New processing methodology of televiewer data for the definition of geotechnical and structural domains

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ABSTRACT

Six structural domains were defined using data from acoustic televiewers and oriented boreholes as part of the reopening of the old Aznalcóllar mining site in Sevilla, southern Spain, by Minera Los Frailes (MLF). Additionally, geotechnical subdomains were defined within each structural domain, classifying the subdomains based on geotechnical parameters obtained from the geotechnical logging of boreholes and through correlations. The methodology used to define the domains allows mine design and planning to be done with enough accuracy to determine the underground excavation needs and the systematic methodology. The main source of this new structural information was acoustic borehole image televiewers (ABI) and, on a much minor scale and as a complement for ABI data, oriented boreholes. This paper describes the methodology used for this definition, some of the challenges encountered during the investigation, the main results obtained and the utility of these defined structural domains in the development of the MLF mining site reopening. Additionally, a preliminary approach to an updated methodology in the definition of structural domains with the combination of televiewer data, both acoustic and optical, with data obtained from other downhole probes is also included.

Keywords: televiewer; geophysical logging; geotechnical domains; mining;

1. Introduction

The old Aznalcollar mining site was exploited in two open pits for polymetallic sulphides (Cu-Pb-Zn) between 1975 and 2001 and is currently scheduled for reopening by Minera Los Frailes (MLF). Due to mine authorities' restrictions, the reopening must be developed as underground mining. Available historical geotechnical data were obtained and used for open pit operations, but the use of this information for an underground mine is not always possible because the information needed for underground design is mainly oriented for support design and stopes dimension, while in open pits, geotechnical information is required mainly for slope characterization.

Underground works support has to be defined systematically to provide a safety factor enough to operate the mine in safe conditions and to obtain a good excavation rhythm and, hence, a satisfactory ore production. With the methodology used to define the structural domains, mine design and planning can be done with enough accuracy to determine the underground excavation needs and the systematic methodology. The main source of this new structural information was acoustic borehole image televiewers (ABI) and, in a much minor scale and as a complement for ABI data, oriented core boreholes.

2. ABI equipment background

The acoustic televiewer is a geophysical borehole logging probe that provides a continuous image record of the borehole wall (ABI), based on the amplitude and travel time of acoustic waves emitted from the probe towards the rock mass in presence of water. Travel time for the energy wave is the period between transmission of the source energy pulse and the return of the reflected wave measured at the point of maximum wave amplitude. The acoustic waves are generated and received by a specially designed piezoelectric crystal with a frequency between 0.5 and 1.5 MHz.

The interpretation of the data obtained with this probe is based on the fact that the amount of energy reflected by the borehole wall depends on its physical properties. Thus, any characteristic of this borehole wall can be recorded, and represented by a flat acoustic image, oriented thanks to a 3-axis magnetometer and 3 accelerometers inside the probe.

The main application of this borehole logging method is the characterization of linear discontinuities (faults, fractures, joints, foliation…) present in the borehole wall. In comparison to oriented core boreholes, a more classic procedure, this method has the following advantages:

- it is not biassed by the drilling method, drilling equipment or drilling operator expertise;

- it detects more precisely small structures like foliation or other thin laminations;
- it measures borehole deviation;
- it can measure the orientation of the maximum and minimum horizontal stress in the rock mass by analysis of the ovalization and breakouts;
- it can be combined easily with other borehole logging methods to better defined the rock mass (like natural gamma or electrical resistivity);
- the final product is more useful;
- finally, but no less important, it is a significantly cheaper method.

Fig. 1 shows an example of an ABI log with discontinuities picked.

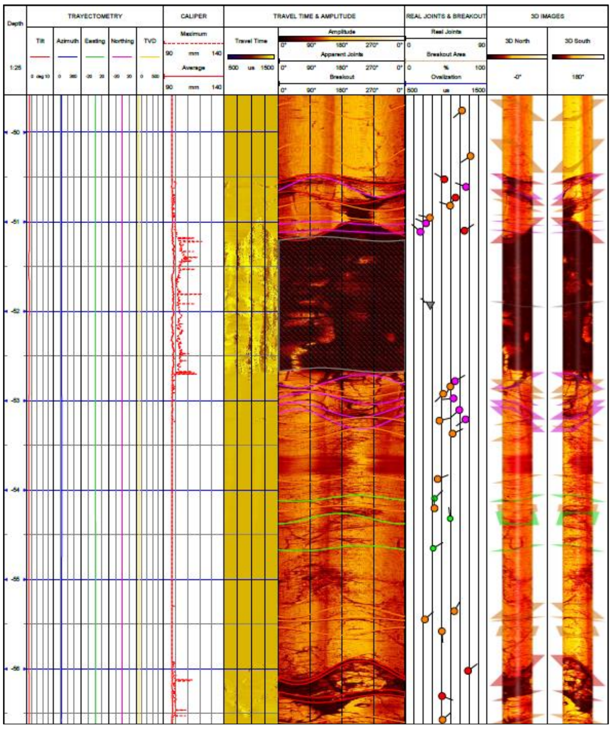

Figure 1. Example of an ABI log with discontinuities picked.

As can be seen in Fig. 2, the intersection with respect to the axis of the borehole of any plane not perpendicular to it creates an ellipse, which developed in two dimensions becomes a sinusoidal curve. The phase of this curve indicates the apparent dip direction with respect to the magnetic north, or the high side in inclined boreholes, and the amplitude of the wave indicates the apparent degree of inclination, or dip, of the plane.

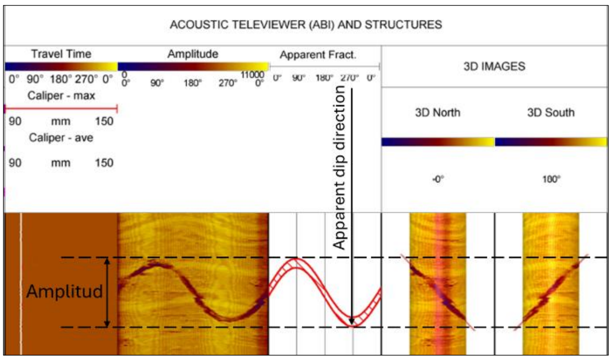

Figure 2. Example of discontinuity orientation measurement.

With the borehole deviation measurement, these apparent measurements can be converted into the real dip angle and dip azimuth of the plane. In other words, the true orientation of a discontinuity in the rock mass can be defined.

Having the true orientation of all the picked discontinuities of a borehole, or various boreholes, stereographic projections can be performed to analyse the dominant sets or families of discontinuities and, therefore, know the abundance of the different types of discontinuities in the rock mass. Fig 3. show an example of a stereographic projection of a family of discontinuities in 3D and 2D.

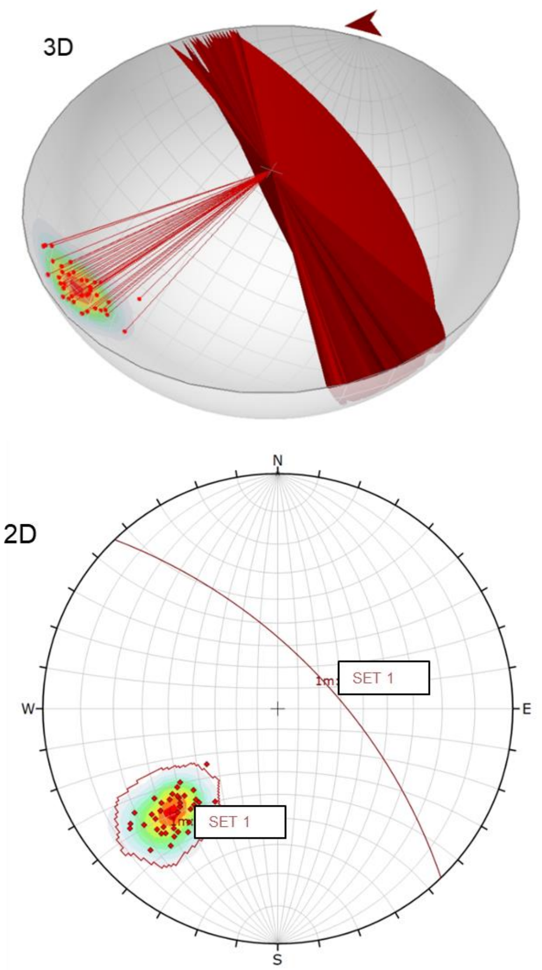

Figure 3. Example of stereographic projections in 3D and 2D

The Terzaghi correction is used to give greater weight to structures whose frequency of appearance is lower, because they are directly influenced by the inclination and direction of the borehole. Thus, fractures with orientations and inclinations similar to that of the borehole will have greater weight because the frequency of being crossed is lower.

3. Specific methodology

The methodology used for the definition of structural domains in MLF is an expansion of the one previously used in Rosario and Rosario Oeste deposits in the Collahuasi mining district, Chile (Sánchez et al. 2013).

3.1. ABI processing adapted to definition of structural domains

A structural domain can be described as a portion of the rock mass, spatially and geographically delimited, with unique structural characteristics. Specifically, a structural domain might be defined by the orientation of the primary and secondary sets of discontinuities and the type of discontinuities that define each set. A simplified diagram explaining this can be found below in Fig. 4.

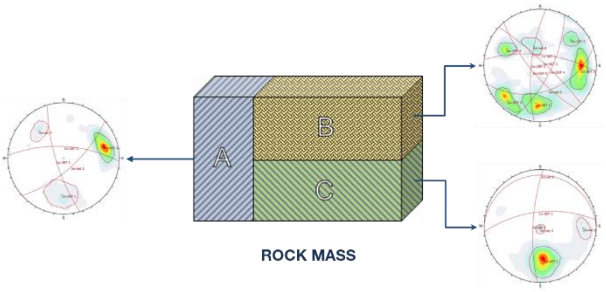

Figure 4. Simplified diagram of structural domain definition.

A structure picked in an ABI log, or an oriented borehole, is fundamentally defined by its depth in the borehole, its dip angle and its dip azimuth. Usually, in the majority of processing of ABI logs, the aperture of the structure is also given, and it is categorised as opened or closed, but no other secondary information is added. This is not enough to define structural domains. Thus, a reprocessing of ABI data to adapt them for structural domain definition is key. A lot of information can be added to the picked structure. In this project, the following data was added:

- the position of the structure in the space by means of coordinates and elevation,
- the rank of the structure (the structures have to be categorised differentiating between major and minor open joints, partially open joints, filled joints, foliation, bedding, etc.),
- the lithology where the structure is encountered,
- its weight after applying Terzaghi correction (Terzaghi 1965).

A preliminary database was created with all this information and plotted in a geomodeling software with the 3D modelling of the mining site.

3.2. Multicriteria structural analysis for definition of structural domains

Multicriteria structural analysis was performed based on the mining site database and geological modelling. The results of the most important queries performed are shown in Fig. 5 as stereographic projections.

Primary and secondary sets of joints were delimited in each structural analysis and compared, checking for changes in dip and dip direction.

3.3. Definition of preliminary structural domains

Preliminary structural domains were defined based on the results of the structural analysis performed. Each structure was classified in the database within one of these domains, allowing multicriteria structural analysis and statistical analysis to be performed in each domain individually.

The preliminary structural domains are considered final if they are validated by all the personnel involved in the project after passing a quality check.

4. Results and discussion

Six structural domains were defined in MLF and named with capital letters from A to F, as shown in Fig. 6. The main factor dividing the different domains was lithology. The distribution of the principal sets in the

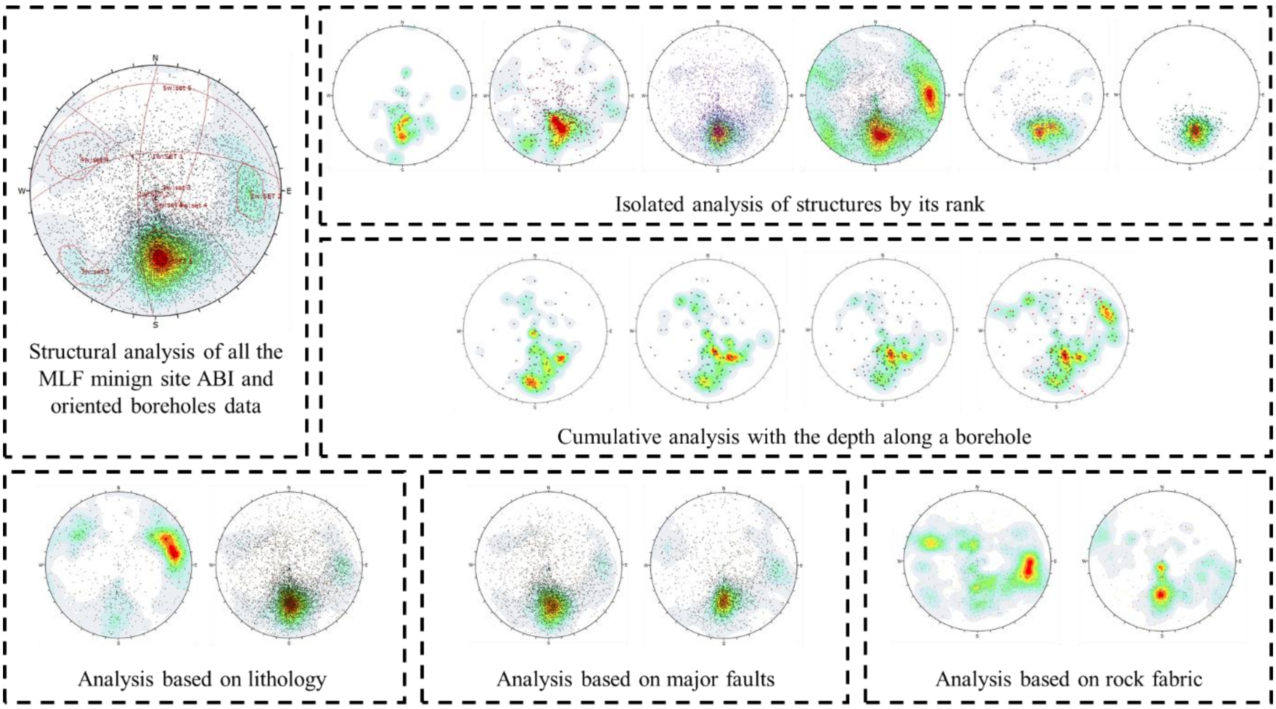

Figure 5. Example of some of the multicriteria structural analysis performed.

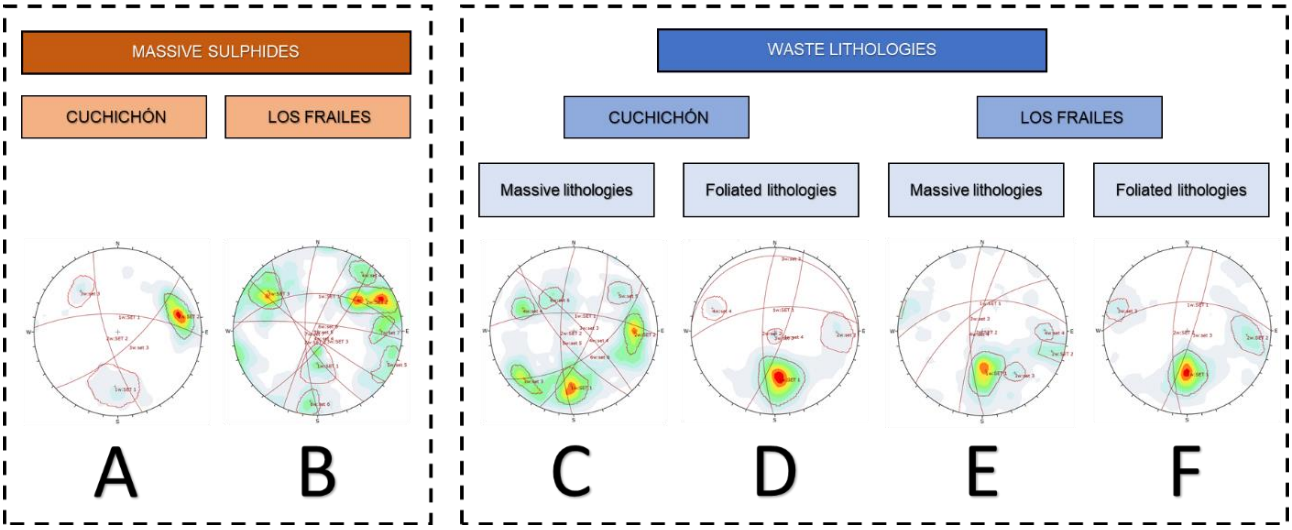

Figure 6. Structural domains defined in MLF (in capital letters).

massive sulphides was less dependent on the rock fabric than the other lithologies in the area.

A second division is tectonic controlled, with the two ore bodies, Cuchichón and Los Frailes, which are separated by a major thrust, having different distribution of poles. The main difference is that in Cuchichón the foliation has a higher dip angle than in Los Frailes.

With this second division, the domains in the massive sulphides were defined, domain A and B, but another division was necessary in the rest of the lithologies of the deposit, the waste lithologies, based on the fabric of the rock. The distribution of poles in the stereographic projections of the strong foliated lithologies in both ore bodies is strongly dependent on the orientation of the foliation, with just one primary set of joints, while in the non-foliated lithologies the distribution is more spread through the stereographic projection. This division between massive and foliated lithologies is more accused in Cuchichón ore body, which has more major faults, but can also be seen in Los Frailes ore body.

A north-south vertical slice of the ore deposit with the structural domains modelled is shown in Fig. 7. The figure shows that domains A, C and D, from Cuchichón, are only present to the south of Fault A LF and Fault MF LF on surface, while domains B, E and F, from Los Frailes ore body, are only present to the north of the fault. This limit between the two ore bodies' areas of influence is Fault MF LF and not Fault A LF or Fault TZ LF, and this was defined thanks to the definition of the structural domains. This tectonic boundary was later corroborated on the field by measuring the change in the foliation of the outcrops at both sides of the fault. The areas with no structural information due to lack of interest for the exploitation reopening are labelled based on the lithology code used by MLF and the major faults.

Statistical analysis of the individual domains were executed to better characterise them and to confirm their differences. An example graph of this statistical analysis is shown in Fig. 8 which is related to the relative frequency of the dip angle and dip azimuth of the discontinuities in Domain A.

The structural database created was merged with geotechnical information to create a new database with structural data and Q-values defined by (Barton 1998) for

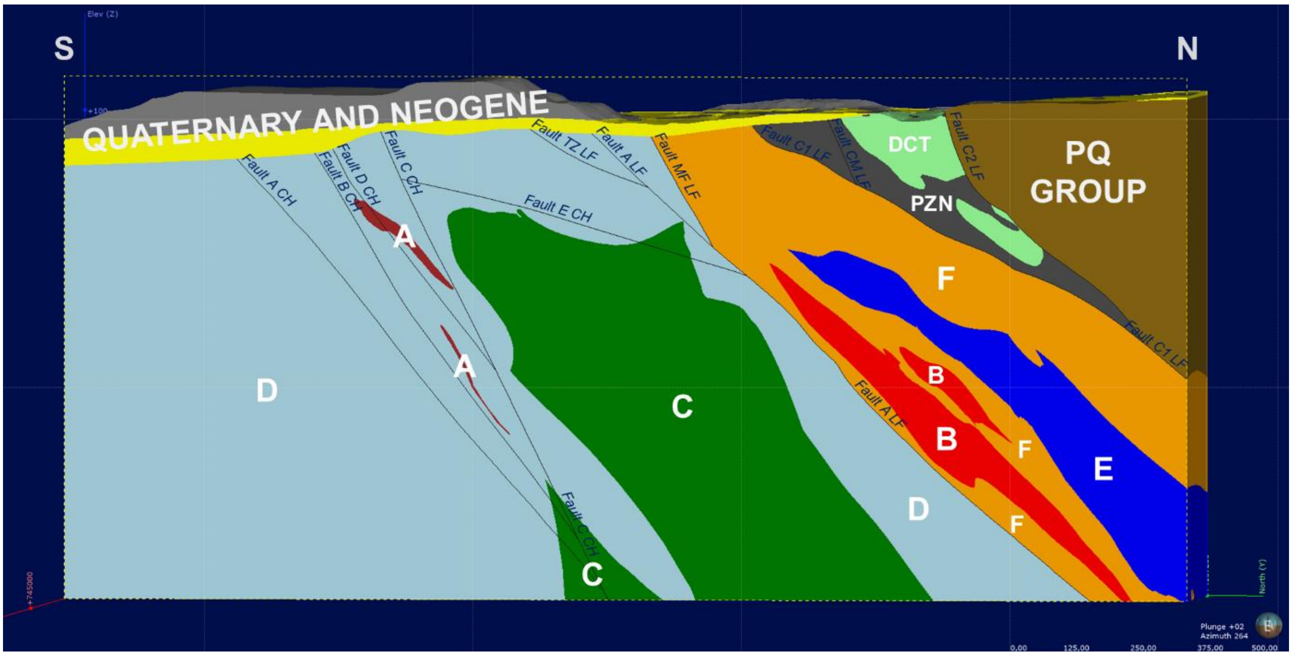

Figure 7. North-south vertical slice of the 3D modelling of the defined structural domains in MLF.

rock mass classification. Each picked structure was labelled with a capital letter showing the structural domain of the structure followed by a number between 1 and 5 based on Q-values, being 1 the worst quality class.

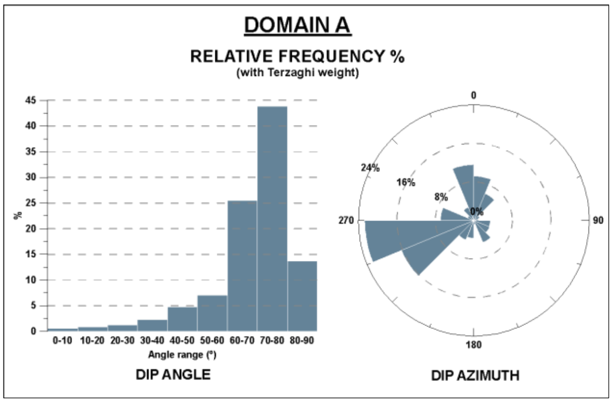

Figure 8. Statistical analysis in Domain A.

With this database, geotechnical subdomains were defined, and statistical analysis were performed. An example of this for Domain A is shown below in Fig. 9 where it can be seen that Q class 4 (Q-values from 0.4 to 1.0) is dominant within the domain.

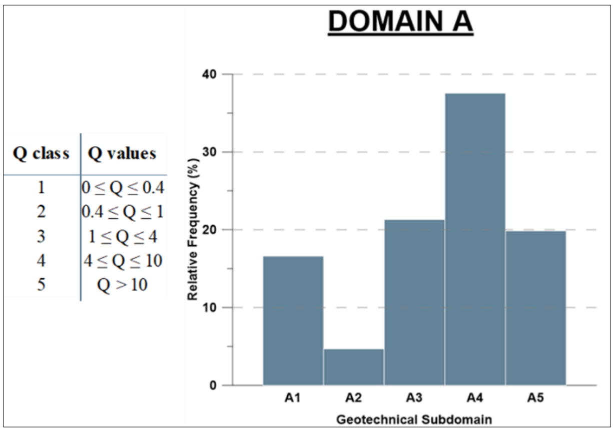

Figure 9. Geotechnical subdomains defined in Domain A

It is scheduled to use these geotechnical subdomains in the mining exploitation plan by defining its spatial limits to be used in support design and stopes dimension.

5. Conclusions

Normally, televiewers, and other borehole geophysical logging works, are viewed as a secondary source of information during mining feasibility studies and are usually postponed until the last stages of the study, when the boreholes available are scarce and the definition of structural domains is not possible or new boreholes have to be performed to complete a grid with enough information to define a geometry.

A televiewer campaign aiming the definition of structural domains should be part of any underground mining feasibility study. It provides structural information that, with the combination of geotechnical data, will be a key tool in support design, stopes dimension and short-term mining planification.

This new methodology of processing televiewer data increases their utility and can be applied to any old televiewer data through quality control and reprocessing.

Additionally, it was clear during the quality control that structural data obtained from televiewer compared to oriented core boreholes is much more useful and reliable.

Acknowledgements

Thanks to all the Minera Los Frailes staff, especially the geology department, for their close collaboration during the execution of the project.

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