Some late night thoughts about geology and geophysics

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The title of my talk is pilfered from Lewis Thomas' (1983) collection of essays entitled *Late Night Thoughts on Listening to Mahler's Ninth Symphony*. Thomas, a biologist, notes that "The relatively new term, earth science, is in itself an encouragement. It is nice to know that our dear planet has become an object of as much obsessive interest to large bodies of professional researchers as a living cell, and almost as approachable for discovering the details of how it works. Seismologists and geologists have already surprised themselves over and over again, probing the movement of crustal plates afloat on something or other, maybe methane, deep below the surface meditating on the evidences now coming in for the reality and continuing of continental drift, and calculating with increasing precision the data that describe the mechanisms involved in earthquakes. Their instruments are becoming as neat and as informative as medicine's CAT scanners; the earth has deep secrets still, but they are for penetrating."

Wallace Pratt, in his foreword to the first "Symposium on geophysics in Kansas" (Hambleton [ed.], 1959) of 25 years ago, anticipated these developments. He quoted Jacob Bronowski, who observed that "The great revolutions in outlook are long in the making, . . . at last they change all our ways of thought." Pratt went on to observe that "The achievements of geophysicists have been less conspicuous in Kansas than in some of her sister states. Nevertheless, geophysics has already contributed an imposing array of new knowledge on the structure and composition of that part of the earth's crust which underlies Kansas. With constant improvement of existing techniques and the prospect of continuing vigorous effort, geophysicists may confidently expect to make even greater future additions to this knowledge." How right both he and Bronowski were! I believe that we are undergoing a great revolution in the outlook about Kansas geology that is changing all our ways of thought. Furthermore, geophysicists, in the main, are leading this revolution.

The revolution has been long in the making. It goes back to the 1940's and the pioneering gravity work by George Woollard, the identification of the Greenleaf anomaly by Paul Lyons, and the work of a host of others. However, like quantized energy change, the results of these efforts seem to leap forward after periods of relative quiescence. I believe that we are in a period of one of these quantized jumps today and that we have learned more about the geology of Kansas in the past few years than we learned in the previous 30 years. For too long, we have been influenced too much by stratigraphers who stressed dull, broad, gentle, epeirogenic uplifts and downwarps to account for thick sedimentary sequences and cyclicity of beds. The flat, dull, uninteresting geology of Kansas has once more become exciting as geophysicists have changed our perception of truth. Gary Zukav (1980) put it well in his *The Dancing Wu Li Masters* when he noted that "Whether or not something is true is not a matter of how closely it corresponds to absolute truth, but of how consistent it is with our experience." Incidentally, despite its title, Zukav's book is about quantum mechanics.

However, rather than dwell upon the revelations of geophysicists, about which you are hearing much during the two days of this 25th Anniversary Symposium, I wish to develop some of my own "late night thoughts" in the form of some speculative and perhaps outrageous generalities.

Griffiths et al. (1980) have observed that the "occurrence of different mineral resources in a region has a linear relationship to the geological diversity of the region." I believe that they are correct, as demonstrated by their worldwide studies of unit, regional, mineral values. However, Griffiths has been constrained to the geologic diversity revealed by surface geological maps. Hence, John Davis' Law of Uncertainty prevails: "The farther you are from a place where a geologic property is known, the greater the uncertainty, and hence the error in your estimate of its magnitude." Furthermore, Markov tells us that the imprint of past geological processes tends to disappear with time.

I take some comfort in Douglas Hofstadter's book (1980) entitled *Godel, Escher, Bach*. The work finds common ground in the parallel ideas of Godel's Incompleteness Theorem, Escher's drawings, and Bach's fugues. It is about recursion, or systems and structures that turn back upon themselves. Recursion also might be described as "a phenomenon defined in terms of simpler versions of itself." "Self-fulfilling prophecies" and "lifting oneself by one's own bootstraps" are everyday expressions of recursion.

I believe that geological events are recursive. One of the best examples of a recursive geological event is the evolution of a salt dome. A salt dome has its origin in the growth of a random upward perturbation on the surface of bedded salt. Because salt is less dense than surrounding sediment, a differential force is produced by a difference in the thickness of the overlying sediment load, causing the salt to flow toward the place of minimum load. This flow creates a peripheral depression. Sediments infill the depression, thereby increasing the force differential, and perpetuate the

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rise of the salt to produce a dome. In other words, a salt dome generates its own growth contemporaneously with sediment deposition.

Deltas may partly generate their own growth in a similar fashion. Mountain systems tend to rise as they are eroded because their deep roots of lower density rock provide excess isostatic compensation. Glaciation is recursive. It changes the earth's albedo and thus causes greater glaciation. As dissection takes place on a plateau, more and more surface area is generated, and erosional and weathering processes increase. A desert condition tends to propagate itself as plants die for lack of water and wind transport increases.

Thus, one might conclude that many geological events are recursive. They produce systems and structures that turn back upon themselves and may be defined in terms of simpler versions of themselves.

Godel's Incompleteness Theorem also states that "no system can be characterized completely unless it is embedded in a larger system." Recursive systems interact with other recursive systems, and recursion is not a constant-rate process; in fact, it may be catastrophic. Increasingly, I am persuaded that many geological events are catastrophic in the manner of Mt. St. Helens and that we simply have failed to look for these events in the geologic record. I think that the Big Thompson Canyon flood is crucial to my argument. According to oldtimers, this kind of flood had never happened before in the canyon. But John Rold's staff of the Colorado Geological Survey found tar paper interlayered with gravels high up along the canyon wall. It had happened before and during the time of human occupation and the use of tar paper.

Let me recapitulate. Many geological phenomena are recursive. When a random perturbation takes place in a system, the resulting feature continues to grow upon itself at a nonconstant rate until the energy of the system is exhausted. Additionally, I believe that Godel's Incompleteness Theorem holds and that a geological event cannot be characterized completely unless it is embedded in a larger geological system.

As another source of stimulation, I turned to the work of Botbal et al. (1977). Incidentally, Joseph Moses Botbal is known to his U.S.Geological Survey colleagues as two prophets and a loss. His conclusions about second-derivative surfaces drew upon the efforts of a British mathematician, George Boole, who created what is known as Boolean algebra. In a general way, Botbal predicted that most mineral resources will be found in geologic environments that are characterized by high rates of energy change. (Such environments are not dull places.) If the energy content of a geological environment, regardless of age, can be characterized, then the second derivative reveals a high rate of energy change. Geophysicists have been doing this for a long time with magnetic and gravity fields.

Because the imprint of a geological event tends to diminish with time, because the farther you are from a place where a geological property is known, the greater the uncertainty of your estimate of its magnitude, and because of the immense range of measures of geological properties, we need to seek some common denominator. I believe that common denominator is a high rate of energy change in both geophysical and geological data. I suggest that basin margins, coastal zones, and a wide variety of structures are indicative of high rates of energy change, whatever the age of the environment, and that we can develop measures of such change.

I suggest further that coincidences of second-derivative surfaces, indicative of various high rates of energy change, are places for occurrence of mineral resources.

Many of the papers of this symposium have focused on the seismic, magnetic, and gravity data associated with the Midcontinent rift system and its relationships to the Salina and Forest City basins and the Nemaha uplift. Interest has been heightened further by the Texaco well, completed at 11,300 ft along the margin of the rift system. Another stimulating development has been the discovery of hydrogen-rich gas in the Flint Hills of Kansas, south of Junction City in Morris and Geary counties. This hydrogen-nitrogen field lies along the eastern side of the rift system. Seemingly, it may represent "outgassing" along the fault system from abiogenic methane deep within the earth, the result of serpentinization, or the result of microearthquake activity that produces free hydrogen from underground water. All three hypotheses require the presence of a rift system. In turn, the presence of hydrogen may tell us something about the rift system.

Other studies show that the Simpson thickens over the rift. Integrated basin analysis indicates that the Salina basin's predecessor, the North Kansas basin, began developing during deposition of the Ordovician Viola, and that the depocenter of this basin shifted eastward in northeastern Kansas during Hunton deposition.

In a different area, Yarger (1983) has noted that a marked magnetic low, trending in an east-west direction across the middle of Kansas, seemingly separates a geophysically subdued zone to the south from a more "busy" zone to the north. The work of Bickford et al. (1981) shows a similar boundary between younger rhyolite-granite terrain to the south and an older, more heterogeneous terrain to the north. Speculation is that this boundary represents a continental margin suture.

Frank Wilson has noted the perils of "linesmanship," in which, depending upon azimuthal prejudice, one can draw a line through any number of possible unconnected events. However, he and others are observing what may be more than fortuitous preference for major alignment of lineaments, structural features, and river courses.

The evidence is becoming stronger for a deep-seated origin and continental scale of major events and their reactivation in a nonconstant time frame, perhaps even to the present. Certainly Don Steeples' work with microearthquakes in Kansas and Nebraska shows coincidence of microearthquakes with major fault systems bounding the rift system, the Nemaha uplift, and perhaps the Central Kansas uplift.

Hence, a great deal of evidence shows that these midcontinental events are, in fact, recursive, nonconstant in time, and embedded in larger systems. I believe that these events have at times been catastrophic in character and that they will be reflected in the geologic record in the overlying sedimentary sequence, and even at the surface. Irrespective of the outcome of the Texaco well and the potential for petroleum in the rift system, as postulated by Lee and Kerr (1984), I would investigate seriously the potential for thickening on the downthrown side of sedimentary units along major fault systems. The potential for other mineral resources also looms large along these systems.

Additionally, I suggest that some bold investigator quantify the energy content of a variety of these geologic environments, both present and past; map their second-derivative surfaces; and with geophysical second-derivative surfaces, attempt to define environments of high rates of energy change. I believe that such environments will contain mineral resources.

So much for "late night thoughts" and perhaps some dreaming. "The earth has deep secrets still, and they are for penetrating."

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