SESSION ONE

earth

NASA Image/Renee Bouchard

Hunting Microbial Communities
in Dry Antarctic Valley Lakes

I'm going to talk about my experiences in both the Antarctic and in the Arctic, and I'll focus more on the Antarctic; right now it's a little bit more exciting.

We started back in the late '70s, working at some of the lakes that are in the dry valleys. And this is one of the largest ice-free regions that exist there. There is a series of lakes with very, very thick ice cover, and nobody had ever probed these lake before, and looked at them in depth, other than just taking some drills and popping small holes in them, and taking a soda straw approach. We wanted to look at them in a little different fashion.

As I started thinking about this symposium, I started categorizing the kinds of risks that we were involved with over this period of time. And for us it really came down to mission risk, the success of our expedition in general, and personal risk, which I divide into transportation to and from the research site.

We usually take large ski aircraft to get down to McMurdo Sound, and then to get up north we use Twin Otters. And then to get into our remote field sites, we'll take helicopters, or, in some cases, on some of the expeditions we've taken Soviet icebreakers around the

Dale Andersen
Astrobiologist, Antarctic/Arctic Researcher, SETI Institute

Dale Andersen has made almost 1,000 dives beneath the thick ice of lakes and oceans. He helped develop a number of techniques needed to explore the lakes of the McMurdo Dry Valleys, including both human and robotic exploration (using the first remotely operated vehicle—ROV—in the Antarctic). In 1991–92, as a member of the Exobiology Implementation Team under the auspices of the U.S./Soviet Joint Working Group for Space Biology and Medicine, he led the U.S. field team on a six-month joint U.S./Soviet expedition to the Bunger Hills, Antarctica. Currently, Andersen (along with Wayne Pollard at McGill University and others) has been studying perennial springs and ice-covered lakes in the Canadian High Arctic.

OPENING PHOTO:
Scott Tyler (UNR) and Bob Wharton (Idaho State) pull Dale Andersen from the water at Lake Hoare, Taylor Valley, Antarctica.
(Image copyright Dale Andersen)

continent, and then taken helicopters inland and have been dropped off. We don't have much control over what happens during those times. We're there for the ride and, hopefully, we make it. And obviously sometimes the weather and the conditions can get pretty bad along those lines as well.

Then, we actually live and work in these remote environments. We have to learn how to do both of those things—we have to learn how to live effectively. That takes quite a bit of effort, if you're going to spend lengthy periods of time in these remote settings.

And, then, it's not just living, but you also have to accomplish some work. Developing the skills that require you to do that work is also something that

> NOW WHY DID WE GO TO THESE PLACES? WE DID HAVE SOME OF THE PROGRAM MANAGERS WHO WERE ASSOCIATED WITH THE PROJECT TELL US . . . THAT WE WERE JUST GOING TO FIND A BUNCH OF ROCKS, AND THAT WE'D WASTED EVERYBODY'S TIME AND MONEY. WHAT WE FOUND WAS A REALLY LUSH, LUXURIANT, MICROBIAL ECOSYSTEM THAT HAD NEVER BEEN SEEN BEFORE.

we've had to overcome over the years. And then there is also the scientific credibility from a personal standpoint. We can put all the effort into going to these regions to do the studies, and if we get there, and the weather is too bad, or if the equipment doesn't work, or we've forgotten something really important, it's just too bad. And, then, we come back with nothing but our hands in our pockets, and say, well, we had some good times. And, then, the program managers yell at us and don't give us any more money. The ultimate currency would be scientific publications. And if you don't get those scientific publications, then you don't get to go back down and do that kind of work again.

And, then, there is the family setting. It's always difficult to be away for these long periods of time, especially when you are in a hostile environment. Your family doesn't know from a day-to-day perspective if you are just wandering around in the snow or if you're drowning underwater or whatever is going on. So that's one of those long arms that's always reaching out to you.

Over time, we've really had poor communication. And it's something that has only changed in the last five or six years. Now we can pretty much have global communication on an instantaneous basis. It used to be that we just didn't have any; it took weeks for something to get through.

Then there's risk to others, or assigned risk. If I'm a leader on an expedition, and I can send people out to do work, my level of risk assessment is different than what I would expect for somebody else, depending on their level of training or what their experience is.

For a program manager, that perspective might be completely different. It's different if they've never been in a field situation similar to that, or if they have any kind of mountaineering or diving experience, or some other kind of experience that they understand personal risk from that standpoint. But it's valuable to have experienced people in those positions.

Again, there are different kinds of transportation risks that I've been involved with: large aircraft, large icebreakers, even Hägglund track vehicles that we can take across the ice shelves among the continental ice, and helicopters. All of those have different types of risk associated with them. And then in some cases, like the Hägglund track vehicles, we drive those personally, so then we have to be able to understand how to drive a vehicle like that, keep it out of crevasses, and understand what to do when it breaks down, which it invariably will.

In the dry valleys, a lot of the ice is not in the valley itself. You have the continental ice flowing through, and you have a barrier that essentially keeps a lot of this from going into the valley. The evaporation highly exceeds the precipitation, so it's quite dry. But some of the small features in between the glaciers are actually lakes. One example is Lake Hoare, where we spent quite a bit of time studying the lake ecosystem itself. Now these lakes are permanently covered in ice, and the ice thickness ranges from about 3 to 4 meters up to 6 meters. In earlier years, about the only way people studied these lakes was to go out and drill a small hole through it, and then take water samples and take some other measurements. But nobody ever really asked the question, what's going on at the bottom? Because most people thought the light levels were so low that there wouldn't be anything on the bottom.

Well, a few years later, we decided to open these lakes up with a bigger hole so that we could go down and look. I guess, for some reason, we weren't smart enough, or at that time underwater cameras were still a hassle to get a hold of, and it was just as easy to put us in the water as it was to take a little camera and drop it down the hole. But that wouldn't have had nearly the fun factor, either, I guess.

We developed a system that allowed us to melt holes through this thick ice. Essentially, we take a copper coil and just put hot antifreeze solution through it, let it melt down the ice. You can see that we can move in and out of that ice cover, as we're melting it. It's like a tunnel, of course, a water tunnel. Then we suit up and we jump in. Originally, we started out in wet suits and double hose regulators, which is kind of ancient history. Over the years, that was obviously not the best solution, because you've got to deal with a really cold wet suit once you get out of it. If it's minus 30, it's not too comfortable to take a wet suit off in those conditions. You can see that we're on tether, because once you go in, you've got one way in and one way out.

A dive hole being "cut" through the ice at Lake Hoare, Taylor Valley, Antarctica. (Image copyright Dale Andersen)

Now why did we go to these places? That to me was the biggest payoff. We did have some of the program managers who were

associated with the project tell us, just before we were getting ready to go in for the first time, that we were just going to find a bunch of rocks, and that we'd wasted everybody's time and money. What we found was a really lush, luxuriant, microbial ecosystem that had never been seen before. And as it turns out, these tunnels that we make through the ice are just like tunnels back through time, 600 million years to 3.5 billion years ago. This gives us a glimpse of early Earth, and, perhaps, of early Mars. If lakes existed on Mars, they would possibly have been ice-covered, and possibly have microbial communities similar to what we see in the dry valley. These kinds of microbial mass communities are very, very prolific.

Our work there is very dependent upon the training that we received. We have to be very safe. We're diving in extremely remote areas where we don't have the opportunity—at least, at that time, in this particular area, we didn't have the opportunity—to get back to a recompression chamber. The closest one would have been in New Zealand, and that's, of course, after a helicopter possibly came out, and picked you up, and dragged you back to McMurdo, and put you on a C-141 Starlifter back to New Zealand.

When we were in other situations, we didn't have that option at all. The nearest chamber was probably several months away. And we worked everywhere from about 40 meters up to the water columns. We have to be very, very careful about the dives that we go on, and the kind of diving that we're doing. That one tether that takes you back to the surface is so very important. So it's kind of like "follow the light." But it's actually very fun diving. It's very exciting to go into these lakes.

We also started a program a number of years ago. Because we can only go so far out on our leash underwater, we really are restricted to the amount of material we can see. So we started a telepresence project where we started using remotely operated vehicles—actually Sylvia Earle loaned us the first ROV [Remotely Operated Vehicle] that was used down in the Antarctic in one of these lakes. A lot of the algorithms that we used for one of our ROVs was actually utilized later on the Mars Pathfinder. Some of guys in the Intelligent Mechanisms Group at Ames worked very closely with us on that. Anyway, that was a very good means of getting out and away from that dive hole, and getting into working with other communities. We also had to learn to operate this kind of equipment in those environments.

Now we just don't follow the microbial communities underwater. We also follow them wherever we can find them. That includes on top of the glaciers. We then have to pick up ice climbing skills and some general mountaineering skills when we want to go up into the alpine areas. So, it's a real skill mix to work in these kinds of regions.

In 1991–1992, I had the opportunity, along with Jim Rice who is here in the audience and Peter Dorn who is in Chicago, Illinois, to go to the Bunger Hills, another ice-free area in the Antarctic, with the Soviets. That was a joint expedition between our two space programs through the Space Medicine and Biology Working Group, and it was part of the Exobiology Implementation Team that allowed us to get together with their exobiologists.

Three of us joined eight Russians. We traveled for two months around the Antarctic continent by icebreaker. We got dropped off by helicopter for the next four-and-a-half months in extremely remote settings with quite a few cultural and language barriers. To be honest, the expedition took place at the very last minute because of the way programmatics worked and the way permissions go, and because the dialogue between the Soviets and the U.S. at the time was kind of slow. We didn't find out that we were actually going until four weeks before we left, so we had to buy everything, ship everything, and get everything down to South America. Hopefully, it was all there when we got there. We actually didn't open up our boxes until we, literally, got to the Bunger Hills and the last helicopter left. It was a pretty quaint setting. We spent some time in some of the huts that they had there, but we also spent quite a few months sleeping in tents on the ground in the rocks. There was a great deal of wind. This is an area that is prone to katabatics.

So we had quite a few difficulties while we were there, but we also had to accomplish some work. All in all, it was a very successful mission, both scientifically and culturally. It was culturally enriching to all of us, and it showed, at that time, even though it wasn't a space project per se, the two space programs were working closely together in an isolated, Mars-analogue environment.

More recently I have shifted poles, and we are now working in the Canadian high arctic. The setting is not altogether that different. It is very glaciated. There are large Alpine glaciers and outlet glaciers, along with large ice sheets. We're studying a series of perennial springs in this region. These are the highest latitude perennial springs in the world, along with those over in Svalbard. This is a great Mars analogue. There may have been springs on Mars coming up through thick, continuous permafrost. This is where we would go to see these. Again, this is a very remote setting to which we take Twin Otters and helicopters, are dropped off and left for a few weeks or months. It's a little shorter logistics train up to the Arctic, so we can get back and forth much easier. Nevertheless, while we're there, we are actually a little more isolated, at times, than we are in the McMurdo dry valley area. ■

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NASA Image/Renee Bouchard

High-Altitude Mountaineering

I've been climbing now for 27 years, and, hopefully, I've done it the right way. I started by climbing small peaks and then aspired to climb higher and higher peaks. As I was going higher, I eventually realized that what I liked about mountaineering was the extreme challenge and how difficult it was and, also, the beauty of climbing these mountains without oxygen—the pure way, the hard way. I had probably a difficult start, though, in my career, being raised in the great mountaineering state of Illinois. But it was in high school that I was reading adventure books: Amundsen, Scott, *Endurance*, and books like that. I came across a story written in 1950—*Annapurna*, and it details the first ascent of an 8,000-meter peak. There are fourteen 8,000-meter peaks in the world, roughly 26,000 feet and above. In 1950, a French team climbed this peak called Annapurna. They succeeded, and it is a very amazing story. It inspired me to start climbing mountains.

The first thing I had to do, obviously, was to get out of Illinois, and I chose to move to Seattle. My other goal in life was to become a veterinarian, so I studied veterinary medicine in the Seattle area. I started climbing voraciously and learned from people who were very experienced, very conservative, and willing to teach me their craft. Eventually, I landed a

Ed Viesturs
American High-Altitude Mountaineer

Ed Viesturs is America's leading high altitude mountaineer, having climbed many of the world's most challenging summits, including ascending Mount Everest five times. He holds this record with one other person. Viesturs is the only American and one of five people to climb the six highest peaks in the world—all without supplemental oxygen. He is currently on a quest to climb all 14 of the world's highest mountains (above 8,000 meters) without the use of supplemental oxygen. He has successfully climbed 12 to date.

OPENING PHOTO:
This image featuring Mt. Everest and Makalu was taken by an Expedition 8 crewmember on the International Space Station (ISS).
(NASA Image # ISS008-E-13304)

job guiding on Mount Rainier, 14,400 feet, which I have now climbed 192 times. Most of those times were as a guide.

I truly believe that my safety and success in the Himalayas is because of my guiding experience, because, as a guide you always have rather inexperienced clients in tow. You are responsible for them. You always have to be evaluating risk and always asking yourself, if this happens, how do I get out of that? So you are always trying to think ahead, or, at least, not waiting until something were to happen. I truly think this has helped me a lot in the Himalayas.

As I was guiding and climbing higher and higher peaks, I started dreaming big. Obviously, the highest peak you can dream of is Mount Everest at 29,035 feet. I thought that if one day I had the chance to go there, it would be an amazing thing. On the summit there is one-third the amount of oxygen that there is here at sea level. To date, almost 2,000 people have stood on the summit of Mount Everest. The kind of clothing that we wear is very lightweight. It's very technical. The boots are thermoplastic. There is foam insulation. The fabrics we use are single-layer GORE-TEX®, breathable, waterproof, and these products insulate us, but we still have to move to create body heat. We don't have any internal heat source other than our bodies. Basically, these products do not help us climb the mountain, but they make it safer. We climb faster and more efficiently.

Most people that climb Everest—I'd say 95 to 98 percent of the people that climb Everest—use supplemental oxygen. Even with supplemental oxygen, it is very difficult to climb this mountain, because the oxygen is mixing with ambient air, and you are only really reducing your relative altitude a couple thousand feet. It is still very difficult, but I decided long ago that if I ever had the chance to go to Everest, or one of the other 8,000-meter peaks, I would not use oxygen to climb these mountains. I thought it would be more interesting to challenge myself and to see if *maybe* I could get to the summit, rather than guaranteeing myself getting to the summit. So, that is a rule that I made long ago and something I've lived by.

I had my first chance to go to Mount Everest in 1987. We were climbing the North Face. With my partner, Eric Simonson, we were part of a large team of about 10 climbers, and it takes 2 months of climbing, setting up a series of 4 camps, and carrying loads to just get into position to go to the summit. In the end, if you can get one or two people from that team to the summit, then that is teamwork, and that's a success. So, Eric and I were making the final dash to hopefully get to the summit. I was climbing without oxygen the last 300 vertical feet of the summit ridge to the top of the world. It was kind of late in the day, and the weather was changing. Eric, rather conservative, as am I—we were looking at the top, thinking that we could probably get ourselves to the summit, but we probably wouldn't get ourselves down. For both of us, that seemed to be a huge decision-making factor. I have always felt that climbing has to be a round trip, right?

But a lot of people lose sight of that. They see this goal that's two hours away and they've spent years of preparing and training and months of climbing, and when it gets to that close of a distance, they're willing to throw caution to

the wind simply to get to the summit and then, hopefully, they'll get down. And a lot of those people, unfortunately, never make it back down. For me, the risk is too great—I don't want to die going to the summit of the world. So we walked away—300 feet from the top. And it's something I thought about every single day for three more years.

Two years later, in 1989, I climbed the third highest peak in the world, Kangchenjunga. We climbed by a very steep and difficult route—this is the technical climbing that we had at 24,000 feet. Very strong team, rather good conditions, and in the end, we reached the summit of Kangchenjunga at 28,200 feet on a very, very pleasant day. And if the weather's good, and you have time, you can stay for about an hour on the summit. If the weather's bad, three minutes, take some photos, and down you go. We stayed for an hour. Looking 80 miles to the west, you could see three more peaks in the distance. And the one closest to the center, the large one, is Everest. And even though I was there standing on Kangchenjunga, I was longing to be back on Everest to finish that last 300 feet.

> "I HAVE ALWAYS FELT THAT CLIMBING HAS TO BE A ROUND TRIP, RIGHT? BUT A LOT OF PEOPLE LOSE SIGHT OF THAT. THEY SEE THIS GOAL THAT'S TWO HOURS AWAY AND THEY'VE SPENT YEARS OF PREPARING AND TRAINING AND MONTHS OF CLIMBING, AND . . . THEY'RE WILLING TO THROW CAUTION TO THE WIND."

A year later, I did go back to Everest. And—we were making the final ascent, 300 feet away from the summit once again. Climbing without oxygen at these altitudes, you go very, very slowly. You take a step and you breathe 15 times. You take another step and you breathe 15 times. And then you think about taking another step, and you breathe 15 times.

But after 12 hours of continuous climbing from the high camp at 27,000 feet, I then, finally, stood on the summit of the world. And to me, this was the most amazing point of my career—to be on the top of the world. I've always told people this is the closest you can get to outer space without actually leaving the ground. This was an amazing moment for me.

The following year, I went to K2—the second highest peak in the world—and by all means, much more difficult to climb than Everest. It's steeper, the weather is worse, and only 200 people to date have climbed K2. And I went there with my great friend from Seattle, Scott Fisher.

At 26,000 feet was our last camp before we made the final dash to the summit. The shelters and tents weigh about five pounds. On K2, the higher you go, the steeper it gets and the more dangerous it gets. And that's where you really,

really have to be careful, and that's where a lot of accidents occur, because people are so focused on just getting themselves to the top, they're not even aware of the weather, their surroundings, and the conditions. And that's something that you really have to evaluate every step of the way. And, luckily, we climbed it on the first attempt. And once you climb K2, you never think of going back.

I also met that year on K2 another great friend, Rob Hall from New Zealand. We became great friends and did many climbs throughout the world. We climbed Everest together several times as well as Lhotse, Everest's neighbor. Lhotse is the fourth highest peak in the world. And what we started to do was to do tandem climbing where we would go and climb Everest over a two-month period, acclimatize our bodies, and then, quickly, in succession, climb another 8,000-meter peak in just three days. And so we could utilize our acclimatization.

Tragically, though, both Scott and Rob died in 1996 on Mt. Everest during the tragic storm of May 10th. I was there with my wife. I was the climbing leader for the Everest IMAX film. My wife, Paula, was our base camp leader. Our expedition leader, and the director of the film, was David Breashears. Very experienced climber, very detail-oriented, and an amazing leader to have on this climb, where you had a very difficult task in taking a 42-pound camera to the summit, doing what other climbers were doing but also schlepping this giant microwave-sized piece of metal to the summit as well. And after six weeks of climbing, we were in position to go to the summit. We were going to go on May 9th—this was a day ahead of everyone. We evaluated the weather conditions. The weather patterns weren't what we were hoping they would be and we decided to go down. Our friends, led by Rob and Scott, made the decision to continue on to the summit on May 10th and then, sadly, the storm occurred, and on that day eight people died—two of them my great friends. There was nothing we could do.

We couldn't climb up to them fast enough; we couldn't get a helicopter to get up to them. And that's the thing about mountaineering. It's one of the places on the planet where rescue is literally impossible, unless you send humans to go do the rescuing. There are no machines and there's no other way to get these people.

Part of the reason, I think, that the tragedy occurred is that people were swayed by the group decisions that were made. It was almost like, if six people are going, then ten people are going, then twelve people are going. You know, there's comfort—there's psychological comfort—in groups with larger numbers. And I think people would say, "Well, they're going, so I'm going to go." And then they kind of just kept pulling each other up higher and higher late in the day as the storm was brewing. We helped with the rescue. We quit filming and stopped what we were doing in relation to our own objectives. We helped bring some people down and then, after that, we managed to pick up the pieces, and we went back up the mountain two weeks later. Not in spite of what happened, but, I think, to show the world that you can climb these mountains and live to talk about it. If you find the right conditions, and if you wait with patience for the proper weather, you can climb these mountains and live to talk about it. The

summit is only half the trip, and the most important half of the climb is, in my opinion, the descent.

I've gone on to climb more. I'm on a quest to climb the 14 8,000-meter peaks in the world without supplemental oxygen. And over the last 15 years, I've managed to climb 13 of them. I have one more to go, which is called Annapurna, the mountain that got me into all of this. So maybe it's poetic that it happens to be the last mountain on the list. ■

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NASA Image/Renee Bouchard

Exploring the Deep Underground

I've been trying to get to Mars ever since I was a little kid. And my solution to this over the last decade or so is, really, to go down instead of go out. And that may be as close to going to another planet as I ever get. After we published a paper with Chris McKay suggesting that life on Mars would be underground, we were looking for ways to study the sub-surface. And, of course, the most immediate and obvious thing was the new information we were getting from drill holes. People were beginning to drill, through the Department of Energy project, and trying to look at deep subsurface microbiology. We discovered that caves were there and that maybe they would be cheaper to get into. And so, after the early part of my career working in extreme environments on the surface, I decided to try caving. The first cave I ever caved was Lechuguilla Cave in New Mexico, which is a notoriously difficult cave. And all I thought at the time was, "Am I going to live to get out of this? I just have to live to get out of this cave."

But after the pain sort of faded, I realized that it was an amazing environment, that I'd never done anything in any place that was so potentially fascinating for the kinds of exotic microbiology that I was interested in as an astrobiologist. And so I realized that I could do

Penelope J. Boston
Director of Cave and Karst Studies, New Mexico Institute of Mining and Technology

Penelope Boston's areas of research include cave geomicrobiology, microbial life in highly mineralized environments, and unique or characteristic biominerals and biosignature detection. In addition, she is involved in astrobiology and the search for life beyond Earth. At New Mexico Tech she is creating a new program, Cave and Karst Studies, in conjunction with the founding of the National Cave and Karst Research Institute. She is extensively involved in educational outreach about caves and karst issues, space exploration, and general science for school children, older students, and the general public.

OPENING PHOTO:
Penny Boston prepares to rappel into the entrance of the immense Lechuguilla Cave, New Mexico.
(Image copyright Val Hildreth-Werker)

two things. One is, I could learn how to cave safely and I could go to these places. And I could then refocus my work to essentially tap into an entire area of biology and mineralogy, and the way they overlap on our planet, that had not been studied before. This is a new field, really, in terms of what we've been doing on Earth. And then it was immediately applicable, of course, to the situation of life beyond the planet.

And, so, most of my research now is focused in one type of cave or another. We tend to pick them for their specific chemical properties, so we're looking for caves that have poisonous atmospheres, that are very hot, that are very cold, that are very extreme in some sense, so that we can look at the limits to life on this planet and learn from that what may be adaptive strategies of life for other bodies in the solar system and, perhaps, someday beyond. So really, to write a field guide to unknown organisms is part of our mandate.

I'm studying the caves that we are looking at as I'm building on the work of other cave scientists in the world. There are a number of really clear lessons that we're learning. These amazing environments show us that caves are really not rare. If you have only ever been in caves as an occasional tourist in a show cave, you may think that caves are a rare phenomena, but really, there are a tremendous number of sub-surface voids on Earth of all different kinds. They aren't just in calcium carbonate-type environments, which are the ones that we often come in contact with, but they really occur in every major rock type. And this is an important lesson for trying to apply our knowledge of Earth caves to other bodies in the solar system.

There are many, many ways to make caves. And, so, one of the areas of active research that we're engaged in is, really, a set of thought experiments about how you can look at the basic physics and chemistry of environments and try to imagine ways that subsurface voids on other bodies could be formed. And, so, we're working that end of the theoretical spectrum of imagining caves on other planets.

The type of cave that we absolutely know exists elsewhere in the solar system are what are known as lava tubes, and these are a natural outgrowth of flood-basalt type, quiet, flowing lava eruptions. And these things are essentially rivulets that freeze on the outside. The rock on the outside freezes. It's a very good insulator, and then it allows the interior to remain molten and lava continues to flow through. Eventually, when the eruption stops, these empty out and you have these beautiful tubes, and so that's a very different class of cave from the kinds of dissolution-dominated caves that we often think of.

Certainly, it was known and recognized by Ron Greeley and other colleagues, even in the Apollo era, that a lot of structures that they were seeing on the moon were lava tubes, or unroofed sinuous rills, which is like a lava tube without its top. As we get ever better imaging of the planet Mars, we have seen that there are lava tubes scattered widely over the planet, and these are quite easy to pick out. Olympus Mons has this little pit crater or little pit collapse feature, a string-of-beads kind of appearance. This is a direct analogue to the way we find these sorts of things on Earth.

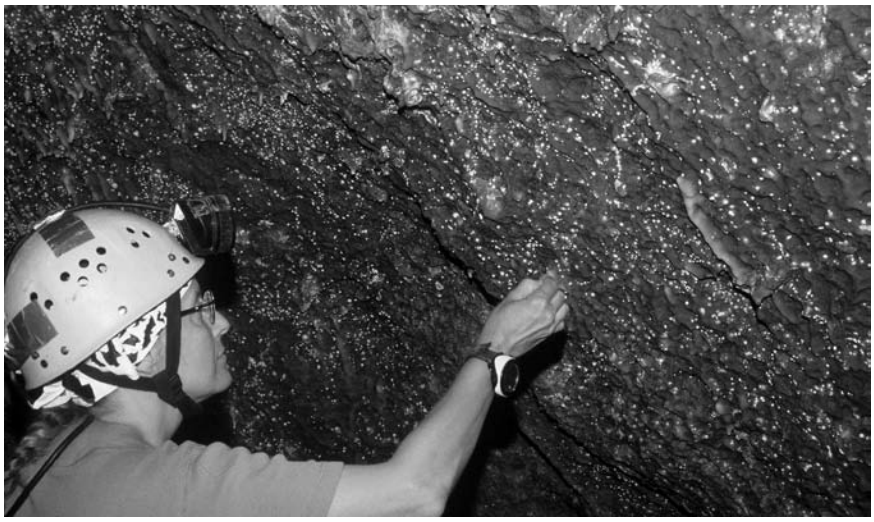
One of the interesting things that's been attributed to the fact that the gravity on Mars is much lower is the fact that the lava tubes scale accordingly. So not only does Mars have enormous examples of volcanism, but it has big lava tubes. The biggest lava tube on Earth is about 90 kilometers long, in Hawaii. That's the record-holder on Earth. But, typically, when you look at these features on Mars, they're hundreds of kilometers long. And the diameters are equally great, so they're on average 3 to 10 times the size of the average diameter of a tube on Earth. So these things are truly enormous.

Not only those places, but when we look at the radar imaging data from the Venus missions, you can see that there are tube-like structures associated even with those weird-looking types of volcanic features that you find on Venus. And, then, even Io, which is such a cooking little moon out there with its tremendous sulfur component, seems to have what is clear evidence of lava tubes. And my dream is that somebody will get a really good image of one that's made out of entirely molten sulfur.

> IN A LOT OF THESE SUBTERRANEAN WORLDS, WE REALLY ARE THE ALIENS, AND THIS IS AN IMAGINATION-STRETCHING EXPERIENCE.

So these are fabulous features. These are places—at least on the Moon and Mars, although I wouldn't recommend astronauts going directly to Io or Venus—that can actually be exploited as human habitat. We just finished a Phase 1 and Phase 2 study over the last four years for NIAC, which is the NASA Institute for Advanced Concepts, looking at the far-future conceptual development, and looking at ways to discover the likely enabling technologies that we would need to make these actually useable for structures for astronauts and bases on the Moon and Mars in the future.

So, I'm not going to talk about all the different kinds of caves because that would be a several-hour lecture in and of itself. But one of the points that I think I want to really press home is that cave environments are typically radically different from the surface. Pictures taken in Saudi Arabia by the very well-known caving team of John and Suzy Pinch have shown that, even in these very hot, blasted sand deserts, when you get into very large bell-shaped caves, there are divable pools. And the air in these caves is near saturated humidity. So it's a complete change from the overlying environment, even in caves that are not sealed. And, so, it's just the barrier of above and below that provides this radically different environment. And this is a big message for astrobiology, that just what might be dominating on the surface of a planet is not necessarily the key to where you actually have to go to look for the life.



Small white patches are actinomycete bacterial colonies growing on cave walls and precipitating the mineral calcite in Ft. Stanton Cave, New Mexico. (Image copyright Kevin Glover)

Cave environments obviously have no sunlight, so this means that any organisms living within them have to make their living elsewhere, either by detrital organic material washing in or, in the case of a lot of the organisms we're studying, they're essentially rock eaters. These guys are disaggregating the parent rock using things like the metabolic product, the organic acids that they give off, and, then, other organisms come along within these little microcommunities, and they oxidize the metals in the rock. And this is how they get the energy to run their entire ecosystem.

They're very high-humidity environments. In contrast to the surface, they're very thermally stable, so even a cave with a big, gaping, open entrance still remains very, very thermally consistent on the interior. New transfer is usually very, very low, with some exceptions. They're very rich mineral environments. And then there's no conventional weather, so it very much is a very different planet in the near-crustal caves than it is on the surface.

And the result of all these tremendously different conditions is that caves are unique mineral factories. There are vast numbers of unique mineral formations that are found in caves. Huge catalogues of them have been seen and the explanations for the occurrence of these is very much in its infancy. One of the things that we are working on extensively is which of these types of mineral formation processes are actually biogenic, and it turns out that there are a lot of them—perhaps even most of them in caves have a biogenic component.

So the organisms that are actually contributing to what's going on in caves are not simply passive observers or users of the environment. They are mineralogically interactive. They are changing the caves. They are actually interacting with the bedrock and they are guiding, and in some cases controlling, the kinds of mineral deposits that are left. A lot of these organisms are novel, and I would venture to say that the bulk of the organisms that we find are actually

novel. They're not known to science. And, so, from one little cave puddle to the next, perhaps we have 80 percent novel organisms that we look at by molecular phylogenetic techniques. So these are truly evolutionarily, self-contained environments, and many of them are actually physically isolated from the surface, and, in that sense, they really are miniature planetary systems within our own crustal environment.

Not only do the caves house this amazing array of organisms that we're just beginning to understand and study, but also they're wonderful preservation environments. So if you are looking for biosignatures, then the subsurface in caves is the place to look. Not only do the organisms live there, but they very often self-lithify. They're engaged in self-fossilization while they're actually alive. So-called U-loops from Lechugia Cave look very organic. They are entirely rock now, but we have been studying their living counterparts in modern caves, and these are clearly the fossilized remains of microbial mats that were inhabiting this cave probably on the order of four to six million years ago when this cave was actively forming. We can also expose the fossils in this kind of material by acid etching.

In a lot of these subterranean worlds, we really are the aliens, and this is an imagination-stretching experience. It's the kind of thing where it would be lovely if we could take a lot of program managers into this kind of environment, because, really, it's the kind of thing where just reading about it doesn't make as much of an impact as if you were actually doing it.

Cueva de Villa Luz is one of the most amazing caves that we're studying. It's a sulfuric acid-saturated cave in Tabasco, Mexico. Gases from the nearby volcano, El Chico, now actually come into this cave and make it an extremely poisonous environment within which to work—tremendous amounts of hydrogen sulfide, carbon monoxide, carbon dioxide, even aldehydes, and various other noxious things. And so we require complete protection from that environment.

The message here is that this cave is the most biologically-rich cave of any that we've ever seen, and it's because of these poisonous gases. These poisonous gases are not poisonous to the organisms that are living there; it's home sweet home. And this is the message. We're not looking at extreme environments just to look at extremes where organisms are just barely hanging on. We're looking at them to look for organisms for which that is the comfortable environment, because those are representative of what we may find as the average conditions on other bodies.

So we're trying to write the field guide to unknown life, and this is a really tough thing to do. But the place that I've been in my career where this makes the most sense to me is in these kinds of protected and evolutionarily-sequestered environments. A lot of the material we look at doesn't even look alive. We've seen white muddy-looking stuff on the walls—that's living mud. That material is made out of cells and filaments that coat themselves with calcite mineral. And they're actively producing this material in caves all over the world. Tiny white dots on the walls are organisms that are busy dissolving the salt in a lava tube and making their living there. So, even though something may not look alive,

and although sometimes we have to work very hard to show that it's alive, all of these environments contain amazing life forms that are busy also leaving traces of themselves.

One of the other aspects of doing the kind of cave work that we do is also giving us operational experience that is very valuable to future life detection missions, whether they be robotic or, ultimately, crewed teams in the future. And that is that we are operating in extreme environments that are hazardous, with an indigenous, sensitive, alien biology. In this case, the alien biology is on our own planet, but, nevertheless, it's very different from our surface environment, and we have to take all the precautions that one would imagine in order to avoid contaminating it while, at the same time, managing not to kill ourselves off while working in very difficult conditions. And so, it is an analogue for operating with life-detection constraints, including even the aspect of working with various collaborators at MIT [Massachusetts Institute of Technology] and JPL [Jet Propulsion Laboratory] and NASA-Langley on robotics that can get us into some of these kinds of environments.

So the caves are out there. I know that as time goes on and we explore the rest of the planets in the solar system, we'll find better and better ways of actually detecting caves besides the lava tubes. We'll find ways to get into them. We'll find ways to drill into them—which will be a lot easier than just sinking a core right down into solid rock—and they will have amazing structures, amazing minerals, and, perhaps, even amazing life as we explore them. ■

NASA Image/Renee Bouchard

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Exploring the World's Highest Lakes

I am a planetary geologist, so I am revolving between Earth and heaven, and part of heaven is Mars. As such, I am very privileged and, also very proud, to be part of Mars Exploration Rover science team, which is proving a lot in terms of exploration. And, as a member of the science team, with my colleagues, we are taking intellectual risks. We have been working for several years to select landing sites, and we tried to match the landing sites to the objectives of the Mars Exploration Rover mission. We were very happy to see that, indeed, in many cases we have been able to reach our objectives.

But, although it's an intellectual risk, it's also a risk for the assets and for the time that has been put into preparing these missions. There is no human life involved in that part of it, but still, you want to make sure that you are doing your job properly. And to do that, you have to do your homework. I would volunteer right away to go to Mars. People here, like Mr. Lovell and [Harrison] Jack Schmitt and others, made me dream as a little girl, and I knew that whatever I was doing with my life, it would involve NASA, planets, and exploration. But still, you have to make sure that the concept you are pushing forward is as close as possible to reality. And to do that, we had to do a lot of planetary geology here on Earth and to try to find the best analogue we can.

Nathalie Cabrol
Planetary Geologist, NASA Ames Research Center, SETI Institute

Nathalie Cabrol is a planetary geologist at NASA Ames Research Center, since 1994, and a SETI Institute principal investigator, since 1998. Her research focuses on aqueous environments favorable to life on Mars, exploration (robotic and human), and the study of terrestrial analogues. Her education includes a master and doctorate degree in planetary geology (1986 and 1991 respectively), both obtained at the Sorbonne University in Paris.

Nathalie enjoys climbing and hiking. She also practices free diving (diving without oxygen tanks). She holds an (unofficial) women's world record for the highest free dive, performed in 2003 in the Licancabur summit lake. Both her passion for mountaineering and diving are combined in her scientific research for the limits of life on Earth.

OPENING PHOTO:
Setting up camp for the Licancabur expedition. (Copyright: 2003 Licancabur Expedition, NASA ARC/SETI Institute. Image by Gregory Kovacs.)

I am interested in lakes. I am interested in past aqueous environments on Mars and their habitability potential—whether those are the best place for life, whether life ever appeared on Mars—these are my drivers as a scientist. And to try to understand that, I am exploring high lakes. Why explore high lakes? Because the higher you go on Earth, the earlier you go back in time. On Mars, basically, you will be going into a core environment temperature that is really low and you are going into a thinner atmosphere and you try to understand what is happening over there. And, so, we are exploring those high lakes. We have been starting in the Andes with volcanic lakes.

And our goal is astrobiology, but as we were going, our exploration kind of caught up with us, and we discovered a brand new avenue of research. And this involved physiology and medicine—and I'll talk a little bit more about that—and, of course, education and public outreach.

Well, why go high? As I said, these are the best analogues to Martian lakes and we want to understand the limits of life. And why do we want to do that? Because right now, the Mars exploration rover mission has proven beyond doubt that Mars was a habitable planet for the type of life we know here on Earth. But that does not mean that there was life there; habitability and actual life being two different things.

So, going back to these high lakes is for us to understand: Is life possible in analogous conditions to those on Mars? So we are going up there, and we are trying to start with crater lakes in the Andes, and we'll try to move on to the Himalayas, because as the lakes in the Andes are slowly receding now because of the climate change, by the same token, on the other side of the planet in the Himalayas, large glaciers are now melting and they are creating new lakes that are probably higher than those of the Andes. This is, for us, a place to really stop and witness the ecosystems forming: How life gets there and develops, et cetera. So this is really something that's fascinating.

And we started with the Andes and, well, you have to imagine, about two years ago, myself entering the office of my branch chief at Ames and saying, "Hi, Chief. I think I have this very bright idea. I would like to climb a 20,000-foot volcano, named Licancabur, at the boundary of Chile and Bolivia. By the way, it's not extinct. And there is a lake on top, and I want to dive on that lake. Of course, it's almost freezing temperature, but I forgot to tell you something, I am a free diver. I am not using oxygen. Can you help me with Code Q [NASA Safety Office]. He actually did, and this is how we started the Licancabur adventure.

We were talking this morning about risk and payoff. It has been the most rewarding experience of my entire life so far. We were blessed by the fact that nobody in our crew was hurt, nobody was really in significant trouble. You will wake up lousy at that altitude, because this is the kind of thing that happens, but nobody got actually sick from mountain sickness. But we had to work with Code Q for six months. And among the people who advised us on this trip was Peter Hackett, and Peter was one of the other guys climbing Everest without oxygen. So we took this very seriously.

But, in the meantime, as is part of exploration, you open one door and many, many others open as you are walking. And so we started climbing Licancabur, trying to determine if there was life up there, and as the title of our project was "Exploring the Limits of Life in the Highest Lakes on Earth," I had never imagined that that could be testing our own limits. And not only were we writing the experiment, but we became part of the experiment. And this became fascinating.

We know how analogous these places are to ancient Mars. The pressure is the same. The temperature is the same. UV radiation—well, according to models, we shouldn't be very far off on this one. It's a very arid environment, yet the caldera is right next to it. We're in a volcanic environment with variable thermal input, and if we have questions about life on Mars, when we go to these lakes, we discover that life is thriving over there.

And so, to us, that was very, very encouraging. Because this opens doors and potential for the study and the search for life on Mars. And going up there normally would help us to understand better from the standpoint of the biology, but it helps us, also, to prepare for a future mission on Mars, because we have a better idea of the type of instruments, of the type of exploration strategy, what we would be able to prepare, and giving heads up to management. And this is very important, too.

> "AND WITNESSING MY FATHER'S LAST DAYS IN THE CONDITION HE WAS IN, AND THE DIFFICULTY HE HAD BREATHING, I SAID THAT THE ONLY RISK I COULD TAKE WOULD BE TO HAVE ONE MORE PERSON TO SUFFER THAT THING."

Our summit camp was around 19,500 feet, and we could look down to two evaporation lakes, Laguna Verde and Laguna Blanca. These two lagunas are lakes which were really perennial lakes 15,000 years ago during the last glacial maximum. And since then, because of climate change, they have been evaporating. And we used those two lakes, which are at 14,000 feet, as an acclimatization area. And we are studying them.

Once again, we stumbled into the unexpected, which is the sense of exploration. And as we were just hoping to spend a little time there, to prepare for the ascent, then we started discovering that we had more analogy with Mars than we had bargained for. Everyday at about eleven o'clock, because this is a thin atmosphere and because you have big gradients of temperature due to the high volcano, you will have huge dust devils roaming around those lakes, and they will engulf your tents and your refuge. And you better not be in the middle of it. So that also tells us about human exploration, that there are things you must be aware of.

But what we also stumbled into were stromatolites [fossilized algae colonies, some of the oldest and continually surviving life forms on Earth]. And the field we stumbled into is 150 square kilometers. And these are on the paleo shore of this larger lake I talked about, Laguna Verde, Laguna Blanca—15,000 years ago this was one lake. And these are fed by hydrothermal springs. And we discovered those stromatolites. When we examined those structures, we discovered that they were biogenic. This means that we had blue and green algae forming then, and we know that these microorganisms are the ones that existed on planet Earth. And you have to go back to archaea [single-celled organisms, among the earliest forms of life on Earth] to see this kind of creature.

So we were on the shores of lakes that are very much analogous to what we are seeing on Mars, and, all of a sudden, we find those primitive terrestrial organisms just colonizing everywhere they can. So that's the cherry on top of the cake. We were not expecting that. We are hoping to develop this aspect, because, obviously, this is going to tell us a lot about the potential of these kinds of lakes.

Laguna Verde is three times saltier than seawater. I learned this the hard way when I tried to dive in it. Eleven pounds of lead would take me to the bottom without any problem. It was an interesting experience, an interesting dive. So they are stromatolite-like colonies. Because what I didn't mention is that we have all these fossil stromatolites that colonized the paleo shore of this lake. But, even better, there are still stromatolites forming today. And this is a very rare occurrence on Earth these days. We are walking on them—literally on the floor, and there is better news than that. I just received three weeks ago some analysis from the lab, and this is a dead ringer for [an existing species], the chemistry is the same exactly.

Our goal was the top of the volcano. And not only do you want to dive on top of this volcano, but you have to get there. We have to make sure that nobody is suffering from hypoxia, from any type of problem. We don't want to climb too fast, because we don't want to be anoxic at the summit. And, so, what we do is that we stop at night at 18,000 feet, at the only flat place we can find on that volcano. Basically, this is a 12 meter by 4 meter kind of flat, and we are jamming our four or five tents on that, with an 800-meter drop nearby. I didn't mention that to Code Q before we went there. But the slope is about a 40–45 degree slope, on very unstable material. We can't stabilize it, and the only thing we can hope for is that there will not be an earthquake that night.

So once we are there, we spend one night there for acclimatization, and once we are on top, the scenery is quite something. The lake itself is a receding lake now, about the size of a football field. And the paleo shore marks the level of the lake in the '50s. That also tells us something: those lakes are disappearing. It is really time for us to understand what is going on there, because they will be lost forever in a few years.

So when we went there, of course, we wanted to dive. We have several objectives when we are doing this. The first one is to characterize the habitat and

Camp near one of the highest lakes on Earth. (Copyright: 2003 Licancabur Expedition, NASA ARC/SETI Institute. Image by Gregory Kovacs.)

microorganisms and ecosystem that are there. And most of the summit lake, like Laguna Blanca or Laguna Verde, is a very shallow lake, which means that also the UV radiation—the microorganisms are going to be affected by that.

The other thing that we are doing is to do physiological research. At Ames, we have the astrobionics group, which is developing the "sea pods". These are monitors that keep track of the team. You are monitoring your blood oxygen saturation, you are monitoring your heart beat and apnea during sleep, because this is happening when you are in the mountains. But the thing we wanted to do here was a little different.

I am a free diver. I never dive with oxygen tanks, because I find them heavy and cumbersome. At 20,000 feet I had to convince many people that it was a good idea to hold my breath. But, basically, people in good health at this altitude will be at about 65 percent oxygen saturation in their blood. And their heart is pumping at around 135 beats per minute.

We wanted to understand what was going on with the oxygen saturation by doing the free diving. There are things we cannot do at sea level, because your blood is always saturated in oxygen at sea level. And if something happens to this saturation and heart beat system, you will see it at this altitude.

I also had another motivation—the very overarching objective is that, as an organism, your body is going to produce, one way or another, more oxygen, and we need to understand that. Because we have many people in this world who are dying from lung and heart diseases. And helping those people breathe better, or maybe find a solution that will help them, that is something that is really important to us. I took this point home because my father passed away from massive heart failure a few months before the expedition. And witnessing my father's last days in the condition he was in, and the difficulty he had breathing,

I said that the only risk I could take would be to have one more person to suffer that thing.

So, this is where, in my mind, there is no question about the risk entailed. If some people wonder why we are exploring, I tell you I know why I'm exploring.

So, we actually monitored the free dive. And we realized that people can be very well with a heart beat of 39 beats per minute—this is how low my heart went when I was diving there—and getting out at 20,000 feet of that kind of water, which is at 40 degrees, with a blood oxygen saturation at 93 percent. Something is producing oxygen in our body. Something remembers that we are aquatic mammals. We need to understand what it is. Nature gave me two good lungs (actually, Stanford is looking for the third one) and a good heart, and I want to take advantage of that to help make headway, to find solutions for one of the most horrendous killers in our society.

So, this is one of the aspects of why it is worth taking risks. On the other hand, on the NASA-related objective, these physiological monitors tell you everything that you want to know about a crew's health status. It was really

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important for us to show that this was working, and we actually did some live transmission of our vitals directly to Ames and Stanford while we were there. That was the first time this was done. That was one of the co-aspects. The other aspect, going back to astrobiology and microorganisms, is that we are actually now in a position to know those microenvironments a lot better.

In the past two years, we have also been involved in pinpointing some interesting effects of the UV radiation. For example, diatoms are experiencing mutation and malformation due to UV radiation. We want to understand this because it tells us something. There are, apparently, mutations that we need to understand better, if it is a mutation toward extinction or if it is a mutation toward evolution. It is really important in a world where you have high UV impact, such as Mars would have been in the past. The other aspect of it is that we are living in a world where UV impact is becoming more and more of an issue. We have trouble with the ozone layer, and if these little creatures over there are developing sunscreen and a UV-resistance strategy, we need to learn about it, because that will help the general public.

Sometimes we have interesting encounters. One of a diatoms [planktonic unicellular algae] we found was thought to be extinct a long time ago. Well, it's thriving in Laguna Verde, thank you. It is having lots of success. It is still there. In another case, we found a diatom that was known to exist only in the Baltic Sea. Don't ask me how it ended up here, but it is there and thriving. Maybe the conditions of salinity and cold are very close to the Baltic Sea.

So we are learning a lot. Stromatolites were the first creatures on Earth, and they are still there. They are evolving and they are telling us about our past. If we are able to decipher what they are telling us, we will know better about our origins and, maybe, possible origins of life on other planets, because those lakes are very similar to that of Mars.

To go back to what many of the previous speakers talked about, managing risk and people, there is, obviously, a physical responsibility. You have catastrophic risk, of course. There is nothing we can do about the volcano exploding on us if we are there when this happens. Everything else we can manage.

I would say that the state of mind I would go with when I leave the U.S. and go to Bolivia would be to say that, as much as I can prevent it, nobody will get hurt on my watch. I am always working on this, and I have to manage a very diverse group of people. This group of people ranges from young people, students, to people who are senior scientists to people who speak different languages.

Last year in my team I had Hungarians. I had Chileans and Bolivians. I am French. I had American people and Spaniards. That makes for good jokes when we are trying to translate one thing to another. We have to make sure that the safety things will get through all the time. My personal standpoint here is that risk is definitely inherent to exploration, and it is necessary for discovery. And I will go a step farther. I say this is also the essence of survival. If we want to do it, we need to explore. We need to explore new ground.

I guess we have to share an ultimate responsibility, as Dale and Penny were mentioning. You have a team with you. You are responsible for them, and you have to have answers. The main thing is that you have to be accountable and responsible for all that. It is hard to think that exploration can be done without taking risk. It is hard for me to think that, ultimately, exploration can be done without losing people one way or another. Even if this happens, we have to make sure that we have done everything possible to mitigate the risk and to prevent it from happening, as much as possible. ■

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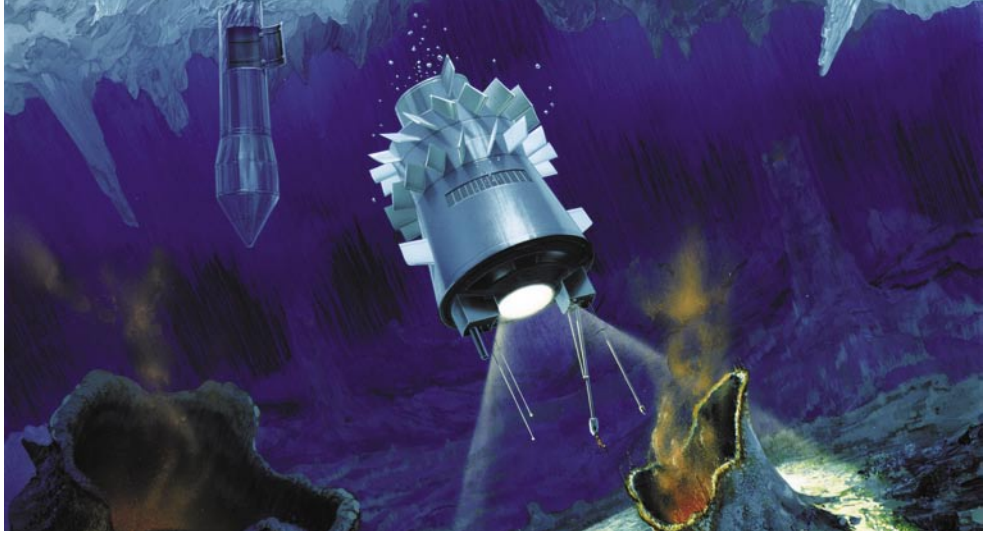
NASA Image/Renee Bouchard



Deep/Underwater Cave Environments

I've come from a rather unusual background in that I came up through engineering school wanting to be an astronaut, but had the good fortune of discovering that there were remaining places to be explored here on Earth in the meantime. As a teenager, I watched a couple of these guys who talked here this morning walk on the Moon. They were my heroes, and it was the U.S. space program that was directly responsible for my going out and getting a Ph.D. in engineering and wanting to work in space. In the process of trying to get into the Astronaut Corps at various times, I have also had the privilege of being involved with a large number of expeditionary projects dealing with things that go down into the Earth as opposed to things that go up. I added it up a little while ago. Over the last 26 years, I've spent 7 1/2 years in the field on expeditions, of which 353 days were below 1,000 meters deep underground, based from subterranean camps. So, I'm either a troglodyte or somebody who's looking for planetary exploration and hasn't been able to get off this pile of rock yet.

What I am going to do here this afternoon is to rapidly take you to three of the most remote places that humans have ever reached inside this planet. This is serious business. It is more serious, in my opinion, than high altitude mountaineering, because of the

William C. Stone
Engineer/Deep Cave Explorer and President, Stone Aerospace

William Stone led the exploration of Sistema Cheve (-1484 meters), (-1475 meters), and Cueva Charco (-1286 meters), among many other deep caves around the world. These Mexican caves represent the three deepest systems in the Western Hemisphere and currently the 8th, 9th, and 21st deepest natural abysses in the world respectively. During the past 33 years, Bill has organized and led 47 expeditions and has spent seven years in the field on exploration projects. He holds 11 patents and patents-pending and is the inventor of numerous other exploration-related tools. He is presently leading the three-year DEPTHX project for NASA to develop and field-test a prototype robot for the postulated Europa lander third stage, the "hydrobot" that autonomously maps the subsurface ocean of Europa.

OPENING PHOTO:
An artist's rendering of the hydrobot, a self-propelled submersible that could be used to explore beneath the surface of the ice-covered ocean on Europa, one of Jupiter's moons. (Source: http://www.jpl.nasa.gov/technology/images_videos/iv_pages/p48326.html.)

multidisciplinary nature and the remoteness. I don't consider expeditionary deep caving as something you do for excitement. You do it because it's an opportunity to explore one of the last true frontiers on this planet. The classic distinction on this subject came from arctic explorer Vilhjalmar Steffanson, who once spent five years working solo north of the Arctic Circle. Interviewed about this one time, the reporter asked [Steffanson], "Well, you're an adventurer, aren't you?" He said, "Son, adventure is what happens when exploration goes wrong."

I have had that motto emblazoned upon my heart in letters of gold ever since. You do not get Brownie points for having your name on a tombstone. You have to come back. With that in mind, I have actually taken a lot of cues from how NASA trains its astronauts when preparing for, and staffing, expeditions. In the subterranean world, where we are about to go, it is a gloves-off environment. The exploration front is now getting to the stage where it is so remote and so difficult to reach that no matter what technology we have at our disposal, and no matter how Olympically-trained and fit the people are who are involved with it, we still get stopped. Every time you go for four or five months in the field, if

"INTERVIEWED ABOUT THIS ONE TIME, THE REPORTER ASKED [STEFFANSON], "WELL, YOU'RE AN ADVENTURER, AREN'T YOU?" HE SAID, "SON, ADVENTURE IS WHAT HAPPENS WHEN EXPLORATION GOES WRONG."

you're lucky, you're a kilometer or two deeper into the planet. I am going to try to give you an idea here just what this world is like. I'm going to show here what would be the equivalent of summitting Everest and K2, but it's all going to be in one continuous trip proceeding down, in order to give you a sequential feel for the logistics and remoteness.

Rising out of the southeastern area of southern Mexico is the Huautla plateau. It jumps straight up about 2,100 meters. The top of it is cratered with gigantic sinkholes. The water that rains on this area for 500 square kilometers all goes internally and, in the process of doing that, it creates some pretty substantially-sized voids.

About 50 kilometers away to the south and a kilometer higher in elevation is Cueva Cheve. This was only discovered in 1986. This underscores the still unknown extent of this last frontier: Cueva Cheve was not even known to the modern world until 1986—just 18 years ago. The endeavors we're talking about require a lot of technology, starting off with the fact that you're going down. You don't just walk down that depth. There are three kilometers of specialized rope that are used to rig over 107 drops and traverses going down into this cave.

Typical vertical drops on some of these things can reach distances of 160 meters straight down. That would be about one and a half times the height of the Vehicle Assembly Building, for those who are here from Kennedy Space Center. A lot of times they're a little bit shorter, but they almost always have water accompanying them. The deeper you go, the more water you collect. The tributaries each add a little bit in until, finally, you're dealing with quite a serious flow. You're rigging lines on the walls to keep out of that, usually. This is life on rope. You're usually carrying around a 25-kilogram pack, which has the supplies that you're bringing. This is very much an inverse variant to the siege tactics that you see used on high altitude mountains where you're building Camp 1, Camp 2, Camp 3, and you start off with a pyramid of 50 people. Sometimes, we've had as many as 150, but 50 is a typical number for a trip for four to five months. That works out to be a good number to work with—you have depth of personnel to handle emergencies in situ. We've generally considered that a team of 12 to 18 is about the minimum you would want for safety and skill redundancy. And the further down you go, you're adding more tributaries until, finally, you're into rivers by the time you get to about the -800-meter level. This would be a little over a half a mile deep in English units. I know nobody around here works in English units . . . except when you're designing planetary craft going to Mars. [Laughter]

One of the things that we've had to deal with is the fact that we are constantly running up against the limits of human endurance. Typically, if you go on a marathon exploration trip, you can stay up for 24, 28, maybe 30 hours, and, after that, if you come back to base camp on the surface, you're out of commission for two to three days while you're recovering. You can't do that underground, because even when you are resting—say at an underground camp—you are consuming supplies, which are finite and paid for at great price of effort. If you want to move efficiently, your people have to be roughly 16 hours from anywhere that they have to go. And, so, we begin to establish a series of camps. I want to dispel the notion that a lot of people have that these places are claustrophobic. In reality, many chambers and tunnels in southern Mexico—owing to the significant tropical yearly rainfall—are so big you can't even see the ceilings or the walls. It really is like being on the dark side of the Moon. These are team endeavors. None of your specialized personnel—divers, climbers, surveyors—get to the "front" without riding on the sweat of a substantial support team. Like high altitude mountaineers, cavers frequently refer to such support crew staff as "sherpas."

Again, when I think of an expedition—and this is a sticking point with me and it may be with others—there are a couple of holy words in the vocabulary of true explorers. And one of those is the term "expedition." To me, this is an endeavor of 20 or more people being out in the field for four-plus months. That's a serious distinction. Anything short of that is what I would refer to as a recon mission. And, so, in the case I'm discussing here, you're on site for four or five months, and people are working daily. It is not uncommon during the early stages of an expedition for the lead rigging team to get caught between known camps, and, so, setting a bivouac is something you plan for as you move in. Generally, it

is for logistics reasons that you don't get as far as you would like—for example, you might not have been able to carry enough rope to continue rigging.

Well, the reinforcement crew comes in the next day with another kilometer of rope and off you go. And then that support crew retreats to the previous camp behind them and the rigging team presses onward. And so it goes on down, until you are now roughly four days traveling distance from the nearest entrance. So, when you get to a place like this, you begin to think about the fact that you're pretty remote, and there really isn't going to be any rescue, except from the people who are with you, particularly if it's something that requires urgent response. If you can get a person back to a camp and stabilize a broken leg or something like that, you can always send out for assistance. But there are places where even that is not possible, particularly when working beyond flooded, underwater tunnels.

The most remote place that we've been so far is at the current limit of exploration in Cueva Cheve. When you get down to a distance of approximately 8 1/2 kilometers inside and at a depth of -1,360 meters, you're moving through river canyons, and you keep thinking that, well, this is just going to keep going down like this. But the problem is that caves are always quirky in terms of geology. All it takes is a slight counterfold in the limestone strata, and that river that was boiling is now static, placid, and leading you into tunnels that are completely waterfilled to the roof for substantial distances, before they usually rise back up into air-filled sections of cave. They used to refer to these places as terminal siphons. In fact, that's the name of a rock band I'm in, so you'll hear us touring someday.

So, you get down to a place like this and here you are, you're roughly 1,360 meters vertically down and 8 kilometers in. Everything down here is paid for preciously by the people who transported this down. You're living on ropes for days to get this here, so you have to be very careful about what you bring. At this point, those in the lead—in this case, trained cave divers—have this enormous pressure on them to perform. And I'm sure that everybody who's flown on a rocket knows this same feeling. Here's 50 or 100 people who have given of their time, of their lives, of their sweat for four months. That's not counting, by the way, in the case of many of these, that we have spent two to four months rehearsing with those same teams over the preceding one or two years. When you get to these places where the tunnels are full of water, now you're into another level of discipline where you have to be aware of the fact that, number one, you're going to be using portable life equipment—what astronauts refer to as PLSS [Portable Life Support System] units for EVA [extravehicular activity]. And that's the way I think of this. I think of this as EVA. And when you do that, you have to be thinking a couple of things. Number one is that anything can go wrong at any time, and so the best way to deal with this is to believe that this place is actively out to get you. When you think that way, you start making checklists ahead of time. In fact, we have them all laminated on waterproof paper. Not only before you go in, but after you come back out. It's the equivalent of pre-flight and postflight checklists.

But there's more to this. I'm going to say one thing here, and then I'll come back to another side of it. We've been talking about issues for reducing risk, one of them being making our equipment "bombproof." That's a bit tough when you look at the places that you have to go through to get these items or the equipment that these people have down here. And the other issue is redundancy. But before I get to that, there's this whole issue of peer pressure that is on you. You have to be ready at any second on one of these things that, if you get 50 feet inside this underwater tunnel and you don't like how you feel, you abort. That's a cardinal rule.

Somebody was asking me recently how many people do I know on expeditions that have died? And I really never thought much about it until I started adding it up. Over the last 18 years, I've lost 16 good friends. People that I've climbed with, worked with on expeditions, people who were very qualified.

> SOMETIMES WHEN YOU GET TO THESE LOCATIONS, THERE IS NO DRY LAND, AND SO YOU'RE LIVING IN HAMMOCKS STRUNG FROM ROCK BOLTS ABOVE THE WATER AND HOPING THAT YOU'RE HIGH ENOUGH THAT, IN CASE THERE'S A FLOOD, YOU'RE NOT GOING TO GET WASHED AWAY. THAT'S THE WORLD YOU LIVE IN WHEN YOU'RE DOWN THERE.

The reason they're not here right now is because they went a little too far—they didn't abort when they should have, they didn't stop and say, "Wait a minute. There's a stack of things that are going wrong here." Nothing ever happens in one blow. Jim Lovell pointed that out this morning. But a string of little events occurs—you start going down there and you get tired. You get tired and you say, "Ah, I don't need to have this extra little piece of safety line here." And, "Oh, well, I don't need to check this other piece of equipment I have for descending a rope." Pretty soon, things start to add up, and you don't have that safety on there and when you sit down, one of those carabiners is unlocked and it comes unclipped, and there you are with 25 kilos hanging below you, and you're hanging on the rope by one hand. You know, that kind of stuff happens. So, you have to get religious in your discipline about how you deal with the technology. This is high technology exploration that's going on down here. More serious than a typical EVA mission outside the Shuttle.

The Portable Life Support System we use is all fully-closed-cycle equipment. There is no air in this system. It's all helium-oxygen running at about 6,000-psi in carbon-carbon tanks. The range on this particular rig is about eight hours and

depth-independent. We developed this particular PLSS because we didn't know how far we were going to have to explore underwater. Sometimes when you get to these locations, there is no dry land, and so you're living in hammocks strung from rock bolts above the water and hoping that you're high enough that, in case there's a flood, you're not going to get washed away. That's the world you live in when you're down there.

In the bottom of this system you're doing 600 meters—that's roughly a half a mile—of diving, starting at the -1360 meter level. When we got to the other side, we established a camp. We were over there for a week and explored another three-and-a-half kilometers beyond the underwater section. These places represent the frontier right now. No one has been able to organize an expedition since to go further. In the case of Huautla, it has been 10 years since anyone visited that location; in Cheve, it was 2003, and it's unlikely that a return there will be fielded before 2007, although we do have that one in the planning stages already. Neither of these places are finished. They are beckoning. They are wide open. And, yet, we can't get the tactical logistics together or the team, because those people all have to be not only vertical trained, they have to be comfortable with where they are in a remote environment, and they have to be able to dive at the same time as well as climb. You start putting all these things together, all these various task loadings, and, pretty soon, the filters get pretty serious. There are not many people in the world who have all these skills.

This is the kind of thing that we are going to have to think about. Who are you going to put on the Moon? What kind of expeditionary-qualified people are you going to put on the Moon? Are you going to live together for a year up there? I mean, the psychological aspects are one thing, but the multidisciplinary training is going to be phenomenal.

If you get away from this logistical problem that we have of getting stuff down to -1,500 meters underground, and you can bring things in on tractor trailers, the whole ball game changes. One of the great natural wonders of the world, just south of Tallahassee, Florida, is a place called Wakulla Springs. Up until 1987, it was basically unexplored. You could look at the entrance from glass-bottomed boats, but nobody had seen much more than 100 meters inside on scuba. And we had an opportunity to go there with National Geographic in '87. But it was in '99 that things really got high tech. This project was a good example of how exploration need drove equipment development. Many pieces of technology we used did not exist prior to 1999. We built all this—a floating, saturation diving, recovery system; 20-kilometer-range propulsion vehicles; dual-redundant, closed-cycle PLSS backpacks; and 3-D, automated mapping systems—on a two-year schedule, once we got the go-ahead from National Geographic and corporate patrons. We had a dual closed-cycle PLSS; six onboard computers running this thing; twin head-up displays; 18-hours range. There is no EVA system in use by NASA that would meet this standard, and I'll tell you why. When we get down there, we're going to be doing missions to distances of about 4 1/2 kilometers from the entrance at 100 meters underwater depth. When you're out there, you

are two and a half hours one-way travel time from the nearest egress point. By comparison, if you're on a Shuttle mission or a station mission right now, and you have a problem with your suit, whether it's an Orlan or an ILC Dover suit, you've got roughly 10 to 15 minutes, maybe 30 minutes in open circuit mode at best, to get back to the hatch. Here you don't have that luxury. You are two and a half hours out, and you've got to figure out how you can do it.

It's important to point out that everybody here was in a situation where, no matter where they were on that trajectory, they had an abort scenario. The maximum mission duration by pre-agreement among the teams was 10 kilometers penetration. And you had a factor of four to one safety margin to get yourself back. Everybody who was doing these would rehearse each mission beforehand for upwards of 12 hours (in the spring basin), and have people come in and tell them, for example, that all of their vehicles were dead, they had to transfer and get towed out by one of their partners. And then you'd tell them, for example, that half of their life support system was gone and they'd have to continue out on that. So you're continuously rehearsing all the various abort scenarios. In that sense, it's no different than training for a space mission. But here, we explicitly included abort capability for every phase of the mission. That isn't true of space flight currently.

A typical mission is all about collection of information about what the frontier is. If you're an explorer, you should be out there trying to collect that data, just like Steffanson said, and get back safely with it.

We built for this project a gadget—known as the "Digital Wall Mapper"—with a very high-grade, inertial guidance unit, phased array sonar, and about eight computers. And it's imaging the wall as you drive through, to build a three-dimensional map of the aquifer. The person in back is the safety diver. Their job is to make sure that when this person is driving this monstrosity, that if they do something wrong, they're going to come up and help them out.

Typically, we would have a support crew follow people in to a depth of about 80 meters. Perhaps 150 meters into the cave the crew is running on helium-oxygen, and they'll have 18 hours supply down there. The people on top have got the biggest sport diving cylinders in the business, and they're dumping out about a thousand dollars worth of helium-oxygen on that support mission just because of the fact that they're wasting it away, breathing it into the water column.

And then off you go for approximately the next five and a half hours, with a typical run down here to 100 meters depth, and then you're back. Now you can't come straight out, as somebody like Mike Gernhardt or anybody will tell you who has done EVA. You have a decompression issue, a very serious one. In fact when you're five hours down at 100 meters, you're almost saturated. At 60 meters down, we had a string of closed circuit cameras following people out. They had flashcards so they could tell if everything was OK, or they needed supplies from down there.

When they reached a certain stage—the completion of their 30-meter decompression stop—six support divers would drop out of the sky, like something

out of a James Bond movie, and come down and take away their closed-cycle unit, give them a regulator, and let them switch up into a pressurized, personnel transfer capsule. They would then be transferred up to the top and into what we call a mini-saturation system, where they would spend the next 12 hours. Total mission duration, about 22 to 24 hours. We did this everyday for three days, took a day off for maintenance, and then did it again, for three months while we were down there. No issues with safety on that entire project with any of the mission crews.

Ten million data points were gathered on this trip to build the world's first three-dimensional cave map. So, in our case it's not only a desire to be out on the frontier, but it's also about bringing the data back home. ■

NASA Image/Renee Bouchard

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A Writer/Climber Perspective

I've been freelance writing for 25 years, mostly about adventure, exploration, spinoffs to archeology and history. But before that, I was a serious climber for about 20 years, from age 17 to 37. I didn't climb high altitude peaks like Ed, but specialized in technically difficult peaks in Alaska. And I still climb, although pretty pitifully.

But for me, the most critical question of my life had to do with the fact that by the age of 22, I had been a firsthand witness to three fatal accidents to partners. It began with my first partner in high school, Dave Lee, who, only four months after we started climbing, was killed on the first Flatiron above Boulder. It was not a very hard route, but when we got a rope snagged and had to unrope, he climbed down solo to retrieve it. He slipped and fell 700 feet, with me watching.

Three years later, I was the first person on the scene when two guys fell out of Pinnacle Gully in Mt. Washington, one of whom was actually in training to be an astronaut. We tried to resuscitate them to no avail, and then had to haul their bodies down to Pinkham Notch. And then, just three months after that, on my hardest Alaskan expedition to Mt. Huntington, after all four of us had reached the summit, on the descent, Ed Burns, the youngest of the four of us, a 20-year-old sophomore in college, inexplicably fell, had a

David Roberts
Writer

David Roberts is a freelance writer living in Cambridge, Massachusetts, who specializes in adventure, archaeology, and history. He has co-led 13 mountaineering expeditions to Alaska and the Yukon, making many first ascents, including the direct north face of Denali, the west face of Mount Huntington, and the southeast face of Mount Dickey. He is the author of 16 books, most recently *The Pueblo Revolt: The Secret Rebellion That Drove the Spanish Out of the Southwest,* published this month by Simon & Schuster in October 2004.

OPENING PHOTO:
Left to right: NASA's John Grunsfeld, David Schuman, and Eric Darcy on the summit of Denali (Mt. McKinley), May 2004.
(Photography by Will Reno)

rappel come loose. And we were descending in the middle of the night, we could just barely see in the Alaska twilight. And without my knowing, even today, what happened, the rappel fell, and he simply fell away from me 4,000 feet, and we never could even look for his body.

The question to me now is, why did I keep climbing after these terrible experiences? At the time, I didn't even really examine it. I mean, I came close to quitting, but I didn't really examine why I kept climbing. I think if somebody had asked me, I would have said, "Well, wouldn't their deaths be even more pointless if I quit climbing?"

So, when I tailed off climbing and got interested in writing about other climbers, including Ed, I got much more interested in this whole question of risk, motivation, and the risk-reward payoff. And, in 1980, I wrote an essay called "Moments of Doubt," an apologia for doing something as crazy and risky and useless as climbing.

My favorite climbing autobiography is Lionel Terray's *Conquistadors of the Useless*, because it is an awkward, but telling, phrase. And just this year, I've finished a memoir about my climbing in which I actually come to the opposite conclusion, that maybe it wasn't worth the risk. And what changed my thinking about this was that I had always thought about risk in terms of the question, basically sort of a solipsistic, selfish question, does the reward I get for making a first ascent make up for the risk and the tragedy of someone dying? And it took me 35 years to realize that that was just a completely self-centered and, therefore, sort of stupid question.

And one of the things I did a few years ago was to go back and recontact Dave's brother and sister, the only surviving members of his family. Forty years after the accident, and I had never communicated with them. And I found that his sister, in particular, was still in a rage with me over that accident, and that she lived with it every day of her life. We spent the most intense seven hours straight in Seattle on a park bench talking about it, and trying to untangle her feelings about it. And I finally realized that the question of, is it worth the risk, is not one you can really just apply to yourself. It really does involve family, the larger society, and humankind, ultimately.

The *Fram* under sail. (Amundsen, Roald. *The South Pole, Volume I*, p. 170.)

I guess if I still had to come up with a rationale for climbing mountains, it would not be anything to do with the thrill of it versus the penalties, but, rather, whether the very endeavor has something inspirational about it that lasts. And I think by analogy with Scott and Shackleton and Amundsen in the Antarctic, they justified their expeditions in the name of science, just as I think NASA is continually doing. And Scott, when he died, had 30 pounds of rocks on his flesh, geological samples. He tossed away everything extraneous, but he somehow thought the 30 pounds of rocks were worth bringing back. Apsley

Cherry-Gerrard's worst journey in the world was to gather penguin eggs in the middle of winter from Cape Crozier, and under the misapprehension of the now exploded theory that ontology recapitulates phylogeny, penguins being the most primitive birds in the world, their embryos would tell us all about early human evolution. It's complete bunk. He performed the worst journey in the world to gather three penguin eggs. But we don't remember Scott, Shackleton, and Amundsen for their science, we remember for their example of daring adventure and exploration and going where no one else had ever been. To me that was the first, and is still the most exciting, part of exploration, to go where no one else had ever been. The only rationale for it is if it inspires other people. Ed Viesturs clearly inspires other people. I have been at talks he has given where the groupies have just gathered all around him. They want more than autographs. Is he a rock

> "I GUESS IF I STILL HAD TO COME UP WITH A RATIONALE FOR CLIMBING MOUNTAINS, IT WOULD NOT BE ANYTHING TO DO WITH THE THRILL OF IT VERSUS THE PENALTIES, BUT, RATHER, WHETHER THE VERY ENDEAVOR HAS SOMETHING INSPIRATIONAL ABOUT IT THAT LASTS."

star celebrity? No, but there clearly is something that touches the human spirit and, as corny as Bush's line is, "the desire written in the human heart" really does have to do with risk and exploration.

One last note, a curiosity from the Renaissance. We're taught, on and off, about the Renaissance, but someone calculated that on a typical Renaissance voyage to the New World, sailors stood a one in three chance of not surviving. And that makes Everest look like a piece of cake. It makes Bill Stone's stuff even look safer. And the collectors of the narrative of the voyages write often about the adventurers, but the adventurers were not the sailors, they were the guys that put up the money. The real adventure was taken by the financiers who backed the expedition. The sailors were just expendable work hands. All of this needs to be put in a historical and multicultural perspective. ■

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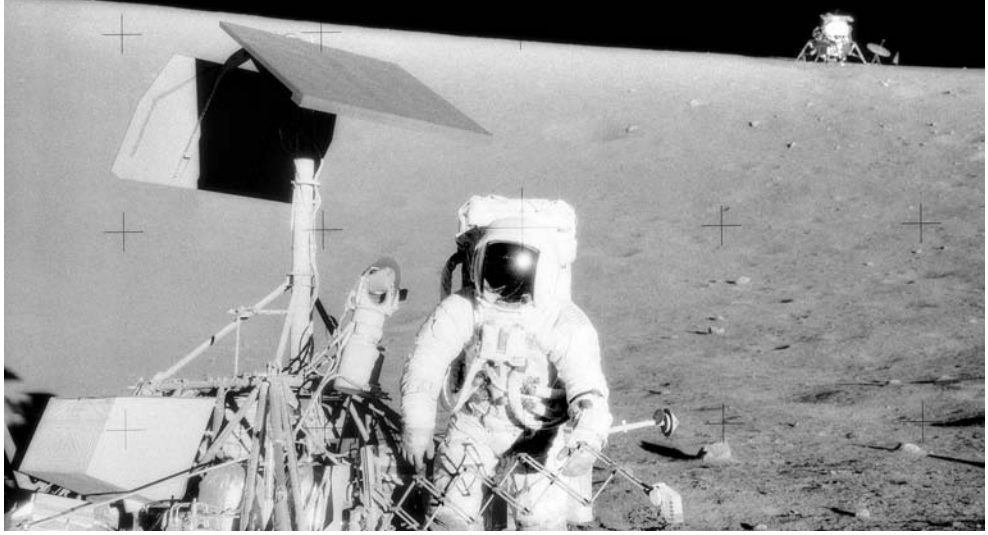

Discussion

CHRIS MCKAY: Okay, what I'd like to do now is to go to open discussion. Keep in mind what you heard, and keep in mind the questions that would be relevant to NASA, in terms of sending humans to explore. Points that David made—is it pointless to send humans, especially now with technology advancing and, people argue, we could send machines. And it ties to these questions that David raised. And what I would like to do is have some audience participation and discussion. You can ask questions of anyone you want, or you can make a short statement.

QUESTION: Darlene Lim, NASA Ames Research Center, and my question is for Bill Stone. I wanted to find out what some of the advantages were that you presented, to say it would be more advantageous to send humans into the aquifer and do the mapping that you outline versus sending in submersibles?

BILL STONE: That's a fantastic setup. There might be one or two others in this audience with similar background, but I think I've found myself in a unique position in having spent about a decade of my life designing spacecraft and another decade designing robots, and now robotic spacecraft. During "CFT," or "copious free time," we do some work underground. The answer to your question goes like this, and I'll try to put it to you as succinctly as I can. There are places where robots are entirely logical to be used first, and I classify those in two situations. First, places that are lethal to humans, and second, places which are currently too remote to get to send people to with our primitive propulsion technology systems. So you send robots in those situations.

Everything else, in my opinion, is best done with people. Now, at some point, you do have to draw the line in the sand to say this is too risky. As I said when I was looking over that list of departed friends—no different from Jim Lovell citing off a list of test pilots he has known—these are dangerous environments. The reason we are still here is because we knew where to draw the line in the sand. Even if we do that, there is still unquantifiable risk, so the game is to say, all right, you want to be out there in person. Probably everybody in this room wants to be out there in person. Do I want to be here today? To be honest, I'd rather be at Shackleton Crater on the Moon right now, for a couple of

OPENING PHOTO:
Charles Conrad, Jr., Apollo 12 Commander, examines the unmanned Surveyor III spacecraft during Apollo 12's second extravehicular activity (EVA-2). The Lunar Module *Intrepid* is at right in the background. (NASA Image # AS12-48-7136)

years with a dozen good, qualified people. I'd be happier there than I am here or at work. Being on the frontier is what I live for. That's where people like Ed Viesturs live. If you don't understand that, you need to go on an expedition somewhere remote. Maybe you'll like it, maybe you won't, but among the people I work with, you can tell right off the ones that are concerned about where they are . . . you see it in their eyes when they get to someplace like Camp 3 or Camp 4.

In fact, people that I've worked with for years on expeditions have a name for it. They stole it from Jacques Cousteau: it's called "rapture of the deep." You can tell because their eyes are getting wider, and they're sitting there at those camps going, "I need to be concerned about getting out of here," rather than focusing on the job at hand, which is pushing the exploration frontier. The people you find that have a bigger smile on their face the deeper you go, those are the people you want, those are the ones you want out there with you at the frontier. Now, to go back to your question directly, why do this in person? Because it is the most stimulating thing that you will ever experience in your life. I have had the privilege of being where no one has been before many times. It is difficult to put into words to those who have not experienced it just how moving that feeling is.

If I had to capture a 20-second image on film that depicted that event and what its importance is personally to anybody who does it, it would be [from] the film Apollo 13 that Jim Lovell made with Ron Howard, where they show the image of flying by the Moon and the astronauts thinking, "I could be down there, lifting that rock up and looking at it in my hand." That's what drives us on. If you look at what we do in our normal lives, it pales in comparison.

CHRIS MCKAY: Bill just made a very good case for human exploration. I think we want to hear a countercase, so somebody in the audience think of a good case for why the space program should just be robotic, why we shouldn't risk human life. If there's no one in the audience who can state that case, we don't have a well-selected audience. Somebody come up with the counterpoint, the argument (so we can pillory them) why robots are sufficient. With that enticement, we'll go to the question here.

STEVE COOK: Steve Cook, NASA Marshall. I won't take that question, but I will say, first off, I think there's a gold mine of analogies here that are applicable to exploration that we need to capitalize upon as a country, to sell and sustain a vision that I don't think we're doing as well as we could today. With all of the experiences you've been having, a lot of these are firsts with me and I've been with NASA for several years. Question now with risk, with respect to Ed Viesturs and to Bill Stone. Ed, you talked about making the decision to hold back—you had the camera crew, this would have been a perfect time to go; your friends did not. I'd like you to talk a little bit about the criteria you used versus what you think or know that they used. Why did they go forward versus why did you stay?

ED VIESTURS: When we go to Everest, we spend six or eight weeks preparing for that final day. That's carrying loads, building camps, acclimatizing. And then the idea is that sometime in May, historically, we know that there's going to be

a window of favorable weather that would allow us to do that final 3,000-foot climb. So the whole preparation leads to that. Once you're ready, then you have to take into account everything that you see around you. The weather patterns—now we can get good weather forecasting. In those days, it was just kind of starting to work, but we would have to base our judgment and what we were thinking about doing on what we were seeing, what we were feeling; our gut instinct has a big role in how I make my decision—you know, what am I seeing and how has that played a role in what I've done in the past. And we made a group decision—David Breashears, who'd climbed Everest twice, I'd climbed it four times by then—as a group, we all felt that the weather patterns that we were seeing were not historically what we were waiting to go to the summit with. So we made the call based on that and, also, just the fact that it didn't feel right. And I think Bill mentioned that, I think the reason a lot of us are alive today is because we know when those red flags are popping up, that we have to listen to our instincts. If we discover later that we made the wrong decision and the weather was good, well, big deal. We erred on the side of safety and being conservative.

Our friends, they had this date in their mind, and that was May 10th. And, a lot of times, climbers do that. Come hell or high water, they will just go for the summit on that particular date—because it's auspicious or whatever. And I've always said, ultimately, the mountain decides when you can go up, and you have to listen to what the mountain is telling you. There are signals, and you can't blindly, stubbornly go up, because we all know that Mother Nature is much stronger than we are. They did start on a good day—it was perfect. And had they turned around in enough time, they would have escaped the storm, which came late in the day, which is something that we saw developing every single day the past two weeks previously. But, again, they got so close to the top, they pushed further and further and further away. That umbilical cord of safety got stretched and finally broke. And I can't second-guess the decisions that they made. I wasn't up there. I can evaluate what they did. I can say that I wouldn't have made decisions the way they made them, but, again, as Bill said, there wasn't one decision that was wrong, it was a multitude of little problems, and then the straw that broke the camel's back was the storm, and then people died.

CHRIS MCKAY: Ed, I'd like to ask you a question. Do you have a personal short answer to the question of why you climb mountains?

ED VIESTURS: I'm a stubborn person, I like challenging projects and, for me, climbing is the most difficult physical and mental thing I can think of doing—especially without oxygen. And I know I have to train, prepare, think about what I'm doing, to be successful at it. And there's a huge struggle to get to those altitudes without oxygen. And so many things can go wrong, and when you succeed, and when you finally are standing on the summit of Everest, it's an amazing feeling. And it's something I can't find anywhere else, and, so, I've become addicted to it.

CHRIS MCKAY: Would you classify what you do as exploration?

ED VIESTURS: I explore myself. And I think that's the interesting part. I think, also, you can be in the middle of the desert, you can be down in the ocean, if you get in trouble, somebody can come and get you. Up there, you're on your own. If you make a mistake, you have to get yourself out of it. And it's a very rare feeling. As normal, sea-level, landlubbing people, we don't get that feeling of isolation where we think about every single step and every single move that we make, [that] there can be consequences because of those. And that's an interesting thing that I feel up there.

CHRIS MCKAY: Thanks. We have a question here.

QUESTION: Dennis Wingo, Skycorp, Incorporated. And this is for Neil, Ed, and you, Chris. I see a commonality between what you do on the mountain, what you do underground, and what you do in the Arctic. And the commonality is a staged approach, abort modes—you don't do everything in one big, fell swoop. And it seems that in the space arena that we try to do that, whether it's a manned system or whether it's un-manned. But especially in the manned, because there's a religious argument (I call it) going on now at NASA: Do we build a heavy lift launch vehicle, or do we use the assets that we have to go back to the Moon and on to Mars? It seems that with the assets that we have now, and that we [will] have in the near term, we could use your staged approach to go to the Moon and go to Mars.

ED VIESTURS: Yeah, for us staging is critical, because we have to not only put supplies at various camps, but it's also the process of acclimatization. So, you need to take the time to go at various altitudes, and then come down to recuperate, and then, slowly, work to a higher altitude. It's kind of a necessity in both aspects, acclimatizing and, also, then, getting your gear in place. Once acclimatized, though, I've developed a system now where we'll go very quickly and—like you said, in that big launch vehicle we'll carry everything that we need, and, in three days we'll do what normally takes two months. We'll climb, moving everything with us, and then go to the summit. That's riskier, but it's also faster, because you're spending less time in a dangerous environment. So, I think the trade-off is worth it. I'd rather climb faster, without the series of camps behind me, but I need to do that initially to acclimatize.

CHRIS MCKAY: Bill, you want to give us the downward view of the same thing?

BILL STONE: It's no more risky than being a test pilot, in my opinion.

CHRIS MCKAY: And your point?

BILL STONE: No, I mean, you can control the risks. There's one thing that you can't control, but you can prepare for, and that's the weather. And we're going to have that kind of phenomenology wherever we go, whether it's a big storm that comes in on Everest or whether it's a hurricane that dumps ten inches of rain over the plateau and you get a 10-meter-high rise in the water wherever you're

at. I have friends who have bolted their way 30 meters up a canyon wall in New Guinea as the water rose behind them. They hung from rock bolts for 32 hours waiting for it to go down. They were prepared, you know. Yes, they were in a dangerous place, but they had their act together.

Let me extend this to space, because I have actually put a lot of thought into this. I've designed space systems. I've designed reaction control thrusters. Things like that. One of the things that apparently has been misunderstood here is that we did have complete control over the situations where we were—even the weather. All of our camps were selected to be above the water. The way the ropes were rigged—all of that stuff was of very high reliability. Further, we trained everyone on the team to know when to replace things, if they discovered that a line was fraying, for example. And there were depots of spare rigging tackle situated at various locations along the way for just such emergencies. We even had ways to get out if a rope broke—equipment for scaling overhung domes. We had all these things covered.

Now, if you switch to trying to think about what are you going to do if you're trying to get to the Moon—which is the next logical target for us to get back to here, and prove that we can live off this planet—the first thing you've got to say is, all right, how are you going to get to low earth orbit (LEO)? And there are only so many ways that we can do that right now.

You've now seen what I do. If you were to say to me, "Would you fly the Shuttle?" or something like that, then I'd have to say, "I have to think very carefully about that," because it does not meet my criteria for having an abort mode at any point in the trajectory. You didn't pay me to come out here to give you sweet talk, so I'm going to talk to you straight. The last time we had a launch vehicle that met those criteria is when these [Apollo] gentlemen were flying. Why on Earth have we not done that now? That's just my personal impression. If I was going to try to put something up there, we'd probably be using ELVs with abort modes to get us out to LEO. Beyond that, you're into the issue of how survivable are your vehicles? You need to be thinking in terms of propulsion, life support, and everything else.

You guys are great at this. NASA is a technological gem on this planet. But, unfortunately, you don't have any true "expedicionarios" here, as we say down in Mexico—true expeditionary people who think, "Two years from now we're going to run an expedition to the Moon." And then go do it. The way NASA thinks these days is, "We can develop these technologies and, maybe, 15 to 20 years from now we'll be back on the Moon." That's too late. That's too late. You've got to get there now and learn from the frontier, just the way we've been doing underground here on Earth. Those places you've seen today were unexplored 12 years ago—completely unknown. We built the technology to go there. Given the enormous resources at NASA, there is no reason that we can't be back on the Moon within five to seven years, max.

QUESTIONER: If the Moon is where you want to go.

BILL STONE: There you go!

DALE ANDERSEN: I want to go back to your question about staging, which was doing things in steps. I think a lot of the issue there is knowing what the stages ought to be. I remember once getting a lot of flack—we were going to the Antarctic to do diving under the ice. I put in travel orders to go to Key West—that was our staging spot. We were going to do training for ice diving in Key West.

Now, maybe you could argue that was a good place to go to stage the Antarctic, or maybe you could argue that it wasn't necessary. So, when we plan anything, any expedition, I like to think: What is our goal? What are we really trying to do? What's the driver at the long end? And, then, what do we have to do to get there? If you look at the way Apollo worked, as I understand it, it was very much that way—as we heard this morning. You want to go to the Moon, so you need to develop docking, you need to demonstrate that you can stay in a spacecraft, and so on. Take something like Gemini—it was a requirements-driven program: If you want to go to the Moon, you're going to have to do this first. It wasn't: Let's do Gemini and see where it leads, or some nebulous concept that, somehow, if we develop these things, a mission to the Moon will miraculously appear from the pieces.

And, I think, as we think ahead to an exploration program, we have to do the same thing: Where do we really want to go, and, then, what are the pieces that lead us there? And I think that's also what Bill was saying. So your question is a very good one, and I think exploration on Earth, and people that plan expeditions on Earth—the logic that they approach can be applied, but the answer is not so easy to come by.

CHRIS MCKAY: Okay. Maybe someone can address my challenge to pick up the case for robots, but probably not you!

QUESTION: Well, maybe I will! I'm from Goddard Space Flight Center, a scientist-type as opposed to a program manager, which seems to have been commented upon today.

CHRIS MCKAY: Derisively, I might add!

QUESTION: It seems to me that over the years NASA has been very ambivalent about people in space and science. Back in the '60s, getting people up there seemed to be something done for its own sake. Putting somebody on the Moon was done for its own sake. Then, in the '70s and up to maybe the '90s, we started getting into a mode where we were trying to be sold on the fact that people had to be there to do the science better. And it never appeared to me that that was the case—that it was a selling job to justify getting people in space, for the most part.

And I guess my question now is: do you think that the public, Congress, and the media are ready to do real people in space as opposed to trying to do the science with robotics? My personal feeling is much of the science could be done better with robotics, but we're not going in that direction right now.

CHRIS MCKAY: Okay. That's a good start to the case for robots. And I think we need to put that case out there as part of the complete discussion, because one

answer to the risks is, don't send people. You avoid the risks. If we go back to Dale's categorization of risks—mission risk, personal risk, and team risk—what you eliminate is the personal risk and team risk by not sending people. Certainly, when Steve Squyres did the MER mission, there was risk. But no one's life was at stake on Mars—it was just a programmatic risk, a science risk. The worst case that could happen was that Steve would have wasted seven years of his life and no publications would have come out of it. Steve might have felt that that was a disaster, but no one would have gotten killed over it.

So, I think the case where we think about risk—we can't just assume that means that humans are in the loop by definition and, therefore, we figure out how to deal with the risk with humans. We have to step back once and say: are humans even an essential part of the program, of the loop, or do we try to do science by robotics?

So, now we've made the case for robots. Let's let the panel and the audience react to that case. David is going to add to that. We've got a momentum going here!

DAVID ROBERTS: No, I actually would strongly believe that robots are the answer. And I think it's probably my father's influence, because he told me years ago, as an astronomer, that there's no way we're ever going to get very far in human terms in space, so the future is going to be robotic. And I found the Mars rover landings more gripping than the original Moon landings, human-equipped Moon landings. And I would say that the Hubble Telescope was far more important and exciting to me than any manned travel in space.

And I think that, for the first time in history, maybe we can actually make the emotional and psychological investment in machine discovery—as we're also doing in the deep sea—in lieu of the conquistador going out there and doing it himself.

CHRIS MCKAY: Okay. Penny, I'm hoping you'll take the contrary view!

PENNY BOSTON: You know I am!

CHRIS MCKAY: What a surprise!

PENNY BOSTON: I think that there is no dichotomy between robotic and human exploration. I think much ado is made out of that. They're obviously context-dependent. There are strong reasons why we're interested in human exploration beyond simply the scientific function. And I disagree that now, or any time in the near future, or even the mid-term future, we can design a robotic instrument that can have the capabilities of the tremendous flexibility that a field scientist can have.

However, that being said, I am a great fan of robotics missions. I love robots—I wish I had whole fleets of them myself. I'm trying to get MIT [Massachusetts Institute of Technology] and JPL [Jet Propulsion Laboratory] to build whole fleets of them—because they're a tool. They're not a viable life form at this point. At this point, it's not as if we're going to send robots or people. They are obviously complementary to the whole scientific process. But science is, fundamentally, a human enterprise, and the value of science is, fundamentally, to us as humans.

And, so, therefore, cutting us entirely out of the loop, I think, is inexcusable.

And, so, wherever in the solar system we can send people, where it makes sense and where people can significantly contribute—and one of the things that they have to contribute is that perception of the human experience of exploration—then I think that we should endeavor to do that, and save the robots to be our helpers and to go places where we can't go, to go first. And even on Earth, where we're exploring certain caves where we have tiny channels that we can't get into, even microrobotic devices there would greatly enrich our scientific exploration.

CHRIS MCKAY: Well said. Dale, and then Nathalie, can respond to the same question, and then we'll take a question here from the woman in black, and then Jim Garvin. Dale?

DALE ANDERSEN: Briefly, I was just going to actually completely agree. I think it's a mix; it's not an either/or case. When robotics are required they should do the job, and when people have the capability to go to those places, people should be in the loop.

I've used both robotics and going there myself, and I have to admit, I've been underwater with robotics, for example, while people at Ames have been diving with me virtually via that robotic device. That's a great way to share your experience in a remote location with a greater population. But it's not an either/or thing; it's just the right tool for the right place at the right time.

CHRIS MCKAY: Nathalie, could you add a little to that? And then we'll go back to general questions.

NATHALIE CABROL: I'm supporting both Dale's and Penny's views, because I've been putting together in the field an astronaut and a robot. And neither are always best, but they complement each other. And for exploring a planet, the human being will bring in his immediate background and an understanding of what's around him, which a robot cannot do now and will not be able to do in a long time. But, by the same token, the robot does not care too much about the environment. Is it cold, is it hot, is there lots of UV radiation? If there is an opportunity, they just don't care, they can last a long time at the surface. Together, they are almost an invincible team, but I would go a little step farther than that. I would say that, no matter what we think about it, exploration is within our genes. This is where part of evolution is right there in us. We wouldn't be here if we wouldn't have been taking risks and going from one place to another and exploring diverse habitats. And another planet is just the next frontier for us; there will be farther frontiers than that.

QUESTION: I'm Becky Ramsey, I'm from NASA Headquarters, and I have to say that regarding human versus robot, I have to come down on the human side, because I want to go. Yeah, and that actually leads into an issue I want to raise. I want to touch on something that we talked about earlier this morning, and that's individual versus government exploration. To bring up the example from this

morning, Burt Rutan is ready to launch in just a couple of days here. What he's done is private financing, small group, hand-picked people. And that seems to be very similar to what you all do, whether it's individual or privately financed or government financed, even if it's a direct NASA project. What you do seems to be very small—one person, five people, even a hundred and fifty people—when you compare that to my colleague and I who work in the same building and have not met before today. That's very different. You know everybody on your team, and you're getting a lot further out there than we are. Is there something to be said for that—can we do this? Can government do this, can an agency like NASA do, in space, what you have managed to do here on Earth? Or do we need to find a different way and look at smaller, more team-focused models to do this?

CHRIS MCKAY: That's a really good question, and when we look beyond Earth orbit to distant destinations like Mars, the question becomes more pressing, because those teams have to be, by light-travel time requirements, more and more autonomous, and less dependent on remote control from Mission Control. Anybody want to address that, comment on that? Penny and Bill, think of an answer, too.

PENNY BOSTON: Okay, I'm thinking real hard, that's a really serious question people are wrestling with. The kinds of expeditionary things that we do are very small compared to a full-on mission to another planet. Therefore, the sheer number of people involved is so large in order to pull off a mission like that. In some ways, I'm not entirely sure that a lot of our experience in these smaller units is directly applicable. Because, by force, you have to involve so many more people, and the level of planning complexity far exceeds anything that any of us do.

So, the question is, can you do that in a governmental environment? Well, I think NASA is doing it in a governmental environment. And I don't see why, fundamentally, that transition from the kinds of missions that we're doing now can't be applied to also incorporate serious, meaningful, human exploration, plus an ongoing program. I don't see that it's not possible, with the caveat that, for certain applications, perhaps small companies are better, for certain limited things. Burt Rutan is also not doing NASA. He is not doing NASA in a can, basically. He is doing a very different scale of things than NASA has to worry about.

CHRIS MCKAY: Okay, I'm going to skip Bill's answer, because I think Penny hit the nail on the head, so we're going on to the next question, which is Jim Garvin.

QUESTION: Well, thanks Chris. I'm Jim Garvin, NASA Headquarters, Moon-Mars. I wanted to comment, and then address, an issue to the panel and everyone about the robot/human dichotomy, because I don't think it is one, and I think we have to pay attention to the great observations you all made. Because, in our history of space exploration, it was the robots that did the reconnaissance, the advance planning, and let the humans, like the great courageous heroes today, do the work. And I would submit to you that it was the humans back on Earth, and Apollo 17 and the others, continuing the work of the robotic spacecraft. So

An artist's rendering of crewmembers setting up equipment during a Mars polar exploration. (NASA Image # JSC-2004-E-18861)

it's that partnership that's important. And in many of the cases you've talked about, robotic reconnaissance wasn't needed to open the frontier. The humans could do that on the fly.

I would dare say I wouldn't want any of you brave people to go to the surface of Venus for the first time. It's probably better for our robot friends to do that. And today, as we think about Mars, I would submit that we're learning through the rovers that Steve [Squyres] will talk about. And what we're planning in the future is the reconnaissance necessary to go to those sweet spots on Mars. So then the humans become important onsite to do that kind of work. And I always marvel, if we think about this dichotomy, humans and robotics work together when we look at the samples brought back from the Moon from the Apollo mission. These multikilograms, each one itself a mini-universe for robotics and people to work together with here, to understand that world on the Moon. Imagine that anywhere we go, whether it be on Earth or beyond.

So, I look at it as the reconnaissance that's important, and today, a lot of that reconnaissance is better done on Mars, on the Moon, on Venus, way out where the origins of the universe are, by the machine. The question is, here on Earth, how can we amplify your experiences in these unique environments to better train us to use that reconnaissance to make the tactical decision to put humans on site, because we need to because it's in our gene pool, or it's necessary; it makes us better samplers. That's the question that I think this risk conference is treating, and I think, at times, that unfortunately comes down to the ugly words "programmatic cost." Where is the timing of that benefit?

CHRIS MCKAY: Okay, good comment. Let's go to Keith for another comment or a question.

QUESTION: Keith Cowing, NASA Watch.com: Okay, you were trying to pick a food fight a few minutes ago, and I love a food fight.

CHRIS MCKAY: I'm trying to claim my role as moderator to stir the conversation.

KEITH COWING: Well, in that case, I'll take that on.

CHRIS MCKAY: You can always fire the moderator, you know.

KEITH COWING: Whether it's robots or humans, in essence, it comes down to us going out there, whether we do it first or second or in tandem, and I guess one observation to make, to throw a little raw meat into this argument, is it's all about what we as a culture are looking to do. When is the last time somebody threw a ticker tape parade for a robot for doing something in space? When's the last time we all cried at a national funeral when a robot didn't work? Just an observation.

CHRIS MCKAY: Let's go to Donna Roberts, since I skipped her in the sequence. Sorry, Donna, you had your hand up a while ago, and then we'll come back to you, Steve.

QUESTION: I'm Donna Roberts, of the University of California San Francisco Medical Center, and my question is, with humans and extreme environments, where safety is utmost, and pushing physical capabilities, what is necessary for medicine? Should it be a first aid kit, should it be medicine, should doctors be there, what kind of diagnostic and therapeutic capabilities should we have?

CHRIS MCKAY: Can we get some quick answer? Penny, Bill, we'll let you answer this one.

BILL STONE: You just got me fired up. If you asked me to go plan an expedition to Shackleton Crater or something, who would you take? And I've thought about this, the answer is, number one, you bet, you're going to have a physician. He/she also would probably be cotrained in dentistry. You may have to have a back-up to that person, as well, who is perhaps cotrained in something else. We try to have a physician on every project that I have ever run. It's just too good a capability to have at base camp, whether they're out in front or not. It's one of those contingency things you have to think about when you're talking about long-duration projects. OK, if you're at a place where you're only an hour and a half away in orbit before you can drop back in—like you are right now at the space station—it's not such a critical thing, provided you have on-demand reentry. You're not going to have that on the Moon. So, yeah, you will have to have physicians out there, no question about it. The question is, what other skills should they have? And if I had to pick two, I would say emergency room experience and dentistry. The other surgical disciplines can be actually done through telesupport from the ground, as long as the individual on the expedition has basic surgery skills, as most ER types have. You can go on from there with all the other skills as well. My estimates for a sustainable lunar base exploratory mission run from 12 to 18 individuals, not unlike the minimum critical mass we currently use on deep caving expeditions.

CHRIS MCKAY: Isn't that something—you go to Mars so you can visit the dentist. That's why we need to send humans. Robots don't need dentists. We

have a question here, and then we'll get to Steve. If you can pass the mike to Steve Squyres. A question here?

QUESTION: This is for Doctor Stone. Scott McGuinness, submariner, a student here [at the Naval Postgraduate School]. Doctor Stone, as a diver, I was looking at your videos, and you go deep into these caves, and you dive. U.S. Navy tables and the Haldanean model don't take that into consideration. So, my question is, how did you mitigate the risk of decompression illness (DCI), and how can that compare to the risk of radiation and all that for astronauts going to Mars? It seems like one of NASA's larger problems is how do we mitigate the radiation hazards of deep space.

BILL STONE: Decompression is not a big issue for lunar and Mars missions, at least from my standpoint. Mike Gernhardt and I could probably debate this for another 8 to 10 hours. The answer to your question is, those life support devices that you saw there had triple parallel redundant decompression engines running in real time—that is, the algorithms were running in parallel on three separate processors at the same time, such that you were guaranteed a valid tissue tension even if two of the three processors shut down during a mission. The algorithms were written in accordance with what we had known to be conservative, and we drew a line that was about 15 percent more conservative above that. It took into account real-time oxygen concentration and then fed that through a head-up display. What that meant in terms of an operational situation is that when a yellow light would come on while you were in the middle of a dive, it would mean that you had to be considering what your decompression scenario was going to be like when you started to come back up. When we got to those stages, we would automatically boost the oxygen concentration, such that we were far in excess of what would be required for a conservative decompression, yet below central nervous system (CNS) toxicity limits. We have never had a bends hit on any of those deep caving projects, even though we're diving at altitude. All of those PLSS units have triplex digital depth sensors that are also sensing atmospheric pressure at the altitude at which we were diving. That was all really taken care of pretty conservatively.

As far as I understand it, and I don't profess to be an expert at this, the issue of space radiation is really one of shielding and stochastic analysis of what the radiation environments are. You don't want to be out there on the 11-year cycle at solar max. If I remember correctly, there were some analyses of deep space radiation loading that were done in the '70s that indicate—and I can't remember a specific citation, maybe Jim knows—that between two of the Apollo flights there was a solar anomaly of sufficient magnitude that if you had been flying to the Moon during that time, there may have been some serious exposure issues. To me, dealing with deep space radiation exposure is actually something you can mitigate through a series of water barriers and things like that. I believe it's 10 centimeters of water that is sufficient to stop most of that. If you check through the right areas and within NASA, and probably JSC [Johnson Space Center] has

people in this, you'll find the answers to those questions. They've been looked at thoroughly. I don't consider that anything more than an engineering problem.

CHRIS MCKAY: Steve Squyres. Introduce yourself.

QUESTION: Steve Squyres, Cornell University. I want to return briefly to an issue that was raised earlier about how small organizations seem to be able to sometimes accomplish more. If you look at what somebody like Ed Viesturs does or what Bill Stone does, or if you look at a group like Burt Rutan and what they are accomplishing there, it's easy to look at an organization like that and say, "Boy, they're lean, they're compact, they're able to get the job done." You then look at larger government agencies and you sense a difficulty there. But I think there is a wonderful counterexample. The wonderful counterexample was what Jim Lovell talked about this morning. It was Apollo.

You look at Apollo, and you look at Gemini, and you look at Mercury, you look at what was accomplished in those days, and it [NASA] was a huge organization. It was in some ways bigger than the NASA of today. Yet, they got things done.

When I look at that, what strikes me is that there was a common thread through those organizations, and that is that they knew exactly what it was they were trying to do. The level-one requirement for Apollo was stated in one sentence by the President. When Ed goes up a mountain, he knows what his level-one requirements are. It is very, very clearly stated. If you have a common goal that is clearly understood by everybody in your organization, I don't think it matters how big the organization is.

CHRIS MCKAY: Good point, Steve. We have five minutes left. We have time for two questions.

EUGENE RODDENBERRY: Hi. My name is Eugene Roddenberry. My father actually created Star Trek and, working in the industry, I have met a lot of people who have been inspired by the show. It's completely different to work in entertainment, but the people who have been inspired have inspired me to look around the world and meet individuals like yourselves. I think you guys have shown that humanity is able to overcome adversities. And the fact that that inspires other scientists and other people in the field to reach for the stars or down to the depths of the ocean—I think it goes beyond that. You guys inspire fans who have disabilities to overcome those disabilities, people who are in relationships, people who have everyday risks that they need to take. I think the fact that they see that humanity can take these huge leaps—these steps beyond—is important. It is very impressive. I just wanted to say thank you to everyone. It's very exciting.

CHRIS MCKAY: Thanks for your comments. The next time you send a message to your Dad, thank him for me. I was one of those Trekkies that got inspired to seek out new worlds and all that stuff from watching the show. It's the only television I watched. Larry?

LARRY LEMKE: Larry Lemke, NASA Ames. I would like to actually follow up on Steve's comment, and some others on this whole question of how do you take the lesson from small-scale exploration and put it into a bigger context. I agree with Steve. I actually don't think that size of the organization per se is the issue. If you look at the participants on the panel, one of the sort of obvious characteristics that they share is that, not only do they plan the expeditions, they do the expeditions. I am reminded of that comment that there's nothing like the prospect of being hanged in the morning to concentrate your efforts. If you look at the way NASA typically plans a large human exploration project, it is sort of notable that the people who are making the decisions very often do not really have to experience the personal consequences of those decisions. I think if that were to change, then the results might change as well.

CHRIS MCKAY: So, you're saying we should send a NASA administrator to Mars? Is that a way of interpreting what you said?

LARRY LEMKE: Or have the NASA administrator to actually design the vehicle. Get the opportunity to fly in what you design.

CHRIS MCKAY: We actually have a few more minutes.

QUESTION: Bruce McCandless, two Shuttle flights [astronaut]. We get back to the human versus robot trade-off. Currently, when you are looking at a Mars mission, you're looking at speed of light transit times, round trip up to 40 minutes. So, obviously, it's gonna be hours when you get out to the vicinity of Jupiter and Saturn. The thing that seems to be missing is the refined decision-making ability, the ability to adapt to unforeseen situations, to recognize something that you haven't been programmed to recognize. I assume that, eventually, computer science will advance to the point where we can send androids. I wonder if anyone would like to comment on the speed of light transit time as a factor in trading off between humans and robots.

CHRIS MCKAY: That's a good point. Maybe I ought to add to that question, how will that influence the autonomy of an expedition on Mars versus the autonomy of, say, a Shuttle or a station where there is virtually no delay—see them as being more autonomous or not. Does anybody want to approach that? Penny? Dale?

PENNY BOSTON: Yes. I think that it's a return to some of this historical stuff that Jack Stuster was talking about this morning: the fact that those expeditions, before there was the kind of instantaneous communication that we all have, were able to operate and do what they needed to do. We seem to somehow believe now that we cannot do that any more. I think that a different kind of planning within NASA perhaps will be necessary to take us back to some elements of that kind of self-contained expedition. ■

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