Kaylen Platt (00:00):

Leslie Gertsch is an associate professor of geological engineering at Missouri University of Science and Technology. She has been active in the space resources community since the late 1980s. In addition to Missouri S&T, she has worked in various capacities with Michigan Technological University, Colorado School of Mines, NASA, European Space Agency, and the US Bureau of Mines, and she serves in the Missouri Mining Commission.

Kaylen Platt (00:47):

Today, Leslie Gertsch will be speaking to us all about lunar mining. And you can start whenever you're ready, Leslie.

Leslie Gertsch (00:55):

Okay. Thank you, Kaylen. Welcome everyone. We'll be going through, very briefly, some broad items that you need to know if you're going to be planning mining on the moon. I want you to know also, before we get into it, that some of this is from my contributions and some are from a couple of the other faculty here at Missouri S&T, Dr. Michael Moats and Dr. Kwame Awuah-Offei.

Leslie Gertsch (01:21):

This is a list of the topics I'll be going over in the order we'll be covering them: terms and definitions, the phases of setting up and running a mine, how you choose a mining method, the beneficiation and processing that'll be done, and how we would adapt these to space. But I won't be talking too much about that, most of it is for you to think about.

Leslie Gertsch (01:45):

All right, for terms and definitions, we start out with a mineral deposit. And it's nothing more than a naturally occurring concentration of geologic materials. It might be in the soil, it might be in the rocks, but it's naturally occurring.

Leslie Gertsch (02:02):

And orebody is a subset of the mineral deposits. It's one of those that can be mined for some net benefit, we often say a profit. But sometimes benefits are not financial profits.

Leslie Gertsch (02:16):

A resource is a mineral deposit that is not mineable right now but it could be later, given improvements in the market, in the technology, or in how much we know about it.

Leslie Gertsch (02:29):

A reserve ... which is what the banks are looking for when you go to them to find financing to make a mine ... is a mineable mineral deposit. And that's a deposit where you know how much of the material is in there that you want to get, you have appropriate technology to extract it with, and there's someone who's going to want to buy it from you. That's what you need for a mineral reserve. Deposits and orebodies and resources and reserves are not the same things, but they are related to each other.

Leslie Gertsch (03:04):

So, definition: mineral resources. This is a pattern, a scale, you could say, put out by the Joint Ore Reserve Committee, or JORC, that's been in use for quite a while. We start with exploration results. And with increasing application of time and money and effort, we can increase the level of geologic knowledge that we can have in the deposit, that it's got what we want, and we can also make sure we have the right materials to work with, the right technologies. And that gets us to proven mineral reserves. Exploration results do not equal proven mineral reserves.

Leslie Gertsch (03:51):

Now, this is one we've used quite often. The United Nations has actually come up with a more complicated approach, that I'm not going to go into in any great detail. But I do want you to think about the differences between this one, which is about all natural resources, including: minerals, petroleum, solar energy, wind energy. All of that can be classified using this rather complicated method.

Leslie Gertsch (04:20):

But when we think about space resources, whether on the moon or elsewhere in space, we're actually starting at the least well-known corner of this. And that is down there in cell number 344. If you want to find out more about this, you can look up the reference there in the lower left corner. It's Series report No. 61.

Leslie Gertsch (04:45):

But again, like with the JORC, we need to increase the degree of confidence in our geologic understanding, we need to increase the technological capabilities we have to actually extract this material, and we also need to make certain we have an economic reason for doing so; economic or environmental or sociological. Remember, I said benefit. It's not just money. All right. Eventually, we want to get to where each of these three cells, or three numbers on the cell, are one. That's the highest confidence in all three of these.

Leslie Gertsch (05:30):

More terms and definitions: When we're talking about reserves or resources even, but especially reserves, what we want is the highest recovery we can manage economically. Recovery is the proportion of the target material that we actually do get. How much is there? Say, it's got 10 pounds per cubic yard of whatever it is we're looking for. If we can get nine pounds out of that then we've got a 90% recovery. That's actually pretty good. Some minerals and petroleum here on Earth, in some situations we can be happy with as little as 10 to 20% recovery.

Leslie Gertsch (06:11):

Dilution is the amount of waste material that's mixed with the extracted mineral. Basically, that means when we grab the stuff we want, we're also going to get some of the stuff we don't want. We try not to do that, but it happens. So we want to maximize recovery and minimize dilution.

Leslie Gertsch (06:27):

Selectivity is the ability of the technologies or the mining method to separate the ore from the waste in place, in the mine. Non-selective methods actually increase the recovery, because you're getting more of the stuff you want, but non-selective methods also increase the dilution. So there's some conflict there.

Leslie Gertsch (06:48):

Efficiency is the ability of the processing method to separate the target material from the waste in the processing plant.

Leslie Gertsch (06:57):

Concentrate is the processed mixture from the plant that consists mostly of the desired material. It's the output from the plant.

Leslie Gertsch (07:06):

The middlings are the mixture of desired and gangue, or waste materials, that are partway through the process. And we usually process them a little bit more.

Leslie Gertsch (07:15):

Tailings are the mixture that's left over, that's depleted in the desired material. It's usually discarded. Now, it's not just thrown out, it actually has to be managed and stored somewhere. You remember some of the recent tailings dam failures, that's not always an easy thing to do.

Leslie Gertsch (07:34):

All right. After terms, let's go into phases of mineral production. The first thing you have to do is find out what occurrences of the target material you can find. Prospecting is the early stage of that exploration, is the more detailed in-depth stage of examining what you found during prospecting. What you're doing in this phase is selecting the target mineral deposit that you hope to turn into a mine.

Leslie Gertsch (08:02):

Development is a process of getting access to that deposit ... and of course, on the moon, that means getting access to the moon. It also means creating the infrastructure so you can get the technology to the mineral deposit and do what you need to there. It also means designing the exact systems of technology and scheduling and layout that you need to extract the mineral you want.

Leslie Gertsch (08:26):

Now, extraction is the actual mining and processing, where you're actually producing material from the raw deposit.

Leslie Gertsch (08:34):

There's always an end to everything and mines have to be closed. In the old days we sometimes abandoned them without much thought. We can't do that anymore because there's an environmental cost to that. So closure consists of remediating any environmental changes that you do not want to be permanent at the site. It also means shutdown, which can be permanent or it can be temporary; what we call care and maintenance for when we need to come back when the market improves. One thing I do want to point out is that deposits are found, but mines are made.

Leslie Gertsch (09:11):

All right, how do we choose a mining method? Here on earth, the constraints that we have to pay attention to are the gravity vector. Now, we don't normally think about that because, everything we've ever done, the gravity vector has always been one direction: down. It's fairly strong and it's constant. It does change a little bit with elevation, but not enough that it really matters most times.

Leslie Gertsch (09:40):

Our atmosphere: it's thick. It's got 21% oxygen, which we need. Earth hasn't always had that, by the way. It's also humid, there's water in the air. We don't think about it because we're so used to it, but it's important. Even more important than that, the atmosphere serves as a buffer from thermal swings, that is sharp, sudden changes in temperature. On the moon ... well, we'll get to the moon in a minute ... but basically we don't have that thermal buffer, we don't have a radiation shield on the moon. We do here on Earth. Atmosphere also tends to shield us from impacts, at least objects that are no bigger than a certain size limit, which is still being determined.

Leslie Gertsch (10:29):

The mining methods that we use here on Earth are derived from human physical capabilities. Even the most advanced mining methods using the most advanced technologies, you can still trace back how they're laid out, how they're planned, how they're scheduled, to people out there in the dirt, standing there, digging things with your back and your shovels, from that. Mines are constrained by having to have people inside them. And, of course, these Earth constraints we've talked about. The mining methods are implicitly based on those.

Leslie Gertsch (11:07):

Now energy, here on Earth, is relatively scarce. Now, we might say, "Oh, we've got all kinds of sources of energy." And we do. But compared to mass, mass is abundant here on Earth because we don't have to launch it off the planet. Of course, it does cost to move tonnage, but it doesn't cost as much as it will in space or at least on the moon's surface.

Leslie Gertsch (11:34):

Water is also abundant. And it's liquid water, for the most part. Sure, we have to deal with water vapor in the air and ice, but liquid water is really important to the way we have learned to do mining on this planet.

Leslie Gertsch (11:47):

Access: Now the location, I'm saying, is easy, because everything we mine on earth is here on Earth. In fact, it's very, very near the top surface of the Earth. The very shallow skin of the Earth is as far as we go down. Our deepest boreholes are down about 42,000 feet, and that was very difficult to do. The deposit itself, the access is difficult because we actually have to get to it only from the Earth's surface. We can't get to it from any other direction very easily.

Leslie Gertsch (12:21):

Now, if we go to the moon, the gravity vector is much lower. Now, this slide was written for all space mining, which of course includes Mars, and asteroids, and icy moons of other planets and so forth. But we think ob just the moon, the gravity, it's still unidirectional, it's still down, but it's got a lower magnitude. So that's something we have to get used to. But it's not as different as it would be on an asteroid or near an asteroid. Don't really stand on asteroids very much.

Leslie Gertsch (12:56):

The atmosphere on the moon is very, very thin. It is there, but it is thin. It's basically, oh, we've got a molecule here, we've got another molecule over there. So we effectively treat it as a vacuum. But there are harder vacuums elsewhere in space.

Leslie Gertsch (13:12):

Access: The location is difficult because we have to get from Earth to the moon. That is not an easy thing. It is energetically very expensive to get anything from the Earth to the moon, and it scales according to mass. So the less we can launch the better it'll be.

Leslie Gertsch (13:31):

The deposit access, it's more like the Earth. This scale, as I said, is for all space mining. It's easier, well, for an asteroid, than it is for the moon. The moon is a lot like the Earth, in that we can only access the deposit from the surface of the moon.

Leslie Gertsch (13:50):

I'm going to go over to energy: At the moment, energy for working on the moon is very limited. But there are some aspects of the lunar environment that will eventually, I believe, make energy relatively easy to get. But it's not going to be that way for a while yet.

Leslie Gertsch (14:07):

Mass: The launch mass, as I mentioned, is extremely limited. It's about $10,000 a kilogram to launch mass from the surface of the Earth. And that's expensive. Water is very limited. We used to think the moon was totally dry. We know now that it's not. But there's still not very much water, certainly no ponds out there that we can access.

Leslie Gertsch (14:32):

And this is what I meant when I was talking about access from the surface. The moon is like the Earth, and it's in that top row, where we've got this whole big planet, there's an orebody there of whatever irregular shape. But we can only get to it from the surface, from one direction. For asteroids, we can get to it, ostensibly, from multiple directions. I've also made this asteroid a disseminated orebody. So it's not one big lump of great stuff, it's sprinkled all through all the rock.

Leslie Gertsch (15:02):

Okay. Choosing a mining method: To choose a mining method, we need to know something about the deposit we're going to mine. We need to know its shape, we need to know how thick it is, how it's oriented; is it long in this direction or is it long up and down? How easy is it to tell the ore from the waste? Can you dig up just ore and right up next to the waste and they come apart easily? Or are they inter-fingered, like that disseminated orebody we just talked about? In which case, you can't find the boundaries very easily. Is the deposit uniform, does it have the same grade or concentration of the material we want throughout? Or is it gradational or is it very erratic?

Leslie Gertsch (15:44):

The geomechanics, and that is the strength, the mechanical behavior of the rock or the regolith, or whatever it is we're moving. And, of course, the strength of the surrounding material might be different.

If the surrounding material is weak, we need a different mining method than if the surrounding material is strong, regardless what the ore strength is.

Leslie Gertsch (16:05):

And, of course, we also need to know what we need to produce and how much of it. How fast? That's the production rate. What health and safety requirements there are? And the environmental effects that the whole process is going to have. What are the limits for that?

Leslie Gertsch (16:21):

The outputs for choosing a mining method: We need to figure out the operating cost estimates, what the capital costs are going to be, the timing of capital investment and development of the project, what production rate we can actually achieve versus what we need to achieve, how selective we can manage to be, how flexible our method can be, and of course the health and safety and environmental effects that we can actually make happen.

Leslie Gertsch (16:49):

Mining, on the Earth, generally consists of two sets of unit operations. Now, a unit operation may need multiple technologies to happen. A single technology system may actually perform multiple unit operations. And we'll see some examples here, in the next few slides.

Leslie Gertsch (17:10):

Mining unit operations, I call first-order separation. And that's dealing with what we find in nature, separating the ore from the waste or country rock, surrounding rock. There are three unit operations there, they're fragmentation, excavation and transportation.

Leslie Gertsch (17:27):

Then the material ... now that we've got access to it, we've got it in our hands ... we take it to beneficiation or processing. And that's, I call, the second-order of separation. That uses processes here on Earth, of comminution ... that is crushing and grinding to make big pieces into littler ones ... separation, and transportation. Transportation's important in every step of any manufacturing process.

Leslie Gertsch (17:54):

This is an example of a mine layout, a surface mine layout. In some respects, possibly similar to what we'll see on the moon. But this is actually a gold mine. And I wanted you to see this just to see what the choice of mining method can do for the footprint of the mine.

Leslie Gertsch (18:15):

The mine pit is this magenta circle in the lower right. Let's see if I can get the laser pointer. There we go. There's our mine pit. The stockpile, we've got two stockpiles for different parts of the extraction process. And there's one in the center and there's one over on the left of that. We have the waste rock storage; because stuff that we had to move in order to get the ore, we've got to put it somewhere. Eventually, we'll probably put it back in the pit. And then there's tailing storage, and that's the waste material from the processing plant. Those are all going to take more volume than they did originally, quite a bit more because we're spreading it out on the surface so it looks big here. So we have to take this into account also when we go to the moon.

Leslie Gertsch (19:05):

All right. First-order unit operation: Fragmentation: breaking the desired material free from where we find it in nature. There are various means of doing it: explosives, mechanical means ... mechanical is what we see here on the right ... thermal ... which we can see on the bottom ... and some chemical means. Generally, on Earth, we don't use thermal and the chemical too much. And of course, explosives ... everybody's favorite ... may or may not be necessary on the moon, but sometimes it is on Earth.

Leslie Gertsch (19:37):

Excavation: After we've broken it free, we need to pick it up. That's what excavation is. Generally mechanical, as we can see here with this track hoe on the right. But on the bottom we're seeing a chemical way of doing it, or a fluid mechanics if you want. And that's where we've dissolved the mineral, in this case it's salt or halite, we've picked it up by the dissolution process and we're going to carry it away or transport it in a slurry.

Leslie Gertsch (20:04):

Now, again, transportation .... here, I've got a picture showing both ... we've broken it free, we've picked it up, now we have to move it somewhere. And that requires surge capacity. And those are those stockpiles we saw earlier. This is a surface miner in a coal mine. We also have other ways of transporting things on Earth. This is a very dramatic shot of a very steep angle conveyor in a large copper mine.

Leslie Gertsch (20:32):

Now we're getting to the second-order separations. The unit operations here, we basically want to comminute, that is break down bigger particles that are material that we want locked within them, we want to break them down to the right size, where the stuff we want is liberated; in other words, it's exposed. And then we want to separate them, as you can see here in this cartoon. Transportation, of course, is implicit in all of these, moving material from one step to another in the process.

Leslie Gertsch (21:02):

Comminution, as I mentioned, is crushing and grinding. And anytime you go past a crushed rock quarry, or even sometimes river gravel quarries, you'll see a processing plant like this; a mobile plant in this case, it's got tracks there. And you put in the material in the top, it crushes it, it screens it ... that is separates the sizes out ... and makes one or more different stockpiles of product, of output.

Leslie Gertsch (21:30):

Comminution, on Earth, takes about 50% of the energy used in mining. It's a very important process. On the moon we've got a lot of very fine material, but it might not be at the right size we need for separation. So just because it's already ground by nature, doesn't mean it's to the right size that we want. Although, on the other hand, it's good to use places where nature is already done part of our job for us.

Leslie Gertsch (21:58):

Second-order unit operation is separation. That's based on differences in physical properties, such as density, magnetism, electrical properties, various surface properties. There's some interesting things in there. Often multiple steps required. Anyway, we need to go on. I'm running out of time here.

Leslie Gertsch (22:20):

A second-order unit operation that's really important is separation of the unlocked, the exposed particles of material we want from material we don't want. This is a diagram just showing the effect of feed particle size on the effectiveness of the different processes that, again, we use here on Earth.

Leslie Gertsch (22:42):

And, of course, transportation. We've got conveyor belts here, but we've also got pipelines. Who knows what's going to work out best on the moon? Lots of people are thinking about that.

Leslie Gertsch (22:53):

All right. So when we're thinking about going from Earth mining to moon mining, keep these things in mind. The first thing is, why is my great idea not being done now on earth? If it is great, find out more about it. If it isn't, figure out why. It may be the reason is a problem only on the Earth and not on the moon. More likely, you're going to have similar problems on the moon. It's very easy to make a prototype run for a short time in the lab. And it's cool, it's a good first step. But it's not the only step. It's really hard to make that big enough and last long enough to be of use in real mining.

Leslie Gertsch (23:31):

Details matter. An example is contaminants in the process stream. I'm going to leave that alone for now just because I'm running out of time.

Leslie Gertsch (23:39):

Scaling up to production levels is extremely hard, especially with new technology, and even more especially in new environments like the moon.

Leslie Gertsch (23:48):

So when we go to the moon, we'll need to understand how mining is done on Earth, even though it will be different. A lot of the stuff we learned on Earth, making mines work, is going to be applicable on the moon. The space operating environment, it's going to be really different. So we've got to know as much about that as we can. And you have to know the target materials. You can't just assume that the regolith on the moon is going to be like your standard gravel bank out in the local creek. It's going to be very different.

Leslie Gertsch (24:20):

So figure out what you need and study what you don't know. We'll leave it at that for today. Thank you.

Kaylen Platt (24:32):

Thank you so much, Leslie Gertsch. If anyone does have questions, you should be able to unmute yourself now.

Heidi (24:38):

Leslie, this is Heidi. I actually have a question. Which method of mining do you think is going to be the easiest to start with on the moon?

Leslie Gertsch (24:49):

The one that most people are paying attention to and thinking about and doing research on, is similar to what you'd see in a gravel pit anywhere in any county in the United States, or any other country for that matter, where you basically have a front end loader sort of thing that picks up the natural material in from areas that seem to have a high concentration of what we want, and trundle it over to some processing unit, like we saw in that one slide, dumping it in ... let's see if I can get back to that. Oh, there it is. Okay. It's going to look different. It probably won't be open to the atmosphere such as it is and it may or may not dump out piles like that. But that's what most people are thinking about.

Leslie Gertsch (25:43):

Now, that's not to say that there aren't other ideas that people have that could be real game changers. There's an idea of putting a tent over the regolith and heating it up with solar power and making the water ... if there's ice in there ... vaporize, and then they can collect it out of the tent. So there's all kinds of cool ideas out there.

Heidi (26:06):

Yeah, that is a really interesting idea, because that'd be a way to get the water, which is needed to have people living there. So that would be a really neat one.

Leslie Gertsch (26:13):

Mm-hmm (affirmative).

Heidi (26:14):

Okay. We do have a question in the chat: so is it a goal to use the in-situ resources on the moon and Mars in future space travel?

Leslie Gertsch (26:24):

Yes. Yes, it is. The whole idea of mining on the moon, and mining on Mars and asteroids, is so that you don't have to take everything with you that you need to explore space, because, until you do, everything in space is just a giant, expensive camping trip.

Leslie Gertsch (26:41):

But if you can actually be there and use materials there, like water, or even regolith to build habitats with so you don't have to ship all the habitats from Earth ... And it doesn't have to be just for people. Having materials mined in the local vicinity actually would help robotic missions as well as human missions. So it is definitely a very important goal.

Heidi (27:10):

Thank you. That was from Amanda, by the way. I'm sorry I didn't say that at the beginning. But, thank you.

Leslie Gertsch (27:15):

Thank you, Amanda.

Heidi (27:16):

Yep.

Josh Robey (27:17):

Hi Dr. Gertsch. This is Josh Robey, University of Illinois. You talked a little bit about, for instance, the machine you see in the slide you're presenting right here as a possible mechanism for mining on the moon. How does that change when you go to the lower gravity environment of an asteroid, for instance? Because there are companies out there that are interested in and planning or preparing for asteroid mining.

Leslie Gertsch (27:47):

There are. Basically, if we were on an asteroid instead of the moon, something like this would have to be completely redesigned. And, very likely, this is not a good mining method for asteroids. For an asteroid, we'd probably want to use something we call bulk mining here on Earth, at least if the asteroid is a disseminated orebody like I showed earlier. In which case, we would want to fragment the asteroid in place, not really shovelful by shovelful like you see here, but more in place and all at once, using whatever natural forces we can apply.

Leslie Gertsch (28:30):

Now, with Earth, as I mentioned, the gravity vector is down in about a constant amount. But on an asteroid, the gravity of vector, as you travel around the asteroid, just points in all kinds of different directions, and it gets stronger and weaker depending on where you are in relation to the asteroid. It's really kind of a pain.

Leslie Gertsch (28:50):

So, for asteroid mining, you'd probably want to use some other source of energy for separation. And possibly centrifugal force, get the thing spinning and have it break apart if you spin it fast enough, and collect it in some magic material bags, probably something like the bags that were used to land some of the early Rovers on Mars.

Leslie Gertsch (29:20):

So there are lots of different things that would have to be reengineered. So a mining method for the moon is not necessarily going to be a good mining method for an asteroid.

Heidi (29:32):

Thank you. We do have one more question really quick, before we start our next talk. And this is from Danielle: What would you say is one of the hardest aspects of mining on the moon?

Leslie Gertsch (29:43):

The hardest aspect, I think, is going to be that it will feel familiar, a lot like Earth, because it does have gravity down and a surface to work on, but it's not quite the same so it's going to trip us up. If it we were totally alien we'd relearn it from the start. But since it's going to be, in some ways, very similar, but not quite, for example, the difference between weight and inertia. Now, the mass is going to be the same. But the weight will be different on the moon, it'll be only one sixth of what we're seeing here. For example, driving a truck loaded with ore, if we take a curve too fast it's going to tend to tip over a lot more easily. So that's going to be the hardest aspect to mine on the moon.

Heidi (30:26):

Thank you.