Lunar Mine Reclamation Principles. O. S. Lawlor[1], [1]U. Alaska, PO Box 756670 Fairbanks, Alaska 99775. (Contact: lawlor@alaska.edu)

Introduction: We propose that lunar mines [1] should be reclaimed to look like craters. Careless mining on Earth can degrade water and ecosystems for centuries, but erosion eventually covers up our mistakes. The lunar surface has no ecosystems but no rapid erosion, so every lost shovel or mine pit will remain for millions of years. Even though lunar permanently shadowed regions are never visible from Earth, in a few thousand years orbital mirror illumination and lunar polar orbital traffic may become common. Poor reclamation will endanger popular and political support for any use of space resources, so we should follow a long term holistic life-of-mine plan from day 1. This paper lays out these principles.

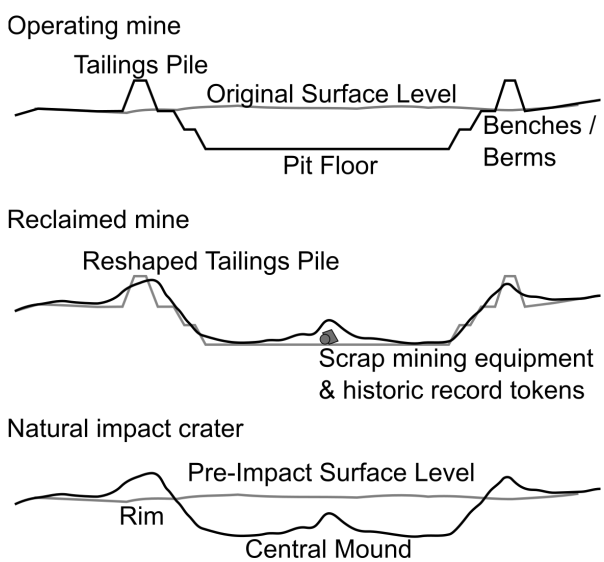
Principle 1: *Safety* over the long term. Deep pits or unstable slopes will remain hazardous indefinitely, so every excavation needs to respect the material slope limit, and ideally be easily traversable by a human in an EVA suit. This limits stepped bench heights to about 1 meter, and reclaimed slopes to about 45 degrees [2], preferably lower. Avoid leaving orbital debris, deep pit traps or hazardous waste on the surface.

Principle 2: The finished site should *look like a natural crater*. Using a circular pit with tailings stored around the rim can mimic a natural crater. For roughly circular orebodies, this is compatible with a terraced road open-pit excavation plan, with minimal backfill work needed to smooth the terraces during reclamation, leaving a shallow ramp out at least one wall to allow equipment or visitors to easily leave the finished crater. Scrap buried in unpredictable places would complicate future use, so any scrapped equipment should be buried in an artificial central mound, a unique location where it will be easy to locate in the distant future while still looking natural–see figure. Avoid leaving random robot tracks, dead robots, broken tools, random cables and other trash.

Principle 3: *Scientific exploration and mining* should be mutually beneficial. Large-scale excavations are likely to reveal scientifically useful stratigraphy and subsurface phenomena that would not have been found by small science oriented rovers: 3D variations in regolith composition, unusual mineral, impact and ejecta processes, and rare discoveries that could reshape our understanding of cosmic history. Scientific exploration can also help mining by better understanding the geology, finding nearby deposits and new materials in existing deposits. Scientific and mining organizations should share live access to mining robot telemetry, share analysis tools (XRF, drill cores), and collaborate on sampling, production, and site development in a synergistic way. We need to develop incentives to avoid science and mining becoming separate silos, working at cross purposes.

Principle 4: We should *use every part of the regolith*. Anything we excavate, we should either use, or store for future use. Icy regolith may contain a variety of volatiles including carbon, sulfur, and nitrogen species that will be critical for future lunar industry and agriculture. Nonvolatile tailings should be stacked neatly for future use, as ore for oxygen/metal/silicon/alkali extraction, or fill for construction. Avoid high grade extraction of a single target material, and dumping or venting volatiles as a mining comet plume.

Principle 5: Leave a durable *historic record* of site operations, at a minimum the original topography and processing undertaken. Scale model 3D maps and diagrams could be pressed or etched into glass tokens made from melted regolith and mixed into the central mound. Avoid offsite or few-copy records (lost), short lifetime technology and language (unreadable), or records made from rare materials (collected for scrap).



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[1] Gertsch L. S. and Gertsch R. E. (2003) AIP 654-1, 1108-1115. [2] Calle C. I. and Buhler C. R. (2020) Lunar Dust.