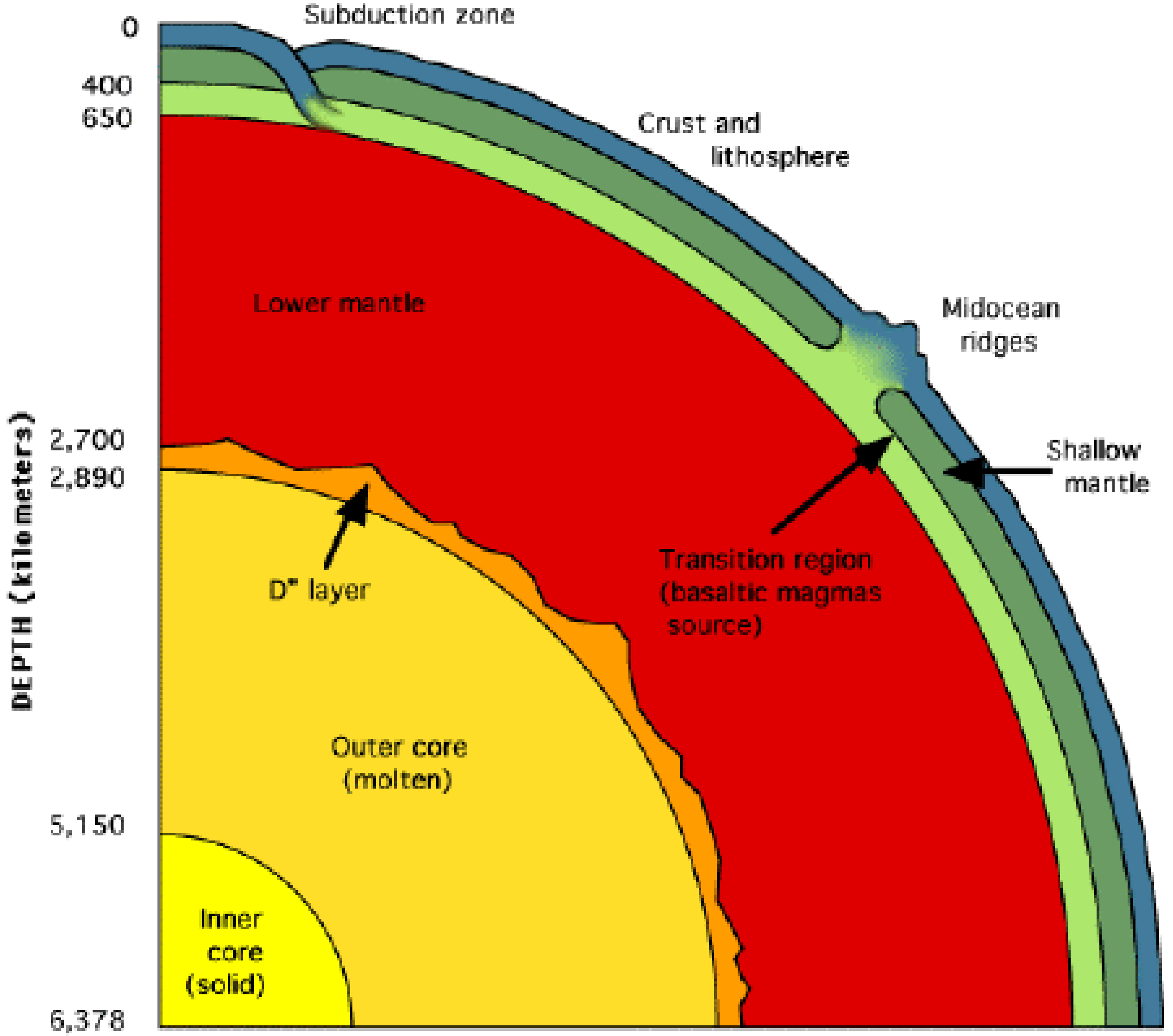
Geothermal energy

Thermal energy is constantly generated in the Earth interior by the decay of radioactive nuclei.

The heat content of the Earth is 10^{31} Joules. This heat naturally flows up to the surface by conduction at a rate of 45 TW, or three times the rate of human consumption from all primary energy sources. However, the bulk of this natural flow is too geographically diffuse (0.1 W/m^2 on average) to be recoverable.



Current global usage of energy is about 5×10^{20} J/year. So, a small fraction of the Earth's total heat capacity would satisfy our needs for many millennia.
However, the problem is HOW to use this bonanza!

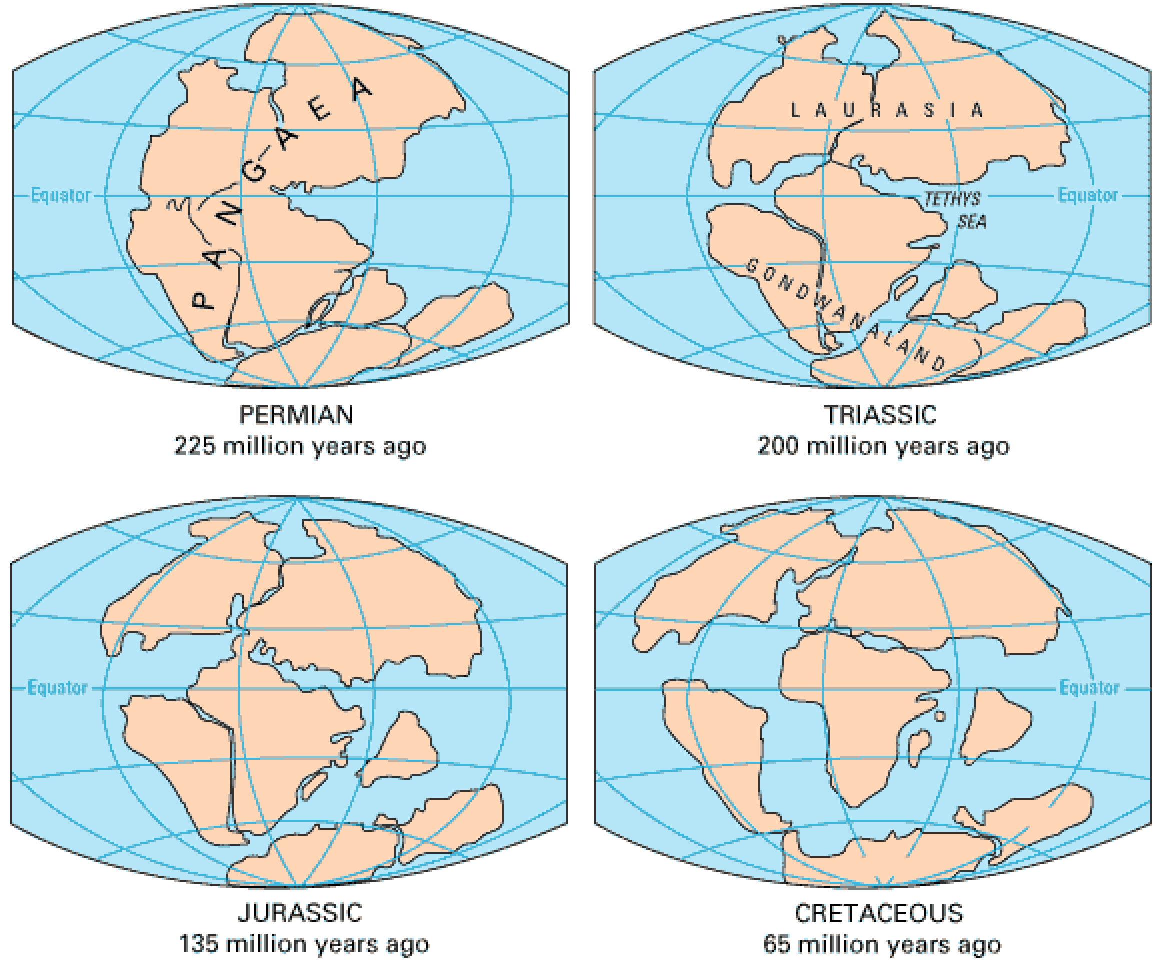
So, not much heat diffuses "by itself" to the Earth surface <u>per average.</u>

So, how to harness the geothermal energy to be our servant?
<u>Easy way:</u> there are some areas where the geothermal activity is much higher than average – where there are hot sources, steam sources, geysers, or lava streams. In such places geothermal energy can be readily utilized.

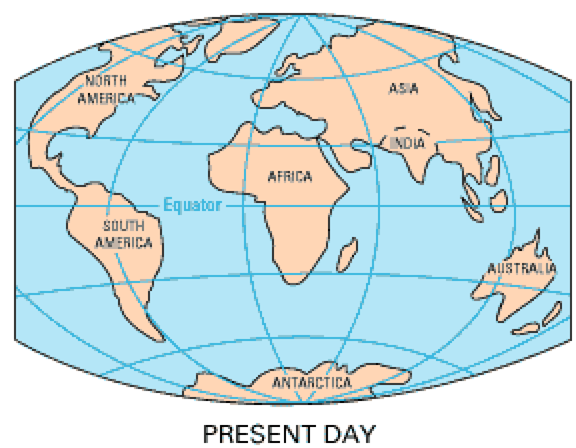
<u>Less easy way:</u> In other locations, geothermal energy has to be <u>mined</u>. Almost everywhere on Earth the *geothermal gradient* – i.e., the rate of temperature increase with the depth under the Earth surface – has a similar value of ~ 30 ºC /km. So, by drilling a 5 km well one can have very hot water! (150 ºC, or 300 ºF).

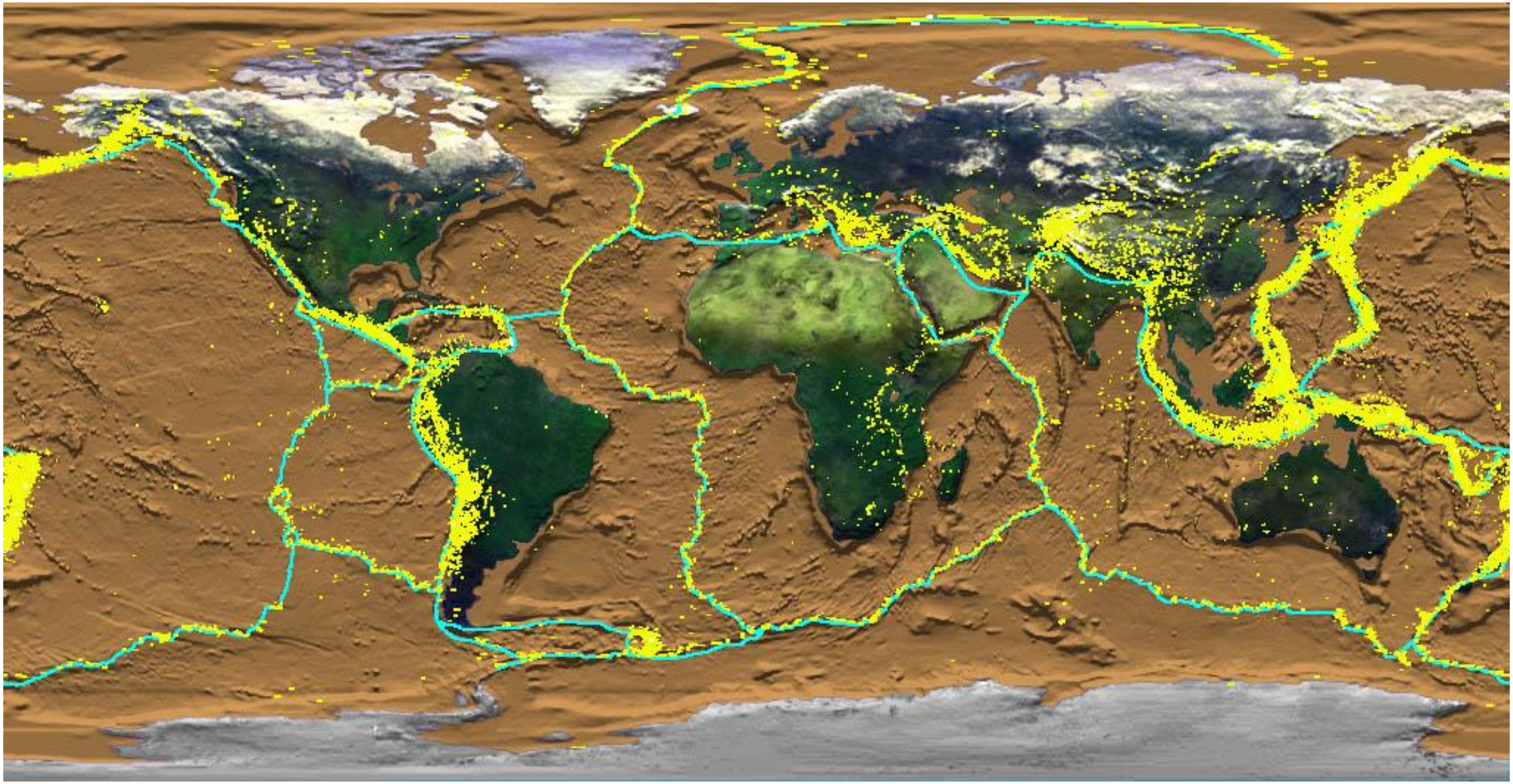
Let's begin with the "easy" geothermal energy – we have to tell the story of Earth's continents, and tectonic plates.

There are several major tectonic plates that are in constant motion relative to one another.



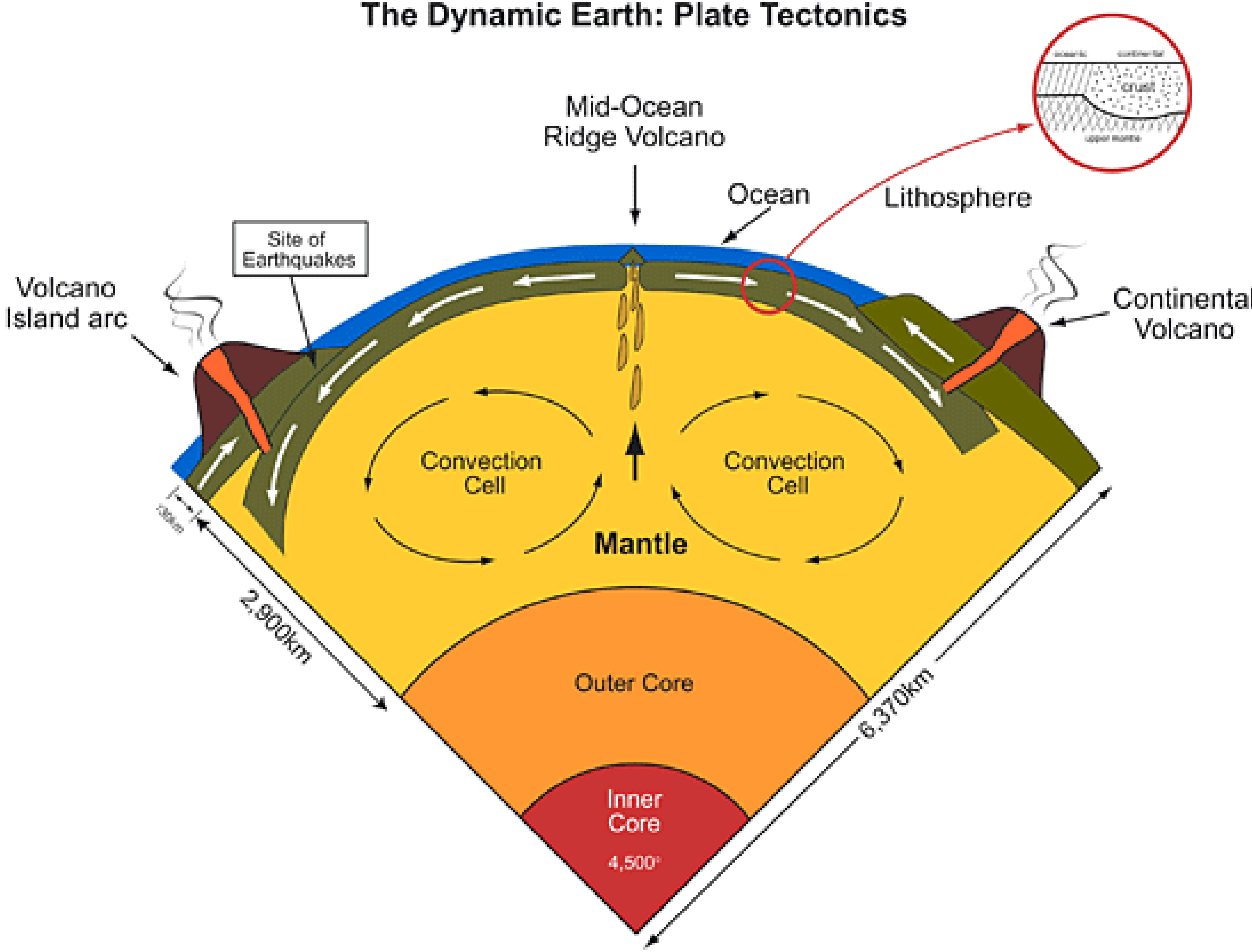
Where they meet, there are "gaps" through which hot magma can get close to the surface.





Tectonic plate boundaries; they are the regions where most earthquakes occur (quakes recorded in history are shown by yellow dots).

The Dynamic Earth: Plate Tectonics



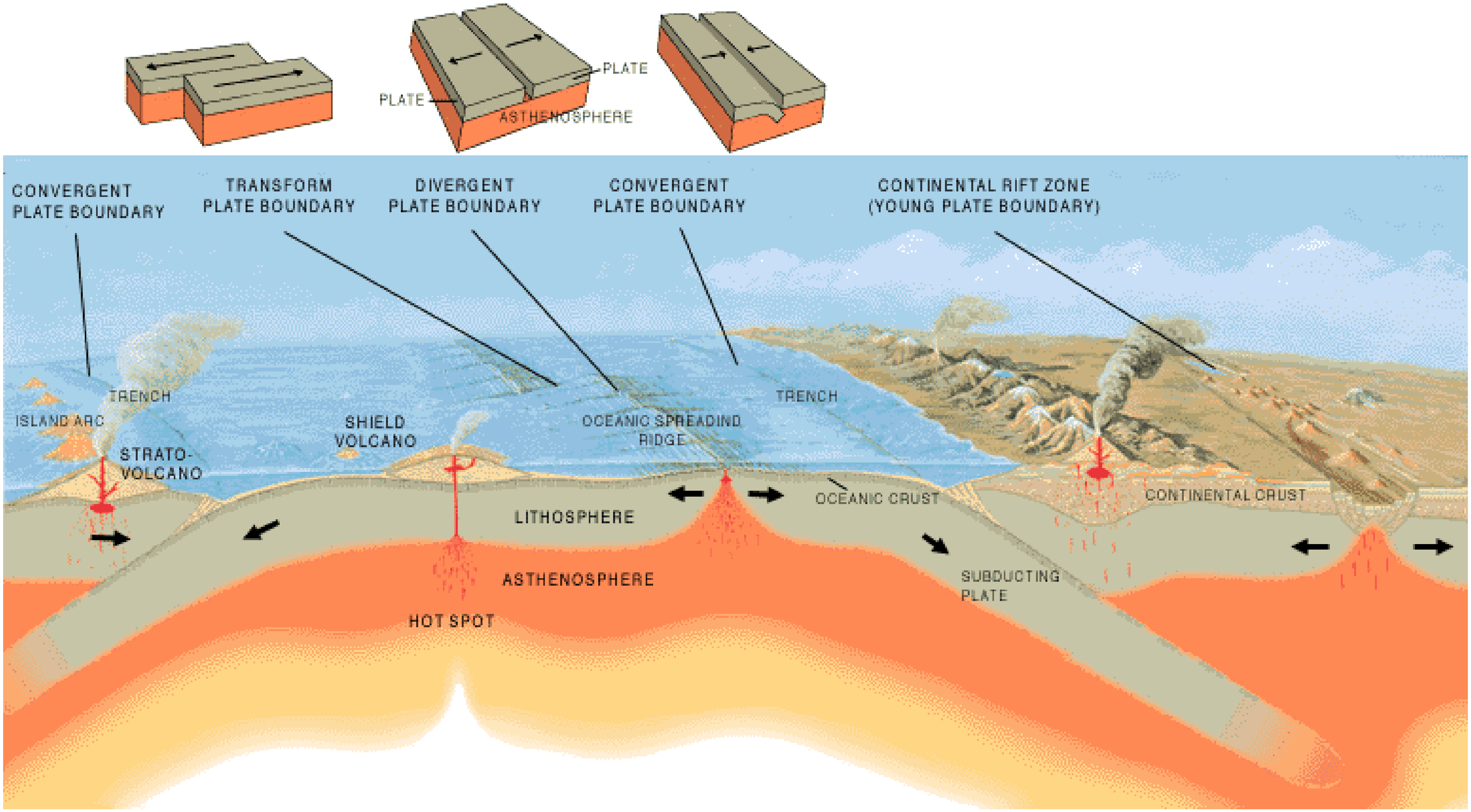
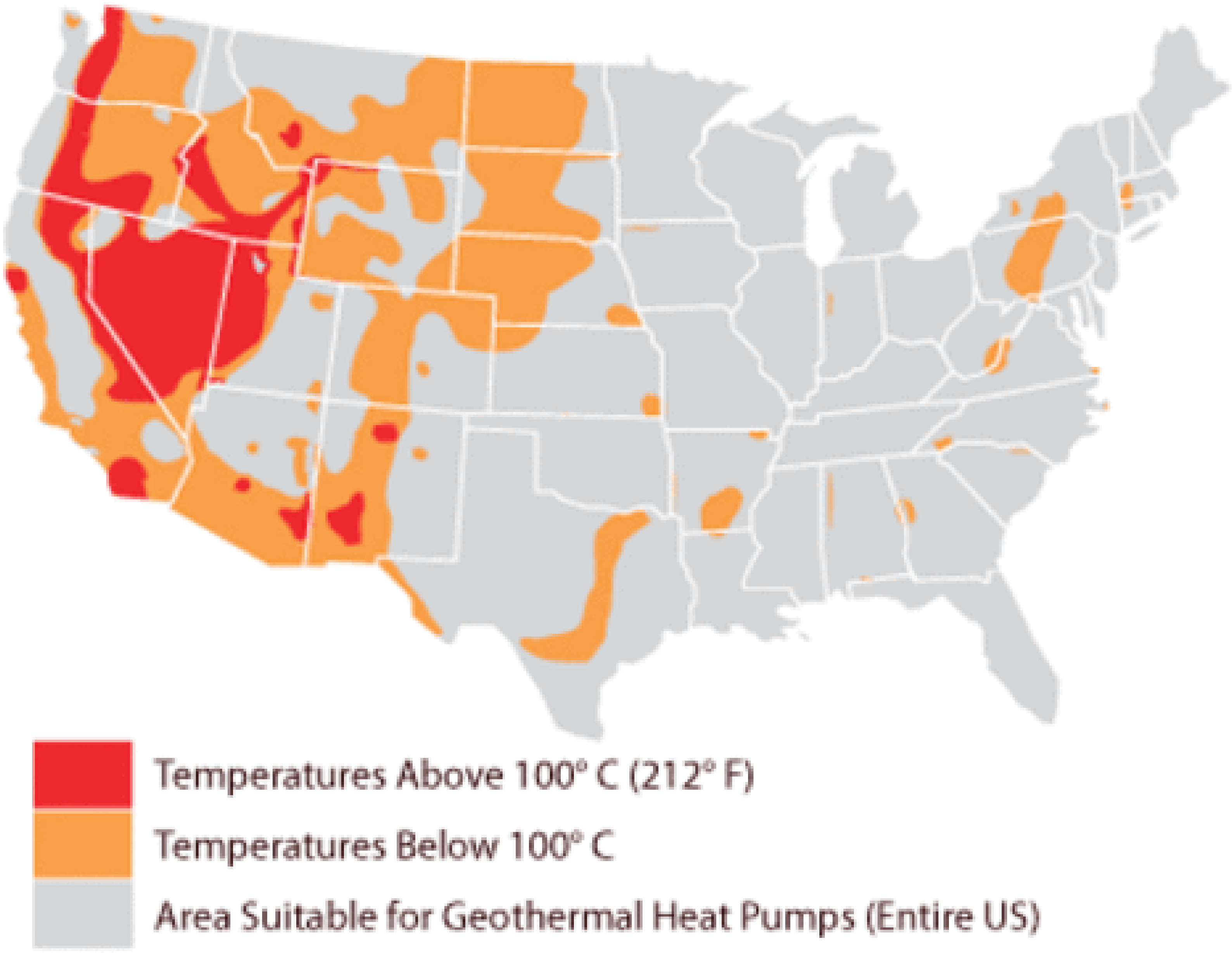
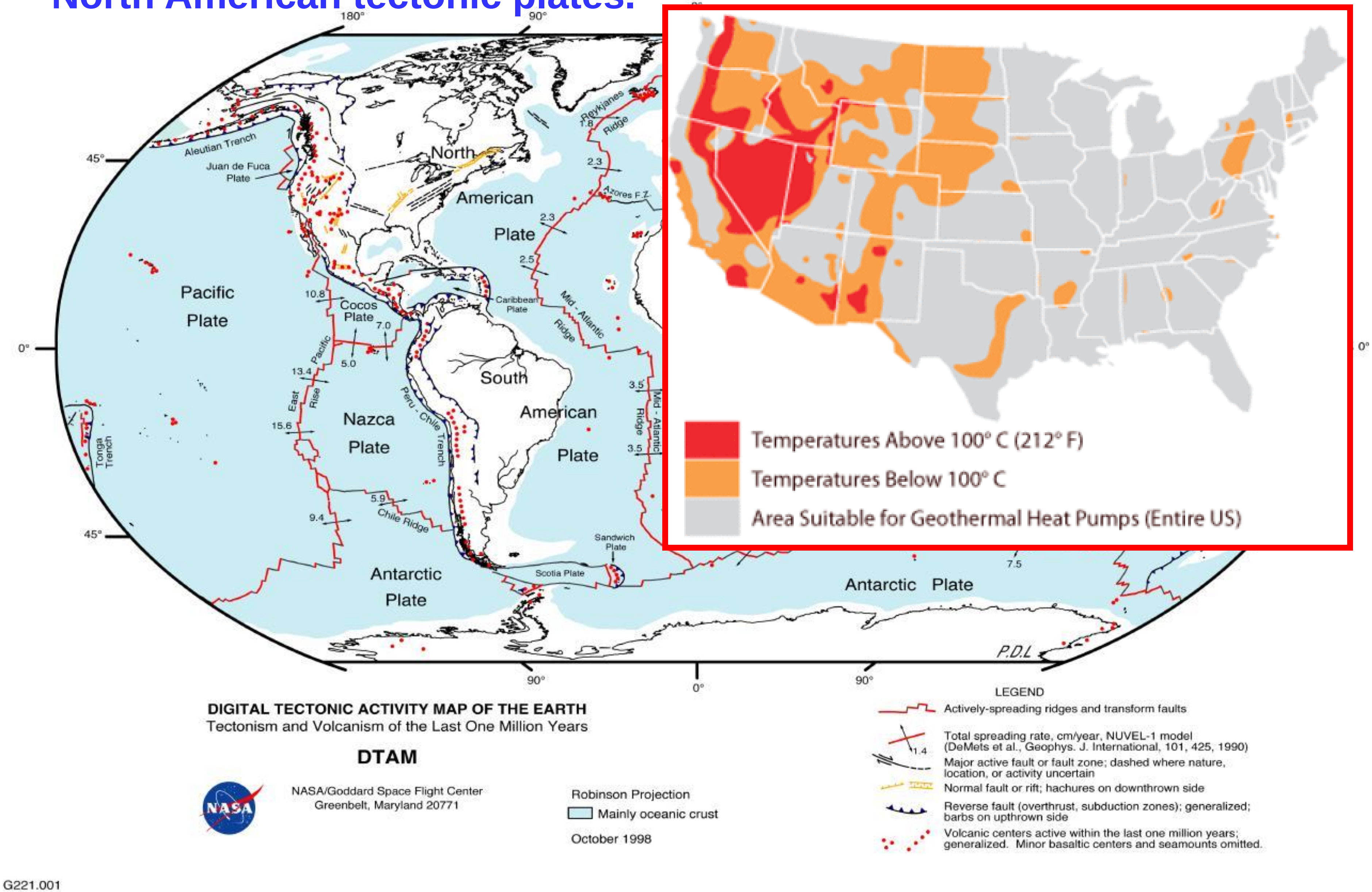


PLATE
PLATE
ASTHENOSPHERE
CONVERGENT
PLATE BOUNDARY
TRANSFORM
PLATE BOUNDARY
DIVERGENT
PLATE BOUNDARY
CONVERGENT
PLATE BOUNDARY
CONTINENTAL RIFT ZONE
(YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-
VOLCANO
SHIELD
VOLCANO
OCEANIC SPREADING
RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING
PLATE

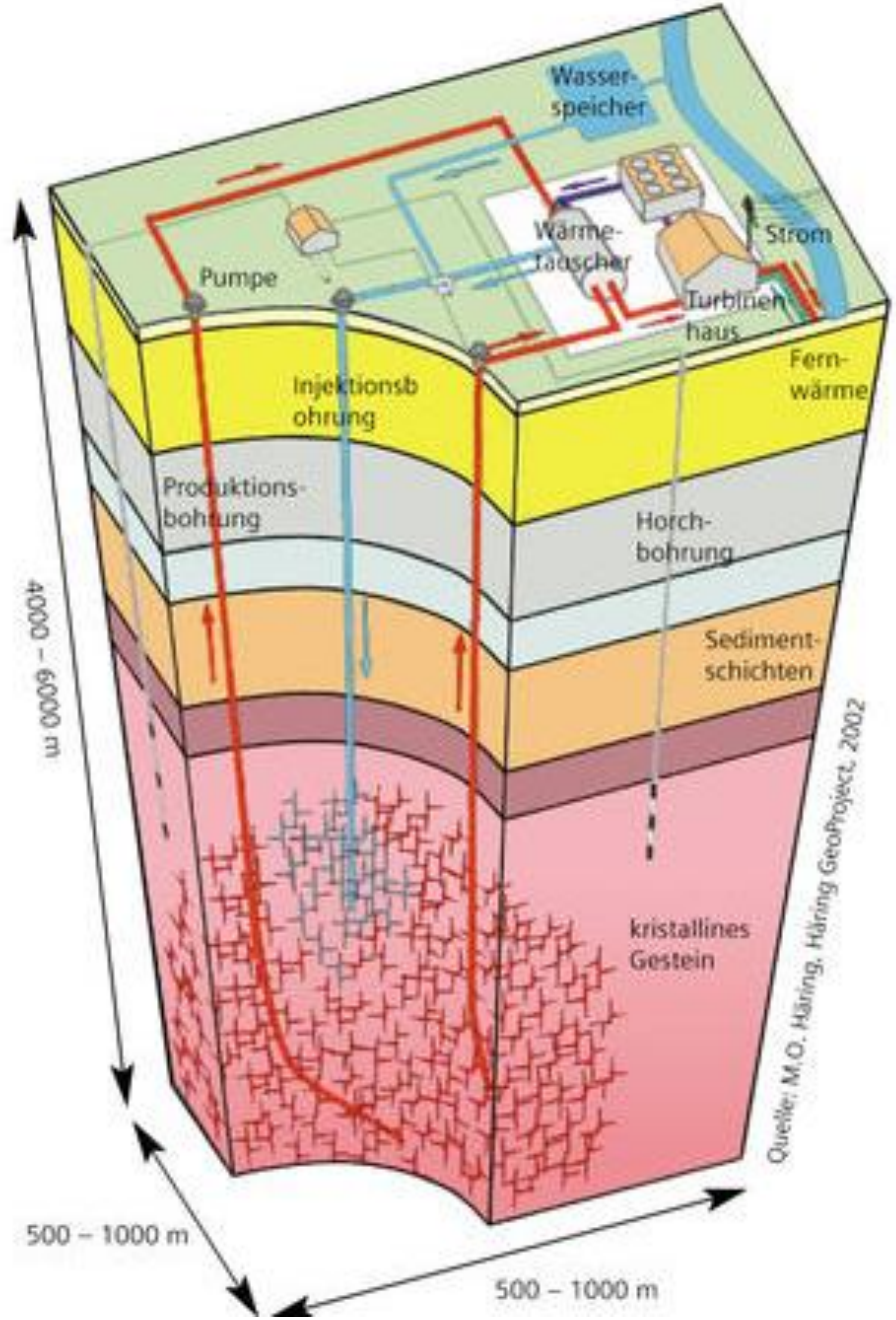

Temperatures Above 100° C (212° F)
Temperatures Below 100° C
Area Suitable for Geothermal Heat Pumps (Entire US)

Note that the areas most favorable for geothermal energy exploatation are those close to the boundary between the Pacific and the North American tectonic plates.



But how to make electricity? Here is a proof that it can be done – the Nesjavellir geothermal power plant, the largest in Iceland (140 MW)

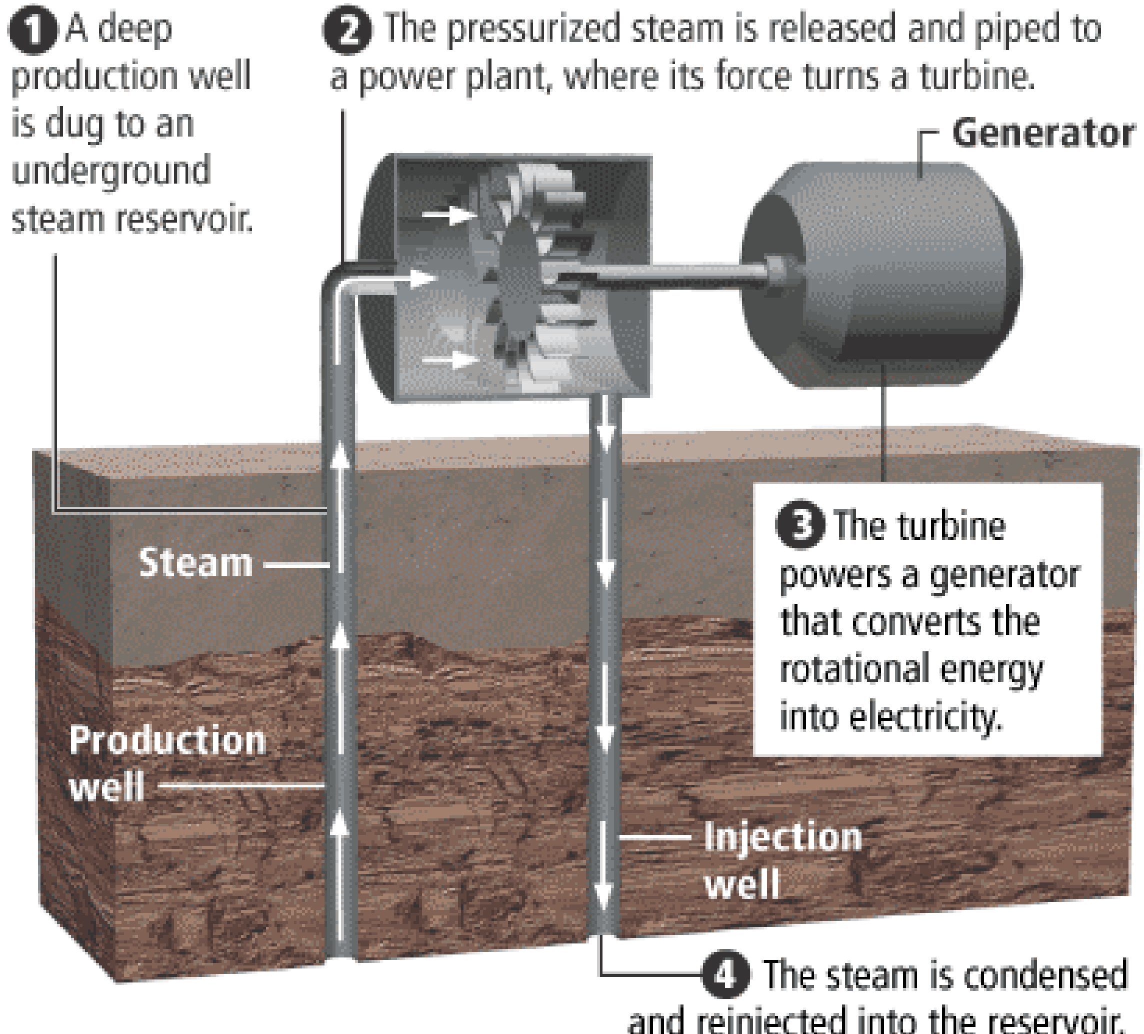
Away from tectonic plate boundaries the geothermal gradient is 25-30°C per km of depth in most of the world, and wells would have to be drilled several kilometers deep to permit electricity generation.


Wasser-
speicher
Wärme-
tauscher
Strom
Pumpe
Turbinen-
haus
Fern-
wärme
Injektionsb
ohrung
Produktions-
bohrung
Horch-
bohrung
Sediment-
schichten
kristallines
Gestein
4000 – 6000 m
500 – 1000 m
500 – 1000 m
Quelle: M.O. Häring, Häring GeoProject, 2002

HARNESSING GEOTHERMAL ENERGY

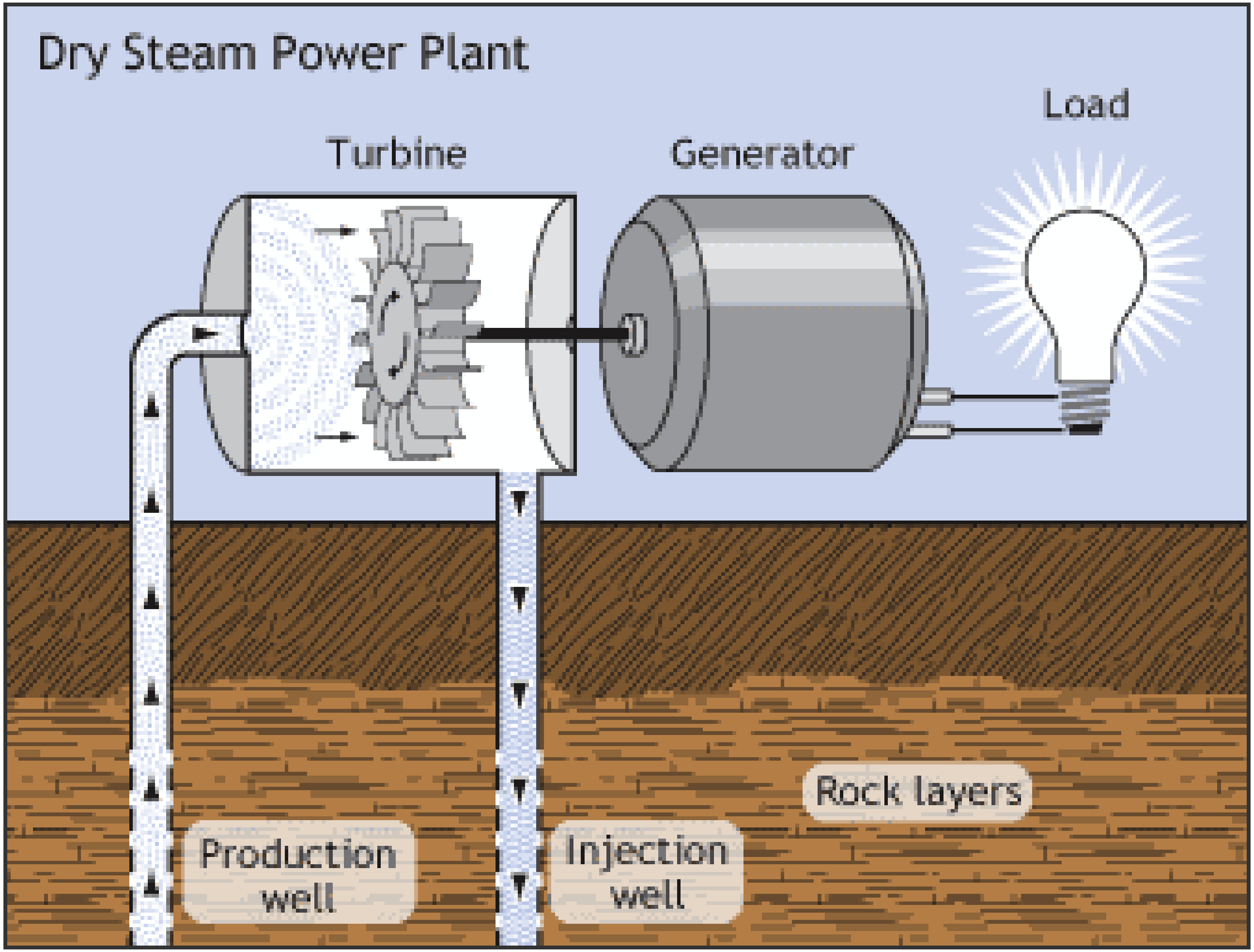
Geothermal power could theoretically satisfy all the world's energy needs. Trouble is, it's expensive to do the deep drilling necessary to tap the heat.

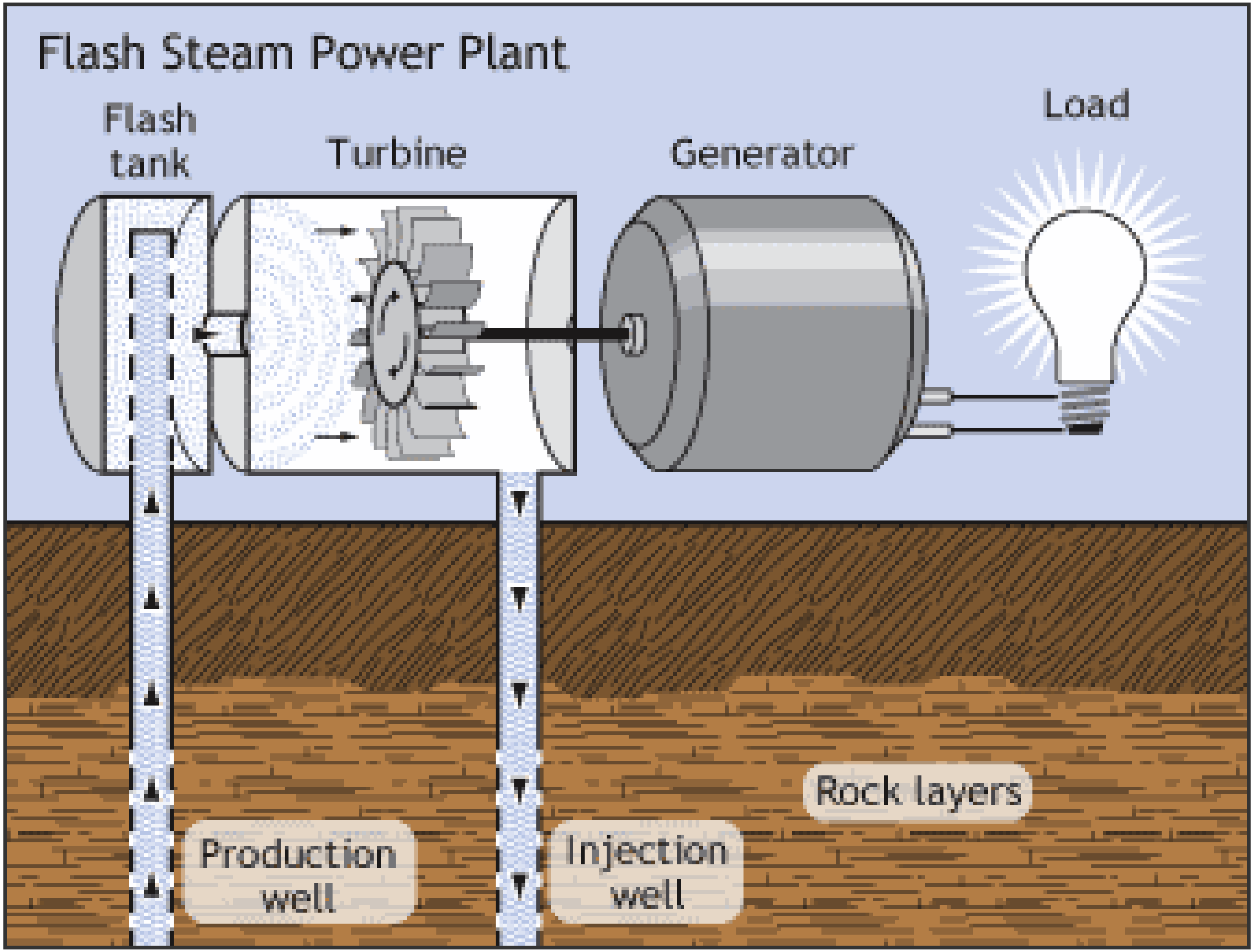
HOW IT WORKS

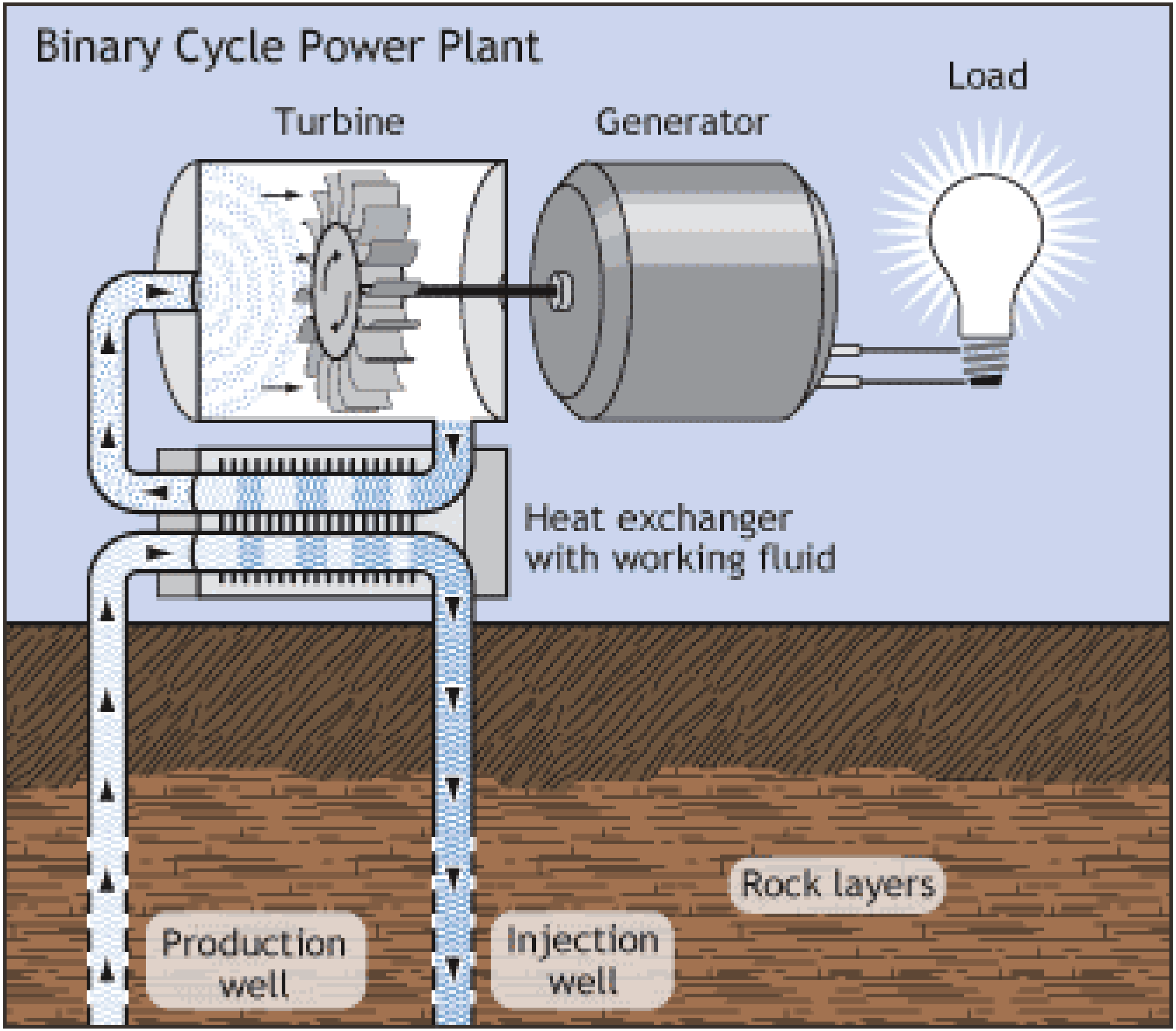


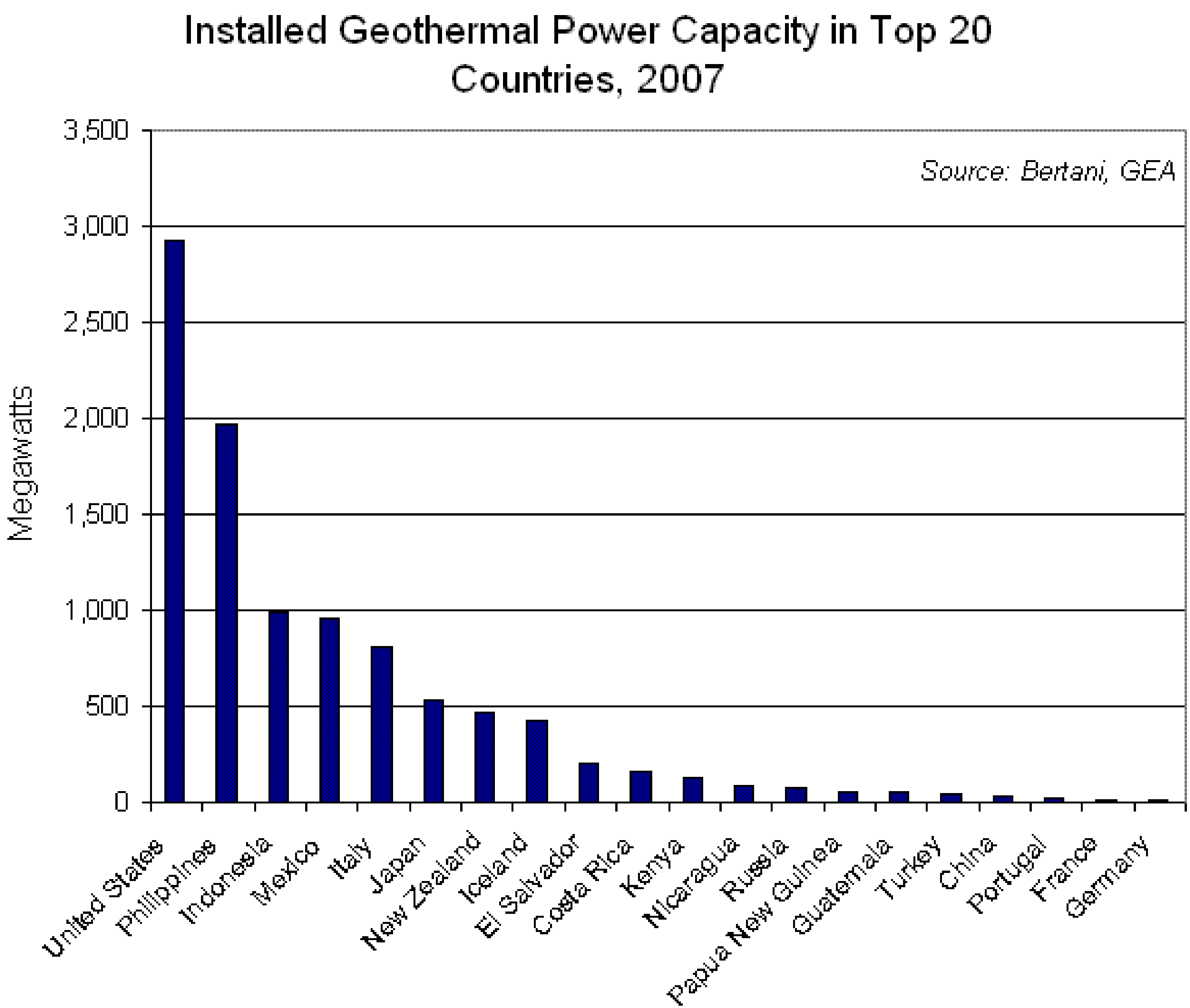
Source: U.S. Department of Energy

SEATTLE P-I


Dry Steam Power Plant
Load
Turbine
Generator
Rock layers
Production well
Injection well


Flash Steam Power Plant
Flash tank
Turbine
Generator
Load
Rock layers
Production well
Injection well


Binary Cycle Power Plant
Load
Turbine
Generator
Heat exchanger
with working fluid
Rock layers
Production
well
Injection
well



Installed Geothermal Power Capacity in Top 20 Countries, 2007
Source: Bertani, GEA
Megawatts
3,500
3,000
2,500
2,000
1,500
1,000
500
0
United States
Philippines
Indonesia
Mexico
Italy
Japan
New Zealand
Iceland
El Salvador
Costa Rica
Kenya
Nicaragua
Russia
Papua New Guinea
Guatemala
Turkey
China
Portugal
France
Germany

Estimates of the electricity generating potential of geothermal energy vary greatly from 35 to 2000 GW, depending on the scale of financial investments in exploration and technology development. This does not include non-electric heat recovered by co-generation, geothermal heat pumps and other direct use. A 2006 report by MIT, that took into account the use of enhanced geothermal system, estimated that an investment of 1 billion US dollars in research and development over 15 years would permit the development of 100 GW of generating capacity by 2050 in the United States alone. The MIT report estimated that over 200 ZJ would be extractable, with the potential to increase this to over 2,000 ZJ with technology improvements - sufficient to provide all the world's present energy needs for several millennia.

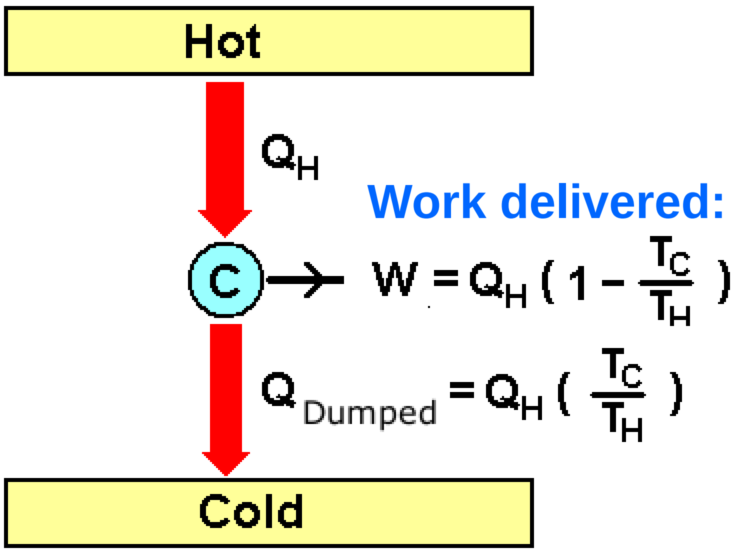
Geothermal energy can be used not only for generating electricity. It is even better suited for heating. Currently, much more geothermal power is used for heating homes than for generating electric power.

One very attractive way of harnessing geothermal energy for heating purposes is by using the so-called *geothermal heat pumps.* Essentially, such pumps can be installed at any location, no matter whether it is close to tectonic plate boundary, or not.

We have not yet talked about heat pumps, but we will – they are important machines that can save us enormous amounts of energy which we now obtain by burning fossil fuels.

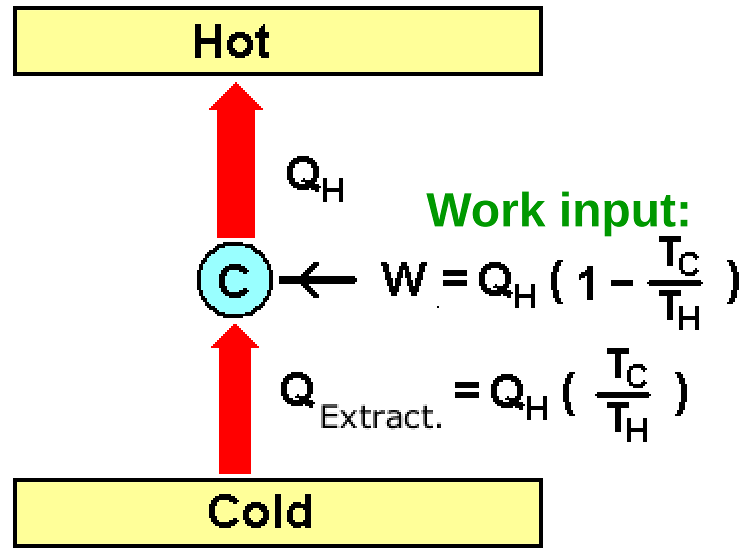
A Heat Pump is a “reverse-action” Carnot Engine:

Carnot Engine:



For, say, T_H = 350 K, and T_C = 280 K, work delivered is only 20% of Q_H, the thermal energy taken from the hot source; 80% is “dumped”.

Heat Pump:



For the same T_H and T_C, a work input W results in a transfer of thermal energy

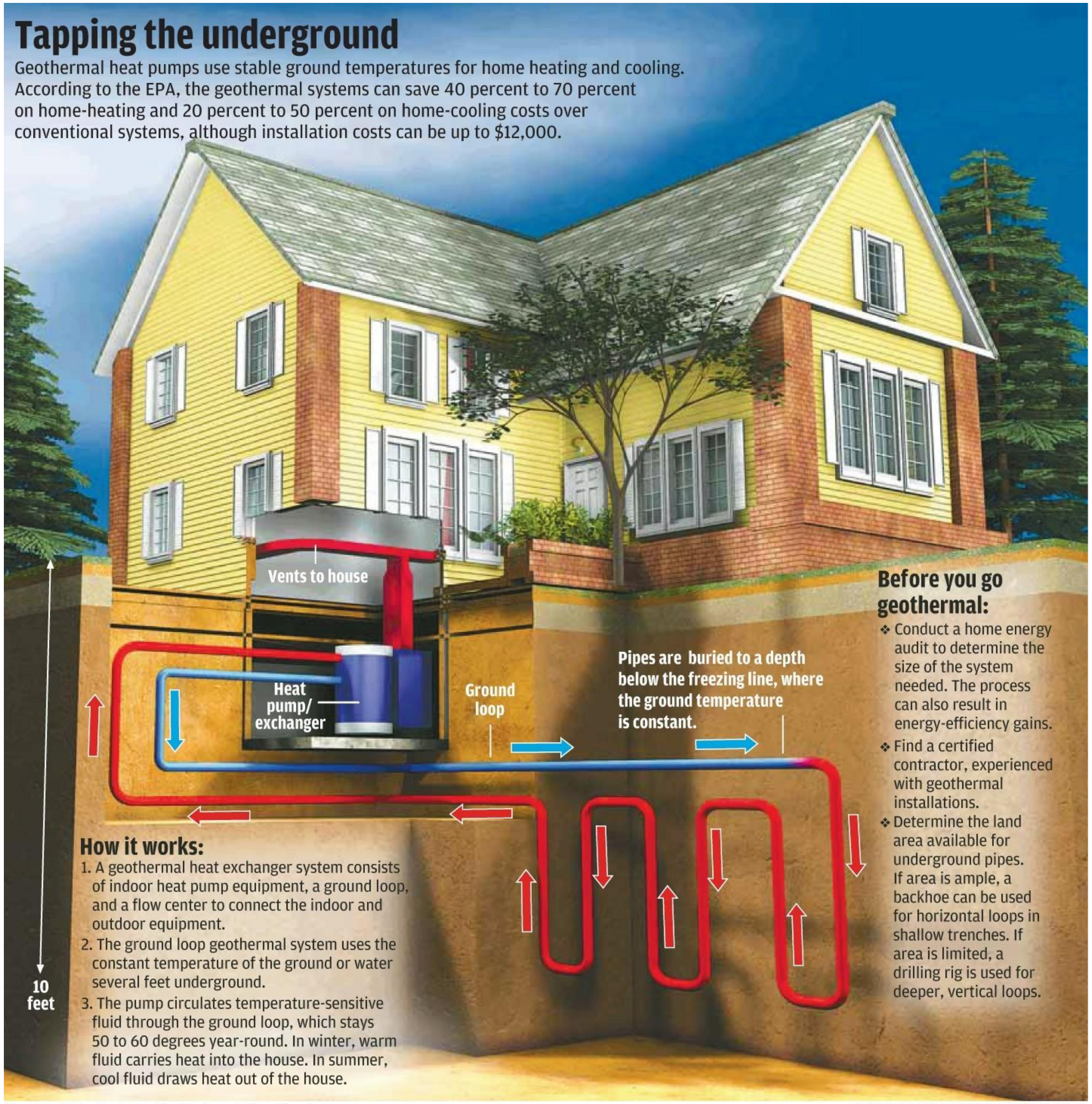
Q_H = 5 x W.

Five times more heat than the energy input!

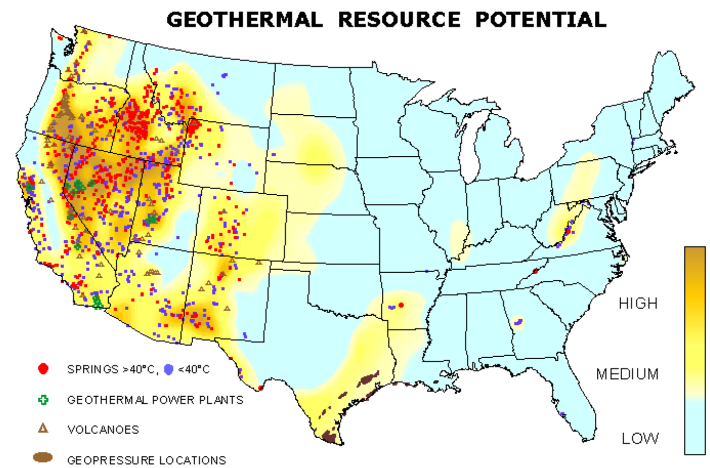
T_C = 280 K, or slightly lower, is a realistic expected air temperature in wintertime.

However, if one could have T_C equal, e.g., 315 K, then the heat pump from the preceding slide would deliver not five times more heat than the work input W, but TEN times more!

This is exactly the idea of a "Shallow Geothermal Heating System" – even a relatively shallow well may be a good "cold source" of such temperature.



Sources: Delta-Montrose Electric Association, About.com
JONATHAN MORENO/THE



The light blue areas are the regions in which there are good conditions for installing shallow geothermal heating systems – in fact, almost everywhere in the US they may be used!