Relevance of Geo-sciences in Planning the Societal Future

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Earth provides enough to satisfy every man’s needs but not every man’s greed

- Mahatma Gandhi
क्या भूलूं, क्या याद करूँ

हरिवंश राय बच्चन
आत्मकथा, 1969
Figure 1.1. Geology as a derivative science (from Van Bemmelen, 1961).
Structure

Geosciences: a perspective
Surface processes
Major issues of societal needs
Our own work
Conclusions
Historical Perspective

Geology: Ulise Aldrovandi in 1603, J-A Deluc 1778 and M.P. Esholt 1657

Ge = Gaia, the Goddess of Earth
ology = A way of thinking, a study

GeoSemiosis: A science of signs and symptoms

What do the rocks tell us,
Conversation with the earth via its fields B, E, G,...

Geology - Meta Physics: Deals with the nature of being and the world

What is there and
What it is like
Historical Development

- 327-287 BCE: Theophrastus: *Peri-Lithon* (on the stones)
- 973-1048 CE: Abu-al-Rayhan-al Biruni
  Geology of India – Indian subcontinent was once a sea
- 981-1037 CE: Ibn Sina:
  Formation of Mountains/ earthquakes- Modern Geology
- 1000 CE: Shen Kuo:
  Land forms by erosion of mountains
- 1769-1839 William Smith
  First map, rock strata/fossils
- 1785: J. Hutton
  Theory of Earth: Old as time needed for mountains to erode
- C. Lyell 1830:
  - Uniformitarianism – Perpetuity of processes

Age

- Biblical: 4004 BC
- Cooling: 75000 yrs
- Isotopic: 4.54 Ga
Geoscience Premises

Uniformitarianism:
Perpetuity of processes, *Present is the key to the past*

Ontology
Meta physics: dealing with nature & essence of things; classification of entities/properties and their change

*Uniformity of rates & Uniformity of Processes*

Methodological (Simplifying assumptions)
Principle of Parsimony (Okham’s razor)

*Amongst competing hypotheses chose the simplest*

Il Lume Naturale (Galileo)
Appeals to the commonsense

*Favor the hypothesis that seems most natural*
<table>
<thead>
<tr>
<th>Domain</th>
<th>Basic Sciences</th>
<th>Geo- Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis</td>
<td>Defined Elements of System amenable to controlled study</td>
<td>Take the world as it is. Controlled study? Scales: large range S&amp;T</td>
</tr>
<tr>
<td>Goal</td>
<td>Develop theories to explain the world</td>
<td>Develop Understanding of the world</td>
</tr>
<tr>
<td>Emphasis</td>
<td>Idealization and General Principles of Universality</td>
<td>Real Phenomena / Happening</td>
</tr>
<tr>
<td>Method</td>
<td>Laboratory Experiment to justify Knowledge</td>
<td>Observation in the field /Hypothesis</td>
</tr>
<tr>
<td>Tools</td>
<td>Facts</td>
<td>Theories</td>
</tr>
<tr>
<td>Role of Data</td>
<td>Verification of Models</td>
<td>Means to provide Conversation with the Earth</td>
</tr>
<tr>
<td>Inference</td>
<td>Deduction followed by Induction</td>
<td>Retroduction/deduction/Induction</td>
</tr>
</tbody>
</table>
...It is the nature of the History of Earth that every geologist has available to him only partial information. Occasional lines from disconnected paragraph in obscurantist chapter are what can be read.

...Violence in handling the book through time has caused many chapters to be ripped and reassembled out of context. This gist still has to be and has been deciphered.

...He (the geologist) sees only the end and has to induce the processes and responses that filled and the response that filled the time since the beginning

DA Pretorius 1973..
4.567 Ga  Solar system formation
4.54 Ga   Formation of Earth
~4 Ga    First Life
~3.5 Ga  Start of photosynthesis
~2.3 Ga  Oxygenated Atmosphere
542 Ma   Cambrian explosion – First abundant fossils
380 Ma   Vertebrate Land animals
250 Ma   PT extinction 90% animal on land die
65 Ma    C-T extinctions  Dinosaurs die
7 Ma     Homonins appear
3.9 Ma   First Ancestor to humans: Australopithacus

200 ka   Modern Humans
8 ka     Anthropocene
200 a    Human activities equal geological amplitudes
Indian Geosciences Contributions with Global Impact

- Deciphered Core Mantle boundary
- Theory of Isostasy
- Granulite formation Theories
- Out of India Mammalian Hypothesis
- Seasonal Reversal of Coastal Ocean Circulations
- Paleoproterozoic Stromatolitic- Phosphorites
- Coesite bearing Ecologites from ITSZ
- Coastal hypoxia
- Cosmogenic radioisotopes dating $^{32}\text{Si}$, $^{26}\text{Al}$,..
- Dating of Deserts, Luminescence
- Planetary Explorations – Moon and Mars
Grand Challenges in Earth Sciences

1. How Did Earth and other Planet form: Source of material
2. The first 500 Ma, the dark age
3. How did life begin
4. How does the earth interior work and its links with surface
5. Why does Earth has Plate Tectonics and Continents
6. How materials control the properties of Earth
7. How Earth shaped life and how life shaped Earth
8. Can Earthquakes, Volcanic Eruptions and be predicted
9. How does the fluid transport affect the environment
Earth Surface
A Spontaneously Self Organizing System
Self Organization at various Spatial and Temporal scales
Atomic particles to continent sizes
Nano-Seconds to Millions of Years

Sed. fluxes
Weath. Clast
Pore fluids
Matrix Voids
Grain surface

Biogeochemical Process – Electron transfer
• Large W-E trending linear dunes
• Heavily modified in present wind regime
Specific areas of Enquiry

• Geo-patterns
  How do they arise and what do they inform about processes

• **Why are they resilient**
  Can they be used as templates for understanding Earth processes

• **What controls landscape resilience**
  Thresholds, ranges, time scales

• **The Connectivity between Climate-tectonics and Landscape**
  Climate/deformation- topography-ecosystem denudation (e.g. Physical and Chemical weathering),

• Soil formation processes : Agriculture
  micro to macro level, spatial and temporal scale, role of biology

• **Transport Laws**
  land-sliding, erosion- overland flow, glacial, chemical, sediment transport
- **What laws govern co-evolution of landscapes, life and ecosystems:** Life is digestion, dilatation, exhaling, decay—forms and pace of erosion, modulated biogechemistry

- **Earth Surface in Anthropocene:** Human impact now dominates the effects geological processes

  **Implications for Water, Food, Energy, Health, Hygiene, .....**

  **The challenge is to**

  **Understand, Detect, Anticipate, Predict, Adjust**

  Landscape response to Human + Climate + Tectonics

  And since Landscape has a finite response time we need to be careful TODAY for a better TOMORROW:

  **Geosciences has a huge role**

  **New Disciplines**

  Geomorphodynamics-Geobiology-Ecohydrology-Ecogeomorphology
In India
As of now, this Is NOT in our Dictionary
Quantitative Earth Surface Science: New possibilities

- Remote Sensing: **meter scale – basin scale**
- Wireless sensor-networks: motions in real time
- Global Positioning Systems, mm scale motion
- Sensors to detect Extreme Events
- LIDAR- high resolution topography – DEM, erosion
- Ground Penetrating RADARS for subsurface
- Molecular biology techniques, molecular proxies
- Isotopic methods to track fluxes of water, sediments, air masses
- Geochronological tools: Atom Counting methods/ OSL/TIMS
- Mathematical modeling capabilities

Advise in **REAL TIME**
THE PRESENT AND THE FUTURE
A Profound Transformation of the EARTH SYSTEM has happened and is happening

During the last 50 years,

• the human population has risen from 2 to 7 billion
• economic activity has increased ten-fold
• the connectivity of the human enterprise has risen
• flow of people, information, products and diseases.

This has implied

• Intensification and diversification of land-use
• Advances in technology has led to rapid
• changes in biogeochemical cycles, hydro-logical processes
• landscape dynamics -MODIFIED
World Population Growth Through History

- Old Stone Age
- New Stone Age Commences
- New Stone Age
- Bronze Age
- Iron Age
- Middle Ages
- Modern Age

Billions of people

- 2.5 million years
- 7000 B.C.
- 6000 B.C.
- 5000 B.C.
- 4000 B.C.
- 3000 B.C.
- 2000 B.C.
- 1000 B.C.
- 1 A.D.
- 1000 A.D.
- 2025 A.D.

NUTRITION
HEALTH CARE
Energy Demands: 15 TW
Energy interior to surface: 46 TW
Atmosphere: CO₂ Concentration
- Year: 1750 to 2000
- CO₂ (ppmv): 300 to 360

Atmosphere: N₂O Concentration
- Year: 1750 to 2000
- N₂O (ppbv): 270 to 310

Atmosphere: CH₄ Concentration
- Year: 1750 to 2000
- CH₄ (ppbv): 700 to 1750

Atmosphere: Ozone Depletion
- Year: 1750 to 2000
- % Loss of Total Column Ozone

Climate: Northern Hemisphere Average Surface Temperature
- Year: 1750 to 2000
- Temperature Anomaly (°C)

Climate: Great Floods
- Year: 1750 to 2000
- Decadal Flood Frequency

Ocean Ecosystems
- Year: 1750 to 2000
- % Fisheries Fully Exploited

Coastal Zone: Structure
- Year: 1750 to 2000
- Shrimp Farm Production (Million MT)

Coastal Zone: Biogeochemistry
- Year: 1750 to 2000
- Nitrogen Flux (10² moles year⁻¹)

Terrestrial Ecosystems: Loss of Tropical Rain Forest and Woodland
- Year: 1750 to 2000
- % of 1700 value

Terrestrial Ecosystems: Amount of Domesticated Land
- Year: 1750 to 2000
- % of Total Land Area

Global Biodiversity
- Year: 1750 to 2000
- Species Extinctions (thousand)
We are at cross-roads in human history. Never before in eight million year history of human kind the planet has been subjected to such rapid and profound changes.....

Our knowledge of Earth System is Our insurance policy for the Future of Our planet

K. MAATSURA, DIR. GEN UNESCO
Security from Over-statements such that Variables are not influenced and manipulated thereby making Uncertainties into risks for Economic and strategic considerations:
Strong Geo-science database and Your Own data
The Malthusian Principle

In every State in which Man has existed, or does now exist,

That the increase of population is necessarily limited by the means of subsistence,

That population does invariably increase when the means of subsistence increase, and,

That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, by misery and vice."

An Essay on the Principle of Population
.. Malthus

1766-1834
Thomas Robert Malthus

Can there be a technological fix always ???
Issues in scaling up,

Large Scale production of crops –
large scale mono cultivation –
Increased vulnerability to single isolated pest

Large energy generation –
environmental issues- Nuclear Waste, CO₂

Large Water resources:
Hygiene, Health and Sanitation and
contamination Issues
Public Knowledge and Policy Response

Normal response is only to

Challenges and Problems, that are:

- Visible and Proximal;
- Short term;
- Doable and solvable;
- Likely to lead to social unrest;
- Interesting and important;
- Affects Articulated Elite & Organized Masses
What can Geosciences do?

Geoscience Provides
A Temporal and Spatial perspective to
Change and its cyclicity

Reconstruction of a long term perspective
Geoscience Research

What is happening now

What will happen in 20-50 years

What will be the implications for human survival, migrations, food security, hazard, energy...

Geological records to understand the Natural variability of Earth on which human dimension can be super imposed
Why Paleo-Science

Reconstruction of time series to deduce natural modes of variability

Paleo records provide a context to recent changes

PALEO ANALOGUES

The Hockey Stick

Krishnakumar, 2007
Geo-Science in Societal Needs -1

- **Groundwater** – towards sustainable use
- **Hazards** – minimising risk, maximising awareness
- **Earth & Health** – building a safer environment
- **Climate** – the ‘stone tape’
- **Resources** – towards sustainable use
Geo-Science in Societal Needs -II

- Megacities – going deeper, building safer
- Deep Earth – from crust to core
- Ocean – abyss of time
- Soils – the living skin of the Earth
- Earth & Life – origins of diversity
heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources (NRC, 2001).
The CRITICAL ZONE

The diagram illustrates the critical zone, which is the upper portion of the Earth's crust where weathering processes occur. It is divided into three main sections:

1. **Forcings**
   - Climatic
   - Tectonic

2. **Weathering in the Critical Zone**
   - Physical
   - Biological
   - Chemical

3. **Responses**
   - Hydrologic
   - Atmospheric
   - Soil

The diagram also shows a time scale ranging from microseconds (µs) to millions of years (mil), highlighting the different processes of ion association, multivalent ion hydrolysis, gas-water exchange, ion exchange, sorption, mineral solution, and mineral crystallization.
WATER

Rain fall never fails: + or -20-30% of mean 80cm/year

Potential Evapotranspiration -100-200cm/year: Net Deficit

Agricultural drought/flood ≠ total rain but timing, duration and intensity

Optimal utilization and distribution of water; Use of abandoned channels for surplus water/new storage

Remote Sensing, New aquifers; New sources of fresh waters/Contaminants

Use of technology of Harvesting, Inter Basin Transfer, evaporation loss, Ecology/ movement pathways
Increased population density implies Increased HAZARD
HAZARDS
• Earthquake
• Tsunamis+ Sea Level
• Volcanic
• Deforestation
• Floods
• Landslides
• Forest fires
• Drought
• Nuclear

GEOSCIENCES
• Risk Estimation
• Vulnerability maps
• Micro-zonation
• Economics of mitigation
• Nuclear Site/ waste disposal – geological locales
• Silicosis
• Contamination assessments -As/F /Radioactivity

EARTH PROCESSES RISKING TO HUMAN LIFE : ROCK- TO ASTEROID- FALL
Earth Quakes, Faulting and Deformation processes

The case of spatial Scales: Micro –continental scale:

- Grain friction and asperities, movements of fluids, volatile and material fluxes, strain accumulation, to reverberation of basin, and excitation of tsunamis across continents.
- Is this a chaotic or systematic process; why do we see a return period of about the same time scale - geological records
- How do earth quakes initiate
- What controls branching of rupture/ fault –rupture interlinks
- Ground motions –peak accelerations and velocity, Earthscope
- Tsunami hazard under sea-level change
Large Spatial and Temporal Scales
Why Paleoclimatology matters?

- Late Pleistocene was not simply cold – it was totally chaotic
- Even modern agricultural processes probably couldn’t overcome such variability
## Collapse of Societies in the past
### Gradual vs. Abrupt

<table>
<thead>
<tr>
<th>Natural</th>
<th>Manmade</th>
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</thead>
<tbody>
<tr>
<td>Soil loss= food, floods</td>
<td>Warfare</td>
</tr>
<tr>
<td>Deforestations</td>
<td>Cultural invasion</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>Disease</td>
</tr>
<tr>
<td>Climate –droughts/floods</td>
<td>Over population</td>
</tr>
<tr>
<td>Insects</td>
<td></td>
</tr>
</tbody>
</table>

### Collapse? What Collapse? Societal Change Revisited

Andrew Lawler  
*Science 12 November 2010: 907-909;*  
Old notions about how societies fail are at odds with new data painting a more nuanced, complicated—and possibly hopeful—view of human adaptation to change.
Megacities: Townships Underground

Urban areas > 5M

**New Scale: New Dynamics, New Complexity**

&

**New Simultaneity of events and processes**

High Traffic
Poor Air Quality
Industrial Affluent
Ecological Overload
High water needs
Higher Waste/Sewage
High Energy consumption
Higher Risk to Hazard
**Sub surface townships**

Conflict between

**Sustainable Environment Vs. Sustainable Economic Growth**
Resources: Energy and Raw Material

Petroleum - carbon constrained

Solar: Pure Quartz

Rare Earths: Nb

Gas Hydrates

Tidal
Surprisingly India is not the leader: It's nowhere in this game.
Our Work on Recent Earth History

Luminescence Dating

Spectroscopy and Radiation effects in minerals
Luminescence Dating


- Good reasons for using these:
  - Directly dates landscape features
  - Ubiquitous dating - natural minerals
  - Mineral deposition/formation events
  - Fantastic time range $10^1 - 10^6$ years
  - Inbuilt checks and rigour - Radiation Eff.
  - Precision – 3-5%

Quartz, Feldspars
Gypsum, Carbonates
Bones, Tooth enamel
1970 Alaknanda Flood: 10m sediment at Haridwar, INSA
Attributed to Deforestation in lower Himalaya
Chipko Movement - Emotional but no real Scientific Data
<table>
<thead>
<tr>
<th>Age</th>
<th>H. Himalaya (%)</th>
<th>L. Himalaya (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern</td>
<td>64</td>
<td>36</td>
</tr>
<tr>
<td>1970</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>230±60 y.</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>400±40 y.</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>800±100 y.</td>
<td>52</td>
<td>48</td>
</tr>
<tr>
<td>5000±700 y.</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>9000±1000 y.</td>
<td>78</td>
<td>22</td>
</tr>
</tbody>
</table>
Albedo Changes – Past Atmospheric Circulation trends


Target Constituency – Land use-Land cover / Paleo-GCM / RCM modeling/
Majority of data is by PRL and this data shows that different deserts responded differently. Aeolian dyanamism in Deserts was not synchronous peaking at LGM.

Modified after Lancaster, 2004
Thar:
Not Man made
Contracted
Human Activity Changing Dynamics locally

Implication for Land Use/Land cover Planning
Imprints of climatic change in dryland geomorphic systems

Sediment-climate connection is non trivial-
Thresholds and Response times
Friends,
Spare a Moment
For those millions

WHO
Were born without Hope
Will Live without Hope
Will Go without Hope

Its Our Social Responsibility
To use Science to impact
their lives for the better
Science in Strategic Planning?
Priorities to be India Centric
Reactive vs. Proactive
Anticipation
vs. Post facto instantaneous response- *Jugad*
Mission Mode Geoscience Inputs
Calls for SYNERGY

*If you fail to prepare then, You prepare to fail*
Thanks...

IGC -2020: DELHI

INSA + MoM + MOES + GSI
Geoscientists of subcontinent

Thanks....