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Geotechnical studies for the Kelian River diversion project, Indonesia

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ABSTRACT: The site investigation program for the proposed Kelian River diversion adopted an integrated approach between mapping, drilling and geophysical studies to overcome difficult site conditions. This allowed optimisation of data along the three alternate open channel routes and at depth to the channel invert level. A total of 26 boreholes, 1466m of drilling and 3400m of seismic refraction survey was carried out. Geotechnical data was presented as summary logs on geological sections to provide suitable models for design studies. Channel slope design adopted a "mine geotechnics" approach to maximise overall slope angles and reduce costs within an acceptable degree of risk commensurate with a civil engineering structure. Physical and geotechnical criteria were used to provide guidelines for final selection of the channel route.

1 INTRODUCTION

The Kelian Gold Mine is located about 150km west of Samarinda in the foothills of the Central Kalimantan mountains of Borneo (Figure 1). Kelian is the largest gold mine in Indonesia with production averaging 360,000 ounces of gold per year and current published mineable reserves of 44 million tonnes.

In 1992 additional resource was discovered to the north east of the East Prampus pit under the Kelian River, a tributary of the large Mahakam River. To allow the pit to be extended the Kelian River will require relocation to a position north of the current river channel.

The preferred diversion option was an open channel compared with a pressure tunnel or culvert due to the reduced risk of blockage. As part of the engineering study for the river diversion a geotechnical investigation was carried out in 1993 for three alternate channel routes (Coffey Partners 1993). The alternate routes range in length up to 1750m, involve excavations up to 100m deep and include upstream and downstream diversion bunds (Figure 2).

This paper focuses on a number of features of the geotechnical study with the principal objectives to:

1. highlight the integrated approach used in the site investigation program between mapping, drilling and geophysical methods,
2. emphasise the importance of establishing suitable geological and geotechnical models,
3. briefly describe the methods used in the channel design studies emphasising how the geological and geotechnical models are applied to design.

2 GEOMORPHIC AND GEOLOGICAL SETTING

The topography in the study area is steep with slopes up to 50° and extending to heights of 120m above the Kelian River. The climate is tropical with an annual rainfall of about 4000mm occurring mostly during high intensity rainstorm events. The slopes are heavily vegetated by rainforest with some areas of secondary vegetation where logging has previously been undertaken.

The geological setting of the study area is dominated by a diatreme breccia pipe formed by a phreatomagmatic eruption during a Late Oligocene to Early Miocene event. The diatreme eruption is caused by explosive venting groundwater vapour which has come into contact with a high level heat source and forms a funnel shaped body of rock locally termed muddy breccia.

The basement rock into which the muddy breccia has formed is a sequence of Paleocene-Oligocene age sedimentary and pyroclastic units intruded by a number of andesite and rhyolite bodies. Folding and faulting of the sequence took place followed by a period of erosion removing the upper part of the pile prior to Plio-Pleistocene basaltic volcanism (Van Leeuwen et al 1990).

Figure 1. Location of the Kelian Gold Deposit.

3 SITE INVESTIGATION PROGRAM

3.1 Approach

The combination of difficult physical conditions and complex geological history at Kelian required a carefully planned site investigation program to achieve the objectives of the geotechnical study. The investigation philosophy adopted involved an integrated approach between mapping, drilling and geophysical studies. The aim was to optimise the geological and geotechnical information along the proposed channel routes and at depth to the channel invert level.

In summary the tasks carried out include:

1. desk studies,
2. mapping,
3. geotechnical drilling, logging, core testing, sampling and piezometer installation,
4. laboratory testing and
5. surface refraction and surface-to-drillhole seismic geophysical investigations.

3.2 Geotechnical methods

Exploration geologists have previously carried out geological mapping of the area and together with mine geotechnical reports provided an existing data base. Field mapping could therefore be limited to a walkover survey of each channel alignment to check and complement the geological mapping.

A program of rock mechanics line mapping was undertaken to extend the existing structural data base from the mine area to the proposed river diversion area. Mapping was limited to the few natural outcrops and bulldozer cuttings on access roads and drill pads (Figure 2).

An extensive geotechnical drilling program was undertaken with a total of 1466m of drilling comprising 1268m of HQ core carried out in 26 boreholes (Figure 2). Drilling was undertaken using a skid-mounted Longyear LY38 rig. The program was divided into three components:

1. 13 vertical diversion channel boreholes,
2. 5 inclined diversion channel boreholes and
3. 8 diversion bund boreholes.

Geotechnical logs were completed for all boreholes and core orientation undertaken on the inclined holes with a clay imprint device and structurally logged. Casagrande and standpipe piezometers were installed in most vertical diversion channel boreholes to allow measurement of groundwater levels over time. Field testing on the core included point load strength and static

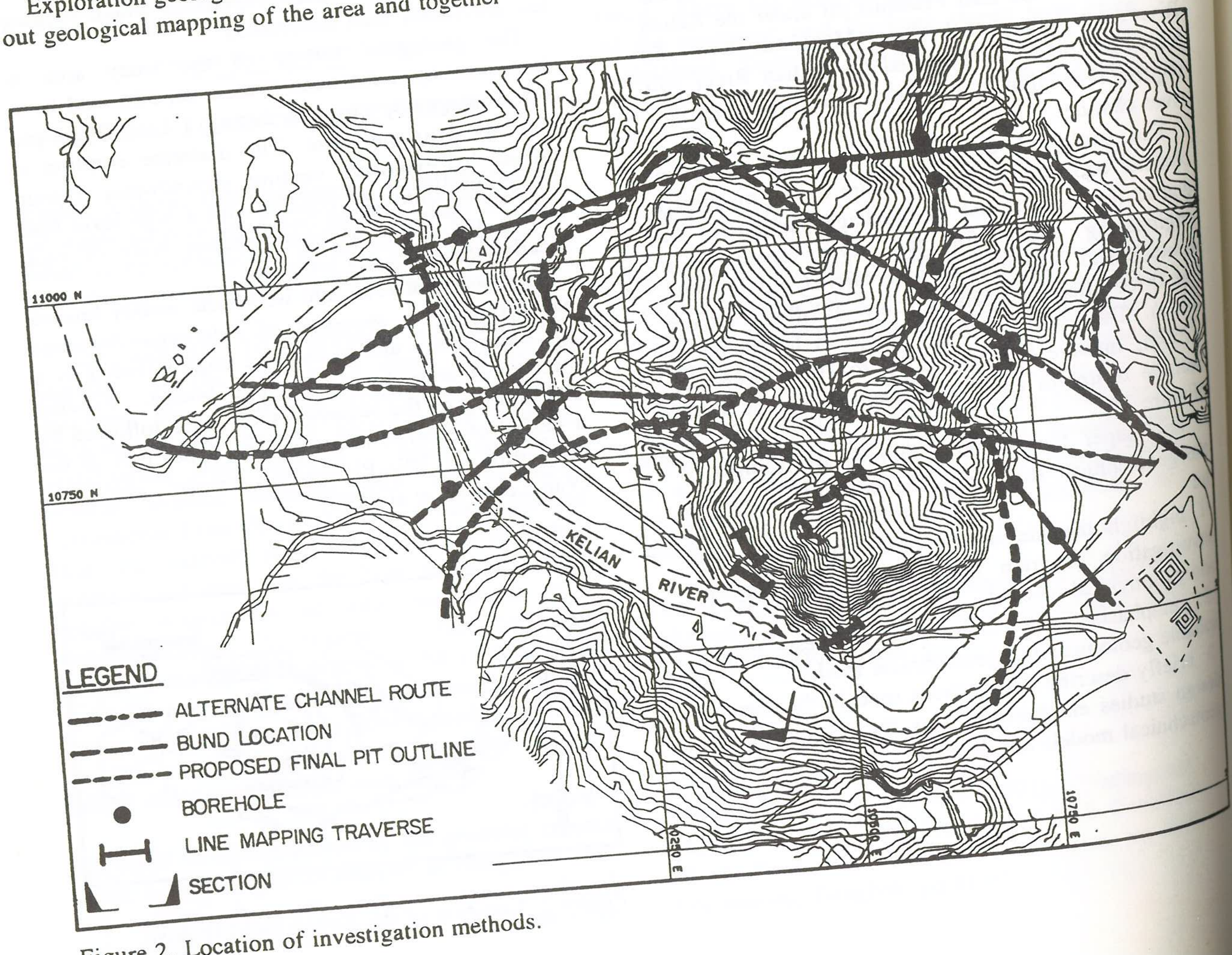

Figure 2. Location of investigation methods.

slake, swell and dispersion potential for channel durability assessment. Packer water pressure testing was undertaken in most diversion bund boreholes for foundation seepage assessment.

The laboratory testing program included rock strength testing comprising uniaxial compressive strength (UCS) and triaxial shear strength tests. A number of disturbed bag samples of various soil materials were tested for basic index properties as part of the construction material assessment.

3.3 Geophysical methods

The geophysical field investigations were an integral part of the site investigation program and were specifically planned to complement the geotechnical program. Two seismic techniques were used in the program. Surface seismic refraction was first carried out which allowed bedrock levels to be mapped and provided seismic velocity information for the soil and rock mass. A total of 3.4km of seismic refraction survey was completed.

Surface-to-drillhole seismic survey was undertaken in six holes. The data was interpreted using interactive seismic raytracing to map the deeper geological structure. This technique was invaluable in aiding the geological interpretation between boreholes.

4 GEOTECHNICAL MODEL

4.1 Site geology and hydrogeology

A simplified geological map of the study area is presented in Figure 3. Five major rock types will be encountered in the river diversion works:

1. Carbonaceous sediments comprising interlaminated carbonaceous siltstone and fine grained sandstone with minor amounts of coarser massive sandstone, carbonaceous mudstone and coal.
2. Tuff consisting of mudstone, fine to coarse sandstone and conglomerate.
3. Muddy breccia comprising fine to coarse, angular to rounded fragments of white porphyry and dark grey sedimentary clasts in a black matrix of "milled" carbonaceous sedimentary material.
4. Rhyolite, a fine grained acid volcanic rock typically exhibiting quartz-sericite to kaolinite-pyrite alteration. Rhyolite forms an intrusive body into the muddy breccia diatreme structure.
5. Basalt occurs as a lava flow which may include a basal layer of laharic breccia representing one or a series of mudflow events on the flanks of a nearby Plio-Pleistocene volcanic cone.

The structure of the area is complex and generally reflects the multiple regional structural events which have occurred in relation to

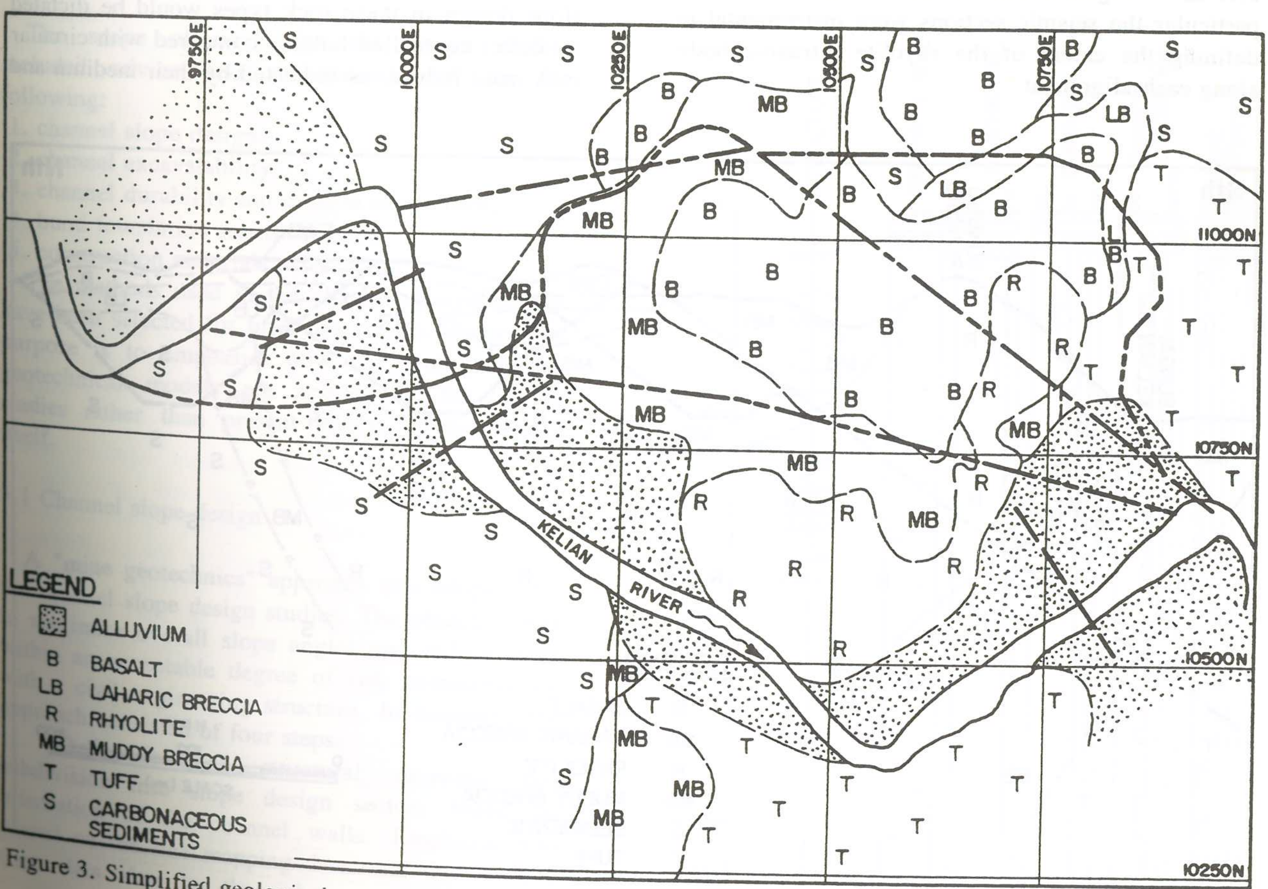

Figure 3. Simplified geological map.

sedimentary basin tectonics and magmatic events. Bedding in the sediments and tuff dip between 20 and 50° towards the north east. Three major faulting and shearing directions are evident striking north east, east and north west and generally steeply dipping. Joint patterns generally reflect the shearing and faulting directions.

Broadly groundwater levels follow topography ranging up to 35m below the highest elevations. A number of natural seepages occur near the base of slopes and particularly appear to be associated with the basalt. Partial or complete loss of drilling mud returns was typically encountered in the basalt and laharic breccia. Packer tests indicated low permeabilities in the carbonaceous sediments, tuff and rhyolite and very low permeability in the muddy breccia.

4.2 Site geophysics

Results of the geophysical studies were presented as interpreted seismic sections for each diversion alignment. Interpreted geological sections derived from surface geology, borehole information and a knowledge of the regional and local geological history were compared with the seismic sections and geological models determined. An example of part of the model is given in Figure 4, a cross section through all three major route options. In particular the seismic sections were instrumental in defining the extent of the rhyolite intrusive body along each alignment.

4.3 Geotechnical description

Geotechnical logs from all boreholes were summarised into a form suitable for plotting on sections (Figure 5). The summary logs outline structure, rock type, weathering, strength, defect spacing and slake potential. The salient features are summarised below.

Weathering typically extends to depths of 5 to 10m apart from the basalt and laharic breccia which is extremely weathered to a dark red sandy clay/sandy clayey silt of high plasticity to depths ranging between 7 and 26m. A paleosol horizon sometimes exists between the basalt and underlying rock mass formed by ancient weathering of the pre-existing ground surface before the basalt flow. The paleosol is usually not present below the laharic breccia probably stripped away by the lahar flows.

Point load strength testing was routinely carried out in conjunction with geotechnical logging with over 330 samples tested. Mean strengths for fresh materials ranged from low for carbonaceous mudstone, medium for muddy breccia and high for basalt, interlaminated siltstone and sandstone and rhyolite. UCS laboratory testing confirmed the point load test results.

Limited triaxial shear strength testing was carried out for muddy breccia and sediment samples. However, subsequent stability analysis showed slope design in these rock types would be dictated by defect controlled failures compared with circular rock mass failure, as indicated by their medium and

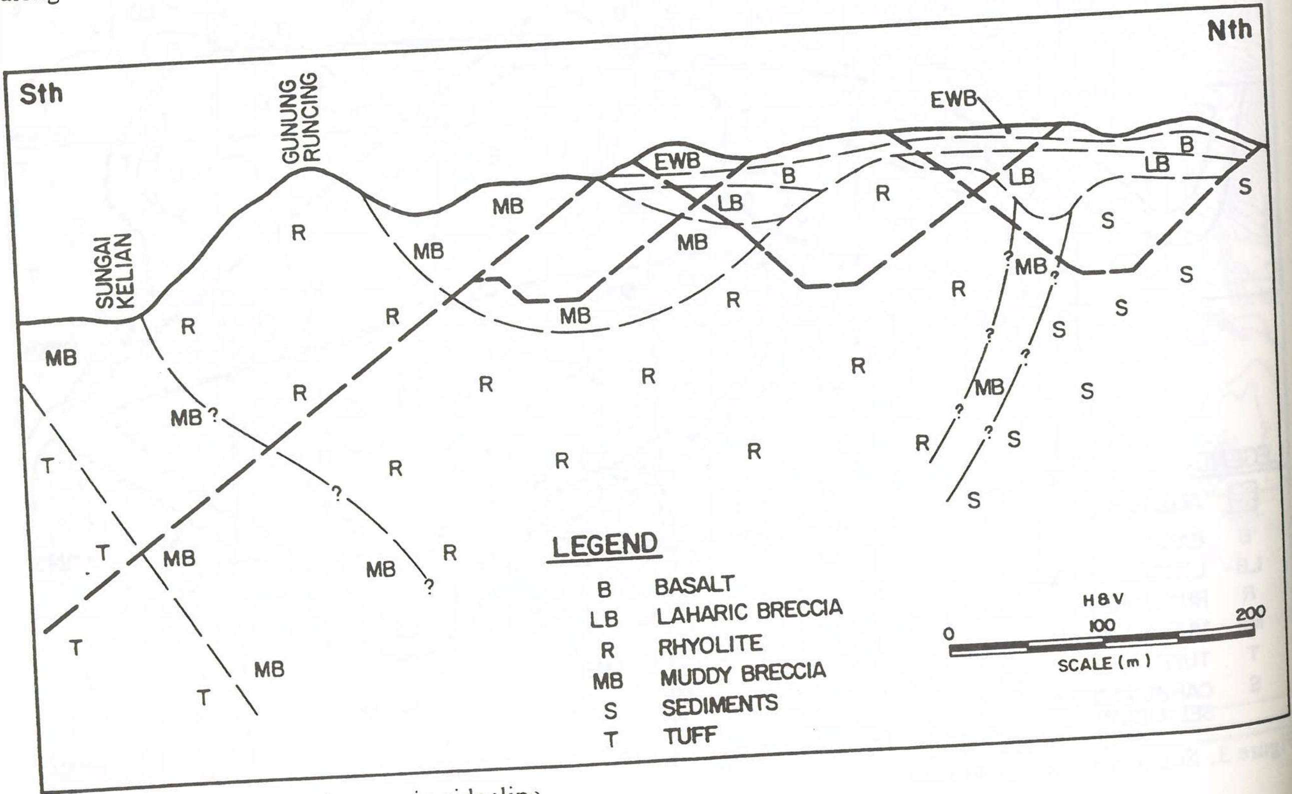

Figure 4. Cross section along main ridgeline.

high strengths.

Defect shear strengths were estimated from previous testing for mine studies, published information and experience to establish a basic friction angle. A design friction angle was derived by taking into account the typical roughness and waviness of the defect through the addition of an asperity angle.

Rock mass quality is generally indicated by the defect spacing. Typically most rock types were closely spaced (100 to 300mm) apart from the muddy breccia which was medium to widely spaced (300 to 3000mm). All rock types contained crushed and sheared zones evidence of the complex structural history.

Slake, swell and dispersion potential was estimated from an empirical test which provides an indication of the weathering potential and durability of materials (Dusseault et al 1983). Most samples tested showed no or slight slaking deterioration after 24 hours, apart from the carbonaceous mudstone which returned 58% medium slaking deterioration. A significant number of muddy breccia samples (18%) also showed medium slaking deterioration. No samples were observed to swell or disperse.

5 DESIGN STUDIES

The scope of work for the design studies included advice and recommendations on the following:

1. channel slope design,
2. channel excavatability,
3. channel durability and erosion assessment,
4. bund foundation assessment and
5. construction materials assessment.

The methods used in the channel design studies have been selected for brief description below. The purpose is to emphasise how the geological and geotechnical models are applied to the design studies rather than present results of the design itself.

5.1 Channel slope design

A "mine geotechnics" approach was adopted for the channel slope design studies. The objective was to maximise overall slope angles and reduce costs within an acceptable degree of risk commensurate with a civil engineering structure. In summary the approach consisted of four steps:

1. Delineation of structural domains and subdivision into slope design sectors based on orientation of the channel walls. Emphasis was placed on the line mapping data over the oriented core data due to the inherent problems with structural borehole data (Sullivan et al 1992). However, the borehole data is useful for confirming the surface structural patterns defined by line mapping exist at depth. This information together with a good understanding of the controls on local geology by regional structural patterns enable surface line mapping data to be extrapolated for use in slope design.

2. Potential failure mechanisms are identified on both the bench and overall scale. Due to the high rock strength and complex geology containing multiple joint sets, faults and shears both scales will be controlled by structural failures involving planar sliding and wedge failure.

3. Stability assessment consisted of kinematic and statistical analysis. Kinematic analysis identifies the critical failure geometries for each design sector which were analysed statistically. The statistical assessment is a measure of the chance that a slope is undercut by a defect or wedge intersection whose dip or plunge is shallower than the slope angle and steeper than the effective friction angle. This method allows the sensitivity of the chance of failure to changes in slope angle to be assessed by taking into account the range in defect orientation as opposed to the mean orientation which may give an optimistic slope angle. Berm widths were assessed by determining the width required to catch

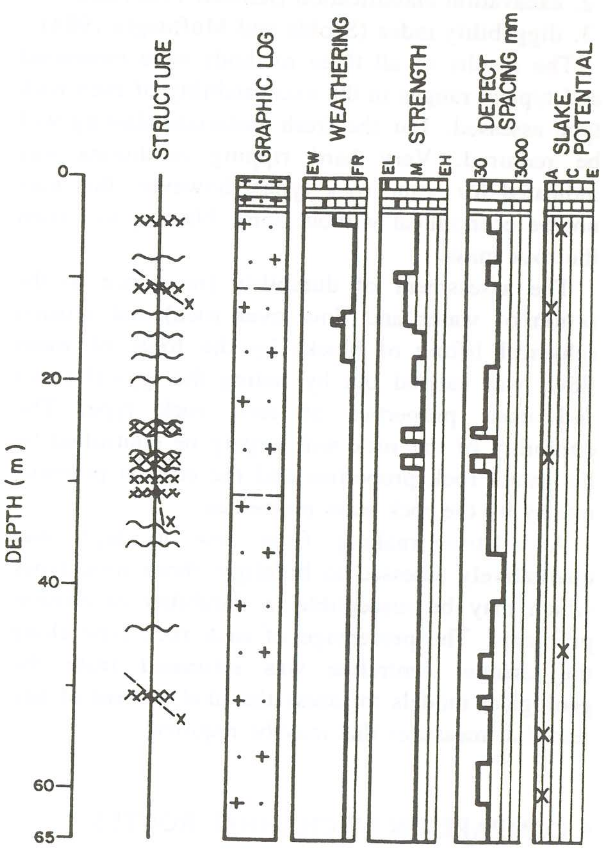

Figure 5. Example of a summary log.

or retain a bench failure. Rock mass failure was also analysed to check assumptions made during the geotechnical model formulation.

4. Slope design was carried out using the following approach:

a) assess allowable bench slope angles in each design sector using the kinematic and statistical analyses,

b) assess the appropriate berm width to retain bench failures and provide long term access to the slopes,

c) formulate an overall slope using the above bench slopes and berm widths with 20 and 10m bench heights,

d) assess the overall and inter-ramp slopes for rock mass and structurally controlled failures and

e) modify the design as required.

Recommended bench slope angles ranged from 35 to 60°. Essential elements of the slope design were slope depressurisation by horizontal drains and control of surface water over the slopes from rainfall runoff.

5.2 Channel excavatibility, durability and erosion

Assessment of material excavatability for the bulk channel excavation was carried out using three methods:

1. seismic velocity,
2. excavation classification (Kirsten 1982) and
3. diggability index (Scoble and Muftuoglu 1984).

The results of all three methods were compared and typical ranges in the excavatability of each rock type assessed. For the fresh materials blasting will be required. Very hard ripping conditions was indicated for some rock types, however, this may not be economical without some blasting to loosen the rock mass.

The assessment of durability (resistance to the action of water and flow over rock) and erosion (physical lifting of blocks by the force of water flow) was carried out by listing the typical intact and mass properties of each rock type. The durability of the rock will largely be controlled by the intact rock properties and the erosion potential mostly by the rock mass properties.

A relative ranking from low to high was qualitatively assessed to highlight those rock types which may be susceptible to durability or erosion problems. The percentage of each rock type along the channel centreline was estimated from the geological models to assess the likely extent of any remedial measures that may be required.

6 COMPARISON OF CHANNEL ROUTES

Results of the geotechnical study indicated it is feasible to construct open channels on all major routes investigated. To provide some geotechnical guidelines for the selection process the three major channel routes were compared based on physical and geotechnical criteria using a relative ranking system. Principal criteria used were:

1. excavation volume,
2. hydraulic gradient,
3. long term slope stability,
4. excavatability,
5. durability and erodability and
6. construction difficulties.

These considerations have an impact on the construction and maintenance costs of the channel. However, this should be compared with the risk to mining operations represented by each channel option. Final selection of the channel route will be a trade-off between cost, mine design flexibility required and perceptions of "risk" associated with an open channel close to the open pit limits.

7 CONCLUSIONS

1. The site investigation program successfully adopted an integrated approach involving mapping, drilling and geophysical studies to overcome the difficult physical conditions and complex geological history at Kelian. This approach allowed optimisation of geological and geotechnical information along the proposed channel routes and at depth to the channel invert level.

2. Summary logs were produced for all boreholes based on the geotechnical logging. The summary logs present information in a form suitable for plotting on geological sections to define the geotechnical model for each channel and bund option.

3. A "mine geotechnics" approach was adopted for the channel slope design studies. The objective was to maximise overall slope angles and reduce costs within an acceptable degree of risk commensurate with a civil engineering structure.

4. The three diversion channel options were compared based on physical and geotechnical criteria using a relative ranking system. These considerations have an impact on the construction and maintenance costs of the channel. However, this should be compared to the risk to mining operations represented by each option and the need for mine design flexibililty.

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