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PREFACE

The Indian sub-continent offers a unique opportunity for geo-scientific investigations. Its geological records extend back to 3.8 billion years. The geological diversity of this region is immense and its collage in the subcontinent includes e.g. a range of multiple Archean nuclei, Least-deformed Proterozoic basins, Kimberlites, evidence of high pressure metamorphism, Large Igneous Provinces (the Deccan Traps Province), exhumed deep continental crust, region of continental reassembly, India-Asia collision zone, classic Ophiolite sequences, regions of Land-Ocean-Atmosphere interactions, ancient sedimentary basins, unique sediment dispersal systems, mega fans, open and closed ocean and sea with diverse circulations and mixing regimes, presence of a large geoid low in the Indian ocean, Deserts-hot and cold, active and passive volcanism, regions of intense inter- and intra-plate seismicity and energy resources of variable kinds.

The sub-continent is also a region with extreme gradients of, temperature, rainfall and winds; cyclones; landform varieties and their dynamics; weathering and erosion, and high amplitude of population dynamics. A large population density implies a substantive human impact with direct implication expanding urbanization, diminishing biodiversity, increasing demand of natural resources, aspects of food, water, and energy security, accelerating dimensions of natural hazards, effects of climate change and the demands of the *Anthropocene*.

It is, therefore, not surprising that the sub-continent has been the cradle of discoveries in geosciences. Several fundamental contribution have been made in the region and, these range from,

1. Deciphering of the Core - Mantle boundary,
2. Development of the theory of isostasy,
3. Development of theories on the formation of granulites,
4. Development of Out of India Mammalian Hypothesis (e.g. the origin of whales and horses),
5. Identification of Seasonal Reversal of Coastal Ocean Circulations,
6. Presence of Paleoproterozoic Stromatolitic Phosphorites,
7. Identification of Coesite bearing Ecologites from Indo Tibetan Suture Zone,
8. Identification of Coastal hypoxia,
9. Development of concepts of cosmogenic radioisotopes dating using Be, Al and Si,
10. Development of Luminescence dating of Deserts,
11. Understanding of climate-culture relationship,
12. Origins of monsoon and mountain building processes,
13. Initiation of Explorations to Moon and Mars with novel results on the presence of water on Moon, high resolution studies on Martian topography using remote sensing, and
14. Development of Indian geospatial system, the *Bhuvan*.

Over the past few years, India has taken major steps in developing its geosciences and geosciences based services further, and all dimension of Earth System Science have been addressed to. Such steps were possible due to help from Ministries of, Earth Sciences, Mines, and Human Resource Development, the Departments of Science & Technology, Atomic Energy, Space and, the Council of Scientific and Industrial Research. These have not only helped develop the basic science elements but have provided a nuclei for development of geosciences services in their truest sense.

Some of the recent initiatives in the Indian Earth System Science have been,

1. The planetary missions to Moon and more recently to Mars,
2. Indian remote sensing efforts that include dedicated satellites like the Cartosat and satellites for geospatial capabilities with the development of *Bhuvan*, the Indian geospatial platform.
3. Deep ocean drilling up to 1.1 km in the Laxmi basin in the Arabian Sea to understand the

patterns and rates of continental erosion in the past, the origin of the monsoon and the role of Himalaya.

4. A continental drilling program in the Koyna region (in western part of central India) to understand the reservoir induced seismicity and the overall science of triggered earthquakes. Scientific drilling to a depth of 5-7 km and a fault zone observatory for direct observations during earthquakes has been planned. Nine bore holes of about 1.5 km has been drilled and instrumented to provide accurate measurement on the seismicity parameters and disposition of active faults.

   A new institution, the Borehole Geophysics Research Laboratory is now functional at Karad, about 200 km south east of Mumbai. This will have a core archival facility and state of the art instrumentation that will occupy a key intellectual space in Indian geosciences.

5. A new National Institution, the Centre for Seismology has been created to achieve a synergy in seismic data measurement, archival, analysis and hazard evaluation.

6. A large network of GPS stations to understand plate and interpolate movements has been in operation. Jointly with NASA and Indian Space Research Organization, these land based efforts will now be buttressed with satellite borne interferrometric capabilities (NISAR) to measure strain across India. This work will be supported by deep bore holes in India, ranging from the Palghat gap region, the Son Narmada Lineament, the Gangetic plains and lower Himalaya, and will help understand the stresses and dynamics of faulting.

7. Procurement of *R V Samudra Ratnakar* by the Geological Survey of India, for advanced geological, geophysical and oceanographic surveys. This will carry out high resolution mapping of the EEZ of India with seismic, magnetic, gravity and deep piston coring systems. Also planned are deployment of sub-bottom profiler, multi-beam echo-sounder (MBES), synthetic Aperture Mapping Sonar, remotely Operated Vehicles, Heat Flow Measuring Systems, etc. for mapping and mineral resource evaluation.

8. A national centre for Geochronology is being commissioned at Delhi and this will provide a unique facility for sample characterization and chronometry of all possible kinds, ranging from accelerator mass spectrometry to radiation damage techniques and to the dating of detrital zircons. This centre is partly functional and its full capabilities will be realized by 2018.

9. Major programs on the near surface geosciences have been taken up and soon India will have six critical zone observatories. This will be supplemented by extensive modeling efforts.

10. Indians effort in the Polar Regions has been strengthened with the establishment of a permanent station at Larsmann Hills to understand the fragmentation of East coast of India and Antractica. Extensive paleoclimate studies on Southern Ocean, Antarctic and Arctic are on their way.

11. Considerable effort has been made to improve climate forecasts and the successes in predictions relating to the recent cyclones like *Phylin* and synergy with local administration saved thousands of lives.

Some of the significant results in regional geology are:

1. U-Th-Pb dating on zircons constrained the time span of regional metamorphism during the Proterozoic. These are the margins of different cratonic areas of the Indian shield.

2. Rengali Province of the Eastern Ghat that was conventionally correlated with thermal perturbations with the Singhbhum Craton has now been interpreted to be part of the Ur supercontinent.

3. Establishment of inverted metamorphism in Himalaya and identification of two crust-forming events during Late Archean in the Indian shield.

4. Reconstruction of architecture of intra-oceanic subduction system within Neo-Tethys and Suturing of India and Burmese plates along the length of Himalayan orogen, from Trans Himalaya in the west to Nagaland Ophiolite Complex in the Burmese Range in the east.

5. A uniform record of latest Paleoproterozoic to early Mesoproterozoic accretionary orogenesis in different Proterozoic mobile belts of Peninsular India has been linked to the growth of a Proto-Greater Indian landmass.
6. In the context of the continuing debate on the nature of Proterozoic tectonics between the two supercontinent assembly events, Paleoproterozoic Columbia and late Mesoproterozoic to early Neoproterozoic Rodinia, the Indian shield provides robust evidence that during ca. 1.6-1.54 Ga, orogenesis was a globally significant crustal amalgamation event, hitherto unrecognized.
7. Identification and reconstruction studies in the Himalayan geology highlighted near-sub-horizontal configuration of the subducting Indian Plate, P-T-t paths in Karakoram, Sikkim, Arunachal and Nagaland Ophiolites, and Early Ordovician tectono-metamorphic event in the Himachal Himalaya.
8. Paleoproterozoic mafic dyke swarms in Dharwar and Bastar cratons helped recognize large igneous provinces, locate mantle plumes, and, by inference, aided in identifying ancient supercontinents.
9. Discovery of oldest well preserved eukaryotic fossils from >1600 Ma old Chitrakut Formation of Lower Vindhyan Supergroup.
10. Establishment of new Late Neoproterozoic phosphogenesis event and algal fossils discovered in the chert-carbonates of Birmania Formation in Rajasthan.
11. Identification and establishment of significant role of microbial mat in the Precambrian time (before the incoming of borers) in framing architecture of sediment successions.
12. Robust U-Pb and Pb-Pb dating of detrital zircon from sediment archives and dating of lithodemic units from several Precambrian basins of India viz. Vindhyan, Chhattisgarh, and Cuddapah allowed workers to propose late-Paleoproterozoic - Mesoproterozic time for Indian Precambrian basins.
13. Sequence stratigraphy and palaeoecological studies in the Jurassic of the Kachchh and Jaisalmer basins facilitated precise intra- and inter-basinal correlations providing a better understanding of the evolution of Jurassic basin along the southern margin of the Tethys sea.
14. Integrated environmental and paleontological studies provided better understanding of colder Oxfordian climate in the Jurassic basin of Kachchh, in comparison to a warmer climate in Europe.
15. U-Pb zircon geochronological estimates of the Deccan Traps showed that the main phase of eruptions was initiated ~250,000 years before the K-Pg boundary and > 1.1 million cubic km of basalt erupted in ~750,000 years.
16. The discovery of Late Cretaceous (90 Ma) diamondiferous Kimberlite event in the Dharwar craton has been linked to Marion hotspot under Indian lithosphere
17. Establishment of the Indian plate as the region of origin of early evolution of several order of mammals including whales, horses and primates
18. Timing and nature of India-Asia collision was established.
19. Elucidation of significant variability in the thickness of crust in Dharwar and southern granulite terrain.
20. Observation of significant anisotropy in seismic velocities below the Indian shield that informed on the shear flow regimes in the mantle.
21. Observations that piggy back Dun basins in Himalaya act as major, transient sinks and control sediment fluxes in the Ganga plain over glacial-interglacial time scales.
22. Evidences of major paleo-glaciation across Himalaya and Ladakh during the Last Glacial Maximum besides the evidence for extended glaciations during 50-60 ka.
23. Modeling validation of field based observations that the River systems in Himalaya aggraded and the landscape was built during the climatic transitions from dry to wet.
24. In the Indus valley, three megalakes viz., (i) Lamayuru (ii) Rizong and (iii) Khaltse-Saspol were inferred.

This is the fourth volume of Glimpses of *Geosciences Research in India* being presented as the *Indian Report to the IUGS* and as in the past (i.e. 2004, 2008 and 2012), this volume presents some flavor of Indian research in geosciences during the past five years. These are contained in 39 invited overviews. These have been written in a manner that would inform both specialists and non-specialists alike. Extensive bibliography with each article will help serious readers to delve deeper into areas of their interests. The volume also provides institutional reports from 14 Geosciences Institutions in India giving their perspective on science/services done by them.

The Editors thank Professor Ragahvendra Gadagkar, President, Indian National Science Academy (INSA) and Professor S C Lakhotia, Vice President, Publications (INSA) and Chief Editor, PINSA for approving our request for a special issue, despite the short notice and significant financial implications. The Editorial Staff of PINSA especially Dr. Seema Mandal and Ms. Richa Sharma did a commendable job of coordinating the publication process and did so with great patience. We thank Dr. Shailesh Nayak for sharing some of the inputs on recent initiatives of the Ministry of Earth Sciences. The special issue came about as the authors and the reviewers did a commendable job in sending manuscripts in a record time. We also thank the Directors of various institutions who kindly contributed to the institutional reports. The Editors feel immensely grateful to all these for their willing cooperation. We also thank the staff of Kamla Print n Publish Press for their cooperation in maintaining the time lines.

We hope that this volume will interest many and will provide glimpses of science that would await them during the forthcoming International Geological Congress at Delhi in 2020. In the mean time we wish the reader a pleasant Geological Congress in Cape Town.

Ashok Kumar Singhvi,
Dhiraj Mohan Banerjee,
Somnath Das Gupta, Rahul Mohan,
P. Chandrasekharan, Talat Ahmad,
Sunil Bajpai, S. Raju and D. Srinagesh
(Guest Editors)

*While the Editors have taken utmost care, the eventual responsbility of the accuracy of maps and data would lie with the authors.