CH2356 Energy Engineering

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Geothermal Energy

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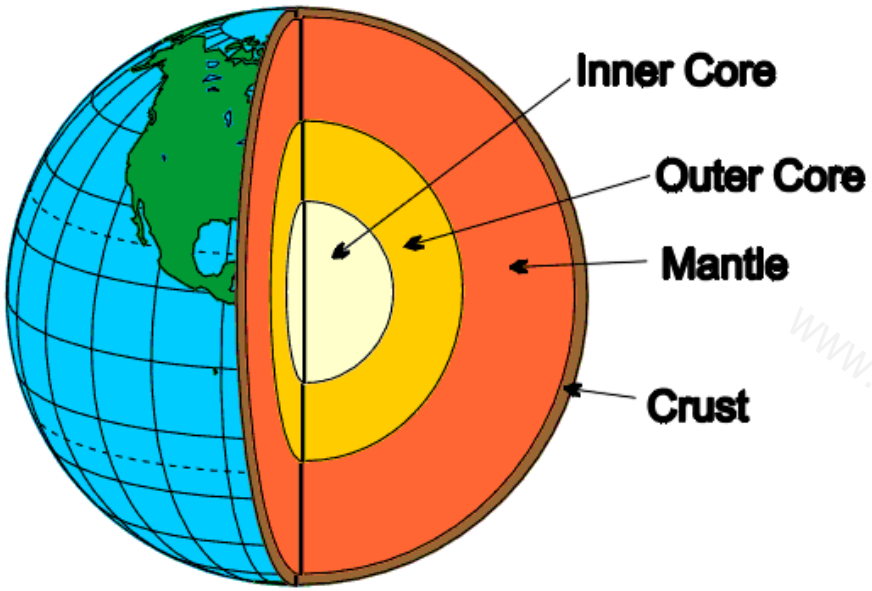
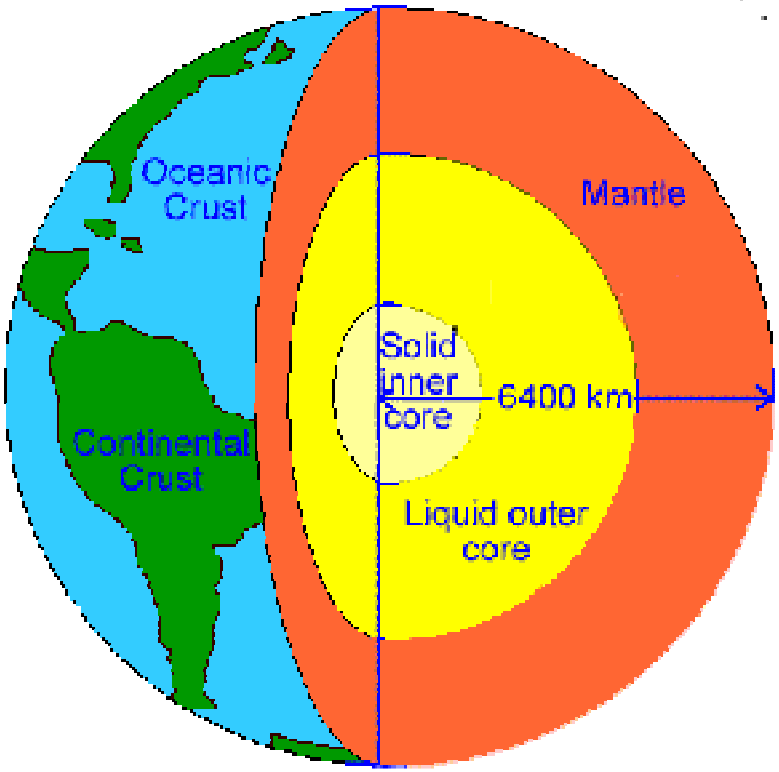
Structure of Earth



- The crust is solid rock.
- The mantle is liquid rock ("liquid hot magma").
- The outer core is liquid nickel and iron.
- The inner core is solid nickel and iron.

Structure of Earth



- The **crust** is very thin (average 20 km). The thinnest parts are under the oceans (OCEANIC CRUST) and go to a depth of roughly 10 kilometres. The thickest parts are the continents (CONTINENTAL CRUST) which extend down to 35 kilometres on average.

- The **mantle** is the layer beneath the crust which extends about half way to the centre It's made of rock that behaves like an extremely viscous liquid. The convection currents of the heat energy from centre of the Earth are what drive the movement of the tectonic plates.

Introduction

- The earth's interior is subdivided into a crystalline inner core, molten outer core, mantle, and crust. Basalt, a dark volcanic rock, exists in a semi-molten state at the surface of the mantle just beneath the crust.

- Drilling in the earth's crust has shown that the temperature of the crust tends to increase linearly with depth. The interior of the earth is much hotter than the crust.

- The source of heat energy is radioactive decay, and the crust of the earth acts as a thermal insulator to prevent heat from escaping into space.

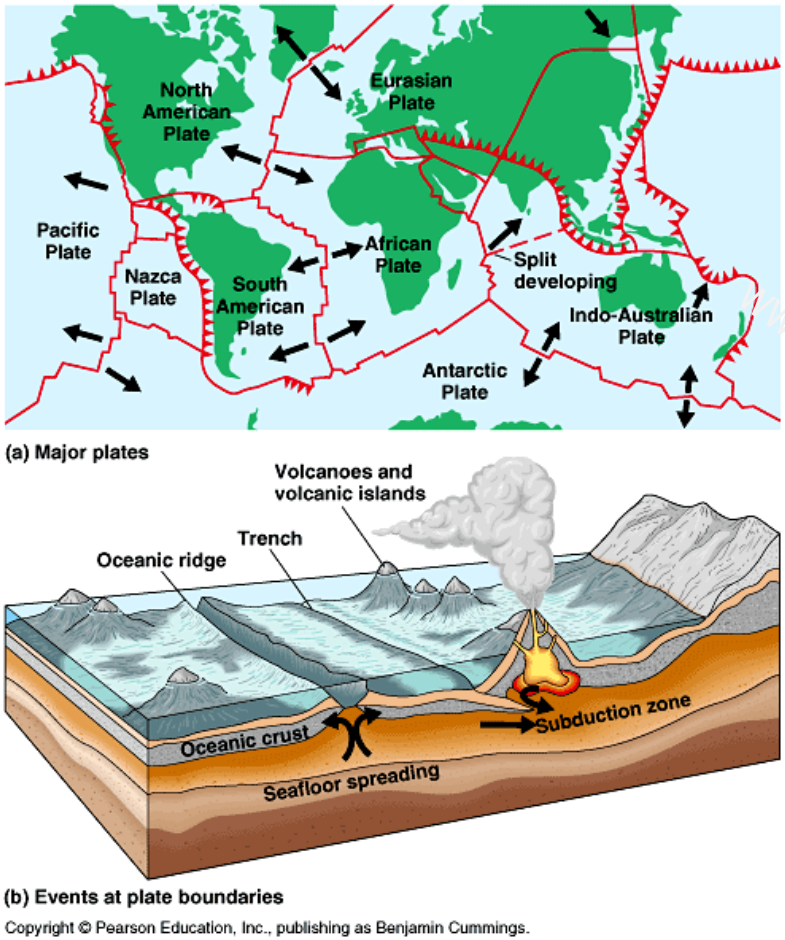
Introduction (contd.)

- Earth's core temperature is estimated by most geologists to be around 5,000◦ to 7,000◦C. For reference, that is nearly as hot as the surface of the sun (although, substantially cooler than the sun's interior).

- Within the crust there is an outward flow of heat from the earth's interior of approximately 50 mW/m^2 which is accompanied by a temperature gradient of about **30 K/km**.

- The most economical sites at which to develop geothermal energy are those where the subsurface temperatures are highest and underground water and steam deposits are closest to the surface. Such sites are found mostly at the borders of the earth's tectonic plates, near active or recently inactive volcanos, hot springs, or geysers.

Tectonic Plates



- The crust of the Earth is made up of various plates of various sizes, that all "float" on the liquid mantle.
- This movement of the plates is what causes most volcanoes, earthquakes, mountain building.

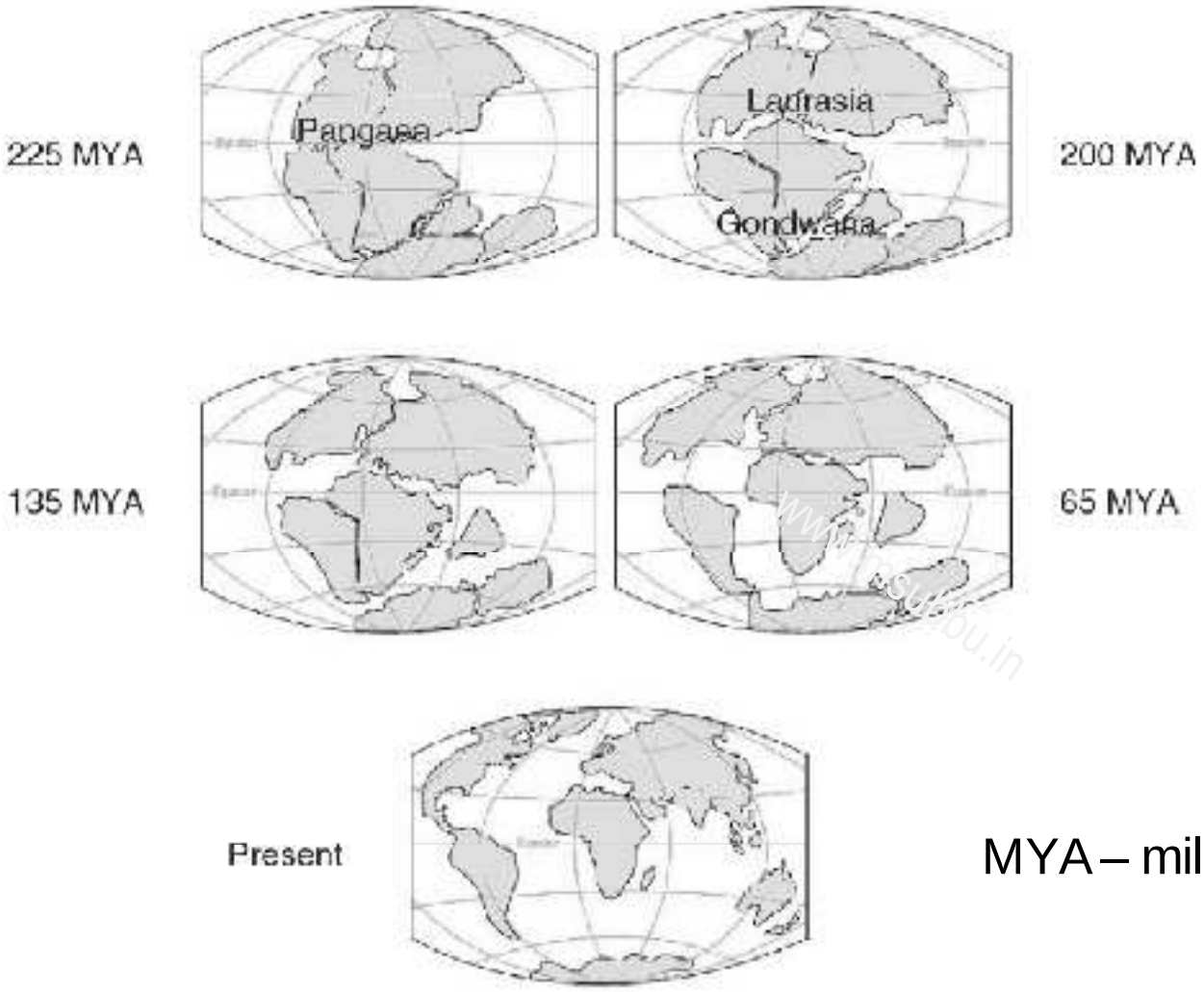


Figure 4-6. Tectonic plate movement [after USGS website, 2001].

In the theory of plate tectonics, the entire crust of the earth is seen as a giant, ever-shifting jigsaw puzzle. The pieces of the puzzle are tectonic plates.

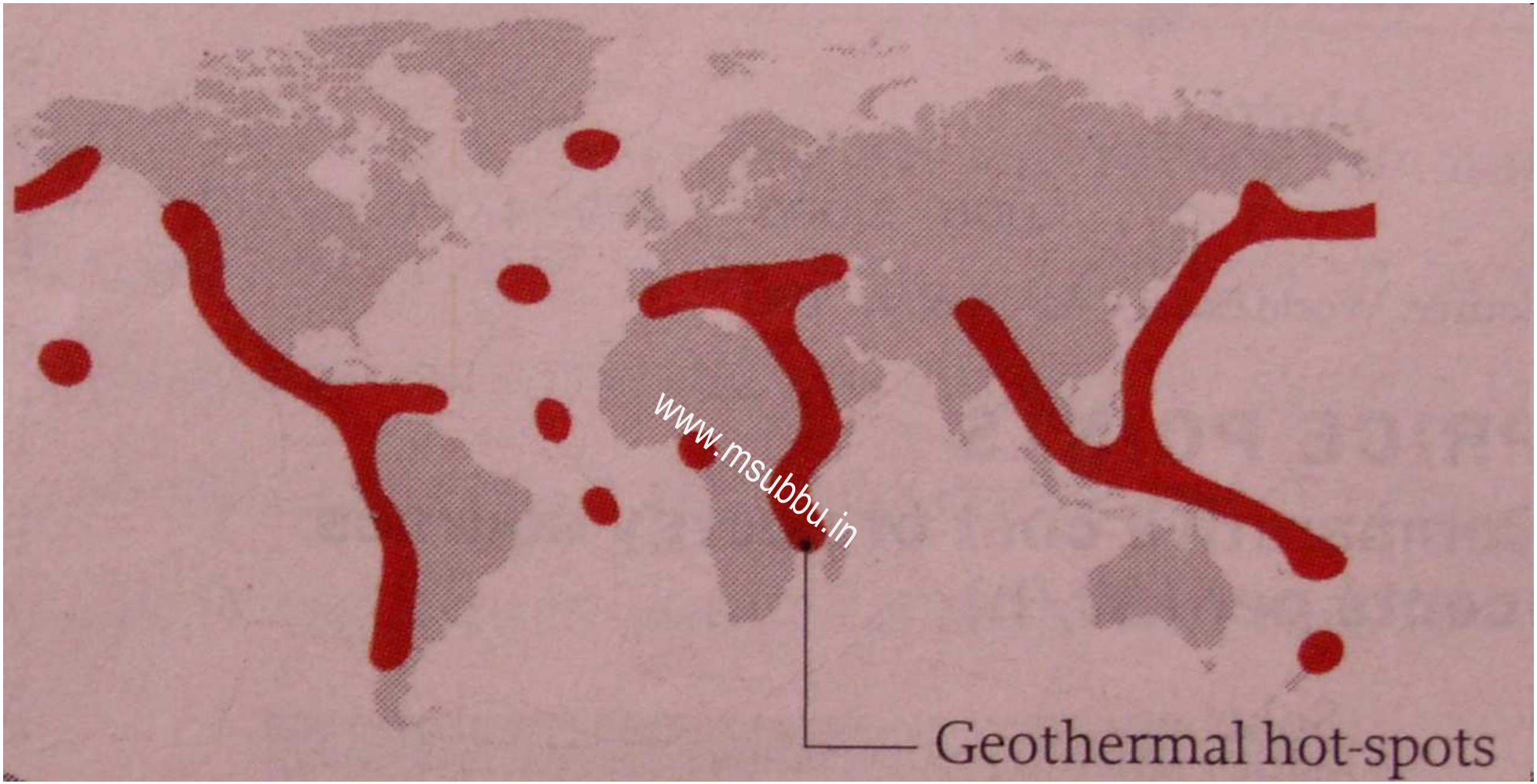
MYA – million years ago

Global Potential

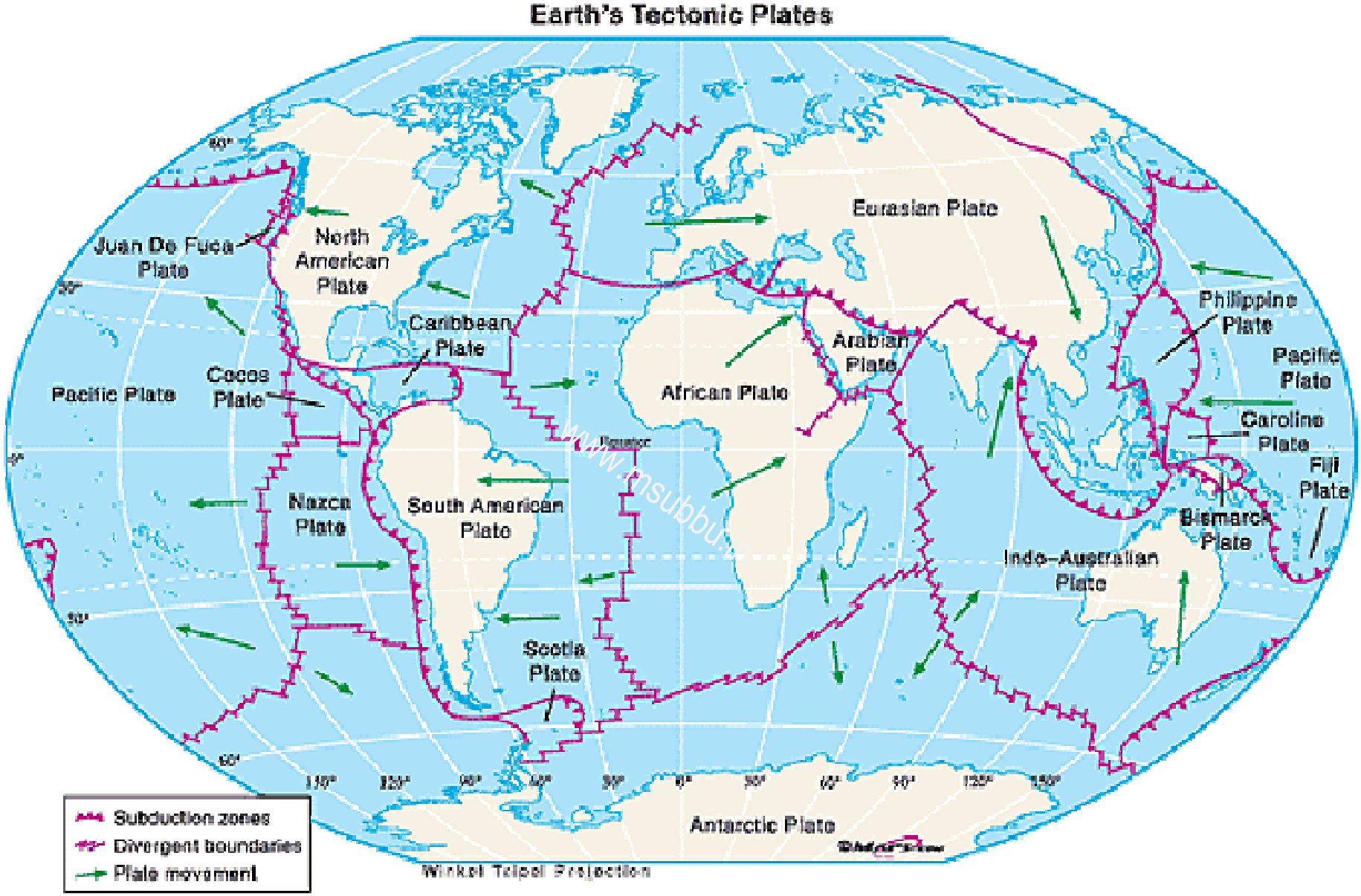
- Estimates of the electricity generating potential of geothermal energy vary six–fold, from 0.035 to 2 TW depending on the scale of investments.

- Upper estimates of geothermal resources assume enhanced geothermal wells as deep as 10 kilometres, whereas existing geothermal wells are rarely more than 3 kilometres deep.

- Geothermal power is too diffuse - approximately **0.1 W/m²** on average



Most of the high enthalpy geothermal resources of the world are within the seismic belts associated with zones of crustal weakness such as plate margins and centres of volcanic activity.



Geothermal Hotspots

- The areas in the world with the highest underground temperatures are regions with active volcanoes or geologically young (under 1 million years) volcanic events. These “hot spots” occur at tectonic plate boundaries or where the earth’s crust is thin enough to let the heat through.

- The Pacific Rim, with its many active volcanoes, has many hot spots, along with Alaska, Hawaii, and much of the western United States. These regions are also seismically active with earthquakes and magma movement, which breaks up rock structures and allows water to circulate. As the water rises to the surface, natural hot springs and geysers occur.

Geothermal Energy - Status

- The largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California, United States.
- As of 2004, five countries (El Salvador, Kenya, Philippines, Iceland, and Costa Rica) generate more than 15% of their electricity from geothermal sources.
- Worldwide, geothermal plants have the capacity to generate about 10 GW as of 2007, growing annually by 3%
- More than half of the geothermal energy is used for space heating, and another for one third for heated pools. The remainder supports industrial and agricultural applications.
- India has a geothermal potential of 10 GW

Location of Geothermal Power Sites, 2005

TOTALS Installed 2000: 7,974 MWe, and 2004: 8,912 MWe (Generated 56,798 GWh/y)

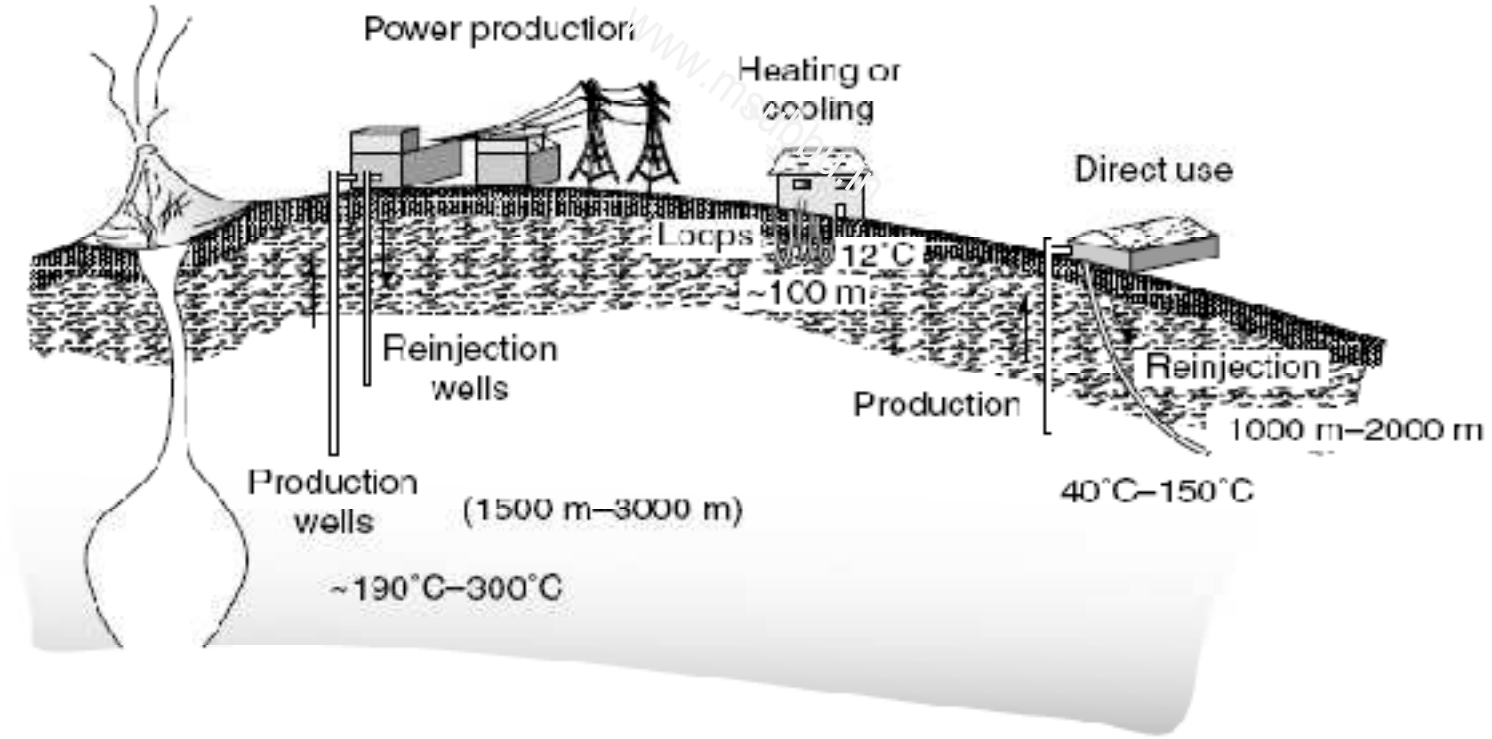
MWe – Megawatt electrical energy

Current worldwide installed capacity is 10,715 MW, with the largest capacity in the United States (3,086 MW), Philippines, and Indonesia.

Conversion of Geothermal Energy

Geothermal power uses the heat of magma below the Earth's crust, which comes from radioactive decay

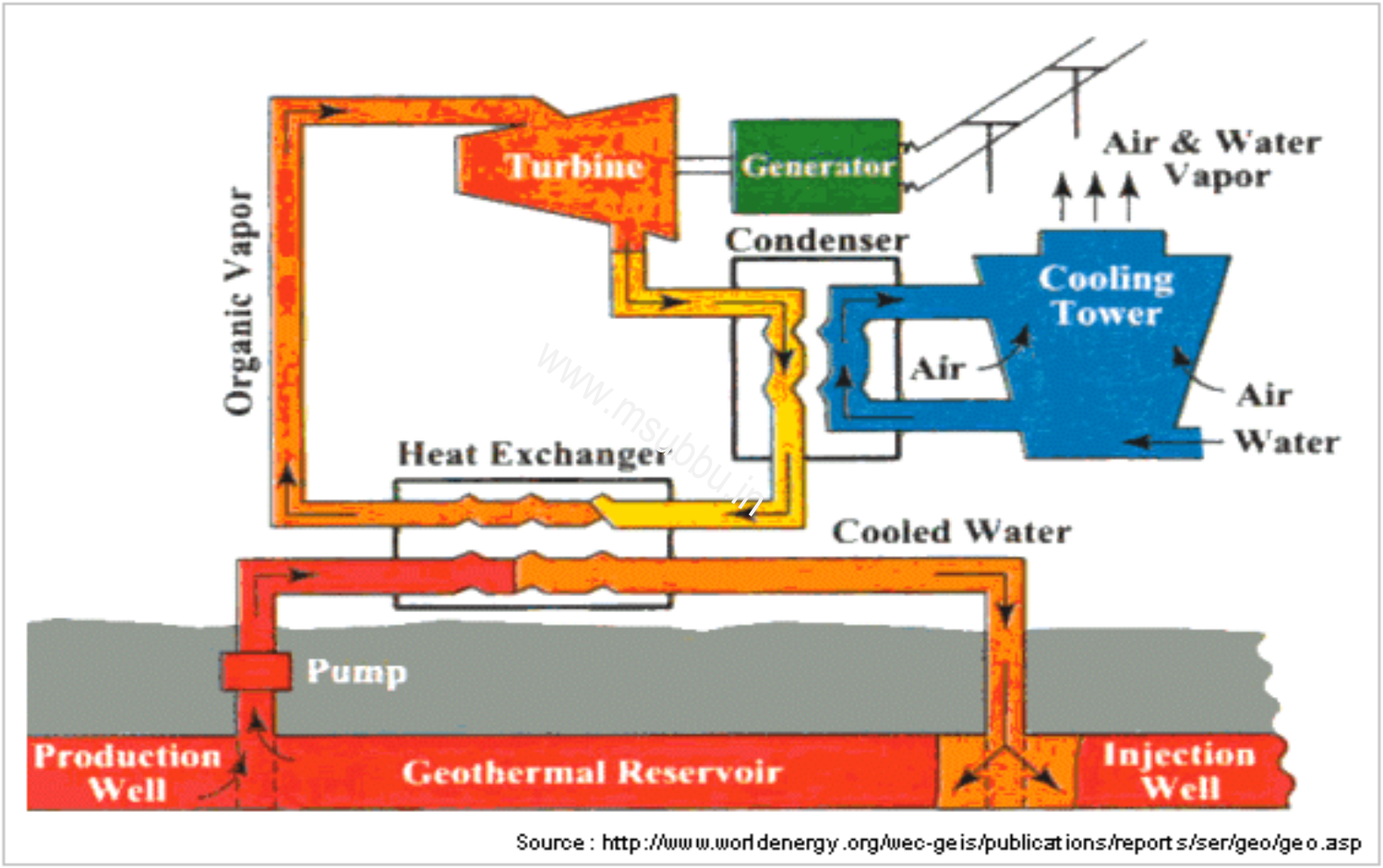
- Direct use
- Electricity generation
- Geothermal heat pumps



Electricity Generation

- Geothermal electric power generation generally uses higher-temperature geothermal resources (above 110◦C)
  - Vapor dominated sources – direct steam conversion
  - Liquid dominated sources – to separate steam from the geothermal fluid
  - Low quality resources – using binary power plant

Schematic of binary cycle geothermal power plant



Source : http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp

Electricity Generation (contd.)

- Electricity generation requires high temperature resources that can only come from deep underground. The heat must be carried to the surface by fluid circulation, either through magma conduits, hot springs, hydrothermal circulation, oil wells, drilled water wells, or a combination of these.

- Away from tectonic plate boundaries the geothermal gradient is 25-30°C per km of depth in most of the world, and wells would have to be several kilometers deep to permit electricity generation.

- The quantity and quality of recoverable resources improves with drilling depth and proximity to tectonic plate boundaries.

Electricity Generation (contd.)

- The thermal efficiency of geothermal electric plants is low, around 10-23%, because geothermal fluids do not reach the high temperatures of steam from boilers.

- Because geothermal power does not rely on variable sources of energy, unlike, for example, wind or solar, its capacity factor can be quite large – up to 96% has been demonstrated. The global average was 73% in 2005.

Geothermal Heat Pump

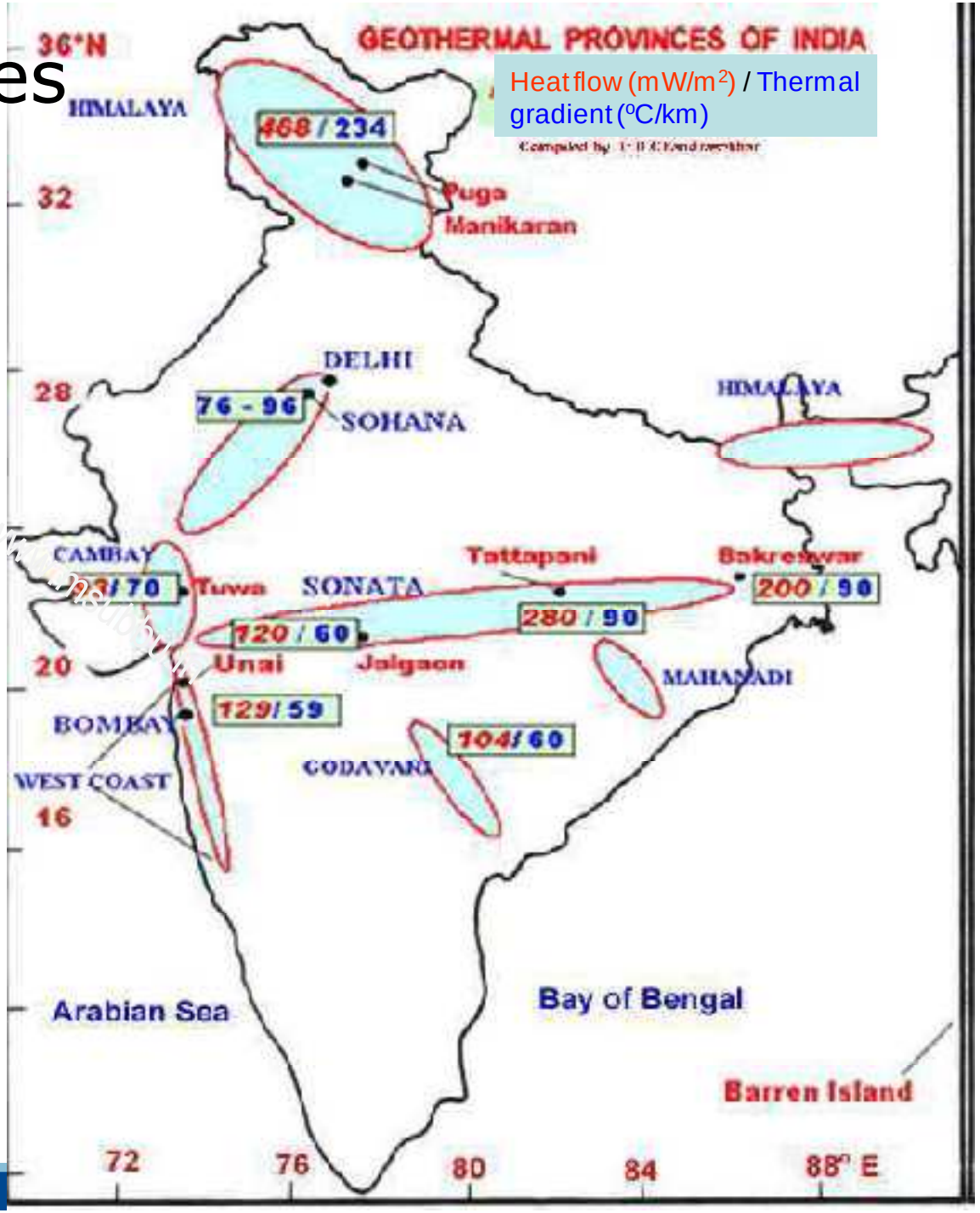
- The GHP energy-conversion process works much like a refrigerator, except that it is reversible, that is, the GHP can move heat either into the earth for cooling or out of the earth for heating, depending on whether it is summer or winter.

- GHP can be used instead of or in addition to direct uses of geothermal energy for space or industrial process heating (or cooling), but the shallow resource used by

- GHP is available essentially anywhere, constrained principally by land use and economics, especially initial installation costs.

Geothermal Provinces of India

- Indian has 400 medium to high enthalpy geothermal springs, clustered in seven province as shown in Figure.
- The most promising provinces are
  - i) Himalaya,
  - ii) Sohana,
  - iii) Cambay,
  - iv) Son-Narmada-Tapi (SONATA)
  - v) Godavari.
- With the recent volcanic eruption, the Barren island, a part of the Andaman-Nicobar chain of islands, is added to the above list.
- Most of them are liquid dominated systems with one or two having both liquid and gas dominated systems.



Manikaran Geothermal Plant in Himalaya

- The first and the last (!) pilot binary 5 kW power plant using R113 binary fluid was successfully operated by the Geological Survey of India at Manikaran which proved the power producing capability of this province.

Environmental Impacts

- Fluids drawn from the deep earth carry a mixture of gases, notably carbon dioxide (CO_2) and hydrogen sulfide (H_2S). These pollutants contribute to global warming, acid rain, and noxious smells.
- Existing geothermal electric plants emit an average of 122 kg of CO_2 per megawatt-hour (MWh) of electricity, a small fraction of the emission intensity of conventional fossil fuel plants
- In addition to dissolved gases, hot water from geothermal sources may contain trace amounts of dangerous elements such as mercury, arsenic, and antimony which, if dumped into rivers, is hazardous.
- Plant construction can adversely affect land stability. (subsidence and earthquake)

Sustainability

- Geothermal power is considered to be sustainable because the heat extraction is small compared to the Earth's heat content, but extraction must still be monitored to avoid local depletion.

- Although geothermal sites are capable of providing heat for many decades, individual wells may cool down or run out of water.