Practical Aspects of Terrestrial Mining for Use in Extraterrestrial ISRU Concepts

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Use of Explosives

pro: best rock fragmentation **con:** creates fly-rock


A common explosive is ANFO (94% NH4NO3 (AN) as oxidizer + 6% diesel fuel (FO)


On earth fly-rock slows down within a few hundred feet and then falls back to the ground.


Loading blasthole.

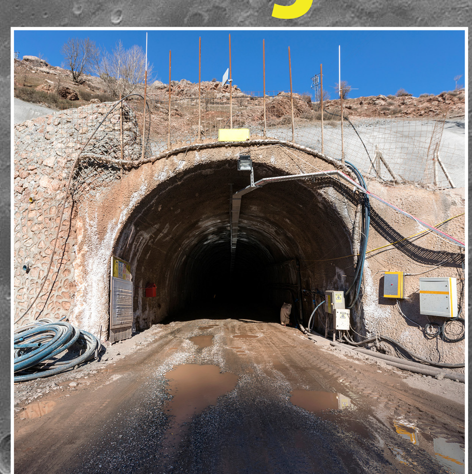

Blast-mats covering the blast area can reduce fly-rock, up to 90% on earth.

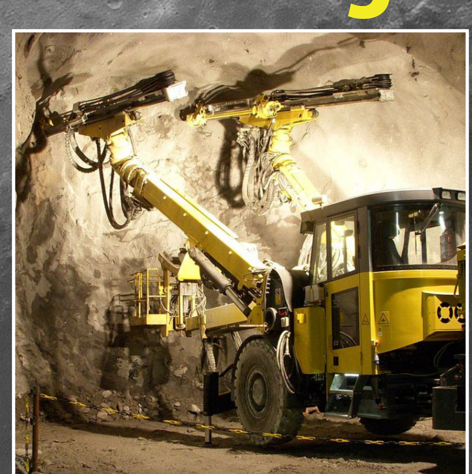

The fly-rock distance can be predicted based on: “Hole diameter, powder factor, burden, explosive charges per meter and stemming length” [1]. The blast design parameters can be altered to minimize fly-rock distance. Fly-rock has an initial velocity of around 2000m/s. For comparison a golf balls initial velocity is about 70m/s. In open pit mining fly-rock can cause severe damage. Fly-rock cannot be entirely eliminated.


In low gravity environments fly-rock distance is exaggerated. On the moon it will travel for a long distance since there is no atmosphere to slow it down.


For extraterrestrial use the blast design parameters and the use of mats need to be optimized to contain fly-rock more than 90%, ideally 100%. The possibility of 3D printed mats for extraterrestrial use should be explored.

Underground Mining




In an underground operation the blast area can be contained and no fly-rock will reach the surface


A horizontal mine entrance from the bottom of a moon crater seems to be a feasible approach.


Portions of the mine would need to be sealed to entrap any volatiles during blasting.

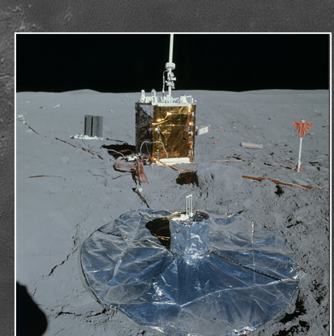

Preferred equipment would be an autonomous underground drill rig. In space employing high maintenance equipment with lots of moving parts can easily lead to a total loss of equipment. Important is an effective autonomous predictive maintenance program using swarm robotics and self-healing technics .

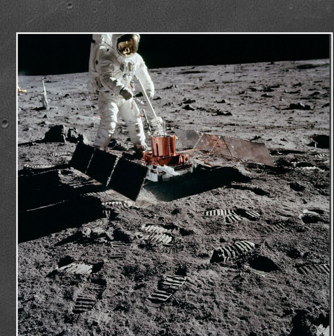

Mined out sections could be used as emergency shelter.

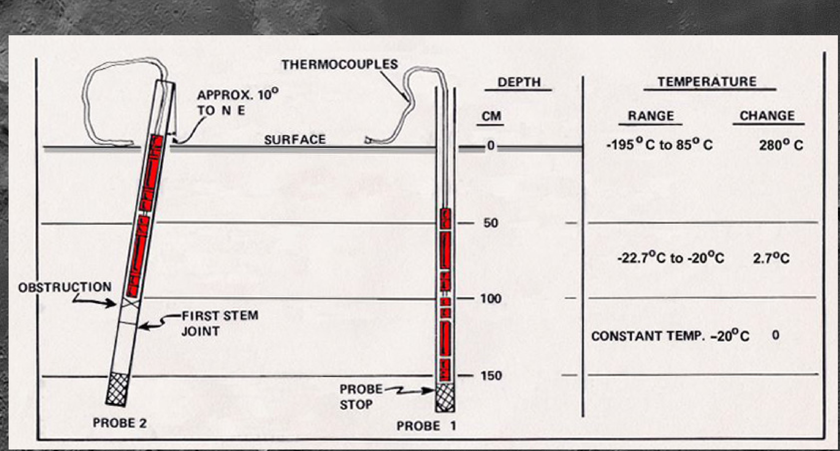
History

Charge Wt. (kg)	Charge No.	Dist. from ALSEP (km)	Detonation Time after LM Liftoff (hr:min)
0.45	6	3.5	[illegible]
1.36	7	2.5	[illegible]
0.2268	7	0.8	[illegible]
0.0567	4	0.16	[illegible]
2.72	1	2.4	[illegible]
0.113	8	0.25	51:40
0.113	2	0.25	54:42
0.0567	3	0.16	75:46

On Apollo 17 mission LSPE, to profile the site terrain, eight plastic bonded explosives composed of HNS and TEFLON charges were positioned to the specifications.

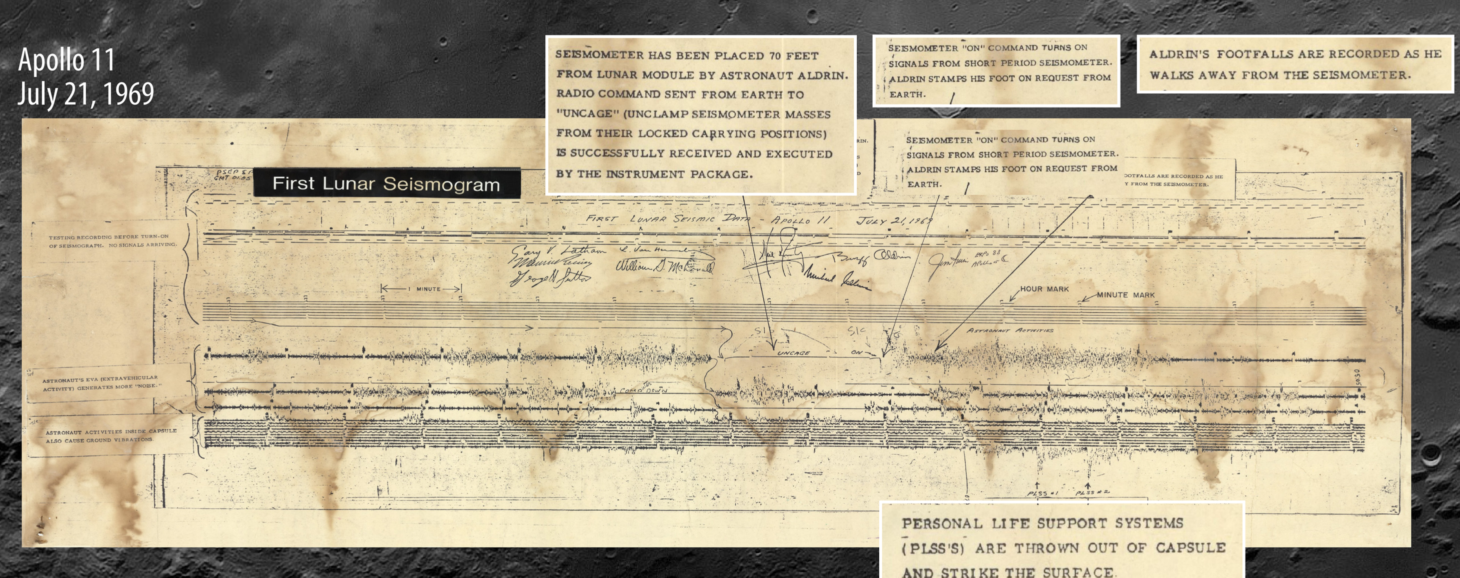

The passive seismic experiment on the moon.


Buzz Aldrin is adjusting the LSPE Apollo 11.



Apollo 15 heat flow experiment.

Apollo 11
July 21, 1969



Heavy Equipment Material Moving

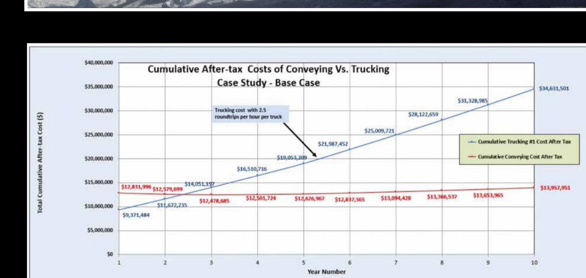

Ore gondola


Conveyor Belt


ACAT D8 & C9 Dozer


CAT 793 Haul Truck


Equipment for material movement like haul trucks and dozers need to be optimize for use on highly abrasive materials like to lunar regolith; e.g., on CAT dozers the high drive is elevated to lessen exposure to dirt and thus minimizes wear and tear on the drive. Decision on conveying vs. trucking depends on the hauling distance from excavation to the processing facility. In general, the longer the distance the more efficient the use of conveyor belts. “Conveyor belts are a more effective and low-cost method of transportation” [2]. Using haul trucks on the lunar surface would require significant haul road design and dust emission suppression.



Cumulative after-tax costs of conveying vs. trucking [3].

Further R&D:

A: Develop concepts for underground mining, i.e., widening existing lava tubes and creating horizontal mine entrances (ADIT).
B: Adapt the use of explosives for lunar drilling and blasting jobs.
C: Minimize parts of any machinery.
D: Establish an autonomous robotic preventive maintenance system.
E: Create systems to mitigate and minimize dust emissions.
F: Invest in further development of self-healing materials.
G: Cooperate with moon missions for field testing.

References:

[1] Murlidhar B. R. et al. (2021) JRMGE, Volume 13, Issue 6, 1413–1427.
[2] Cassandra (2017) LOCKER
[3] BEUMER Group GmbH 59269 Beckum, Germany

Glossary:

ALSEP: Apollo Lunar Surface Experiments Package
ANFO: Ammonium Nitrate Fuel Oil
LSPE: Lunar Seismic Profiling Experiment
HNS: HexaNitroStilbene
TTEFLON (PTFE): Polytetrafluoroethylene