Matthew Golombek

August 9, 2022

Erik M. Conway,
Interviewer

Q: This is Erik Conway. I'm talking to Matt Golombek about the InSight mission's landing site selection process, and I think it's August 8^{th} [2022].

Golombek: Ninth.

Q: It's the 9^{th}. Okay, it's August 9^{th}. See how out of date I am.

So, Matt, of course you've been our landing site guru at JPL now since Mars Pathfinder. Tell me how you got involved with the InSight mission process.

Golombek: So the PI of the mission is about my closest and earliest colleague at JPL. I actually knew him before I got here, because his advisor when he was a graduate student was my postdoc advisor, and we were working on similar things, namely the Tharsis region of Mars and how it got to be there. After I accepted the job here, after my postdoc, he was the first person I looked up. [laughs] And he was just finishing his postdoc or he was just starting it or something, I can't remember, but we're effectively the same age and we've been at JPL for within a few years of each other. I think he's got a few years on me. So we've been close colleagues forever.

I was involved in all of the precursor proposals that went before InSight that were to do geophysical observatories, and mostly it was a personal thing to help them out with site selection, about where to put these things down and what to do with them. So there were at least one or two proposals prior to InSight, and the first one was called GEMS. That was the first InSight proposal, which NASA insisted that the name get changed, because I guess there'd been some spacecraft already called GEMS.

So the deal we made, since this is mostly a geophysical mission and I'm a geologist, was that you still have to land the spacecraft, so you need to find a landing site, and I said, "Well, I can give you a landing site. You need a landing site, I'm your guy. [laughs] And let me be in charge of the geology portion of the mission, so let me lead the geology investigation, even though it's rather ancillary to the whole project and what it does."

So, yeah, I helped write the paragraph. There was one paragraph about landing sites in the GEMS proposal that got us to Phase A, and then I got pretty heavily involved in Phase A in terms of trying to determine where to land and how to minimize all the trade studies that typically happen if you have multiple landing sites in lots of different places. So there was a lot of legwork in the beginning of Phase A, and that culminated with a presentation at the Concept Study Report, which is the big review, the big giant NASA review where they come to, in this case, JPL, and everybody gets dressed up in jackets and ties, which normally, of course, I never do. [laughs] At Von Kármán, we all went up in front and sat. The landing site was one of those deals, because it's a hot-button ticket. Everybody knows you have to land, and everybody has an opinion. [laughs] So I've been pretty much involved from the very beginning of the entire project.

Q: As you said, there's one paragraph in the proposal, but it took a lot of legwork to get to that paragraph.

Golombek: Well, the first paragraph was—so at the very beginning, there were initial constraints based on latitude and on elevation, and the elevation had to be below minus-2 kilometers, and the latitude had to be pretty close to the equator. I can't remember exactly. Maybe 5 or 10 degrees north, and it was a pretty thin latitude band. If you just plot the elevations on Mars and you look, there's not a lot of Mars that's at that latitude range that's below that elevation.

And the paragraph in the original GEMS proposal just said "We know about the constraints. Here's an area called Elysium Planitia that meets those to first order." And I think we even picked a latitude and longitude that was in that band and said, "Well, we'll start looking here." And that was it. There was nothing more about the landing site in the original GEMS proposal.

Now, when it was selected for a Phase A study, along with two other Discovery missions, then we got more serious and said, "Okay, let's be specific. Where, in fact, can you?" And that's where we started doing a lot more legwork. So we knew from Phoenix that it was not what you call a rock-tolerant landing system, okay? [laughs] It's got three legs and it can accommodate anywhere from 35- to 45-centimeter-high rocks, which was better than Viking, but not as good as the MERs or Pathfinder, for sure. And we'd already gone through the Phoenix experience, where Phoenix started out and they said, "Well, we can land at Viking 2 with 20 percent rocks," and by the end of the mission, they didn't want any rocks anywhere. They wanted it like zero percent rocks. [laughs] They were so rock-hysterically-averse.

So we knew that rocks were an issue, and we knew from previous work with MER, areas that had high winds, which are never a good thing when you're on a parachute, because your whole spacecraft and parachute accommodate that, and you have to get rid of those winds somehow. So we looked around, and there were three areas that met the latitude and elevation constraints, and one was either at the very end of Valles Marineris, where it opens up and debouches into the Chryse Planitia, and that's in canyons, and there's a high rock abundance and you could never fit 130-kilometer ellipse in the canyon. It was just impossible.

Then there was an area near Isidis Planitia that also the remote sensing data suggested had high rock abundance and atmosphere storm tracks that went north and south across the equatorial region. So we said, "Well, that's not so good."

Then we looked at Elysium in a little more detail, and that was the area that eventually we zeroed in on.

An interesting tidbit was that in the very beginning of Phase A, some of the engineers at Lockheed Martin—because this is a Lockheed Martin spacecraft—felt that it could land at much higher elevations than the minus-2, and suggested that we actually go look in the Highlands for places to land. The JPL EDL engineers didn't agree with that. It didn't have enough margin for them, and there was a little bit of a fight going on between JPL and Lockheed Martin. [laughs] But that didn't stop us from go looking around the Highlands as well, and the trouble with the Highlands is there's all these big craters and you can't find a smooth, flat place that's big enough to stick your ellipse that doesn't have one of those craters in it. If it has a big crater, then it has slopes that are too high.

So we actually looked around the whole plant, but eventually we decided that there was this one area in western Elysium Planitia that had generally low rock abundance, met the elevation constraints, did not have high winds, and our initial mapping, we could put down about—I think we put down 16 sample ellipses and we looked at them and some of them had very low rock abundance in the remote sensing data, and so we made a decision right then, during Phase A, which is somewhat unusual, and said, "This is where we're going to land." So that there's only one place that we're now designing the power system, everything on the spacecraft, the thermal system, the whole spacecraft is now being built for this one place, and we were betting that out of that 16, one of those ellipses—we only need one [laughs]—one of those ellipses would pan out.

And the other interesting aspect about InSight was there were no science constraints on the landing site. It was just land someplace, because—well, you had to deploy the instruments, which means you needed relatively low rock abundance, smooth and flat, because the instruments didn't like rocks or slopes either, but, interestingly enough, you also wanted a place that had broken-up regolith down to 5 meters, so that your mole would have a chance to dig down to it. So we had sort of these semi-science constraints which were through the instruments, but no other science constraints, "I want to land on the delta," or, "I want to do this or that or the other." No, just land, a place where you can put your instruments out, we're going to be happy. So that simplified things. I didn't have to talk to any scientist outside of myself. [laughs] It was just find a place that met the requirements, and that was the initial part.

We recognized one of the truly interesting aspects about the InSight selection was that the area that met the constraints was due south of MSL, Curiosity, and on the exact same orbit track as Odyssey and MRO, and that's a problem because those are servicing MSL for telecon, and there are strict requirements about what you can do with a spacecraft on the same orbit that you're servicing telecon. And it took almost a year to negotiate with MRO to figure out that we could take images of the landing site in high resolution, HiRISE dominantly because that's the highest resolution, and CTX, because we hadn't mapped these. We needed high-resolution images to be able to come to some idea of what the hazards were.

And it was very—I mean, it literally took a year to work through all of Lockheed Martin engineers about what could be done and what couldn't, and they came up with this suite of requirements of if you were within so many degrees of off-nadir to MSL, you could go off a little bit more to image the area, because you have to roll the spacecraft target to camera.

What was even more interesting about this was that—so HiRISE took almost no pictures initially, because we had to wait for all of this to be worked out, but there was one human on the Earth who actually knew exactly how to do this, and his name was Mike Malin. He must have known something about how Lockheed does this, and without telling anybody, he got 90 percent coverage of that area in CTX before HiRISE ever really started imaging. [laughs]

Q: So he has to have just queued that stuff up and just didn't tell anyone.

Golombek: We sent him a note. We said, "Here's where we're looking." We gave him this big box that was, I don't know, it was 10 degrees across, and he just started snapping pictures. We saw them. They were coming in. We're looking on the MRO server, and here are all these perfect pictures. [laughs] And they weren't even released to anybody yet, because Malin doesn't release anything until he has to. [laughs]

So we had to get into the inner sanctum of MRO to see these images, and that turned out to be a huge boon, because having 6 meters per pixel, we could identify smooth and flat, even at that scale, areas that were better than other areas, and we got maybe a dozen HiRISE samples, just enough that targeted the different terrains, so we mapped out the whole area in terms of terrains at 6 meters per pixel, and then we got samples in HiRISE. You could quickly see which terrains were smooth and flat and relatively rock-free, and which ones were not, and that was an *enormous* benefit, *huge* benefit that went around.

So I think by the time of the Concept Study Report, we probably had five or six HiRISE images, and we had already 90 percent CTX coverage, and that was enough to identify what we call the smooth plains, which was the super smooth and generally rock-free areas that we wound up settling on.

Then we did the standard thing of once a year, basically, for the development period, we had a down selection, so went from sixteen to four, which were preferentially in the northern part in those smooth plains, and then we narrowed it down to maybe two or three, and then at the third year, we selected the site. I think we might have had a somewhat provisional site. And by the end, we had gotten, oh, probably 70 percent of the ellipse, 130-by-25, *big* chunk was almost full of HiRISE images, so we could map all the big rocks and see what the rock abundance was, we could measure the slopes, so we had a really good idea what things were going on. Then I guess there was Planetary Protection Review, that there's no water there, which there wasn't, and some other things like that.

So, yeah, it was a wild ride, and it was so much fun. InSight—you must know, having listened to people tell you about projects at JPL, that projects have personalities.

Q: Mm-hmm.

Golombek: And some projects are wonderful to work in and you feel like you're appreciated and you're working as part of a team and there's real camaraderie, and it's a wonderful experience, and InSight was that always. We always said that Bruce's number one requirement was that there be no jerkoffs on the team. [laughter] And somehow he selected everybody on the team, were really good people, and it was a pleasure to work on the project and with everyone there.

Q: That's great, great. Sounds like it was a lot of fun.

Golombek: It was.

Q: So you kind of talked about the general process of site selection, but who else was involved? I know you didn't have the big open community meetings you had on MSL and Mars 2020, but what did you have?

Golombek: Yeah. So we had the project science team, and because site selection was part of the development activity, at every major review there was a site selection presentation that showed where we were. The engineering, the Standing Review Board, was fully aware of where we were with site selection, so the entire engineering team knew what was happening, as well as the review board on the engineering side.

Then within the landing site selection itself, we had a Council of Terrains and a Council of Atmospheres, which I don't think we quite called—I'm trying to think. With MER, we had the equivalent, but we didn't call it that. And at Phoenix, I don't think we had anything called that name, because it was sort of internal. But we named it Council of Terrains and a Council of Atmospheres for MSL. Devon Kipp, thought that was a way to make it sound like we were important, you know. [laughs]

And we did the same selection of investigators from the science community via an open, competed, request for proposals to answer specific questions that were relevant to the selection, as we did for MSL, which had happened before, right? Is that right?

Q: It happened before InSight, yes.

Golombek: Yes, okay, it did. Yes. I was thinking back to Phoenix. Right. So MSL had a Council of Terrains and a Council of Atmospheres, so we did the same for InSight. The Council of Terrains included everyone that was working on specific data products that were important for the selection, so we had the rock mappers, we had the thermal inertia people looking at the thermophysical properties, we had the SHARAD people to look for subsurface reflections. That was important for planetary protection. So that was radar.

We had DEM producers, so the USGS at Flagstaff again produced the Digital Elevation Models from both the stereo HiRISE and CTX. We had an HRSC DEM producers from DLR in Germany, and they all formed the Council of Terrains, and that was co-chaired by myself and Devon Kipp, who was the lead engineer on the landing site side. So we had biweekly meetings and summarized what we were doing and making sure we were staying with the project schedule and all that.

In addition, there was a Council of Atmospheres that was run by David Kass, so he was the chair, and there was a selection of five or six members of the atmospheric community to provide specific data products, so there were things like—InSight was an interesting mission because it was arriving at dust storm season. So you don't get to choose when you get to Mars, right? If you're on a Type 1 or 2 trajectory, you get there at whatever time the orbit is with respect to the Earth, and some of those times, it's southern spring/summer, which is dust storm season, and you don't have a choice. You're going to arrive at that time. And when you're planning the mission, you don't know what the atmosphere's going to be when you get there. You don't know if it's going to be clear. It's going to be a raging dust storm, it's going to be a regional dust storm or decaying dust storm.

So David had to characterize four atmospheres beforehand, and then as the spacecraft was on its way, we had MRO and Odyssey, and we'd be getting weekly updates about what the status of the atmosphere was, so that prior to arrival, we would select the correct one that we had already worked on and given pressure and temperature density curves to land in, and we would choose the EDL routine that would best match that atmosphere. So the atmosphere, if it's a dust storm, you get more atmosphere higher up, but the area with maximum g-loads on the spacecraft during entry and descent is further down, and it affects the whole atmosphere, so the whole EDL trajectory changes a little bit, and you need to fine-tune the EDL algorithm to be expecting that.

Q: Right.

Golombek: So David had to characterize four different atmospheres, which hadn't been done previously. We always knew that we were in low dust storm season or which part of the season, and you really only had to do one, but this one was interesting because you were arriving at dust storm season.

Q: So how did you choose these team members? Were they competed?

Golombek: Yes. So we did it the same way we did for MSL. We had a Critical Data Products Initiative, which for MSL was funded by the Mars Program Office, and it made the case that these data products were critical for EDL, and we wrote an RFP, Request for Proposal, from JPL, not from NASA. We, of course, had to get NASA approval. And we wrote down all the things we wanted, and we were super specific. It's not like a NASA AO that says "Learn about Mars." Well, there's a million ways to learn about Mars, okay? This was "We need Digital Elevation Maps at this resolution, at this scale," yadda, yadda. I mean, it was super specific about what we needed.

Then they went through review. We had a full review panel, and the best one was selected, and then we went into negotiation with them for a specific contract to provide those things, and those members then became members of the Council of Atmospheres and the Council of Terrains.

Q: Okay. So was MSL the first time you'd competed those? Other times, you just picked who was going to do it?

Golombek: Yeah. So MSL was the first time we had an open call. MER, we just had members of the science team that helped out with certain aspects. Phoenix—oh, Phoenix had one. It probably had a call too. I remember that.

Q: Oh, okay.

Golombek: So there may have been a call there, but I don't think we called it Council of Terrains and Council of Atmospheres, but it was similar. Then by that time, we were in the swing of it. So MSL was like that. Then we've done it ever since. The interesting aspect is the Mars Program Office refused to pay for it because it was a Discovery mission.

Q: Right.

Golombek: It was using all Mars Program data, and there was an agreement, of course, to collect data from the Mars Program to help with InSight. [laughs] But, anyway, that's politics.

Q: They wanted it to come out of the project budget.

Golombek: Yeah, and that's what happened. Right. Then, of course, at some point you're going to ask about what happened when we didn't make the launch date, right?

Q: Yeah. [laughs] Well, yeah, sure. Why not now?

Golombek: [laughs] Since I brought it up.

Q: Yeah.

Golombek: So we were on target, “we” now being the Council of Terrains and the Council of Atmospheres. We were ready. We selected in October, late September of ’16, I guess? Yes, ’16. Right. We landed in ’18, right? Yes. I think that’s right. Yeah, that’s right.

So we had selected the landing site. We’d gone through all the internal reviews. We had gone through an independent peer review that Gentry—Gentry’s reviewed every selection I’ve ever done. [laughs] We’re like comrades now. He knows me and I know him. [laughs] And we had a full external review of the landing site, and we went through planetary protection review in late October, and we were ready. We had selected.

The project declared—it was just about Christmas of that year—that the SEIS was not ready. It couldn’t keep a vacuum in the instrument, and they scrubbed the launch. I distinctly remember December was a quiet month, and we knew this was brewing and it might be happening, and I started to write the InSight landing site selection paper, the one I sent you, and I’m writing it and I’m going, “I don’t know if this is going to be a mission or not.” [laughs] A landing site selection, if you don’t have a mission, is an academic exercise, right? I don’t do academic landing site selections. [laughs] It’s got to be a real mission for me to get involved. I kept wondering, while I’m writing this massive paper, whether it was ever going to get submitted or not. [laughs]

So, anyway, I think it was just around—it was in December, and I don’t remember if it was at Christmas or right after or a little before, but they said, “We’re not ready. We can’t launch.” And I had just about a heart attack, because the place that we selected only had elevations that were slightly below minus-2.5 kilometers elevation, and there was nothing lower, and we hadn’t done any work on any other landing sites. And at that time, I didn’t know what the atmosphere was like for the next opportunity, which was 2018, right? Yes. So twenty-six months later. And you arrive, because the atmospheric pressure changes by 25 percent, and you don't get to choose which season you arrive at, you get whatever atmosphere Mars has at that time. You don't get to pick it, right? If you did, you'd always pick the maximum atmosphere, and that would help your EDL a lot, right?

And I'm going, "We found a landing site that meets the constraints. I don't have any place I know to go that's a half a kilometer lower. There's no win here. That's only a loss. If there's a change in the atmospheric pressure and if we need to search for someplace lower to give us more time for EDL, it means a whole new selection activity, and nobody wants that, including me." [laughs] So for several weeks, I'm screaming. I was the person screaming about "Armageddon is coming!"

Well, it turned out that in 2016, we were just before the maximum atmospheric pressure, and at 2018, we were on the other side of that maximum atmospheric pressure at almost exactly the same pressure as we were in '16. So there was no change. We just said, "Okay, we're done. We selected the site. We got nothing else to do." Actually, we did continue to image the site with HiRISE. By the end of that two years, we mostly—yeah, we filled in as much of the ellipse as we could, we continued to map out the rocks, and then we did the full EDL after we'd done all that for the '18 one. But that was just kind of sweeping up.

So, yeah, so that was a bit of an uncertain time. It turned out it only took the atmospheric guys about a week to figure that out, and then it was like, okay, no change in the landing site, so we kept imaging it, and I think we retooled the EDL safety. We had very specific software. For any area that we mapped out, we had a hazard map that says what the probability of success would be if you landed at that particular part of the map, and you could then take a full Monte

Carlo simulation of all the places within that ellipse you might land, tally them up, and you get a single number, which is your probability of success for that ellipse.

And that, of course, was important for as you're arriving at the planet, you never quite exactly hit the spot, right? You're coming in at a particular place and you might be slightly off, and you have to figure out which TCM (Trajectory Correction Maneuver) to do to get as close as you can. You never quite exactly hit the center of the spot that you—the ellipse that you map beforehand, but usually by then the ellipse is smaller because you're so much closer to the planet and you're already starting to feel the gravity. So your ellipse is usually pretty close to where it is, but there's this whole drill that occurs during approach, where you're calculating out, you know, we hit the center point, we map it out, we calculate the numbers, we report it to the project, and that's part of the decision tree for a TCM. So we did all that, yeah.

Q: We already mentioned that you didn't have open community meetings. So why not?

Golombek: So, technically, for a PI-directed mission, the PI is the selector of the landing site.

Q: And not NASA.

Golombek: Not NASA. So Bruce actually, as the PI of InSight, had the—and part of that goes to the initial proposal and the Concept Study Report after Phase A was quite specific about where we were landing and what we were doing. So the acceptance of that proposal is effectively the acceptance of that site with the details of that. In reality, the process is no different than if it's not. You still have to show it to Headquarters and explain your reasoning and so on and so forth, but it was not as big an ordeal as what it typically is for a non-competed mission. Especially in those situations, you have full community input, you have the big open workshops and everybody gets their say, and NASA really looks at those carefully because they want to make sure that you haven't not listened to anybody and you've done things completely aboveboard and in an open a way as possible. So none of that really mattered for InSight. We still report to Headquarters about our decision and why we selected it, but it was fairly pro forma. There wasn't a whole lot more to it.

The Planetary Protection Review was more specific. That had to do with specific—you know, you could not go to an area with water or ice within 5 meters of the surface, and there were other very specific planetary protection requirements on the landing site. Those were done in 2015, so we didn't have to redo them.

Q: I think you had four site selection team meetings, and the question I wrote was, what was the focus of each, or did they not really have focus?

Golombek: Each one had a specific—there was a goal at the end, and the meetings, again, they were more generally Council of Terrains- and project-specific, so they were much, much smaller, and for the most part, it was mostly the project listening to us; that is, the Council of Terrains telling the project our conclusion.

So at the first one, we started out with sixteen. "Here's the four that we wish to go forward with." And that was interesting. That was done at the first science team meeting, which was at IPGP in Paris, and a big chunk of the science team showed up for it, and we had a full day of agenda. I remember I broke all the rules in France. I started a meeting at 8:30 in the morning, which you don’t do in France, right? You don’t start anything before 9:00. [laughs] That was a big faux pas. But we went till 4:30 with presentations on all aspects of the mission, and all of these scientists were listening to us, and they never came back for another one. That was it. [laughs] It was like, “Okay, they know what they’re doing. Leave ‘em alone.” [laughs] So that was number one.

Number two was probably narrowing it down to maybe two, something like that. I can’t remember exactly. I’d have to go look at my notes again.

The third one was “Here’s pretty much the site we’re selecting.”

The fourth one must have been after—I’ve forgotten the details.

But, anyway, each one had a specific goal and end point. So the first one was dominantly to the science team. All the subsequent ones were to mostly to the project. Then the last one was to the peer review panel and the project. That was the official selection by the project. Again, that was done in probably September ’16, I think. Yeah.

Q: Somewhat broader question this time. So what new tools have become available for site selection, I mean, since you started with MPF or maybe you can start with MER. It doesn’t matter. But what would you say are kind of the new tools and what are the most significant?

Golombek: Yeah, that’s the interesting aspect, because with InSight, we figured that we knew what we were doing because we had done MSL, and MSL was the—you know, we mapped all the rocks, we mapped all the slopes, we had done everything that was humanly possible to do, and we thought that we had reached—or at least I personally thought that we knew all the tools and that there weren’t going to be any surprises. And what’s interesting is even if you do the same task again a second time, there's always surprises. [laughs] And the tools, you develop newer tools that do the job better than you did it the first time.

So, an example, MSL had pretty much complete stereo HiRISE data and DEMs across the ellipse. There may have been one or two little areas that didn't have it. But when we tried to put those DEMs together, they all had seams at the edge between one DEM and the other, and getting rid of those seams was a devil of a time, because each stereo pairs its own little universe and you try to map them down on the same surface, but there's always going to be slight tilts and adjustments. So we never really figured out a particularly good way to deal with that for MSL.

For InSight, we had almost complete coverage from CTX, which is the broader scale, and we just had samples at HiRISE, but the CTX joints had to be put together, and during MSL, we hadn't actually developed a really good method to fully do the CTX DEM. So that was kind of developed a lot during InSight, and there we came up with a much more sophisticated way to actually merge those DEMs side by side so that you wouldn't have these cliffs at the edge that would, of course, always trigger a crash in the spacecraft, because that's like coming down on a cliff, which is never a good thing. So that was one thing.

We'd bin things in 150-by-150-meter boxes, so we had a slope distribution within that box and we had a rock distribution within that box and we calculated a probability of successive landing on that slope and rock distribution for each of those 150 meters throughout this big giant long ellipse, and that set the stage for—at some point, you may ask me about what we did for Perseverance in 2020—but that set the stage for a level of site selection specificity that no one had ever imaged or believed could be done.

So in that situation, is it okay if we go to that a little bit here? It's a little bit off topic, so it's kind of up to you.

Q: Oh, sure.

Golombek: So for 2020, it's landing in a very small circle which is—I thought it was 8 or 10 kilometers. It wasn't even much of an ellipse; it was almost a circle. Let's call it 10 kilometers. So it's the smallest circle ever, and we had the ability to do what's called TRN, Terrain Relative Navigation, so it can figure out where it's coming down, and it had a divert capability that allowed it to go perpendicular to the entry direction by several hundred meters in either direction. So it could pick any place, either north or south—well, in this case, it would have been north, yeah, mostly north and south—from the entry trajectory for the projected landing point, and it could target the safest place it could find that it could divert to.

It had no hazard avoidance, so hazard avoidance we typically call where it's seeing what's down beneath it as it's coming down, and it reacts to that and avoids bad things. TRN doesn't do that. It takes a map that you already produced that says where the good things and the bad things are, and then it goes to the place that you said were good. Well, think about that for a second. Now the onus is on us geologists to tell them where the safest place is. It's not just "Here's the ellipse and here's where you can move the whole ellipse around and you're going to get this amalgam within it." We need to find the safest places *within* that ellipse. And they targeted a ellipse that you never, ever would have targeted without TRN. There's cliff faces in it! [laughs] You would *never*—that's not smooth and flat and boring. It's the antithesis of it.

So by the time we got to the end, we had to produce maps that would allow the spacecraft to do TRN, in other words, the best registered and corrected base maps ever produced on Mars, so that TRN could do its job. Well, now, again, that's on me, right? That's me. *And* I need a hazard map at meter scale that said every meter on that place was safe or not safe, and what percentage safe or not safe, and if I screwed up and said it was safe, and they land there and it's not, then whose head's gonna roll, right? It's not the engineers doing hazard avoidance. It's Golombek's, because he didn't get it right. [laughs]

So now we took this ellipse, and 90 percent of it sucked. Ninety percent of it had 10 percent or more hazard. So we landed in 8 percent of that ellipse we said was safe, and we did horrendous things to figure out it was safe. We had individual interns looking at each spot [laughs] that didn't have rock abundance, and all sorts of things that had never, ever been done before to get to that. I doubt we could have gotten there if we hadn't had that InSight as that intermediate step beyond what we did for MSL. A lot of tools were the same. We had the rock detection software that we used to find the rocks and slopes and all those similar sorts of things, but it was taken to the nth degree and required a level of exactitude that no one had ever done before. So that was, yeah, truly beyond. And don't even ask me about sample return, because those ellipses are 120 meters! [laughs]

Q: Jeez. [laughs]

Golombek: A hundred and twenty meters, which you would say, "Oh, that's great!" But now I need to find 120 meters and I need to find a place where you can't even see the rocks in the HiRISE. They're too small. [laughs] So, anyway, it's not getting easier.

Q: No, despite the fact that tool—so the tool development is actually making things harder to some degree.

Golombek: Or the requirements, and pushing the requirements to this nth degree, is making things more difficult. So I'd say a lot of the basic tools haven't changed all that much, so stereogrammetry, getting stereo DEMs from them, we have state of the art, we know how to do that. We do it pretty well. There's a few tweaks here and there, some of the things about getting the boundary of the DEMs together and smoothing those out. The rock abundance, we did all sorts of things beyond what we had done previously to try to make sure that there were *no* rocks of any size, so we wound up running it and not even knowing if they were real rocks. We just wanted places where there were no detections anywhere by any of them, even if we weren't sure about the detections. [laughs] It kind of pushes you to that. So a lot of tools were pretty similar, but sort of pushing it to the nth degree made it—you had to be more careful in what you thought you knew and what you didn't know, in terms of the data.

Q: You had, I guess, one new tool, is the orbiting radars. How did those factor into this? I guess there are radars in MRO and Mars Express, right?

Golombek: Yeah. So Mars Express didn't help much. That's mostly far deeper.

Q: Oh, I see. Okay.

Golombek: Yeah. So we were looking at SHARAD, which is the shallow. SHARAD is not actually designed for looking at the near surface. It's actually better looking at tens to hundreds of meters below the surface. But there was a planetary protection requirement that there be no subsurface interfaces that—I guess they were concerned about trapping water at shallow levels, and we thought SHARAD was our best way to see if there were any subsurface reflectors that could be of concern, and we used it mostly—we did it for two reasons. One is, could we get any idea about what the physical materials were in the top few meters, and to see if there was any evidence of subsurface reflectors that might influence the planetary protection.

And we also had them look at the—so we had a C-band radar on InSight, and we wanted to look at the Earth-based radar, because it had a wavelength that was near the C-band, just to make sure we had a radar reflective surface. So we had both of those in that contract for the radar investigation, and that turned out quite well. Those guys did a smash-up job and wrote a bunch of papers. And they saw a few reflectors, but not much, so it strengthened our case for the planetary protection, and it gave us just a wee bit more—we were more certain that we would have a radar reflective surface. There was nothing unusual about the radar properties. So you clearly want to have the radar detector working on your spacecraft as you're coming down. [laughs]

Q: Yeah, yeah. We're about out of time. Is there anything important that we should talk about?

Golombek: You got most of it, yeah.

Q: Okay, great. Thanks for your time.

Golombek: Always, and continue to do all that good stuff you do, because I think it's really good that JPL has somebody like you, because things disappear when you get done with them, and they're gone. People are gone.

Q: Yeah, corporate knowledge vanishes.

Golombek: Yeah, yeah, yeah.

Q: All right. Great to talk to you, Matt. Take care.

[End of interview]