14 April 2011

Oceana Gold (NZ) Limited
Golden Point Road
Macraes Flat 9483
New Zealand

Attention: Mr. Marty Hughes

Dear Marty,

Macraes Gold Mine – Footwall Fault
Peer Review of PSM Report

This report presents a peer review of the Pells Sullivan Meynink (PSM) report concerning predicted ground movement of the west wall and plant site as a result of proposed mining of the Round Hill East and Southern pits (Ref 1). The review is based on information in the PSM report, together with knowledge of the area and other information provided by Oceana Gold (NZ) Limited (OGL).

It is not intended that this review address any geotechnical issues beyond the use of geomechanics analyses to predict the future pit slope behavior in response to mining. The main reviewer (Dr. John Tinucci) has not been involved in assessing other geotechnical issues at the mine or has visited the mine to assess rock mass conditions, but has drawn on the knowledge of other URS staff (Richard Davidson) who has been involved for many years. The reviewer's 28 years of geomechanics expertise includes the analysis of geomechanics problems utilizing continuum and discontinuum numerical models in assessing the stability of open pits.

1. SUMMARY OF PSM REPORT

The PSM report presents the results of geotechnical analyses assessing the likely movement due to mining of the Round Hill East and Southern pits. The report concluded the following main points:

- Movement along the Footwall Fault will be reactivated with mining.
- Mine plans assume mining south of 15250 m N and a minimum 25 m distance from pit floor to Footwall Fault.
- Footwall Fault displacements are predicted to be 0.5 – 2.5 m beneath the plant and about 10 m at the TSF dam.
- Mining north of 15250 m N is predicted to result in Footwall Fault displacements of about 10 m beneath the plant.
- Most movement beneath the plant is predicted to occur between 2015-2017

The report recommended the following key points:

- Movement trigger rates are recommended as:
    - 50 mm/day generally and 10 mm/day at the plant
    - Doubling of the daily rate

  - Noticeable batter failures or floor heave
  - Distress within plant site
  - Greater than 20º change in displacement vectors
- Recommended plotting and reviewing movement data daily
- Mine plan should be changed to divide the pit and/or increase the floor offset to the Footwall Fault if the west wall behavior changes.
- Pit slope design parameters are recommended.

2. Comparison with Round Hill and Golden Point Pits

A discussion of historic movements is summarized in Section 2 of the PSM report. The successful use of start-stop mining to control wall movement is mentioned and was based on allowable movement rates ranging 2 mm/day and 10 mm/day (c.f. 7 mm/day indicated on Figure 4) at the Round Hill and Golden Point pits. Displacements during mining were about 4 m total and there was a rapid increase after 1999. However, only 0.17 m of displacement has occurred over 6 years (Figure 6) since mining ceased in 2002.

PSM reviewed previous analyses (by others) of movement of the west wall of the Round Hill and Golden Point pits. It is mentioned that the geometry, groundwater levels, rock mass strengths and back-analyzed Footwall Fault strength are well understood. There is a limited discussion of the role of other geologic structures (e.g., faults, shears and jointing) other than that provided in Figure 7.

There is no discussion of failure modes which the model should or should not be capable of simulating in a reasonable way. Sliding along the Footwall Fault is the primary failure mode in three dimensions. Other manifestations of failure would include observations of surface cracking (tensile regions), floor heave and rock fall regions (shear failure), or open/close jointing conditions (stress orientations). The lack of explicit simulation of rock structure within the pit such as pervasive ramp shears and the locking up (stick) of the rock mass after cessation of mining followed by continued slip once mining is restarted is a concern. The report does not utilize other known field conditions (e.g., floor heave, bench failures in footwall, groundwater elevation, etc.) to demonstrate the validity of their analysis results. Although an added level of complexity, such discussions are useful for understanding failure mechanisms predicted by the analyses.

3. Analysis Comparison with Frasers South Pit Behavior

Three types of analyses were performed in an attempt to back-analyze historic movements in the Fraser pit. The report mentions that displacements of the west Fraser wall had moved about 20 m and movement near the Fraser offices was about 0.5 m.

Earth Pressure Analytic Estimate – Given that the earth pressure analysis discussed is only a simplified limit equilibrium method, it does not estimate displacements. Assuming a series of block “wedges” sliding on the Footwall Fault, the analysis predicts the balance of forces, which are expressed as factor of safety values. The rock mass was assumed to behave as a continuum. These analyses reportedly confirm the following.

- The offset distance from the pit floor to the Footwall Fault and the presence of groundwater are important factors in assessing stability (or lack of stability) of the west Fraser wall.

- A offset distance of 25 m from the pit floor to the Footwall Fault is appropriate as long as the rock mass strength is adequate ($C>0$ and $\varphi > 45^{o}$) and the fault is completely dewatered.

Unfortunately, simplified analytic limit equilibrium analyses cannot estimate displacements or rock mass behavior after deformation occurs. They can be valuable for conservatively estimating stability given an approximation of the balance of forces provided conditions are representative. In the case of Fraser pit, such conditions are not representative because the slope is failing, yet it stops moving when mining stops. Limit equilibrium analyses cannot represent this condition.

2-D Phases[2] Modeling – The 2-D finite element modeling included discrete behavior of the Footwall Fault and the groundwater pressures. The rock mass was assumed to behave as a continuum. Reported model results consist of strength reduction factors (similar to factor of safety) and displacements for cases with and without groundwater pressures. Maximum displacements are reported to be more than 10 m at the tailings dam location under groundwater pressures (2.5 m displacements under dry conditions). This represents a factor of 4 times more displacement when the rock mass is under groundwater pressures. Figure C5 suggests the ground surface moves the same magnitude as slip along the fault, as if "block sliding" movement occurs.

3-D FLAC3D Modeling – PSM was not able to get the FLAC3D finite difference model to successfully run. The reason for this is unclear. In the reviewer's experience, FLAC3D should be capable of modeling a single fault with a continuum rock mass. Finite difference models are particularly adept at solving problems very close to the limit of equilibrium and conditions of large displacements.

3-D Abaqus Modeling –It appears from the write-up that PSM adopted a pre-existing 3-D model of the Round Hill and Golden pits, developed back in 2002, to calibrate the 3-D model to historic displacements (c.f. P 23, Section 9.2.1). However, this is unclear from the document. Abaqus is a finite element program. The model did include the Footwall Fault as a discrete slip-interface surface. The rock mass was assumed to behave as a continuum.

The basis for the assumed initial stress field is not discussed. The stresses were assumed hydrostatic ($\sigma_H = \sigma_h = \sigma_v = \rho gh$). Given the low angle of the Footwall Fault representing thrust faulting conditions, it is likely that the horizontal stresses exceed vertical stresses and their orientation are influenced by major geologic structures.. In the absence of stress measurements, an estimate of stress conditions can be made from field observations of jointing conditions (e.g., joint orientations where joints are open versus closed or producing groundwater seeps).

The use of strain-softening behavior is mentioned with citation to reference #8 regarding sliding behavior. However, there is no discussion on appropriateness of strain-softening behavior, nor is there discussion on how softening was implemented in the constitutive model.

Pseudo-dynamic analyses were undertaken, but the results would not be applicable to assessing stability under static conditions. There are no discussions of what was done for pseudo-dynamic analyses or the magnitude of earthquake accelerations represented. The calibration results (Figures D10 though D13) indicate the model over-predicts displacements at prism locations prior to 1999 and under predicts displacements after 1999 (including dynamic results which are not applicable). It appears that dynamic results were used to compare to the static displacement measurements, which may not be appropriate for this problem.

The effect of varying the rock mass strength was not examined in these analyses. It is well known that a reduction in strength parameters has a greater effect on displacements than reduction in moduli. Given that it is not known how the authors used strain-softening behavior (a form of post-peak strength reduction), the results do not account for variations in strength. It is noted that in the draft report the authors mentioned that it was not possible to vary strength parameters because the model became unstable.

It is not clear from the write-up whether groundwater pressures were included in the calibration runs. Given the results of the analytic and 2-D models, it seems that this would be a very important condition to examine.

4. Prediction of Round Hill and Golden Point Mining Stability

The calibrated 3-D Abaqus model was used to predict behavior of the Round Hill and Golden Point pits. Results suggest maximum displacements are 1-1.5 m at the plant site and about 4 m at the tailings dam embankment. It is not clear whether these reported displacement magnitudes are from static model results (Figure D17) or pseudo-dynamic results (Figure D18). It appears that the reported displacements are from the pseudo-dynamic model (comparing Figures 24 and D18), in which case the comparison may not be appropriate.

It is also unclear whether these results include groundwater effects or account for the calibrated modulus reduction. There are no discussion of what parameters from the calibration runs were carried forward to the predictive runs.

5. Discussion

The analyses results presented in the PSM report have considered the discrete presence of the footwall fault, but have treated the rock mass as a continuum. It is well known that the intersection of the geologic structures (faults, shears and joints) provide an increased degree of freedom in blocky rock mass behavior. It is this behavior that must be simulated by models to compute large displacement when the rock becomes unstable. This behavior was not represented in the models.

Measured displacements in the west wall of the 127-m deep Fraser pit were about 20 m (Figure 13) at the Fraser fuel farm, which is about 774 m laterally away from the toe of the slope. The 3-D numerical model predicts only 4 m of displacement near the dam embankment above the west wall of the 225-m deep Southern pit, which is 736 m laterally away. There is no explanation for this difference (e.g., surface water infiltration, geologic or rock mass differences), nor are there discussions as to whether the predicted model results represent lower bound or upper bound displacements. Based on past displacements, it is possible that the model predictions could be significantly low.

It is a concern that these model results may significantly under predict the magnitude of displacements expected from mining the ultimate pit because the discontinuous nature of the rock mass has not been accounted for in the continuum models. Historically the ramp shears outcropping in the pit floor (westerly dipping) have been demonstrated to play a significant role in the stability of the pit walls. The start-stop mining approach has been proven successful for conditions when highwall movements become large. The slowing of movements when mining stops is thought to be related to stick-slip behavior of the jointing which allows the blocky rock mass to “lock-up” when mining ceases. When mining recommences it takes time for the blocks unlock and large movements continue. This is due to the time required for mining-induced stress redistribution to propagate through the rock mass (i.e., local-scale joint slip).

It is this stick-slip behavior that the continuum models fail to reproduce. This would explain why the numerical models could not demonstrate the sudden increase in displacements after 1999 mining. Work by the URS predecessor Woodward-Clyde NZ and their consultant Geonet in 1996-7 clearly demonstrated this mechanism with 3-D FLAC and UDEC modeling, which was confirmed by a Review Board and later by consultant Rick Call who assisted the mine in establishing movement thresholds.

PSM is quite correct that this stability problem must be solved using 3-D analysis. Conditions at the “nose” in the west wall between the Round Hill East pit and Southern pit result in low confinement. The low confining stress allows failure to occur at lower shear stress levels. Although this mechanism has been represented in the Abaqus model via the 3-D geometry, it is this area that would likely experience even larger displacements had the rock mass been represented by discontinuum behavior, implying that these model results may under predict the expected displacements at the tailings dam and plant site. In the past modeling, the 3-D effects of the adjacent rock mass were judged to be an important limiter of the movement along the Footwall Fault and ramp shears.

Groundwater pressure on the faults is as important a factor in the analysis as including the behavior of the discontinuities. However, there is very little discussion on their impacts. The analytic and 2-D numerical model results indicate that if the slopes are dry they are barely stable (Figure 17 and Table 8.2), but under the presence of groundwater pressure they are clearly unstable. This mechanism appears not to have been investigated in the more detailed 3-D modeling. Ground water control and depressurization along the fault from vertical pumping wells and horizontal drains were crucial in allowing the Round Hill and Golden Point mining to be successfully completed.

Fundamental questions to be addressed for Macraes Phase 3, is whether the stick-slip behaviour of the 3-D rockmass will continue, or is there an elevated risk of an uncontrolled failure once the confining effects of the adjacent rock mass are diminished? Also what are the implications of an uncontrolled failure of the pit wall on the MTD and the Plant Site. Even if the movements are successfully controlled with start-stop mining, can the plant site facilities be insulated and protected from large expected differential movements?

6. Conclusions and Recommendations

PSM have developed an impressive 3-D model for the Round Hill East Phase 3 expansion at Macraes. Numerical modeling is useful for predicting future response of rock masses to changes in stresses brought about by mining. However, a number of key questions remain. Regardless, it is important that the appropriate failure mechanisms be fully represented in the models.

It is recommended that PSM consider the effects of the major discontinuities in the analyses, beyond the presence of only the Footwall Fault. Key features, as illustrated in Figure 7, could be discretely simulated in the model so that the rock mass behaves as a blocky rock mass. A suitable analysis program such as 3DEC, which is the three-dimensional version of the UDEC program for modeling 3-D discontinuum rock masses might be helpful in this regard. This type of 3-D modeling could go a long way toward addressing the fundamental question posed above.

When calibrating the model, significant field observations should be demonstrated by the model. For example, in the case of Frasers and Round Hill East, it would be extremely valuable to demonstrate the magnitude of floor heave if the model can reproduce the floor heave shown on Photo 1.

We understand that the mine plan pit excavation sequence is currently being reviewed to limit movements and consequences on the Plant Site and TSF. Discontinuum modeling of the mining sequence can help guide development of alternatives and assess their effectiveness. The objective of these alternatives would be to take advantage of geometric stress confinement (ie. joint lock-up behaviour) by exposing as little of the wall at depth at any one time as possible while still attaining the mining tonnages. Proactive ground water control measures should be designed and simulated to assure their effectiveness.

We look forward to Rob Bertuzzi's view on these concerns and the questions posed above, and continued contribution to this important dialogue with your design and operations team.

Sincerely,

John P. Tinucci, PE, PhD
Principal

Richard R. Davidson, CPEng
Senior Principal and Vice President

URS

REFERENCES

1. Pells Sullivan Meynink, (2010), “Round Hill East & Southern Pits”, Report PSM71-107R, November 26, 2010, pp 42 + appendices