PEBBLE ENGINEERING GEOLOGY

DISCUSSION OF ISSUES

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ABSTRACT

The proposed Pebble Project, by Northern Dynasty Mines, Inc. (NDM) and Anglo American plc, is a relatively low grade copper-gold-molybdenum sulfide deposit in Southwest Alaska. The deposit outcrops on the surface (Pebble West), which would be mined by open pit mining methods, and extends under non-ore bearing rocks (Pebble East), which would be mined by underground block caving. The deposit is situated on a drainage divide, with the Upper Talarik River draining to the east and south, and the North Fork and South Fork Koktuli rivers draining to the west and southwest, respectively.

Mining of the ore deposit would result in an open pit and underground mine located at the headwaters of the South Fork Koktuli Watershed and the Upper Talarik Watershed. The mine waste (tailings and waste rock) would be stored in two Tailings Storage Facilities located in the South & North Forks of the Koktuli Watershed.

The open pit at Pebble West is projected to have a pit lake after mining. Pit water can potentially be impacted by the composition of the rock remaining in the pit walls, especially that material which has been further exposed by fracturing and rubbilization due to mining. If the water in the pit is of poor quality, as the result of decomposition of sulfide minerals, and the hydrology of the site is such that water from the pit can migrate from the pit downgradient to ground and surface waters, there could potentially be long term impacts to water off the minesite.

It is highly likely that subsidence will occur as a result of the block caving at Pebble East. Subsidence at the surface will allow water to enter the underground mine from above and come in contact with the broken rock that will remain underground in the mined areas. The rock in the remaining underground workings in the deposit will be mineralized. This could lead to decomposition of the sulfide minerals and to acid mine drainage. If a flow path exists from the mine workings to ground and surface waters down gradient from the mine, migration of contamination off the mine site would be a long term issue.

Tailings dams will be built to contain the waste, several with heights in excess of 700 feet. These tailings dams must stand in perpituity. There is a risk that a large earthquake might cause failure of a tailings dam. A catastrophic release of a large amount of tailings could lead to long term environmental damage with huge cleanup costs. The probability of such a catastrophic failure is very low, but the consequences should it occur are very high.

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A 104-mile industrial road will connect the mine and the port site, and the concentrate pipeline will parallel this road. The pipeline will be engineered with leak detection systems and shutoff valves, which can limit, but not prevent, spillage of concentrate and/or waste water, because the material between the shutoff valve and a break can still leak from a ruptured pipeline.

Concentrates are moved via conveyor to onto a ship for transport to a smelter. Care is required as the concentrates are loaded aboard ships at the port site. Concentrate spills during ship loading has been an issue in the past with several similar loading facilities in Alaska.

Finally, mines must be "designed for closure." The mine's operating plan must anticipate the final configuration of the mine at closure. Alaska reclamation law requires that an adequate financial surety for closure be provided to the bond holding agency. Regulatory agencies, including those in Alaska, have a history of underestimating the closure costs for metal mines. The form of the financial surety held by the regulatory agency is also important. Mine closure typically costs tens to hundreds of millions of dollars, so the cost of reclamation is significant liability to the regulatory agency, and by association to the taxpayer. Regulatory agencies in Alaska can now accept corporate guarantees. A corporate guarantee, a letter from a corporation to a regulatory agency saying it will pay for reclamation, is not backed by any tangible security.

I.   INTRODUCTION

The proposed Pebble Project, by Northern Dynasty Mines, Inc. (NDM) and Anglo American plc, would mine is a relatively low grade copper-gold-molybdenum sulfide deposit in Southwest Alaska. The deposit both outcrops on the surface (Pebble West), which would be mined by open pit mining methods, and extends under non-ore bearing rocks (Pebble East), which would be mined by underground block caving. Copper accounts for about 50% of the gross value of the deposit, gold 34%, and molybdenum 16%.[2]

Although NDM/Anglo has yet to file all its applications, information about the nature of the project is available in NDM's applications for water rights and dam construction permits which the company submitted in 2006 to the Alaska Department of Natural Resources, as well as in company publications related to its efforts to attract investors. This information will be used as a basis for analysis.

The deposit is situated on a drainage divide, with the Upper Talarik River draining to the east and south, and the North Fork and South Fork Koktuli rivers draining to the west and southwest, respectively. Mining of the ore deposit would result in an open pit and underground mine located at the headwaters of the South Fork Koktuli Watershed and the Upper Talarik Watershed. The mine waste (tailings and waste rock) would be stored in two Tailings Storage Facilities (TSF) located in the South Fork Koktuli Watershed (TSF at Site A) and the North Fork Koktuli Watershed (TSF at Site G). Mine waste rock would also be used to construct the large tailings dams necessary for the project.

For this analysis it is assumed that mining at Pebble will utilize state-of-the-art technologies, competent and diligent mine operators and mining consultants, who typically provide much of the technical oversight for mine design and operation. However, it will also be assumed that a

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[2] Technical Report on the Pebble Deposit, Prepared For Northern Dynasty Minerals Ltd., Roscoe Postle Associates Inc., Apr 2005, p. 17-2.

range of typical mining environmental-related problems/issues will also occur. Typical problems include: dust related issues with open pit mines; elevated levels of contaminants in ground and surface waters for sulfide mines; traffic and noise impacts on surrounding communities, etc.

The potential to see one or more of these typical problems at Pebble will be relatively high, but the potential impact for any one problem is relatively low. The reverse is true for the potential of catastrophic problems - that is, even though the potential for catastrophic problems is low (e.g. tailings dam failure, acid mine drainage impacting surface water off the minesite), the impact from an occurrence would be high. These potential catastrophic issues must be mentioned because, unfortunately, the lessons learned about them are all based on actual occurrences at modern mines somewhere in the world.

II.   OPEN PIT MINING at PEBBLE WEST

The initial discovery at the Pebble site of a low grade copper-gold-molybdenum deposit that outcrops on the surface was made in 1988 by Cominco, Inc.[3] This site is now called Pebble West. Since this deposit outcrops at the surface, and is disseminated, as opposed to vein-structure, the Pebble West deposit would be mined by open pit methods.

Open pit mining utilizes mass production techniques to move large quantities of ore and waste. These techniques include using an ammonium nitrate and diesel fuel mixture as a blasting agent. This is a very effective and relatively inexpensive explosive. The blasted material is loaded on large haul trucks (300+ ton capacity) for transport. This material goes either to the mill for processing; or, for material that is not ore grade, to a waste storage site for disposal; or, "clean" waste may be used as tailings dam fill or for other mine construction purposes. Classification between ore and waste is done on the basis of tests of the blast hole rock performed in an onsite laboratory. When the blasting takes place mine geologists flag the blasted material for transport to either the mill or waste site.

Open pit mining is the least expensive way to mine, and has facilitated the development of low grade ore bodies. Open pit mining produces more waste than a similar sized underground mine because all the material around and on top of the ore must be moved, as opposed to selectively mining only ore (with the exception of access tunnels) as is typically done underground.

The non-ore waste is significant because this waste is often only sub grade ore, and typically contains many of the sulfide minerals found in the ore. Decomposition of these minerals causes heavy metals and metalloids to be leached from the waste, which can contaminate surface and ground waters on and off the minesite.

Dust

Blasting, loading, and hauling the ore and waste along mine roads creates dust. In addition to the nuisance factor associated with dust, the chemical composition of the dust can be of concern because of the metal content of the mined material. Copper, molybdenum, and other metals of potential concern (including arsenic, mercury, lead, etc.) can be a component of the dust.

Dust at mines is usually controlled by using best management practices (BMPs). BMPs for dust control at mines include the use of road watering to suppress dust, as well as the occasional use of chemical additions (e.g. calcium chloride) to further stabilize the road surface material. Dust suppression BMPs can be effective if the BMPs are rigorously followed, but elimination of dust

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[3] http://www.northerndynastyminerals.com/ndm/Pebble.asp, June 12, 2007

is impossible. Some days are just too dry (e.g. high temperatures combined with drying winds) for the suppression methods to be effective. Dust can also be a problem in winter months when desiccating winds move dust if snow is insufficient to cover the ground. Similar dust control issues can arise at the tailings pond and waste rock storage locations. While utilizing state-of-the-art dust control BMPs can eliminate most of the dust generated from mining, some dust will escape the minesite.

Pit Slope Rubblization

Open pit mines look like an upside down layer cake, with each descending layer smaller than the one above it. If the mined material were perfectly solid, then pit walls could be vertical. However, the natural fractures in the rock and the different inherent strengths of the different rock types determine the slope of the pit walls that can be left during mining to create a stable working surface.

Blasting to loosen the ore and waste in the pit also further fractures the rock remaining in the pit walls. After the mine closes pit walls will gradually "rubblize' due to the effect of gravity, aided by freezing and thawing, vegetation roots, etc. In time rubbleized pit slopes will eventually reach a stable angle-of-repose slope which will be shallower than the overall slope used during mining.

The final spit slope will be composed of material that is more porous than the surrounding host rock because it has been further fractured by blasting and rubblized by gravity.

Post-Mining Pit Lake

At Pebble West it is projected that a pit lake will form after mining.[4] Pit water can potentially be impacted by the composition of the rock remaining in the pit walls, especially that material which has been further exposed by fracturing and rubbilization due to mining.

Pit lake water quality is of concern for two reasons. First, if the water in the pit is of poor quality then aquatic organisms that attempt to colonize the pit lake after mining could be impacted. Second, if the hydrology of the site is such that water from the pit can migrate from the pit downgradient to ground and surface waters, there could potentially be long term impacts to water off the minesite.

Predicting water quality for pit lakes is an evolving science. While the basic science behind predictive models for pit lakes is sound, the amount and variability of the data inputs required by these models most often renders the modeling results to be a best guess. Pit water quality modeling is an evolving science, and the predictive results from these models must be viewed with an appropriate degree of caution.

At this point there are no published predictions for Pebble pit lake water quality, but this is an important issue that must be carefully analyzed because of the potential for long term impacts.

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[4] <u>Draft Environmental Baseline Studies Proposed 2004 Study Plan</u>, Northern Dynasty Minerals Inc, July 2, 2004, p. 8-8.

III. UNDERGROUND MINE at PEBBLE EAST

The Pebble East deposit was discovered in 2004 by drilling through overburden east of the initial deposit discovery.[5] Pebble East lies under an increasingly thick wedge of unmineralized overburden that is too thick to mine economically by the open pit method.
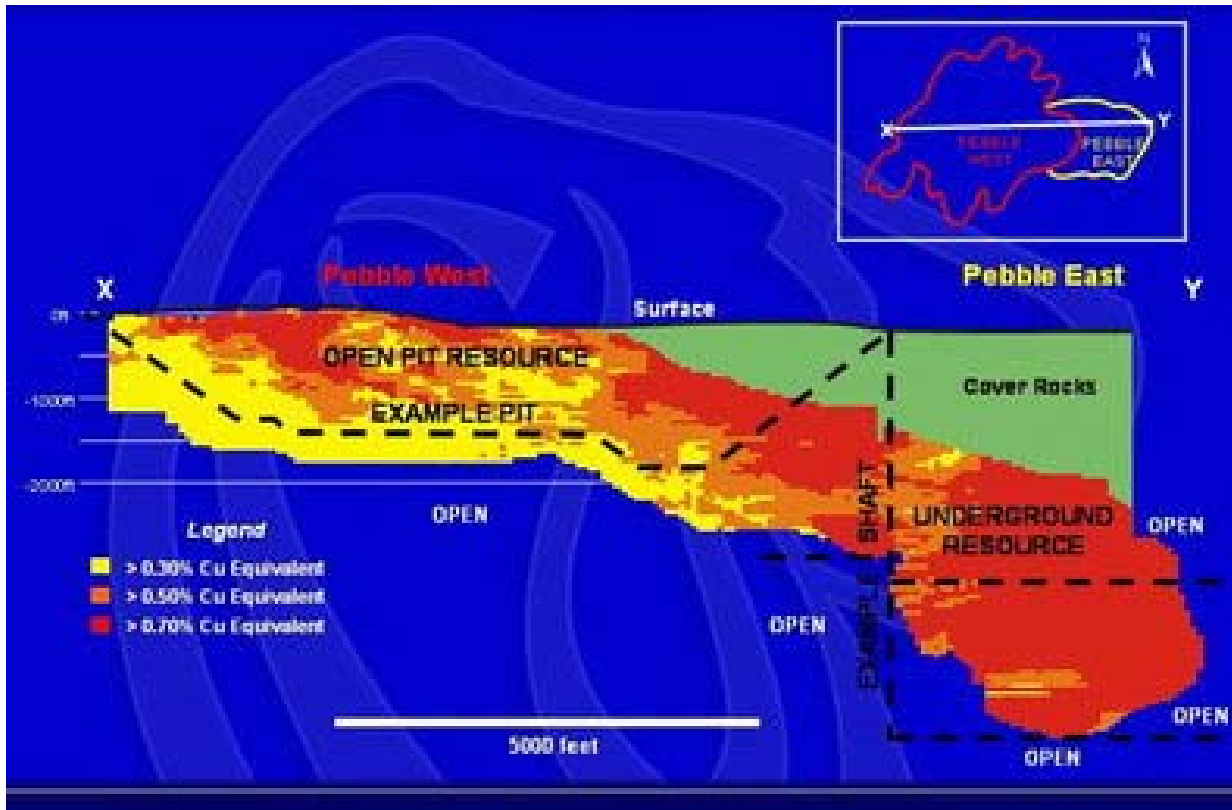

Figure 1: Pebble Deposit Cross Section

Underground mining is more expensive than open pit mining because access to the ore body is gained by drilling a series of shafts and tunnels through non-ore rock. Underground mining is much more labor intensive than open pit mining, requires more safety and support equipment, and is much less productive in terms of ore production per man-hour than open pit mining.

Ore for an underground mine must be of comparatively higher grade to justify the increased costs of this type of ore extraction. The ore grade at Pebble East is higher than that at Pebble West,[6] but is still relatively low grade in terms of what is usually seen for an underground mining operation.

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[5] http://www.northerndynastyminerals.com/ndm/Pebble.asp, June 12, 2007
[6] http://www.northerndynastyminerals.com/ndm/Pebble.asp, June 12, 2007

Underground Mining Methods

There are several types of underground mining. The most common underground mining method is probably the "open stope" method where mine tunnels and shafts are cut to follow veins of ore. The ore is often mined in "stopes" which are essentially non-tunnel zones that contain only ore. After the ore is mined out, the stopes and access tunnels are abandoned.

A second type of underground mining is generally called the "room and pillar" method. This method is used in underground mines where the ore occurs in massive (or disseminated) zones, something like the situation at Pebble, where the copper-gold-molybdenum mineralization is distributed throughout an extensive ore body.

Access tunnels and shafts are still required, but the actual mining of the ore is done by alternatively mining a "room" of ore, then leaving adjacent "pillars" of ore as support. The rooms that have been mined can be backfilled with mine waste, sometimes with the addition of cement to provide further stability, and the pillars can then be mined to remove the remaining ore.

Room and pillar mining is an efficient way to mine because the ore is selectively mined. Like open pit mining, drill holes are tested for ore grade before blasting, but unlike open pit mining, non-ore material is usually not blasted. If backfill is used and the pillars of ore that were left for structural support are then mined, all of the ore can be removed.

Backfilling can also provide long term structural stability for the underground workings, depending on how much of the mined underground space is backfilled, and the strength of the backfilled material. If underground workings are not backfilled, they will eventually collapse. The collapse of the mine workings can cause subsidence on the surface above the mine.

However, because the Pebble deposit is low grade, the only type of mining that is likely to be potentially economically viable for Pebble East is termed "block caving." With underground block caving, no pillars are left to support the mine working during mine operation. In fact, block caving is designed to induce collapse in the ore zones. Ore moves downward under gravity and is collected at drawn points in access tunnels underneath the ore body.

Figure 2 shows this process diagrammatically. Block caving is the cheapest way mine underground and, since maintaining production rate is often a problem at underground mines, provides the highest production rate for ore of all the underground mining techniques.
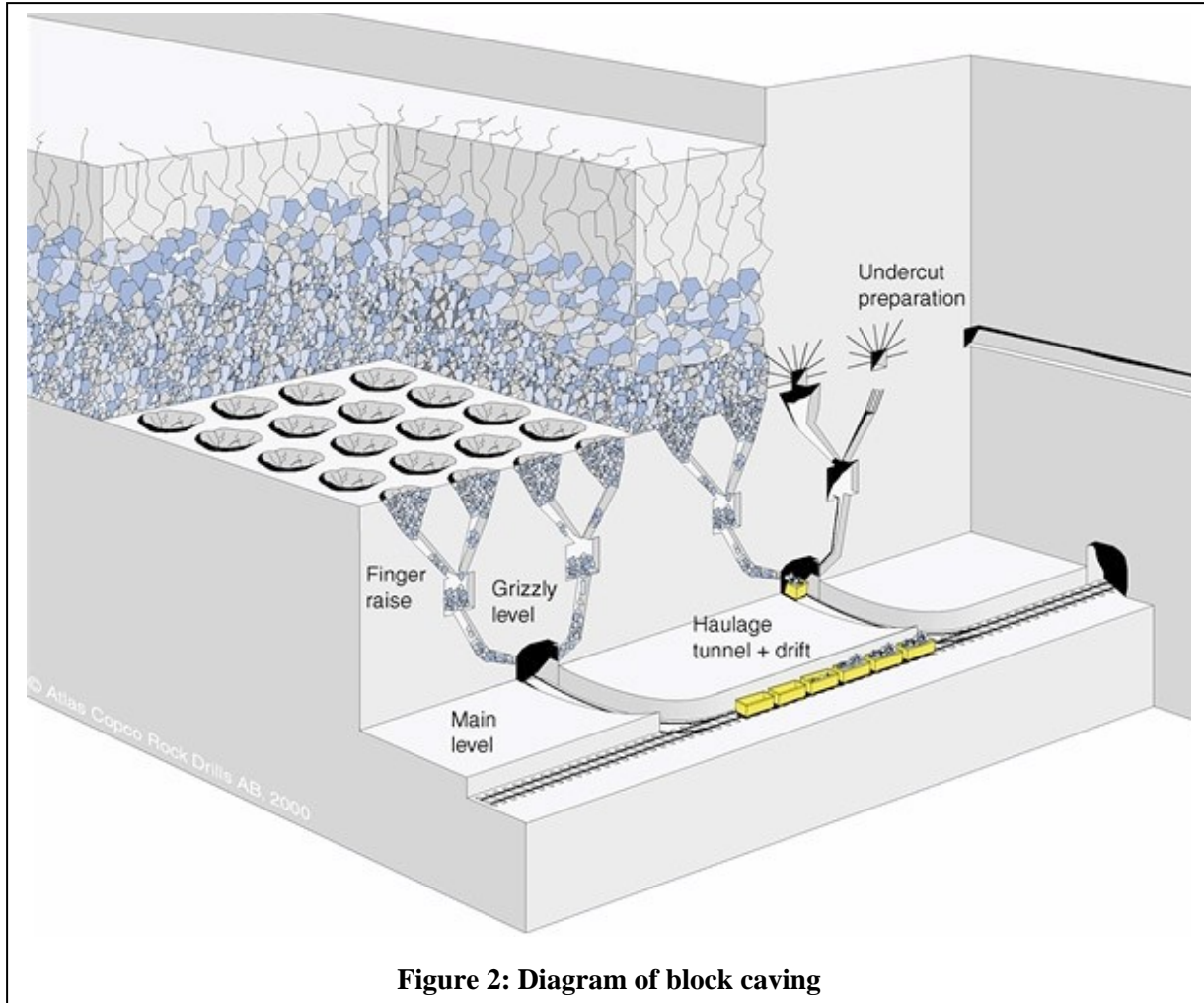
Figure 2: Diagram of block caving

Block caving does have several disadvantages. Since gravity and fracturing are the primary agents utilized to move the rock to the collection point, ore dilution is sometimes a problem because significant amounts of subgrade wall rock are collected with the ore. Another disadvantage of block caving is that large underground spaces are mined and destabilized, and these voids usually cause subsidence features to appear on the surface. Figure 3 shows some examples of surface subsidence.

Figure 3: Subsidence due to block caving at the San Manuel copper mine, Arizona

It is highly likely that subsidence will occur as a result of the block caving at Pebble East. Subsidence at the surface will allow water to enter the underground mine from above and come in contact with the broken rock that will remain underground in the mined areas. The rock in the remaining underground workings in the deposit will be mineralized. Unlike the situation prior to mining, where the sulfide deposit was essentially isolated from oxygen, the mined area will have water and oxygen available to it. This could lead to decomposition of the sulfide minerals and to acid mine drainage. If a flow path exists from the mine workings to ground and surface waters down gradient from the mine, migration of contamination off the mine site would be a long term issue.

The information presently available to the public is not sufficient to determine the extent to which acid mine drainage and groundwater and surface water contamination may be a problem, but it one of the most important issues in terms of potential long term impact from the mine, and needs to be carefully researched and addressed.

Because block caving will most likely cause surface subsidence, and because Pebble East is a sulfide deposit, the critical determining factor will be the hydrologic regime of the minesite. Predicting the hydrology of the area, and controlling post mining groundwater migration, will be

critical factors in determining whether it is possible to contain contamination from the closed mine.

IV. WASTE DISPOSAL

Mining at Pebble will generate two different waste streams - Tailings and Waste Rock. Each of these waste streams is further subdivided into two categories.

Tailings:[7]

(1) Bulk Tailings - Approximately 95% to 97% of the total tailings, which although they will probably be non-acid generating, will contain elevated levels of metals and residual process chemicals from the mill. Not all of the copper and molybdenum can be recovered, and other metals like arsenic, selenium antimony, which also appear in the ore, are purposely diverted to the tailings.

(2) Pyritic Tailings - Approximately 3% to 5% of the total tailings. These are acid generating, and contain a majority of the rejected metals in the ore. This material will be placed in an area of the tailing impoundment that will be permanently flooded with water in order to deny oxygen that could lead to acid drainage.

In 2006, NDM submitted applications for two tailings storage facilities at Pebble. See Figure 4. Tailings Storage Facility A, which will store approximately 2 billion tons of waste, incorporates three embankment structures in the South Fork of the Koktuli River, situated near the headwaters. All tailings embankments will be progressively raised in a series of staged expansions. The north embankment will ultimately reach a height of 700 feet, and the southeast and southwest embankments will reach ultimate heights of 710 feet and 740 feet, respectively.[8]

The Tailings Storage Facility at Site G would provide storage for approximately 500 million tons of tailings and potentially reactive waste rock,[9] including a main dam along the outlet of an unnamed tributary to the North Fork Koktuli River as well as a smaller saddle dam constructed along the headwaters of the tributary during later staged expansion of the tailings impoundment. The main dam would reach an ultimate height of 450 feet, and the saddle dam would ultimately by 175 feet in height.[10]

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[7] Pebble Project Tailings Impoundment A, Initial Application Report, Knight Piesold Ltd., 2006, Pebble Project Initial Application for Certificate of Approval to Construct a Dam filed with the Alaska Department of Natural Resources, Table 5.1

[8] Pebble Project Tailings Impoundment A, Initial Application Report, Knight Piesold Ltd., 2006, Pebble Project Initial Application for Certificate of Approval to Construct a Dam filed with the Alaska Department of Natural Resources, Executive Summary, p. 1

[9] Applications for Water Right, Pebble Project, North Fork Koktuli River, Northern Dynasty Mines Inc., 2006, Pebble Project Groundwater Right Applications filed with the Alaska Department of Natural Resources, p. 3

[10] Pebble Project Tailings Impoundment G, Initial Application Report, Knight Piesold Ltd., 2006, Pebble Project Initial Application for Certificate of Approval to Construct a Dam filed with the Alaska Department of Natural Resources, Executive Summary, p. 1
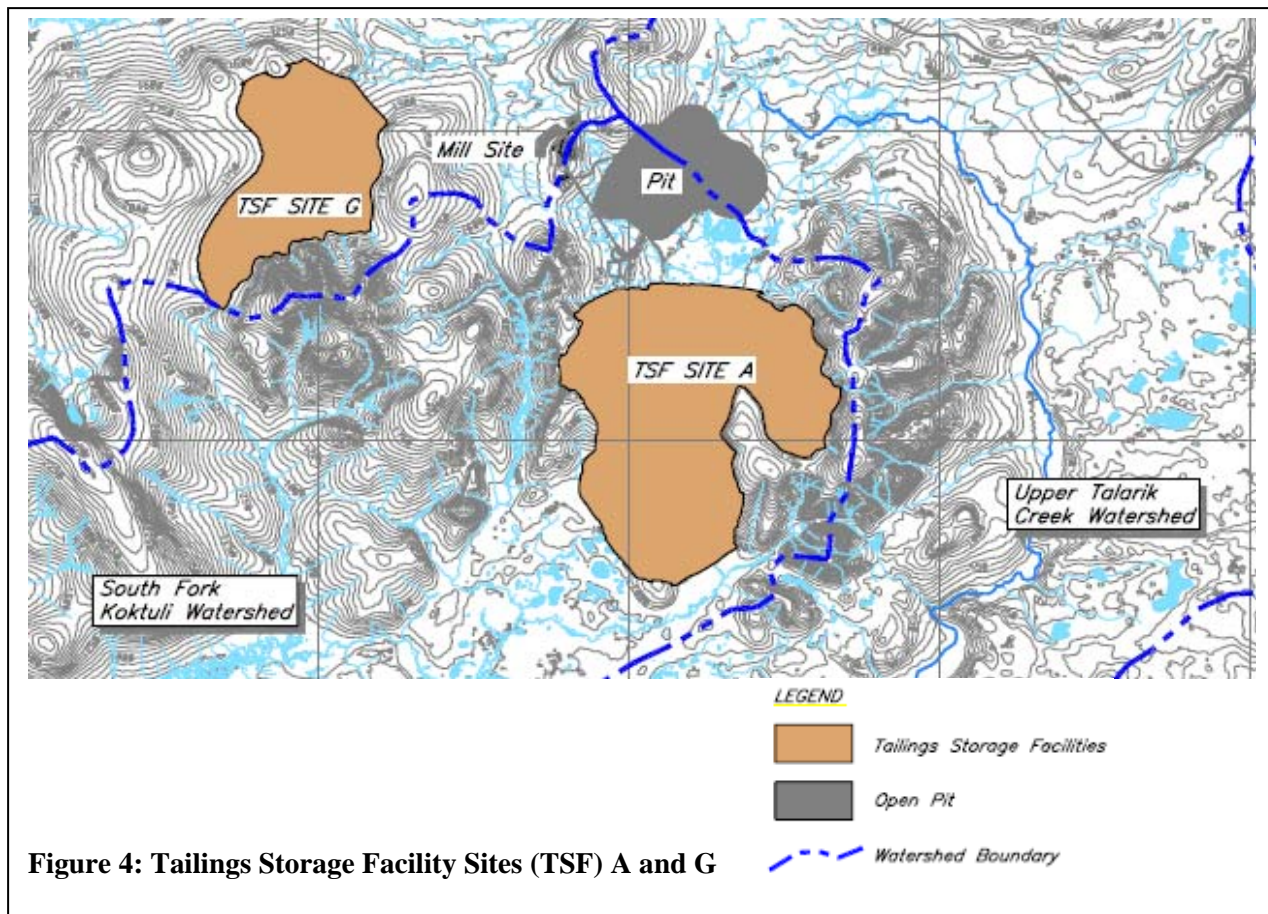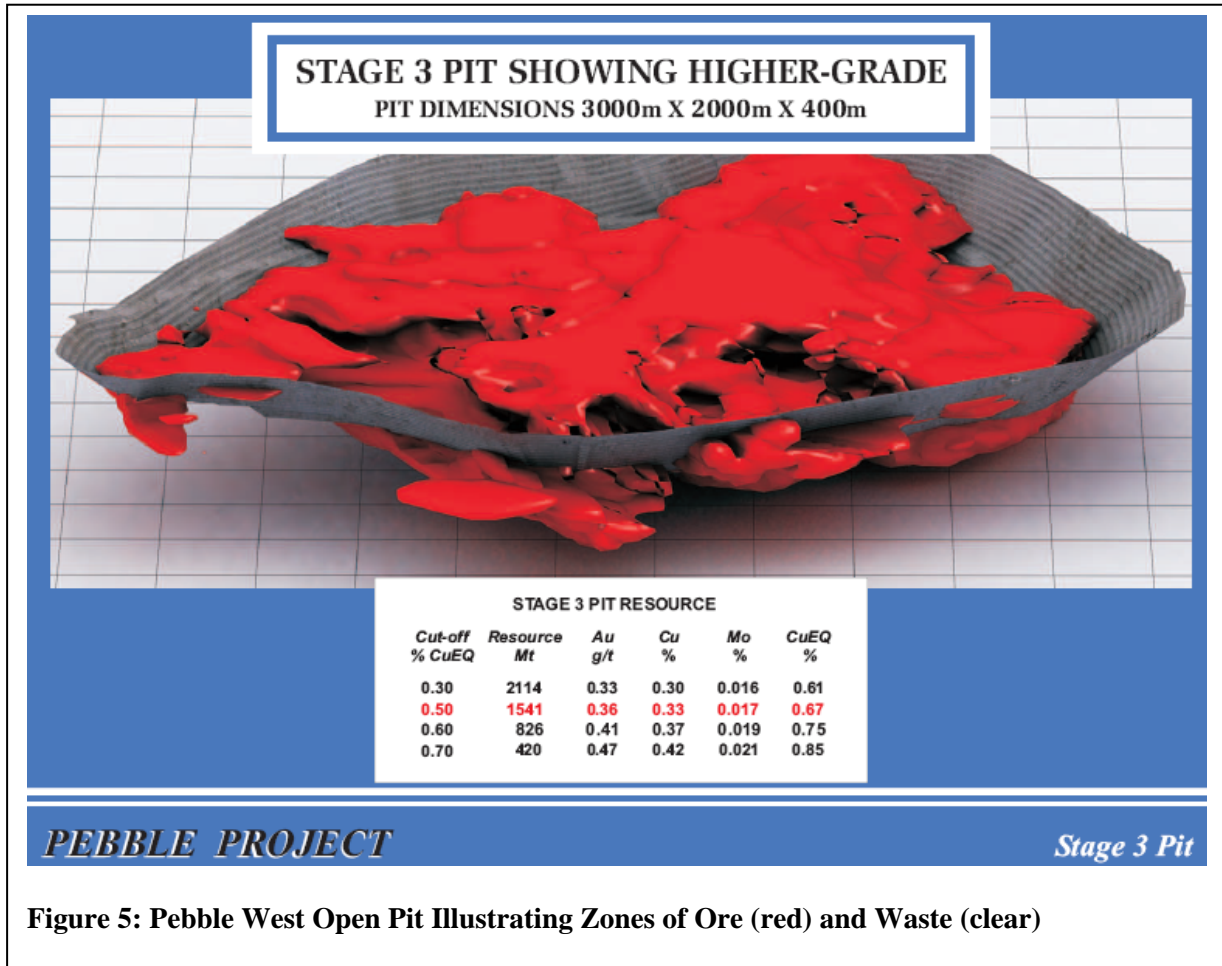
Figure 4: Tailings Storage Facility Sites (TSF) A and G

Waste Rock:

(1) Overburden from cover rocks that have not been intruded by the geothermal fluids that carried the metals into the deposit. These can be seen in Figure 1 (in green). Some waste rock from the ore zone could also be classified as non-acid generating if it was not intruded by these geothermal fluids, but careful testing will have to be done in order to make this distinction.

(2) Waste material (non-ore) from the ore zone will contain elevated levels of sulfide minerals, since this is a disseminated orebody. Much of this material will be classified as potentially acid generating, and will be placed with the tailings under water in order to reduce the rate at which sulfuric acid and metals are generated.

Even in an open pit mining operation with no "overburden" cover to be removed, as is largely the case for Pebble West, a significant amount of sub-ore grade waste can be generated. As previously mentioned, each blast hole is tested for its copper-gold-molybdenum content. Mined rock surrounding blast holes that does not equal or exceed the "cutoff" grade of copper-gold-molybdenum mineralization becomes waste rock, even though the amount of non-ore sulfide minerals may be significant. In a typical disseminated ore body, a significant amount of the mined rock will be classified as non-ore. For Pebble West this will be approximately 20% of the

total rock to be mined.[11]   Figure 5 illustrates what the ore and waste in the Pebble West (and probably in Pebble East) might look like.[12]

STAGE 3 PIT SHOWING HIGHER-GRADE
PIT DIMENSIONS 3000m X 2000m X 400m

STAGE 3 PIT RESOURCE

Cut-off % CuEQ	Resource Mt	Au g/t	Cu %	Mo %	CuEQ %
0.30	2114	0.33	0.30	0.016	0.61
0.50	1541	0.36	0.33	0.017	0.67
0.60	826	0.41	0.37	0.019	0.75
0.70	420	0.47	0.42	0.021	0.85

PEBBLE PROJECT   *Stage 3 Pit*

Figure 5: Pebble West Open Pit Illustrating Zones of Ore (red) and Waste (clear)

At Pebble West NDM has said there is a near-surface resource of 4.5 billion tons (in all categories) containing 24.7 billion pounds of copper, 42.1 million ounces of gold, and 1.35 billion pounds of molybdenum. The adjacent Pebble East deposit is said to have a resource of 3.7 billion tons containing 42.6 billion pounds of copper, 39.6 million ounces of gold, and 2.7 billion pounds of molybdenum.[13]

This is a total resource of 8.2 billion tons (as of 2007), of which over 99% would be waste that will remain on site. The resource estimate does not include potentially acid generating waste rock, which would also have to be placed behind the tailings dams. The proposed capacity of both Tailings Storage Facilities A & G is 2.5 billion tons.

This strongly implies that the required waste storage space for the mine will have to be approximately three times that which was indicated in the Tailings Impoundment Applications

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[11] Pebble Project, Northern Dynasty Minerals, Nov 2004, p. 24 "Low cost Mining" (Waste to Ore Ratio 0.23:1)
[12] Pebble Project, Northern Dynasty Minerals, Nov 2004, p. 30 "Stage 3 Pit"
[13] What is the Pebble Project?, http://www.ndmpebblemine.com/pages/Publications.php, June 15, 2007

made by NDM to the Alaska Department of Natural Resources in 2006. It also raises the questions of where this additional waste storage capacity may be located, and what non-mine resources might be impacted.

V.   TAILINGS DAMS

Waste rock from mining will be used to construct the tailings dams. It is likely that all of the overburden waste will be used for dam construction, and it appears that waste from the open pit and underground mines that will be classified as non-acid generating will also be required for construction purposes. There are no permanent waste rock storage locations shown in the preliminary site drawings submitted by NDM. There are several potential "buttresses" depicted at the base of the tailings dams which are also effectively storage piles for waste rock.

At the present time no geochemical testing results have been released to indicate what contaminants might be contained in drainage from the mine waste that will be used to construct the tailings dams. Even the non-acid generating overburden needs to be carefully tested for "neutral" drainage contaminants. Metalloids such as arsenic, selenium and antimony can leach from both non-acid and acid generating material. Since the dams will be constructed in the headwaters of drainages, seepage from this material used to construct the tailings dams has only limited containment, usually a small seepage collection dam downgradient from the main tailings dam, to collect any contaminants.

Groundwater monitoring wells should be placed below the seepage collection dam, and seepage collection wells can be constructed between the seepage collection dam and monitoring wells, but are not typically installed unless the monitoring wells show potential problems. Seepage collection wells are expensive to install and operate, and if needed could require long term or permanent maintenance.

Using non-ore waste from the mine as construction material carries some additional risk because it comes from material with elevated mineral content. As material is drilled and blasted from the mine, it is tested to determine whether it will be processed as ore or waste. If it is waste, it will also be tested to determine whether it is either potentially-acid generating or non-acid generating. To accomplish this a "cut-off" value for distinguishing between non-acid generating and potentially-acid generating material is established on the basis of extensive laboratory testing and field experience (once the mine has been in operation of a period of time).

There are two potential pitfalls with this approach to segregating acid and non-acid generating material. First, the cut-off value must be correctly established. Unfortunately the literature on acid mine drainage is replete with examples where initial estimates of acid generating potential were wrong, and material that was thought to be non-acid generating turned out to be acid-generating, resulting in a significant release of metals. Predicting whether mine waste will or won't leach metals, either by acid generation or by neutral drainage, is still an evolving science.

Second, even if a conservative cut-off value has been correctly established, any waste segregation scheme still depends on testing to accurately characterize the waste being classified, and for mine operators to then put this material in the right place. Only a fraction of the waste to be removed from a given area can actually be tested. Drill holes are sampled on the basis of an average sample along a specified length of the drill hole (usually 10 foot averages, but it could be more or less), and each drill hole is considered to be representative of a much larger volume of material (usually half way to the next drill hole). Most geologists have walked mine waste

dumps and seen rock that should have been taken to the mill as ore. Some mineralized material will inevitably be misclassified as non-mineralized, which could lead to the release of metals in places where it was not anticipated.

Waste monitoring and containment schemes, like groundwater monitoring and collection wells, need to take these issues into consideration. While misclassification or misplacement of waste will probably not lead to a massive acid mine drainage, unless it is done irresponsibly, it is likely to lead to low levels of contaminants being released from "non-acid generating" material. Thorough monitoring, and a backup means of containing and collecting unanticipated release of contaminants, are an important element of any monitoring and containment scheme.

Long Term Tailings Dam Stability

Unlike a dam built for impounding water, which can ultimately be drained if the structural integrity becomes questionable, a tailings dam must be built to stand in perpituity. The tailings material behind the dam will never go away. Even with an obvious requirement for long term stability, since 1970 the number of tailings dam failures has significantly exceeded the failures for dams used for water supply. See Figure 6.

One of the mechanisms for dam failure is static load induced liquefaction,[14] which can result in large landslide-like failures on the downstream face of a dam. This is a phenomenon that is much better understood today than it was 10 - 20 years ago, and the engineering considerations required to avoid this type of failure are now routinely applied during the analysis of the design of a tailings dam.

Some other long term failure mechanisms include cumulative damage (e.g. internal dam erosion and multiple earthquake events), geologic hazards (landslides, etc.), and changing weather patterns.
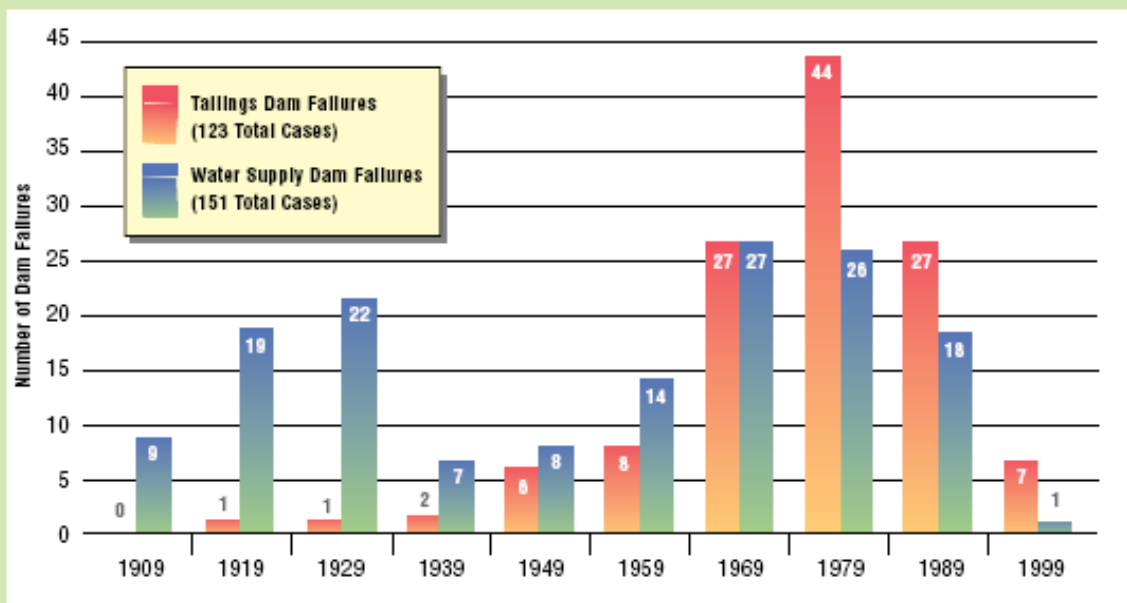
Another important failure mechanism is an extreme event. Dams are engineered to withstand overtopping from the probable maximum flood, and from shaking from large earthquakes. But in each of these instances assumptions must be made as to magnitude of these "maximum" events. And, as one leading tailings dam design expert has noted:

> "As time goes on, the largest event to have been experienced can always be exceeded but can never be made smaller. In fact, the bulk of dam safety expenditures for most owners of conventional hydroelectric dams are devoted to improving spillways and foundations to accommodate these new and higher values."[15]

In particular, there is a risk that a large earthquake might cause catastrophic failure of a tailings dam, with the release of a large amount of tailings, and could lead to long term environmental damage with huge cleanup costs. The probability of such a catastrophic failure is very low, but the consequences should it occur are very high.

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[14] Static liquefaction refers to the loss of strength in saturated material due to the build up of pore water pressures unrelated to "dynamic" forces, most typically earthquakes.
[15] "Stability Aspects of Long-Term closure for Sulfide Tailings", Steven G. Vick, from: Seminar on Safe Tailings Dam Constructions (sic), Gällivare, Sweden, 20-21 September 2001, Technical Papers

Figure 6: **Tailings Dam and Water Supply Dam Failures** (from: CASE STUDIES ON TAILINGS MANAGEMENT, International Council on Metals and the Environment, United Nations Environment Programme, November 1998, ISBN 1-895720-29-X)

There are several potential sources of earthquakes that might affect Pebble. The source for the largest potential earthquake comes from the subduction zone along the Aleutian Trench south of the coast in the Gulf of Alaska. This was the source of the famous 1964 magnitude 9.2 Alaska earthquake.

There are also a series of fault systems that parallel the Aleutian Trench on the Alaska mainland north of the subduction zone. One of these faults is the Denali Fault zone. A magnitude 7.9 earthquake occurred along the Denali Fault in 2002. Another of these parallel faults is the Lake Clark Fault. This is the fault that comes closest to Pebble.

A final seismic threat is what is generally termed as a "floating' earthquake, that is, one that is not associated with a known fault. It is generally assumed that this floating earthquake would occur under the site being evaluated, but would also be of a lesser magnitude than an earthquake associated with a known fault system.
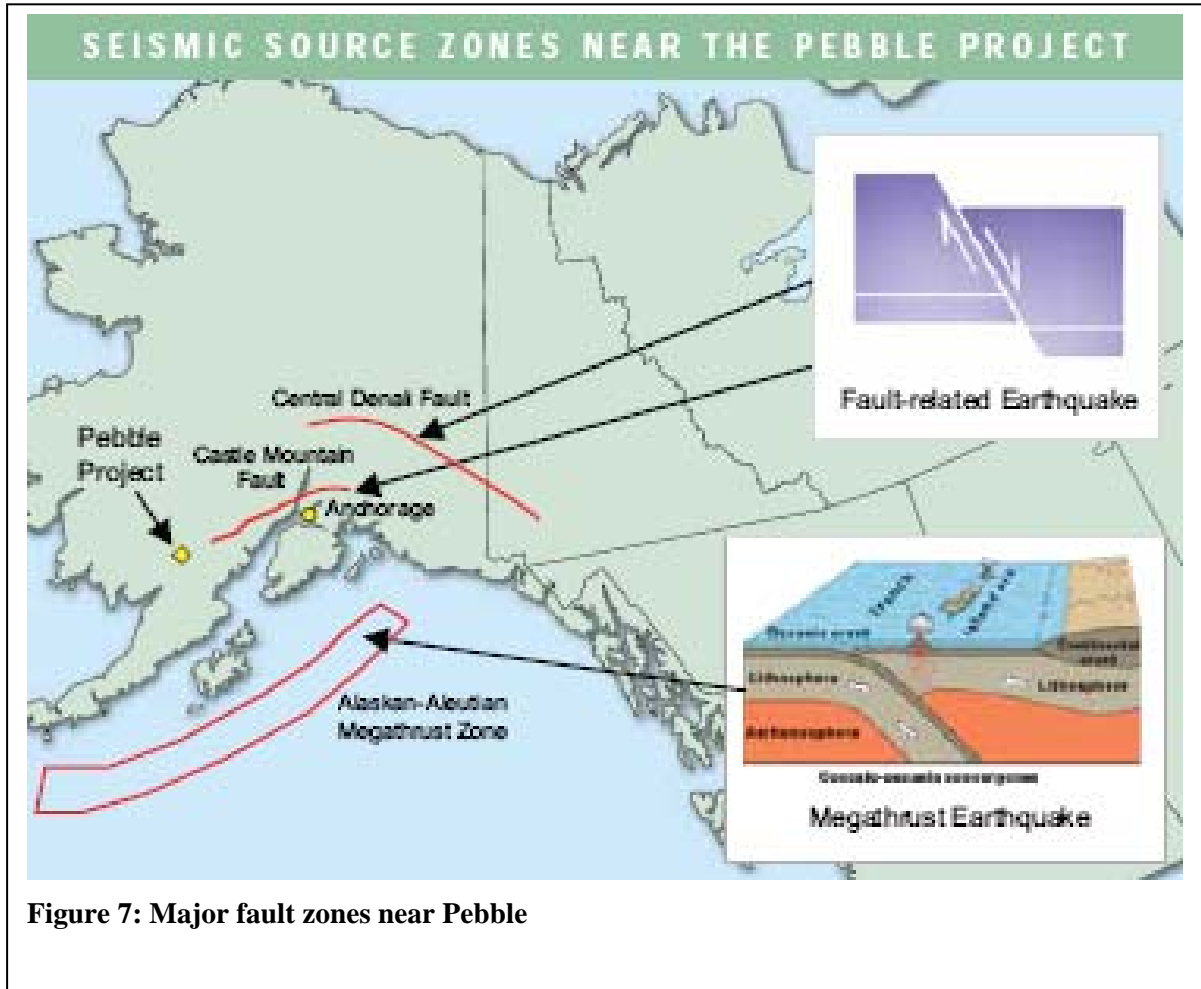

Figure 7: Major fault zones near Pebble

There is usually some flexibility in choosing the magnitude of the earthquake used in calculating the amount of ground motion that could impact the tailings dam and other critical mine facilities. Two factors are generally critical to this choice - the magnitude of the largest earthquake event that might be experienced on a given fault system, and the distance that that earthquake might occur from the project site.

The energy from an earthquake dissipates as it radiates from the source (the source is most often a linear feature rather than a point). So, the further away a location is from the source of the earthquake, the less energy is available to cause motion at the dam location. The Aleutian Trench is approximately 125 miles from the Pebble site, as is the Denali Fault. The Lake Clark Fault (an extension of the Castle Mountain Fault) is less than 20 miles from Pebble. The Lake

Clark and Denali fault systems are thought to be similar, so an earthquake of roughly similar magnitude might be expected along either of these fault systems.[16]

The largest earthquake that is thought to be able to occur along any one fault system is termed the maximum credible earthquake (MCE). The size of the MCE is usually estimated based on the seismic history of the fault, and the characteristics of the fault under consideration compared to similar fault systems. The International Commission on Large Dams (ICOLD) has published guidance on estimating the safety factors to be used in calculating seismic risk for dams, including tailings dams.

> "According to the current ICOLD guidelines, large dams have to be able to withstand the effects of the so-called maximum credible earthquake (MCE). This is the strongest ground motion that could occur at a dam site. In practice, the MCE is considered to have a return period of several thousand years (typically 10'000 years in countries of moderate to low seismicity)."[17]

The choice of the "return period" is important because the longer the return period, the larger the earthquake that might be expected. The larger the earthquake, the more energy (i.e. motion), and the longer the period of shaking that will take place at the site under consideration. At Pebble NDM consultants have decided to base their calculations on the "maximum possible earthquake." It is not clear if the intent is that the maximum possible earthquake is equivalent to the MCE, because a return period of 2500 years has been chosen instead of the normal 10,000 years as referenced above.[18] In the Pebble Project Backgrounder paper "Assessing and Managing Seismic Risk" it is stated that the 1 in 2500 year earthquake induces a horizontal acceleration of 0.25g, and that they are using 0.3g as their 'design event.'[19] While this horizontal acceleration might approximate the 1 in 3000-5000 year event, it is unlikely that the design event is as large as the 1 in 10,000 year event.

While it is possible that 2500 years may be an appropriate choice for the MCE, the details of this justification need to be carefully documented. Using a seismic event with a return period of 2500 years means there is a 100% probability that the dam will experience an earthquake of this magnitude sometime during the 2500 year period. Over 10,000 years the dam is likely to experience an earthquake of this size four times.

Using an earthquake with a return period of 10,000 years would mean that the dam would have to be designed to withstand more energy and longer shaking. This means more expense in building the dam, but it would make the dam less likely to partially or fully fail over the long term.

Tailings Dam Liner

To insure that the tailings dams remain stable over the long term from seismic and static load-induced liquefaction, the portion of the dam that provides its structural integrity (the majority

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[16] "26 km of Offset on the Lake Clark Fault Since Late Eocene Time", Peter J. Haeussler and Richard W. Saltus, U.S. Geological Survey Professional Paper 1709–A, 2004.

[17] "Earthquake Safety of Existing Dams for Irrigation and Water Supply in Rural Areas", Dr. Martin Wieland, Chairman, Committee on Seismic Aspects of Dam Design; International Commission on Large Dams (ICOLD), December 2001

[18] "Assessing and Managing Seismic Risk", Pebble Project Backgrounder, www.ndmpebblemine.com/pages/Publications.php, 15Jun07, pp. 2-3.

[19] Ibid., p. 3.

of the dam material) will utilize a synthetic High Density Polyethylene geomembrane liner, a low permeability till blanket, and a drain system to prevent water from saturating the dam. Water in the dam would significantly increase the susceptibility to dam failure from both static (water saturation) and dynamic (earthquake) loading.

It should be noted that the liner is to protect the structural integrity of the dam, it is not a liner meant to prevent seepage from the tailings escaping from the tailings pond. Today, many tailings facilities that impound potentially acid generating (PAG) material do employ a liner under the entire tailings impoundment. Only a portion of the Pebble tailings impoundment(s) will contain potentially acid generating material (both tailings and waste rock), and this part of the impoundment will permanently remain under water in order to limit the amount of oxygen that reached the PAG waste. While the water cover is needed to isolate the PAG material, it also provides additional pressure that will tend to force water through the PAG material.

It appears that most of the tailings dams and tailings pond area will be built on glacial moraine deposits, with a cutoff wall and/or grout to impede the leakage of water under the dam. This is all standard practice, and should minimize the amount of seepage into and under the tailings dam. There will be some seepage, and it is planned that the majority of this seepage will be trapped by either the seepage collection system inside the dam, or seepage collection wells placed below the dam. Wells are not planned at present, but could be employed if the seepage collection system does not work as designed. If the seepage collection system does not work as planned and wells are employed, then they will have to be maintained for a very long time.

It is impossible to completely stop the flow of water through waste material in a tailings pond, but a bottom (and top) liner would significantly slow this seepage compared to having no liner, as with the present proposal. The tailings ponds will be built over glacial moraine material, which could provide a flow path from the tailings pond and under the dam. The seepage collection pond below the dam is designed to intercept most of this seepage, but some will escape. Measures like liners and seepage collection wells below the seepage collection pond could be needed to keep seepage to a level that would not impact waters outside the mine site.

VI. MINERAL PROCESSING (MILL)

After blasting, ore is moved from the mine to the mill, and waste rock is taken to its final storage/use location. At Pebble this would probably be either to the tailings pond, or for use in dam construction. Since the ore contains approximately 0.3% copper and 0.02% molybdenum at Pebble West, and 0.6% copper and 0.04% molybdenum at Pebble East,[20] plus a very small amount of gold and other precious metals, approximately 99% of the ore that is processed will remain onsite as tailings. Waste rock would add to this waste total. As is typical for most metal mines, 99% of all the material mined becomes waste that requires onsite disposal.

At the mill the ore will be processed to create several metal concentrates, most probably a copper concentrate and a molybdenum concentrate which will be shipped off site for final processing. Ore is first crushed size of approximately six inches or less, and is then ground to the consistency

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[20] "New Resource Estimate Confirms Pebble East As One Of The World's Most Important Copper-Gold-Molybdenum Deposits," Northern Dynasty Mines News Release, Tue Feb 20, 2007.

of fine sandy clay. It is in the grinding process that most of the electrical energy at the mine/mill is consumed. After grinding the ore goes to the floatation tanks, where chemicals are added to separate the sulfide minerals from the non-sulfide host rock. Over 90% of the tailings will be created at the first stage of floatation. These "bulk" tailings have a relatively low sulfide content, since the objective of the floatation process is to recover as much of the copper and molybdenum sulfide mineralization as possible. After the first floatation operation separates the sulfide minerals from the non-sulfide host rock, another series of floatation cells is used to further separate the initial sulfide float into concentrates of copper and molybdenum. A third floatation product is a pyrite concentrate that will be placed in the tailings pond. This material is highly reactive and must remain permanently under water in order to inhibit the creation of sulfuric acid and acid mine drainage.

Northern Dynasty has not disclosed what chemicals will be employed in the processing, but typical floatation process chemicals include:

- *Collecting Agents* – Collectors induce specific minerals to adhere to froth bubbles; and modifying agents induce or depress adhesion of specific minerals to the bubbles. The collectors are organic molecules or ions that are absorbed selectively on certain surfaces to make them hydrophobic. These are thus the most important and the most critical flotation agents. Typically these are ethyl, butyl, propyl and amyl xanthates (e.g. Potassium Amyl Xanthate)

- *Frothing Agents* – Frothers are organic surfactants that are absorbed at the air/water interfaces (bubbles), and create a sudsy situation that allows the minerals that have bonded with xanthates to attach themselves to air bubbles in the froth. The two main functions of frothers are to ensure the dispersion of fine bubbles in the ore-pulp and to maintain an adequate stability of the froth on top of the pulp. (e.g. Methyl Isobutyl Carbinol (MIBC), and also Pine Oil)

- *Depressors* - Depressors are inorganic compounds which selectively cover the mineral surfaces to make them hydrophilic and thus decreasing their affinity for collectors. The use of depressors increases the selectivity of flotation by preventing the flotation of undesirable particles. (e.g. cyanide – While cyanide is primarily used to dissolve gold from ore/concentrate, it is sometimes used in small amounts in base metal floatation operations to keep pyrite from being collected in the floatation cells.)

- *Activators* – Activators are generally soluble salts that ionize (dissolve) in water. The ions in solution react with the mineral surfaces to favor the absorption of a collector. Activators are used when collectors and frothers cannot adequately float the concentrate.

- *Flocculant* – Flocculants are used to collect suspended particles to help separate water and solids. Flocculants are polymers, essentially water-in-oil emulsions. Flocculants are found in tailings, but generally adhere to particles and are not particularly mobile in the soil.

- *Surfactant* – Surfactants are products that carry out essentially the same role as detergents (for example washing detergents). They are designed to reduce the hydrophobic characteristic of organic contaminants to such a level that they are removed from the solid particles.

- ***Lime*** – Lime is used primarily to raise the pH of the processing solution to the desired level.

- ***Acid*** – Acid might be added at the end of the water treatment process to bring a discharge of treated mill water, which may be elevated due to the addition of lime, down into a pH range mandated by water quality standards.

The residual process chemicals remain either in the concentrate or the tailings, and some will be recycled with water that is recovered from the tailings and concentrate water that is returned to the mill. There is some toxicity associated with these process chemicals. Most are used in relatively small amounts in relation to the volume of tailings and the amount of water used for processing. Most process chemicals are organically-based, and will degrade in the environment. Cyanide is the process chemical with the most toxic potential. The degradation of some process chemicals (including cyanide) can also produce toxic byproducts, like ammonia, which are toxic to aquatic organisms. Because of the dissolved metals and residual process chemicals, the water coming directly from the mill is usually toxic, and most aquatic organisms cannot survive in this water.

The copper concentrate and a molybdenum concentrates from the floatation process will be transported to the port on Iniskin Bay in Cook Inlet via a concentrate pipeline for loading mineral-bearing concentrates onto ocean-going vessels, as well as for receiving freight and operating consumables. A 104-mile industrial road will connect the mine and the port site,[21] and the concentrate pipeline will parallel this road. At the port site the concentrate will be dewatered, and loaded onto ships for sale and transport to smelters around the world. The water that is removed from the concentrates is contaminated, and will be returned to the mine via a parallel pipeline to be reused at the mine. These pipelines will be engineered with leak detection systems and shutoff valves, and should have ditch or berm containment to help contain any spillage, especially in the vicinity of stream crossings. Shutoff valves can limit, but not prevent, spillage of concentrate and/or waste water, because the material between the shutoff valve and a break can still leak from a ruptured pipeline.

Care is also required as the concentrates are loaded aboard ships at the port site. Water is removed from the concentrates at the port site before loading onto ships. When this water is removed, the concentrates become more susceptible to wind blown dispersal. Concentrates are normally stored temporarily in a storage shed, and then moved via conveyor from the storage shed, along the loading dock, and onto the ship. Great care must be taken to in designing and operating these loading facilities in order to prevent the escape of concentrate that can cause contamination.

There are presently three ship loading facilities for metal concentrates - at the Red Dog mine port site; at the Greens Creek mine; and the Skagway ore loading terminal, which handles ore concentrates from mines in the Yukon. There have been handling and loading-related contamination issues at all of these sites.

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[21] http://www.ndmpebblemine.com/pages/RoadPortPower.php, 15Jun07

VII. RECLAMATION AND CLOSURE

Modern mines "design for closure." That is, the mine's operating plan attempts to anticipate the final configuration of the mine at closure, which not only leads to operating procedures that complement and speed up mine closure, but also minimize short and long term closure costs. The goal of all mining companies is to achieve a "walk-away" closure. This minimizes long term liability and is the most cost effective process for a company.

Unfortunately, it is seldom possible to achieve a true walk-away situation at a large sulfide mine. At minimum tailings dams must be inspected and minor repairs must be made due to storm and stream related erosion. At worst, perpetual water treatment may be required. At Alaska's other sulfide open pit mine, Red Dog, perpetual water treatment will be required. Perpetual water treatment can easily double the cost of closure (and run tens to hundreds of millions of dollars), so it is in the best interest of both companies, who are obligated to pay for treatment, and the public, who is ultimately responsible either for the closure costs or for the environmental damage that will occur if a treatment is not performed, to avoid the need for perpetual water treatment.

Mining-regulatory agencies in two states, New Mexico and Michigan, currently ban perpetual water treatment.[22] Other regulatory jurisdictions, including Alaska, have taken a position that mines which require perpetual water treatment will be allowed to open if an adequate financial surety for treatment is provided. There is obvious risk in this. It assumes that regulators can accurately predict what the water treatment costs will be in perpetuity, and that the financial instrument will remain valid for that time. There are, unfortunately, examples where the amount of the financial surety for treatment has been inadequate, or more commonly that it was not thought that water treatment would be required, yet post closure conditions required it.

Reclamation Bond Calculations and Surety

Alaska reclamation law requires that a bond amount be calculated for the closure of a mine, and that an adequate financial surety for closure be provided to the bond holding agency. For state lands the bonding agency is usually the Alaska Department of Natural Resources, but the Alaska Department of Environmental Conservation also has overlapping bonding authority for solid waste disposal facilities, which includes mines that could generate acid mine drainage.

The cost of the reclamation is usually initially calculated by the mining company, and these calculations are then confirmed or modified by the regulatory agency. Regulatory agencies, including those in Alaska, have a history of underestimating the closure costs for metal mines.[23] While it is logical that the mining company take the first cut at calculating the reclamation costs, since the company is in the best position to define the site-specific tasks that must be

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[22] See the New Mexico Mining Act at Chapter 69 - Mines, Article 36 Section 69-36-12-B; and, Michigan's Non-Ferrous Mining Statute and Rule (Part 632). Part 632 consists of Sections 63201 to 63223 (the "Act") and Parts 1 to 6 of the promulgated rules (the "Rules") R. 425.409(b)

[23] There has been one large mine bankruptcy in Alaska, at the Illinois Creek mine. The bond held by the Alaska Department of Natural Resources was not sufficient to close the mine, but agency was able to reopen and operate the mine under contract to a private company and secure enough funding to close the mine. The Center for Science in Public Participation has published two reports on reclamation bonding. One addresses reclamation bonding in Alaska - Alaska Large Mine Reclamation Bonding – 2005, David M Chambers, June 2006 - and concludes that present bonds for Alaska mines are underestimated by approximately 40%. The second report analyzed mine reclamation bond estimates nation wide - Hardrock Reclamation Bonding Practices in the Western United States, James R. Kuipers, PE, Center for Science in Public Participation, February 2000 - and came to a similar conclusion about the inadequacy of reclamation bonds nation wide.

accomplished for mine closure, there is also an inherent bias to pick the lowest costs as reclamation and closure estimates. Companies, and the contractors that work for them, are trying to minimize their operating costs and the amount of money that will be required as a financial surety for reclamation. State and federal regulatory agencies do not have the manpower necessary to thoroughly check, and recheck on a periodic basis throughout the life of the mine, these reclamation bond cost estimates. It would be more appropriate for the regulatory agency to hire a consulting firm with the expertise and manpower necessary to fully analyze these cost estimates. But this is virtually never done.

The form of the financial surety held by the regulatory agency is also important. Mine closure typically costs tens to hundreds of millions of dollars, so the cost of reclamation is significant liability to the regulatory agency, and by association to the taxpayer. In Alaska regulatory agencies generally accept cash, insurance bonds, letters of credit, or corporate guarantees.[24] By far the most potentially problematic of these surety forms are corporate guarantees. All of the other surety forms are readily convertible to cash that can used by the regulatory agency to reclaim a mine should the operator go bankrupt. A corporate guarantee is merely a letter from a corporation to a regulatory agency saying it will pay for reclamation. The corporate guarantee is not backed by any tangible security.

Before 2000, few state and federal regulatory agencies accepted corporate guarantees. Since 2000, some regulatory agencies have decided to accept corporate guarantees, largely because the cost of bonds and letters of credit has increased sharply. A significant part of this increased bond cost to the mining industry is due to the rate of mining company bankruptcies that occurred in the 1990's. The more recent, but historic, rise in the price of metals has stimulated the opening of new mines, and reopening of closed mines. Consolidation of companies and mining assets, rather than bankruptcies, is characterizing the mining industry in this period.

Once a regulatory agency has accepted a corporate guarantee as the financial surety for mine closure, the agency is essentially "on the hook" for the cost of the mine closure if the corporation is not able to meet its financial obligation. Corporate guarantees obviously reduce the cost of mining for companies, but whether they will result in an additional financial burden to the public will depend on the ability of these agencies to accurately determine whether each individual corporation will be able to meet its financial guarantee in the long term. Unfortunately, agencies in several jurisdictions that depended on corporate guarantees (prior to 2000) have been forced to use public funds for mine closure and water treatment.[25]

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[24] A summary of the reclamation surety requirements for state and federal regulatory agencies in Alaska is:

Alaska Department of Natural Resources - corporate surety bond, letter of credit, certificate of deposit, deposit of cash or gold (11 AAC 97.400 - 5Jul06)

Alaska Department of Environmental Conservation - self-insurance, insurance, surety bond, corporate guarantee, letter of credit, certificate of deposit, or other proof of financial responsibility approved by the department (AS46.03.100(f) - 9Mar05)

Bureau of Land Management - surety bonds, cash, letters of credit, certificates of deposit, negotiable United States government, state and municipal securities or bonds; investment-grade rated securities, insurance (43CFR3809.555 - 1Oct06).

US Forest Service - bond of a corporate surety, cash, negotiable securities of the United States, irrevocable letter of credit, performance bond, any other types of bond specified in the Forest Service Manual (36CFR228.51 - 1Jul06).

[25] In Montana the State and BLM have had to provide public funds to provide approximately $30 million for water treatment at the Zortman-Landusky mines that was to have been provided by the bankrupt Pegasus Gold Corporation. In Nevada, the legislature had to appropriate $600,000 to establish an emergency response fund so that

VIII. CONCLUSIONS

Because Pebble involves a mining sulfide deposit located in an area with significant surface and ground water, Pebble is likely to have water contamination issues that will require mitigation.[26] The success or failure of this mitigation will determine the long term environmental impact from the mine itself.

Mining at Pebble will take place not only in an area that has never seen mining, but also in an area that has very little in way of transportation or human infrastructure. The mine itself will have long term environmental impact, and this impact will be proportionally increased by the human infrastructure necessary to support the mine. This infrastructure will remain after mining ceases.

In this report the emphasis has primarily been on analyzing the potential environmental issues with the Pebble mine. Whether a mine is managed in a manner that leads to "good" or "responsible" mining also includes important social and economic issues, as well as those issues focused on environmental concerns. The pros and cons of the social and economic impacts must be weighed along with the environmental impacts. And, there is no mine that hasn't had some significant problem during or after its operational life.

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the Nevada Department of Environmental Protection for the interim operation of bankrupt mine sites. In the 1990's approximately 50 percent of the $480,000,000 in total bonding liability was covered under self-bonding.

[26] "… the combination of proximity to water resources (including discharges) and moderate to high acid drainage or contaminant leaching potential does increase the risk of water quality impacts and is a good indicator of future adverse water quality impacts." Comparison of Predicted and Actual Water Quality at Hardrock Mines, Kuipers et. al., 2006, p. ES-12.