the project (auto-calibration).

Applying the principles of the Structure from Motion, 3D images are processed immediately on site or off-site using a cloud based service. The first requires according computing power on site, the latter needs a transfer of potentially large amounts of data over a network in order to send the photos and receive the results. Several software packages exist that allow for a close-to-fully automatic processing of image data to consistent 3D models.

Figure 1 left shows a picture of a drone in a surface mine. It carries an off-the-shelf SLR camera and in this case flew the bench face and the muck pile before hauling. On the right side a stack of images is displayed, the overlap between the images was approx. 85%, i.e. each part of the surface is visible in at least 5 images.

Figure 2 showcases a crucial step for reaching accurate results in multi-photo reconstruction – the determination of the camera locations based on identified correspondences between the photos. In the example the drone flew operator controlled hence the "grid" of camera locations is not regular.

Figure 3 presents a snapshot of a 3D image taken of deposited tunnel excavation material in order to document the heap and to measure its volume. The computation of the 3D image requires the user to define a region of interest for the 3D measurements (optional), all other computation steps perform automatically.

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Figure 1: Drone ready for take-off in a surface mine (left) and stack of highly overlapping images (right).
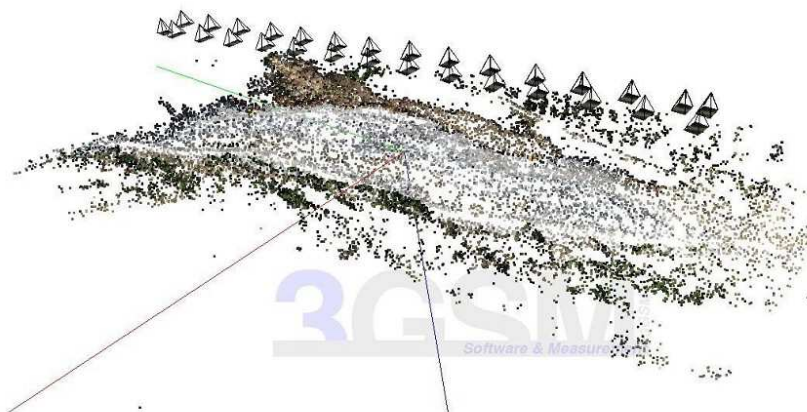


Figure 2: Intermediate result during 3D image generation: the small pyramids indicate recovered camera locations based on a subset of 3D surface points.

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Figure 3: 3D image of a deposit (ca. 300 x 50 m)

## 3. THE APPLICATION OF IMAGES IN SURFACE MINING

There are several reasons why aerial 3D imagery fits so well to surface mining sites: (i) large areas need to be acquired (surveyed), (ii) several parts are difficult to access or not accessible (e.g. highwalls), (iii) usually no vegetation obstructs the rock surface, (iv) drone flights over uninhabited areas are easier to perform from the legal point of view. The following sections showcase examples for 3D image generation from drone imagery applied in a surface mine and thus demonstrate its fields of application.

### 3.1 Blast design

Incomprehensive knowledge on the geometry of a blast site and especially the face may lead to unexpected blasting results (Moser et al. 2007). Economic consequences of poor blasting in a surface mine or quarry include:

- Additional efforts for loading and hauling
- Efforts for secondary breakage
- Too much fines
- Reduced crusher performance
- Additional wear of equipment due to uneven floors

More importantly, safety-related issues are also associated with:

- Fly rock incidents
- Excessive vibrations
- Air blasts
- Excessively damaged rock walls and floors leading to safety hazards

3D images provide a straightforward data basis for improving blasting results as they provide both (i) detailed information on the geometry of the blast site and (ii) a visually clear and detailed representation of the rock mass conditions. They enable to proactively design and optimise the drill pattern and loading according to the actual bench face geometry. This becomes a particular evidence at irregular bench faces, blasts with several free faces, or very large blast sites. The comprehensive data set from an aerial 3D image enhances the information of a face profile. It additionally provides the detailed geometry of the top of bench and in particular the conditions along the crest line.

Once the 3D image is generated and the drill pattern specified, real burden information is available, i.e. the distance from the borehole to the closest location of the free surface in any direction (360° spherical search). The 3D image may be colourised according to the current burden situation with reference to the design burden and a site-specific corridor of acceptance. Current burden values within the corridor of acceptance are coloured green while burden values below or above are the coloured red or blue, respectively; hence making problematic areas obvious. By overlaying the colour codes to the 3D image, a self-explaining representation of the burden situation results (see Figure 4). In a proactive design approach, this information is used to adjust the location and/or the inclination of certain boreholes in order to adapt to the bench face geometry. Adjustment criteria may include minimisation of light and heavy burden areas or avoidance of (too) small borehole spacings. The so-called minimum burden is the key information for the optimisation of a drill pattern (cf. Moser et al. 2007). Since aerial 3D images provide detailed information on the top of bench, borehole length can be easily designed to match a horizontal plane or ramp. The result is a borehole map with co-ordinates for each borehole collar, the length, inclination, and bearing for each hole, as well as corresponding profile/burden data.
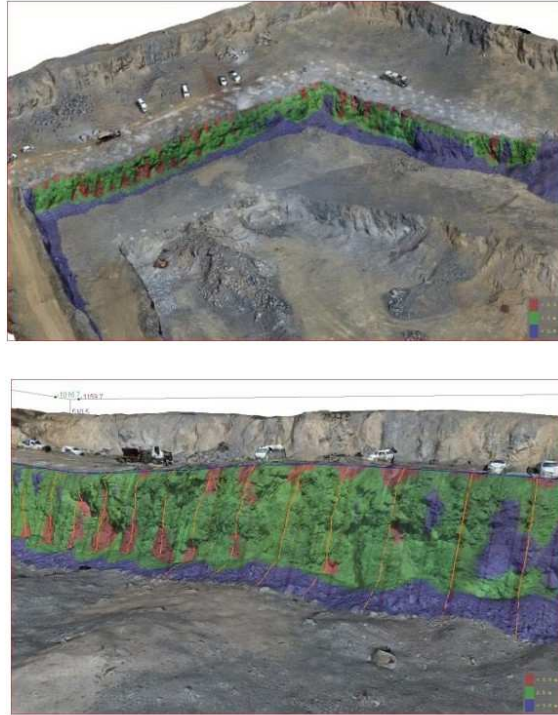


Figure 4: 3D image of a blast site including colour-coded visualisation of burden over the bench face area (left); detailed view with borehole profile locations (right). Green: design burden; Red: light burden; Blue: heavy burden

A complete blast design requires to audit the pattern as drilled, i.e. each borehole location and its course. Several sophisticated possibilities exist such as GPS with rover receiver, drill rigs with included GPS, down-the-hole probes, and drill rigs with such measurement possibility included. A basic method to audit as drilled borehole collars is the use of a tape measure along and across a predefined reference line. Aerial 3D images of blast sites with already drilled holes also allows to audit the collar positions directly (see Figure 5 left). In such cases neither a rover receiver nor GPS on the rig is required.
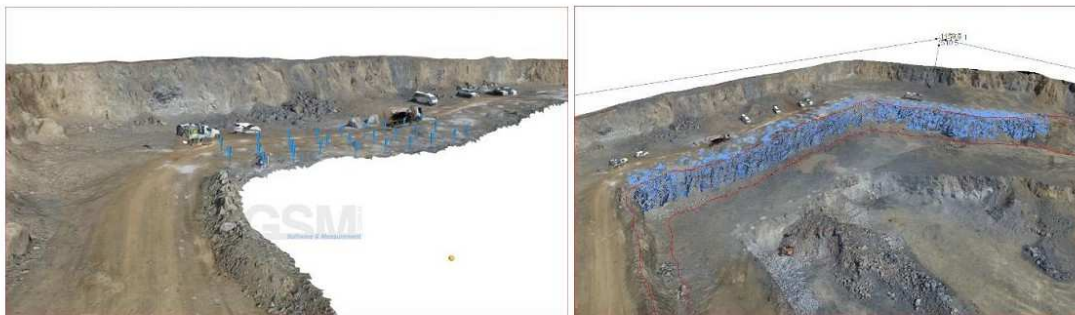
Figure 4: 3D image of a blast site including colour-coded visualisation of burden over the bench face area (left); detailed view with borehole profile locations (right). Green: design burden; Red: light burden; Blue: heavy burden

Figure 5 right shows the bank volume of the readily designed and audited blast. Together with the updated burden charts from the audit and the according profile plots, this provides information for an adequate loading of the holes.

(Stewart 2017) describes the geometric and economic impacts of proactive blast design including auditing using 3D images: Production time was reduced by 10% and the efforts for secondary breakage went down significantly.

### 3.2    Post-blast analysis

The 3D image survey of section 3.1 includes information before executing the blast (pre-blast survey). A drone flight after the blast allows for the analysis of the muck pile and its fragmentation (post-blast analysis). The post-blast 3D surface needs to be registered in the same co-ordinate system in order to enable comparative analyses. This is usually accomplished by geo-referenced surveys. If geo-referencing is not available, it is still possible to register the 3D models in a common local co-ordinate system based on common parts in the pre- and post-blast survey that remain unchanged in the 3D images.

Figure 6 depicts an overlay of two 3D images (pre- and post-blast) as well as a vertical section through the model. The resulting graphs visualise the shape of bench face and muck pile at this location. The power trough becomes obvious. Its location and depth is determinable simply from the data.
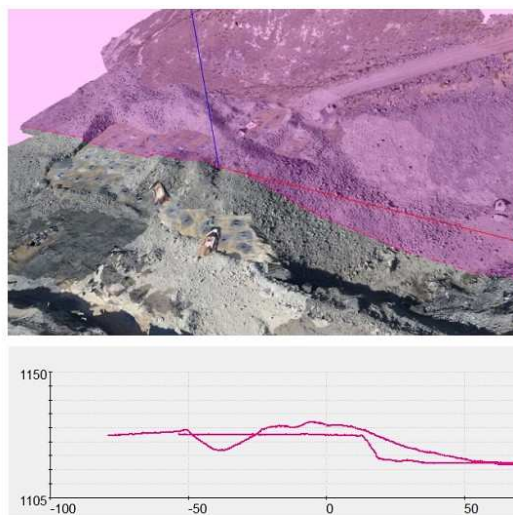


Figure 6: A section through 3D surfaces pre- and post-blast reveals the shape of the muck pile and allows the determination of depth and location of the power trough (arrow).



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The volume of the muck pile is determined by the comparison of the two surfaces pre- and post-blast. The embedded volume between the surfaces corresponds to the volume (see Figure 7). Note that the precise volume of the muck pile is available once the whole muck pile has been cleared from the new free face. So, only a third drone flight after mucking (post-mucking survey) enables the precise determination of the blasted volume, the real bank volume, and the accurate volume of the muck pile. With this information at hand the swell as the ratio between the muck pile volume and bank volume is determined.

Another key parameter for describing blasting results is the distribution of particle sizes (fragmentation). Several software solutions are offered on the market. Some rely on the segmentation of particles by 2D image analysis (e.g. Split, WipFrag). The required scale information is introduced either by objects of known size in the photos or by basic stereoscopy with known camera distances (Motion Metrics). Also geometric approaches exist (Thurley et al. 2015) performing an analysis of the shape of the muck pile. Using 3D images, both ideas nicely combine and enable taking out the best of both approaches. Figure 8 shows a section of a 3D image from a muck pile and the resulting delineation of particles. The applied algorithm analyses the shape of the surface and combines the result with image processing algorithms.



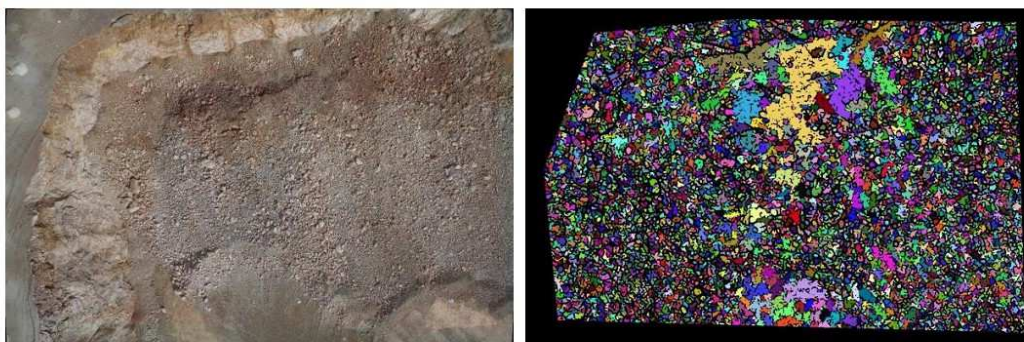Figure 7: Volumetric description between two arbitrary shaped surfaces.

Figure 8: 3D image of a muck pile (left) and automatic particle detection based on the combination of geometric analysis and image processing (right).

3D images form a self-explaining type of documentation. Whenever an incident occurs, the presence of data that is easily communicated also to non-experts in the field is beneficial. In addition to the 3D images the generation of a video document of the blast is useful. The video additionally enhances the means of communication as mentioned.

Topographic maps are inherently generated from 3D images and are available for free when performing blast design or blast documentation. Figure 9 shows a topographic map from a part of a surface mine where a blast site has been designed.
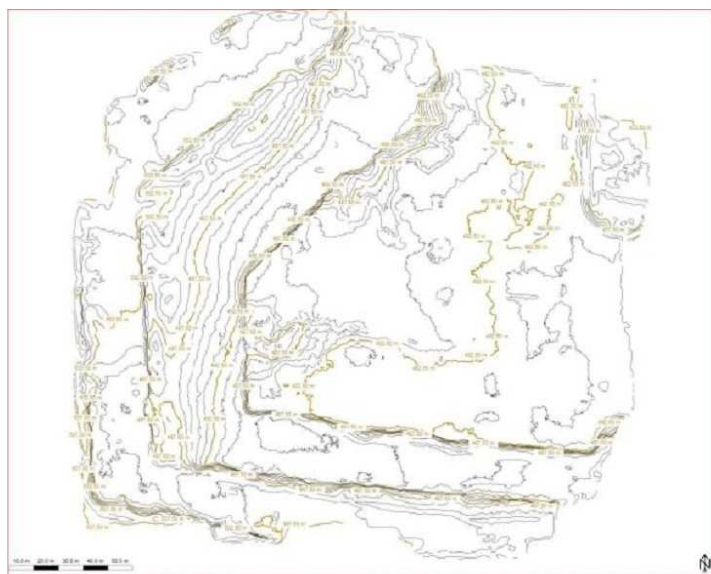


Figure 9: Topographic map of a surface blast site and its adjacent benches and ramps.

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### 3.4 Geometric rock mass characterisation

The natural representation of the rock surface with a 3D image allow for qualitative and quantitative assessments. Qualitative assessments include the face quality in general and the presence of open and/or large joints, cavities, or weak zones, e.g. mud seams or faults.

For a quantification of (geometric) rock mass properties spatial measurements are required. Software tools exist that enable the determination of joint orientations, joint sets and their spatial variation, as well as quality parameters such as joint frequency, or joint spacing. Such characterisation of the rock mass may also happen automatically or semi-automatically. Approaches as described by (Slob 2010, Riquelme et al. 2014) aim to identify planar regions in 3D point clouds. Figure 10 and Figure 11 outline the principle of a topographic analysis of a 3D surface.

The basis is the set of normal vectors over the surface. Their spatial distribution resp. their density lead to clusters of the normal vector's orientation. The clusters are then used in a second processing step for the generation of areas that may correspond with joint surfaces (see Figure 11).

The possibilities within quantified rock mass characterisation provide a profound data basis for defining the geometric parameters of a fractured rock mass such as the number of joint sets, joint set orientations and its variation, joint set spacing and its variation, joint set persistence, etc. High resolution surveys also enable the measurement of the waviness and roughness of the exposed joint surfaces. The basic input parameters for stability assessments of benches, inter-ramp slopes and overall pit slopes are quickly available, and can be easily audited additionally.
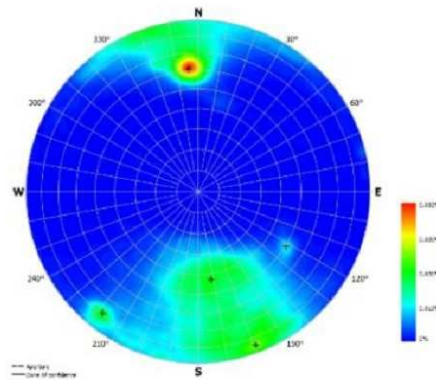


Figure 10: Section of a bench face (left) and automatically analysed orientations of surface normal including colour-coded density distribution (right)

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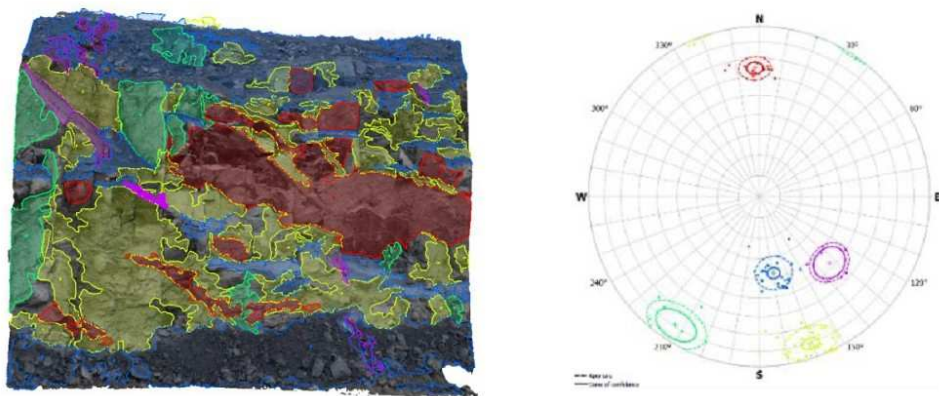www.efee.eu /newsletter@efee.eu

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Figure 11: Automatically determined surface areas, clustered according to their spatial orientations (left) and according plot in the stereo net (right).
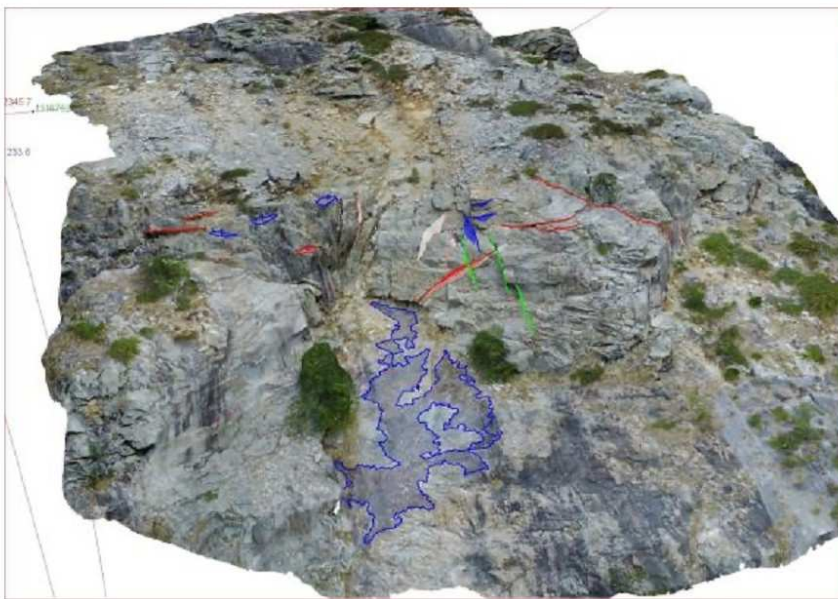


Figure 12: Basic geologic mapping of a rock wall area with difficult access forms the basis for stability assessments.

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## 4. CONCLUSIONS

The use of aerial 3D imagery taken with drones allows for performing several surveying and assessment tasks in surface mining and allow for the determination of several key performance indicators. The consequent determination of such parameters lead to comparable results between different blasts and shall help to improve the quality of drilling and blasting works in terms of productivity and efficiency while still preserving high safety standards. Surveying and assessment tasks related with the application of aerial 3D images include:

- Surveying of bench face, top, and floor
- Face profiling – pattern, profiles, minimum burden
- Blast design
- Post-blast analysis
- Rock mass characterisation - geological mapping
- Mine plan update
- General documentation

Key performance indicators determined from 3D images:

First drone flight (pre-blast):
- Pre-blast volume – as designed (prediction)
- Pre-blast volume – as drilled (prediction)
- Location of hole collars
- Thickness of seams, orientation, location (geological mapping)

Second drone flights (post-blast before mucking):
- Volume of the muck pile (estimation)
- Bank volume (estimated)
- Height and width of the muck pile
- Power trough volume
- Power trough cross sections – location of minimum
- Fragmentation distribution
- Visible half barrels – Number, average length, total length

Third drone flights (after mucking):
- Volume of the muck pile (real)
- Bank volume (real)
- Percent cast as a volume ratio
- Swell of the muck pile volume
- Back break – Distances, Volumes
- Number and length of half barrels and burn cuts

Using aerial 3D imagery from drones covers a wide range of application in surface mining making this technology a viable standard operating procedure.

## 5. ACKNOWLEDGEMENTS

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