Vision 2005: Earth Sciences

The Department of Science and Technology (DST) implements many programmes through which research is promoted in frontier areas of science and technology. The Science and Engineering Research Council (SERC) has played a pivotal role in this regard. Taking note of the global trends, SERC has decided to prepare 'Vision 2005 Document' in various disciplines. The Programme Advisory Committee on Earth Sciences has prepared a 'Vision 2005: Earth Sciences' document based on indepth discussions with a wide cross-section of the scientific community. The document indicates the areas of research in Earth Sciences that need to be given added thrust in future.*

Preamble

Man's inquisitiveness about and his dependence on environment and the processes contributing to its change form the basis of studies in Earth Sciences. Over the years, our understanding of the processes operating in the earth has increased considerably. This has led to a variety of new questions and new avenues of research. The emphasis today is to quantify the earth's endogenic and exogenic processes which control its internal dynamics and shape its surface and fluid envelops, the sum total contributing to global change. Such a study involves not only the contemporary events and processes, but also those of the past, as what we observe today is a cumulative effect of the past and present processes. More recently, study of the interactions among the various components of the earth systems – lithosphere, hydrosphere, biosphere and atmosphere – has gained considerable importance as these interactions influence global change on various spatial and temporal scales.

Studies in the earth sciences in India are also slowly undergoing major changes. The current emphasis is to substantiate the classical approaches of exploration, description and data gathering with quantitative aspects of data processing, and interpretation of processes and events contributing to the observations. It is also evolving from a subject of individual inquiry to larger programmes involving scientists with complementary expertise and capabilities. Thus, earth science programmes are becoming more multi-institutional/multi-disciplinary, with increasing applications of the concepts and methods of mathematics, physics, chemistry and biology.

A major impetus for this shift comes not only from the need to understand and quantify better the spatial and temporal evolution of the Indian lithosphere but also from the recognition that such knowledge could form the basis for sustainable development of our natural resources. In addition, the recurrence of natural hazards has reinforced the need to learn more about the mechanics of these phenomena and develop predictive modelling capabilities.

The emerging challenges require, on a continual basis, appropriate human resource development in terms of skills and expertise, as well as facilities and infrastructure. The direct interface of the Earth Science Programmes with exploration/exploitation of both renewable and non-renewable natural resources (like energy, groundwater and minerals) calls for a much closer tie-up of its R&D programmes with the industry, user agencies and concerned government departments.

Resume of research activities in identified areas and their impact

India is a large country integrating a variety of geological features and phenomena. These include the Archaean cratons and their accreted mobile belts, the Himalaya – a classic example of continent – continent collision process, the Deccan volcanic province – one of the largest outpourings of continental flood basalts on the earth's surface, Proterozoic cratonic basins (Purana basins) of unique character, well-preserved sections of stratigraphic boundaries, some of the largest rivers of the world – the Ganga and Brahamputra and a variety of well-preserved archives of past climates and environment. Extensive studies of these geological features have resulted in a number of important contributions in the field of earth sciences. Many of these studies stem from the thrust areas identified in the earlier DST document 'Challenging Areas in Earth and Atmospheric Sciences'.

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Future research directions: Objectives and research areas

Considering the available results of the completed and on-going researches, relevant panel reports and existing scientific and social environments, the task before us is to identify areas which hold promise for creative excellence and for the well-being of the society. It is expected that such areas would have a high likelihood of significantly enhancing our basic understanding of the geological processes/events and would yield results of general interest and application. This is indeed a difficult task even in the best of situations, because with the progress of research, new questions continuously arise which could drastically change the directions of enquiry. Nonetheless, we are listing below a few themes/areas for pursuing future research activities to enlarge our understanding of the earth processes. Other factors which have been considered in arriving at the list include: (i) the expertise of scientists, (ii) technology, manpower and financial support which are available at present and which may become available in due course, and (iii) the current international research trend. Additionally, future strategies in earth sciences must take into account basic and applied aspects in order to be able to cater to the ever-increasing human requirements.

While indicating the future directions, all areas/components of earth science were not considered; hence the topics listed below cover only selected disciplines.

Researches in other areas such as oceanography, limnology and atmospheric sciences, are being addressed to by specialized panelists of the DST.

Areas of opportunities

i) Evolution of the Indian crust
1. Precambrian cratons and mobile belts (including greenstone belts and granulite terrain)
2. Purana Basins
3. Phanerozoic Basins
4. Mesozoic–Tertiary volcanic provinces
   - The Deccan and related traps
   - The Panjal traps
   - The Andaman arc
5. Himalayan Orogenic belt

ii) Structure and dynamics of lithosphere and mantle
1. Continental crust (thermal structure, thickness and physical nature)
2. Role of fluids (in geological processes)
3. Experimental studies (phase equilibria and physical properties of deep interior)
4. Lithosphere structure and plate dynamics

iii) Earthquake processes
1. Himalayan seismicity
2. Intraplate seismicity
3. Neotectonics and Palaeoseismicity

iv) Reconstruction of palaeoenvironments, palaeoclimates and past global changes
1. Infra-/inter-trappean sedimentary sequences of Deccan province
2. Regolith sedimentology
3. Palaeobiology and environmental shifts
4. Quaternary sedimentation pattern, climate history and global changes

v) Earth science application for societal needs
1. Geohydrology
2. Mineral resources and fuels
3. Environmental geology and natural hazards
4. Preservation of national heritage

The above-mentioned areas have been briefly discussed in the 'Vision Paper' with regard to some emerging problems under each theme. But we must realize that all geological problems start in the field, and it is strongly recommended that field study be recognized as an inherent and pervasive part of the research/education of earth sciences.

Interactive geoscientific studies

The geological sciences draw on tools and knowledge developed in other scientific disciplines. At the same time, geological research has contributed concepts and techniques to these other disciplines. For example, the structural determinations of high-temperature superconductivity drew heavily on mineralogical principles, and the similarity between the perovskite structure of these superconductors and mineral structure of large parts of the mantle is an example of closed relationship between geoscience and physical sciences. From the curiosity of studying geological materials on submicroscopic domains, the earth scientists also developed or refined several analytical devices (e.g. EPMA, Ion Probe, high P–T equipments) that were then applied in many other fields.

Increased understanding of the earth processes as well as emerging newer concepts and methodologies require interactive research programmes involving geoscientists, physicists, chemists, biologists and mathematicians. For molecular phylogenetics, a palaeontologist has to interact with biologist and organic chemists. Similarly, a petrologist and mineralogist would need a physicist to peep into the intricacy of heat and mass transport problems associated with matter in subcrustal depths. Even within earth sciences most research works are multidisciplinary about which an emphasis has been given in this document. Interactions seem to be legion, and most frontier research topics relate to more than one theme. Again, present day computational capabilities have revolutionized the handling of vast amounts of data generated in earth science research. We now require to develop quantitative models for a number of earth processes. Even such traditional disciplines as mapping and palaeontology are becoming increasingly quantitative with the advent of digital analysis and computerized data base. The main emphasis of this theme is to recognize research problems in geosciences which need to be seen from different angles since solid earth of a geoscientist is in a way a science of solid state physics. To account for several earth science phenomena we also need to develop theoretical/mathematical models. Compilation of geological history and study of modern processes and their rates would allow mathematical modelling. For example, modelling is required for geochemical cycling, which brings together results from studies of various aspects, including mantle evolution, global tectonics, rock–water interactions, organic evolution and palaeoclimatology.

Numerical computer simulation is needed to develop, rather more rigorously, for a number of earth processes involving inputs from physical chemistry, statistics and other fields. We need accurate projection of the data-based interpretation for prediction of the natural processes. Even chaotic systems are subjected to statistical prediction. For example, the quantitative treatment of isotope exchange between rock minerals and fluids needs intensive integrated research in fluid–rock interaction and fluid flow within the crust. Many research problems of integrated nature can be conceived and formulated, but only a few are mentioned below.

In igneous petrology where study of silicate melts is made, geochemistry is definitely an essential research component. But to advance our understanding of many related processes, such as element partitioning between melt and crystals and crystallization sequence of minerals, a full knowledge of silicate melt structure is necessary. For this we need interaction with physicists and chemists. To study viscosity behaviour of melt, solubility of water in the silicate melts and structural nature of the melts, we need Raman Spectroscopy and polymer chemistry and related fields. In addition, spectra of ferrous/ferric iron requires knowledge of Mössbauer spectroscopy and crystal structure. Furthermore, to elucidate the petrogenesis of diversified igneous rocks, Rayleigh fractionation equation are used for elemental data so that vector calculations can be made for representing the composition of the derived liquids (resulting from the removal of given phases) and of cumulates (resulting from crystallization of model liquid). Clearly, we need inputs from experimental studies of crystal/liquid and element partitioning between them.

The lithospheric evolution of the Indian region forms an important interactive research area that would involve seismological, heat flow, magnetic, gravity, electrical, isotopic and geochemical studies of specified segments/transects in India. The studies may be carried out in stages as a multidisciplinary research project.

A long-term approach in metamorphic petrology is to outline P–T–t paths which indicate dynamic time-dependent character of metamorphism for a given crustal segment of overthrust belt. The geothermobarometry, based on thermodynamic principles, when applied to zoned minerals or to incompletely reacted mineral assemblages would help to define the paths of pressure/and temperature variation followed by the individual rocks. Chemical data on the zonation of minerals would additionally provide a wealth of information on the thermal processes that took place during metamorphism of rocks and growth of minerals. This shift of metamorphic petrology from a static mode (aimed at working-out the mechanical and thermal processes involved in metamorphism) needs numerical modelling. In this effort, the thermal response of the rocks to tectonism can be determined by computer modelling of the transient temperature distribution in a rock mass of specified physical properties, assuming certain boundary conditions. This forward approach complemented by petrological observations would unravel details of thermo-tectonic evolutionary history.

Manpower development and infra-structural facilities

The successful implementation of research programmes in any field requires personnel in various categories, appropriate infra-structural facilities such as equipments, current books and journals. India has a wealth of experienced earth scientists, but many of them are trained primarily in the classical approaches and are very specialized. The need today is more broad-based and earth scientists with good background in basic sciences, particularly mathematics and physics and chemistry, are required to carry out many of the interdisciplinary programmes and develop capabilities for modelling the results. In this context, there is a need not only to overhaul the current compartmentalized education system in earth sciences in the universities, but also to encourage scientists from basic sciences to immigrate to various areas of earth sciences. The earlier PAC had prepared a detailed document on Earth Sciences Education in India (*Current Science*, 1994, **67**, 74–77).

To ensure front line scientific research in earth sciences, a continuous series of training programmes by way of workshops, summer schools, advanced short courses in selected topics, are required to be encouraged. Contact programmes need to be initiated particularly in institutions where infrastructural and instrumental facilities are available such as the WIHG, NGRI, PRL and IIT's. Interdisciplinary teams must be motivated to prepare instructional materials for dissemination. Refresher courses in modern trends in earth sciences with basics in physics, chemistry, mathematics and computer applications, mostly of remedial nature, should be formulated and distributed to various institutions/universities largely through video-lectures and correspondence materials.

Research in earth sciences, or for that matter any other disciplines, is considerably influenced by current awareness which in turn depends on the availability of a wide range of journals – both basic and applied. Indian universities in the recent past are faced with a major financial crisis, particularly in respect of library grants. The situation requires immediate redressal by way of long and short term measures. As a short-term strategy, there is an immediate need for five to six regional units equipped with computer database, such as GEOREF toegether with the required infrastructure for the dissemination of library materials to other users. Earth science data rely heavily on precise measurements. Collection of these data, particularly those dealing with geochronology, isotope systematics, chemical composition, requires sophisticated instruments. This is an area where most of the Indian universities and institutes lag behind the international scene. Consequently, we need to strengthen and augment the instrumentation facilities so that the country's research efforts can be maintained at an internationally competitive level. The approaches for strengthening and updating the instrumentation facilities are discussed in detail in a separate document prepared by the PAC on this topic.

Conclusion

The potential and promise of research in earth sciences in India, both in basic and applied areas, are vast. The areas delineated in this Vision Paper should be interesting enough to stimulate a scientist in his imagination and to identify a specific problem, suiting his background, resources and infrastructural support that he may muster. The time is now opportune to follow-up some of the most challenging themes intensively by launching national programmes (interactive/multidisciplinary) through appropriate linkages between industry, universities, Government laboratories and survey organizations. Through these coordinated efforts and interaction between scientists of related and varied specialization we are expected to generate a more positive research environment whereby scientists would have access to library and instrumental facilities, with their maximum utilization. As a consequence, these would result in excellent research in the country whose spin off would naturally be toward the development of technology and science that would foster country's economic growth and meet societal needs as well as enhance defence, archaeology, dam, irrigation and geotechnical activities.