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3D implicit modelling and geometrical analysis of structural fabrics: Implications for future pit design and optimization

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Pit design plays an integral part in the economic viability and safety of opencast mine operations. It requires integration of complex geotechnical variables that are dependent on a thorough understanding of the volume of interest and its structural evolution. Any analysis should include the interaction between the following parameters: **1)** angle of the design pit wall (e.g. crest-to-toe, inter-ramp or bench face angles) and 2) geometry of planes of anisotropy or potential failure planes (e.g. bedding, lithological and intrusive contacts, foliations, fractures/joints and faults).

Historically, analysis has been hindered by unrealistic geometrical representations of lithological and structural features, e.g. lithological contacts (bedding), foliations and faults, mainly due to coarse, often manual, *explicit* triangulation during 3D model creation. Recent advances in rules-based, *implicit* 3D modelling (also known as conditional geometrical modelling) have allowed the construction of smooth, high-resolution, geologically-realistic surfaces that honour a wide range of data (drillhole logging, surface mapping, geophysics). Crucially, the continuous lateral variation in the orientation of surfaces may be interrogated by extracting triangle orientations and using such data to populate 2D or 3D grids. Such grids may also be populated, using interpolation, by hard data (such as bedding orientations from mapping and downhole oriented A/OTV data). These grid points can be projected onto a pit wall after which the apparent dip, expressing the angular interaction between the pit wall and plains of anisotropy, may be calculated. This technique allows for the creation of accurate *apparent dip angle* maps. *Apparent dip angles* may subsequently be interrogated or filtered using, for instance, lithology-specific friction angles. They may furthermore be compared to inter-ramp stack angles. This allows geotechnical engineers to augment the more traditional approach of analyzing radial 2D design sections, which rely on median or average values for several parameters.

The analysis of two open cast mines of Kumba Iron Ore, namely Sishen and Leeuwfontein (part of Kolomela Mine), demonstrate the technique. In both cases, zones with relatively favourable pit wall angles (potential failure planes with apparent dip angles that are below the rock-shear failure threshold and/or dipping into the face) are highlighted. Similarly, relatively un-favourable zones, where bedding is steeply dipping out of the face or exceed a critical friction angle are highlighted. The latter zones require monitoring from a geotechnical perspective and may even justify the definition of specific geotechnical design sectors. Alternatively, slope angles within more favourable zones may be optimized (e.g. slope angles may be increased) to reduce waste rock mining. The technique is applicable only to high resolution, implicitly-built, 3D models, combined with high-quality structural data derived from pit mapping and/or downhole oriented core. These results need to be further analysed using the appropriate numerical stability designs.