Pebble Alternative Tailings Storage Options

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Our Pebble Articles

- *Overview*
- *Block Caving*
- *Water Management*
- *Nearby Mining Claims*
- *Keystone Dialogue*
- *Perpetual Maintenance*
- *Tailings Storage*
- *Alternative Tailings Storage*
- *Opposition*
- *Powering Pebble*
- *Earthquake Risks*

At the **proposed Pebble Mine**, the mine developer intends to store the mine's sulfide **mine tailings** under an artificial lake enclosed by earthen dams, which must be maintained **in perpetuity**. This plan has been put forward in several project analyses (**2006** , **2011** (32 MB)) and is detailed in our article on **Pebble Tailings Management**.

There are alternatives to producing tailings in open-pit volumes and interring them in conventional impoundments. These options vary from established to speculative, and from feasible to implausible.

The alternatives can be grouped into three general categories: Improved conventional impoundments, non-impoundment storage and disposal, and completely alternative mining methods. All mitigate some of the largest risks of conventional mining in sulfide ore, metal leaching and **acid drainage** from waste rock and sediment stored on the landscape.

Options for Improving a Conventional Impoundment

The least radical mitigation strategy is to modify and improve the currently proposed tailing impoundments. This leaves unresolved the central problem of **perpetual maintenance**, as the facilities would still need to resist erosion, large storms, earthquakes, and future economic or political situations that compromise facility maintenance.

All Downstream Dam Construction

Tailings dams are typically constructed in **one of three ways** : upstream, centerline, or downstream. This refers to how the dam is raised from its initial level. Downstream dam construction is the most durable and reliable construction method. Centerline and upstream dams are progressively less stable, and also progressively cheaper to build. Dams resting on buried tailings (downstream) or rising vertically against a tailings mass (centerline) are more vulnerable to earthquake shaking than pyramidal downstream-constructed dams, and would generally be more vulnerable to large storm events, long-term earth deformation, and possibly to general leakage.

The most recently suggested dam construction method for Pebble is centerline construction. **As proposed** (32 MB), Pebble's earthen dams would use conventional downstream construction initially, and then switch to a centerline elevation method. If a purely downstream construction method were used, the earthen dams would be entirely self-supporting, and less likely to fail over time.

Geomembrane Lake Liner

Some tailings impoundments use a plastic liner, known as **geomembrane** , to reduce water infiltration into the surrounding geology, and hence slow down **acid mine drainage**. A liner would improve seepage water retention, perhaps substantially, although Northern Dynasty Minerals **contends** that the fine-grained tailings would themselves form a suitably impermeable barrier. Long-term performance of a liner is difficult to predict. Most modern plastics were developed less than 100 years ago, and plastics have only been in widespread use since World War Two. It is not known how geomembrane will degrade after decades or centuries under water-saturated tailings.

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Impoundment of Waste Rock

The developer has indicated an intention to pile non-tailings waste rock in uncontained heaps around the mine excavations. Waste rock has historically been a major source of mine-related water contamination of natural waters. While waste rock typically has less acid-generating potential than tailings, it is seldom contained and thus has a higher potential to escape into the environment.

Pebble will produce copious volumes of waste rock. Recent estimates suggest it will produce 1.5 tons of wast rock per ton of ore early in its life (first 25 years), rising eventually to a peak of 2.6 tons of waste rock per every ton of ore, during its underground minging phase. If acid drainage is identified from waste rock piles on the landscape, it may not be economically feasible to move or contain the offending rock. Even if it is possible to move waste rock into the impoundment, the tailings impoundments may not be built large enough to contain it. Tailings impoundments would need to be more than twice as large (and probably much more than twice as expensive).

Some effort would be made to segregate potentially acid-generating waste rock from more inert rocks. If this was successful, it might enable more efficient management and containment of the more hazardous waste rock.

Concrete Dams

Theoretically, Pebble's earthen dams could be made stronger by constructing them out of reinforced concrete. This is not a practical option for two reasons. First, concreted dams are extremely expensive, and the same time and money could presumably be used to build much larger earthen dams. Second, the long-term durability of structures must be considered for perpetual storage, and a concrete dam is more vulnerable to degradation over the long term than a large, stable earthen dam.

Chemical Buffering

The acid generating potential of sulfide rock can sometimes be neutralized by thoroughly mixing it with carbonate rock (limestome). Although attractive in theory, the historic record of this technique has been mixed, due to real-world chemical complexities.

The Iliamna region, where Pebble will be located, lacks extensive carbonate rock. However, unidentified local rock might still be found for this, or lime could be imported. Such an operation would require excavating, transporting, crushing, grinding and mixing the buffering rock into the tailings stream. The amount of buffering rock required would depend on its alkalinity and the quantity of acid-generating tailings.

Overall, this solution would require much more energy, infrastructure, and equipment. If only pyritic tailings were buffered in this way, some hundreds of millions of tons of buffering rock would likely be required. Chemical buffering still does not address the problem of harmful drainage not associated with acid, most notably selenium and arsenic.

Options for Alternative Storage and Disposal

Conventional impoundment is not the only storage method currently in use. Offshore discharge, dry stacking, reburial, cementing, and in-pit disposal are among the other options available.

Dry Stack

Removing most of the water from tailings allows them to be stored in piles, rather than as a mud slurry. The resulting "dry cake" can be piled on the ground like ordinary dirt. This is known as dry stack storage. Dry stack tailings are more structurally stable than wet tailings, and the risk of catastrophic flowage or escape is reduced. The recovery of metals and processing chemicals from the tailings is more efficient since they are recovered with the extracted water. The tailings impoundments themselves are more versatile in structure and location, total facility size is slightly reduced, and rehabilitation is easier.

The acid-generating potential of Pebble Mine would not be totally eliminated by dry stack storage, since it is

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very difficult to keep such a massive volume of tailings completely sheltered from moisture in such a wet climate. Groundwater seepage and acid drainage may be a problem wherever the tailings were exposed to moisture. Dry stack is currently most effectively used in deserts, not in wet climates- although it is conspicuously being used at Alaska's much smaller Pogo and Greens Creek mines.

Since it is the combination of oxygen and water exposure which leads to acid generation, limiting oxygen availability could theoretically reduce acid formation as well - and this is the purpose of the artificial lake which overlies tailings in most conventional tailings impoundments. The use of an oxygen-limiting cover will be attempted at Greens Creek Mine, to seal off the stacks of dry cake after mine closure. Preliminary tests suggest that this technical challenge has not yet been effectively solved, so this "enhanced dry stack" method is still experimental.

Lake Disposal

Disposal of tailings into **nearby Lake Iliamna** has also **been considered** . While this idea could provoke a strong public backlash, the lake might securely entomb tailings in its deep north end. The developer has rejected this idea.

The long-term environmental effect of submarine tailings disposal in the sea is **not known** , let alone what the effect might be in confined large lakes. From a perpetual storage perspective, Lake Iliamna has previously hosted glaciers, and future glaciations might excavate the tailings and deposit them on dry land or into Bristol Bay, meaning the disposal method is not "forever" - but it is very likely the tailings would remain in the lake bottom for the rest of human civilization.

Offshore Disposal

Saltwater disposal into Cook Inlet or Bristol Bay would be much more expensive than disposal into Lake Iliamna, since tailings would need to be piped a minimum of 60 miles to reach tidewater, and then might need to be transported much further, either by underwater pipeline or by ship, to reach sufficiently deep water. Disposal into the sea is attractive, since it dilutes tailings into an immense volume of water, which is itself in circulation with the Pacific Ocean.

The primary concern with offshore disposal would be the physical and chemical impact of the tailings themselves on the local area, as they would constitute millions or billions of tons of ore mud. Bristol Bay and Cook Inlet already have substantial natural inputs of sediment from glacial rivers, which could eventually bury the tailings (perhaps over hundreds or thousands of years), and thus lessen their long-term impact.

The long-term impacts of offshore tailings discharge are unknown. The potential effects of disposing of hundreds of millions of tons of tailings, whether pyritic or inert, into either body of water are unclear, and would require further research. Offshore disposal is complicated by the importance of the **Bristol Bay and Cook Inlet fisheries**. Recently, deap sea tailings disposal was thoroughly **evaluated** Big for use in Papua New Guinea (and the evaluation itself was **critically evaluated** by advocacy group **MiningWatch**). Noted tailings engineer blogger Jack Caldwell also **comments** on the study. Even it was scientifically proven that such disposal was feasible, this option might face insurmountable political opposition.

In-Pit Reburial

Tailings could be returned **to the pit** after mine closure. Advantages of in-pit reburial include the extreme durability of the containment structure (the pit), removal of the tailings as a surface landscape hazard, and displacement of what would be a water-occupied pit lake with solid tailings. Conceivably, the walls of the pit could be sealed or grouted before filling, to reduce their water permeability. The pit itself would still require **perpetual management**.

In-pit reburial would still initially require a conventional tailings impoundment facility, since the tailings could not be returned to the pit until mine closure. Due to the high cost of moving the tailings a second time, it is unlikely that this would be done, in practice. Even if formally mandated, several situations could preclude pit infilling, such as if the pit was declared unsafe, or if the mine owner declared bankruptcy.

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If in-pit burial were pursued, it is unlikely all the tailings would fit in the pit, due to the expansion of ore volume when it is powderized and mixed with water. Some form of tailings impoundment would still need to existent in perpetuity, even if the major impoundment facility were reclaimed. In-pit reburial could also endanger any current or potential nearby underground mining, and therefore might need to be delayed until the conclusion of all mining operations, which might be more than 30 years after the conclusion of pit mining.

Finally, filling the pit would make it far more difficult to re-open the pit at a later date. Temporary mine closures are common, and a mining firm would be very reluctant to fill in the pit if there was any possibility it might be re-openned in the future. Given the enormous size of the Pebble deposit, it's very possible that the mine would go through periods of quiescence and re-activation, as metal prices (copper, gold, molybdenum) and operating costs (oil, gas, machinery, labor, etc.) fluctuate. Simply put, filling the pit with tailings would badly damage a very valuable asset.

Cemented Tailings

Pebble’s tailings **could be mixed with cement** , turning them into solid masses of concrete. While this solution is used for backfilling tailings in underground mining (e.g. at **Greens Creek**), this tactic requires the tailings to be stable only for a short period of time. The long-term behavior of cemented tailings is not well studied. In the case of sulfide tailings, the sulfides may oxidize and chemically break down the cement by consuming the carbonates. Finally, cementing tailings physically stabilizes them but does not necessarily (or usually) render them geochemically neutral. If all of Pebble’s tailings were cemented with 5% to 10% cement by volume, this would require 10,000 to 20,000 tons of cement per day. These cemented tailings might be stored by various means - such as conventional impoundment, underground filling, or in-pit reburial.

More likely, however, only the most hazardous pyritic tailings would be cemented, which would be some fraction of the total. Although the actual fraction of pyritic to inert tailings isn't known, this article assumes 10% of tailings would be pyritic, based on recent **mine model** (32 MB). This suggests that 200 million tons of pyritic tailings would be produced by a hypothetical 25-year mine, requiring 10-20 million tons of cement. Alaska possesses large limestone deposits that could be mined for the cement's raw materials. Notably, cement production has its own costs and externalities, especially CO2 emissions.

Export Sulfides

Pebble’s more hazardous pyritic tailings could theoretically be exported via **ore ship** . Pebble’s proposed port is projected to be able to service Handymax-sized bulk carriers, which can carry up to 50,000 tons of cargo. Over 25 years of mine operation some hundreds of millions of tons of pyritic tailings would be generated. Transport of 200 million tons of tailings would require approximately 4,000 Handymax loads, in total or one vessel every 2.5 days. An ultimate disposal method for the tailings would still need to be identified, such as deep-sea burial.

Options for Alternative Mining Strategies

Porphyry deposits like those at Pebble are traditionally mined using open pit mining and **block caving**, a large large-scaling underground mining method that essentially produces a self-collapsing "underground open pit", from the bottom up. These are not the only methods by which modern mining is conducted. Other methods of mining potentially leave less tailings footprint, although they may be impractical at Pebble.

Selectively Targeted Underground Mining

However, the Pebble deposit may be quite variable in its richness. Theoretically, a selective underground mining method like **drift-and-fill** could be used to target the richest ore. This would be a viable option only if Pebble’s highest-grade ore has a lucrative combination of purity and accessibility.

The primary advantage of this practice, from a tailings management perspective, would be the reduction in total tailings quantity. Tailings could be stored in any number of ways, such as surface impoundment

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or **underground reburial** . Even underground reburial would not fully eliminate the issue of **acid mine drainage**, since the tailings would still be available to contaminate groundwater. Cementing the underground tailings might further mitigate the risk of acid drainage. The practice of cementing underground tailings is common.

Extracting Without Digging

Known as **In-Situ Leaching (ISL)** , this mining method involves drilling boreholes into the ore body and then pumping solvent fluid frequently after blasting or **hydraulically fracturing** the body to increase its permeability. The solvent fluid absorbs metals. It is then pumped back out, and metals are extracted from the fluid.

ISL has been used successfully for copper and uranium extraction. ISL has a very low ore production rate compared to pit mining and block caving. On the whole, less ore would be processed, and a lower percentage of metals would be recovered from the ore. If ISL was economically feasible at Pebble, it could lead to long-term sustainable mining of the prospect, provided potential groundwater pollution could be managed.

Managing underground water contamination and flow is extremely difficult. As with pollution concerns associated with hydro-fracking and underground **waste fluid injection** , effective ISL could still be associated with hard-to-manage groundwater pollution. If the ISL was conducted below the surface aquifer, however, it might only impact relatively deep waters which already contain a heavy load of salts and other minerals.

While attractive in theory, ISL is likely to be a very poor option for Pebble. Pebble’s high-sulfide copper minerals are resistant to dissolving in solvent fluids. To date, gold has never been successfully extracted on a commercial scale using ISL. Sustainable mining advocates might prefer to see Pebble selective mined only for copper, which is a **crucial industrial metal** and whatever non-gold metals could also be extracted with ISL. Gold mining itself has a **low industrial value and high external costs.** This does not resolve the fundamental problem of the low solubility of Pebble's copper-bearing minerals.

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