Editorial

Emerging relevance of Earth System Science

T N Narasimhan

Professor Emeritus, University of California at Berkeley, USA.
Member, Editorial Board, 'Journal of Earth System Science'.
e-mail: tnnarasimhan@lbl.gov

Three years ago, leaders of the Indian Academy of Sciences made a decision to change the name of the *Proceedings (Earth and Planetary Sciences)* to *Journal of Earth System Science*. This was a thoughtful decision. It reflects an appreciation of the changing role of earth sciences in the broader context of human knowledge. It is also compatible with the needs of a technological society that severely stresses the limits of natural resource systems vital for human survival. The avowed vision of the Academy is to uphold the cause of pure and applied sciences. In the modern technological world, 'cause' of science necessarily includes service to society.

As one browses through the pages of JESS as it punctually arrives every other month, one finds scholarly articles in established disciplines such as climatology, meteorology, structural geology, geomagnetism, stratigraphy, geochemistry, oceanography, planetology, seismology, petrology, and the like. Although each of these fields may deal with more than one subsystem of the Earth, one somehow misses the spirit of visualizing the Earth as 'system' that underlies the journal's name change. In fairness though, one should expect a time-lag between the inception of a new way of thinking and its functional acceptance. Therefore, without being critical, it is worthwhile to pause and reflect on why the Earth as a system has become relevant.

One way to get started in this regard is to inquire why we do science, and how the Earth fits into it. We engage in science for two reasons: First is intellectual curiosity, the rare gift that Nature has bestowed us humans with. We have an innate desire to know why the material world around us functions the way it does. In the sixth century B.C., Greek thinkers introduced the notion that the material world around us can be understood in terms of predictable patterns of cause and effect according to laws that are immutable, unchanging with time. During the sixteenth century A. D., Francis Bacon (Broad 1959) formalized the scientific method of establishing laws based on careful observations. And he went further, suggesting that the knowledge of how the material world functions can be practically used to improve the quality of human life. The upshot is that pure intellectual curiosity has become intertwined with the second of the two reasons, namely, practical benefit to society. Thus, as earth scientists, we are engaged in science partly to understand why the Earth is the way it is, in response to the events and forces of the past that shaped it, and partly to use the information to improve the quality of human existence.

Following James Hutton's founding of modern geology during the second half of the eighteenth century, modern geology largely took shape during the nineteenth and early twentieth century. To facilitate comprehension, the Earth was studied in terms of identifiable components such as rocks, minerals, fossils, sedimentary successions, earth-structure, land-forms, the water-scape, climate, the oceans, and so on. By the middle of the twentieth century, these narrowly focused studies had produced a substantial body of information to facilitate deeper inquiry into the causative physical and chemical processes. With a critical body of observational data available, the middle of the twentieth century focused on elucidation of processes, leading to the ascendancy of geophysics

J. Earth Syst. Sci. **116**, No. 6, December 2007, pp. 465–467

and geochemistry. With focus shifting to processes, the boundaries among hitherto well-defined disciplines began to blur. The recognizable interconnections among various components of the Earth on various spatial and temporal scales had to be given attention in order to decipher Earth's history. It became apparent that on a grand scale, the Earth constitutes a giant system within which, the core, mantle convection, subduction of lithospheric plates, volcanism, outgassing, orogenic movements, oceanic circulation, climate change, geomagnetism, and geomorphology are all interlinked. These grand connections of the Earth system are driving intellectual curiosity and the excitement of discovery of the modern earth science venture. Concomitantly, knowledge of the Earth has continued to be used to discover and exploit natural resources such as minerals, fossil fuels, and water for human benefit.

Until about the middle of the twentieth century, science was largely motivated by intellectual curiosity. Scientists had the luxury of keeping a distance from matters of policy and governance. However, emerging findings about the impact of science on the human habitat has progressively rendered it difficult for scientists to restrict themselves to the pursuit of intellectual curiosity. Rather than merely finding newer and newer sources of natural resources to be exploited for human benefit, science has found itself evaluating the adverse impacts of past exploitation on the human habitat, and devising ways of minimizing or eliminating the negative consequences of its own creation. Science finds itself in a position of being its own police, with the responsibility of advising society about the alternative resource-use strategies available for human survival in a fragile habitat.

As it happens, the issue of survival of a technological society in a fragile habitat exceeds the scope of science. Whereas science deals with immutable laws of a material world, society governs itself through human laws that change with time. When the habitat is in danger, the choice of the most beneficial strategy to adapt will be based, not on science, but on human values. In this interconnected process, science has to work closely and constructively with society, being keenly aware of its own place in the larger scheme. Social policy and law cannot do without science, but yet, science cannot be the ultimate arbiter.

This imperative for science to monitor itself, and to actively participate in social governance has led to a need for focusing attention on Earth systems from a perspective that is different from intellectual curiosity. Whereas intellectual curiosity looks at the Earth system from the Earth's core to the outer limits of the atmosphere and beyond, survival of technological society necessitates focus on Earth system components surrounding the human habitat: the atmosphere, the hydrosphere, the crust, and the biosphere. The role of the biosphere is especially significant. Historically, geology's principal concern has been the inanimate Earth, and the history of life on it. Only over the past half a century has recognition emerged that life itself may have significantly influenced geological processes. It now appears that the Earth's history over the past 3.5 billion years of its 4.5 billion-year history might have been radically different from what it is now had it not been for the existence of life. For example, the evolution of an oxygen-enriched atmosphere from a primitive carbon dioxide rich atmosphere around 2.5 billion years ago is thought to be due to photosynthesis by primitive microorganisms.

Contemporary focus in the earth sciences is, of necessity, in the human habitat. From the perspective of 'Earth systems', attention is on that fascinating phenomenon called the hydrological cycle. Closely woven around this central phenomenon are the geochemical, nutrient, and erosional cycles. Survival of life depends on these cycles, and in turn, life influences their functioning. The dimension that life brings to the understanding of the near-surface Earth is unique and cannot be matched even by the cosmos, which after all, is inanimate. The inanimate world can be rationalized with immutable physical laws. But life, endowed with a discriminating mind, defies being framed within predictable laws. Thus, the near-surface Earth system, with its component of life, constitutes an infinite source of intellectual challenge to the curious and to those concerned about human survival on a finite, delicately interconnected Earth.

Clearly, no human can comprehend in detail every aspect of the vital cycles that govern the near-surface Earth. Inevitably, one has to devote practical attention to this or that small part of the whole. However, what emerging knowledge suggests is that we be cognizant of the significance of our part in the larger scheme. Regardless of the particular part to which we devote practical attention, or the specific method or tool that we employ, our common goal is to understand the Earth. This mind-set is conducive to seek knowledge from others so as to better understand the part of the Earth system that interests us, and to convey our knowledge to others who may similarly benefit. To this end, it is essential that we distill unifying ideas and concepts that may otherwise be masked by jargon and specialized symbols. It will also benefit us to occasionally pause to think of the broader context and share our geo-philosophical musings.

The Earth-system perspective brings with it the need for recognizing certain unique attributes that set earth sciences apart from physical sciences. Major developments in physics during the nineteenth century led William Thomson (1891) (Lord Kelvin) and James Clerk Maxwell (1864) to believe that precise measurement and quantification with numbers are so essential to understanding Nature that there is no science without numbers. This perception continues to persist, probably with justification, in modern physical sciences. But, caution is necessary in extending this notion to Earth systems. The laws of thermodynamics and mechanics have contributed enormously to our insights into how the Earth functions. Nevertheless, such insights possess inherent imprecision and uncertainties due to difficulties of access to observation, attributes of instruments, multiplicity of spatial and temporal scales, complexity of geometry, coupling of processes, feed-back mechanisms, and ignorance of forcing functions. Imprecision and uncertainties magnify as the system expands to encompass more and more components. However, lack of precision and uncertainty do not negate our ability to augment our understanding of the Earth. The human mind has remarkable abilities to synthesize information. Consequently, the framework of Earth System Science demands of us a willingness to draw upon our intuitive, semi-quantitative, and quantitative faculties to achieve our ultimate goal of understanding the Earth. There is more to understanding the Earth than quantification. It is important to note here that this perception of the role of quantification within a larger context is not a rejection of quantification. Rather, it is an expression of awe for the extraordinary complexity of the Earth system.

Closely connected to quantification is the desire for prediction. Here again the best that science can do is to find rational explanations for observed Earth phenomena in terms of physical laws, and to speculate on the conditions that might have existed in the past that were responsible for the present manifestations. Earth sciences are inherently historical (Frodeman 1995). Although one may attempt to foresee how a given system might behave in the future, such an attempt is fraught with uncertainty. Uncertainty magnifies with the complexity of the system and time. Given the inherent limitations of quantification and prediction of the behaviour of Earth systems, science faces the formidable challenge of helping society devise ways of wisely managing Earth systems amidst uncertainty of future availability of vital resources.

Contemporary India eagerly looks ahead for economic boom and prosperity through the miracle of new technologies. However, the realization of these ambitions ultimately depends for success on how well India's water resources, the landscape, the waterscape and the ecosystems are rationally managed. Because of India's long history of human habitation, and because of the country's large population, these systems are already under enormous stress. Unfortunately, there is no indication that management policies based on sound science will be set in place any time soon. Simultaneously, India's earth scientists appear to be reticent to become active in moving the country towards science-based management of Earth systems. If India desires to move in the direction of rational management of its Earth-resource systems, the appropriate guiding framework will be to look at the subcontinent from the perspective of the hydrological cycle, and its linkages to geochemical, nutrient, and erosional cycles. In combination, these vital cycles constitute an awesome portion of the Earth system. In facilitating this, JESS can potentially play an inspired role of leadership.

References

Broad C B 1959 *Bacon and the experimental method*; In: 'A short history of science, A Symposium' (Doubleday Anchor Books, New York) 27–33.

Frodeman R 1995 Geological reasoning: Geology as interpretive historical science; *Bull. Geol. Soc. Am.* **107** 960–968.

Maxwell J C 1864 Faraday's lines of force; *Trans. Cambridge Phil. Soc.*, **X**, Pt. 1, p. 27.

Thomson W 1891 Electrical units of measurement; In: 'Nature Series, Popular Lectures and addresses' (Macmillan and Co, London and New York) v. 1, Constitution of Matter, 80–134.

MS received 3 August 2007; revised 8 August 2007; accepted 8 August 2007