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REVIEW OF THE EVALUATION OF CROWN PILLAR STABILITY FOR THE PROPOSED EAGLE MINE

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Rock Mechanics, Rockburst Monitoring, Rockburst Control

EXECUTIVE SUMMARY

Kennecott Eagle Minerals has submitted a Mining Permit Application for their Eagle Project in the Upper Peninsula of Michigan. Owing to concerns regarding the mine crown pillar stability and the potential for mining induced subsidence and its affect on the surface and ground water, the Michigan Department of Environmental Quality had the Itasca Consulting Company carry out a review of the supporting geotechnical work. This led to a modification in the mining plan that would not let the mining elevation exceed a mine elevation that left a substantial and stable crown pillar. Apparently there were still some concerns about the stability of the crown pillar, which has caused this review to be carried out.

The concern with respect to crown pillar stability for the mining plan presented in the 2006 Mining Permit Application for the Eagle Project of Kennecott Minerals was warranted. The initial geotechnical work did not establish a stable crown pillar, and there was insufficient geotechnical and hydrological data available to determine the subsidence and hydrological response due to mining.

Subsequent geotechnical work has resulted in establishing an upper mining elevation limit that will allow for mining to be carried out below and not have any effect on the surface. The Mining Permit Application for the Eagle Project has been modified to incorporate this upper mining limit (Phase 3). Additional geotechnical data collection will take place during mining and a Phase 3 crown pillar study will be carried out. The Itasca Consulting Group has endorsed the revised Mining Permit Application.

I concur with Itasca and conclude that the Phase 3 mining limit at the 327.5 m elevation results in an 87.5 m thick pillar that is stable. The additional field investigations and data analysis to be carried out will determine whether mining can take place above the Phase 3 mining limit, and if so, will establish a stable crown pillar that precludes adverse subsidence and hydrological affects.

Hence, I recommend that the Mining Application Permit for the Eagle Project be approved.

1.0 INTRODUCTION AND BACKGROUND

The initial geotechnical design study for the Eagle Project of Kennecott Exploration Company was carried out by Golder Associates Ltd. (Golder, 2005). This study was the basis for the underground mine design proposed by Kennecott Eagle Minerals in their Mining Permit Application to the Michigan Department of Environmental Quality (MDEQ) for the Eagle Project (Kennecott, 2006). A transverse blasthole stoping mining method is to progress from the 143 m level up to the 383 m level, with selective mining above this elevation based on further geotechnical study of the crown pillar. The geotechnical study assessed the stability of the crown pillar using several different relationships using typical rock quality values. A stable crown pillar was found to range from 40 ft to 145 ft depending on rock quality and factor of safety. There apparently was concern about the stability of the crown pillar and any resulting subsidence, hence further work to improve the geological characterization, evaluate the effectiveness of the backfill program, and to better evaluate the stability of the crown pillar including subsidence. As a result of this study (Golder, 2006a), the top of the mining was reduced to the 357.5 m level resulting in a 57.5 m crown pillar height. This crown pillar was judged to be stable if the rock mass quality (RMR) value is above 70. Numerical modeling of this crown pillar showed that a maximum vertical subsidence of only 2 cm would result from mining, which would not have any affect on the surface.

This additional geotechnical work did not remove all the concerns regarding the stability of the crown pillar and possible adverse effects on the surface or ground water regimes. Hence, the MDEQ contacted the Itasca Consulting Group, Inc (Itasca) to conduct a technical review of the Eagle Mine crown pillar stability analyses that had been carried out by Golder. The Itasca technical review (Sainsbury, 2006a) was critical of the Golder analyses to determine the stability of the crown pillar, as well as questioning their conclusions regarding crown pillar stability. This led to further geotechnical work by Golder (Golder, 2006b), who then proposed reducing the top of the mining from the 357.5 m level down to the 327.5 m level, resulting in an increased crown pillar height of 87.5 m. Further, additional geotechnical work would be carried out underground during mining to determine a final crown pillar geometry. Itasca (Sainsbury, 2006b) agreed with this approach and recommended that the initial mining be limited to the 327.5 m level, and that detailed and complete geotechnical studies be conducted to determine a stable crown pillar that precluded adverse subsidence and hydrologic effects.

This revised mining plan for the proposed Eagle Project Mine was accepted by the MDEQ, but apparently there are still concerns by outside groups regarding adverse effects that the mining might have on the surface and hydrologic stability of the area. Because of these continued concerns, the MDEQ requested a third party technical review of the crown pillar stability evaluation for the Eagle Project Mine proposed by Kennecott Minerals.

I was selected to carry out this review, as well as to review the methodology utilized in the evaluation, and also to make recommendations in order to proceed to address any remaining questions relative to the issuance of a permit.

2.0 REVIEW OF GEOTECHNICAL WORK FOR EAGLE THE PROJECT

The initial geotechnical work in support of a mining permit for the Kennecott Eagle Minerals Eagle Project was carried out by the Sudbury, Ontario office of Golder Associates. A technical review of this work was carried out by the Minneapolis office of the Itasca Consulting Group for the MDEQ.

2.1 Review of Golder Crown Pillar Stability Evaluation

Golder Associates are one of the oldest and most respected geotechnical engineering firms in the world. They have offices all over the world including numerous offices in both the US and Canada. They have provided consulting services for most of the large mining companies throughout North America. In addition, they have carried out a large number crown pillar stability studies in Ontario where surface subsidence and collapse are a continuing problem above old mining camps.

Crown pillar stability assessments (Golder, 2005) were made for a number of pillar geometries and thicknesses, as well as two different values for RMR, using the Scaled Span and the CPillar techniques. Results for these assessments were presented as Factors of Safety (FOS) for the crown pillar stability. The Scaled Span results indicated low FOS values for most geometries while the CPillar results gave high FOS values. The Scaled Span technique is more widely used and accepted in practice. No specific crown pillar thickness was recommended, but it was stated that if the crown pillar were to be stable the FOS had to be greater than 2.0. They also stated that more diamond drilling from underground was required to better define the rock mass quality data, and when this became available the crown pillar stability needed to be re-assessed. They did not point out that since all of the crown pillar thicknesses analyzed with an RMR value of 75 were less than 2.0 they would not have long term stability. Further, there was no subsidence analysis carried out in this study.

A second geotechnical study (Golder, 2006a) was carried out after receiving additional borehole data to refine the rock mass quality data. In addition, an updated mine plan was developed that moved the top of mining to the 357.5 m elevation, resulting in a 57.5 m crown pillar. The stability of this crown pillar was assessed, as was surface subsidence. The CPillar study again indicated a high FOS, but the Scaled Span study indicated a FOS of 1.2 for a 70 RMR value. This crown pillar was stated to be stable despite the previous statement made that the FOS had to be greater than 2.0 in order to be stable. It was again stated that during mining on the lower levels more data would be collected to better assess the stability of a final crown pillar. Model studies of crown pillar deflection were carried out that indicated there would be a maximum vertical subsidence of only 2 cm, which was judged to not be a problem.

A final geotechnical study (Golder, 2006b) was carried out which included data from additional boreholes, as well as results of unconfined compressive strength tests on cores. It was determined that to have a FOS greater than 2 and a probability of failure of less than 5% the mining elevation should be limited to the 327.5 m elevation, which would result in an 87.5m stable crown pillar. It was again stated that crown pillar stability would be reassessed using geotechnical data obtained underground so that a final stable crown pillar height could be determined. Modeling again was carried out regarding the behavior of the crown pillar and it was again determined that subsidence would be less than 2 cm for a wide range of elastic rock properties. The vertical stress in the models was the overburden stress, while the horizontal stress used was twice the vertical stress.

The Golder geotechnical studies started out with minimal rock quality or rock property data, however, successive studies included additional core data as well as rock property testing results. It should have been apparent from the initial study that the stability of the crown pillar over the wide ore zone near the surface could be a problem, and that there was insufficient reliable geotechnical data available to really assess its stability. Hence, a thick stable crown pillar could have been recommended, as was eventually the case, and the stability of a final crown pillar determined from a detailed geotechnical study carried out underground as the mining progressed upwards. Similarly, the subsidence study, which didn't include structure or hydrology, should have been qualified as presenting preliminary results which indicated minimal subsidence effects, but further studies needed to be carried out when the geology, hydrology, structure, rock property and horizontal stresses were better defined. In situ stress measurements had previously been carried out in the area, but were apparently not found (Bickel, 1993). Stress measurements were made underground at the Mather B mine in Ispeming, and also at the Minimax Mine in Babbitt, MN, some 200 miles to the west. In addition, in situ stress was also measured on surface at Babbitt in the Biwabik iron formation. These results indicated a range of horizontal stress from $K = 1$ to $K>>2$.

In summary, I think that the initial Golder evaluations of crown pillar stability and subsidence were overly optimistic. The Scaled Span data did indicate that a much thicker than proposed crown pillar would be required until a more detailed geotechnical study could be carried out underground to determine a stable crown pillar. I think that had this been pointed out in (Golder, 2005) the Eagle Project Mining Permit Application would likely have been approved by now.

2.2 Review of Itasca Crown Pillar and Subsidence Evaluation

The Itasca Consulting Group started out in Minneapolis providing numerical modeling programs and consulting for numerical model mining and geotechnical studies. They are the leaders in this field. They expanded into providing mining, geotechnical and hydrological consulting, and now have offices in a number of countries throughout the world.

Because of concern regarding crown pillar stability and adverse subsidence effects from underground mining at the proposed Kennecott Minerals Eagle Project by the MDEQ and

others, Itasca was asked to carry out a review of their Mining Permit Application. The purpose of this review was to determine if the conclusions presented regarding crown pillar subsidence and hydrologic stability are defensible.

The Itasca technical review (Sainsbury, 2006) was very critical of both the conclusions and the procedures used to reach those conclusions with respect to the Mining Permit Application and the geotechnical studies included to support it. Specifically, Itasca concluded that the analysis techniques used to assess the Eagle crown pillar stability were not up to best industry standards, and that the hydrologic stability of this pillar was not considered. Hence, they stated that the conclusions made within the Eagle Project Mining Permit Application are not considered to be defensible. They also pointed out that the Scaled Span analysis clearly indicated that stability of the crown pillar should be a concern.

I believe that part of the reason for the very critical tone of the Itasca review may have been caused by including the term 'defensible' in the scope of their review. To me it implies that there could be legal ramifications, hence resulting in extra scrutiny for all phases of their review. On the other hand, Golder continued to state in successive reports that proposed crown pillars were stable despite their having factors of safety less than 2. This was obviously a red flag that caused their work to be looked at more critically.

The initial point load testing Golder carried out to estimate the compressive strength of the rock was criticized for not conforming to standards, but later testing of rock cores showed little differences in the estimated UCS versus the actual UCS. The values used for in situ stress by Golder in the modeling were considered to be underestimated, but were within the range of the in situ horizontal stress determined underground at the Mather B mine in Ishpeming. The results of the numerical modeling carried out by Golder were judged to have a low level of confidence because of uncertainties in the input parameters used. While this is no doubt true, there is still not enough known about the rock properties, the geologic structure and the hydrology to provide reliable results from modeling. The reported results did indicate, however, that for very good ground that had an elastic response subsidence would not be a problem. Criticism with respect to the Golder study not including long-term, time-dependent behavior of the Eagle crown pillar is only partially valid since Golder did mention that long-term crown pillar stability was to be evaluated when underground access was available and additional rock mass quality data collected. However, not including the crown pillar hydraulic stability in the crown pillar subsidence analysis or in the bedrock hydrogeological investigation was a valid criticism of the Golder study.

As a result of the Itasca review a new mining plan was developed by Kennecott based on further geotechnical study (Golder, 2006b). The proposed mining plan would restrict mining above the 327.5 m elevation until a detailed geotechnical investigation could be carried out underground, concurrent with production mining being carried out on the lower levels. Itasca reviewed this work and concluded that the 87.5 m thick crown pillar was stable and sufficient to allow mining to be carried out while the detailed field investigation was in progress (Sainsbury, 2006b). They recommended that mining not be

carried out above this new mining limit until further best practice analysis were conducted to determine the expected crown pillar subsidence and hydrological stability.

In summary, Itasca was very critical of the Golder work supporting the Eagle Project mine permit application until a substantial crown pillar was left that would allow time for a thorough and complete geotechnical investigation to determine a final and stable crown pillar.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The concern with respect to crown pillar stability for the mining plan presented in the 2006 Mining Permit Application for the Eagle Project of Kennecott Minerals was warranted. The initial geotechnical work did not establish a stable crown pillar, and there was insufficient geotechnical and hydrological data available to determine the subsidence and hydrological response due to mining.

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Hence, I recommend approval of the Mining Application Permit for the Eagle Project. I would also recommend that in situ stress measurements be carried out underground to determine the in situ stress field.

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