# NWX-NASA-JPL-AUDIO-CORE (US)

**Moderator: Anita Sohus**
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Coordinator: Excuse me. This is the Operator. Today's conference is being recorded. If you have any objections, you may disconnect at this time. Thank you.

Woman: Thank you very much (Delana) and welcome everyone to our Mars Insight -- Finding a Place to Land Telecon. We are delighted today to have with us Dr. Matt Golombek, who was the project scientist on Mars Pathfinder, a project scientist on Mars Exploration Rover, and now is a project scientist on the Insight Mission. He is the person who has correctly identified appropriate landing sites on Mars for 20 years.

He has been with us before, telling us the story about how other landing sites have been selected and we're looking forward to hearing the story of Insight today. So I'm going to turn this over to Matt.

Matt Golombek: [Slide 2] Hi everybody. Just go straight to the second slide and we'll just dive right in. Selecting a landing site is a somewhat interesting activity. Why do you want to select the landing site? Well, because the mission will fail if you don't land safely, and these missions tend to cost a fair bit of time, energy, and money -- somewhere in the hundreds of millions to several billion dollars.

So I don't go to Las Vegas and I don't gamble. And I kind of view it as something that we have to do everything humanly possible to make sure that our interpretations of the surface are correct and suitable for the spacecraft.

You'll select the landing site during project development. That's because the spacecraft capabilities change during the development. No matter how good the engineers think they know how to build it, there's always things that wind up changing during the actual development and build. And you have to have the people who are seeking the landing site clued in onto what those are so you don't make a decision and then have the capability of spacecraft change and you picked the wrong spot.

So what do you actually do? How do you select the landing site? Basically you have to understand the engineering constraints that the spacecraft has as it comes in and lands on Mars, and then you have to define those spots on the surface of Mars and actually map those constraints onto Mars.

So basically, you're using remote sensing information about Mars to learn about what the surface is like and in fact actually make predictions of what you think the surface will be. Obviously you don't want to get it wrong.

So what do we look for with a landing site? We look for something that's smooth, flat, and boring. You want a rock-free plane that's safe for landing and roving. It also must address the science objectives of the mission and it must comply with planetary protection.

In the past 20 years, there have been five selections of efforts for successful missions to Mars. I consider my honor to have been intimately involved with every single one of these, and hopefully going for another couple here before I'm done.

So why is it important? Well, it's obviously important for the Mars exploration program. It's ground truth for your remote sensing data. Then I would just say that you definitely don't want to encourage anyone to try to do this sort of thing for a living. It limits you in terms of where you can work -- really pretty much just JPL. So there's only one place where you can work. And you only have work when there's a lander to select the landing site for. And you don't have control over that, either. So like I said, I've been pretty fortunate in the past 20 years to have had a steady stream of landers to work on.

[Slide 3]. This is an elevation map of Mars. And blue is low, and red is high. And you can see that most of the seven sites are actually pretty close to the equator -- within 15 to 20 degrees, 30 degrees I guess at the most. There are a couple that are outliers, but you'll notice that they're all in the lower elevations.

So let's think about why that is. The elevation and the density of the elevation is what helps slow the vehicle down. You use an aeroshell and friction of the atmosphere as well as a parachute. So the lower you go, the more time you have. And engineers like to have a little time between all the events that need to happen. So you really want to be as low as you can.

In addition, if it's a solar powered spacecraft -- and many of these are -- then being near the equator gives you more solar insolation than you would near the pole. And you can thermally manage your spacecraft much better at near the equator because the temperature change day/night is about 100 degrees Fahrenheit on the surface. Basically the hardest job of operating on the surface of Mars is keeping yourself warm at night and managing the power that you bring in and put into the battery to help keep yourself warm at night. Electronics don't like to be in minus 50 degrees.

[Slide 4] Page four. Picking a landing site generally takes years. We generally do it depending on the cadence of the mission. We were ready to do Insight in about three and a half years, but it was delayed in its launch from 2016 to 2018 and that gave us a little bit of extra time.

Here you can see -- I won't go though this in gritty detail, but we have a series of workshops to get all of the information that we can out on the table. And we have a series of down selection events where, in this case, we went from about 22 ellipses -- I'll show you those in a minute -- to about four and then to picking an actual site and, in fact, certifying it.

[Slide 5]. This is what determines your elevation. It's the entry descent landing, or EDL as we call it. You arrive at the outer reaches of the atmosphere. You dump off the cruise stage. You orient yourself quite precisely with respect to the atmosphere, and you come in on an aeroshell. The heating and ablation of the aeroshell is what slows you down, mostly.

At a given time, you'll jump out the parachute, and you'll come down. You'll dump off the forward heat shield and you use a radar altimeter to measure the closing velocity. When you get to the proper altitude, you'll detach from the parachute, you'll fire the thrusters -- in this case thrusters -- and in this case, you'll land on legs. And on the first sol you have to open up the solar panels and do a whole variety of things.

This entire series of events takes seven minutes or so -- seven minutes of terror. Roughly 50 or 60 pyrotechnic devices must kick off every single one of these events and deployments. Any one of these will result in a failure of the mission. So you can't be almost there; you have to be 100% there in order to land safely.

[Slide 6] shows the landing site constraints for Insight. The latitude had to be near the equator. Initially we were at about 15 south to 5 degrees north. Later we narrowed that down to five north to two south, and later after that it was three north to five degrees north.

So things kept getting more and more constrained with time. The elevation needed to be below two and a half kilometers with respect to the geoid on Mars, or the geoid potential. That tells you how much atmosphere you have. I'll talk about that in a minute.

The ellipse size, the most accurate we can place this ellipse on the surface, is about 139 kilometers by 27 kilometers. We chose a reference ellipse of about that size and that's what we use to site our ellipses.

Thermal inertia is a measure of the resistance to a change in temperature. Things that change temperature fast have very small particles. We know there are areas on Mars that have thick deposits of non-load bearing dust that could be meters to tens of meters thick. So this is not a good place to land a solar powered spacecraft, because it would sink right through the dust and you wouldn't get much solar power from it. So we get rid of places with low thermal inertia.

We don't want too many rocks on the surface because rocks are protruding up from the base and they can harm the vehicle on landing. [We] need to be pretty flat -- less than 15 degrees, and we must be able to deploy our instruments, which have the same, interestingly enough, rock abundance and slope requirements.

Then for the first time for this site selection, we had to figure out what we are going on at three to five meters beneath the surface because this spacecraft has a mole that needs to penetrate by a hammering mechanism that goes down three to five meters. And it can't penetrate solid rock or solid ice; it needs broken up soil. So we had to figure out a way to understand whether or not the site we were selecting had a broken-up regolith that was at least three to five meters deep.

Also, completely for a first for this landing site selection, there were no science requirements outside of the requirements to deploy the instruments. That's because this spacecraft is carrying a seismometer and a heat flow probe, and they can do that job pretty much anywhere. Doesn't matter where you are -- as long as you land safely, and you can get the heat flow probe down three to five meters, you're in good shape. So, no science requirements, which dramatically simplified the site selection.

So let's now see how these constraints constrained where you can go on Mars. I guess I didn't really talk right up front that the Insight mission is a Discovery class mission. That's a fixed price mission. It was selected via proposal by a team of people -- of which I am one. We proposed a mission of science that it could do as well as an implementation, and we were very fortunate to be successful in that.

The two main things it's doing is understanding the internal structure of Mars -- does it have a core? How big is the mantle? How think is the crust? What is its constituency? Are they convecting? Is the inner core liquid? That all goes to the initial differentiation of the planet.

[Slide 7] So back on slide seven now. Here is Mars now color coded by elevation. Anything in red is too high. Anything in green is nice and low. And anything in kind of beige is just barely okay. And as you can see, Mars didn't get the memo of wanting to have low places near the equator.

Basically, the planet is composed of a southern hemisphere. Two-thirds of the surface is composed of highlands that are heavily cratered and thus believed to be ancient. The green is the northern lowlands that's dropped down about five kilometers -- much less cratered and much younger. And we're sitting sort of right in the border of that.

And you can see with these latitude constraints, there's just no place to go. There's Valles Marineris and Chryse Basin. There's Isidis and Elysium, and to the east of Elysium is Amazonis. And there's problems with most of these. Valles Marineris is too small to get a big giant ellipse in. The southern port of Isidis is too rocky, as estimated from remote sensing data.

[Slide 8] And as you can see in the next slide, slide eight, the thermal inertia wipes out most of Amazonis Planitia and the eastern part of Elysium Planitia. So the only place available is that little part of western Elysium Planitia just near the left part of that rightmost arrow that isn't too fluffy and dusty and meets the elevation and latitude constraints.

[Slide 9] And the next slide on [9] shows a blowup of that region with the five north to two south and the latitudes or longitudes of 135 to 145. And this one small area has elevations below minus two-and-a-half kilometers and meets the thermal inertia constraints. You can see the low thermal inertia in gray to the east and the black are the elevations that are too high.

[Slide 10] So we have a hardly over-constrained problem here of not having much to select from. And this box here that shows the areas that satisfies constraints is shown in slide ten in a little more detail, reference ellipses that in the remote sensing data these are estimates of rock abundance from thermal emission spectroscopy that show rock abundance of less than 10% that meets the criteria.

As you can see, we've tried to put them in places that don't have black areas in them. We were pretty successful there. Then we started to image.

[Slide 11] Basically, we had to target in, slide 11, this area with high resolution images from the Mars Reconnaissance Orbiter [cameras]: CTX images at six meters per pixel, and HiRISE images at 25 centimeters per pixel. And this shows 16 or so ellipses with terrains that we mapped from the surface characteristics that we could see in those images.

[Slide 12] The next slide, 12, shows that our favored surface is what we call smooth terrain. In the left it's from CTX, in the right it's HiRISE. You can see this is a remarkably smooth and benign surface.

[Slide 13] In slide 13, for an example of this particular terrainm we almost didn't find any rocks. There's one rock we saw in this entire area that's hundreds of meters across. You can see that casts a shadow in the opposite direction of the small craters that you can see. These are secondary craters from a large crater, about 1,000 kilometers to the north, that have spewed these small, secondary craters all the way across the ellipse. That created quite a bit of consternation, because craters could be hazards as well.

[Slide 14] shows the smooth terrain on the left and a more etched terrain on the right.

[Slide 15] As you can see on slide 15, the etched terrain is much rougher. It has aeolian bedforms -- those bright things that were blown around by the wind -- and also you can identify a lot of rocks there as well.

[Slide 16] So we ascertained that the smooth terrain was the safest in slide 16, and you can see that we favored the four ellipses to the very northwest of this map that are dominantly on that smooth terrain. All of the other ellipses had more hazardous etched terrain and transitional etched terrain that had more relief than rocks and so on.

[Slide 17] So we made a down selection on slide 17 about a year and a bit, a year and a half to almost two years after the start, that narrowed it down to four ellipses -- E5, E8, E9, and E17 -- that are dominantly on this green smooth terrain.

[Slide 18] Then we told MROs HiRISE imager in slide 18 to take images of these ellipses. Here shows the situation at the second down selection workshop in January of 2015, the [imager] coverage that we had gotten in these four ellipses. The green ones are monoscopic images. The blue ones are stereo, where we have two images from different vantage points that allow us to determine slopes and elevations quantitatively by using stereogrammetry.

[Slide 19] shows our terrain map for these four ellipses. You can see the azimuth of the ellipses changes depending upon when you launch. We have about a month and a bit launch window.  When you launch changes the geometry at arrival a bit. It turns the azimuth of the ellipse from north-northeast to south-southeast, so from the white to the blue to the yellow [ellipses].

[Slide 20] In slide 20 is our situation at the time of selection. As you can see, we had filled in about 90% of our favored ellipse by October of 2015.

[Slide 21] shows our unfortunate aspect -- in December of 2015, a leak in the seismic station, the instrument SEIS. The vacuum container had a leak in it. We could not get the required sensitivity of that instrument and the launch was suspended. Both we, as a project, and NASA agreed with that.

We worked in January of 2016 for a revised launch, which of course required more money as well. We were granted an approved project for a launch on Cinco de Mayo in 2018. So we're six months or eight months away now.

This revised timeline had a different trajectory, a type one trajectory that gets there in less than nine months, really. This opportunity had different conditions for arrival. This changed the velocity of arrival. The latitude and ellipse size weren't changed much, but the elevation could have changed a lot.

[Slide 22] I'll show you in slide 22 the things that we were most concerned about for this change of launch opportunity. The latitude -- not much because we're staying on the surface for a full Mars year. The elevation -- we were very concerned about because the thickness of the atmosphere on Mars changes by 25% seasonally. You can only launch to Mars once every 26 months and you get to sample whatever the atmosphere is when you get there and you don't get to control that. It just so happens that this event, or opportunity, in 2018 had about the same pressure.

[Slide 23] So if you look on page 23, it shows how the pressure changes with the aphelion and perihelion. When you're at closest approach, Mars has the [second] most elliptic orbit of any of the terrestrial planets.

So due to that ellipticity of the orbit as well as the tilt with respect to the ecliptic, we have very unusual and extreme seasons on Mars which results in a 25% change in the atmosphere. That's shown on page 24 where you can see, for the arrival in 2016, our trajectory arrived at $L_s$, or the angle around the Sun, that Mars is at 231. That sample of the atmosphere, VL1, was about 8.4 millibars, and it just so happened we were the luckiest project ever. For 2018, the pressure was almost exactly the same -- arriving at the other side of the maximum pressure hump at $L_s$ 295.

[Slide 25] So in fact, none the elevation, none of the requirements, the engineering requirements on landing site selection on slide 25 changed. And that was amazing because with two years between one launch and the other, we didn't really have time to find a new landing site, with all of the imaging that we needed to do. Thus we could keep the same landing site.

[Slide 26] shows the ellipses for 2016 and that change in azimuth from east-northeast to east-southeast with time in the launch -- so from white to blue to orange.

[Slide 27] Now compare that to slide 27 for the 2018 launch opportunity and you can see this opportunity is even better because the azimuthal change is a little bit less. Shown on there are the nominal ellipse, the dashed, as well as a potential smaller ellipse, if tracking allows. So, our 2018 ellipse is miraculously unchanged for the Insight landing site.

[Slide 28] What I'll do is introduce and go through each one of these requirements and show you how we know this site meets the requirements. We've already gone through the latitude and the elevation and the ellipse size.

[Slide 29] Next thing is thermal inertia. So thermal inertia as I said is the resistance to a change in temperature.

[Slide 30] If you took all of Mars on slide 30 and plotted up the albedo on the Y axis and the thermal inertia on the X axis, you would see that 90% of Mars falls into three areas called A, B, and C. A has extremely low thermal inertia and extremely high albedo. So those are those dusty areas and we will never land in those, or not likely, anyway.

B has low albedo, so it's relatively dust-free because dust is bright at high albedo, and very red, but it has moderate thermal inertia. And you can see the Opportunity rover landed in that suite at Meridiani Planum.

And all of the others are in unit C, which makes up the lion's share of Mars, which has intermediate thermal inertia and moderate albedo -- so slightly dust but not so dusty that you would sink in and disappear. And the Spirit land rover landed there as well as the VL1, VL2, Phoenix. And you can see Insight is right next to VL2 so it's pretty much like places we've been.

[Slide 31] shows the thermal inertia. It's incredibly monotonous for this part of Elysium -- around 200 thermal inertia units.

[Slide 32] In higher resolution, page 32 shows a higher resolution thermal inertia that shows that we can't possibly have more than probably a micron's thick of dust. The most it could be would be a millimeter or two.

[Slide 33] Most of the thermal inertia is quite similar. If you convert that to grain size -- shown on slide 33 -- most of the surface is made up of fine to very fine sand. And it's pretty much cohesion-less down to probably about a meter or so, which is the thermal wavelengths that are being sampled here.

So this suggests that we have a soil or sandy surface that is probably that way all the way down to about a meter. So one meter out of my five meters that I need for a broken-up surface with no rock [for the heat flow probe].

[Slide 34] The requirement is that the rock abundance be less than 10% of the area covered by rocks. We've done simulations to show that the failure increases rapidly above that.

[Slide 35], shows the rock density in numbers of rocks in 150 meter by 150 meter bins as measured from the shadows cast by the rocks in the HiRISE image.

[Slide 36] That translates in slide 36 to the risk -- anything in green has effectively no risk or less than a single percent. And anything that's starting to get to ten -- which is in yellow -- or red higher has some rick. The mean rock abundance is 1.2%. It's so low that we easily meet our rock constraint.

[Slide 37] says that the slope shouldn't be more than about 15 degrees. That's bad for the lander. As it comes down, it [would have] trouble radar tracking the surface. It also can skip off the surface if the slope is steep, and we'd have trouble deploying our instruments.

[Slide 38] shows our slope map from our digital elevation models as well as our photoclinometry, and the area greater than ten degrees is less than 1%. So we easily meet our smooth and flat and relatively rock free.

[Slide 39] Now, for the most interesting part: how the heck can you figure out that you have five meters of regolith for the penetration of the mole? And this took a little bit of scratching of our heads. So stay with me. This is the fun part.

[Slide 40] shows what we call a rocky ejecta crater. So this crater is about 200 meters in diameter and you can see big, chunky rocks out in the ejecta blanket. You can also see all those bright aeolian bedforms, so that's probably sand that's been harnessed by the wind and moved across the surface. It's obviously filling this crater in, but the ejecta has all of these big, hard rocks.

Well, let's think about that for a minute. In order for the ejecta to have hard rocks, there must be hard rock in the subsurface that is getting caught up in the ejecta from the crater. The physics of this is that the ejecta from craters comes from about 10% of the diameter of the crater.

So for this 200-meter diameter crater, most of the ejecta came from about 20 meters depth. At 20 meters depth, there had to be a layer of strong, coherent rock for there to have gotten into the ejecta to be now out on the surface.

So basically, what we did was we used the cut-off diameter of rocky ejecta craters to map the thickness of the broken-up regolith.

[Slide 14] That's shown in slide 41. As you can see, crater A in the lower left has lots of rocks in the ejecta. That crater is 112-meters in diameter and it found hard rock at about eight meters down.

However, crater B in the upper right is similar in morphology. It's not much younger or older. It's about the same degradation state. And there's no rocks in the ejecta. That crater is about 75 meters in diameter, and thus at six meters depth, there was no hard rock to be had. That suggests that at this location, there's a broken up, fragmented regolith composed mostly of sand-size material that is at least six meters thick. And at eight meters thick, there's rock. So, we can use this as the ability then to map the thickness of the broken-up regolith layer.

[Slide 42] shows the situation. This is a thermal image at 100 meters per pixel. And anything dark in this has high thermal inertia and thus is rocky. And you can see all these little small blotches in, for example, ellipses nine and ten. And those blotches are those rocky ejecta craters that are big enough to get down beneath this fractured and broken up regolith and into hard rock.

Now also look just to the east side of ellipse E8. There are large -- these are over ten kilometer large -- craters. And there's no rocks. There's no thermal signature. They're not dark. And there's no rocks in those crater ejecta. So that means that if those are ten kilometers diameter, at 100 meters down, roughly, 20 kilometers at 200 meters down there's no rock anymore It must be soft sediment.

So we can use then the diameter of the rocky ejecta craters to map the thickness of this regolith layer.

[Slide 43] That's the nighttime thermal inertia. Same story there. I won't go over it.

[Slide 44] shows a cross section of what we think this terrain looks like. So on top is what we call the regolith. You can see closely there's just not many rocks in that that we can see with our HiRISE images. That grades down to a blocky ejecta that is stuff that was probably once or twice hit by craters. That grades down into fractured bedrock, which is in place and not broken up. And that's probably been fractured by the craters but not ejected. And then down below that is the talus. This is kind of a cross section.

And we think in this example the regolith is about five to ten meters thick and it doesn't show any big rocks or boulders in it. And you can see the surface doesn't show much in the way of rocks either. That suggests that we have a relatively thick regolith layer at Insight landing site to allow our mole to get down three to five meters.

[Slide 45] actually shows our ability to map the thickness. It shows the accumulative number within five-kilometer points of the number of rocky ejecta craters, and interestingly enough the center of the ellipse looks like it has the thinnest regolith -- about three meters. That should still be sufficient. We might be able to use this for targeting.

[Slide 46], we also use fragmentation theory. I won't go through this in detail. Basically it says as you go deeper, you should get bigger rocks as you hit them with more and more craters.

[Slide 47] maps that.

[Slide 48] shows the synthesis of the theoretical particle size with depth using this theory to get at how many rocks there are that could impede the mole. The mole can't move rocks bigger than 20 centimeters. Thus, we need not too many of those to allow the mole to get all the way down.

[Slide 49] shows a hazard map. Thus we've taken all of our data and put it into a hazard map that's determined by the capability of the spacecraft to land on things with slopes and rocks.

[Slide 50] That's shown on slide 50. Detailed models estimated the chance of tip over for different slopes, the chances of not being able to deploy a solar panel if there's a big rock in the way, the chance of impacting a big rock, the chances of tilting or not being able to deploy a solar panel if you're perched on a rock.

[Slide 51] And that's all convolved then with our hazard map to slide 51 which shows the probability of success for an ellipse of that azimuth and that center point for center points that's shown anywhere on this map. Contoured are the areas of probability of success. And you can see the center point of this example black dotted ellipse is at about 99.2% probability of success to the best of our knowledge. And thus we can use this to quantitatively determine the best landing site.

Because the azimuth changes with where you are in the launch window, right? It rotates clockwise. Once we launch, we would actually run these simulations and pick the best spot, and then we would use them for trajectory correction maneuvers, as we got closer and closer to Mars.

[Slide 52] For anybody who wants to read 90 pages of dry science. No, this is exciting science literature available in the open. Space Science Review has just published little bit earlier this year is a landing site paper that goes through all of this in incredible, gritty detail. It's guaranteed to put you to sleep if you have trouble sleeping. And truly exciting reading for anybody who's into this stuff.

[Slide 53] These are a suite of papers that were also published just recently that get at many of the aspects that I've described on the thickness of the regolith. That's the Warner, et al paper. The meter scale slopes from both photoclinometry and DEMs [digital elevation models]. We actually used radar to get below the surface. We mapped the Corinto craters and looked at crater degradation, among others. So these are all things that you could go look at if you wanted some extra reading.

So there it is -- 53 slides in 40 minutes. How's that? Gives you 20 minutes to ask questions if anybody stayed with me and has them. I'd be happy to answer whatever you have.

Kay Ferrari: We're still here, Matt. And I have a question. Since the majority of landings have occurred around the equator, it would seem that eventually you'd start landing these missions close to where you have a functioning mission underway. Was that ever a problem for you in making this decision?

Matt Golombek: If you go back to slide three -- since I think you guys are all looking at this on your computer -- you can see the Insight landing site is about 600 kilometers north of Curiosity.

At some level, you would kind of not want to do that. The reason is that you will always have an ellipse, an uncertainty as to exactly where you come down on the surface. The Insight ellipse is 130 kilometers by 127. If you had another functioning spacecraft that was inside that ellipse, you would have a possibility of landing right on top of your functioning spacecraft. And that's probably not a risk that you'd want to intentionally take.

Now, for a mission like Curiosity where the ellipse was down to about 20 kilometers because of a technology called aeromaneuvering, you could perhaps land next to it and go over and have a look. But in general, the engineering constraints and the scientific constraints overwhelm any particular desire to have the two robots hold hands.

Woman: Thank you very much. Anybody else have questions for Matt?

(Ken): Yes. Matt, I do. This is (Ken) in North Carolina. On slide 45 if you're looking at the ellipses with the point density map, just north of the ellipse it looks like there's a crater with a couple of it almost looks like butterfly wings around it.

Matt Golombek: Yes.

(Ken): Can you describe how that crater formed?

Matt Golombek: Absolutely. So that's called a lobate apron, a lobate debris apron crater. You can see it has almost kind of an outer fluid texture where it looks like -- and a lot of the model simulations suggest -- that crater accessed some kind of water. It's generally thought to have been ice. Let's see, that crater is what, 15 almost 20 kilometers in diameter. So two kilometers depth, there probably was ice when that crater impacted.

You can see that crater is pretty fresh, so it's fairly young in that regard. In fact, these craters exist all the way across Mars at all the latitudes. I think I showed on slide 42. So there's your butterfly crater up top, but you can see there's a whole family of these to the eastern end of the E8 and others that have a similar morphology.

So, the suggestion here is that there was ice buried at some point. The surface that you're looking at is Hesperian. Let's see, in billions of years, that's probably maybe 3.7 billion years in age. So sometime since then, those craters hit and they drug up ice from that depth.

Did that answer the question?

(Ken): Thank you. I was curious if there was any ice present there today and how deep it might be.

Matt Golombek: Yes. So interesting aspect of Mars exploration is planetary protection, which basically says that before you go to determine if Mars ever had life, you don't want to bring the life with you. The current planetary protection guidelines for spacecraft that are fairly clean but not heat sterilized are that there be no liquid, water, or ice within five meters of the surface at any site that you've selected.

So our current spacecraft are not heat sterilized. I think the price tags for the Viking landers -- which did biology experiments on the surface -- to heat sterilize them in 1970s or 60s was $30 million or more because you can't use plastics and rubber and stuff.  You're going to heat soak this thing. You have to go to other kind of designs.

Mostly, the spacecraft that we're sending now are not heat sterilized. It costs too much to do it. It would make the missions too expensive. So we actually had to have a planetary protection review of this site to say that there was no evidence of water or ice within five meters of the surface. We were perfectly honest and we said there's evidence for ice down below that, but there's nothing in the data that suggest the shallower levels have ice now or any time in the recent past.

Man: I have a question.

Matt Golombek: Yes.

Man: Hello?

Matt Golombek: Yes, go ahead.

Man: Okay. Are there any future plans for landing a rover on the polar caps? I remember a decade or so ago, that mission failed. Is there anything in the works to revisit that?

Matt Golombek: Yes. So they weren't rovers, first of all. They were fixed landers, the 2001 mission. And it wasn't actually going to the polar caps. It was going to the polar-layered terrain, which is adjacent to the polar caps. But that's close enough. The polar-layered terrains are large mounds of finely layered water ice. The polar caps are similar water ice, but they have seasonal $CO_2$ ice as well that freezes at the poles.

Man: Okay.

Matt Golombek: The Phoenix lander went to 65 degrees north and found ice five centimeters down beneath the surface. There have probably been proposals to send other missions to the polar caps but none are in the active works at the moment.

Man: Okay. Thank you.

Matt Golombek: Yes.

(Adrienne Provenzano): Hi. This is (Adrienne Provenzano). I'm a Solar System Ambassador. So a couple years ago I had a chance to visit a meteor crater in Arizona. So that was a good example of rocky ejecta. And I'm just wondering how you came up with this sort of reverse engineering process for your landing site.

Matt Golombek: In terms of a reverse engineering in terms of what?

(Adrienne Provenzano): Figuring out how deep the regolith would be and how you determine that from diameter.

Matt Golombek: You know, I took that as a criteria and we just had to put on our thinking caps. Yes. We had to do a little studying about how crater ejecta is sourced and then we had to think about the suggestions for the depth and so on. There was some literature to suggest that the northern plains had this rocky material depth.

So after thinking about it and getting some new data and reading the literature, that was part of our invention I guess.

(Adrienne Provenzano): So do you think this is going to be used for other landers like moon landers or other sites?

Matt Golombek: It totally depends on whether that's a criteria that's important for the landing, right? For example the 2020 rover -- which is kind of a copy of the Curiosity rover that's being built now at JPL -- there's nothing in that mission that is seeking anything below the surface. It's not sampling. So the subsurface doesn't matter all that much to it. And it hasn't mattered for most of the missions.

I'd say they're probably interested in it because they have a ground penetrating radar on that mission that would tell them about what's happening underneath, but there's no science requirement or engineering requirement that requires you to understand that or even map it out.

So you spend your effort on the things that matter for the mission and that's what you do your work on, yes.

(Adrienne Provenzano): So is Insight -- if I'm remembering correctly -- is that the mission that's going to leave samples to be picked up later on or is that a future mission?

Matt Golombek: No. So 2020 is a rover that will collect and cache samples. So it has a drill and it will drill samples and put them into test tubes and leave those sealed tubes on the surface for some subsequent mission to gather together and potentially bring home to the Earth.

That mission is launching in 2020. It would then need a subsequent mission to go there and collect those samples and put them in a little return capsule. It would then need to launch that capsule into orbit around Mars. You would then need an orbiter to collect that capsule and bring it back to the Earth and land it somewhere that met the criteria.

So those are all kind of big ticket items. The 2020 rover, like the Curiosity rover, are a couple of billion-dollar missions. And the missions that would be needed -- probably two more after the 2020 rover -- are probably of similar cost and complexity. So those have not been approved yet. They could be and they could happen, or they could not.

(Adrienne Provenzano): So since you figured this out, are you working on the 2020 landing site now?

Matt Golombek: Yes. I'm affectionately known at JPL as the Landing Site Dude.

Matt Golombek: That's kind of what I do for a living. And yes, I am in the midst of the 2020 landing site selection as well.

(Adrienne Provenzano): That's great. Thank you very much.

Matt Golombek: You're welcome.

(Christopher): Matthew, my name is (Christopher) from Hudson, Wisconsin. I had a question on your earlier comment about atmospheric pressure.

Matt Golombek: Sure.

(Christopher): I was intrigued when you said that you kind of get when you get on the 26-month windows for arriving and that you lucked out on the atmospheric pressure is going to be good for Insight's arrival. I'm just wondering if it was a different or maybe for a future mission if that arrival would put you on a lower part of the trough, do you then change the delta v(elocity) for getting there or do you plan on it just has to stay in orbit until the pressure gets to where you want?

Matt Golombek: No. So yes, so go back to page 24 and that shows the atmospheric pressure at the Viking lander one surface. And it's amazingly repeatable. It goes through this seasonal cycle and the pressure varies by this 25%. So the delta v is the amount of impulse you need to get the rocket from Earth to Mars. And that varies by each opportunity. And you can only launch to Mars when the Earth and Mars are approaching closest approach on the same side of the Sun.

That only happens because of the rotation of the Earth and Mars around the sun every 26 months. But it has no consequence for the season. It's just where you are as these two planets are meeting up.

So in this slide on 24 you can launch and arrive at anywhere through that seasonal pressure cycle. And where it makes the big difference is if you have less atmosphere. Let's say you arrive at the $L_s$ 150 at the minimum of the pressure. Then you probably need to go lower in elevation for the same mass and landing system, or you have to carry less payload so that your system has more ability to accommodate that lower atmospheric density.

It's fully the luck of the draw. So you're going to sample this, depending on the opportunity. We in the landing on Mars business, we know what these opportunities are. They're completely predictable, and you know what the season is for Mars when you arrive. So there's good opportunities and there's not so good opportunities. And sometimes we take that into account.

For example, one of the reasons that the 2003 Opportunity had two Mars exploration rovers -- Spirit and Opportunity -- is that it was an unusually advantageous opportunity where you launched with less delta v -- and thus you could get more mass -- and the pressure arrival was relatively high. And that was looking so good, that the NASA administration asked JPL to build two rovers instead of one because your bang for your buck was even better.

(Christopher): Great. Thank you so much.

Matt Golombek: You're welcome.

(Ted Blank): Hi, Matt. (Ted Blank) in Arizona. I had a little experience with amateur seismology. And one of the things that we read or learned was that you want to put your sensors in solid rock if you can, so you get the best least attenuation of the waves.

Is there any concern that the regolith might be too broken up and you might find yourself with things insulated somehow from the seismic signals you're trying to detect?

Matt Golombek: Yes. That's a great question. Let me answer that in two ways. If you're a seismologist, then what you like to do is put your seismometer in big, concrete vaults that are built in the bottom of buildings that are seismically separated from the building, even out in the field. Given the choice for very sensitive seismometers, you build a hull, you line it with concrete, you'd bolt the seismometer down to the concrete, you put a top on it, you'd have air conditioning and heating to maintain the temperature, and so on.

So yes, so for the seismologists on the Insight mission, they wanted us to carry along a concrete bag and they wanted us to dig a hole and no -- I'm just kidding. If they had their druthers, they would certainly do that. If they had their second choice, they would land on solid rock and we'd bolt the seismometer down to the rock. But that is obviously not a good thing for the HP3 [Heat Flow and Physical Properties Probe] mole that wants to get down to depth.

So there was a compromise reached at a high level that one, it would be very difficult to find solid rock on Mars. It's a very highly cratered place, and you expect all this ejecta and broken up stuff. It wouldn't be sure. This isn't a rover, so you don't get to choose. If you got this giant ellipse of 130 kilometers, there's virtually no chance of being sure you could come down on solid rock.

So they built it super sensitive and they said it's okay to be deployed on soil, but we would prefer to have all three feet on the same kind of material. So part of our job for deploying these instruments is to place all three feet. Each of the three feet for SEIS has a spike, so they would actually prefer to be on soil or sand and those spikes would kind of penetrate down into the ground and give it some stability.

The second answer to the question is that on the Moon where there are no, I call them, healing processes, where the moon has been subjected to impacts for 4.6 billion years. There's this giant megaregolith that has ejected material that's two kilometers thick everywhere. It's just repeatedly broken up stuff by giant impacts. There's nothing to put the rocks back together.

Now on Mars, we've been to many places like the Opportunity rover at Meridiani Planum, as well as the Curiosity rover at Gale crater, where there are sedimentary rocks at the surface today. So there are clearly processes that have made rocks and made them stronger.

So we have observations that say we don't have a megaregolith like the Moon, which produced extreme scattering for the seismic experiment on the moon and made interpreting the data very difficult. So we actually think in that regard Mars is stronger near the surface. There's a variety of other arguments that go that way. But it suggests that we will have a less scattering situation for the seismic waves on Mars than the Moon.

(Ted Blank): Great. One other thing -- is the mole going to monitor the resistance on the way down to determine whether there are layers or what kind of a…

Matt Golombek: Yes. Absolutely. So, the way it works is it hammers for a short period. It has thermocouples, and it sends a pulse of heat, and it measures the thermal conductivity in short increments as it goes down. It knows the orientation, location, and it can actually go around some rocks with a face. So it tracks the distance. It knows precisely how deep it's gone for a given hammer. So that's a measure of the cohesion or the difficulty in terms of digging.

In addition, it does so after the seismometer is placed on the surface. So we actually have a hammering experiment that uses reflection of those waves produced by the hammering mole to get at the elastic properties of the shallow surface. That's particularly important because it gives you sort of a standard model for what the subsurface is where your seismometer is placed. And it gives us a way to test our hypothesis that we have a broken-up regolith and we can actually measure the thickness.

So once we land, for example, we should be able to figure out where in the ellipse we landed pretty quickly, and we'll have a prediction from our rocky ejecta crater as to how thick that ejecta layer is. Then we can go about hammering and figure out precisely whether we got it right or wrong.

(Ted Blank): Thank you.

Matt Golombek: Yes.

Man: Matt, I think I know what regolith and bedrock are. But what's talus?

Matt Golombek: Talus is just stuff that's fallen down a cliff. So that was an image of a near vertical face, or a very steep face -- 60 degrees -- with then talus is broken up material. It's probably at the angle of repose, about 33 degrees or so.

Man: I see. Thank you.

Matt Golombek: Yes.

Man: Matt, could you give me an Earthly analog to where Insight is going to be touching down? What's the closest place on Earth -- not in terms of latitude and longitude, but in terms of the actual of the geology, the aerology of the place?

Matt Golombek: I cringe when you say aerology because this is just a sidelight. I'm not an aerologist. I'm a geologist. But I happen to work on Mars. Anyway, that's nomenclature. But, nowhere there.

There is no place on Earth that matches this location. There are places produced by different processes that might mimic this situation. There is no place on Earth where you've had three billion years of impacts that has built up a regolith that's three to ten meters thick. What happens on earth is you have water and stuff gets cemented together and it gets eroded and carried down. And as most of Mars has no exact Earth analog.

However, just for fun and actually more than that, the seismologist want to run a test of this hammering experiment. And they want to see if the hammering will produce reflections from this regolith change with density, with depth, that is observed. And thus they asked me -- I'm the only geologist on Insight. Everybody else is a geophysicist that works on the geophysical part. They said, "Where would you go that you could mimic and provide a place that's somewhat similar in terms of now, being quite specific, the seismic velocities with shallow depth?"

There were several other requirements as well. Had to be within few hours' drive of Southern California so we could get there pretty easily. And you wanted this situation where you went from a very soft sediment near the surface to sort of a rubbly layer to kind of intact rock. And actually, we found a place like that. There are several young volcanic flows in the Mojave Desert in southern California. I guess the closest city of any size is Barstow at the juncture of I-40 and I-15 for anyone who's driven it.

And these volcanic flows or basalt flows on the surface, they're tens of thousands to maybe a thousand or several hundred thousand years old. So they're quite young. In the Pleistocene, the Mojave had lakes. It was wetter. These lakes deposited silt and clay in the bottom of the lakes. That's what lakes do.

Then everything dried out. This wasn't from humans; this was just changing of the environment. Those dry lake beds are sitting on the surface. All of the silt -- which is particle sizes between sort of microns to tens of microns -- is blown off of these lake surfaces and accretes on top of these very rough surfaces of these lava flows.

They're tremendously interesting to go visit because at the surface there are clasts of basalts that are ten centimeters -- so five inches or so -- that are right at the surface. And there's all this light dust right beneath it. And if you take a shovel, you can dig down a meter and you'll find no rocks in this silt.

What happens is when it rain, the silt is clay. It expands. More silt gets blown in underneath it, and you keep this what we call a pediment or a regolith surface of these rocks, of all that right size sitting at the surface. Then there's a meter or more up to three to five meters of this silt which then grades into this tephra from the basalt and then broken up kind of broken up surface lavas before you're getting down to intact.

And there were soil scientists that were doing work out there and they actually brought a geophysicist, Jeroen [Tromp], and they did a seismic line. And it has the increase in seismic velocities and elastic properties that we think is likely quite similar to what we have at our location on Mars.

So we're probably going to go out there and try the tests for this location. If you want to visit them, one of them is in the Cima volcanic field. That's in the new Mojave National Park. They won't even let us go in there and hammer there. But there are other locations on bureau land management. One's the Amboy crater and there's one other one that we can access and we'll probably go out and run an experiment there.

So, different process but maybe similar analog style in terms of the physical properties and what we think Insight will find after it's down.

Man: Fantastic answer. Thank you.

Matt Golombek: Yes.

Woman: Matt, we want to be mindful of your time. It's now 1:09. So are you able to take one more question?

Matt Golombek: Yes, absolutely.

Woman: Okay. One more question.

Man: I've got one but it's off topic a bit. Matt, have you ever given any thought to where humans should go first on Mars?

Matt Golombek: Yes, actually. Several regards. As you know, SpaceX has been talking about sending spacecraft to Mars. They actually had a project that they worked with NASA of sending a so-called Red Dragon capsule which is their dragon capsule that they now fly up to the Space Station. It will be ready for, I think, seven people or something. And they were going to send one of those to Mars in 2018 or 2020.

And there was an agreement with NASA and because I'm the only landing site dude that there is, they asked for some help, and we went looking. The things that typically are being looked at - and okay. so that's one.

And then the human missions, the exploration initiative folks at NASA are also thinking about where to send humans on Mars. And there have been several workshops that have begun to look at that.

And they all center pretty much on an outpost style for going to Mars. So first of all, sending people to Mars is not like going to the Moon where you can go there and back in a week and have a good time, plant your flag and have a few footprints.

It takes nine months to get to Mars. You just can't get there much faster. If you're going to go down to the surface, it's going to take a similar period of time. And you want to come back off the surface and get home. So now you're talking about a three-year trip, or two and something, no matter what you do. It could even be longer.

So most of the scenarios that are being conceived of are talking about setting up an outpost that you go back to over and over and you kind of set up shop there. And if you're going to do that, the thing that becomes most important in site selection are, in fact, resources. And the number one resource for humans, and 90% of what we are, is $H_2O$. It's water. And thus, you want to find places on Mars where there's water.

Well, as somebody said, we know there's tons of water at the polar caps. It's ice and it's kilometers thick. We know. But the polar cap on Mars is like the pole on the Earth. So half of the year -- and this is a Mars year -- is going to be black. And most people don't like to stay in Antarctica when it's black so they go in the southern summer.

And there's a reason that we send spacecraft into space from Cape Canaveral and why Russia sends it from Baikonur. And it's because the Earth is a rapidly rotating planet and if you rotate against the spin, it's just like taking off for a landing into the wind with an airplane. You get an assist. And it's a significant assist and the closer to the equator you are, the bigger the assist you get.

So generally they want ice and they, just like everybody else, they want to be near the equator. You know, they're thinking of big, giant solar panels that are getting power and they like the more moderate thermal conditions near the mid-latitudes than the poles.

So here's the yin and the yang. The current surface temperature and pressure of the surface of Mars is too cold for liquid water anywhere. It's too dry. It's too cold. Water would either be in a gaseous state or a frozen state, and the frozen state is only in the equilibrium with the current conditions on Mars at latitudes above 45 degrees.

So you're already getting off your equatorial bulge and things are getting colder and the weather is getting worse.

The big search is for sources of water at plausible locations that you could potentially get them as near the Equator as you can. And the initial looks have found areas where there's water as part of the mineral structure -- what we call clay minerals -- and sometimes you can have up to 5 or even 10% of OH molecules that are absorbed into the mineral structure of these clays.

We know these clays exist on Mars. We've mapped them from chrism or near infrared spectroscopy. Some of these deposits are thick enough that I guess you could imagine bulldozing them and heating them and drying out the water and so on. Okay, so that's one. People are looking at what we call hydrated silicates.

The second thing is that there appear to be locations near 40 degrees and 35 to 45 degrees below where ice ought to be stable on Mars today where there are, in fact, tens of meters thick concentrations of relatively pure ice that probably formed when the pole of Mars had wobbled in its axis. Mars is not stable like the Earth in keeping its axis tilted at 23 degrees. Mars is at like 25 degrees now and it could go to 45 degrees. If that occurred, all of the ice at the poles would be driven to the equator -- opposite what it is now -- because that would be the coldest spot.

And it looks like there could be sequestered water ice that's fairly pure and thick at areas between 35 and 45 degrees north latitude as well as areas in the southern latitudes at nearby elevations. Remember the south is super high in elevation and everybody wants as much atmosphere as they can get.

And so most of the locations there have been looked at are on the edge of the Argyre and Hellas impact basins, which are large impact basins in the south where the elevations get lower. Or [they're] at areas near the dichotomy boundary where the elevations are well below the geoid minus three kilometers or more and that looks like there are concentrations of this water ice.

Folks are starting to look at that and think about what you would do there. This is not like putting a straw down and pumping out liquid water. In one case it's locked up in the rock. You'd have to, I don't know, pulverize the rock and heat it up to drive the water off.

In the case of the ice, it's harder than concrete. It's not going to be easy to scrape or anything. It's not like you just poke a straw down and pump it out. So it's going to be hard to get to and hard to process and hard to create.

Now having said all that, there is suggestion that there could be a liquid ground water table at kilometers depth on Mars. There's no proof that exists but if there is enough water on Mars and you go down at the fractured space, you could imagine a ground water table like we have on the Earth but it's likely to be kilometers or more. And generally, drilling down kilometers is not something that's done remotely.

For any of you that know about drilling oil wells or anything on the Earth, it takes thousands of people and they're all watching it and monitoring it. It's not something you kind of do remotely.

So the big question is where are volatiles? How do you get them? What's the best way to get them? And then they also talk about "well okay, if this is the place we're going to set up shop, we need a flat, smooth, boring place we can land. We need interesting geology to go explore to find out whether life could have ever started on Mars early on," and that sort of thing.

So they talk about these exploration zones that could be tens or a hundred kilometers in diameter that have super highways to go get the resources and big solar panels and landing zones and habitat zones and all sorts of things like that.

Man: Thank you very much, Matt. I am guaranteed that your job is secure.

Matt Golombek: Okay. Well, I would say as soon as I get it wrong, I'm going to be dumped out. If I ever get it wrong, I'll be gone in an instant.

Man: Always welcome back to New Jersey. Thanks again.

Woman: Thank you very much, Matt. This was fascinating as always. We appreciate you spending some time with us today. And thank you everyone out there for joining us. We're going to take a little bit of a break now. Our next telecon will be on December 7th. And that will be The Universe of Learning -- NASA's Search for Water in the Universe.

So thank you all for joining us. Have a wonderful thanksgiving.

Man: You too. Thank you, Matthew.

Matt Golombek: Okay, bye everybody.

Woman: Thanks, Matthew.

END