

**A LARGE LUNAR SURFACE TESTBED FROM LOW COST MATERIAL.** Douglas Rickman<sup>1</sup>, <sup>1</sup>Earth Science Office/MSFC/NASA, 320 Sparkman Drive, Huntsville, AL 35805 doug.rickman@nasa.gov.

**Introduction:** For users needing to simulate the lunar surface, several distinct avenues have been used. Numerous volcanic areas, including Hawaii, have been used. While providing very large areas and scenic interest, field parties to such an area is expensive and limits testing time. An alternative is to build test facilities locally. This has been done many ways, contrast GRC-1, GSC-1, BP-1 and the KSC Morpheus facility [1-4]. GRC-1 is a mixture of sand and clay; GSC-1 and BP-1 are waste materials created in the process of crushing basaltic rock. The Morpheus field used salvaged concrete and crushed quartz rock [5]. Here I report about a 30 m X 30 m test area at MSFC which was both low cost and relatively high fidelity [6].

**Transportation:** Development cost includes the price and the transportation of the material. The transportation cost can be much greater than the purchase price. For example, the construction of the MSFC Lunar Surface Testbed was initially built using 200 tons of simulant material, which cost \$1,400 at the quarry. Transportation from Flagstaff, AZ to MSFC was ~\$40,000, ~\$0.13/ton-mile. Therefore, attention to shipping is very important. Long distance overland shipping of bulk materials can be done by truck or rail.

*Trucking.* Trucks in the U.S. can move 18-25 tons per load. Three trailer configurations are relevant: flatbed, end dump, and belly/bottom dump. Flatbed haulage is easily obtained and usually the cheapest per ton-mile; but the material must be containerized. Super sacks are the most common container. For quarries, loading containers is relatively slow, therefore, material to be containerized will cost considerably more, at the quarry mouth. Belly and end dump trailers can be loaded much more rapidly. Belly and end-dump operators can also place the material where desired if the subsurface can bear the weight of the truck. Unloading containers is more complicated. The scale of the work to be done must be remembered. It is one thing to unload and move a single ton. 200 tons is a very different challenge.

*Railroads.* Rail shipping is much cheaper per ton/mile than by truck if enough tonnage is moved far enough and sufficient time is available. Simulant materials can be shipped using aggregate or mill gondolas. Each car can move ~100 tons of rock. Gondolas are loaded and unloaded from above. The unloading is done by positioning a backhoe on top of the car and scoping material into an adjacent dump truck. Only if very large volumes are frequently moved are bottom-dump hoppers or rotating-dump cars used.

Charges are based on the car type and number, supplier, distance, fuel cost, the type of material, and required schedule. The 200 tons, which cost \$40,000 to move by truck, would have cost \$15,000 (\$0.051/ton-mile) by train. However, additional cost elements must be included, staging at each end, loading and unloading. Use of sidings or spurs is required. Unless the source quarry and the receiving Center have rail facilities, there is likely to be a cost associated with use of someone else's facilities. Notably, many quarries no longer have direct rail access and many previous sidings are no longer in existence or not serviced. Many siding owners are unwilling to tie up their sidings, and railroads will not permit allow just anyone to operate heavy equipment near their tracks and equipment. The loading can be done with front-end loaders, conveyors or other techniques, but the height of the gondola side above the ground must be considered. The unloading of aggregate gondolas is done by placing a backhoe on top of the gondola. The backhoe then moves the material into adjacent dump trucks for transport to the final location. For unloading two gondolas at MSFC, estimates were obtained in 2013 of between \$8,000 and \$10,000.

Rail service is also not as easy to schedule or time as truck service. Gondolas staging, movement from the quarry to the railhead, loading, pickup and transportation, unloading and delivery to the site must all be done serially and involve multiple companies.

**Geology and Producers:** The lunar surface can be roughly be described as having an average particle size of ~50  $\mu\text{m}$ , composed of glass, plagioclase, pyroxene and olivine, cratered and having scattered boulders [7,8]. Assuming composition is relevant, there are several terrestrial types of rock generally considered suitable for low-cost lunar simulants, gabbros, diabases, basalts, their meta- equivalents, and basaltic cinder and ash. In general, presence of vesicular glass, crystal size and absence of metamorphic minerals strongly favor the use of cinder and ash. In the United States there are producers for each of the relevant rock types. By far most of the production, though not all, is for construction. Except for cinder and ash, the mine or quarry operator will blast and then crush the stone. In mines the rock will be ground further, normally to particle sizes substantially smaller than 1 mm.

In a quarry, the process of sizing the material after crushing is called grading. The product grades available from each producer vary substantially. Products smaller than 8 mesh, termed manufactured sand, are

finer than many operations produce. However, the crushing process invariably produces a waste dust-sized material that must be captured to meet air pollution standards. Such dust is very suitable for a simulant [4].

As cinder and ash is not blasted and crushed, the fine waste product is not created but the production costs are much lower. Mines and quarries are large-scale operations; the purchase of a hundred tons is a small order. In 2013, 200 tons of product from hard rock quarries was between \$20 and \$40 per ton at the quarry mouth. Material from cinder pits ranged from \$7 to \$20 per ton. Special run material or processes requiring special handling, such as loading into super sacks, can increase the cost per ton substantially. If the material is a waste, the cost may be much lower. Prices for quarry products are quoted based on the customer taking delivery in the quarry or cinder pit.

Relevant and active quarries east of western Texas are working metabasalts or analogous intrusive rocks. Basalts and volcanic ash/cinder are available in most of the Rocky Mountain States. The sources closest to MSFC are at Knob Lick, MO and Butner, NC. The closest basalt is in Knippa, TX.

There are cinder pits in most of the states of the Rocky Mountains. For creation of the MSFC Lunar Surface Testbed, only sources in New Mexico, Arizona and Colorado were considered due to shipping costs. To find sources State geologic surveys and mining regulators, local universities, volcanologists and industrial mineral specialist were consulted. Material from Merriam Crater (Miller Mining, 35.323° -111.284°) was chosen, with secondary candidates near Raton, NM (36.821° -103.880°) and McCoy, CO (39.972° -106.703°).

**Health Risks of Silica:** Experience showed that it is critical to obtain samples of candidate products, even in the most unlikely basalts [6]. There are two health risks, if the particles are respirable and the presence of “silica” phases. Respirable crystalline and amorphous SiO<sub>2</sub> are risk factors for cancer and silicosis [9]. The Hazard Communication Standard requires labeling of materials containing 0.1% or more of a known or potential carcinogen (29 CFR 1910.1200 A.6.3.1). The required analyses, when done on basaltic materials, are complicated by interference with plagioclase, which must be properly addressed. It is important to actually measure the abundances using a certified lab familiar with basaltic materials. Details are provided in [6].

**Lunar Surface Testbed:** The testbed was created to test autonomous, hazard avoidance using a free flying lander, the Mighty Eagle. It was important to have broadly reasonable spectral properties, particle size distribution, and minimal cost. It was also desired that

the Testbed “look lunar,” be useful for other types of tests and fill the field of view of the sensor, a Bumble-Bee3 stereo camera at 30 meters altitude, and be as inexpensive as practical. To prevent detection of surface textures yet avoid respirable dust, particle sizes between 6 mm and 10 μm were needed.

Flights were designed to launch and land on steel plates on opposite sides of the testbed to avoid damaging the lander with exhaust blown material [10].

The site of the testbed was treated with herbicide, a rock berm emplaced on the downslope and a clay berm upslope, covered with geofabric and then covered by 200 tons of “Black Cinder Sand” to an average depth of approximately 12 cm. 25 tons of “Biosphere Sand” was used to top the surface.

Fake rocks, made from polyethylene and admixed crushed stone, were used to make boulders. Hollow and lightweight, these have appropriate external morphologies to simulate lunar boulders. To make them appear spectrally appropriate the boulders were liberally coated with contact cement and while wet, heavily dusted with fines sieved out of the Biosphere sand. As the contact cement dries it pulls the particles together, greatly reducing any visibility of the cement. After being rinsed to remove very fine, loose dust, the boulders are both easy to handle and effectively invisible on the testbed except for their shadows.

Craters were simulated by hoeing outward in a radial pattern. This permits creation of craters approximately 30 cm deep. As these would be a hazard to the lander in an emergency landing on the testbed, like the boulders the craters were placed away from the center line of expected travel.

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