RESEARCHING THE EARTH: LIVING IT, LOVING IT, AND SHARING IT

(SLIDE 1: TITLE SLIDE)

Thank you, Steve,

Hap, and fellow members of GSA,

Like many of you, I've discovered that our planet Earth is an amazing and special place—it's our home in a vast universe of other earth-like planets, un-earthlike planets, moons, suns, stars, galaxies and nebulas. Inspired by an article on Gene Shoemaker while I was in 9th grade, I dreamed of becoming an astronaut and leaving this planet. That was not to be; I got stuck here on earth…fortunately! I love this planet and the life I've lived on it—with my son, Robert, with my friend of many decades and husband of a few years, Jerry, and with my fellow geologists.

Every geoscientist has a different story to tell. Science is a highly individualized way of life—and we who are scientists typically cherish our freedom to follow our nose into mysteries and challenges. In a 1967 book called "The Art of the Soluble", Peter Medawar said "Scientists are people of very dissimilar temperaments doing different things in very different ways. Among scientists are collectors, classifiers and compulsive tidiers up; many are detectives by temperament and many are explorers; some are artists and others artisans. There are poet-scientists and philosopher-scientists and even a few mystics."

(SLIDE 2: MOTIVATION, EDUCATION, OPPORTUNITY, APPLICATION, SUPPORT)

But, I suspect that in spite of our dissimilar temperaments, we all have at least five ingredients in common in our lives, and we owe thanks to many for how these have played out in our careers. The ingredients are: motivation, education, opportunity, application, and support. Let me briefly summarize how these have threaded through my life.

(SLIDE 3—MOTIVATION)

Motivation appears as sparks of curiosity that lead to research at various times in life, sparks that need to be nurtured as soon as they appear. I confess that I don't know when I became motivated to be a researcher. But, judging by an incident that I don't remember but that is part of the Werner family lore, it was certainly well before I ever heard the word "research", or probably even before I heard the word "curiosity. Evidently, when I was about 3, I was quite taken by trying to figure out what was in the bottom of a ditch on our street. It was a good slimy, stinky Pennsylvania ditch, and it apparently fascinated me. The bottom was well beyond the reach of my arms, or any available stick and I must have gotten extremely frustrated and motivated to find out what was there. Curiosity finally got the better of judgment, and I decided that the only way that I was going to figure out what was in the bottom of this ditch was to jump in. Problem solved….for a 3-year old! It never occurred to me that I probably should not be wearing my best dress and my brand new shoes when I did this…**(SLIDE 4)** Needless to say, what I found in the slimy bottom of the ditch was absolutely wonderful and benign compared to what I happened when I got back home that day. **(SLIDE 5)** Who was I to complain decades later when my my own child showed the same fascination with mud?!

(SLIDE 6) My motivation manifested itself again in 8th grade when I made a resolution that I was going to get a Ph.D. Why did I make such a resolution? Young people today probably have trouble believing that there were actually times in which, if you were a girl in 8th grade, you took home economics, and if you were a boy, you took shop. PERIOD. I really didn't want to take home ec, I had absolutely no talent for sewing, I despised the pink linen that I was assigned to work with, and I really wanted to be down in the shop where the boys seemed to be having much more fun. But, the more that I tried to get out of home ec and into shop, the more the school system decreed that I would take home ec.

When I looked around, I saw that the people who had the control and the kind of freedom that I wanted were those who had an education. I clearly had to get more education than anyone else if I wanted to control my own destiny. A year later, in 9th grade, we were all required to take the first general science class. It was 1957, the year that the Russians launched Sputnik. Like many kids of that time, I turned my eyes to science and space. I wanted to go to the Moon.

I was lucky enough to get a job the summer after high school in what I thought was "science." In hindsight, I really think that my vision of a scientist was distorted for quite a while by images of medical doctors, because this was really the only vision available in my small rural town. I became assistant to the pathologist at the local hospital. This meant, in fact, that I scrubbed down the morgue after autopsies for a whole summer, helped examine a very large number of tonsils under the microscope, and occasionally even had to carry an amputated arm or leg from the operating room to the deep freezer. I never told my parents what this job involved, and I suspect that they confused it with my volunteer duties as a "candy striper," in which role I took milkshakes and cheery smiles to the hospital patients!

(SLIDE 7: EDUCATION) My parents had come out of small, poor northwestern Pennsylvania towns during the depression. My mother was valedictorian of her senior class in high-school, but her six brothers got to go to college, not her. My father had a civil engineering degree from Penn State, but wouldn't take me to the shop where he worked because "girls didn't do that." However, they had vowed that their three daughters would have college educations, and sacrificed a lot to provide that to all three of us. I ended up going to Allegheny College, a small liberal arts college at the huge, scary distance of 60 miles from my home—farther than I had been in the first 18 years of my life. I thought it would be fun to be a chemistry major because I'd had such a great chemistry course in high school—perhaps not accidentally taught by a woman, Dawn Taft.

(SLIDE 8) My job the next summer, after my freshman year in college as a chemistry major, was ‘real research’ with a chemistry professor. The job was to analyze mouse blood in a cancer research program. After that summer, I was pretty sick of blood and organics and I couldn’t quite see that I was on the right path to the Moon. Combined with the fact that I have no ability to memorize long molecules and organic chemistry was my next required course, I decided that the powers that be had put organic chemistry in the requirement, just like home ec, as a signal that I was on the wrong path. I switched majors to physics and math.

(SLIDE 9) Interestingly, two of the three physics faculty at Allegheny were women. Georgie Scovil showed no mercy on me in the solid state physics classroom, nor when I fell asleep in the hammock at her house during a physics discussion. **(SLIDE 10)** Barbara Lotze is one of the most inspirational women I have ever met—she landed in a refugee camp in Hungary when the Russians invaded Budapest in 1956, got out of it by getting a Ph.D. in quantum mechanics, immigrated to the U.S., worked a year in our college library to learn English, and then became my quantum mechanics professor. There weren’t many women role models back in the 50’s and 60’s but those who I encountered in high school and college were truly inspiring, as is Catherine Skinner who has been an inspiration for me for decades through GSA and MSA. There were only three physics majors in my class at Allegheny and, in the tradition of the day, the two guys were allowed out all night and, like all the women, I was locked in the dorm at 10:00, which made it impossible to collaborate on homework assignments. **(SLIDE 11)** But, we were so excited about what we were learning about solid state physics that, with the plotting of the guys, I managed to escape one night. We spent the night constructing our version of a lattice out of marshmallows and toothpicks to present to these two women the next morning.

(SLIDE 12) These were now the early days of the 1960's. The US finally had satellites in orbit, and one of the big research areas was refining a problem that went back centuries: What is the exact shape of the earth? There was pragmatic need for this information: the detailed shape of the earth affected the orbits of satellites. I obtained a NASA internship to work at Goddard space flight center during the summer of 1963. The first day that I walked into my internship, I met my boss, Bill Kaula, and found out that he was a very intimidating West Point graduate. He introduced himself by saying, in about this tone of voice and speed-- "My research is to determine the shape of the earth from satellite data. Program these tesseral harmonics on the computers downstairs." Thinking how I had barely mastered a slide rule and had just survived my first course in DIFFEQ, I said "Sir, what's a tesseral harmonic, and what's a computer?"

I left Allegheny College as a starry-eyed physics/math major wanting to study the planets and go to the Moon, and 7 years later left Caltech as a pedigreed planetary scientist wanting to study the wonderful earth that I'd learned about by being in a geology-based program. **(SLIDE 13)** I'd camped out in the field for the first time in my life—in July in the hot remote desert south of Canyonlands National Park. I'd learned things like: Gene Shoemaker, my beloved mentor and thesis advisor, was not attentive to logistical details…giving me a four-man USGS tent with no tent stakes when he took me to Canyonlands. Or, I learned that puppies as field companions in the 110 degree heat of summer in Canyonlands are hard to take care of, and that they will not take on a mountain lion but can outrun a hawk that is determined to have a puppy for a snack. I learned that chipmunks will eat every label off your month-long supply of canned goods in a day. And, I learned how to drive a 4-wheel drive USGS Jeep up and over Elephant Hill in Canyonlands in a tight skirt, nylons, and stupid shoes!

By the time I left Caltech, I was more realistic, had gotten married, and had a child along the way. The manned space program was actually that--a <u>manned</u> space program and it had passed me by. To put this into perspective as an American, the Russians first put a woman into space in 1963; my undergrad and graduate student years were 1960-1971, and the first American woman, Sally Ride, flew in 1983. To this day no woman has set foot on the surface of the Moon. Yet, as I have explained to my wonderful son—who is here today-- my dream of being an astronaut seemed intact because, along the way, opportunities and my interests had changed, and interactions with good scientists as teachers and mentors had guided me from childish dreams into realistic visions.

SLIDE 14

My 1960's dream of being an astronaut did not restrict me to flying in a space ship. The opportunities that I had during my years of undergraduate and graduate education to work with researchers who were trying to define cancer in mice and humans, who were using the very first post-Sputnik satellites to solve the classic puzzle of the shape of the Earth, who were training astronauts, who were designing and exploring the planets with unmanned space craft, and who were tromping the deserts of the southwestern U.S., gave me a love of the earth and planets that took on quite a different form from my first visions of life as an astronaut. By then my dream of becoming a “real” geologist had crystallized.

(SLIDE 15) While I was doing my thesis on the dynamics of the impact at Meteor Crater with Gene Shoemaker as my advisor, I was sharing an office with Tom McGetchin, who was studying diatremes and having a great time doing field work. I wondered how I, without a background in geology, could study volcanoes?

(SLIDE 16) The answer came in 1975 when I saw the famous photograph of Old Faithful geyser taken by Ansel Adams. A-ha!!!-- I figured…I can first study geysers—which should be simple pots of boiling water-- and then apply the results of my research to volcanoes, learning about rocks along the way. By this time, I was an assistant professor at UCLA, and I was about to learn that geysers are not simple pots of boiling water. To truly understand a geyser, one needs both thermodynamics and fluid mechanics well beyond what I had mastered.

I took an unpaid summer to go to Yellowstone with my 8-year-old son as a field assistant, the family bank account as the research support, and a VW camper towing a 12-foot trailer traversing the hills and valleys of the Basin-and-Range province in Nevada toward Yellowstone. Based on this summer, I laid out a rather optimistic 5-year plan to study geyser and volcanic eruptions, and submitted a proposal to the National Science Foundation. They funded it as a ‘high risk’ possibility. A true opportunity in my life—

this one created by the support of peer review and colleagues willing to make a decision about gambling on a young person. I am profoundly grateful to both my peers who served on that panel and the program managers, Alan Gaines, later John Synder, as well as my peers in the UCLA geology department, led by Gary Ernst, John Christie, Gerhard Oertel, Ron Shreve, and John Rosenfeld for the opportunities that I had as a young professor. It was a very special and critical time in my life.

I had a goal to try life in academia, government, and private sector. Circumstances unfolded so that the next part of my career was in government, in the USGS. There I was also to find incredible support, especially through the branch chiefs Dave Stewart, Phil Bethke, and Patrick Muffler, and Bob Tilling and Dallas Peck at the Office and Director levels. Like my UCLA colleagues, they listened to what I had to say, and it was there in the USGS that I met my life-long friend and mentor, E-an Zen.

(SLIDE 17) With new resources and colleagues, my five-year plan for Old Faithful research stretched out. When I started filming the of Old Faithful in the 70's, a Super-8 camera was state-of-the art, then it was replaced by an early heavy clunky videocam when it became available. My smoked drum recorders, which were really a dumb idea, were replaced with USGS seismometers and a support tech. My National Park Service colleague, Rick Hutchinson, and I ran around under the plume of Old Faithful to collect water during eruptions, hoping that the geochemistry might tell us something about the sources of the water in Old Faithful (it wasn't a dumb idea, but it also wasn't very successful). Then, Jim Westphal and I designed a pressure-temperature probe to put in the conduit to record recharge, and, when the technology became available, a mini-video encased in ice and supplying its own light source. We now know that the conduit doesn't look like the cartoon on the lower right, but is much more complex.

Before showing the complexity of the conduit and explaining its significance, I need to introduce a concept not widely recognized in geology. A parameter of unique importance in fluid dynamics is the sound speed of the fluid being considered. For liquids, such as water, the sound speed is more than a kilometer per second; for gases or vapors, it is a few hundred meters per second. The speed is determined by the bulk modulus (the inverse of the compressibility) and the density of the substance. The greater the bulk modulus, the higher the sound speed. Bubbly liquids, such as boiling water or water with air bubbles have very low bulk moduli (great compressibility), but high densities and hence, they can have very low sound speeds—as low as a meter per second. In fact, if I walked across this stage at 2 meters per second immersed in boiling water, I could be walking supersonically at Mach 2!

(SLIDE 18) Another rule of thumb in fluid mechanics is that if a fluid is going to go supersonic, it will reach Mach 1 conditions and go supersonic in the throat or constriction of a nozzle. Old Faithful has chambers and constrictions, the smallest of which is only 4" in diameter. It is here that Old Faithful probably achieves supersonic flow during eruptions, and it may be here that the conduit will seal itself shut sometime in the future.

SLIDE 19 : My 5-year plan is now in its 39th year, and has found application in unexpected places. **(SLIDE 20)** It got interrupted in its fourth year, 1979 when Gene Shoemaker asked if I could apply my fledgling ideas about Old Faithful to the eruptions of sulfur and sulfur dioxide into the vacuum above Io, the fiery red satellite of Jupiter.

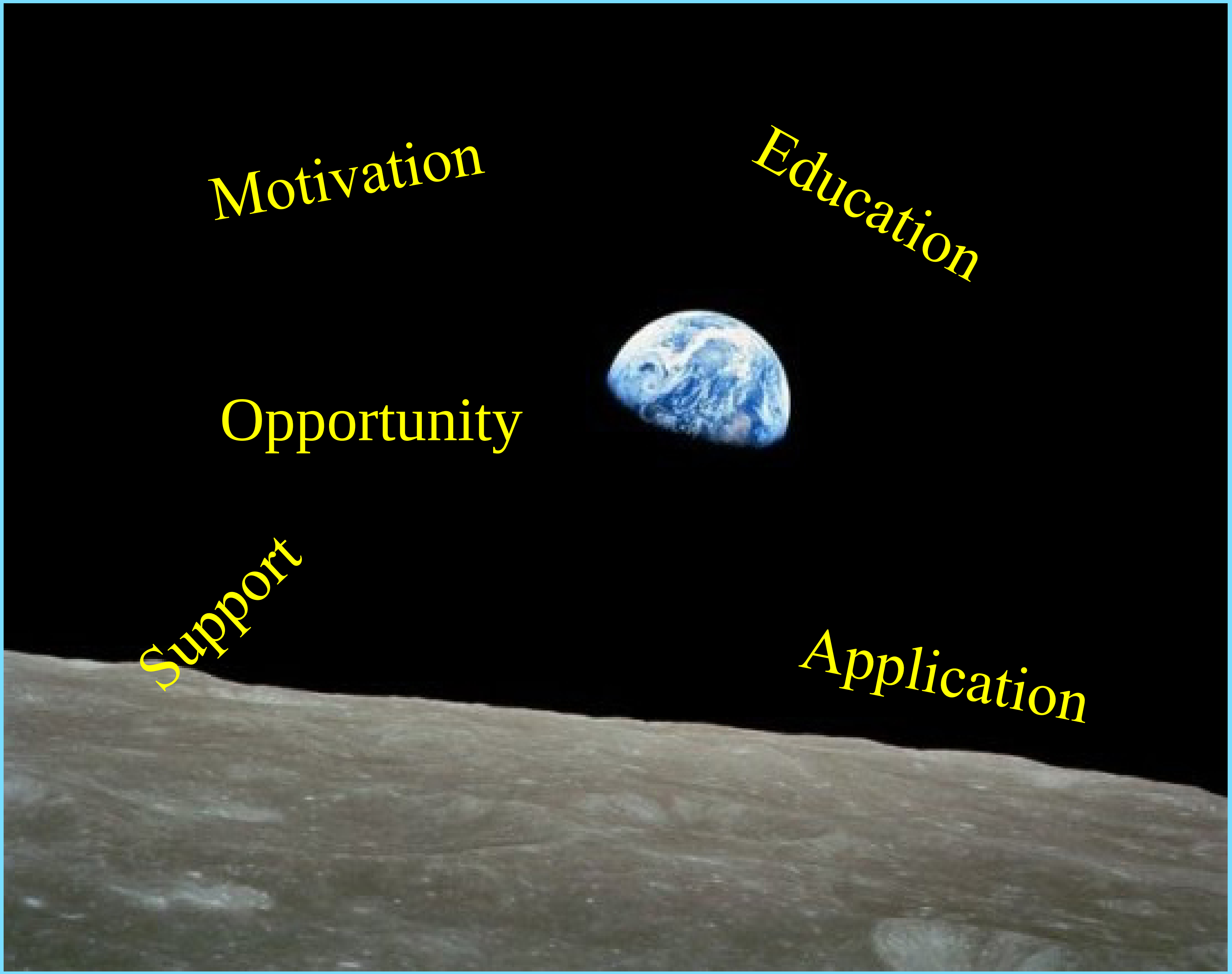
This was definitely a stretch of terrestrial thermo- and fluid-dynamics because the flow of materials from reservoirs into a vacuum produces supersonic flow, shock waves, and very nonintuitive phenomena. **(SLIDE 21)** However, this was an exercise that served me well when Mount St. Helens erupted the next year, discharging materials from a reservoir at a pressure of roughly 100-200 times atmospheric into the lateral blast. **(SLIDE 22)** Less than a decade after Mount St. Helens erupted, it was back to space with the discovery of geysers on Triton, a satellite of Neptune, and then later, **(SLIDE 23)** on Enceladus, a satellite of Saturn, in 2006. As my 5-year plan extended to 39 years, in order to solve the problems that I wanted to solve, I had to solve some that I wasn't trying to solve at all **(SLIDE 24)**. That's a short summary of how I got involved in mineral thermodynamics, crazy second derivatives, and river hydraulics.

The need for geoscientists in the world is increasing as we face problems acquiring, distributing, and recycling natural resources, and building societies resilient to natural hazards, on this increasingly crowded planet. As family, friends, teachers, mentors, peers and funding agencies, we need to keep in mind the five elements that determine the abilities and careers of future geoscientists: **(SLIDE 25)—**motivation, education, opportunity, application, and support. To the extent that we can enhance these, we will be building the technical capacity to understand and use the fundamentals of geoscience.

But there is a sixth element in anyone's career that can't be discounted **(SLIDE 26):** luck. "Luck" has placed me here on this stage. It was luck that so many geysers erupted throughout the Solar System over the decades of my career. It was luck that the 1983 flood on the Colorado River produced a giant wave in the Grand Canyon just after I had discovered that hydraulics provided an easy way to understand and to teach some very nonintuitive phenomena in volcanic gas dynamics. It was my “luck” that Steve Marshak and Jim Kirkpatrick rescued me from my utterly unsuccessful attempt to experience life in the private sector and brought me to UIUC a dozen years ago. It was luck that brought the students, collaborators and colleagues I’ve encountered along the way. **(SLIDE 27)** Thank you very much, colleagues and members of GSA for this career, for this honor, and for your attention today.

Researching the Earth:
Living it, Loving it, and Sharing it

Susan W. Kieffer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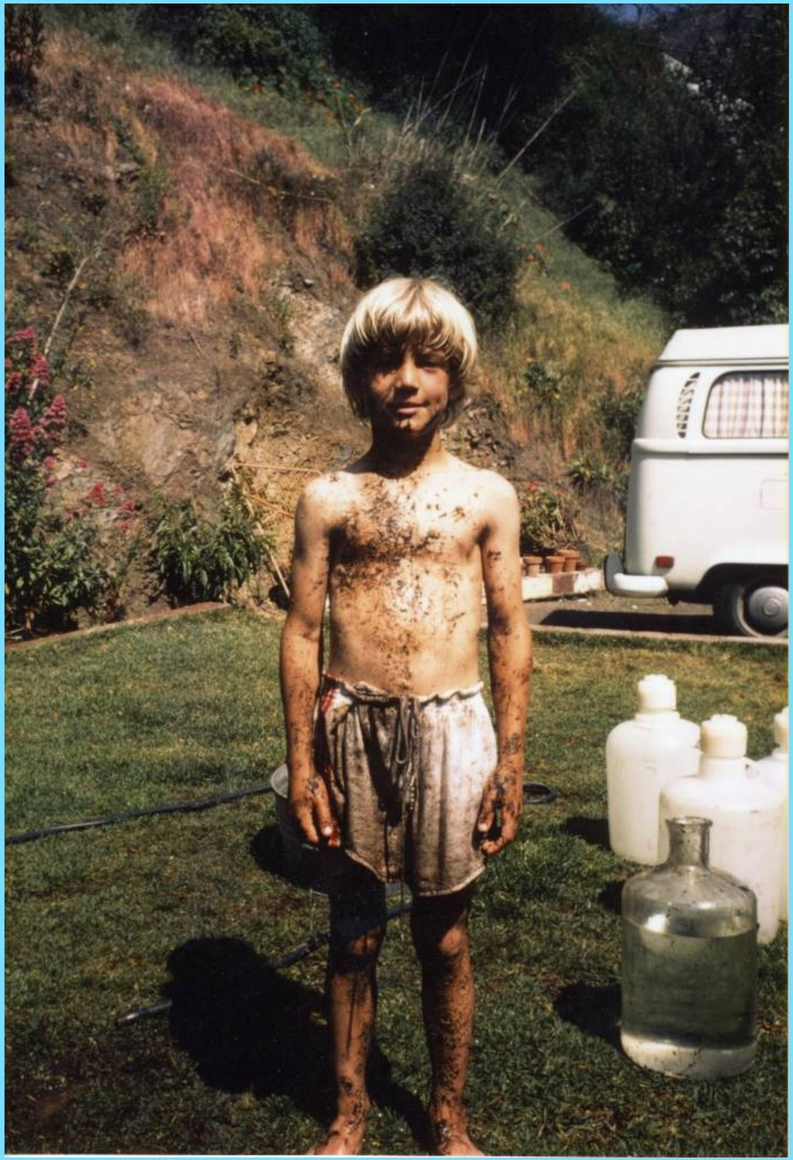

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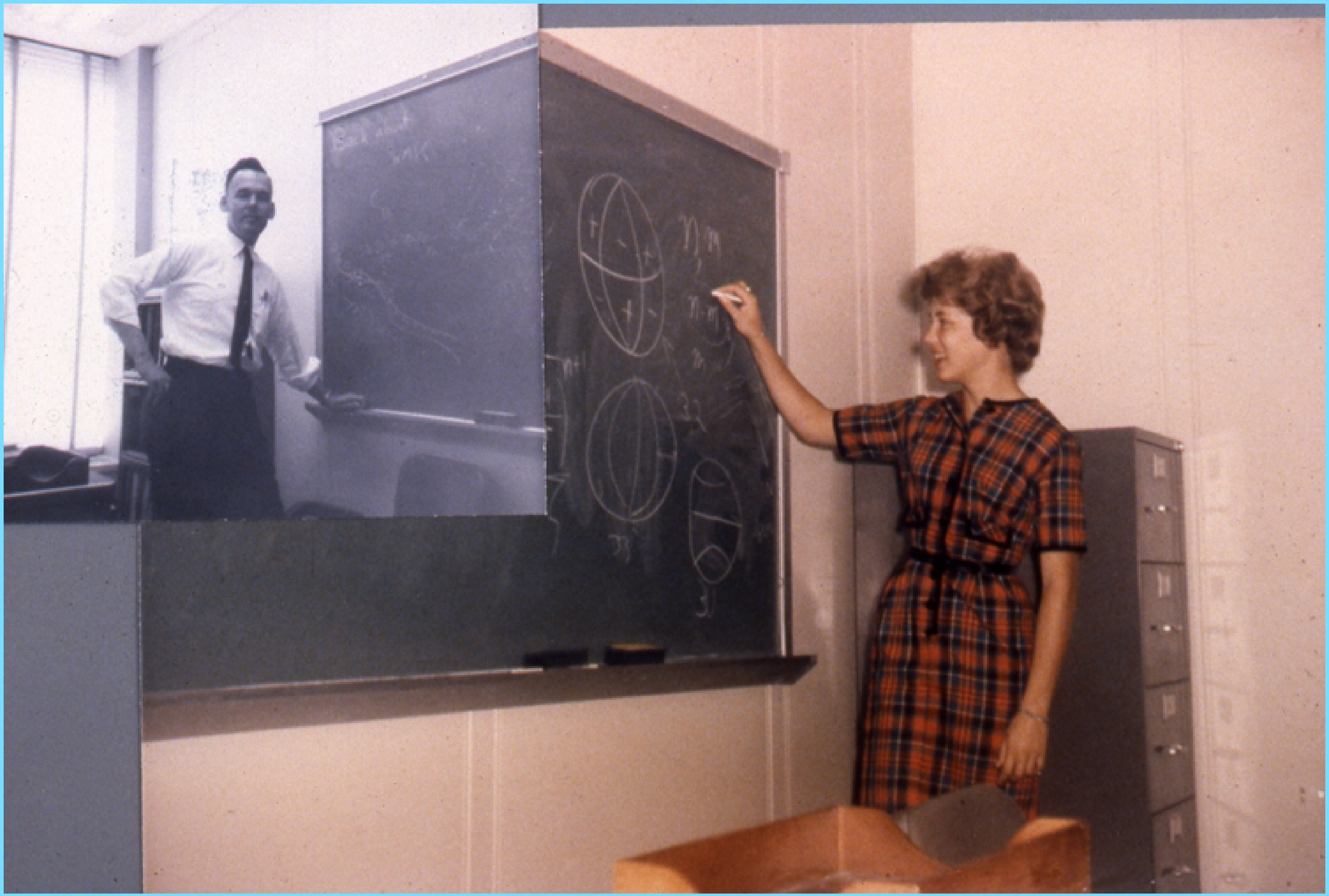

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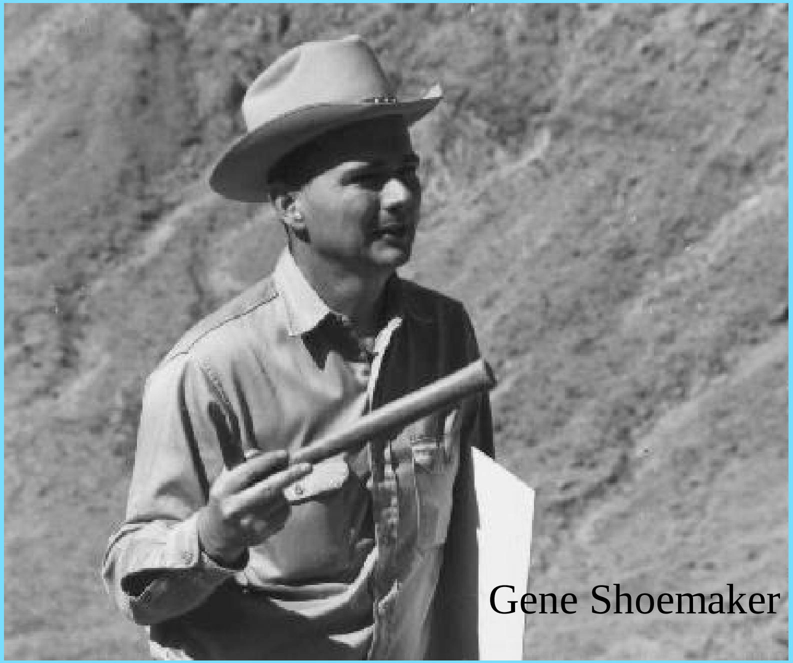
AFTER FIVE WEEKS — Pretty Sue Werner details her experiences living alone for five weeks in a remote section of Canyonlands National Park doing research for a doctoral thesis. "I wouldn't have missed it," she said of the stay. Sue liked Moab as well as her stay in the colorful park.

Education >>Opportunity

Education >>Opportunity


Gene Shoemaker


Ansel Adams, 1942

OPPORTUNITY

SUPPORT

SUPPORT

Volunteer and
Super-8 camera

Smoked drum
seismograph

USGS seismograph
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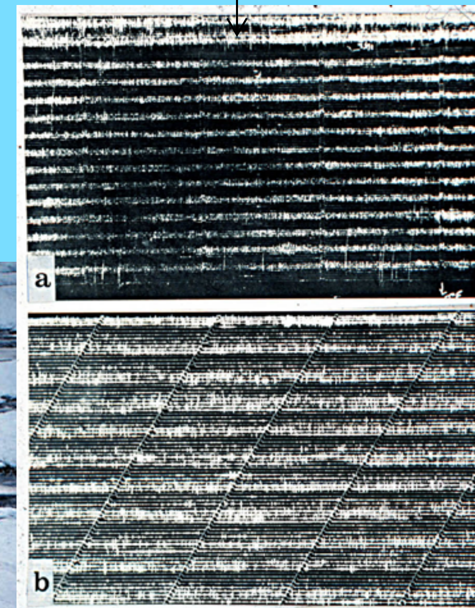

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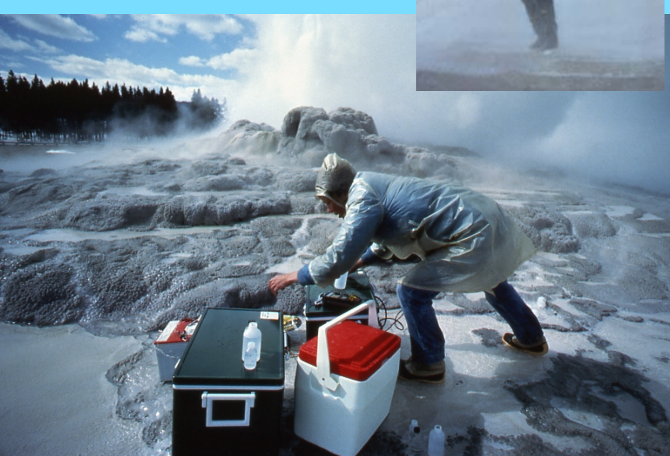
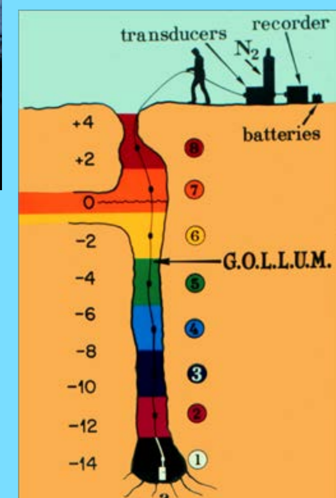
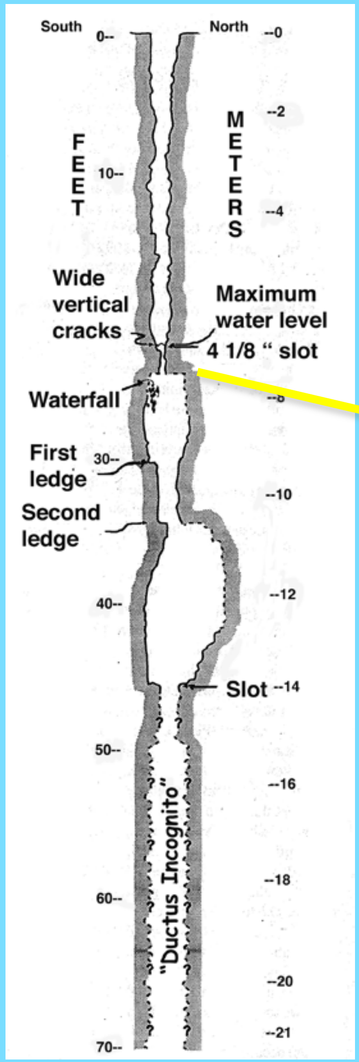
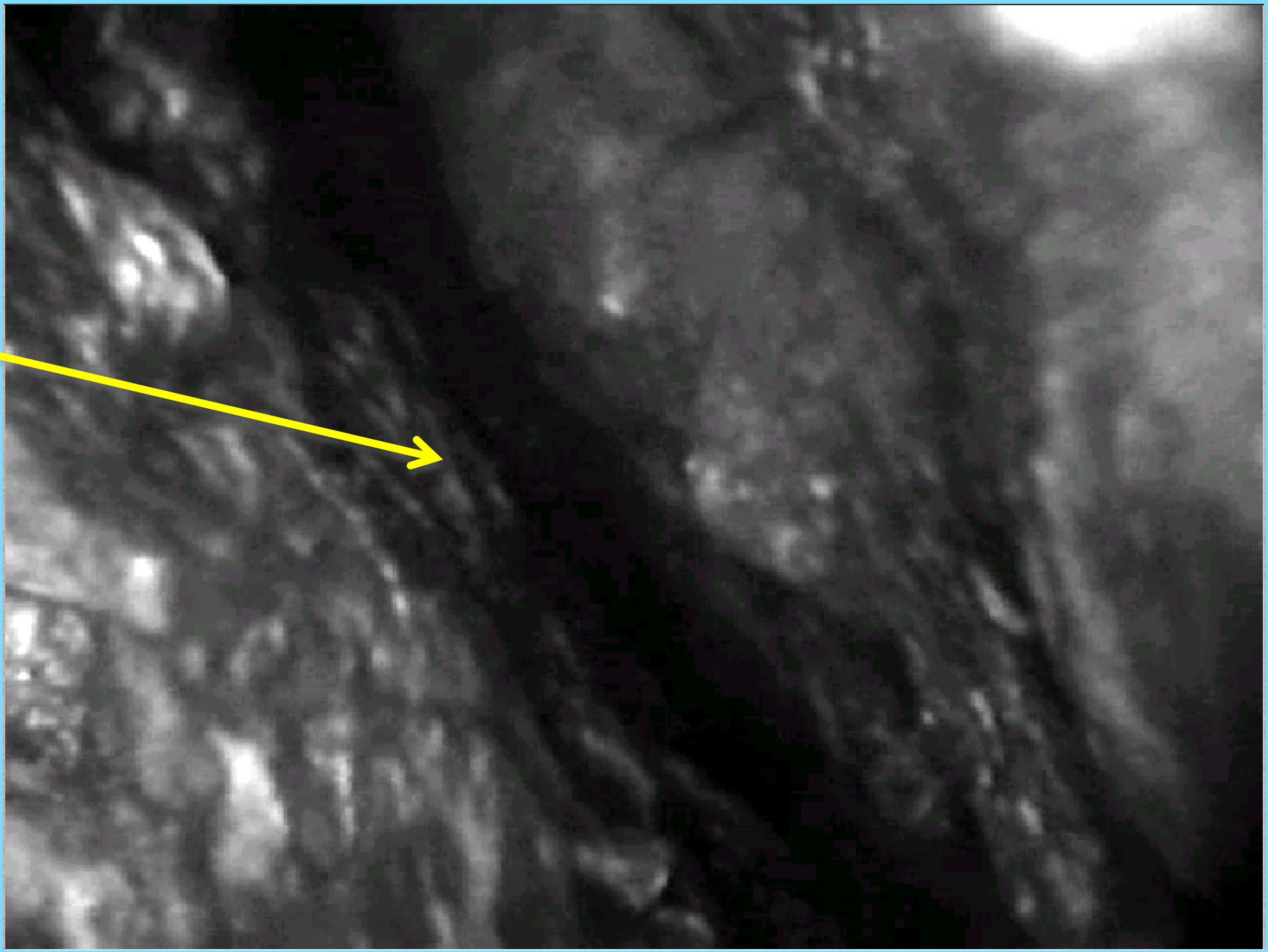


P-T probe



Application: Old Faithful's 4-inch constriction





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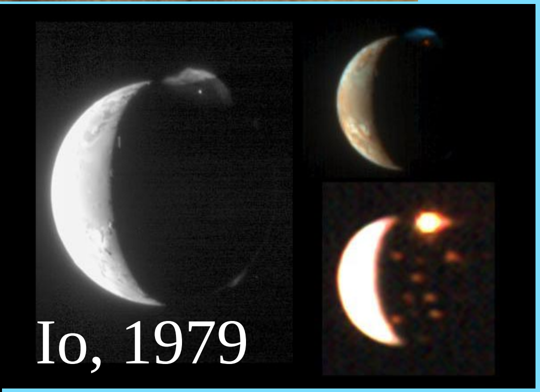

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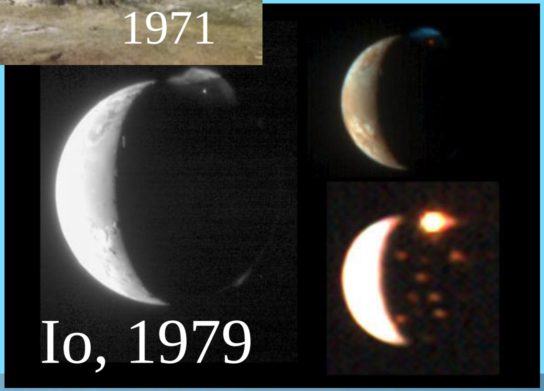

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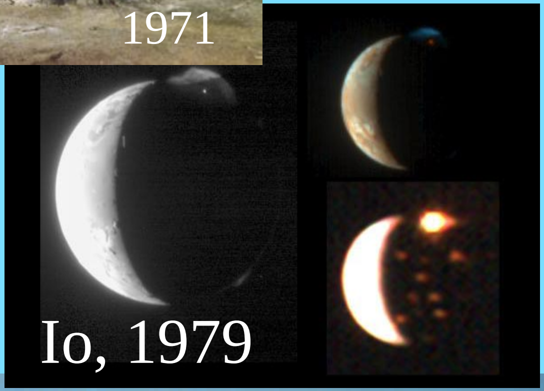

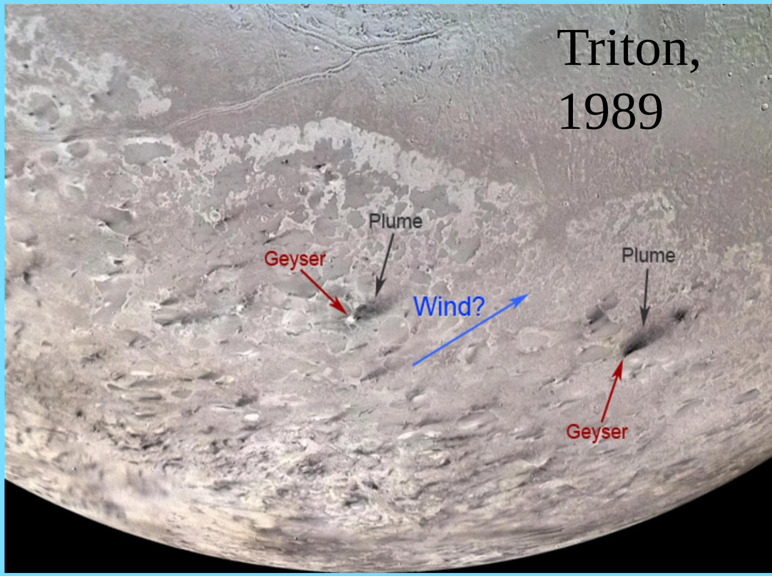

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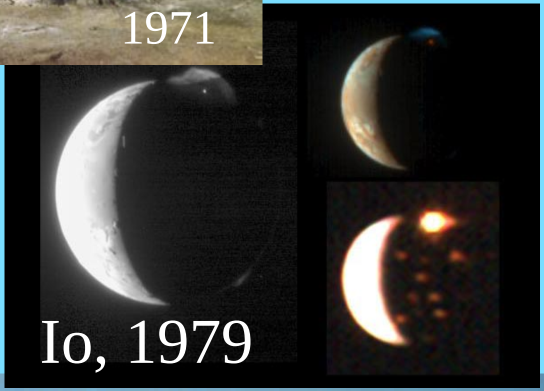

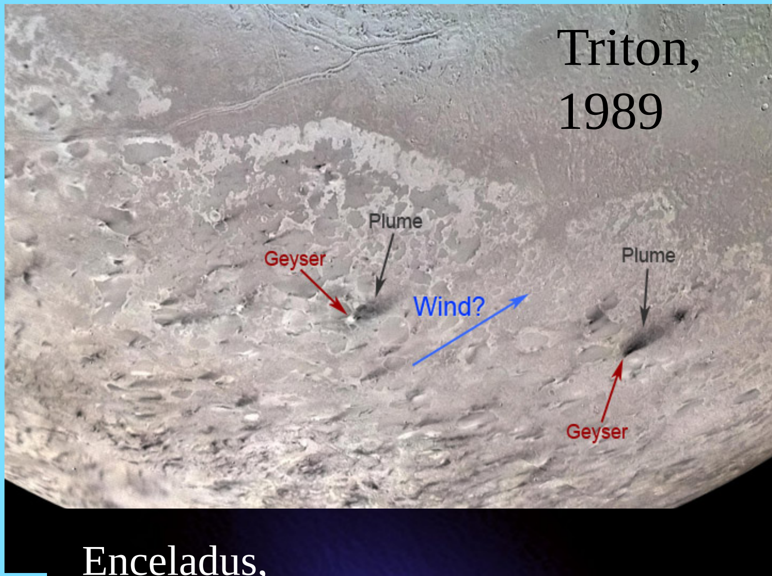

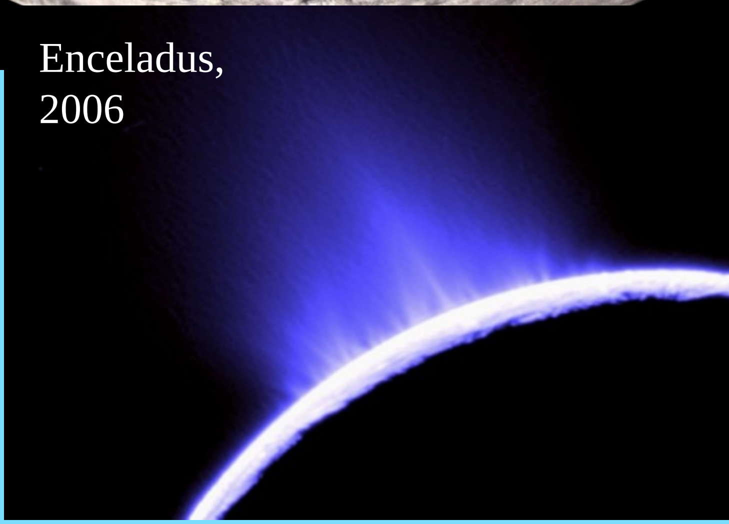

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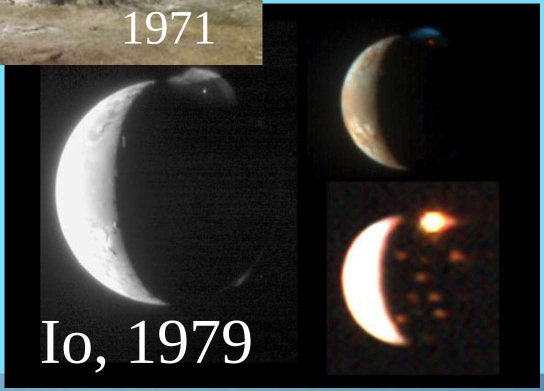

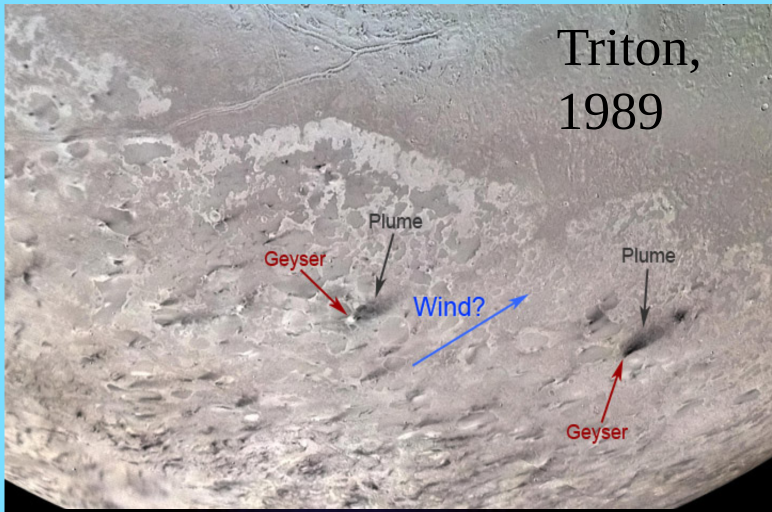

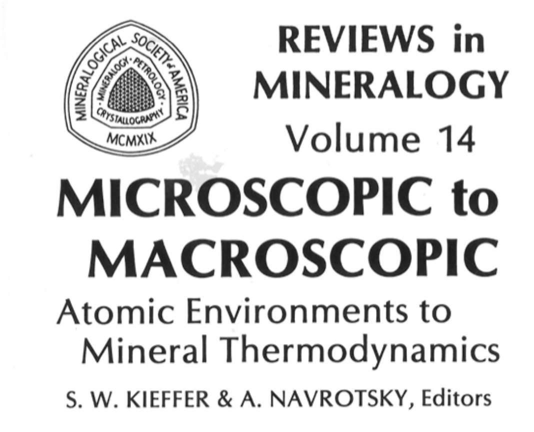
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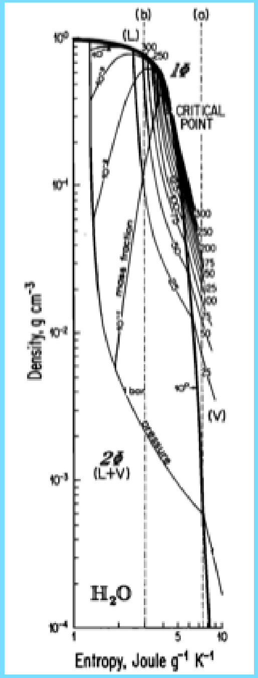
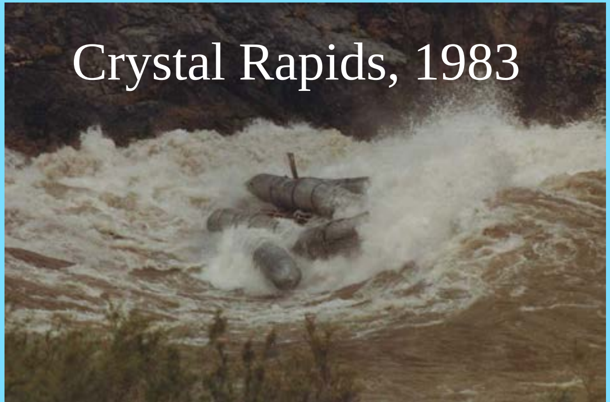
REVIEWS in MINERALOGY
Volume 14

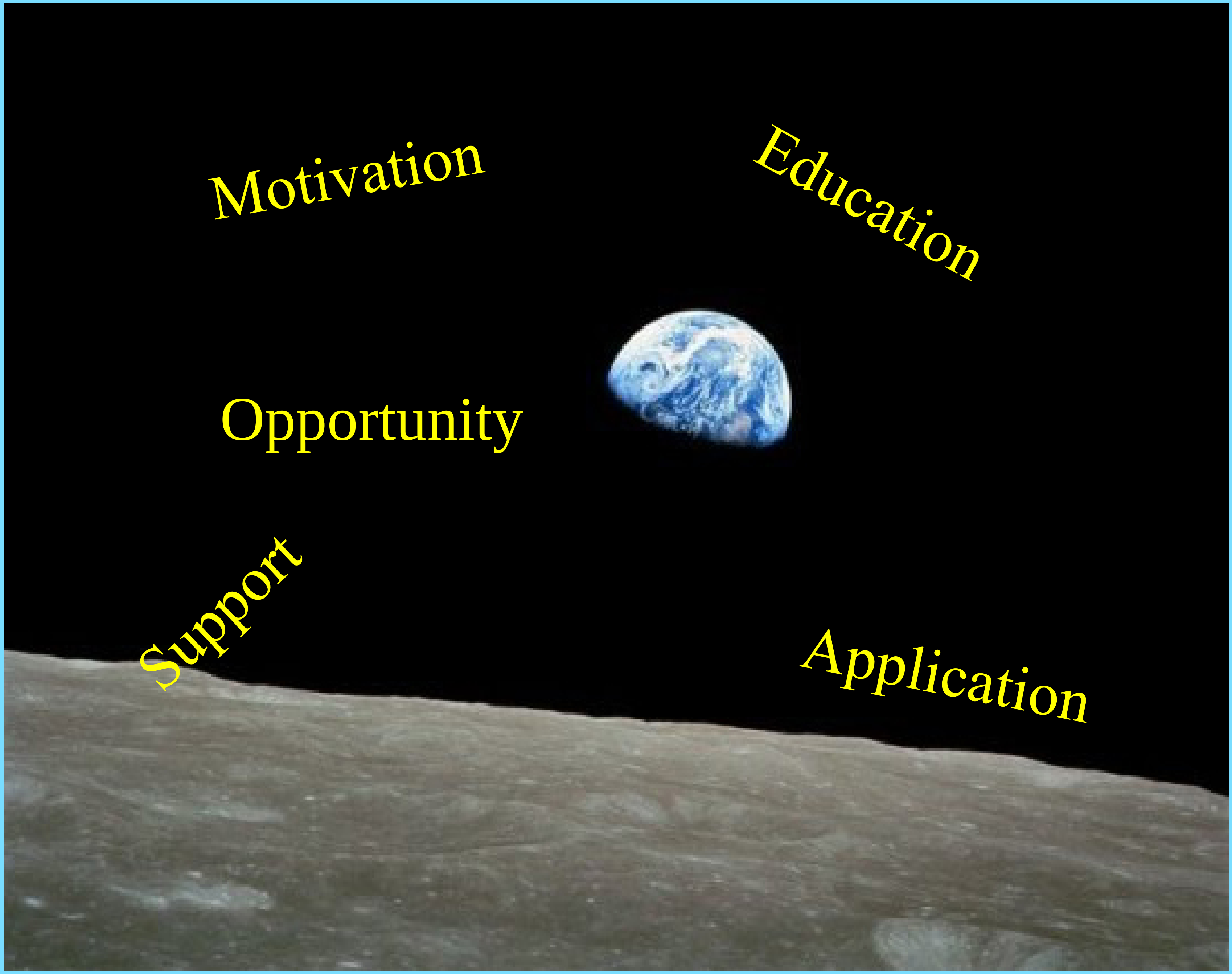
MICROSCOPIC to MACROSCOPIC

Atomic Environments to Mineral Thermodynamics

S. W. KIEFFER & A. NAVROTSKY, Editors






Motivation
Education
Opportunity
Support
Application


LUCK


THANK YOU!