1. Introduction

1.1 What is Physical Geology all about?

Physical Geology examines the earth materials, processes, surface morphology, internal structure, evolution, resources and environment.

Visit the URL: http://cs.ndsu.nodak.edu/~slator/htm/PLANET to use "Geology Explorer: Planet Oit Information" being developed at the North Dakota State University.

The subject-matter of these studies includes[1]

- ***Earth and the earth processes***
  - Nature and Scope of Physical Geology (Chapter 1)
  - Earth's Interior (Chapter 2)
  - The Sea Floor (Chapter 3)
  - Plate Tectonics (Chapter 4)
  - Mountain Belts and Continental Crust (Chapter 5)
  - Geological Structures (Chapter 6)

- ***Earth hazards, primary earth materials:***
  - Earthquakes (Chapter 7)
  - Time and geology (Chapter 8)
  - Atoms, Elements, Minerals (Chapter 9)
  - Volcanism and Extrusive Rocks (Chapter 10)
  - Intrusive Activity and Origin of Igneous Rocks (Chapter 11)

- ***Secondary rocks and their formation:***
  - Weathering and Soil formation (Chapter 12)
  - Mass wasting (Chapter 13)
  - Sediments and Sedimentary Rocks (Chapter 14)
  - Metamorphism and the Metamorphic and Hydrothermal Rocks (Chapter 15)

[1] The chapter numbers here refer to those in the textbook: PHYSICAL GEOLOGY: EARTH REVEALED by David McGeary and Charles Plummer (WCB/McGraw-Hill, 2002). You can also explore the companion website of the book's other version (you will need to match the chapter titles here, though, because the sequencing of chapters in the version presented online differs from your video-adapted version) at the URL: http://www.mhhe.com/earthsci/geology/plummer/student.mhtml

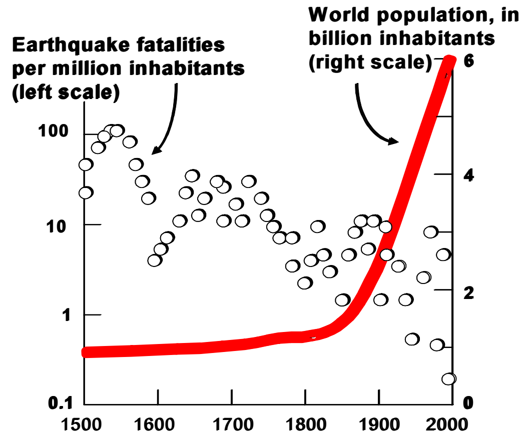
- ***Other surface processes, resources and the environmental issues:***
  - Streams and Landscapes (Chapter 16)
  - Groundwater (Chapter 17)
  - Deserts and Wind Action (Chapter 18)
  - Glaciers and Glaciation (Chapter 19)
  - Waves, beaches and coasts (Chapter 20)
  - Geologic resources (Chapter 21)

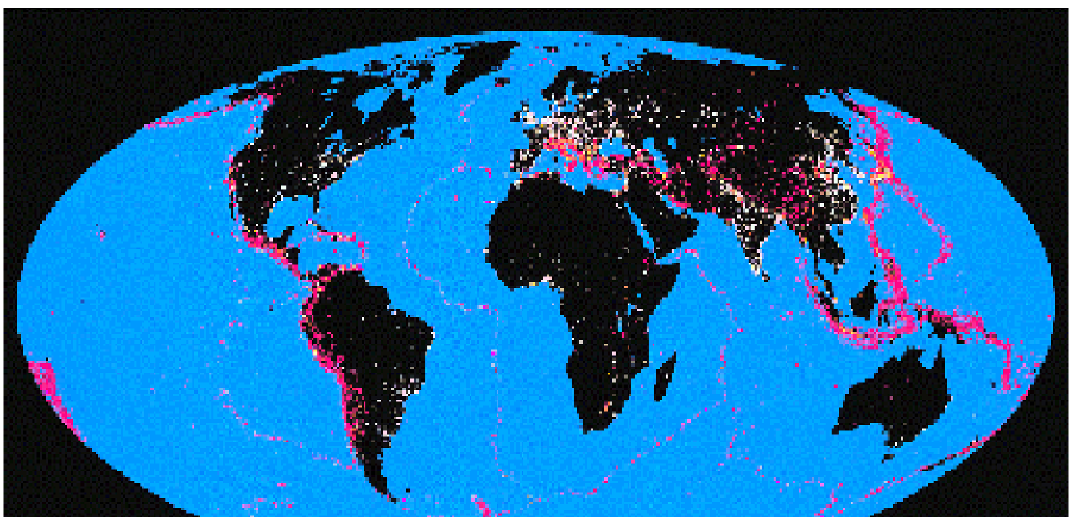
1.2 Current Concerns:

The current concerns in these studies include the following.

- *Earth hazards like earthquakes and volcanism and the processes that govern them*.

Earthquakes are likely to occur just as frequent today, for instance, as they always have through the earth's history. But then, while the world population has been rising exponentially, earthquake fatalities have been actually declining, when normalized for this population growth. A better understanding of where and why these earthquakes and the resulting fatalities occur has



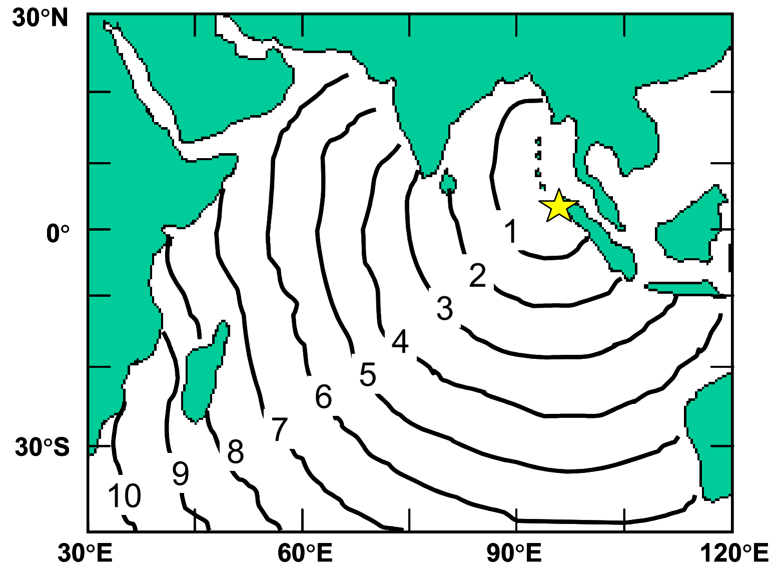


Earthquake epicenters (red dots) and the megacities (white dots)
Source: http://wwwneic.cr.usgs.gov/neis/pANDs/global.htm

clearly helped. This is despite the fact that, as the above map shows, most of the world population lives in the regions that tend to be particularly earthquake-prone.

Much remains to be done as yet, however, judging from the experience of the magnitude 9 "Great" Sumatra earthquake of December 2004 and the Indian Ocean tsunami. This disaster's 200,000-plus fatality count belies the fact that tsunami arrival times are predictable, even though the wave amplitudes are not.

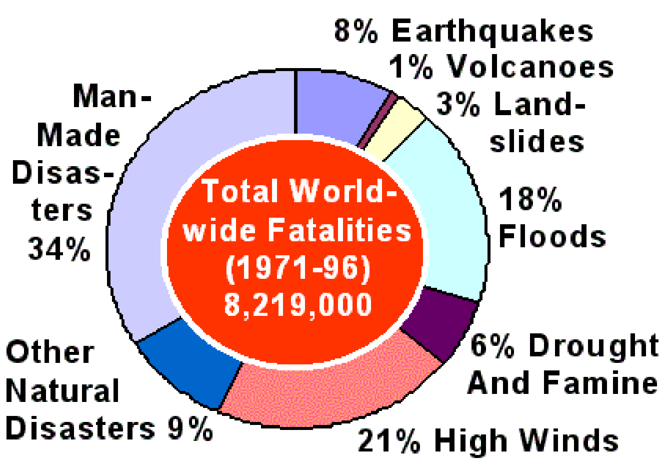
Tsunami arrival times, in hours, from the December 2004 Sumatra earthquake (star denotes the epicenter of the magnitude 9 temblor off Bandar Aceh, Sumatra)



http://staff.aist.go.jp/kenji.satake/Sumatra-E-html

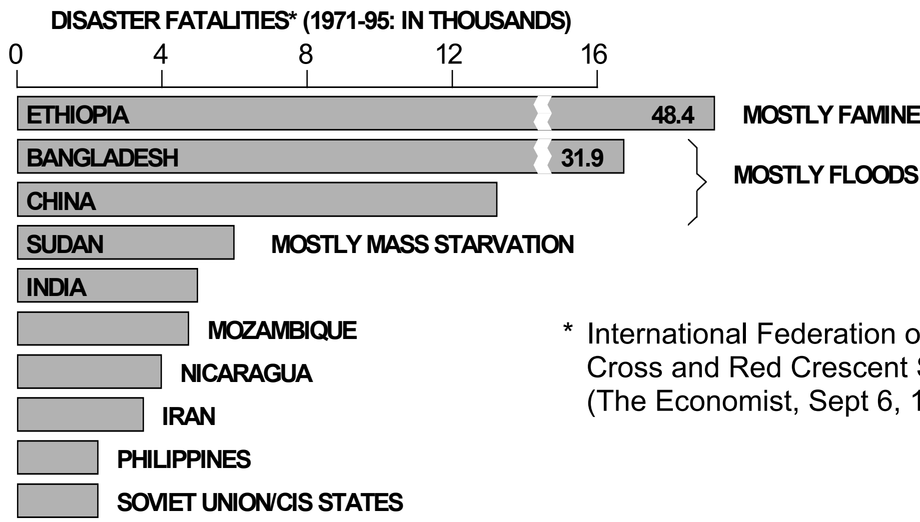
- *The issues like global warming, environmental and/or evolutionary impacts of catastrophic events, waste disposal, coastal habitat etc.*

Earthquakes and volcanism hardly produce calamities on the same scale as those related to climate, however, as the chart below shows. Note that almost one-half of the disaster fatalities worldwide during 1971-96 were related to climate, not to earthquakes and/or volcanic activity that together accounted for barely one-tenth of these fatalities.

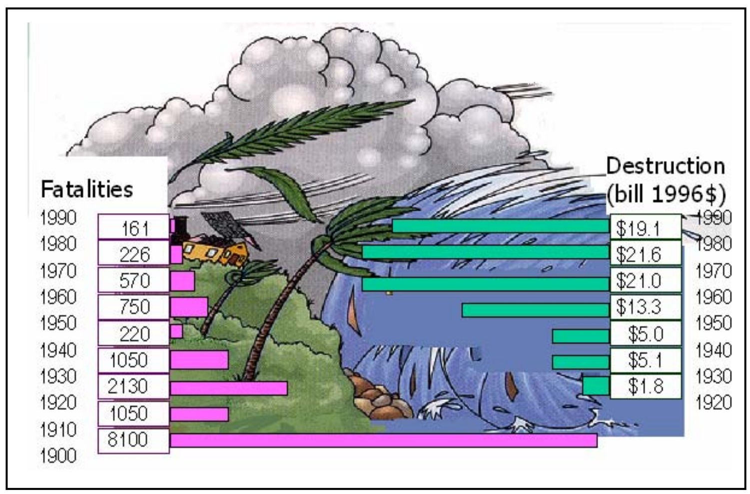


(Source: http://www.economist.com)

Mitigation efforts do substantially lower the fatalities from disasters like floods and hurricanes, at exponentially rising costs though, judging from the 20th century U.S. statistics summarized below. This only worsens the lot of the socio-economically less advantaged countries even more, however, as the chart below clearly shows.



* International Federation of Red Cross and Red Crescent Societies (The Economist, Sept 6, 1997)



The 20th century U.S. hurricane fatalities and destruction

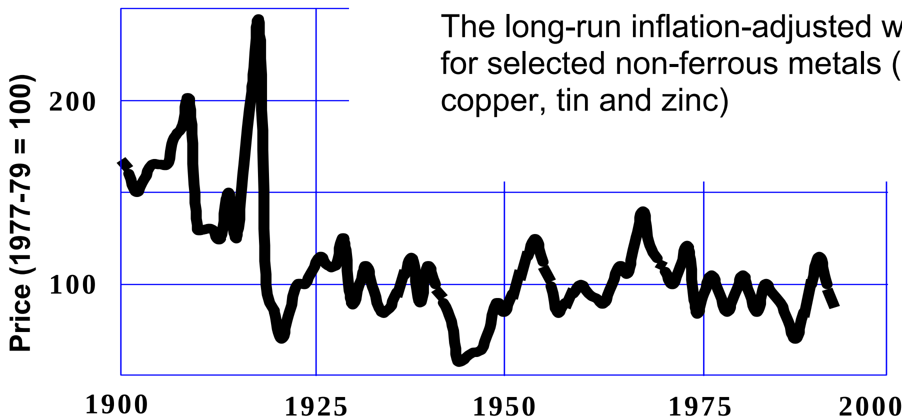
As for the climate related problems, two emerging issues, both associated with global warming, raise particular alarm:

– through the 20th century, precipitation has appreciably declined in the 0º-30ºN latitude band, so hurting farming and raising the prospects of water-wars in the region where most of the world lives; and

– if the melting of polar icecaps weakens Gulf Stream and destroys the Global Conveyor Belt of thermohaline circulation — the two ocean currents that keep Europe warmer than usual — then Europe may abruptly revert to an Ice Age similar to what lasted during 13th through 17th centuries.

■ *The potential exhaustibility of mineral and energy resources.*

The availability and use of mineral and energy resources has defined our economic well being throughout history. Many of these resources tend to be exhaustible, however. In the case of metallic minerals, supply has largely kept pace with the demand for most of the 20th century, thanks to advances in extraction technology. Not surprisingly, therefore, the long-run inflation-adjusted world prices of the nonferrous metals such as aluminum, copper, tin and zinc have only fluctuated since 1920 about their 1977-79 levels. But the recent upsurge in their demand can rapidly alter this scenario.



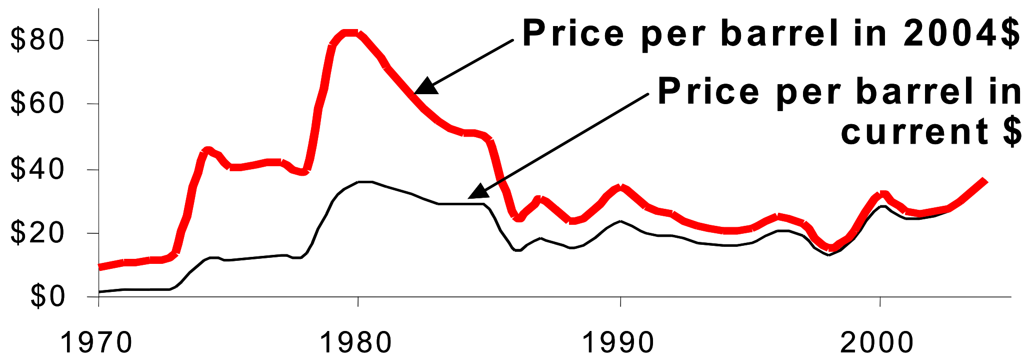
The long-run inflation-adjusted world prices for selected non-ferrous metals (aluminum, copper, tin and zinc)

Energy resources, particularly oil and natural gas, present a far more disconcerting scenario. For instance, recent USGS estimates, tabulated below, suggest that we have already used up about 18% of the world's total oil and natural gas endowment of almost 6 trillion barrels of oil equivalent.

	Current Reserves	Current Consumption	Total Reserves
Petroleum	1.1 TBO	0.028 TBO/yr	3.0 TBO
Natural gas	0.8 TBOE	0.014 TBOE/yr	2.6 TBOE
Total	**1.9 TBOE**	**0.044 TBOE/yr**	**5.6 TBOE**
		Already Consumed:	**1.0 TBOE**

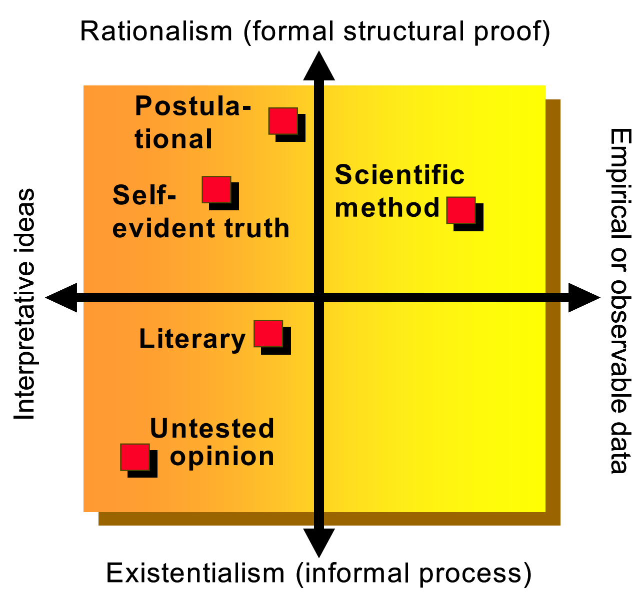
http://www.usgs.gov/public/press/public_affairs/press_releases/pr1183m.html

This does not seem alarming until we realize that, in another 40 years or so, we will be well past the Hubbert peak when one-half of the resource has been used up, and will be then have to contend with poor quality and high extraction costs, even if the worldwide demand rises at a modest 10% annual rate. The graph of world crude oil prices since 1970, in the nominal (or current) as also real or inflation-adjusted U.S. dollars, shown below (http://www.bp.com/ and http://www.eia.doe.gov) is very revealing in this respect. Note the rising trend since 1997-98, raising the ominous prospects of the return of the 1970s.

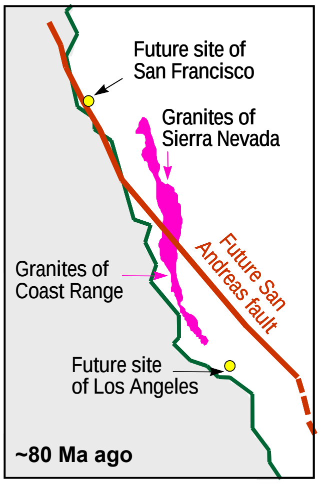


1.3 Geology and the Scientific Approach:

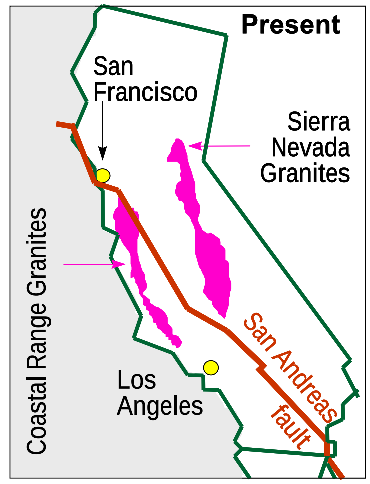
Geology is perhaps the friendliest face of science that we encounter in daily life, whether at work, or at home, or when we visit a National Park! Science is a continuous quest for the basic rules that apply equally all over the universe. Discovering these rules over such a vast single system then becomes a process of rationalizing empirical observations and securing better observations to refine the resulting structural formalism – as the schematic illustration alongside explains, scientific process necessitates amenability to falsification as the basic premise for any model or proposal. How else can the theoretical construct as also the empirical data be examined conjunctively if we are to ascribe finality to either of them as the prelude to any enquiry?



Unlike most other lines of scientific enquiry, considerations of space and time severely limit laboratory modeling of the earth processes, however. This is hardly an insurmountable problem. For instance, the notion that San Andreas Fault is a boundary along which North American plate has slipped by ~560 Km relative to Pacific plate in the past ~80 Ma can be easily disproved by producing incontestable evidence that rocks younger than this age occur adjacent to one another across the fault. What we notice, instead, is that ~24 Ma old volcanics here have been offset by ~330 km.



The off-setting of ~80 Ma old Sierra Nevada granites by the San Andreas Fault. The map on the left is a reconstruction of what these granite outcrops may have been like when they were emplaced while that on the right shows how the block to the west of the Fault has moved north relative to the other block.



Formidable as they sound, these numbers are hardly unverifiable. A kilometer of displacement in a million years simply implies a millimeter of average annual displacement, after all, or a centimeter of displacement over a decade. Therefore, as the above geological data correspond to rates of 7 mm/year for the past ~80 Ma that accelerated to ~11mm/year in the past ~25 Ma, proving these inferences merely requires observing a ~10 cm decadal displacement along this fault, as we indeed do.

Let's Play the Numbers

The off-set or displacement of Sierra Nevada and Coastal Range Granites by the San Andreas Fault = 560 km

Age of these Granites = 80 Ma

Rate of displacement $= \dfrac{560\text{ km}}{80\text{ Ma}} = \dfrac{560\text{x}10^6\text{ mm}}{80\text{x}10^6\text{ year}} = 7\text{ mm/year}$

1.4 Three Basic Assumptions:

The following three assumptions are therefore basic to geological studies.

- *Present is the key to the past, i.e., the geological processes taking shape today are the same as they have always been.*

For instance, limestone is essentially an marine sediment, and forms in the deep ocean bottom by way of precipitation of Calcium Carbonate ($CaCO_3$) or, in the case of shallow coastal seas, from the accumulation of organic debris. Thus, since Mount Annapoorna, the 8,091 m (or 26,545 ft) tall Himalayan peak, is made up of limestones with ~200 Ma (million years) old Ammonite fossils — and ammonites was a deep sea creature — we would conclude that an ocean existed, ~200 Ma ago, at the site where we now have Himalayas, the world's loftiest mountains today, whose rise apparently resulted from the uplift of that deep sea floor.

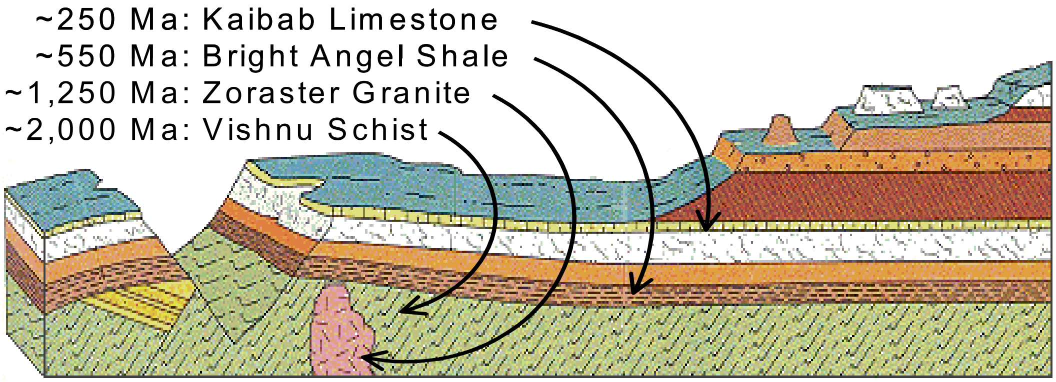
The limestone peak of Mount Annapoorna, the Himalayas.

The presence of ammonite fossils indicates a deep sea habitat.

- *In an undisturbed succession of layers, the one at the bottom is the oldest (this is the principal of superposition of strata).*

A case in point would be the majestic Grand Canyon of Colorado River, a 1.5 km deep, 15 km wide and 450 km long canyon that exposes ~2 Ga (billion years) history of sedimentation, mountain building and erosion. Note that the Paleozoic sediments exposed in the following view of the Canyon are largely horizontal. Now look at their ages, in the geological

section of part of Colorado Plateau from Grand Canyon on the left to Zion seen as buttes towards the right, shown below, and notice how the ~250 Ma old Kaibab Limestones overlie the ~550 Ma old Bright Angel Shales.



- *The principle of cross-cutting relationships, i.e., an intrusive rock is bound to be younger than the rock formations it intrudes.*

The above geological section of the Grand Canyon also has an excellent example of this common sense principle and its use. Notice how the ~1.25 Ga old Zoraster Granite has cut across the older, ~2 Ga old, Vishnu Schist formation but not into the younger Bright Angel Shales.

Another example of this is the famous Ship Rock in New Mexico. Shown below, this is a volcanic neck that now rises 420 meters above the desert floor in the 30-35 Ma old Navajo Volcanic field.