ORAL HISTORY TRANSCRIPT

WILLIAM R. MUEHLBERGER
INTERVIEWED BY CAROL BUTLER
AUSTIN, TEXAS – 9 NOVEMBER 1999

BUTLER: Today is November 9, 1999. This oral history with Dr. William Muehlberger is being held for the Johnson Space Center Oral History Project. It is being conducted in his offices at the University of Texas in Austin. Carol Butler is the interviewer, assisted by Kevin Rusnak and Sandra Johnson.

Thank you for joining us today.

MUEHLBERGER: You're welcome.

BUTLER: To begin with, if you could tell us a little bit about how you first became interested in geology.

MUEHLBERGER: In geology. When I was six, we moved from New York City to California. I have no idea why my parents did it in the middle of the depression, but anyway, they did, and I was picking up rocks. I think the two things that really got me into geology were, first of all, Boy Scouts, where one of the fathers would take a carload of us hiking every Sunday up into the San Gabriel Mountains behind Hollywood, where we were living, and he knew all the trees and all the birds and all the rocks and that sort of thing, a great teacher [therefore] of that sort of thing.

Finally, instead of taking study hall my senior year in high school, I took a semester of physical science, a course that was a combination of meteorology, astronomy, and geology. That settled it, in my mind, so I started as a geology major. I graduated out of high school in January, and I was going to apply to go to Cal Tech [California Institute of

Technology], and their entrance exams weren't until April, so I went to Los Angeles City College for a semester and took courses while waiting to take the exam. I started at Cal Tech in the fall.

Where else do I go? I'm in geology.

BUTLER: Okay. While you were starting out as a student in geology, what were your initial thoughts of what you would be doing, or your interests?

MUEHLBERGER: I had a dream that—well, let's go back a bit. I started in the fall of '41. Then along came Pearl Harbor and the war, so I ended up having two years at Cal Tech before I went to active duty in the Marines. They sent me to Berkeley to become a civil engineer, so [I am] one semester shy of having a degree in civil engineering.

Then—after the war, back to Cal Tech as a junior again in geology, and eventually went on through my master's, started my doctorate, and got called back in the Korean War. Then when I got back, my doctoral area, which was west of Death Valley, was part of a super secret rocket range and all that sort of stuff, and I hadn't been shot at in the Korean War, so I wasn't about to get shot down by my own people, so I started over and did a different doctoral project.

My dreams during grad school days were, I would spend four or five years in each of the Southwestern states, learning the geology of that region, so I'd have enough knowledge to really be able to do a teaching job. Ultimately I wanted to get into teaching.

While they were in the Korean War stuff, I ended up doing groundwater geology for the Marines at Camp Pendleton in Southern California, a lawsuit over water rights, and I was the only guy in the office who was both an engineer and a geologist, so it came out pretty useful for me. I ended up being the boss man, even though I was only a first lieutenant. Had captains working for me. Finally we ended up with a major in the office, and he decided this

was going to be run in the military style, so I was demoted from being boss, but who cares. I didn't have to go to Korea.

During that time we had to get things ready for going to court and this kind of business, and the lawyers said, "We got these things we've got to present at that date." I said, "The only way that's going to get done is to have another six people or so here." So they had a clearance from the headquarters of the Marine Corps, if you found anybody of the right talents, grab them, they'll be transferred.

So this guy walks in, says, "Hey, I'm scheduled to go out Friday to Korea with a rifle company, and I have a bachelor's and master's in geology, and I sure as hell would rather do geology." So we talked a little bit, and it was quite clear he knew his business, so we got him off Thursday afternoon. [Laughter] He'd gotten his master's here at Texas.

During one of our tasks up in Los Angeles, we finished it early, so we went over to the annual meeting of the American Association of Petroleum Geologists, just to get into the science of the stuff again. He ran into the chairman of the department here, and the chairman mentioned he was out recruiting, and the guy says, "I've got you a prospect." [Laughter] So the dickering started. So I went to some of the faculty and they said, "You can always do that five-year thing. You'll never find out whether you can teach unless you try it. If you don't like it, you still have the fallback position." So I decided I'd teach. Here I am still, still doing the teaching.

So I completely changed my story around of my life's plans, and I spent most of it, [in] my early summers in the northern part of the state of New Mexico, working for the New Mexico Bureau, while I teach here during the school year. That was a great benefit, too, having known a guaranteed job in the summers, without having to go and find the grant money to do it, and all this sort of thing.

So I ended up teaching, and I wasn't going to live east of the Rockies, or if I was, I was going to be within eyesight of them. And guess where we are? You have to drive a long

hard day before you see anything that isn't horizontal as you go west from here, either. But it's a good group to work with, and exciting times. I had a great time.

BUTLER: Sounds like it's worked out pretty well for you.

MUEHLBERGER: I think so. I haven't regretted any part of my career.

BUTLER: That's good.

MUEHLBERGER: So why stop.

BUTLER: Absolutely. When did you first become aware or even think about the possibilities of applying geology to space or to other celestial bodies, the Moon and so forth?

MUEHLBERGER: Well, I didn't think about it. Others did, for me, and got me involved. Back in 1964, when the astronauts were first down at—well, they were at Ellington [Field] then—JSC [Johnson Space Center] didn't exist at that time—the U.S. Geological Survey [USGS] and NASA geologists got together and put together a big set of courses to teach the astronauts geology. They figured that part of that should be field trips, where they go out and see these things in real life, rather than hearing about them.

So their first field trip was down the Grand Canyon with the local gods who had mapped it all and knew all the geology, and they saw the sequence in layered rocks and the different kinds of layering, and how do you tell which way the currents were going, and what these fossils tell us, and all that kind of stuff. Of course, on the Moon, forget it. You don't have any of that kind of—the layering is done there by either lava flows or meteorites

smacking in, throwing stuff all over the place, and that's your layer. So it's a different kind of sequencing, but you still have a sequence of events happening and plan it out that way.

So they wanted their second field trip to be involved with basic mapping, field geology mapping techniques, and looking at folds and faults and this sort of thing. Well, a big gun in [the] U.S. Geological Survey had mapped the Marathon region out in West Texas early in his career, and we were using that area as our summer field camp area. I [had] organized it and we were running it, had been running it for quite a number of years. So we went out with big god, Phil King, a wonderful old guy, now gone, but he still is a great guy, a USGS geologist and a NASA geologist, and the four of us wandered around for several days looking at areas and picking out the kind of thing to teach the astronauts about these techniques.

So when we got it all organized, Phil says, "I don't have any more time to waste on this. Bill, you take over." So I did. So the next step then, what we did was train all of the USGS and NASA geologists. We walked them through all these things, so that when we brought the astronauts out, there were two astronauts to a geologist, and that was a carload. So it wasn't one on one, but it was one on two, teaching, showing them how to use a compass, how to read an aerial photograph, how to pace these things out.

So each of them mapped an anticline, which is a fold, [in] which layers are bowed up, shall we say, and a syncline and a normal fault in which the top side goes down, the reverse fault, and the top side goes up and over, in a strike-slip fault where the rocks move horizontally. So they had one of each kind of structure before they were done with the two days. We ended up taking them into Big Bend National Park [Texas] and some of the volcanic rocks down there, introducing them to volcanic geology. So that was my contribution, shall we say, back in '64.

Then there was nothing. I ended up being the chairman of the department during that period and spent the next four years in that lousy job. [Laughter] Then by that time, Apollo

11 had flown. The guy that used to have this office was [J.] Hoover Mackin. He was part of the geology group trying to design the hand tools and the procedures that the astronauts would do on the Moon. That whole end wall down there, which I've got covered up with other kinds of things now, was covered up with hand-colored copies of the geologic maps of the Moon as they were being interpreted from the telescope photographs. So that represented the state of the art of understanding the Moon at that time, so as each quadrangle would be sent to him, he'd color it up and stick it up on the wall and fill in another hole in the map of the Moon.

I used to come in here, talk with him about these things, and across the hall he had all of the pictures taken from the orbiters and those kind of things. Just a fun time to see these things, but here I was earthbound, as it were, not only looking at rocks on the surface, but just finishing up a project where we got from any wells that went clear through the sedimentary rocks into the basement, samples of those basement rocks. If there were cuttings, then, of course, you picked out the pieces to figure out what the heck rock it was. If it was a core, you were in great shape because everything's still in the original position.

So these were all over North America, so we ended up making a crude map. Actually, it wasn't bad, as it turns out, of how North America was put together through time, in ancient time back when the crust was forming.

The other interesting thing about that project was, we never found rocks really old. We knew the Earth was four and a half billion years old. The oldest rocks we found were about two and a half billion. So where's the other two billion? Well, we figured the Moon might be it. It turns out, of course, that's where the old rocks are. They didn't get washed away or involved in plate tectonics like things here on Earth do and get wiped out on you, or the big impacts that obliterated all the early history of the planet.

So where were we leading to? [Laughter] So Apollo [11] was flown, and the way NASA set up the contracts for the field geology experiment, and all the other experiments,

was Apollo 11, 12, 13 were a group, and the people bid on the experiments in that package. [Apollo] 14 and 15 were another group. Apollo 11, 12, 13 were supposed to be just "Can we do it?" No, Apollo 11 and 12. Excuse me. Then we demonstrated we could. We landed at two different places and landed remarkably close where we were supposed to. Then 13, 14, and 15 were walking missions, where they landed, went out a second time, and walked to some unique object. That's the reason you landed at that place.

Then 16 through 20 were to be the ones where we had a better space pack, where you could stay out for seven hours instead of five, you could charge it up a third time, so that means you could go out on three different traverses, and you had a vehicle to drive, which meant you could really go long distances, which meant now you landed in a place that had a complicated variety of things to do.

So they had already contracted through Apollo 15, and they're now thinking of these big science ones, 16 through 20, with the vehicle and all the rest of it. But President [John F.] Kennedy had said, "We're going to send a man to the Moon and bring him back safely." One. Not do it again and again and again. They had ten different missions they were talking about. By that time already the television crews were not totally enamored with seeing this again and again, so they figured, "Let's spread out the whole thing."

So Don [Donald] Wise, who at that time was chief scientist at NASA headquarters, called me up one day and said, "Bill, could you put together a group of scientists from universities in your region to do the science on one of these last big missions?"

I thought about it about five minutes and said, "No. I don't even know the geology, much less all the other kinds of sciences that could be done." Didn't sound plausible. He had been calling other people, too.

Then it wasn't many weeks later that Gene Simmons, who at that time was chief scientist down at JSC, called me up and said, "Bill, can you put together a group of geologists in the schools in your region to do the geology on one of these missions?"

Well, that sounded almost practical, so I said, "I'll think about it. Sounds like it's interesting, anyhow," and I wanted to get out of being Chairman besides.

So at the Apollo 11 Lunar Science Conference, when all of the lab types came and presented all their data, they had a meeting, one of these evening smoke-filled room kind of things. It's the only one I've ever been in. And here were NASA management, U.S. Geological Survey, and a couple other guys like me snookered into this whole business. NASA laid out the requirements, the time schedules, all of the things that would be going. "If you have the contract, here's what you have to do with it."

Well, I got to thinking that, first of all, I'd have to get out of teaching, so that means I'd have to go through the end of this semester before that's possible. I'd have to get a whole bunch of other people out of their teaching. Then we have to learn the geology of the Moon. Then we have to train the astronauts to do it, as well as being in Mission Control while they're doing it. And I figured there isn't enough time to do that. The only people that were already trained were the U.S. Geological Survey people. They'd been at it for years and they were doing it.

So I raised my hand and made that pronouncement that, "If you gave it to me, since there's such a short time schedule and we don't know these things, I'd turn around and hire the USGS because they already are ready to go and they've got the manpower trained to do it." Well, that killed the evening. [Laughter] By doing this, they were hoping to spread out, instead of having a bunch of government agencies doing this project, have it spread around the country, different university groups doing the different parts of the science. Most of the other sciences that were involved were university groups—the geophysics, looking at solar particles that were coming in, and all the other kinds of crazy things, but the geology was being done by the U.S. Geological Survey…[a] competent organization.

So a few weeks later I got called from the USGS management, Arnold Brokaw, who said, "Bill, would you like to be a co-investigator with us on the Apollo 16 through 20?"

I said, "You know damn well I would be. Besides that, I don't want to just be a name on the bill of sale here; I want to be an active part of it, full time."

"Okay, okay, send in your dossier and all that." So I did.

Then a few weeks later, he calls back and says, "Bill, do you mind we put you on as principal investigator?" Holy Toledo. I knew that the Moon was up here in this wall, but that was about it. [Laughter] And here I am suddenly the head man. Luckily, there were still some years before I had to do the head man job. So I ended up being the principal investigator, left teaching for a couple of years, went full time [with] the USGS, and tried to accomplish the job. I'd like to think it worked, but you always look back on it and think, "Oh, my God, what are you doing?"

BUTLER: Well, it seems to have worked pretty well.

MUEHLBERGER: Yes. It was one of the most fascinating times of my life, as you can imagine.

BUTLER: I can totally imagine.

MUEHLBERGER: It was one of those seven-day-a-week things, all day, and you'd spend half your night on the airplane getting to the next spot. Didn't see my family very much, but fortunately I still have the same wife.

BUTLER: A good woman.

MUEHLBERGER: Yep. When you've got a good one, you hang on to her.

BUTLER: Absolutely.

MUEHLBERGER: I knew you'd say that. [Laughter] Where are we? I guess that's more than enough of that historical part.

BUTLER: That's great. That's a good overview.

MUEHLBERGER: See, what it really amounts to is, is politics.

BUTLER: Yes.

MUEHLBERGER: Because you've got to have a broad base to be able to sell these big giant-buck projects. Then, of course, what happens? Apollo 13 blew up shortly after this meeting. They canceled several missions. Well, Apollo 15 became 16 in equipment. It was still called 15. Then they just canceled 18, 19, and 20. So three-fifths of my job never got done. [Laughter]

BUTLER: Very unfortunate.

MUEHLBERGER: I'm still waiting. Love to see it happen, but it probably won't happen in my lifetime, but I'll keep trying.

BUTLER: Absolutely. No reason to stop trying.

MUEHLBERGER: Nope.

BUTLER: When you were first working with the astronauts, even before you became principal investigator, with that early group back in '64, how was that relationship with the astronauts? Did they get into the geology very well?

MUEHLBERGER: I saw them, the pair that I had, which in one pair was [Alan B.] Shepard [Jr.] and—not Dick [Richard F.] Gordon [Jr.]. [Charles] Pete Conrad [Jr.]. That was one pair one time. I got acquainted with that pair quite a bit, but the other pairs, of course, were off doing their things. About all I really had in terms of them would be to get their autograph. Everybody gets autographs. I would judge that virtually all of them were seriously interested in trying to learn this stuff. Some of them learned it better than others. When you look back at the training that the crews that went to the Moon had, at least for the last three, 15, 16, 17, where we had the vehicles, I would judge that those people had the equivalent of a master's degree in geology before they went. Rather strange kind of a degree, of course, because you don't have to worry about a lot of the things that a typical geology major or any geology major working here on Earth would have to worry about.

I don't remember any crossways kinds of things in these. It was fun.

BUTLER: When you were first building the training for the Apollo, the ones that were going to be long-duration science missions, how did you plan for those? How did you figure out how to train the astronauts and what to look for?

MUEHLBERGER: You've got to remember I walked into this. I ended up being understudy for the guy who was the principal investigator for 14 and 15, Gordon Swann, U.S. Geological Survey.

What we did, there were two different aspects of this thing. We ran all of the field trips that they went on. Every month there was a two-day field trip somewhere. It was

operated as if we were on the Moon, so the crew was out there. First of all, there's an aerial photograph which had been interpreted as "Here are the things that are here, and here's the route that you ought to go to check and make certain these are the correct interpretations." And that's all I knew about the area, most of my group.

Then we would be sitting there playing Mission Control with the astronaut who was going to be on the radio at Mission Control, would be the capcom, he was there working with us, and he talked to the crew. So we talked to him, and he talked to the crew, sort of a short-circuiting of the Mission Control approach to life.

These exercises got more and more complex through time, and they were trying to be similar in length in the kinds of things they would be doing when they went to the Moon, because we had to interpret the landing site. Once the landing site was picked, we had the job of designing the traverses that they would do, and training the astronauts on how to do them. So we would set up these field trips to similar kind of things so they would get familiar with that feel.

Then the last exercise was a full-up thing, we're in Mission Control and they're out there in the field somewhere radioing back and everybody playing that this is the real thing around the Moon bit.

The other part of it was run basically by the Johnson Space Center geologists, who had all the lunar samples. The astronauts were taught about all the different kinds of rocks and they saw all the lunar samples, [so] they had a knowledge of what we'd collected already, so that when they went to their area, they could see something different or, "They're all like the ones we've gotten back there, so we'd better get a bunch of representative ones," or whatever the case may be in that thing.

So there's two different groups that were teaching at them. We always had one of the Johnson Space Center people working with us so that there was some cross-reaction in this whole thing. Most of the problems that I saw came between the USGS management and

NASA management, but I learned how to avoid that, who to go around and go to somebody. [Laughter] In case of Johnson Space Center, we'd go straight to George [W. S.] Abbey, who at that time was the assistant director to Chris [Christopher C.] Kraft [Jr.], and Abbey could solve our problems for us, or if he couldn't, then we went all the way to headquarters and talked to Rocco [A.] Petrone.

I never did learn the real system. You're supposed to talk through. Hell, you don't get anything done if you try that. You go to the guy that's got the responsibility. The guy, the head science director was one to avoid because he hated the USGS, and since I was now hired by them, [and] he tried to hire me, so I'd be working for NASA, running a USGS project, that automatically put me in the wrong pocketbook.

So there's two kinds of geology that were done: field geology and the lab stuff and the lectures. Some of the lectures were done by my people, who were some real pros. God, I'm impressed with the quality of people that were assigned to this whole job. I'm lucky to be able to work with and learn from them.

BUTLER: Took a good group of people to make it all happen.

MUEHLBERGER: Oh, boy. Well, that was the exciting thing, too, because you had the top scientists and engineers all with one goal: Let's make it work. Let's get everything we can out of that hunk of country. As I saw my job, it was the engineering of the science. Let's make sure we can cram into the time available every possible thing that could be done. The routine things, let's find out how to do them as quickly as possible.

I really ought to deflect here for a minute and talk about some of the basic things that the astronauts had to learn, the routines in the field geology business. We had a little tripod [called a gnomon] with a rod sticking in it that was free-floating, so it was always

perpendicular to the ground, and it was painted with one-inch stripes so it was a rod in which you knew the dimensions on that thing.

On one of the legs was a panel with colors on it, and you knew the real colors, so therefore when the pictures came back, the photo lab was supposed to match the real colors rather than invent colors like they seem to do so often. That was set down in front of the rock that was going to be sampled, with the color thing pointing at the rock and into the sun. Then they would take two pictures. This gave a stereobase to look at it. Then they took one, sort of a regional one, so just looking at that rock you were seeing enough of the setting that you could figure out where that rock was sitting on the Moon before they picked it up. Then they picked it up, told us the bag number. These bags had little aluminum strips to them and they could pull those things like a baggie and give the Teflon bag a flip and then bend these aluminum tags over and the thing was sealed in that bag. We knew the number of the bag, if they remembered to tell us. [Laughter]

One of my guys kept track of all the bags and what rocks were in each one, so that while they were on their way back from the Moon, they could say, "These are the most important rocks that were collected. They're in that rock box," or, "They're in that box. That one's going to get opened first," setting up the whole priority scheme for the receiving lab.

The other routine that they had to learn, this one, two men, a little dance to get that rock documented into its position, because how many years had that rock sat in that position, is one of the questions. Several ways of doing it. There's an amount of radiation damage or little micrometeorites had been pecking away at it, and there are different experts that could analyze these things, say, "That was sitting there two and a half million years." I take it on faith that they know what they're doing, or the radiation guys, how much damage there is to depth and X million.

Then, of course, the rocks get tumbled around when they get banged, so that one side will have a different history than the other side. These were important for figuring out how

often did meteorites hit the Moon, i.e., how many can we expect because we're right next to the Moon. So that's one of the basic routines. Then all our field trips, they had to do that.

The other basic one was simply taking a panorama, where they get off the vehicle. The first guy off goes out a short distance and takes a 360-degree film panorama while the other guy's getting all the tools out and this sort of thing and getting ready to start work. While this guy's doing this panorama, he's sort of looking around and saying "Well, there's a rock over there we'd better sample, and we'd better do our core over here," trying to design what's going to happen in these next few minutes that was assigned to that place.

The panoramas were important because after they were all done before they left, then the other guy took one from a different place, and that one showed, of course, all their footprints. You could check to see which rocks were now missing. You could add in some other details that way. If they still didn't know where they were, you could use those two panoramas, because there's now a stereobase, and you could look at the distant mountains and play triangulation games and locate the actual craters they were standing by on the Moon.

The panoramas were—well, it was Jack [Harrison H.] Schmitt, the geologist astronaut, who thought up the idea, instead of just standing at a point and pivoting around, actually stepping sideways each time you stepped, so you moved sideways a little bit. That makes each pair of pictures that you took a stereopair, so you could use that for the near field as well as worrying about the distant things. Neat idea. So that became ingrained into the way they danced in a circle.

Our first field trip with them was a week over in Hawaii, on the big island, and every day we did one of these exercises up in the volcanic field somewhere. We had a photo team that was over there with us, so every night they'd be in the photo lab running all the film through, setting up the panoramas of the day before, so you could see, "Look, guys. You've got a big gap here and you didn't do it right." "Well, let's do it this way." Until it became an

automatic routine. By the time they got all done, the camera was mounted on a bracket, so they didn't have to hold it. All they had to do was pull the trigger, aim their body. If that had been a 45, they would have had a bull's-eye every time. They would have destroyed the rock if it was a pistol, they were so good at aiming their body at the target, wherever it might be, that they were wanting to photograph.

Experience, the endless looking at what you did the day before and learning from that, going on and on, getting the routines down. I'm sure we'll have to do the same kind of thing on Mars when we go, or back to the Moon. There's a lot of dull, dumb kind of stuff you've got to learn, but it's the same way with all the other equipment that they had to lay out. The first time they did it, it took a lot of time. Then you put on a space suit—oof! And then the time jumps like crazy until they did it enough times that they could do it quickly and efficiently.

BUTLER: Practice makes perfect.

MUEHLBERGER: Practice makes perfect. It might not be perfect, but it's damned good. [Laughter] Those photo routines were an important part of trying to get more information and data back. Nowadays with the electronic gadgetry that we have, using the electronic cameras, you send it right back to wherever you want to send it. But film is still good and useful. It doesn't have the bit problem. Of course, you can't use the film till you get it all the way home. [Laughter] They both have their uses and needs.

BUTLER: Were there other aspects that the astronauts had to perfect as much as they could before they—

MUEHLBERGER: Well, of course, they had to learn our vocabulary and we had to learn theirs. That was the other part of these field trips. Each one is set up as if it was a mission.

Let me go get one. The cases have fallen apart through the ages. They'd have cuff checklists just like they had on the real thing, which is at that stop, and then the other side of the page would be the instructions on what you're to do. Then you can flip the page. It also would tell you how far was the next one. These were designed by the astronauts for their own use, so one of my guys, seems to me he spent half his life, between flying to the Cape [Canaveral, Florida] and flying to Flagstaff, doing these modifications until finally everybody, the crew had what they wanted. Those are the things that went with them.

So here's the photo interpretation [*referring to documents*]. You see the green in here and the black line. They were the traverse that was to be run. And away you'd go. So these exercises would last between three and four hours each. Then we'd have lunch. Then when they were done doing it, we'd have a radio talk back and forth, in which we'd ask questions and they would explain things or they would try to amplify what they'd learned, so we figured we had the answer now. Then we'd go have lunch, and then that afternoon we'd go walk through the same trip.

One of my guys had been out with the crew, so he had a radio and he could hear both sides of the conversation. He could see what they were doing, which we couldn't. We didn't have a TV on the fake rover that we used. It ran on a battery and ran sort of like the rover, but it was still mimicking. You didn't have all the good gadgetry. So then he took over and said, "Okay, back room. They told you this and this and this. Now, look. If you had asked this question, look what you would have learned." And they thought, "Oh, we blew it." Or "Crew, you told them this and this and this and led them off on this wild goose chase, when you should have phrased it this way," or whatever.

So we were each learning how each of us sees these things as well as what we're going to say about them, so when they finally get to the Moon they knew those rocks

perfectly well. They could have said, "That's an anorthosite," but I don't think I ever heard an astronaut on the Moon say that, except for Jack Schmitt, who's a Ph.D. in geology, and I can't think of a better trained person to go to the Moon than he was.

So, very different. So these exercises were the major training game to get them designed. Then, of course, the real exercises or the real things on the Moon, we talked those over with them so many evenings there at the Cape, they knew it all by memory. Fact is, the main use for the geologic maps that they had on the Moon was to replace the fenders they seemed to tear off all the time. [Laughter] Have you ever seen those pictures?

BUTLER: Yes.

MUEHLBERGER: There they are [*referring to documents*]. This is my copy of one of them that went—not this particular set, but that's got the Apollo ones over in the file cabinet there.

BUTLER: It's good that they were useful and it's good to have it memorized, too, so that they— [Laughter]

MUEHLBERGER: Yes. Well, the advantage of the Moon, of course, you know where the sun is, and therefore with the shadows you always know east is where the sun is. There aren't too many dark shadowy days where you can't see, like around here. So that's one of the main points, I think, in there.

BUTLER: We've talked about the training for the astronauts and building the lines of communication with them so that you both knew what was going on, but you had mentioned earlier that when you were named as principal investigator, all you knew was the map hanging on the wall in here. How did you yourself become—

MUEHLBERGER: Knowledgeable enough?

BUTLER: Yes.

MUEHLBERGER: Well, I knew a little more than that because we had all the [Lunar] Orbiter pictures across the hall, and there was a Ph.D. grad student from astronomy over here working with [Mackin] to interpret those things and to sort of make a catalog of really good pictures of impact craters, really good pictures of this and that and that. I used to lean over their shoulders and ooh and aah.

This guy now teaches at Brown [University], Pete [Peter H.] Schultz, remarkable guy. If his dissertation had been published when he got it done, he would have had credit for about half of the features descriptions and proper interpretations, but it took too long to get it out, and by that time other people had done the same work. That's just plain competition.

But anyway, I knew a little bit about it. So then one of the things I did was—oh, I should have pointed out, my name was the first in line of about ten people on the proposal that the USGS put in. There was Leon T. Silver, California Institute of Technology; Thomas H. McGetchin, Massachusetts Institute of Technology; Spencer Titley, University of Arizona; and then about six U.S. Geological Survey people. It was quite clear, nothing but academic types were listed first and then the government types down below. The PR game again. You had a guy from Cal Tech, MIT, and Arizona and Texas. That covers a fair hunk. [Laughter]

BUTLER: [Laughter] Sure does. Sure does.

MUEHLBERGER: So what I did was call a meeting because we were coming up on having to pick a landing site for 15 and 16 and 17, and there had been a whole bunch of potential landing sites that had been hyped earlier as the telescope work was being finished on each map area. If you're going to land on this map area, where's the best place? What would we learn at that place?

So we held ourselves a two-day meeting with one person, laying out why this is such a great landing site kind of thing, and going through all the different things, then making our own priority list of places we ought to land, based on what we'd—so what that was, was a great learning experience for me, because I really didn't know that much about them. So I learned a heck of a lot about lunar geology just from that two days. Of course, you just keep on learning from then on. If you don't, you'll soon be walked all over, face in the mud. But that was my real basic one.

BUTLER: That's a good way to get into it, like you said.

MUEHLBERGER: Yes. As long as you've got all the brains there, take advantage of them.

BUTLER: Were there any other aspects of pre-mission? You talked about selecting landing sites, and we've talked about the training for the astronauts. Other pre-mission aspects that you were involved in?

MUEHLBERGER: Yes, the biggest thing, of course, was working with the engineers and Mission Control people to set up time lines. NASA has—here's the commander and the LM pilot, the two guys who are going to land on the Moon. So here's the time line, right down to the second, practically. Every little second's got to be filled with something. That means that there's absolutely no time for these people to think on their own, because they're always

following a schedule. That's the advantage of going to Mars: you can't get to them because the radio signal won't get there for twenty minutes. They can think on their own. We needed to do that.

But we did a sneaky thing on Apollo 17, because there we had the only scientist that was ever flown to the Moon, as well as Gene [Eugene A.] Cernan, remarkable, capable pilot. Their first field trip was with Bob [Robert A. R.] Parker along with them. Bob was their Capcom. He's a physicist Ph.D. I had one of the NASA geologists [Gary Lofgren], and offhand I can't remember which one right now. Sorry. We all flew to El Paso [Texas], rented a station wagon, and I took them all through the Big Bend country. We'd stop at some place and I'd turn my back to the things we were looking at, and said, "Describe it to me." And Cernan turned out to be remarkably good, [he had a] nice capability of descriptive things and what's there. So we figured, well, Gene could pick up this aspect, you know. How are you going to have two people whose trainings are so different working as a team? You've got to each do that. Well, they ended up, I think, a remarkably good team.

What we ended up doing was, on the Moon Schmitt got off and ran around telling us what he was seeing, which meant that we changed—I have to step off for a minute. In the science back room we had a TV camera that looked at the geologic map that was projected into Mission Control. So when you're looking at Mission Control, it was the left most screen, which was never up on public TV because Captain Video's cameras were looking across at the opposite side, which is the action that was going on on the Moon and down to the Capcom and that kind of play.

So on that thing we would put a note, "Here's the time of arrival at this spot, the time of departure, and the tasks to be done there." So at each place then that was slipped on so it would be up on the screen, so the Capcom could see it. As things were done, we would check them off, in other words, his notes, so we could make sure that the crew was carrying it through at the timing that was available.

So when Schmitt was running around, we'd make up a new one and then remove the first one, and that became what we did at that spot. In effect, he was running the mission from the Moon. I was the official one. But what the heck? I can't see that stuff like he can. Besides that, he knows it better in the first place.

While Schmitt was doing that, that was about a minute he had available to do that, Cernan got out, got the tools off, set the TV antenna so we could start getting TV, started the gravity meter so it could detect the pull of gravity, and then we started the tasks. On the time line, Schmitt had a whole bunch of stuff listed in there, all just plain baloney, tasks that he was doing. So the time line was full. We were covered. [Laughter] But we set it up this way. All of those within the geological world certainly knew it, and I had a sneaking hunch that the top brass knew it, too, but this is a practical way out, and they didn't object. That, I guess, is the key point, to have it done that way.

BUTLER: That was a very successful mission, so it worked out.

MUEHLBERGER: Yes. And the other thing Jack did at the end of each place as they're driving off, he summarized everything that he'd seen and learned, so by the time they landed in the Pacific Ocean, we'd written a report about that landing site that was better than the one we used to write for the previous missions, the ninety-day report, ninety days afterwards where the rocks were all opened, you had a chance to see them, you had all the film, you had the chance to talk to the crew, and integrate that to the "Here's what we did on the Moon." We had one that good before they landed, and then it grew from there. My judgment, of course, is send scientists. It happened.

BUTLER: Luckily they were able to work it out so he could go.

MUEHLBERGER: Oh, boy, that was a day when there was a big splashdown party going on at one of the apartment complexes right across from JSC, and that evening they were going to be announcing the Apollo 17 crew. Schmitt was there, Gordon was there. Schmitt and Gordon were a pair as backup on Apollo 15, and since I was the backup, or the understudy, I was the geology team leader for them, so I knew Jack from that. So I really then worked with him on two different missions. I'd also known him when he was an undergrad and I was finishing my doctorate at Cal Tech. So almost incest, I guess. [Laughter] Wrong word there. We ought to scratch that one and add another word.

BUTLER: When the announcement was made—

MUEHLBERGER: They were all kind of antsy, and finally the announcement was made. Dick Gordon was probably one of the more unhappy people, but he recognized that, yes, they're going to have to send Schmitt. If Apollo 18 had happened, they would have gone as a team. Gene Cernan's partner—

BUTLER: Joe [H.] Engle?

MUEHLBERGER: Yes, Joe. Of course, was cut out and Schmitt was placed in there, and Joe wasn't a very happy guy either, because here's their opportunity to do something. But looking back on it, I think they did the only thing that was possible. You've got to send a scientist, especially when you have the National Academy of Sciences, who were the chief honchos of trying to select these scientist astronauts. Then if you didn't use them, what kind of an engineering organization are you? [Laughter] Anyway, so he went.

BUTLER: Looking at both his selection and also the integration of working with Mission Control, building the time lines, and so forth, and just the whole focus on the science side, because initially there wasn't that much, like you said, "Let's get to the Moon first and see," how did that work out for you in integrating those two parts?

MUEHLBERGER: The integrating parts, I can credit Jack [John R.] Sevier as an absolute genius at being able to work with us and with the rest of the directorate and integrating all of these different egotists, each scientist with his own experiment, my God, one of the greater egotists of all, a bunch of prima donnas, and trying to make them all work together and satisfying the time demands and the time needs that they have, squeezing it down until, yes, we can get it done in this hunk of time, Jack was the most instrumental person in that. Unfortunately, he died here a few months ago. I hope you talked with him before he went. He would have been able to tell you a lot of stories. We spent a lot of evenings in his house, his wife isolated in the bedroom while we harangued these science/engineering questions around.

BUTLER: Unfortunately, we weren't able to talk with him before. That's a big loss for us.

MUEHLBERGER: Yes, yes.

BUTLER: And for everyone.

MUEHLBERGER: There's nobody like him. But he was instrumental, and you've got to have somebody like him in the system to act as an interagency actor, whatever you want to call him, coordinator.

BUTLER: It's fortunate that he was able to be there and help make it all happen.

MUEHLBERGER: Yes, yes. Another one of my heroes of that era.

BUTLER: Looking more specifically at Apollo, you said you were involved to some extent on Apollo 15.

MUEHLBERGER: Yes, I was there on all the field trips. I was in the science back room. Actually, maybe I ought to explain how we set up the geology part of the science back room.

BUTLER: Absolutely. That'd be great.

MUEHLBERGER: Something like twenty-nine people…were involved in the things that we were involved in. In the science back room itself, the geophysicists with their equipment were off in one wing of it, and most of the rest we occupied, other than the one console that the science coordinator, which is Jim [James A.] Lovell, so I talked to Lovell when I became PI, but Gordon Swann talked to him before that. Then a couple other engineers on that panel. The rest of them were geology crew people.

So here's Lovell's console and we were sitting at a table like this with our map laid out in front of us, and in my case I had one on each side of me of my guys, and there were others sitting behind me at another table with the TV camera over at another one of the geologists who kept track of where we were, and a little arrow out front, everybody out there, the tourists, would know where they are now. Bob [Robert] Sutton would sit there taking three-by-five notes. Every rock had its own card, and he kept them sorted by kind of rocks.

Tim [Mortimer] Hait was standing at an overhead projector with an endless roll of transparent stuff, and with his felt-tip pen he was just writing the geological things as they

came into the conversation, in sequence. Of course, they were up on the wall projected where we'd all see. So you could look back and see ten, fifteen minutes into the past before it got rolled up and you're seeing something newer. So he was sort of the time historian of the stuff.

Sitting next to me was Dale Jackson, who was my immediate science czar. He didn't have to fight Jim Lovell to get something done or worry about some of those tasks. All he was thinking about was what's the science that's getting done, and making sure that I got it done. Lee Silver was sitting behind me, being another one who was just sitting, thinking about these things rather than getting involved in the nitty-gritty of the operation.

Then down in another room we had our photogrammetry team, where they had a Polaroid camera so as each stop on the TV camera got started, the first thing it did was do a 360-degree pan. That was for us. So these guys were photographing that Polaroid. Another one of my geologists was down there and he would circle, as the stuff got visible, rock, something or other, and within a couple of minutes I had this whole panorama sitting in front of me, with time clicks on it, because the camera moved so many degrees per second. So you could use this to say, "Captain Video, can you go five clicks to the right and zoom in on a rock you'll be seeing?" So when we didn't have to look at the crew, we could go look at geological things and try to help us out on what we're doing there. So that team was invaluable that way.

Then we had two court reporters that were just sitting there taking down the entire transcript, because by the time NASA would get to us with one, it would be months later. So we had our own transcript being made right in the group.

Then we had about four or five people we called the Tiger Team, who were over in Gene [Eugene F.] Kranz's office. He was the head flight director. He was not occupying that office during this time, so he loaned us his office. These guys were just simply sitting there

and would write up what we learned on this EVA, what we missed, and how to modify the next day's EVA so we could get that stuff into it if it was necessary.

On Apollo 16, they ended up having to write a position paper on why we had to keep the third EVA. When the guys separated in orbit, red lights came on in the command module. It's saying the engine wouldn't work, words of that effect, and that's bad news. The only engine you've got left then is the one in the lunar module, and if you went and landed and came back, you'd have no gas to get home. So they had to stay in orbit for several orbits until they finally figured out it was a false alarm, and then they landed. But the LM had a seventy-two-hour guarantee or something like that, and they didn't want to extend. The crew, instead of going out immediately, ended up sleeping first, and they didn't sleep well. And it goes on downhill, some of those kind of problems.

But the last traverse was out to a crater as big as Meteor Crater in Arizona, the only big one nearby that we thought we could get to, and that one therefore would drill way deep into the Moon and dump stuff up on the surface and give us things we wouldn't ever find otherwise. We'd made that our number-one priority spot to go to, and they were threatening to cancel the third EVA and come home.

Well, these guys wrote a defense of it, and we got enough of the EVA to get there and do that job, but not all of the other stops that we had planned in between. So they were invaluable in that sense. What we learned on each EVA, the secretary typed up and it was distributed to everybody in Mission Control before the next day, so everybody had a summary of that sort of thing.

Whew. Is there anybody else? That sounds like a herd. That was basically the setup of how we operated in there.

BUTLER: So you were in there for 15, 16, and 17?

MUEHLBERGER: [Apollo] 15, I was over there in the Tiger Team, part of that bunch, and 16 and 17, I was the guy sitting there talking with Jim Lovell when necessary and talking to the other guys, having an endless conversation, it seems, and then you discover something's happening you didn't know about, and you go into a frenzy mode. Really something.

BUTLER: When it came time for Apollo 15, this was the first of the long-duration missions with the rover and everything, and you said you were working in the Tiger Team. As the mission was going along, building up to the mission, were you involved in the selection of that landing site at all?

MUEHLBERGER: I can't remember the exact—I didn't get a vote. One of the guys was part of my team, was one of the six, who had a vote, so one of our reasons to have that meeting, for example, was of all of the different landing sites was let's get our cards together and all agree on what's most important. The geochemists had different reasons. The geophysicists had different reasons for things.

When you look at the landing sites, there's the Moon. We landed Apollo 11, Apollo 12, Apollo 13 didn't make it, 14, and they left a seismograph behind that's still working. We knew we had to land in the lunar highlands somewhere. Well, that's over here toward Apollo 11 again, but right in the same line. And the geophysicists wanted the third point of the seismograph, so they had a big triangle that they could triangulate, and they wanted it as early as possible. So 15 was that most northerly site picked before we went to 16, and then 17, of course, was up for grabs in those days. But 15 and 16 were fundamentally picked at one time in their sequence. The things seen on Apollo 15 that ended up making Apollo 17 go where it was, thought they'd seen some volcanoes. Well, that was wrong. That's why you go and check. You can't interpret these photographs 100 percent right all the time. It would be nice if you could. No, it wouldn't, because it's more fun going out and looking. [Laughter]

[The Apollo 17 site was the only one that was not picked from telescope geologic interpretation. Telescopes have about a 1 km resolution. All the important time distinctions were picked out from that imagery! Actual landings sites used Lunar Orbiter photography with about 20 m resolution. Apollo 17 had Apollo 15 Panoramic camera film with 2 m resolution. What a difference for planning traverses! We could see boulder fields, boulders that had rolled down the mountainside (their tracks easy to pick out), i.e. we could target specific important elements before going and design traverses accordingly. A great help.]

BUTLER: Absolutely. [Laughter]

MUEHLBERGER: That's what geology's all about, going to find out what you [were] really supposed to learn there.

BUTLER: Go out there and play with the rocks…

MUEHLBERGER: Well, if you go into northern New Mexico near Taos and look at the Rio Grande Gorge, the widest part of it there, that's a 1:1 scale model of the Hadley Rille on the Apollo 15 landing site. So we set up a field trip for them there, where they worked along the edge of the cliff, and a mile away on the other side with their telephoto camera, they took a panorama. Then as they worked their way down to farther stops, then they did it again. That gave us a stereobase to study the rocks on the far side, and they did it on the Moon. It's really neat. You can pretend you're there on the Moon, because you can see this stuff in stereo and you can see the different layers and work out a better history than you would have had otherwise. Of course, the locals in Taos love it. "Our canyon was cut with water. Yours was cut with lava, though." And they're both just lava flows stacked up. That was one of the last

of the field trips before they went, but it was a perfect 1:1 analog to what they were going to do. Get rid of a few greasewoods and things. [Laughter]

BUTLER: That's interesting.

MUEHLBERGER: But the mission itself, since I was sitting in the other room, I don't know what kind of headaches appeared during the thing. They always do. They couldn't get to a couple of the points. In the overall, I don't think it mattered. Their prime reason for landing there, they were close to the mountainside of the ancient rocks [on] which we thought there ought to be some rocks big enough of the lunar crust sitting there that got blasted out of the Imbrium impact crater and standing there in those mountains. Where they landed at the kink in the rille would be a good place, and secondly, we could see this canyon and figure out maybe a little better why it's there and all that kind of good stuff.

So Dave Scott picked up this thing and started describing it. "It has big white rectangular crystals that are flashing at me." He knew what it was. He knew anorthosites, but he was unwilling to say it when millions of people were listening, for the fear that he could be wrong. It's too bad. But that's the rock that the newsmen nicknamed "Genesis Rock" because it would tell us about the origin. It's the first time we had a rock—about the size of my fist, actually a little smaller. I used to have a plaster cast of it, but I gave it to the Children's Museum. First time we had enough of a rock where we could destroy a bunch, do all the lab stuff necessary, and find out that, yes, the Moon was born at the same time as the Earth was, and meteorites, which confirmed the astronomers' assumption that the planets are all formed in one big episode, instead of flying in and joining the team, however else you might want to do it.

That rock, Genesis Rock, gave us that sample material to prove that, up to that time an assumption. Now we know it. Actually, when you look at a thin section of that rock, if

it's got "Genesis", it's got "Exodus" and "Deuteronomy" and probably even some "Revelations" in it, but it was a battered up hunk of rock.

BUTLER: Was the rock a surprise?

MUEHLBERGER: No, no, it was anticipated. At the end of Apollo 11, they scooped up a lot of dirt, too, and then you get a lot of information out of dirt, because you don't know where any of those particles came from. Some of them could have come halfway around the Moon and be there. John Wood, from the Harvard Smithsonian Observatory, sat there with a microscope, picking out little white crystals, and they were all the same composition, and he says, "The lunar highlands are going to be anorthosite." Well, he was right, going through little tiny pieces of it. But until you had a big piece, you wouldn't be able to convince everybody.

BUTLER: Had a good find.

MUEHLBERGER: Yes, that was well worth it. He picked up a lot of other interesting things, too, but that was one of the prime things, of course. There were big cheers in the back room about it.

BUTLER: Were there any other highlights from Apollo 15 that you remember, or problems or issues, both before and after the mission, like looking at the samples afterwards? Anything that came up that was surprising or that confirmed?

MUEHLBERGER: I can't remember anything specific right now, for some strange reason. Probably because as soon as the mission splashes down into the Pacific, the engineers are

suddenly out of a job, so their game from then on until the next launch to tinker and work with the next mission. So we had to have the Apollo 16 landing site and all of its traverses designed before that happened, before 15 splashed down. And since 16 was my first responsibility, my time and efforts started going that way although I did spend a lot of time with the 14 and 15 pictures.

I got started in the Mission Control stuff right after Apollo 14, when the rocks and everything had gotten back, sitting there trying to look at the photos and figure out what the heck was done and where did we find these rocks and that rock and so on. And, of course, finding the golf ball Al Shepard [hit]—one of them was visible. The other one he managed to sink in a crater somewhere. You can't see it. That was easy.

So at the moment, right off the top of my head, I don't have any big memories about that. Fun mission, two great guys. Of course, we never really saw the third guy, command module pilot, because they were trained by a totally different group. That was another thing about NASA. They managed to split things up in these little segments. So the orbital guys trained always from an airplane, looking down, the high-flying jet. Geologist pilot would take them and do these trips. Then they'd get done with the jet level and they'd get into a light plane and fly at a low level over the same place, just to see what it was that he was really describing, so he could better understand all these things. I got to go on one of those, went from Mount Lassen to Mount Hood. Wow, what a trip.

BUTLER: That must have been fascinating.

MUEHLBERGER: I would have loved to have done that some more. [Laughter] We also tried having the command module pilot join us on one of these field trips, just to have him get involved in a different perspective. He flew over in his T-38 and then landed and came and joined us. I don't know whether it was useful or not, but we did it. I would like to think it

would be, just so you see more in detail, so you have a better chance of interpreting when you get up in orbit.

BUTLER: It's a perspective so different, as you mentioned earlier.

MUEHLBERGER: Quite different, yes.

BUTLER: Being able to see it from both angles would be helpful, I would think.

MUEHLBERGER: That's the nice thing about having pictures on the ground as well as pictures from space. You can use both in illustrating the different facets of the whole thing.

BUTLER: Definitely. As you were planning for all of these missions, did you spend a lot of time looking at the samples from the earlier missions, especially the ones you hadn't been involved with?

MUEHLBERGER: I never did. Never had the time. During the ninety days after each mission that we spent there at Johnson Space Center, writing up all the reports and everything, I'd go over to the lunar lab each day and see what's been opened and cleaned up so I could see what the rocks were. But there was certain [members] of my team that were assigned to work with those rocks all the time, so they were the contributors of the information about the rocks, and other guys would work with the photographs. They were always periodically trying to find the crew so we could talk to them and ask them questions.

As soon as 16's splashdown, of course, then 17 was on your neck and you were going off of that. When 17 splashed down, it was easy. All of a sudden all we had to do was look at the rocks in the photos and talk with the crew. We didn't have another mission to plan.

Wow, it really was different without all those endless other commitments of time and, "How do I get another roll of film aboard so that they don't run out?" That went all the way to NASA headquarters before I sold one more magazine of film. "You're sending a scientist to the Moon, gang. Don't handicap him without giving him enough film."

BUTLER: Absolutely. Got to have the tools that they need.

MUEHLBERGER: Rocco [Petrone] agreed, and away it went. One pound. Then, of course, the question is, what do you want to give up? They charged the vehicle against the geology team, so we had 450 pounds or something like that. You know, made it really look bad. "Take a wheel off." [Laughter] There weren't any spare tires, so you couldn't remove those. They had enough. They always keep a safety factor in these things, and by 17 they were willing to start shaving some of those safety factors down, they'd been so successful. As a matter of fact, by 17, they had the fewest failures on that mission of any of them, and, again, I guess it's just experience. You learn about these things and make sure they don't happen again. That's a key problem.

BUTLER: Absolutely.

MUEHLBERGER: Other than breaking fenders. [Laughter]

BUTLER: [Laughter] Hopefully they'll come up with a good fix for that next time.

MUEHLBERGER: Yes. It so happens that they would put their geology pick in a holder on their pants leg so it would stick out as they would go around the vehicle, and those fenders, of course, are flimsy as the devil. All they have to do is stop the rooster tail of dust from

coming up over you, which is very important. You've got enough dust problems as it is on those missions. And luckily they took along some duct tape. [Laughter]

BUTLER: Ah, the universal fixer.

MUEHLBERGER: The universal fixer. Right.

BUTLER: Speaking of like the fenders and duct tape and the weight on the lunar module, were you involved in some of the discussions on any of the tools that they used?

MUEHLBERGER: Oh, yes. Actually, the first meeting I ever went to after I was officially blessed as being principal investigator, Gordon Swann called me up and said, "Well, Bill, you really ought to come down to this meeting and get a little bit familiar with things. It's on geology hand tools."

So here's the geology hammer with the head, and the handle was an oval-shaped handle that you grab onto. Some engineer had gotten in a space suit and couldn't get the hammer to hit on the head, so they redesigned it so that the head was askew to the handle. Well, any normal human being would try to work it as a regular hammer. The Apollo 11 crew had a terrible time, so they had to redesign the hammer, put it back to its original shape. Golly.

Then the other thing was, all of the tools had an extension handle that you put on and gave a 90-degree twist, it clicked and locked into place, except for the hammer and its extension handle, which was a squeeze grip. You know what happens. You grab the hammer, you hit the squeeze grip, and there goes your extension handle. So they had to redesign that.

Here's about thirty people sitting in this room, solving a problem of two dumb things, and I don't know how many salary dollars that represents. It's bound to be a bunch. Then I saw later that to fix those things and do the rattle and roll tests and make sure it was space-worthy cost about 25,000 dollars. That was bucks in 1970. I'd hate to think what they—I could be rich.

BUTLER: Absolutely.

MUEHLBERGER: And then two days later, I was in Washington at a meeting, and where should Apollo 14 land? Total other extreme from this sort of thing. What a way to be introduced to business. [Laughter]

BUTLER: So many parts, they had to each come together and make it happen.

MUEHLBERGER: It was largely Lee Silver and Jack Schmitt working together that designed the rake that was taken along. When you just scoop in and pick up the soil, there's an occasional rock sitting in there, and so you're trying to amplify the variety of rocks that you bring back. Well, you're not going to take four scoops if you can help it, so what they did was design this rake with the tines equally spaced so that they'd scrape it through and shake it, and all the finer stuff would come out and you'd have all these little pebbles that were left, just bring them back. They represent—they're big enough pieces that you could cut a slice and see it in thin section under the microscope and really learn a heck of a lot more by having a variety of those. They invented that and got it aboard. It was used in the last couple of missions, a really useful tool.

But I never designed one. I just ended up hearing about redesigning tools. There was a stereocamera that they were going to use, and because of the small company bit, this little

outfit got this contract. Well, instead of modifying a Hassleblad or a Kodak camera, one of these already workable and working, they were designing their own shutter systems and, oh, Lordy, and they could never get any consistent workings out of it. I made the statement, "It'll never work," and that kind of caused a flurry of, "You're not supposed to say that out loud" kind of thing. But it was true; it never worked. So we didn't have it. It's all right.

BUTLER: Had enough other things that did work.

MUEHLBERGER: Yes. Some things that probably should have taken and didn't take.

BUTLER: I'm sure you can always think of something else.

MUEHLBERGER: Oh, yes. The way it goes.

BUTLER: We'll take a brief pause here and change out our tape. [*Recorder turned off, brief interruption*]

MUEHLBERGER: ...our geology field trips. The backup crew for the mission went through exactly the same training that the prime crew did, so that's why I ended up being the "backup PI" [principal investigator] for Schmitt and Dick Gordon, who were the backup crew for 15. The only difference was, they left about a half hour later on the field trip loop than did the prime crew, and therefore we had two mission controls, one for the prime crew and geologists working with them, and one for the backup, two different sets of two-way radios on different communication systems so that we could talk to our crew rather than interfere with the other one by doing that.

So those field trips used to be a great chaos. The prime crew got to drive this vehicle—I can't call it a—stop for a moment. [*Tape recorder turned off*] These fake lunar rovers, ["Grover"]. [*Referring to photographs*] So the prime crew got to use that. Here's Apollo 15 crew at the "Hadley Rille" Rio Grande Gorge near Taos. So the backup crew used a jeep that had been modified a little bit to pretend that was their vehicle they were driving on the Moon. You can see they wore a fake backpack with all the tool hangings and the radio and everything in the same place, filled with styrofoam so it didn't weigh much, rather than 150 pounds of stuff they'd be lugging otherwise. So they had the radio. Their camera was hanging on their chest in exactly the same place as it is on their space suit, so that they didn't have to worry about learning a new position to take their pictures with when they used the space suit.

Everything was as close as possible in operating like we were on the Moon, and they could take stuff off. The TV antenna didn't work; it was just a fake TV antenna that they could move it around and pretend they were aiming it at Earth, this kind of stuff. So the backup crew didn't have that, but the odds of—none of them ever went. I take that back.

BUTLER: Jack [John L.] Swigert [Jr.] on Apollo 13.

MUEHLBERGER: Yes. The measles bit stopped them. So, anyway, the training was always the same. It was a big advantage, as it turned out for me, because I got well acquainted with working with Schmitt and with the Capcom that they had, who became the Capcom in 17. So Bob Parker, the physicist astronaut, and us got well acquainted throughout all that sort of stuff.

BUTLER: Built a good relationship.

MUEHLBERGER: Yes.

BUTLER: While you were doing some of the field training, were you involved with them in setting up the ALSEP [Apollo Lunar Surface Experiments Package]? Did they do any of that during these trips?

MUEHLBERGER: No. On these trips we never did those. It was purely the geology part of them. The ALSEP training was done there at JSC or at the Cape. We hauled two freight car loads of basalt near Flagstaff [Arizona] to the Cape to cover up the seashells. [Laughter] So they could look a little more like the Moon. Then dug craters into it, salted it with certain kinds of rocks. I spent all kinds of time trying to find Jack Schmitt's dissertation rocks to slip in there on the last exercise. [Laughter] I got a hold of them two weeks too late.

BUTLER: [Laughter] That would have been good.

MUEHLBERGER: I thought that would have been great, because his dissertation area in Norway, where mafic/ultramafic rocks are the same kinds of things we're finding on the Moon, so it would have been logical kind of rocks, except they'd have a little—in those days we used red fingernail polish to paint on there and then ink in a number on top of that, the number of that sample. But I think every geologist used fingernail polish because it goes on easily, and when it sets up it's nice and hard and then you use your india ink and you've got a good contrast there. But we were just hoping and praying that we could get the dang things, and they were hidden in the recesses of Harvard's collections. Oh, well.

BUTLER: Good idea.

MUEHLBERGER: Great idea, but didn't work. So, where were we?

BUTLER: Having mentioned the ALSEP, were you involved in any of the planning for that? You said not in the setting up.

MUEHLBERGER: No, because each one of those instruments had his own research group working with it, a principal investigator and the guys that were then responsible for it. They would be there at Mission Control, too, in case there's some problems, "What can we do now?" Like when John [W.] Young accidentally tripped over the heat flow cable and tore that off of the heat flow experiment. You could just see the heat flow guy frantically trying to convince NASA that, "Yes, we've got to fix it."

And actually it was an important thing to do and it cost a lot of time, because what we had to do is redesign each of our traverses so we could get back to the ALSEP area, which is right near the lunar module, in plenty of time so if they wanted to unhook those cables and take them into the lunar module and then try to scrape them clean so the connectors would work, what do you have to scrape with? You don't take files and things like that. You've got lunar rocks. So you really don't have any good guarantee that you could make a good connection.

The fear was that if they did want to do it, the crew might stay up all night making sure that it would work, instead of getting a night's rest and all this. So at the last minute it was decided, "No, we're not going to do it." And a very disappointed PI, as you can imagine.

BUTLER: What was the background of the experiment, if you could tell us a little bit about it?

MUEHLBERGER: Well, they drilled a three-meter hole into the Moon. We hauled that rock back with us. Then stuck this tube into the Moon, which detects the—there are different thermometers on it, I'll call them, that detects the heat flowing out of the Moon, which gives you a clue as to the radioactivity or whatever it might be down there that's causing the heat. It might be just leftover heat from the accumulation of the planet. Most of it seems to be radioactive decay, the way it is here on Earth, too. Some kind of rocks have lots of radioactive materials in it and some don't. The limestones around Austin are about the lowest background you can worry about, if you worry about those things. If you want to get a good radiation background, go up into the high mountains in Colorado, because you can get it out of the sky as well as from the rocks. Beginning geology lecture here. [Laughter]

BUTLER: [Laughter] That's okay. It gives some good background. Were they able to do the experiment, try it later on Apollo 17?

MUEHLBERGER: Yes, they did it on 17, worked all right. Of course, then they had redesigned the cables such that there was no way they were going to get torn apart. I remember Lee Silver behind me jittering, "Watch out! Watch out, guys! Watch out!" as they were walking by the cables. I turned around and said, "Lee, they're going to have to tear the planet apart before they can get those cables unhooked. Forget it." [Laughter] And I think that phrase—and I said it differently. [But] it's in the Apollo 17 movie that they used to show all the time, the half-hour things. After each mission, they generated a film about each mission.

That's the other thing. Always in the back room there was a NASA cameraman taking film, and quite often a still-camera guy, too. So there's gazillions of—I don't know what they took. Very quickly you don't pay any attention to the camera anymore and you're doing your job.

BUTLER: You had some rather exciting things to be focused on.

MUEHLBERGER: Well, yes. You'd better focus on that rather than giving a big smile to the camera. [Laughter]

BUTLER: [Laughter] That's right.

MUEHLBERGER: Or giving them your best profile instead of the other one, or whatever the case may be. To heck with it.

BUTLER: Talking about Apollo 16, and this was the one that you were starting with and was fully going to be under you and so forth, tell us about that and how it went.

MUEHLBERGER: I tried something different with the field trip training on one exercise, just to—I wanted these guys to be able to understand how we make maps. The only time they'd made a map was back there in '64 out in West Texas, and that was on earth, and I'd worked in an area in Northeast New Mexico one summer near Capulin Mountain, a little perfect volcano that's a national monument out there, and mapped the region for the state of New Mexico on a groundwater project.

It was the kind of an area where you had a half a dozen different volcanoes that went, "Burp," and rolled their lava flows out across the country. If you worked it right, you could figure here's where they overlap, and therefore we've got to go here to see which one's on top. So I let them make their own map of this hunk of country, starting from each volcano and then tracing out the margins of the flows, and then, "Okay, now where do you want to go to go and check this out?" Luckily there are just enough roads that you could use the roads, a

little bit of walking to do this, and we went out and did it then. So as far as I know, they're the only crew that ever made their own map and went out and field-checked it before going to the Moon, where somebody else made the map and there to go field-check it.

BUTLER: Did they take to the exercise pretty well?

MUEHLBERGER: Yes, they seemed to, because we ended up all jammed in one car instead of the usual thing of having lots of vehicles. The other problem on those field trips was, they always had their T-38s sitting there waiting for them. We'd dump them there, then we'd go to the commercial airport, and X hours later we'd be heading off. So quite often we didn't make it to home base that night. You were in some airport motel on the next day. Spent too many hours that way. That's one special field trip that I remember that was different with them.

They also had decreed that you could bring wives on the Hawaii trip, which had never been done before and never done since. That was great for me because I got to take my wife over and we played tourist for a couple of days before the week of crew exercises, and then we played the weekend afterwards, and then finally back to work again. So I doubt if she would have gotten over there for quite a while later.

BUTLER: I'm sure she appreciated that.

MUEHLBERGER: Oh, yes, yes, because I was away from home a hell of a lot. I was averaging five and a half days a week somewhere. That gets old.

The interpretation of our landing area on Apollo 16 turned out to be totally wrong. We thought we'd be in lunar highlands volcanic rocks, and since they were lighter colored than the ones we'd been landing on, it was quite clear they were not going to be the basalts. That's the most common rock here on Earth, except the floor of every ocean is basalt, so you

don't see it. It's all those pretty colors on that map [*pointing to a Tectonic map on the wall*]. But in New Mexico you've got a bunch of basalt flows, and Hawaiian islands are spectacular examples of them. Naturally, you run field trips into those.

But where we find these other ones, these andesites, there's a couple of areas near Los Vegas that we used for field trips there. One was really spectacular because here this volcano had erupted on a fault, and the fault moved afterwards, horizontally, completely separated [it] into two halves, so you can go right to the center of it and work your way up through a whole series of layers of what happens during the history of a volcano. I liked it, anyhow, as a geological one. [Laughter]

And you have gas blowing stuff out, pumice and the sort of junk that would be blasted out, as well as stuff that comes up liquid and flows down and stuff that comes out partly liquid, breaking up into pieces as it flows. It's hard to call it flowing when you're breaking yourself into a gazillion little hunks, but the inner part of it is still liquid. It's the outer part that all breaks apart.

So they got to see a good variety of the kind of rocks that might have been there on the Moon, except the other interpretation, which was the minority interpretation before we landed there, was this is simply material that was blasted out of the Imbrium basin and skidded across the countryside for hundreds of miles, stirring up whatever was there as well, and making these irregular-shaped mountains and valleys. That turned out to be the right interpretation. Everything was what that rock [*pointing to plaster cast*] turned out to be, "Big Muehly."

So here their training was salted toward one answer and it became pretty obvious by the end of that first EVA, where they stopped at a couple of craters and sampled around the lunar module, no volcanic rocks. We were all looking at each other. "Now what?" [Laughter] "What do we change? We still have to go in those mountains and make sure that's something different or the same [as] the stuff we just landed on." So we ended up, in

effect, keeping the same traverses as much as we could, except, as I mentioned earlier, we had to fight for that last one because of the false alarm on the command module lights.

So they did a remarkable job, in my view, of doing all the different sampling procedures and getting everything the way the plans had gone, and bringing them back. Then we'd look at the rocks and we'd resurrect the other alternative and junk the one that we'd gone with.

BUTLER: Luckily their training was enough that then they could—

MUEHLBERGER: Yes, luckily they'd seen all the lunar rocks from before, so they were at least familiar with the different kinds of beat-up rocks that happen in a meteorite impact area. It gets blasted apart, partly melted, then cemented together again as you're flying through the—I can't say "air." [Laughter] Through space. Till it finally gets to the landing spot. Like the "Big Muehly" had that big glass rim on it. Probably had one all the way around it. Must have been a terrible place to be with all these broken-up pieces and all this glass, molten rocks as well as solid pieces. Obviously we wouldn't have survived. It happened so long ago, we don't have to worry about it.

John [Young] and Charlie [Charles M. Duke, Jr.] were a very complementary pair in the way they worked. Charlie was talking all the time, jabbering away and describing things, and John, whenever he did say something, you'd better listen. It was important. We caught on to that pretty quickly early in the game. John would correct things that he saw that made him interpret it differently than Charlie. They worked together, as I see it, quite well. Did a heck of a good job, especially with the handicap that we gave them by telling them the wrong kind of stuff that they're going to be finding.

BUTLER: Did they give you a hard time about that later?

MUEHLBERGER: No, they never did. We deserved it. [Laughter]

BUTLER: I'm sure they realized that you were just making—

MUEHLBERGER: What bugs me is, I liked the minority interpretation, but because the guys that had spent their lifetime on this stuff said, "This is the way it is," I accepted that, rather than quizzing them even greater. The guy who stuck by this other interpretation was such a weird character that you could see why the other ideas became the more prevalent ones. Very different personality.

BUTLER: I think that wasn't the only time that you were expecting one thing and then ended up with another.

MUEHLBERGER: No, we blew it on Apollo 17, too. There, there was this dark mantle covering all the countryside, and the gospel was if there's anything really dark or really light, then those must be new because they haven't had time for the meteorites to turn them into the general gray dull background that the Moon is supposed to be. Well, that dark mantle, therefore, was supposed to be a very young deposit, and there were little bitty craters that looked as if they could have been sources of this stuff. Of course, they turned out just to be meteorite craters, and the dark mantle turns out to be some of the oldest volcanic rocks on the Moon, not the youngest.

But that dark mantle also kept us from finding out, or knowing until we landed there, what forms this valley. The valley had a tilt. It wasn't flat. With that tilt, I assumed that the topographers had screwed up and this valley was supposed to be horizontal and for some reason the geometry didn't work, the trigonometry, to get this thing level. Ended up it was

tilted and it was covered with basalt lava flows with this dark mantle coating over the top of it. So once they got there and landed and went to some of the craters that were in the valley floor, and here they get these big beautiful basalt samples out, you know what the floor is. So in the long run, realized, hey, with that tilt and with the lavas the way they were, they should have flowed right off out of that area. So that tilting is later. So we could start working out the tilting history of the Moon, which we weren't able to up to that point.

So I ended up getting to do some science rather than just the engineering of the science by finding out that we'd landed on the east side of a great big arch and the west side of it ducks down into the Serenitatis Basin and some of the tilting was before most of the flows filled in over there. Rats! We didn't have a landing site over there to get some of that stuff. But by the numbers of craters per unit of area, you can come up with a reasonable guess as to how old those lava flows are there, based on the other places we'd landed on lava flows. So you could come up with some pretty good stories about how this happened.

Within the black soil was another spot where they found the orange soil. One of the stops we made in Hawaii was one of the very recent craters out near Kilauea, part of that crater chain, and it only had erupted a couple, tens of years beforehand. But because you're dealing with water on the Earth, all these rocks come out with water in them on Earth. There isn't a rock on Earth that doesn't have some water. There isn't a rock on the Moon that has any, except the water that evaporated out of their space suits, which we knew the isotopic composition of, so that's no problem, or the Pacific Ocean, when they opened the spacecraft, or the urine bags, which we knew the chemistry of, too, so those were the only traces of water found on any of the specimens.

But here this volcano is a cinder cone, with all the stuff that blows and freezes on the way back down, makes this perfect little cone, but within it had been one of these places where the water had been steaming through it and made it all rusty. Typical. Takes the iron and rusts it. You've got rust colors in them. It was a nice orange color. So when these guys

said, "Hey, we're on the rim of this crater," which had been suspected to be a volcano rather than impact crater, "we've got orange soil here," and they hack away and produce this thing, and everybody's eyes go bugged. "We've got a volcano!" Hot dang! We had something interpreted right. Well, it ain't. [Laughter] It's volcanic material, yes, but it just happened to have been blasted out of that crater by a meteorite.

And at the time, nobody remembered that they'd found some orange soil on Apollo 11, a few grains scattered through the soil there. They were all over the place, but they happened to be in a specific chemistry of volcanic glass. So it wasn't a volcano, and we cheered for nothing. [Laughter] But it was an interesting deposit in being able to sample it. There was even a long discussion as to whether we should go back there on the next EVA, change things and go see that some more, but we were convinced by the core that was taken there and the grab samples that they had done, and we probably had enough sample material, and let's not. And I'm so glad we didn't.

The next EVA went to the base of the mountains where these huge boulders were. You could see it had rolled down the mountainside, so you knew where the boulder belonged, up on the sequence of rocks that must be up there. And they went on and did those things and accomplished everything that I think we could have possibly have done in the time that was available. They actually went even beyond the limits that NASA was going to allow them to go. They parked their vehicle at the maximum limit and then they walked. [Laughter] So they've got the mileage, all the records of distance and time out on the surface and all that. Probably Apollo 18 would have exceeded that if we'd gone.

BUTLER: Each one goes a next step further.

MUEHLBERGER: Yes, carry on from what you've learned. We got off into 17 there.

BUTLER: That's all right. One topic flows into the next. But going back to 16, you mentioned "Big Muehly" a couple of times, the rock, and during our break you talked to us a little bit about it. Maybe you could tell us the story for the record.

MUEHLBERGER: Sure. It [Apollo 16] landed, it put out the ALSEP, and then the remainder of the time that's available, there were two big craters immediately west of the landing site that they were supposed to go and go sample. Well, the ALSEP took more time than expected, so they ended up going to this one crater. They parked on the near side, the side closest to the lunar module. They walked around, they were sampling on the far side. Meanwhile, we spotted this rock with the TV and had Ed Fendel, who we used to call Captain Video, to please look at this rock for us, and he did. He zoomed in on it, saw a big rectangular white crystal flashing at us, and figured [that] the only crystal that does that is anorthite, the feldspar, and that's lunar crust, and that's not what we're supposed to be finding here.

And we also saw a little crater next to it, that we thought was a bounce crater, and it was right in the right direction to have come from Theophilus, which we suspected might have been a possible source of lunar crustal stuff thrown into our region. So here we were. First stop and we've got a hunk of lunar crust. We're in this volcanic country. What a stroke of luck. So we asked them to pick it up. Of course, we had no idea how big it was, because there's no trees, no fences, no nothing on the Moon to tell you size. They were clear over on the other side of this big crater. So as they got close to it and saw what it was that the back room wanted, they started complaining mightily because it was so big. When finally Charlie Duke gets into the crater and reaches over and sort of rolls the rock up the side of his pants, we could see that, yes, this was a big rock. It's in the transcript. I don't remember the exact phrase Charlie and John started saying, but, "Muehlberger, if this thing makes us fall into the crater," or something. You can read that. So it ended up being nicknamed "Big Muehly."

It's the biggest rock that ever came back from the Moon. [Laughter] The next biggest came from the Apollo 15 mission.

But we'd trained the guys, and everybody had told them, "You don't need big rocks. Something no bigger than your fist is all that's necessary for the laboratory types. So don't pick them up." And right off the bat we did this. So they left it at the foot of the lunar module until the very end when they knew they had the weight and the capacity to bring it home. So now we've got it here and it turned out to be typical of all the rocks brought back from that sample place, that landing site.

BUTLER: But yet it's unique because of its size.

MUEHLBERGER: Yes, and it's all sliced up. There's actually a sliced-up model of it sitting there in the lunar receiving lab, and pieces from different places have been cut out and sent to various experimenters who wanted to do their thing on something, whatever their thing was.

BUTLER: They had another interesting stop, I believe it was on Apollo 16, where they went to House Rock.

MUEHLBERGER: House Rock. Yes. That's North Ray Crater, the crater we saved for EVA 3, the big mad dash to this 1-kilometer-diameter crater. Actually, it's a little bigger than Meteor Crater. I got it back up on the photography that we had available for that landing site.

On Apollo 14, they're going to fly over with some good cameras and take some pictures of it, but the cameras failed about five minutes before the spacecraft got over the landing site, so on later orbits, what they did was take the Hassleblad that the guy had and mount it in the window and roll the spacecraft as the spacecraft went by, taking pictures. So

they were taking them aiming into the same place, giving us stereocoverage of that spot by doing that.

That film has about a 20-meter resolution. That means a typical house wouldn't show up, wouldn't be big enough. So we saw this rock on the rim of this crater, and, of course, it got nicknamed House Rock immediately. My photogrammatrist guy says, "We found you all the rocks down to about 5 meters in size." "Come on, guys. You've got to be telling me lies." I've looked at the machine and I couldn't see some of these things they were claiming were rocks, but they put them as Xs on the map.

[And] the radar people were telling us, "This place is so rocky, you're not going to be able to land." Well, that was kind of a scary thought, especially to the crew. But I don't know quite how it got sold that, "Yes, we can land here." When the crew tipped over and saw the landing site for the first time, they exclaimed, "I don't see any rocks." And everybody breathed a sigh of relief. But what the radar was telling us must have been seeing into the Moon for rocks to be reflecting their signals back. What we learned the hard way on that one was that the radar is sensitive to iron, and all the other landing sites had been on basalt, which are high-iron minerals. These things weren't. So it must have been seeing some 3D thing, in effect, there. As it turns out, virtually every rock in the landing site that was big enough to be in the photograph, those guys had spotted off of that crummy photography. I still don't know how they did it. Incredible.

BUTLER: Good eyes, I guess.

MUEHLBERGER: Yes. Great imaginations, too. [Laughter] Well, they had something. I was impressed, to say the least.

So here the crew gets up to the rim of this giant crater, and, of course, we're running tight on time all the time because we have to get back and launch, keep the guarantees from

failing on us, because you don't have your friendly gas station to come out and pump up your tires or whatever it might be. Then they were done in that area and they suggested, "Why don't we go over to House Rock." "Fine, go do it."

God amighty, they started walking and they'd get smaller and smaller and smaller, and they're still not there and the time is running out. You start fretting, and they finally got to the darn thing. Of course, there's no pictures that show you the whole thing because it's simply so big. Well, they got some really intriguing rock samples out of that thing.

They didn't want to walk too close to the inside of the crater, but they did take some panoramas across there, really amazing spectrum of rocks. That would have been a great place to have been able to spend a lot more hours, but no way. Had to drive home.

BUTLER: They always have to balance those needs.

MUEHLBERGER: Oh, yes. Safety comes first. That was rule one. You never broke that one.

BUTLER: Absolutely. If you didn't have that, then—

MUEHLBERGER: Something was wrong.

BUTLER: —you probably wouldn't have had much support for all the missions.

MUEHLBERGER: No. No. That's right.

BUTLER: Talking about the photographs before the mission and looking at it and planning it out, there were some discussions for going to the Tycho region on Apollo 16, is that correct?

MUEHLBERGER: Yes. Well, there were all kind of suggestions. Jack was pulling for Tsiolkovsky, which is a huge crater on the back side with a mare in the middle of it, but to get there—well, getting there wouldn't be any problem because the orbiting tracks were easy, but to communicate with them, you'd have to put up some communication satellites [that are] going around, that you could get communications back there. And launching all that stuff used up more money than they had saved by not sending Apollo 18, 19, and 20. So that's out of the game.

Tycho, being one of the youngest craters on the Moon, and we'd landed a Surveyor on the flanks of it, was certainly fascinating from the impact crater history idea. NASA was worried about the requirements of the energy required to get off. See, what they preferred to do was just go in the standard figure of eight, so when you blast off of the Earth heading to the Moon, you end up looping the Moon, and you come right back to the Earth. So if for some reason your equipment screws up, you're going to live the rest of your life doing a loop around the Earth and the Moon. So if you blast off into one of the other orbits, then you've got to have the guarantee that you can get back into the right orbit to get home again.

That Tycho being way off in the bottom of the Moon was well out of the range that they were really interested in trying. So we decided, because of what we'd seen on Apollo 15, the suggestion that this valley had big cliffs and it was sitting at the edge of the Serenitatis Basin, we were hoping that we would see the impact results of that basin as well as the Imbrium Basin. By sitting down in that valley with whatever leveled it off, we had some other stuff and we had this young volcanic that was making a dark coating all over everything.

Boy, that was another one of those stupid mistakes, because right out in the Serenitatis Basin is a big arcuate, a crater that got filled in by younger lava flows, doesn't have a dark mantle on it, but the rim of the crater has. So that should have told us it was old. Krrrr. [Laughter]

BUTLER: Sometimes it's hard to catch everything.

MUEHLBERGER: Makes you wonder. Well, I guess the only thing we can say in defense of it is, everything was going so fast, you didn't have time to sit and think long enough about some of these things. You're running. If you had punched them off every six months or a year apart, you might have had time to think these things through and come up with a better answer. You might have ended up talking yourself out of that spot, though. That might not have been what you wanted to do.

BUTLER: They did manage to come back with interesting information, even if it wasn't what was expected.

MUEHLBERGER: That's right. That's right. Fascinating.

BUTLER: Moving on to Apollo 17, we've talked about it a little bit back and forth here, but were there any points on Apollo 17 or any big issues that came up besides with the orange soil and, of course, Jack Schmitt running around and doing his interpretations?

MUEHLBERGER: I described how we set up the thing, so he ran the mission for me. I appreciated the help. [Laughter]

BUTLER: Good to have.

MUEHLBERGER: Well, we went to every spot that was preplanned, with one exception, and that was one of the craters in the first EVA after they set up the ALSEP. They didn't go as

far as we had originally planned into this big crater field sitting out there, but as it turns out, they were all going to be in the same thing, so the nearer one, which we did go sample, did the job, as far as we can tell, perfectly well.

They had sort of a small butterfly net kind of a thing which, because we had these long traverses between stops, and no samples in between, they designed this traverse sampler where Jack would just reach out with a little butterfly cup, you know, a butterfly net, and scoop up a scoop and stick it into the sample bag and let us know when he did it, so you just did it by time along these traverses. That way there are samples scattered all over the landing site, which was never done before in any of the other missions. I think that was an idea of his, too. I don't remember now specifically who thought up the Dixie Cup scoop.

BUTLER: It turned out pretty useful, too, if I recall, in that it got some sample of the landslide material that it wouldn't have gotten otherwise.

MUEHLBERGER: Might not have gotten otherwise. That's right. Yes. There was one spot where we stopped, and I had no idea they were going to stop. We hadn't been told. The guy that had the gravity meter wanted another reading in between these things, and that caused a bit of shock. "Why didn't you let us know so we could plan and tell these guys what we ought to be doing here?" Of course, as soon as they stop, Jack says to us, "What do you want us to do, guys?" [Laughter] We didn't even know they were going to stop. So there was a quick frenzy and dream up of what's the most logical thing to do in the few minutes that the gravity meter needs to level and get its reading and we can get off again. I don't remember now what we did. It's in the records, of course.

BUTLER: We can look that up.

MUEHLBERGER: Yes, some rocks they picked up and probably a scoop of soil. I remember somewhere in there we used one of those core tubes and sunk it in, but I doubt if we did one there. Anyway, that's the only time that we got caught short that I know about.

BUTLER: Jack Schmitt called the Moon "a geologist's paradise." What do you think about that statement?

MUEHLBERGER: Well, he's prejudiced. He's been there. [Laughter] Yes, what the Moon did for us was, in effect, see the complete evolution of a small planet, most of it sitting there visible for us, and it did it early in its life, and a lot of the things that happened to the Moon, of course, happened to the Earth. We're a bigger planet and we're still evolving. We've got an atmosphere, thank God, some of these other good things.

BUTLER: It's handy.

MUEHLBERGER: Yes. But the Moon has a core just like the Earth, the mantle and this outer scum we call the crust, it also preserves for us these big impact events. Doesn't matter where you look at the Moon, there's circles 300 to 400 to 600 kilometers in diameter and they overlap each other everywhere. The Moon and the Earth are in the same orbits. That means we got hit, too, and these big ones on the Moon stopped a little over 3.8 billion years ago.

Until about ten years ago, we couldn't find any rocks on Earth that were older than 3.8 billion. Now we're finding little scraps and pieces here and there that take us back farther in time. That means we had a crust that got obliterated by these big things, and started over again, melted that stuff so the brains of the minerals lost their memory and they started over after the impacts.

So that really changes your thinking about the Earth. Then, of course, the meteorite craters that we have on Earth, which there's quite a few, but there aren't enough. We haven't found two-thirds of them, probably, of the big ones. They probably have been destroyed by the geological processes that we have here. I'm sure you've heard about the one that wiped out the dinosaurs right across the pond there in the Yucatan. Boy, that would have been a bad day. [Laughter]

BUTLER: Very bad.

MUEHLBERGER: Now we've got some beautiful debris deposits ringing the Gulf on our side, where the tidal waves hit it, took everything that was there and tumbled it into a mess. So Houston would have had a problem. [Laughter] "Houston, I've got a problem."

BUTLER: Would have been a very short-duration problem. Wouldn't worry about it too long. [Laughter]

MUEHLBERGER: That's right. [Laughter] In one of the papers I've written and what I use in some of my talks, I've superimposed Texas on the big crater on the Moon called Orientale, [which is] on the side of it, and when you look at it, you can see that Texas would have been wiped out almost completely, if not by the crater itself, by the junk tossed over on it. And if it hit Texas, that would have knocked off Miami and L.A., too. Those things, it's a good thing we got done with that episode of solar history, stellar history, or planetary history, whatever you want to call it.

So, yes, in that sense we're seeing a planet go through its lifestyle. And turning around, looking at our own Earth, it's given us a lot of insights [that] we didn't think about. In geology we're always talking about the things that are going on today are what's going on

in the past, so we interpret them in that manner. Sometimes they went faster, sometimes they went slower, and we don't really have many glaciers today, but we can figure out where the glaciers were.

We're getting more and more aware of these impacts, and some of them are oil and gas fields, which turns out to be a useful thing to know, because it gives you a different thing to explore for, for oil and gas. Probably a half a dozen oil fields in the U.S. that are in old craters, because you crushed up the rock, managed to get it buried, and crushed-up rock has lots of spaces to allow the oil to accumulate in it.

BUTLER: In going to the Moon, in a couple of situations, as you mentioned, you went in expecting one thing, thinking that one area would be a certain way and it was different. In fact, the whole history of the Moon, what had originally been thought of, changed throughout the Apollo Program.

MUEHLBERGER: Oh, my, yes. It was a horrendous shock to most of us, the Apollo 11 basalts coming up to be 3.7 to 3.8 billion years old, older than anything we'd dated here on Earth. Holy Toledo! Right off the bat. And that's some of the youngest stuff on the Moon, because it's sitting there in very big sheets, not very much pounded up by meteorites, just the top few meters are all smashed up by them, but the rest of them are visibly—they've got folds in them and you can see the edges of the lava flows and all that kind of good stuff. Come on, guys. That made quite a difference.

BUTLER: Certainly learned a lot.

MUEHLBERGER: The other thing it did—there's a bunch of things it did. At Apollo 11, they had a whole bunch of different laboratories that were analyzing for carbon, how much carbon

is there. That equals life in some people's thinking, anyhow. So when they reported their results the day of the Lunar Science Conference that all the carbon people gave their papers in succession, they all got a piece of the same sample, and they came out with numbers that are really tremendously different. As they go back through all this, they discover it's how clean they got their lab. And as a result, we've learned how to clean labs, which means the hospitals are a hell of a lot cleaner and our own research labs are a lot cleaner.

BUTLER: That's an interesting correlation.

MUEHLBERGER: There was a whole—[out of] trying to see how much organic debris there is on the Moon, all you're doing is checking how dirty your lab was. [Laughter] Sort of what it amounted to.

BUTLER: One way to learn. [Laughter]

MUEHLBERGER: Yes. One of the cleanest labs was the one at Cal Tech, which has the worst smog at that time in the world.

BUTLER: That's pretty good.

MUEHLBERGER: And it was all burning gasoline mostly. When I grew up there, we used to burn our paper trash in the back yard and in incinerators. They gave that up. That was the first thing that got eliminated, back yard trash burners.

BUTLER: Probably just as well.

MUEHLBERGER: Oh, yes. Oh, yes.

BUTLER: As Apollo 17 was the last mission, manned mission to the Moon, unfortunately. As you said, they originally planned for others, but for various reasons they had to cancel them. What were your thoughts as it came to a close?

MUEHLBERGER: Tremendous degree of sadness that we didn't carry on the whole thing to the end like the original plans called for, because it was so damn exciting and you're learning so much and you're getting to work with and compete with the best there is, which forces you to do the best you can. Incredible competition in that whole group, the best laboratories in the world, and now all of a sudden we're not going to do that anymore. What are we going to do?

Well, I got involved in other NASA stuff, as it turns out, and I'm still involved in training astronauts or trying to teach them. Hell, you can't teach them. They soak it up so fast. All I've got is experience over them. And once they go fly in orbit, around Earth, they beat me out any old day.

In some ways it was nice to be home instead of the constant treadmill that you're on, because as soon as one mission's over, you've got to have the plans ready for the next one, and you're constantly playing with that, and half your team is working on the next mission beyond that. So you get schizophrenic in a way, trying to keep all these thing sorted out.

I came back here, and the guy that had occupied this office, Hoover Mackin, actually he died before Apollo 11, of open-heart surgery, and they couldn't put him together. So I, being chairman, I wasn't getting anything out of it, I decided, "I'll take his office." So all these bookshelves were here and his maps were there for a long time. I just filled it up with my stuff. But his memory still hangs around here.

BUTLER: That's good.

MUEHLBERGER: Really great people it was.

BUTLER: He was a founder in helping it all—

MUEHLBERGER: Yes, a member of the National Academy of Sciences and all that good stuff, as well as being a fun guy. So.

BUTLER: The Apollo Program, as a whole, we've talked here about so much of the science aspects of it and the later missions, but yet the Apollo Program originally started for political reasons, and we talked earlier about some of that. Actually, today is the anniversary of the falling of the Berlin Wall, the whole Cold War.

MUEHLBERGER: That's right. Yes.

BUTLER: And a lot of the impetus behind the Apollo Program. Did you think much about the political side of things and what it had all been about?

MUEHLBERGER: Not really. I generally worry about politics the day before I vote. [Laughter]

BUTLER: That's a good time. [Laughter]

MUEHLBERGER: I try to ignore the rest of the baloney that gets spewed out all the time.

When you look at the things we've learned about geology, most of them are the results of military or political decisions. At the end of World War II, we flew our airborne magnetometers off all our coasts to make a map of the magnetic fields in the Gulf, as well as the Atlantic and Pacific. That was simply to find submarines.

So you know what the background is, but what that did was show us that the magnetic patterns are different in the Atlantic than they are in the Pacific. In the Pacific you have these big bands of magnetism. We didn't know why, but here they were and here's these big scarps in the ocean floor in which the bands change their position. You can see them here and you can match them there. So that meant there must have been a huge ancient fault that moved in one way or another. It wasn't until a bunch of years later that the idea of spreading ridges and transform faults came into existence, and they actually moved the other way, which solved all kinds of geometric problems that were impossible before.

Then along comes the "Let's stop blowing off atomic bombs in the atmosphere," and we had an agreement, but we're going to do them underground. Now, how do we detect them? So our underground testing section is out where we have lots of earthquakes, and the Russians, theirs where there's lot of earthquakes. How do you tell an earthquake from an atomic bomb? So that underground test detection program set up for the first time identical seismic stations at many places around the world. Of course, then with the growth of computer capabilities, we could do more playing around to locate where that explosion or earthquake was, not just 60-mile-diameter radius, but a few miles.

As a result, then we started spotting these earthquakes. Most of them in the world happened on the tops of the mid-ocean ridges or at the big ocean trenches where the volcanoes are above them, and laid out for us the plate ideas and where the plates are moving relative to each other is where you get earthquakes. Political decisions get you geological data.

I actually, when I did this basement rock project that I was talking about, that was funded by the underground test detection program. If we can figure out what the differences are in our own crust, in our seismographs set up here at the surface, they have to read through that, we can eliminate all that geological noise and you can see Russia better, the way it was sold.

So you can thank, or blame, the military and politicians for the ultimate advent of plate tectonics, which is now the ruling thing in geology and gives us a frame in which you can predict and interpret, where before we had no way of predicting. We did a lot of interpretation. Most of it was sort of like opium-smoking. [Laughter] Looking back on it, you wonder how could you sell people those concepts?

So here's the Moon. Same thing. We're going to beat the Russians and send a man to the Moon. Close call, but we made it.

BUTLER: What do you think will—this is just speculation, I'm sure, but what would you think it would take to get back to the Moon, to continue exploring or to establish a base?

MUEHLBERGER: I would think a president that's got some guts to make pronouncements like that, because what you're going to have to do is sell Congress for ten- and fifteen-year periods that this is worth funding. And I don't know how that would work nowadays. With no longer this challenge of "Let's beat somebody," you don't have that incentive, unless you want to do it as a thing on your own. Maybe we can say we've got too many people and therefore we've got to ship some off. Let's find a place where we can convert it to places people can live—the Moon, Mars. Trouble is, we can reproduce faster than we can ship people to other places. [Laughter]

BUTLER: A whole new problem.

MUEHLBERGER: Yes, that's another problem.

BUTLER: Hopefully we can find a way to get back there.

MUEHLBERGER: But it would be fun. The cost of it, when you compare it with the cost of other things, really fairly minimal. We spend more money on liquor than we do on space. I do, too, probably. [Laughter] You can make all those kind of comparisons, you know. Tobacco taxes could probably fund a mission to the Moon. Why don't we use it that way instead of passing it off? Some of the boondoggles we have invented are really something.

BUTLER: Oh, yes.

MUEHLBERGER: Let's not get into those kind of—erase that off the record. [Laughter]

BUTLER: Okay. Well, after the Apollo Program, you moved in and did some work with Skylab, is that correct?

MUEHLBERGER: Yes.

BUTLER: That was obviously very different. Instead of looking at another planet, now you're looking back at the Earth.

MUEHLBERGER: Right. Well, I hadn't thought about anything about the Earth while doing the Moon stuff. The first Skylab mission, the guys came back after putting up the umbrellas and things, trying to repair that so it could be habitable again, Pete Conrad mentioned to the

management that, "If you taught me a little bit about the Earth, I think I could have taken some useful pictures." Of course, they'd been doing that in Mercury and Gemini, but for some reason there was nothing done for that initial pair of guys going up to Skylab.

So that triggered things off, and it was only a couple of weeks before the next crew was going up, so they got, I think, three hours' worth of lectures from—my mind just failed me. I said it earlier this morning. Paul Lowman. Paul gave geology stuff and another guy did oceanographic and atmospheric things. So, bing, they're off.

In the meanwhile, though, that gives them a couple of months to put together a group of people for the real long mission, the last Skylab mission. Every five days you go over the same point. So I ended up being part of that probably because the people down there knew me. You call up people you know rather than start from scratch, to get together a team of people to hit them up with all the spectrum of things that you might be able to do from orbit.

So I was assigned global tectonics…wow! You only get one hour to talk to them before they go, so what do you do? This is before—plate tectonics had just been invented and it wasn't that big a thing yet. But I talked about the big transform faults, the strike-slip fault, the San Andreas, the Dead Sea fault, the Alpine fault the length of the South Island of New Zealand, the one lengthwise in the Philippines, and one down in South America. "They're all about the same size and they have similarities and differences, and I don't know what they are. What can you find out for me?" Then in the mountain-range building, stories or different things you could get photographs of and illustrate.

Then what the guys at JSC would do is send us the transcripts of whatever comments they made that were pertinent to our topic, so that five days later when they go over that thing again, you could call down to JSC and they could have radioed up and gotten this information. So it was quickly put together, but seems to me worked quite well experiment in remote sensing. Of course, they had cameras, batteries of cameras on there that were looking straight down. They covered the whole United States and much of Mexico and a lot

of other countries we had agreements with. Of course, in those days, also there was a lot of political problems of "You can't take pictures of my country." Well, don't tell them. [Laughter]

Then after the mission, of course, we got to talk to the crew about what we were doing. They were shrewd observers. They really got a lot of unique pictures and they spotted a lot of things we didn't know a thing about. They talked about these cloud rings. No clouds over the ocean, rings of clouds around a blank area [in between]. Navy guys looked at each other and wondered, and the meteorologists didn't know anything about them. The pictures came back and then they started figuring out and they could ultimately pick them out. They're little tiny things on the weather satellite, because they're only about fifteen, twenty miles across. But they never paid attention to them before.

What it turns out is they're cold water eddies coming up from the bottom of the ocean, so you get a circle of cold water in the tropics, and the tropical air immediately coagulates at the edges of it, and you've got a ring. The other thing is, that water coming up is bringing food particles. Therefore, the fish are going to be there. So you've got a new way to find fish.

Another day the Skylab crew commented, "There goes a big dust storm off the west coast of Africa." Then they looked at the weather satellite, and lo and behold, you could see this faint thing. Of course, nobody looks at that. They're looking at cloud patterns. That's what they're trained for. So that thing was tracked all the way across the Atlantic into the Caribbean before it got that they couldn't see it anymore. So that means a lot of the rain that I get here in Austin has dust particles from Africa. Six months of the year it comes up to the Caribbean. The other six it comes into the Amazon basin, so the Amazon gets free fertilization from the African desert. Maybe they get germs from there, too.

BUTLER: Entirely possible.

MUEHLBERGER: Sure. But the most obvious things are the oceanographic and atmospheric things because they change so quickly. Then you can look into the sun's reflection on the ocean and see the changes in the current patterns and all the other things that are there. Geologically it'd be harder to prove. But when they take pictures along some of these faults, you see things that you never connected together before in your mind.

And that's one of the ways these has been useful for me, is I'll put a picture up on the screen from one of the Shuttle crews and say, "Look. Here's a great picture, but if you had only waited a few seconds and got these things in line, I don't know what it'd be like, but I think it'd be even better." So you play the competition game and they're going to get it. If it's clear that day, you've got yourself a much better picture of that thing.

I've used them in my teaching, because I've been along a lot of these areas on the ground, so with these pictures taken from orbit, you're seeing the whole forest, shall we say, whereas down here on the ground you're seeing the individual trees. So here's a sand dune and here's how it moves. Well, there's the whole pattern of them. Which way is the wind blowing? You can go and on with these kind of stories. But that's the current game to play with the Shuttle crowd, and with Skylab you only get that one hour to talk to them. With the Shuttle, they're going to go up in different orbit tracks and different things, different time of day and different seasons, a variety of other ways of going at some of these things.

But now we've got pictures taken from 1965 till now, thirty-four years, and some of them, you're seeing the same feature but through the years, so you've got a lovely time history. I've given talks about the environmental destruction of Earth, using pictures ten years apart, taken from the Shuttle in the same areas, and you can see the growth of cities, the elimination of the Brazilian jungles, the desiccation of the Aral Sea, [in] now today Kazakhstan and one of the other "stans," the boundaries between countries. Actually even between states in the United States, you can see some of them, different patterns of use.

BUTLER: Shows again the use of the big picture plus the information from the ground.

MUEHLBERGER: Right.

BUTLER: Make it all work as a system.

MUEHLBERGER: Yes, that's the current buzzword, the "Earth system."

BUTLER: Were you involved at all with the Apollo-Soyuz?

MUEHLBERGER: Yes, I was a co-investigator on that one, as logical follow-on. Farouk El-Baz put together the team of us. Actually, it was most of the people that did the Skylab thing. That was a kind of restricted one, because while they were docked with the Russians, there were no pictures to be taken. Then once we were on our own, we could do what we want. So it was only about four days' worth of actual photography, but we'd set up some things to do.

The things that were of most use to me were at the north end of the Dead Sea fault zone, because Skylab got some great pictures from about the Sea of Galilee south to the Red Sea, but the northern part we didn't have anything, and I didn't know much about it. So we had a couple of tracks that went right over it and they took these stereosets which I then used with existing geologic maps and made my own geologic interpretation, which is different from what the Turks had done there. So they invited me over and we went and spent a bunch of time in there and looked at all of the different things. I was right, as it turned out. Made me feel good, or I wouldn't have told you about this story. [Laughter]

BUTLER: You definitely want to get the ones where you're right.

MUEHLBERGER: Oh, yes. Every once in a while you are right. You might as well talk about it. [Laughter] There's too many times you aren't.

BUTLER: So you probably didn't work a whole lot with any of the Russians?

MUEHLBERGER: We didn't work with the Russians at all, strictly with our own troops.

BUTLER: In between Skylab and Apollo-Soyuz, after that there wasn't anything for a while.

MUEHLBERGER: There wasn't anything for a while, yes.

BUTLER: Before Shuttle.

MUEHLBERGER: Yes. Let me take five minutes off.

BUTLER: Absolutely. [*Tape recorder turned off*]

In between Skylab and Apollo-Soyuz and then Shuttle, you came back to work and were teaching.

MUEHLBERGER: Yes. Well, all that time I was teaching. Apollo-Soyuz, fortunately, flew during the summer, so I could be down there in Mission Control during the mission. Skylab, I never was. Didn't need to. The phone works. In those days, the mail service worked.

BUTLER: In coming back to teaching, did you integrate now your experience with Apollo into the classroom?

MUEHLBERGER: Oh, yes. Oh, yes. Just the history of the Moon became a part of the whole course, as it were. Still things to learn, but for a beginning geology class, the important points of the formation of the planets, melting, impacts, final melts, and then it's just sitting there, the cold rock taking a beating ever since.

But coming up on the Shuttle stuff, they had to redesign and rebuild that thing so many years, in the meanwhile they let the Skylab crater, and that was a mistake. There was a big space station sitting up there waiting to be added to. Too late now.

Before we ever got the Shuttle up, Mr. Abbey would send Sally Ride and one of the other astronauts up here and spend the day sitting here. "What can we do in geological science from orbit?" She was assigned the job of being the scientist to think up the kind of scientific things that could be done by the astronauts looking out the window. So she'd come up here in a t-shirt and her jeans, with the knees out, looking like a typical student around here. It was just amazing. I've got a picture of her over there when she was on the field trip in New Mexico that I set up.

We evolved some ideas, and since none of them knew anything about geology, almost none of them, figured that they needed some kind of a field trip, and since I'd spent a lot of my career working in northern New Mexico, earlier for the New Mexico Bureau of Mines and later on NASA grants and teaching our summer field geology course and things like that, I got quite familiar with it. So I figured there would be a good four-day field trip, pick them up in Albuquerque and take them a vanload at a time. So I could talk at them at any time and they could ask me questions at any time. Four-day cram course is what it amounts to.

Of course, I started out with just Skylab pictures and Apollo-Soyuz pictures, of things from orbit, and you've got volcanoes up there of every shape and size and chemistry. You've got river-cut canyons of different shapes. You've got glacial-cut canyons. You've got ancient and modern sand dunes. You have continent to marine right through the beach and transition. So, a lot of good things and it's pretty country. I could do the same thing out in the Big Bend, but there half the time you're surviving rather than learning, and that's not the point here. You want to do it in a nice place to learn.

So after we talk about the details, I can show them these pictures taken from orbit so they can see what the pattern of these things looks like from their vantage point. It seems to have been useful, because it's still going on. Of course, the trip itself has evolved through time, too, as I add new pictures or lately I've been talking up some of the Mars analogs that are in those things or in some of that area. I also have them stand at the edge of the canyon here and look into the canyon, say, "There's Hadley Rille," and show them these pictures with these guys doing these things. Dave [David R.] Scott standing at the rim of the crater or the canyon. And I've even got telephoto pictures taken so that they can see what you can really see on the other side. We're actually standing over here in this road when I'm talking with them. That was taken from the other wall. So I can give some ancient history. We trained 15's crew here, kind of stuff.

BUTLER: I'm sure they get a kick out of that.

MUEHLBERGER: Oh, yes.

BUTLER: Hearing about that.

MUEHLBERGER: And then the Mars analogs. And this last time, added a day into the field trip on geophysics. We were doing gravity studies on the Moon. This all evolved from Pat Dickerson, who got her doctorate from me three or four years ago. I've forgotten how many already. But she works down there on the Earth Obs [Earth Observations Office, Building 31] group at JSC. We'd gotten involved in this Mars meeting over at LPI [Lunar and Planetary Institute, Houston, Texas]. "Okay, we've landed on Mars with people. What do we do now? What equipment do we send with them? How do we train them? What kind of mix of skills should there be? How do we communicate with them?" These kind of questions, because the Mars missions, the engineers had worked out all of the orbital stuff. But then this chapter of, "What are we going to do while we're here?" was a blank. And that's what this meeting was about. So that gave me the impetus to talk about some of these things that are up there in the Mars version, rather than the terrestrial version things.

Pat had sent a Christmas card to Paul [W.] Bauer, who's the assistant director of the New Mexico Bureau of Mines in Socorro, a guy we know, and he answered back saying that, "We're doing a groundwater study in the Taos area." Well, hell, you know, we stay in Taos for this field trip. He didn't have any geophysics done, so it was a logical thing to let it grow. I was delighted to have Pat work this idea up, so we got laser rangefinders and GPS [Global Positioning System] units to hold and locate ourselves, two-way radios, gravity meters. The Socorro crowd was up there. They had all of the things laid out for us on what each crew would be doing.

So out they'd go, locating where the gravity stations would be done, and coming behind them were two more astronauts doing the actual gravity readings, radioing them back to Mars base, where a geophysicist was sitting there with a laptop computer, punching in all this stuff. So by the end of the day, had all the data reduced and here you could see the profile you just did, the change in gravity, and compare it with the map and see the results. Turned out to be marvelous training thing, because you're doing something useful, helping

these people locate where the bottom of the—where water is in the Taos basin. That's what, in effect, you're doing with this instrument. And each one was doing a separate line, so it was all new. It's not just make-work. And it was valuable to the people of the city of Taos, the Indian reservation, and all the rest of that sort of stuff, as well as them learning a technique that we could use, or might use, on the Moon or Mars, looking for water. So it's now a five-day field trip instead of a four-day field trip. Luckily, Mr. Abbey bought it, no trouble at all, because that cost time and [that] equals money. So the New Mexico people got a lot of data and we got the experience.

BUTLER: Good for everybody.

MUEHLBERGER: Yes. Well, probably none of the people that did this will go to those planets, but by the time we do go, they'll be up in the management positions and they'll have a little feel, a better feel, for what it is that these guys are going to do or try to do.

BUTLER: How do the Shuttle astronauts adapt to the geology training? Are they pretty receptive to it?

MUEHLBERGER: Oh, my, yes. Out of the couple hundred that went through this thing, I think there's only one that I have any qualms about as being uninterested.

BUTLER: That's good.

MUEHLBERGER: Every time we look at these pictures after a mission, they say, "God, it was better than that." You've got them on the screen, big megasize, and I'm thinking, "Wow, isn't that fantastic," and they're saying, "Hell, it was better than that." I don't know what they can

really see. This has been one of the ploys I've tried to get so I could go fly. "I don't know what they can really see, because they're telling me it's better than these pictures. And if I did, maybe I could then find out and do a better teaching job."

BUTLER: Sounds like a good argument to me.

MUEHLBERGER: I tried that out on Senator John [H.] Glenn [Jr.] when I briefed his crew. He was really listening. He was really interested in the subject. It was afterwards I discovered he had to go buy his own camera in the drugstore when he flew [the first time], so he could take his own pictures. NASA wouldn't furnish him one because they didn't want him to be fooling around with this other stuff. But, about halfway through, I stopped and said, "Damn it, John, I could have been the geriatric specimen on this mission. Besides that, I could find out what these guys can really see. They keep telling me it's better than this." And he smiles and says, "After me." [Laughter]

BUTLER: Then you need to call him up now and say, "It's my turn." [Laughter]

MUEHLBERGER: Yes. He's gone. I go down next week. I think I'll go and see Mr. Abbey and bug him about this, once again.

BUTLER: There you go.

MUEHLBERGER: Sorry. It's an off-to-the-side thing, but I was delighted to see him so interested in learning, asking good, intelligent questions.

BUTLER: Absolutely.

MUEHLBERGER: He wasn't along for the ride. He was going to be doing something.

BUTLER: That's good. And that's good that so many of them were interested.

MUEHLBERGER: Half of them, roughly, in the past, anyhow, used to be military pilots, flown all over the world and don't know what they've been looking at. So here I am helping them find out. "When you're flying to L.A., you're going to go over this and this and this." "Oh, yes."

When I show them some of the picture taken from orbit, every once in a while I get some 35-millimeter slides taken from somewhere they've been flying in some T-38, "And if you can identify these, Bill, you can have them," one of those kind of things. [Laughter] Luckily, I've been able to work them out since they give me a long enough string of pictures that you can find something that is familiar enough that, "Oh, yes, they've got to be in this region," and you can work backwards.

BUTLER: Sounds like you've got a pretty good rapport with them.

MUEHLBERGER: Yes. Of course, looking at the Earth is different from all the other stuff. They're trained to work checklists, got to do this, got to do this. If this happens, then I do this. That's the whole kind of training. All the equipment that they're going to be working with in the laboratories on the Shuttle, they learn how to operate all that stuff. That's a different attitude or approach than exploring, where you don't know what you're going to find, but let's see if we can find it and figure it out or work these things together.

Exploring the Earth is a different thing. You see something that grabs your eye you didn't know about, take a picture of it. Very often those pictures have been educational as the

devil. There's one Shuttle picture looking at the eye of a hurricane, with little thunderstorm topknots sitting in various places. The weathermen hadn't realized that you might have thunderstorms inside a hurricane, which equals tornados. These extra real strong bursts that they talk about apparently are those things. Until that picture came along, they hadn't even thought about it. That's only about five years now that that idea's gotten in. God knows how these pictures will change something.

BUTLER: A lot of benefits.

MUEHLBERGER: And they don't cost much to take, and they're all sitting on the Internet, so all of us get to use them.

BUTLER: Good for everybody.

MUEHLBERGER: Good for everybody.

BUTLER: We're going to pause here real quick and change our tape out, if that's okay. [*Tape turned off and changed*]

You mentioned the hurricane and that particular picture and how much can be learned from that. Are there any others that you can think of offhand, pictures taken from the Shuttle Program, that made a big difference in any particular areas of earth science?

MUEHLBERGER: The pictures they've been taking of active exploding volcanoes are an obvious thing. There are actually at least two volcanic eruptions that the only report about that eruption is the picture. The locals never mentioned it or you never got to some place where—because there at the Smithsonian has a volcano. I've forgotten exactly what they call

it. Research Center, in which they are interested in how active is the earth. How many volcanoes are erupting at any given time, [that] kind of a problem. And how big are some of those, and this sort of business.

When Rabaul went off, we had pictures from the LANDSAT spacecraft that looked straight down, but when you look at the Shuttle pictures looking in from the side, you see that there's two layers of clouds. Two volcanoes were going off simultaneously. One was dominated by water, so it was making a big white plume. The other was dominated by rocks, with a brown plume. And if you look straight down on it, you only see one of them. That opens the eyes of the volcanologists who would be on the ground looking up at the things, if they're not dead. So the volcano business, it's been a very helpful kind of a thing.

In my own interests, which are the business of mountain-building and this sort of thing, many of these pictures have opened my eyes to things I hadn't thought about, and also the pattern of things. You see them in a diagram in a textbook, but until these things come along, they don't work in my brain that well. So they've been really helpful to me in visualizing the whole thing.

I've put together a CD on the Arabian Plate, its boundaries, and when I go down next week I'm going to proofread this thing that should be ready to—it's on the CD, but now let's see if we've got all the links and connections done right. And that's for astronaut training. Coming around [through] the Gulf of Aden and the Red Sea, it's pulling apart, and along the Dead Sea fault they're sliding by, and over through Iraq and Iran, they're crunching up and making big mountain ranges and volcanoes. So you've got all the different kinds of boundaries on that one plate, as well as a lot of places where we don't have any decent pictures.

So there's a big "please" built into this thing. "We don't have any pictures of this area, and we'd really love to have some to help us on down the line." And these things supposedly will go on the Space Station, sit there as their library of stuff, and if for some reason we need

a picture of some specific place, then they can refer to the CD and look at this frame and just left of the E that's printed in there, or whatever, there's what we're looking for, and we need a good 250-millimeter lens picture of it, or whatever you want to dream up.

There's two pictures taken on [Skylab], the southern half and the middle half of the South Island of New Zealand, the Alpine fault, and that had been one of their targets for their 84-day mission. They figured they'd taken enough pictures of it, so they X'ed out worrying about the Alpine fault anymore. The commander happened to float by the window as we were going by one of the last couple of days of the mission, looked down, saw this late afternoon, perfectly clear, spectacular view, grabbed the camera and got those two pictures. We've yet to improve on those pictures. Here again, it was just serendipity. Luckily, he looked out the window at the right time.

And, heck, here's an old Xerox copy, so you can't see it in the camera very well, but that's Gemini, the best picture we still have, looking south along this thing. And here it is on the cover of the *Journal of Geological Education*, 1968. How educational. God, there's no people in that picture. Literally aren't, because you don't have the Nile River [in it]. I've been there. Golly, that's empty. I used to think that West Texas and Chihuahua Desert were deserts. They're tropical jungles compared to Egypt and the Sinai. Ridiculous how empty it is. It rains every fifteen years, once. I happened to be there about a month after they'd had one of those rains, and their two-lane asphalt road, which runs along the Red Sea, where it goes across the wadis, as they call them—we call them *arroyos*—the road's gone.

BUTLER: When it rains, it really rains.

MUEHLBERGER: That's right. And because there's no soil to soak in the water, it just runs off and away it goes.

BUTLER: There's a lot to be learned.

MUEHLBERGER: There's lots of other pictures, and I'm sure that as soon as we stop, I'll think of them all. [Laughter]

BUTLER: Of course. That's how it works. You mentioned using the CD for Space Station. Have you done other planning ahead for Space Station Earth observations?

MUEHLBERGER: Yes, the project I've been working on for the last six months is the India Plate crash, which occupies most of Asia. The reason I started with the Arabian plate is that it hasn't moved very far yet, so you're dealing with beautiful structures and simpler problems, but India has been jamming in there for 50 million years and is beaten up stuff clear up by Lake Baikal, 1,000 kilometers to the north. So you need to work out all these different pieces. Boy, am I learning a lot of geography and geology by doing this. That's fun for me. And I get paid for it.

BUTLER: That's even better.

MUEHLBERGER: On occasion. [Laughter]

BUTLER: That's good to still be able to keep learning and building on all this experience.

MUEHLBERGER: That's what life's all about. Keep learning. Otherwise, you'll have big footprints crawling up your back.

BUTLER: Looking back over your work, specifically on the space program, was there a point that you would consider your biggest challenge?

MUEHLBERGER: Biggest challenge. I'd say the whole Apollo Program was that, was one continuous challenge. I don't know what to discriminate out of that as the max problem time. It could have been when we had to defend saving the last EVA on Apollo 16, where you had just overnight to get the documents together to sell management to say yes. Instead of a seven-hour EVA, they gave us five, and we ran with it.

BUTLER: And pulled it off successfully.

MUEHLBERGER: And pulled it off, yes. If only that House Rock hadn't been so far away. [Laughter] If we'd known, probably would have told them to drive there. Then we would have had the TV camera there. As it was, we didn't see anything. All we were doing was hearing them. They'd gone over the edge.

BUTLER: Good reason to go back.

MUEHLBERGER: That's right. Go back and really look at that crater. Just land it on the rim. Heck, that'll be a skill.

BUTLER: Quite.

MUEHLBERGER: But they could.

BUTLER: Certainly have enough technological advances to help.

MUEHLBERGER: Well, even then, though, they were landing within a couple of yards of the pre-planned point, except for Apollo 11, and there they deliberately had to go downrange to miss all the rockpile.

BUTLER: That's interesting that that's the only one that they had that problem with.

MUEHLBERGER: Isn't it, though? Dumb computers. [Laughter] But look at where we've landed at Mars. Every one of them has been a rockpile. Luckily, the rocks aren't too big, so you wouldn't sit there tilted too badly, but you don't want to be tilted too much.

BUTLER: Is there any one point that you would say was your most significant accomplishment or contribution to the space program?

MUEHLBERGER: Well, I like the fact that I did get some science out of it, namely this business of the buckling of the Apollo 17 site and the wrinkling of the lava flows out in the mare basins that I ended up writing about and contributing that aspect to the history, rather than running a team of guys who were all smarter than me and who were doing the science while I was doing the running around to make sure that the—to get the engineers off their back.

BUTLER: Would you have ever imagined where, as you were starting out, that you would even be involved with the space program?

MUEHLBERGER: Never dreamed that I'd ever been seeing anybody go to another planet, much less be involved in it. I've always been a science fiction fan, so I've always had that attitude. Never thought it would come to pass. Here it did.

BUTLER: Here it did, and hopefully it will continue.

MUEHLBERGER: Amen.

BUTLER: Before we close, I'd like to ask Kevin and Sandra if they have any questions.

MUEHLBERGER: Sure.

RUSNAK: I did have one. I wanted to ask you about being a scientist involved with NASA, which is traditionally an engineering organization—

MUEHLBERGER: It has to be.

BUTLER: —how the relationship between the scientists and the engineers was.

MUEHLBERGER: I think the biggest problem at the time was during the Apollo days, when you had the really big names of the geochemists and the geophysicists working, and they were the types that wanted their way, now if not yesterday.

BUTLER: Egos you mentioned before?

MUEHLBERGER: Yes. And that kind of thing automatically sets up conflicts. There were four of them, nicknamed the Four Horsemen of the Apocalypse. [Laughter] They'd get together and dream up something, you know, and hit the top brass either at JSC or preferably at headquarters, where the brassier types lived. Having been half an engineer myself and then a geologist, I think I could see the engineer side a little better, and I'd like to think that because of that I got along better with them and was able to work with them. Let's accomplish the practical, but let's make sure the practical includes every damn thing I want. [Laughter] But, you know, don't say it quite in those tones. Push it to the max, but you can do it in a nice way. Sometimes you get farther.

Sometimes it's like that big ten-foot rubber ball you see the people hitting and running along with, whatever that game is. Then you're the only one standing on the other side and you run like hell and you run into it, and you sink way into it. You think, "Man, I've made some progress," and the next thing you know, you're on your back. [Laughter] And the ball's rolling all over you. That'll happen in any of these big agencies.

I think I had more trouble with the USGS people that I was working with. I guess a government agency assigns these people to their project because you've got money, not necessarily that they're going to work for you. So I had some guys that were off doing their own thing, and I figured since I was paying their salary, they should work for me 100 percent of their time. A couple of them, I was lucky to get 20 percent. That irked me. I figured that was a waste of my tax dollar.

RUSNAK: So do you think, then, NASA placed a high enough priority on the science in the Apollo missions as much as was practical?

MUEHLBERGER: Once they got sold on the idea that the science needed to be done, yes, I think they did. That was largely the selling of Gene Shoemaker, who sort of invented the

whole thing himself. He made the first geologic map of the Moon, demonstrated you could do it using these photographs. He organized the Astrogeology Branch of USGS. He told NASA that, "Once you're on the Moon, what are you going to be doing? Geology," and making sure that that was done. Eventually he was pushing so hard, he got crosswise with NASA management and they didn't want him around. So we took over. He was PI for the first missions, Gordon Swann the middle set, and me the last set. Gene's gone, killed himself in a car wreck. But Gordon Swann's the one you ought to get, because he was Gene's backup and my backup.

BUTLER: We'd love to talk to him.

MUEHLBERGER: So he's been through the whole thing and he lives just west of Sedona, so you'd probably have a lousy time having to go to Sedona.

RUSNAK: That's all the questions that I had. Thank you.

MUEHLBERGER: Thank you.

BUTLER: One question occurred to me. You mentioned Gene Shoemaker. Of course, we've talked about Jack Schmitt. Had you ever considered becoming part of the astronaut program yourself, or trying to?

MUEHLBERGER: Only recently, since the Shuttle days. By the time I got involved in this thing, how old was I? I was in my forties. So that was an old man to those guys. No, I guess not really, because [John] Glenn is two years older than I am. Or am I two years older than he is? It's close.

BUTLER: Close enough. I think you fit in the category together.

MUEHLBERGER: Yes, I've thought about it, but at the time I could have done something about it, it was too late. They were all picked and they were all competing with each other. I've applied to go in the Shuttle, been turned down. Could try again. [Laughter] Actually, one of our Earth Obs people did go, but he worked for the Office of Naval Research, so there's a big lobby organization. University of Texas doesn't have a very big lobby front down there.

BUTLER: Well, who knows what might be possible.

MUEHLBERGER: That's right.

BUTLER: And you certainly had quite an important contribution with what you did.

MUEHLBERGER: It was fun.

BUTLER: We appreciate you sharing it with us today. Thank you very much.

MUEHLBERGER: You're welcome.

[End of Interview]