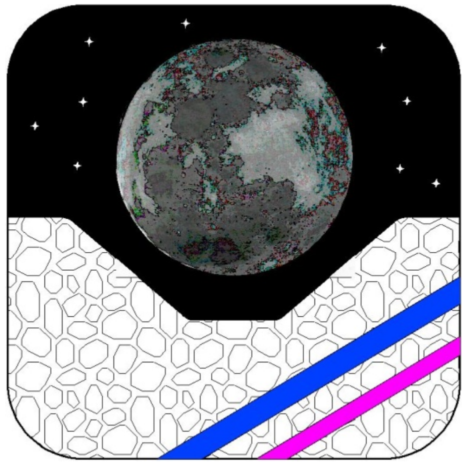


Lunar Settlement Calculator
Ores, Step 3
Notes

Tom Riley

Work in progress
January 3, 2014
File: BMDOresNotesmmddyy.docx

The Big Moon Dig – Return with us now to the Moon as we are preparing the ground for a real lunar settlement through study, simulations, team building, and exploration.

1. Purpose

These are the technical notes for the third Big Moon Dig lite game, Ores. This little game is about how to find and use resource on the Moon. This game is intended to improve the player's understanding of what ores are, the differences between how ores were formed on the Earth and Moon, and how we will go about finding ores on the Moon.

If we are to return to the Moon, we must make the absolute maximum use of everything we can find on the Moon itself. We cannot stay permanently if we must bring everything from Earth. Nothing is more important than utilizing local lunar resources.

This version is only a lite game in the form of a short quiz on key questions about finding ores on the Moon. Most of the questions have a [_] Other box which invites you to add your input in the text box at the bottom of the quiz. Later we hope to expand all these lite games into a fully-fledged App for multiple platforms that will actually support the settlement of the Moon though the Big Moon Dig approach.

Above all, to return to the Moon we must get millions of people to buy into a vision of progress for all humankind that includes manned space exploration. This game is one small step in that process.

2. The Big Moon Dig Way

The Big Moon Dig is a specific approach to the problem of humanity returning to the Moon and building settlements there:

We start with the idea that the human population of the Earth will build to a peak of about 10 billion around 2050 and then move on to a sustainable Earth. This process will be difficult, dangerous, and historic. But it will also be exciting, even exhilarating.

Throughout this difficult time, humanity will need visions of positive futures and great tasks to keep our efforts focus, positive, and productive. Space exploration is certainly one of those great tasks.

We ask the question: On a world of 10 billion people what is your greatest resource?

We answer: 10 billion people!

We also note that if we try to tackle the problems of the 21st century using only the tools of the 20th century we will surely fail.

Our approach then is to use tools of the 21st century, like the Internet and social media, to take on one great problem, furthering the human exploration of space. One such tool is a complete reorganization of how space exploration is done called a Massive Online Vetted Exploration (MOVE).

In the 19th century, a few dozen people participated in grand polar expeditions and a few hundred thousand followed the much delay accounts in the newspapers. In the 21st century millions of people will participate in grand explorations over the Internet and billions will follow them near instantaneously through social media.

Our short stories and these lite games that we are working now are the early steps in the MOVE expeditions.

If all that is just a too little heavy for you, then let’s just go back to the Moon for the fun of it!

3. What we want from the Moon

We clearly cannot build a human settlement on the Moon without extensive use of the materials we find there. We may then start our exploration by simply saying what we need from the Moon:

1. Radiation protection -- Mass to stop the radiation of space from harming our settlers in the form of a thick layer of lunar regolith.
2. Micro-meteorite protection -- A mechanical shield to prevent us from small meteorites hits that might punch holes in our habitats, again in the form of a thick layer of lunar regolith.
3. Thermal protection -- A heat shield to protect our habitats from the intense heat of the Sun by day and the deep cold of the sky by night, once in the form of a thick layer of lunar regolith.
4. Water -- The primary necessity for life to be obtain from the permanently shaded carters near the poles.
5. Power -- From the Sun to run our life support and electronic equipment as well as heat and cool our living spaces.
6. Cooling -- We can dump waste heat to the clear night sky.
7. Oxygen -- Made by breaking down local water with power.
8. Rocket fuel -- Hydrogen again made by breaking down water with power.
9. Science platform -- A place to stand to study the universe.
10. Commercial products -- Something to send home that can offset some of the cost, like Helium 3.

But, what we need most are things that are far less tangible:

11. A positive vision of the future -- With so many problems like global warming, we simply need a positive vision of the future for the entire human race.
12. A great task -- With human population first peaking and then stabilizing, we need great unifying task s that provide positive direction for all our efforts. Space exploration is clearly one of these tasks.

4. General Game Notes

This is only a game and we are not trying to make it hard; getting back to the Moon has proved hard enough. Most of the answers can be found in these notes and you may correct your entries on each question as often as you like by simply making changes and pressing the [Submit] button again.

The name requested is just for reference only and can be an internet nickname or character name if you prefer. It helps if you keep the same name on all our lite games so that you can be entered correctly on our BMD Leader Board.

All inputs will be entered by first checking answer boxes and then clicking the question [Submit] box. Your score for that question then shown. Wrong entries can simply be replaced and resubmitted until you get a score you like.

All the questions in this game are multiple choice with [_] check boxes. Most are marked "-- [Check all that apply]", but a few are marked "-- [Check one]".

Your score for each question is shown with each submission. There is a maximum of 10 points per question but you are penalized both for wrong answers and for failing to check the right ones. Checking the [_] Other box also gets you credit, but an entry in the text box is then expected

When you get the end of the questions, you can request a total score and a listing of your answers which shows the correct and incorrect responses. You may then go back and correct any of the answers if you like.

When you get all your answers to the best of your present ability, you will be invited to archive the result. This simply means your result will be automatically e-mailed to The Big Moon Dig when you click the [Submit] button. There it will be added to the archive file and this will make you eligible to be on our BMD Leader Board on our main BMD game Web page.

5. Getting Help

The notes below cover most of the quiz material. You can find additional helpful resources on the Big Moon Dig Site:

- The Big Moon Dig home
- The Big Moon Dig games
- BMD Lite Game on Lunar Locations
- BMD Lite Game on Lunar Habitats
- Graphics of BMD settlements and equipment
- BMD Why & What essays
- Stories based on the Big Moon Dig effort

Please contact us with our feedback form if you have any questions.

6. Naming Conventions

By international treaty, the primary system of measurement on the Moon is the System International (SI), the metric system. All calculations will be done in SI first. The now obsolete English system value is sometimes provided in parentheses.

For historic reasons, and again by international agreement, human habitations off Earth are always referred to as “settlement” and **never** “colony”. One only has to think back to the American Revolution to appreciate the terrible baggage the word "colony" carries.

Few mountain tops on the Moon have formal names. The peaks are commonly given the name of the nearest named crater.

When the word "Moon" is capitalized, it refers specifically to Earth's moon as a proper noun; when it is used in lower case, it can mean any moon. The Moon's more formal name, Luna, is almost never used. This is a bit sad as the name beautifully refers to a young goddess who is the huntress of the night. The Sun's formal name is even more neglected, Saul.

7. Definition of an Ore

This third lite BMD game is about finding ores on the Moon. An ore is a mineral that occurs in sufficient concentration and volume to be of commercial interest. The two key concepts are concentration and commercial interest.

This definition is pretty much the same for the Earth or the Moon, but the interpretation of the key concepts differs slightly particularly when considering early lunar settlements. For example, on the Earth, commercial interest means economically valuable. On the Moon, we take commercial interest to mean anything that early settlers can actually use themselves. Only a very view products would have enough value to ship back to Earth, for example Helium 3.

Concentration takes a slightly different interpretation, again especially for early lunar settlers. There are plenty of useful materials that are distributed widely on the Moon, for example iron and titanium. These will be of value to early lunar settlers only if they can be located in sufficient concentrations that they can be farther concentrated and then reduced to the metallic form without a large industrial operation. It may be a very long time before we have kilometer wide strip mines on the Moon. To get started we need to find practical processes that can be worked by modest robots and processing equipment.

Critical minerals that are common on Earth, but are rare on the Moon, for example water ice, can be considered of commercial value there.

8. Sources of Ores on Earth

The forces that create ores are quite different on the Earth and the Moon. We therefore first need to first understand how ores are created on Earth:

8.1. Water

Ores for many metals, notability gold and silver, are created when a water based fluid circulates deep underground. When centennial crust is folded into mountains by plate tectonics, the outsides of the bottoms of the folds are made less dense but are very deep below the surface. Water can work its way down and there become very hot and under very high pressure. Many minerals that have only very low solubility on the surface, go readily into solution under these extreme conditions.

This mineral laden fluid then works its way up slowly and as it does the temperature and pressure drop. At critical sets of temperature and pressure, a mineral may become insoluble and therefore come out of solution at a specific depth. There it tends to fill the cracks forming veins of ore. Metallic gold and quarts happen to come out of solution under about the same conditions so many of the best gold ores are in quartz veins.

Unfortunately, the Moon has never had either water or plate tectonics.

8.2. Ocean Spreading

Plate tectonics also leads to ocean floor spreading. Once again, water can work its way down into cracks in mid-oceanic ridges and dissolve minerals. When this liquid vents back into the deep ocean it creates a black smoker. The dissolved minerals simply come out of solution in a great cloud of dark particles when they hit the cold sea water. The particles fall to the bottom and build up in layers of ore. These layers occasionally first get buried and later get pushed to the surface.

Unfortunately, the Moon has never had oceans or plate tectonics.

8.3. Life and Oxygen

In the time before life on Earth, there was no oxygen in the atmosphere; the air was reducing. Under these conditions a number of minerals will dissolve in sea water, most notably iron. The seas of the early Earth were a deep green in color from all the iron.

Then over a few million years one cell plants evolved that could live by photosynthesis. They used the carbon dioxide from the atmosphere, water, and sunlight to provide their energy to live. They excreted oxygen as a noxious waste product into the water and then atmosphere.

The free oxygen converted the seas from reducing to oxidizing and the iron came out of solution and sank to the bottom of the sea in what was a geological instant. Now all the great iron ore deposits on Earth are old sea bottoms from that period.

Unfortunately, the Moon has never had seas or life.

8.4. Meteoroid Strikes

Meteors can occasionally form ore bodies on Earth such as the nickel deposits in Canada. It is not clear if the processes that formed these deposits would occur on the Moon however as they, like gold, may involve water flow through splintered rock.

At least we have finally found something that does occur on the Moon, and occurs in spades, trumped and doubled. In fact, some of the strikes that produced basins brought material up from deep within the Moon. But, again there was not water to form veins.

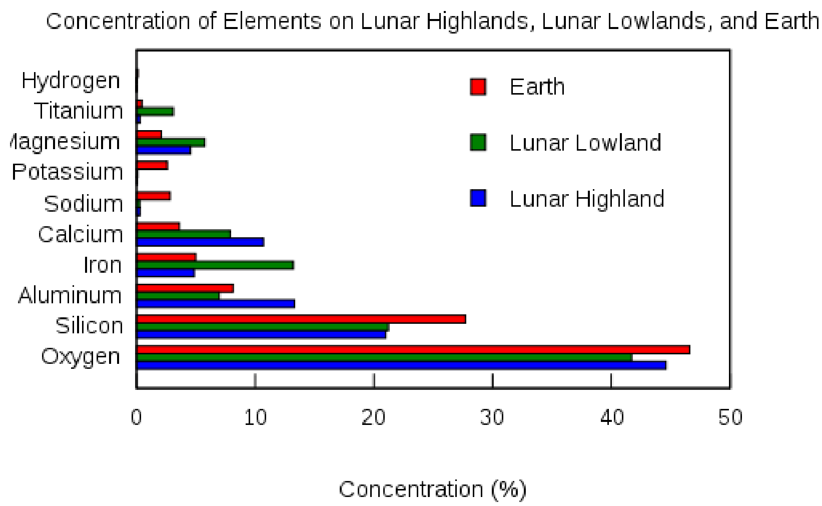
8.5. Volcanism

Volcanism can form ore deposits on Earth, for example diamonds. The vast majority of Earth's diamonds come from the cores of ancient volcanoes, called Kimberly Pikes. These volcanoes are of a very specific type that draw material from very deep within the Earth and bring it to the surface very quickly.

Both the Earth and the Moon were molten to a great depth. They then cooled over millions of years. During this process, heavy minerals tended to sink. This formed a iron core but also laid down different mineral layers with depth.

Diamonds are a good example of a mineral that occurred on Earth in ores only at considerable depth under specific types of crust. Only a specific type of volcano originates at this type of deep layer and only occasionally do they erupt violently enough to bring diamonds all the way to the surface layers without allowing them time to decay into graphite. Consequently, diamonds are rare on Earth.

The Moon certainly has volcanism, and the Moon clearly differentiated after its formation. The lunar seas are great flows of ancient lava and a few volcanic cones do exist on the Moon. Only ground exploration can determine if ores were formed of value to early lunar settlers.



Relative abundance of elements on the Moon, NASA

9. Sources of Ores on the Moon

Earth's history and the Moon history are so very, very different. As a consequence different ores formed in different ways.

9.1. Meteoroid Strikes

The Earth actually has gotten more meteor strikes than the Moon. It is simply more massive and bigger. The strikes on the Moon were not subsequently hidden by water erosion and plate tectonics so they are more visible today. The possibility of ore bodies being formed by these strikes, and still being there, is real.

For example, about 2% of the meteors that have struck the Moon are iron or stony iron. Long ago a body formed that was big enough to differentiate and form an iron core; it was probably out in the asteroid belt. Later it was shattered by a major collision. As a result, a rare few meteors are mostly metallic iron.

When an iron meteorite strikes the Moon the iron is converted to vapor, iron steam if you will. As this material spreads out from the impact site, it cools and forms microscopic iron balls. These balls are a significant part of the lunar regolith and can be magnetically separated.

Lunar regolith can contain other magnetically separable grains, such as Black Sand an ore for titanium. Magnetic separation of lunar regolith is a simple and low energy process that in some places might produce an ore concentrate of value to early lunar settlers. This would require handling a large volume of sand and dust but many other activities, such as digging radiation protection trenches, require similar handling efforts.

9.2. Solar Wind

The solar wind has been striking the surface of the Moon for many millions of years. It contains significant quantities of a few light volatile elements that could be of great interest to early lunar settlers. Of particular interest are Helium 3 and Argon. As a general rule after hitting anywhere on the Moon, such volatile material sticks the grains of lunar regolith for a while but then is lost again to space, driven off by the heat of the Sun.

However, there are cold traps in the form of preeminently shaded craters at both lunar poles. These are some of the coldest places in the universe and ices of volatile elements can remain there for long periods attached to rock grains.

The possibility of exploiting these cold traps is one of the primary reasons for considering the polar regions for a lunar settlement.

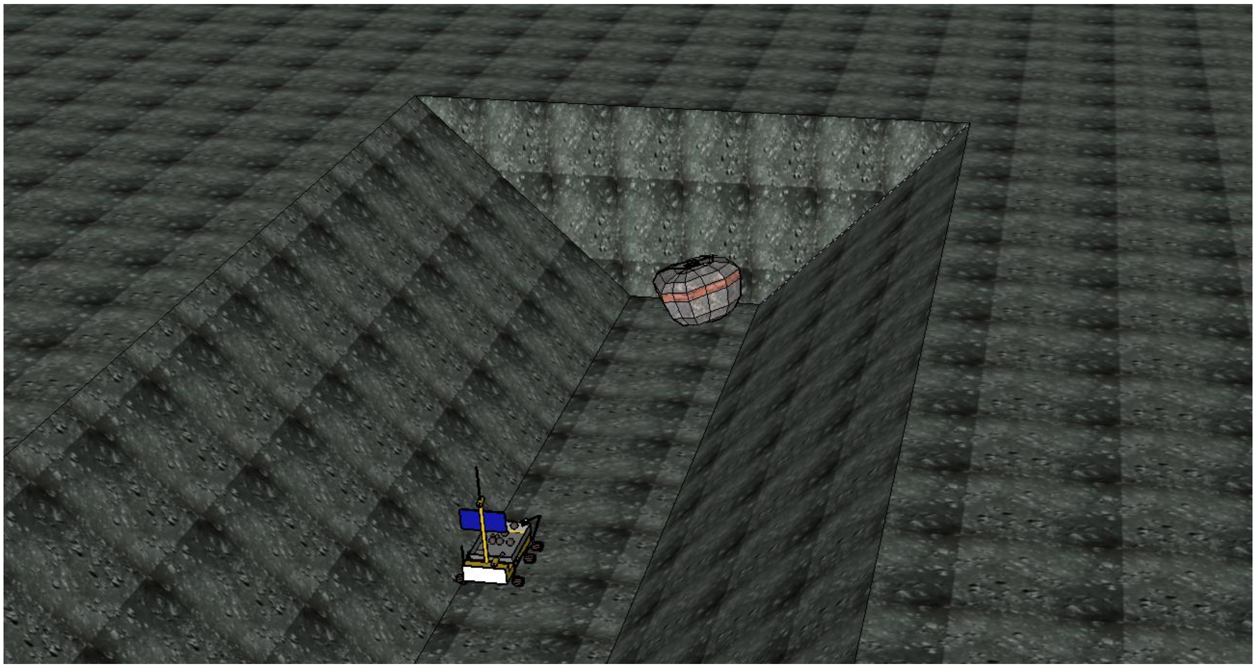
9.3. Comet Water

The cold traps can capture other volatiles too, of particular interest water or H_2O. The source of the water largely comets but common meteors contain about 5% water by mass too.

On impact all the water vaporizes and most of it is lost to space. The small part that remains is stuck to rock grains and through many jumps driven by the many light/dark cycles, a small fraction of what's left finds its way to the permanently shaded craters where it can stay put for millions of years.

A test involving crashing spacecraft into one of these dark craters have proven that detectable amounts of water are present. One should think of minute ice grains mixed in with the regolith, not skating ponds. Still water is such an important material for early lunar settlers that recover of this water will be a critical activity.

It is also important to note that the area around permanently shadowed craters will have higher levels of volatiles. Micro-meteor strikes will simply sputter traces of the material in the crater for a few kilometers in all directions. This means that even if a small robotic rover cannot handle a climb down the steep cliffs of a crater wall, we still should be able to judge the amount of water in the crater bottom from the levels measured in more accessible areas nearby.



Digging Rover in trench with erratic

9.4. Planet Differentiation

When the Moon formed the surface was molten to a great depth. As the surface cooled, heavy minerals tended to settle down. This process of differentiation was probably not as uniform as it was on the larger Earth, but it was powerful enough to form the lunar highlands and a small lunar iron core. As the Moon cooled a variety of minerals crystallized our of the melt at different depths forming potential ore veins.

Later the Moon was hit by asteroids that blew large basins, such as the South Pole/Aitkin Basin. This explosive process tends to turn over the layers of rock to form a ring of mountains around the edge whose top layers are upside down to the rest of the surrounding geology. These may expose ores from great depths.

Such places have been detected from orbit and are called the mineral hills of the Moon. Later meteor strikes have covered these hills with a blanket of generic lunar regolith so they are hard to evaluate from orbit.

This flipping process could bring deep buried layers of mineral to the surface where that might be of use by early lunar settlers. It will take ground exploration to determine if any of this material actually constitutes an ore.

Exploring such hills may prove difficult for a small rover. Fortunately the later meteor strikes may have come to our aid. In addition to throwing dust they also may throw boulders some distance. On Earth there are numerous large boulders, called erratics, that are hundreds of kilometers from the rock beds that parented them. Earth erratics are carried by glaciers, which have never occurred on the Moon. There are erratics on the Moon, which appear in may Apollo shots, but they are moved by distant large meteor strikes, not glaciers.

We may then be able to explore for difficult to reach mineral deposits by essaying erratics that happen to have ended up in locations accessible to a small rover.

9.5. Volcanism

There is quite a lot of volcanism on the Moon. Apollo to the Moon brought back samples of the lunar low lands that showed them to be ancient lava flows. These samples showed numerous material of interest but there was not time to explore enough to expect to identify actual ore deposits.

There are also cone volcanoes on the Moon and open vents. These are relatively rare and have not been properly explored. Unfortunately none of the known examples occur near the poles.

The Apollo explorers did discover some striking orange volcanic glass at one site. This does demonstrate that volcanic vents have occurred during the history of the Moon.

10. Other mineral considerations

The special needs of early lunar settlers will require special consideration of certain minerals:

10.1. Ores on the Moon but not on Earth

Some materials are so common on Earth that no one would bother to call them an ore, for example water and oxygen. We have already discussed water from permanently shadowed craters but there are other minerals that contain significant amounts of water or oxygen that are not tightly chemically bound in the particular mineral. In these cases, least some of valuable material can be released by simple processes like heating.

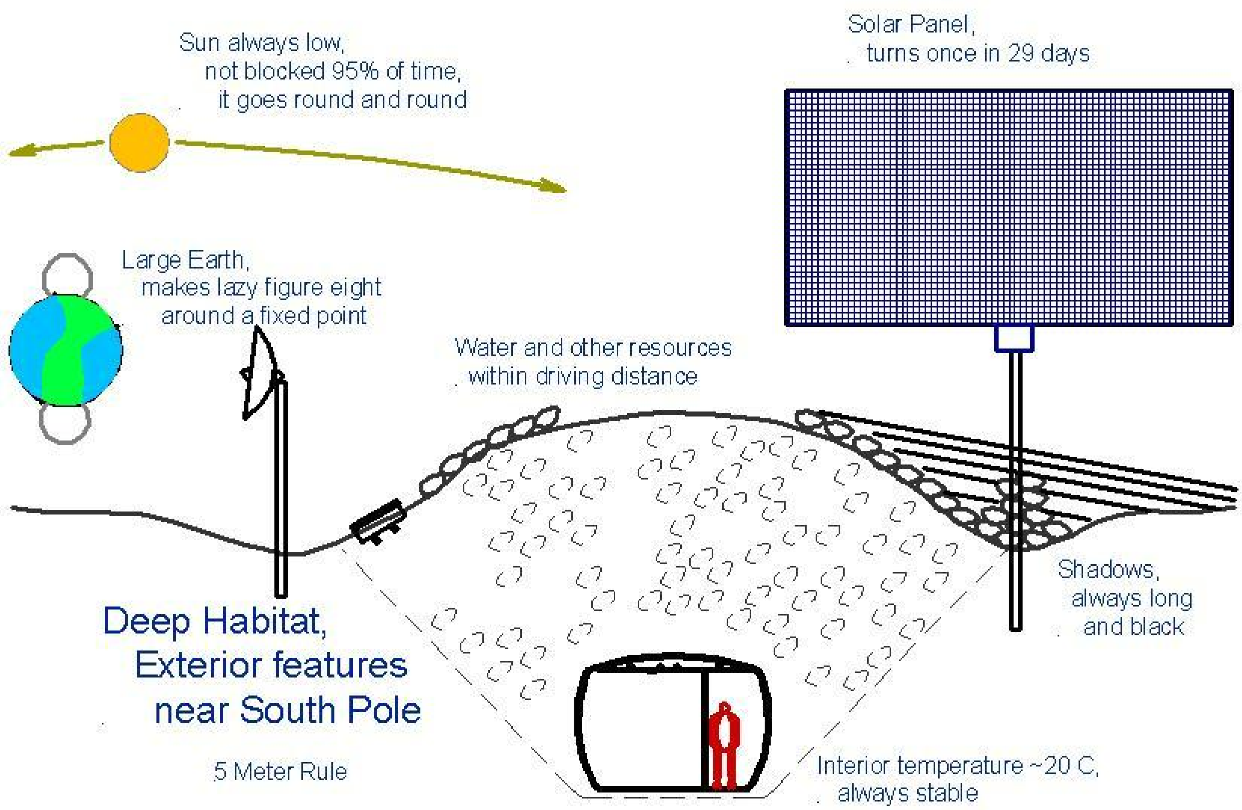
10.2. Minerals rare on Earth but not on the Moon

The chief candidate here is Helium 3. This rare isotope of Helium is currently used in medical examinations and in the future could be used to generate energy though fusion reaction. It does occur on Earth but is very rare. On the Moon, it is a component of the volatiles left by the solar wind and could be harvested in quantity. It is one of the few materials work shipping back to Earth from the Moon.

The concerns for this plan are that Helium 3 recover on the Moon would require an industrial process that is simple but would have to be of considerable size before economically viable amounts of Helium 3 could be produced.

As a potential power source, Helium 3 has promise but that promise is a long way off. First we would have learn to fuse Deuterium which is available on Earth but would give off dangerous radiation when fused. We would then need to develop a means of fusing Helium 3 which is much harder to ignite but which give off much more energy in the fusion process and it gives of much less dangerous radiation.

Of course if we got real good at fusion, we could move on up to Boron 11. Which is again even harder to ignite than Helium 3 but it gives off even more energy, again with low radiation. Boron 11 is readily available on Earth; we use it for washing powder.



Deep Habitat showing cross-section

10.3. Things to common to be ores but valuable just the same

There are many things common on the Moon that will be very useful to early settlers but that do not meet the usually definition of an ore:

1. Regolith for shielding -- The lunar regolith, ground up rock, is the only feasible source of mass to shield lunar settlers from radiation, micro-meteorite hits, and extreme thermal swings.
2. Rocks for cairns -- Piles of rocks, or cairns, can be used as survey markers to lay out construction sites and as markers on trails. Rocks with some color are of particular interest in the gray world that is the Moon. People have been building cairns for these very purposes since the stone age.
3. Rocks for construction -- Rocks can also be used for construction. Of particular interest are stone arches and retaining walls to keep back the mountains of regolith.

10.4. Special Moon uses

Some materials will have special uses on the Moon that would not make since on Earth:

1. Reactive Metals -- Metals such as pure calcium and magnesium that have limited uses on Earth because the react strongly with oxygen and water, can be used in their pure metallic form on the Moon. One material that is badly needed is a good electrical conductor for power cables. A metal much too reactive to use exposed to the elements on Earth could be plowed under a few centimeters of lunar regolith and last for thousands of years on the Moon.

11. Methods of concentration

In nearly all forms of metal extraction the first step is to concentrate the raw material into an ore concentrate. On Earth this normally means grinding the ore to a fine power with a ball mill and then extracting the metallic particles in a open water based process. Figuring out ways to do this on the Moon will take some thought and experimentation:

1. Magnetic separation -- As mentioned above, several valuable materials, like Iron micro spheres, can be separated from the lunar regolith by simple magnetic extraction.
2. Heat extraction -- The volatile materials, like water and Helium 3, can be extracted by simple heating fine material to several hundred degrees C in a pressure container.
3. Water extraction -- Nothing on the Moon has ever experience liquid water. Subjecting lunar regolith to supper heated steam should extract a number of minerals. Additional study is needed to determine if any of these material are of value and how to recover all the very valuable water afterwards.

Only concentration methods that are simple and low in energy use are likely to be of use to the early lunar settlers.

Sojourner Rover on Mars, by NASA

12. Communication Speed with Earth

Electronic communication times between the Earth and the Moon can cause problems. A typical two way communication for anywhere on Earth might typically take:

1. Equipment Delay on Moon, 4 msec typical
2. Moon to Earth transmission at speed of light , 1.28 sec
3. Equipment delay on Earth, 4 msec typical
4. Earth to Geostationary Satellite, 0.12 sec
5. Equipment delay on satellite, 4 msec typical
6. Satellite to Earth, 0.12 sec
7. Equipment delay on Earth, 4 msec typical
8. Earth data processing, 10 msec typical
9. Complete return trip

This is all added up on the accompanying spread sheet to about 2.9 seconds. This is enough of a delay to cause problems with remote control of robots.

13. Methods of Search

At least for the first critical time period of our MOVE expedition, we be dependent on very small lunar rovers comparable with the first Mars rover, Sojourner. These are simply the largest units we can expect to get to the Moon with modest resources. Such rovers have limited capabilities both as to mobility and instrument carrying capacity.

Using the MOVE expedition approach, as described in our short story "The Big Moon Dig", each rover will be operated by three shift teams of highly trained volunteers.

The technical limitations of the small rover will require the team to work the rover from one pool of light where it can get power though its solar panel to the next pool of light. This task will be made all the harder by the low angle of the Sun and the many local shadows.

They will also have to work from one communication hot spot to the next. A small rover will not be able to communicate directly with Earth, so it will have to maintain radio contact with the primary communication instrument back at the settlement site.

Small rovers will also be very sensitive to the slope of the ground they are traveling over. The high vertical photo panels of near arctic rovers will make them top heavy. Their wheel support structures allow for considerable adjustment for slope, but the slope adjustments will have to planned for every movement.

The targets for testing will consist of the regolith along the path and boulders thrown up by local meteor hits. Testing the local regolith for volatiles will build up a map of concentrations which could lead to good sources. Beyond that erratic boulders will be of specific interest as they represent samples of materials thrown in from some depth.

14. Types of instruments

We will need a good sweet of scientific instruments to build up a good data base of lunar resources. The smaller rovers will not be able to carry a very big instrument but in this day of miniaturization there are still a number of good choices:

14.1. Sojourner Class (shoebox)

Our small rovers will be built by university, or even maker hoppy groups.

14.1.1. UV Florescent Spectrometer

If you shine an ultraviolet light on many minerals, they will fluoresce in very distinctive visible colors. With UV LED available and modern optics we should be able to get this instrument down to the size of a few packs of cards and a fraction of a kilogram.

14.1.2. Slow Neutron Spectrometer

For years the minerals around the bore hole of a oil will have been logged using slow neutrons. A neutron source sends out neutrons of controlled energy. These neutrons can penetrate up to a meter of rock before they are absorbed by the nucleus of an atom. The atom then gives off a gamma ray that can return to a separate receiver on the rover. The energy of the gamma rays is sensitive to the type of nucleus that generated it.

This is one of the few instruments that is actually designed for an environment more challenging the space -- the bottom of an oil well. There are also decades of Earth data to build on.

14.1.3. Volatiles Probe QCM

All space equipment has to be tested to be sure that it can survive in the environment of space. One of the tests is to put the instrument in a vacuum chamber, heat it up, and demonstrate that it stops outgassing volatiles after a time. Sensor for this test is a Quarts Crystal Microbalance, which is about the size of a hockey puck and consists of two crystals, one exposed and one sealed away. The exposed crystal is cooled to liquid nitrogen temperatures so that volatile material will stick to it. The frequency of the crystal oscillation, often 15 megahertz, is exquisitely sensitive to the mass of the crystal including any material stuck to its surface.

For a small rover the cooling would have to be done by thermally connecting one crystal to a thermal panel facing deep space. A patch of regolith under the rover would be first heated and then exposed to the crystal. The beat frequency of the two crystals will then precisely tacks the buildup of volatile materials. You can even get an idea of what materials are present by warming up the crystal afterwards very slowly and watching the built up material sublime off the crystal.

14.1.4. Electro-Magnetic Permeability

A pulse of microwave energy sent into lunar regolith will experience some degree of absorption and reflection. The amount of absorption is related to the percentage of ferromagnetic material, such as microscopic iron spheres, that are present. This could be a very simple instrument but it would provide only limited information.

14.1.5. Seismic Microphone

To understand the deep structure of the Moon we need a substantial array of seismic sensors located over a large area. Such a dedicated instrument array is unlikely at the moment, but if we are able to build a fleet of small rovers and they each had one seismic sensors then we would build up a useful data set over time. The microphone would only be recorded when the rover was completely still.

14.2. Curiosity Class (small car)

Large rovers can carry multiple instruments and strong working arms. There major drawback is that they cost several hundred million dollars and take three to five years to build.

14.2.1. SAM -- On Mars

Sample Analysis at Mars (SAM) is basically an automated chemistry lab that would fit in the trunk of a car. It is currently on Mars as part of the Curiosity Mission. It is the most complex single instrument that NASA has ever built. The cost and time to construct are both commiserate with that complexity. At the heart of SAM is a mass gas spectrometer.

1.1.1. Strong Arm

Big rovers can have strong arms with lots of attachments like drills and Rotating Abrasive Tool (RAT). Such an arm supports the other instruments by collecting very precise samples and delivering them to the input of the other instrument.

1.1.2. LIDAR

If we are serious about building a settlement we need to survey the site properly. Laser based ranging instrument called LIDAR can do just that but may be difficult to miniaturize for a small rover.

2. Questions

Here are the questions for this quiz, with the answers:

1. What are the key characteristics of an ore?
   [X] Concentration
   [X] Commercial interest
   [_] Color
   [_] Mass

2. What forces form ores on Earth?

   [X] Plate tectonics
   [X] Water
   [X] Life
   [X] Volcanism
   [X] Meteor strikes

   [_] Other, use the text box below

3. What forces form ores on the Moon?

[_] Plate tectonics
[_] Water
[_] Life
[X] Volcanism
[X] Meteor strikes
[_] Other, use the text box below

4. What minerals might be consider ores on the Moon but not on Earth?

[X] Water
[X] Oxygen
[_] Other, use the text box below

5. What minerals, even if not ores, might have special uses on the Moon?

[X] Lunar regolith
[X] Lunar rocks
[_] Other, use the text box below

6. How might we concentrate ores on the Moon?

[x] Magnetic separation
[X] Heating
[X] Water extraction
[_] Other, use the text box below

7. What instruments could a small rover carry to study minerals?

[X] UV Florescent Spectrometer
[X] Slow Neutron Spectrometer
[X] Volatiles Probe QCM
[X] Magnetic separator
[X] Seismic Microphone
[_] Other, use the text box below

8. What instruments could a large rover carry (that a small one could not) to study minerals?
-- [Check all that apply]
{X} SAM of Mars
[X] Multiple function strong arm
[X] LIDAR
[_] Other, use the text box below

9. How should we use our small rovers on the Moon?
-- [Check all that apply]
[X] From light pool to light pool

[X] From communications hot spot to communication hot spot
[X] While watching the slope very carefully
[X] Slowly and with great care
[X] Working as a team
[_] Full speed ahead and damn the torpedoes

3. Summing Up

We trust you learned something new about the Moon from your work with the Big Moon Dig lite games. If you have any questions please contact us through our feedback form.

Please check out our other games and stories on The Big Moon Dig.

____-

Reference Materials

The following books, Web sites, and courses were used for this work:

Books:

1. Tom Riley, *Hard Squared Science Fiction, Vol. 01, The Dark of the Moon* (e-publication)
2. David Schrunk, Burton Sharpe, Bonnie Cooper, Madhu Thangavelu, *The Moon, Resources, Future Development, and Settlement* (Springer, second edition)
3. Harrison H. Schmitt, *Return to the Moon, Exploration, Enterprise, and energy in human settlement of Space* (Copernicus, 2006)
4. Ben Bussey, Paul Spudis, *The Clementine Atlas of the Moon*, (Cambridge, 2004)
5. Michael Light, *Full Moon*, (Knopf, 1999)
6. Motomaro Shirao, Charles A. Wood, *The Kaguya Lunar Atlas: The Moon in High Resolution* (Springer, 2011)
7. Antonin Rukl, *Atlas of the Moon*, (Sky Publishing, 2004)
8. Robert Godwin, *Apollo 16, The NASA Mission Reports*, (NASA, 2002)
9. Andy Harris, *HTML5 Game Development for Dummies*
10. Dug Sahlin, Chris Botello, *YouTube for Dummies*
11. John Walkenback, *Excel VBA Programming for Dummies*
12. Ed Tittle, Chris Minnic, *Beginning HTML5 & CSS3 for Dummies*
13. Aidan Chopra, *Google SketchUp 8 for Dummies*
14. Andy Rathbone, *Windows 8 for Dummies*
15. Steven Suehring, Janet Valade, *PHP, MySQL, JavaScript & HTML5 for Dummies*
16. James Floyd Kelly, *Getting StartED with Windows Live Movie Maker*

17. Leonard A. Schlesinger, Charles F. Kiefer, *Just Start, Take action Embrace uncertainty Create the Future* (Harvard Business Review, 2012)
18. John Berger *Contagious, Why Things Catch On* (Simon & Schuster 2013)
19. Nassim Nicholas Taleb, *The Black Swan: The Impact of the Highly Improbable* (Random House, 2010)
20. Nassim Nicholas Taleb, *Antifragile, Things That Gain from Disorder* (Random House, 2012)
21. Leslie Grossman, *Link Out: How to Turn Your Network into a Chain of Lasting Connections* (Wiley, 2013)
22. Rick Hanson, *Hardwiring Happiness, the New Brain Science of Contentment Calm, and Confidence* (Harmony, 2013)

Courses:

23. Chris Stevens, "EwB App Design", http://apps.excelwithbusiness.com/Home.aspx

24. Karl T. Ulrich, “Design: Creation of Artifacts in Society” (Coursera, University of Pennsylvania}
25. Eric Rabkin, “Fantasy and Science Faction: The Human Mind, and Our Modern World” (Coursera, University of Michigan)

Web Sites:

26. “Hard Squared Science Fiction, Vol. 01, The Dark of the Moon”, (Internet) http://woodwaredesigns.com/EBook/EBook.html
27. “The Big Moon Dig”, (internet) http://bigmoondig/BigMoonDig.html
28. SONO, A world of Knowledge, Infinite Possibilities, (Internet) http://getsokno.com/redvinef/controllers/login.php
29. “User Manual SONO Platform” (Internet) http://soknocommunity.com/xoops/docs/UserManual.pdf
30. Tom Riley, “Brain Apps” (Internet) http://bigmoondig.com/Essays/BrainApp.pdf
31. “NDAs for Free” (Internet) http://www.ndasforfree.com/
32. “Moon Base Alpha” (NASA, Internet) http://www.nasa.gov/offices/education/programs/national/ltp/games/moonbasealpha/index.html
33. Adrien Treuille “Foldit” (Internet) http://fold.it/portal/
34. “EteRNA” (Internet) http://eterna.cmu.edu/web/
35. ILIADS (LRO data access, NASA, Internet) http://opensource.gsfc.nasa.gov/projects/ILIADS/index.php
36. Audacity (Sound software, Internet) http://audacity.sourceforge.net/
37. Firebug (debugging software, Internet) http://getfirebug.com/
38. Simple Games Java Script Library, simpleGame.js (Internet) http://www.aharrisbooks.net, http://www.aharrisbooks.net/h5g/simpleGamePractice.html
39. Goggle X-Prize Moon (Internet) http://www.googlelunarxprize.org/
40. Lunar Reconnaissance Orbiter, (Internet Wikipedia) http://en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter
41. “TED, Ideas Worth Spreading,”, [Technology Engineering Design] (Internet) http://www.ted.com/
42. Sample Analysis at Mars (SAMS), (NASA, Internet) http://ssed.gsfc.nasa.gov/sam/
43.