From *AEG News*, vol. 45, no.4, and vol. 46, nos. 1-3.
***AEG News* is published by the Association of Engineering Geologists**

SPATIAL THINKING WITH A DIFFERENCE:
AN UNORTHODOX TREATISE ON THE MIND OF THE GEOLOGIST

By Sarah Andrews

Author's note: Since writing these, I've come to the conclusion that the term might be, more accurately, "4D thinking," but then again, that *is* the difference.

PART 1: DEFINITION OF TERMS

The toughest technical challenge I face in writing mystery fiction about geology and geologists is the job of making my geologist-sleuth compelling to my readership. I am successful only if readers identify with her, and that means I must take them so deep into her mental processes that they begin to perceive the world as a geologist perceives it. It takes a little mental aikido to get non-geologist readers to go there, as most lack a geologist's capacity to think in four and more dimensions. Worse yet, I have to accomplish this stunt without the aid of graphical illustrations or hand gestures, and within the two-dimensional constraints of narrative language (which is based on a linear sequence of events, and must depend on the imaginative powers of the reader to infuse the imagery of space around that time line). Hard as I try, many linear-thinking readers tell me, "I just skip over that science stuff."

Within this struggle to communicate, the perceptual limitations of linear-thinking people become obvious. The utility of being able to think in three dimensions becomes increasingly clear. And the rarity and importance of thinking as geologists do—visualizing three-dimensional objects changing through time in response to geological processes, an open-ended capacity we could call n-dimensional thinking—stands out in stark relief. Asserting our talents to the rest of humanity is long overdue. We are the modern wizards, those people who can, using the barest shreds of evidence, "see" through solid rock, back through time, and into future events.

With increasing frequency, I am asked to speak about our style of spatial thinking. When David Simon asked me to move from the lecture to the written word—a brave man, he said, "An article, or as many as you'd like to write,"—I figured it was time to arrange my observations into some sort of manifesto. I do this with some hesitation, as I have no formal education in neurological processing, or whatever field purports to codify mental machinery, so sticking my neck out like this could get embarrassing. But it may be precisely because I have no preordained notions that I'm able to notice what I notice.

I propose four short articles:

1. Definition of terms: characteristics and talents of the spatial thinker
2. The education of the spatial thinker: alienation and mentorship
3. The spatial thinker in the workplace: importance and applications of the talents
4. Thinking spatially into the future: a forward mission statement

Characteristics and talents of the geologic thinker

Not only can we think in four or more dimensions, we can arrive at rational solutions using incomplete, even ambiguous data. We perceive multiple working hypotheses as a natural outcome of our thought processes, and automatically debug them even as they spring from our minds. We think within a temporal framework more common to historians than scientists, but can adjust our time scale any number of decimal places to the left or the right with ease. We work as comfortably qualitatively as quantitatively, think out loud, are results-oriented, and frequently get there via a process we've just invented. How do we do this? Let's examine these characteristics in more detail.

Orientation in space and time

In simplest terms, a spatial thinker is one who can easily conjure mental images of three-dimensional objects. Those spatial thinkers who are drawn to study geology can further imagine how such objects might change through time in response to various processes or combinations thereof. So-called linear thinkers, by contrast, cannot close their eyes and visualize simple, flat figures comfortably, much less 3-D objects that change under the influence of dependent and or independent variables.

Our perceptual talents strongly influence the way we perceive and interact with our environment. By way of illustration, let's consider the spatial thinker in contrast to the linear thinker. Put the two in cars, give them identical maps, and tell them to drive to a location on that map. The spatial thinker easily decodes the graphical language of the map, matches symbols to landmarks with ease, and perceives himself as piloting the car through time and three-dimensional space. Not so the linear thinker. While he does not lack depth perception, his world is largely a movie "coming at him," as if projected on the windscreen of the car. Unable to decode the map, he may have to have an experienced assistant take him over the route so that he can memorize, as a sequence of snapshots, each place where he must turn. Geologists always know when they are asking directions of linear thinkers because such folks are oblivious to cardinal compass directions and the relative positions of such large objects as mountain ranges, oceans, or the rising and setting sun, and instead begin with statements like, "Well, you know the new Walmart…"

Hitched to this near-gyroscopic affinity for navigating the three dimensions of space is great ease interpreting the fourth dimension, namely time. Philosopher Robert Frodeman has observed that geological reasoning is both interpretive (an achievement, in the face of incomplete data) and historically-based, offering, "the best model of the type of reasoning

necessary for confronting the type of problems we are likely to face in the 21st century." (*GSA Bulletin*, August 1995, v. 107, no. 8, p. 960-968).

Pattern matching

We are great sponges for observed patterns, both the concrete patterns of visual observations and the more abstract patterns of process and response. We sort and store our observations, ready to retrieve them for comparison and reference. Although no two observations are precisely identical, we find that we can nonetheless categorize them, over time and through the accumulation of experience, into themes and variations. Moreover, this talent for observing, sorting, and matching patterns grows and becomes more highly tuned through additional experience. Repeated patterns become ideas, and new patterns lead to new paradigms and paradigm shifts. You know you *aren't* talking to a geologist if a person says, "But last week you said…"

Intuition

We use the scientific method, but do so with liberal infusions of intuition. Given a problem and an hour to solve it, we typically spend the first three minutes intuiting the answer, and then spend the other fifty-seven backtracking through the scientific method and rigor to check our results through data collection and deductive logic.

The fact that we are so often right the first time leads to the question of how intuition functions. I hypothesize that intuition is the constructive interaction between our conscious, or rational minds, and our unconscious, or diffuse, awareness. The unconscious mind absorbs data, stores it, and sends up flares to the conscious mind, which deductively reduces the data into a solution or multiple working solutions. We have an unusual capacity to throw our conscious minds out of gear and use our diffuse awareness to absorb what's around us. With the gate between the two realms wide open, we are able take in wide swaths of information at high speed. Without this capacity, we would, like others, have to rely on the smaller view of the world that lies within the narrower, less inspired focus of the conscious mind alone. This comfortable union with our surroundings occurs particularly readily when we are outdoors doing what we quaintly call field "work." Thus suitably relaxed, we "noodle around" for a while, and in the process begin to perceive not only our answers but also gain a more accurate summation of the questions.

Using intuition, we often perceive problems as perturbations in the patterns of time and space, an uncomfortable experience. A hallmark of intuition is that it functions in leaps rather than by neatly ratcheting intervals. The buildup toward the leap, and the precipice over which it must occur, produces anxiety. This anxiety increases until the moment of release into the *aha!* of realization; thus it becomes a compass. Approaching solutions in this manner is less lineal than iterative or circular, because as the irritation of anxiety propels us to resolve ambiguity, we near not only answers, but often our first true glimpse of the question. Or, as my friend Walt Whippo once told me, "The answer is implicit in the correct statement of the question, so if you can't find the answer, you haven't accurately defined the question."

Perception of ambiguity
We are also natural experts at grappling with ambiguity. Using our diffuse awareness, we specialize in noticing ambiguities, irregularities, and uncertainties, and are able to perceive them where others cannot. The perception of ambiguities depends in part on the ability to work with qualitative data, and not just quantitative data, which have the limitation and luxury of being discrete. By working qualitatively, we can mentally bridge gaps without having to plug in assumptions, and as a result, it becomes possible to work with uncertainties, rather than simply overriding them; thus ambiguity itself is resolved as our pattern of observations moves toward being inclusive of the perceivable universe.

Not only can we visualize three-dimensional images, we can receive incomplete, often ambiguous data in random order and arrive at a rational solution to a problem involving four and more dimensions (the three dimensions of space plus time, and several processes or objects moving through time). The classic example is the geologist as submarine captain, removed from direct visual observation of sea floor topography and torpedoes, quickly making the correct decisions to avoid disaster. Moreover, the he typically perceives not just a single solution, as would be dictated by quantitative analysis, but many, including all possible outcomes given the possible influences of missing data; the process therefore includes a risk assessment in which the "best working solution" is identified.

Questioning authority
Once a geologist deduces working hypotheses, he then automatically and continuously challenges them. This is because the world is an analog place of non-discrete possibilities, where all solutions are at best viewed as trial approximations en route to an improved understanding; straw dogs set up only to be torn to pieces. This is the ultimate questioning of authority, a scrutinizing and scrupulous taking of responsibility of all data and even one's own results, and as such the ultimate pragmatism.

PART 2: THE EDUCATION OF THE SPATIAL THINKER: ALIENATION AND MENTORSHIP

In part one of this series, I made a first pass at describing my observations of the mind of the geologist. Having outlined the nature of our special talents, I think it's equally important to say something about their nurture. Specifically, what happens when the spatial thinker goes to school?

School systems seem to spend a lot of time categorizing and labeling children. The first label I got was "under-achiever." That was in the 1950's. Now that I am the parent of a grade-school child, I hear about "learning styles" and "learning disabilities," but the game is the same: some well-meaning soul with the current teacher's training is struggling with the monumental task of imposing the three R's on a highly variable group of kids. This soul is most often a linear thinker, but several of his charges are bound to be spatial thinkers.

Not all teachers' categorizations are reductive. The most useful summary of students' learning styles that I have encountered would peg the nascent geologist as a "concrete random" thinker (sadly, I don't know the author of this wisdom). Such students are interested less in the glories of process than in the pragmatism of results. They do not need information fed to them in a set order, nor does it need to be complete, for them to arrive at a rational result. They usually find not one possible answer to a given question, but many. They arrive at our multiple working answers through intuitive leaps rather than by chugging down a preset track. Not satisfied by received wisdom, they instead question data and ambient paradigms, and aren't satisfied until they integrate their new findings with everything they have previously held, dismantling outmoded results and reassembling their knowledge from the ground up. They are equally demanding of authority, wishing for but seldom finding a master worth following. This makes them quite a challenge to teach. Woes betide any teacher who tries to bluff or bully them. Sound familiar?

Contrast this with "concrete sequential" thinkers, who must receive information in a set sequence so they can crunch it through the "correct" formula, and arrive at "the" answer; such rule-following requires that authority be in place before these students can get started. Such thinkers make good engineers. Or consider the "abstract sequential" thinkers, who, although capable of taking information in any order, similarly require pre-established authority and values process over results en route to "an" answer. We meet these thinkers as mathematicians, much to our consternation (intellectually opposite from the abstract sequential, the concrete random usually does well in geometry—literally, "the measurement of the earth"—but grits her teeth through other math courses, being graded down for "not showing the work" or taking a different route than the teacher had in mind). And let's not overlook the "abstract random" thinker, who can take information in any order, arrives at "THE" answer, because he IS the authority. We meet these thinkers as upper managers, or worse yet, encounter their names in the voting booth.

Turning 90 degrees to everything else

The above summary was constructed—by our anonymous sage—in the hope of enlightening the average grade school teacher, who more often thinks sequentially than randomly, and is as often more interested in the process of learning than its results. He prefers nice, straight "yardsticks" by which to measure a student's performance. He teaches linear subjects, such as reading, which is after all the job of decoding a sequential string of words, and he's been taught that children who gaze out the window—when they aren't wiggling—should be on drugs. He has twenty to thirty young charges to process each year, and wants them all to sit still, keep their minds on the blackboard, and throw him no curves. Just imagine what it does to his nerve endings when he is charged with educating a student who is hard-wired to question authority, who prefers accuracy but gets bored with precision, and who is clearly smart but does not seem to be "measuring up" to her potential. He lacks insight that this child is engaged in the stupendous task of gathering and sorting multi-dimensional observations. He is inclined to label such children. His list may include such self-esteem-crushing tags as "difficult," "quirky,"

"dreamer," "marches to a different drummer," or worse yet, "lazy." If the kid has a sense of humor, she is, "a character." The modern PC term is, "attention deficit disorder."

What this teacher doesn't recognize is that his student is in fact a perfectionist who, having created her own standards, can never live up to them. What he doesn't know is that this child is working much harder than most of the other kids in the room. She is acquiring information not linearly, or arithmetically, but geometrically, or even *n*-dimensionally. Her intuitive style makes her appear anxious, and as she absorbs not just the class lesson but also everything that every other kid in the class is doing, she becomes over stimulated and overloaded and withdraws slightly to dampen input to manageable levels. Overall, she is building a bigger program, one that, for its preponderance of dimensions, takes longer to construct.

In *Stranger in a Strange Land*, Robert A. Heinlein's sci-fi classic, the hero is a human who has the capacity to instantaneously disappear. A special high-speed observer is asked to figure out how he does this. He performs his stunt in front of her and then reappears. She reports that he hasn't really gone anywhere, but has turned "ninety degrees to everything else," and is therefore not visible. It strikes me that the multi-dimensional thinker is a stranger in the strange land of academia, constantly turning ninety degrees to most teachers' understanding.

Reading

The spatial thinker is typically a slow reader. While she can take in the meaning of a picture or map at a glance, text reading is a linear-sequential action, and therefore alien. What understanding she does pry from the written word is filled with ideas, images, and myriad other triggers that set off cascades of ideas and associations that she must test and integrate each new idea, because she is not content to take much of anything on faith.

Take my own grade-school experience as an example. I could not navigate a first-grade reader until third or fourth grade. My mother—who taught English at my school—labeled me her "under-achiever" as I flailed in the wake of my fast-reading, linear-thinking older siblings. Typically, I had to read each sentence several times to understand it, could not keep my mind from "wandering." I frequently fell asleep from the strain. Unable to manage reading assignments, I skidded through school with B's, annoying a great number of teachers who thought I should be pulling A's. In high school, they wondered why I scored low on the SAT's. Someone finally asked if I had finished the test, explaining that one's score is in part dependent on how much of the test one completes. I said, "I got about halfway through it." I was packed off to the remedial reading lab, retook the SAT's, and this time finished the test and doubled my scores. I did not, however, advance to grade-level reading proficiency. The year was 1968. I was a bright high school senior now reading at the eighth grade level. The remedial reading teacher tested me for every form of dyslexia then documented, but found none of them. "You don't want to read any faster," she concluded, and informed me, "You're just lazy."

By the time I noticed that I was not in fact lazy, I had earned both a B.A. and M.S. in Geology. In the geoscience curriculum, I at last found teachers who perceived my talents, and I could learn from maps and illustrations rather than insurmountable texts.

For many of us dyslexia is painfully familiar, and yet we feel we have to cover up this "deficit." I suggest that this thin spot in the capabilities of many spatial thinkers is in fact the flipside of tremendous capacities. Moreover, a spatial thinker's dyslexia may crop up not only in her ability to read, but as trouble being precise with arithmetic, or as difficulty spelling (this often improves when we write on a computer, I suspect because the machine more closely approaches the speed of our thoughts than does handwriting).

Ambiguity

Spatial thinkers seem to perceive ambiguities where more linear-thinking students do not. Perception of ambiguity can, however, make learning uncomfortable. Take for example my son Duncan and his buddy Nate when they were both four. Nate had learned to write numbers by counting on his fingers sequentially and then writing the numbers down. He counted one and wrote 1, two and wrote 2, and so on to 6, at which instant Duncan, viewing the 6 from across the table and thus upside down, said, "No, Nate, that's a nine." I took Nate's paper and turned it right side up to Duncan, then upside down again, then right side up again, and said, "It's a six, it's a nine, it's a six." When I returned the paper to Nate, he resumed his exercise as if I had not interrupted it, counting to seven on his fingers and writing 7 en route to writing 8, then 9, then 10, delighting in performing as he had been taught. Duncan's response was quite different. He burst into tears. Both boys are very bright, but Nate is the linear thinker of the two. Duncan, by linear measure the "slower" of the two (he could not yet count dependably in sequence to ten) perceived the ambiguity embedded in the unintended oddities of written language. Because he perceives such ambiguities, regardless of the intellectual and emotional discomfort they bring him, he may appear to struggle, and may seem to some observers less precocious, but he develops highly original ideas and excels at solving problems.

My favorite definition of creativity is "the ability to embrace ambiguity." This equation can also run the other way: the ability to embrace ambiguity is the foundation of creativity, and we need all the creative minds we can get.

Alienation

By the time he was seven, Duncan had encountered one teacher who wrinkled her nose and called him "young," and another who greeted the originality of his thinking by calling him "blabbermouth." He avoided the first teacher, and shut down and quit learning in the presence of the second, convinced that he was stupid. I moved him to a different classroom, where his new teacher praised him with the mysterious, "He's a whole to parts thinker," which I suppose meant that she figured he was born to write the cookbook rather than to follow it, but he bloomed in the warmth of her love and respect.

Duncan's story is all too common. Spatial thinkers quickly despair in educational systems that fail to perceive and encourage their strengths. And a child alienated from systems is a child less likely to work within them or reform them as needed. But when fully perceived and appreciated, such students flourish.

The old adage that it takes all kinds to make a world is correct: as my husband/geologist says, "Somebody's got to drive the busses," i.e. someone who would not climb out of his mind with boredom and start staring out the wrong window. But likewise the world needs its wizards who can "see" into hillsides, predict where to drill to find hidden resources, and imagine new ways of solving old and new problems. And, as importantly, such talent should not have to suffer the alienation of not "fitting in." Spatial thinkers thrive on mentorship of their intellectual peers, and deserve the support of perceptive, imaginative teachers. And may I suggest that advocating for their needs, and acting as their mentors, helps heal the wounds so many of us received in our own school experiences.

PART 3: THE SPATIAL THINKER IN THE WORKPLACE: IMPORTANCE, APPLICATIONS, AND LIABILITIES OF THE TALENTS

In part one of this series, I offered my observations on how geologists think. To recap, a spatial thinker is someone who can visualize objects in three dimensions. The geologist adds the fourth dimension, assimilating and assembling discontinuous and ambiguous data in three dimensions, and then, tracking multiple processes through time, constructs an historical understanding and projects process/response into the future, arriving at pragmatic, rational results. In short, we are the modern wizards, the clever souls who can peer through solid rock, interpret the record of the past, and predict future events. We do essential tasks such as locating natural resources, cleaning up toxic spills, and ensuring the public safety by identifying such hazards as earthquakes and landslides. So why do we so often work in obscurity? And why aren't we richer, or, for that matter, less often out of work?

Perhaps wizards are by nature more motivated by curiosity than by greed. Or perhaps we have a built-in aversion to the kind of politics it takes to make the shift from specialist/expert to boss/entrepreneur. We do have extraordinary talents. But greatness can amount to a glorified frustration if we can't communicate it to others, and it becomes a handicap if our frustration in and of itself develops into an aversion. This handicap deepens if we confuse responsibility with authority. Let me explain what I mean by this. Then I can make some wild assertions about where we can go from here.

The incomprehension of the linear thinker

It can be exceedingly difficult to communicate four-dimensional perceptions to our more linear-thinking colleagues. Engineers, for instance. Or those mathematicians-in-disguise who call themselves hydrologic modelers, or, for that matter, CFOs or CEOs. They often

have a hard time understanding exactly what a geologist does, much less why our work is essential. A few favorite horror stories shall illustrate my point:

1. The petroleum engineer who told me (when I stepped into his office to pick up the well logs from which I needed to run up the cross-sections and contour maps basic to evaluating an oil field for tertiary recovery), "Oh, don't worry, I've already done the geology." I asked to see "the geology." He flipped to the back of his report and unfolded an array of well logs that looked like a cross-section, smelled like a cross-section, and, had I followed through with my temptation to gnash my teeth on it, might even have tasted like a cross-section. He had labeled the logs, and had drawn lines that looked like correlations, but had achieved geo-gibberish. That was the moment I realized that a certain number of engineers think that a geologist's real function is to pad the "appendices" sections of engineers' reports.
2. The modeler who refused to look at my drilling data before designing a pump-and-treat system for a Superfund site. When he presented his completed model in committee, the project manager turned to me and asked what I thought. I had to say that, considering that we were trying to clean up the highly heterogeneous, interbedded clays and gravels of an alluvial fan system, ignorance of the sedimentary architecture when positioning wells and injection intervals would at best produce extreme inefficiency. Unfortunately for me, the modeler was also my supervisor.
3. The CFO who appeared at my office door saw that I was staring out the window at the mountains, and bellowed at me to get back to work, to which I replied, "You work your way, and I'll work mine."
4. The corporate president who barred me from project screening meetings, telling me to instead, "Just do the geology." I recall a low-gravity oil project that felt like a loser. I asked the president to let me look at it, but he refused, telling me that the engineers had it well in hand. It was only after he had signed a commitment to purchase, drill, and apply steam to the project that he sent me to the field to gather up the logs and now "do the geology." Within half an hour on site, I discovered that the consultant who had sold him on the project had doubled the oil-in-place evaluations by shifting the shale/sand baseline a few ohms to the left of the point of deflection. I immediately informed the president. Less than a year later, when I was laid off as the company began (no surprise) to flounder, I saucily asked which project he was going to blame on me (it being by then a corporate tradition to scapegoat each departing employee with a failed project). He named the project with the inflated evaluation. "Why?" I asked. "Because you were right," he replied.

Ambiguity

Communicating geology to non-geologists can be difficult precisely because it requires the special mental machinery of the four-dimensional thinker to grapple with its

uncertainties and ambiguities. Geology is a science, but also an art: it takes special talent and techniques to be able to work with its unique array of process-response linkages, all of which must be massaged from incomplete, sometimes even contradictory data.

Geologists often work qualitatively in tandem with colleagues who think quantitatively, but are unable to convince them of answers that are not "discrete." I recall on more than one occasion getting into heated debates with engineers who kept a death grip on the holy writ of digital data while I flew out into the thin air of analog gut instinct.

Thin air

It was thin air that I was staring into when the CFO took me on. What he didn't know was that staring into space is precisely how we work. It is our capacity to throw our brains into neutral and let connections assemble in hyperspace that makes it possible for us to see connections that others can't. We relax into the work. We become one with the landscape rather than taking it by presumption or brute force. We go into geology in part to be outside, to melt into the big picture: it is there, and doing that, that we feel most at peace. Why? In the office, we can't turn off the machinery. We take in so much information so quickly that it is only out in the big picture that everything pops into a reasonable sense of scale. We need to get out into the simplicity of field work in self-defense, so we can unwind, so we can go soft-focus and let those things that are lastingly important to us click into place.

Well, that's all very pie-in-the-sky, you say, as you pensively recall the days long ago when you actually last got out into the field for the space of perhaps half a day. The harsh reality is that most of us wind up in an office somewhere, and must rely on data being fed to us from somewhere or someone else. To progress in our careers, we increasingly take on management chores. Which means that we work with other people, which in turn requires that we communicate with them. And the client. Or the board of directors. Or the regulatory agents. Or the planning commission or city council. So let's take a closer look at what and how we think, so we can build better bridges to other minds.

Authority

As I noted above, the fact that we are grappling incomplete, ambiguous data means that we usually arrive at not just one, but many possible answers to a problem. Our answers look like elaborate Venn diagrams of overlapping possibilities. We must subject each array of possible answers to an analysis of probabilities, and choose the most likely answer. We then attack our answer, because we know that, in the absence of complete data, there is no such thing as absolute certainty. We in fact subject our work to continuous scrutiny, always on the alert for that next datum that could blow our entire array. This amounts to a sort of built-in scientific method, or, quixotically speaking, a questioning of one's own authority.

Aversion

In part two of this series, I observed the nascent geologist in school, and pointed out a number of ways in which we get to feeling marginalized. The bottom line was that we were going places intellectually that most of our teacher's couldn't go, they labeled us, and that resulted in alienation.

From school, we move into the workplace, where we once again discover that we perceive the natural world in a way that is incomprehensible to most people. This is a functional handicap in several ways. First, when we try to communicate our perceptions to the unequipped, we're essentially trying to transmit a four-dimensional understanding onto a flat screen that's stuck on pause. It's been said that in the land of the blind, the one-eyed man is king, but the authority of kinghood is only conferred if the blind comprehend the need for sightedness. Second, in the workplace as in school, our perceptivity does not always end with inanimate objects. We are still keenly, intuitively observant of those around us, and we need a special kind of down time in order to cope with what can amount to over-stimulation. Third, because we come into the work force already alienated, negatively sensitized to the incomprehension of linear thinkers, we tend to draw back from what looks like more of the same. And fourth, there is the double frustration of being intellectually flexible enough to understand the importance of what one's linear-thinking colleagues do, while not having one's own work understood in return.

Responsibility meets authority

Our intellectual talents can again become a handicap if our drive to debug our own results backfires. Because we can see more deeply into a problem than our linear-thinking colleagues—can see how easily we might be wrong, or have an incomplete answer, or how the answer might shift given additional data—we have trouble letting go of our work, in essence taking too much responsibility for results. It becomes difficult to delegate tasks, because we want to micromanage the process. Venn diagrams looming in our heads, we start mumbling weasel words, which gives our linear-thinking colleagues the impression that we're unsure of our answers. If the affliction becomes severe, we can barely function.

Our scrutiny of results (authority) and the built-in impossibility of ever arriving at a discrete answer (responsibility) can become blurred together until we think that if we assume authority, we will collapse under the weight of our capacity to err.
This tendency to take on too much responsibility can leak not only into how we deal with technical issues, but also into managerial problems. It was a computer engineer who helped me to understand what was going wrong the time a temporary employee began bucking my commands. "Do you have control over her paycheck?" he asked.

"No," I replied. "When I ask her to do anything she doesn't understand, she goes over my head to the boss and tells him I've got it wrong. And he's an engineer, so he doesn't understand what I'm trying to get out of her."

"Then you're saying that your boss has told you to direct her work, but has given you no authority over her. How are you supposed to carry out that responsibility without sufficient authority?"

My friend's two-by-four having been accurately placed alongside my cranium, I told my boss, "Give me the authority so I can carry out the responsibility."

"Doing" the geology

I've reprised some of my most spectacular failures in order to make a point. How much better it would have been for each of these projects if I had been able to convince my colleagues that they should let me in fact "do" the geology, which after all is not just arriving at a technical understanding but also making sure that that understanding is put to work. The reality is that perfect communication is never possible, but as we mature professionally, we learn to assert the bottom line, and our authority. A huge part, then, of "doing" geology becomes figuring out how to achieve adequate communication, or in lieu of that, how to grasp a better mandate and prevail anyway.

"Give me the authority so I can carry out the responsibility" can be turned around: I suggest that we are born to the authority of our talents, so why give it up? Why accept employment that would marginalize us? The answer is not to collectivize and form a geologists' union (our approach to authority makes it easier to herd cats), but we can champion our geologic talents tenaciously (better honest arrogance than hypocritical humility). We can become the boss, and rather than trying to push the linear thinkers, let them follow.

PART 4: THINKING SPATIALLY INTO THE FUTURE: A FORWARD MISSION STATEMENT, OR HAVING A CAREER THAT'S BIGGER THAN THE JOB

If you thought I was sticking my neck out with some of the statements I have made in the first three sections of this tirade, brace yourself. Here's where I get political. Here's where I suggest that we apply our talents, and skills, and experience more powerfully, both for our own sakes and to address the challenges faced by all of humanity. For our sakes and everybody's sake, we should have a greater voice in our changing world, in the public as well as the private sector.

In the first three parts of this dissertation, I identified the extraordinary intellectual talents that I observe in my fellow geologists. To recap, we are able to arrive at solutions to four-dimensional problems via a hard-wired scientific method of multiple working hypotheses, viewing multivariate systems from the top down, as integrated wholes. We do this at high speed, using both qualitative and quantitative measurement and intuitive, deductive logic in a rolling, iterative fashion, successfully addressing incomplete and ambiguous data. Add to that our unique skills and experience in identifying and working with hazards and resources, and we emerge as the obvious source of wisdom for an array of key issues that face humankind.

And yet we are underemployed, and those of us who manage to work continually within the profession typically retool our resumes four or five times within our careers. We too often work ourselves out of a job, either finding too much of a resource or solving the problem we've set out to solve. Luckily for us, humanity keeps consuming and the surface of the earth keeps moving. And yet our profession is marginalized in these times of economic contraction. When students ask me if there are really any jobs in geology, I grin. I tell them that (literally) the sky's the limit, because geology intersects everything else…even the sky. I suggest that they quit looking at school as a machine that will prepare them for one single job and try looking at it as preparation for a career. The training is critically important regardless what they do with it, precisely because it's time to develop new jobs with the old skills. I suggest that they consider augmenting their education by taking an internship on Capitol Hill, either as a Senate page or better yet, as a science aide to a lawmaker. I tell them to then dive into the private sector and pick up experience at various resource- or hazards-based jobs and then return to politics, and this time with an agenda. I advise them that because theirs is an intelligence that continues to expand and develop with experience, they should not expect it to be completely developed before they are forty, fifty, or…if they keep their hearts and minds open, their professional abilities will still be expanding until the day they're hauled off to the glue factory. I tell them that theirs is a brand new world that needs new hybrid forms of knowledge and intelligence, and that school is only a place to begin to develop their intellectual muscles; beyond that, working as a geologist is rather like joining the Peace Corps, because most often the people who hire us (two- and three-dimensional thinkers) don't really know what the job is. Like Peace Corps volunteers, our job is to learn to think, learn to gather and process data, enter the workforce, absorb experience, evaluate our surroundings, and *then* decide what needs to be done.

Who can better address humanity's growing problems with resource assessment, exploration, and exploitation, be it minerals, geologic hazards, land use, or planning for a changing future, than a geologist? Who can do a better job of integrating complex, interacting systems toward pragmatic results? Who is better suited to project into the future the impact of decisions that will impact these systems? And turning these questions around, does it make sense for us to leave our future in the hands of folks who can't fully perceive these systems? I don't think so. A box is an object that has three dimensions, so it's essential to be able to perceive at least four in order to think outside of it.

I'm not suggesting that ours is the only type of intelligence, and I'm well persuaded that it takes all kinds to make a world. There are lots of jobs we're not suited for, which would irritate us or bore us to tears, but for a great many critical tasks, our input is sorely needed as we face the increasingly complex global impact of humanity on the Earth and vice versa, and our input is needed now, not decades from now when the current generation of geology majors begins to mature. So I suggest two things: first, that we offer that input; and second, that we make our input heard and implemented. In short, we need to identify a greater mandate, seize it, and assert it to the rest of humanity.

This may sound like lofty thinking, but I assert it selfishly. Life's more satisfying when our input is heeded. The more adequately we fill our own shoes, the more fulfilled we become. And our input is indeed needed. As I've suggested in earlier parts of this rant, we are the modern wizards. If this concept jars you, ask yourself why our culture is so short on wise elders who are consulted in moments of change and difficulty. Do the wise ones not exist, or are they (we) misperceived? Ask also how so-called "primitive" cultures regard those persons who can read nature's myriad clues on a high-speed, multi-dimensional basis. They may be feared, but they are revered, and their wisdom is regarded. They are called medicine men and women, or witches, or wizards, or seers, and there are a certain number born into each generation precisely because they (we) are needed. *Our* culture is something of an oddity, having espoused rationality at the expense of other ways of knowing, but I assert that there is nothing weird or dark about subtler, more deeply integrated forms of knowing; rather, I suspect that such ways of knowing are simply (or complexly) that which is done by those of us who more fully observant, the four-dimensional thinkers. The bonus of living in our current culture is that we can harness the best of both worlds, and let scientific training humble our =assign meaning to gibberish.

But back to my ambition to move the four-dimensional thinker into a position of greater influence. There's an obvious rub here. Seizing a mandate is a political maneuver, and geologists and politics don't usually mix. Politics strike most of us as an absurd fascination with matters of little lasting consequence that occur within short time frames (why should we get excited about something that happens within only a few thousand years?), and worse yet, the business of politics seems weighted down by processes (committee meetings…yecch!) that are too short on results (leave me alone, I just want to look at rocks and get something *done*).

Most of us can recall a moment or five in which we have tried to offer the benefit of our wisdom to someone less wise who inexplicably holds a mandate. Such ventures can be frustrating in the extreme, because while we are being practical, others are being political (ever wonder what Custer's cavalry scout said just before, I presume, he sensibly got back on his horse and vamoosed before the arrows started to fly?)

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Being largely apolitical by nature, few geologists show little talent for seizing mandates. Most of us seem to prefer that our mandates be handed to us in the form of employment, an arrangement that allows us to fiddle with interesting puzzles and be left unmolested while someone else worries about handing us a check at comforting intervals. While we prefer to be paid well for our efforts, our employers either undervalue us because they don't understand our input, or they shrewdly discover that we are more motivated by interesting work than by money. Not coincidentally, we rarely command high fees for our services or percentages of the riches we find. I recall a story about a geologist who discovered a huge gold reserve, only to find himself taking hats and coats for the money guys when they came to town to see how their investment was coming along. He got the glory of having the mine named for him.

Ouch.

Some of us do better than others at this game. I have made a study of those colleagues who have not only distinguished themselves as geologists, but have also made a success of working in political situations (there are many who weren't very good at the science and so found a path into management, but I don't have room to gripe about them here). Some of these doubly-able ones serve to bridge the gap between science and policymaking (i.e. as state geologists), some serve our profession as association officers, and some have become successful at running businesses, becoming the boss instead of the employee. I observe that these people have a few things in common: They are confident around other people. They like to be in charge and are not satisfied with just going along to get along. They perceive a bigger picture, expanding their sense of "the system" to include those processes that connect the product to the consumer. And most of them had damned good mentors.

True mentors are those rare creatures who teach us so much that we are inspired to give something back out of sheer gratitude. In past sections I've also touched upon the alienation so many of us feel as a result of being subjected to standardized schooling, here characterized as those institutions that focus on the ways that we are different and do not perceive our strengths. Mentors can help us find and develop our strengths, even to the point where we can tolerate working with process; process without the pragmatism of results is anathema to most people with talent for geology. But understanding process as a system, and learning how to guide the system towards results, can make it tolerably pragmatic. Moreover, the detachment borne of being able to take the long view—a temporal capacity at which we excel—enables the geologist to ride out the short-term ups and downs of process.

My greatest mentor, Edwin D. McKee, taught me to make sure that my career was bigger than my job. This meant that I should recognize that our profession is a system with many moving parts. We maintain our own literature, and grow our own societies. We network in and outside the workplace, supporting the advancement of individuals as well as the advancement of our science. And we gather to enjoy the company of those people who understand us best—our professional peers. It's a good system, and it pays us in ways that money cannot measure.

As we search out mentorship, we need also to become the mentors of the coming generation of geoscientists. Too many geology departments are in decline precisely because the merit of and need for its graduates is so thinly perceived. Perhaps also the times truly are changing, and curricula need to be reintegrated. How many of us were offered a good course on geopolitics during our university training, or resource economics, or a really good course on professional comportment? These were subjects I found later, on the job, and at the feet of my mentors, and when I turn to my students in Geology 102 and suggest that they are consumers of geologic materials their jaws go slack.

As a parting thought, I've found myself—as a writer about geology and geologists—holding up a mirror to our profession, and part of what I see is a grossly underdeveloped sense of our place and value in our culture. We are humble to a fault and too willing to

hang onto the fringes of society rather than roar from the heart of it. I feel that it's time to approach the game differently. It's time to question our system of education, and find new paths for ourselves and for those with our talents who will come after us. It's time to assert our truest value.

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