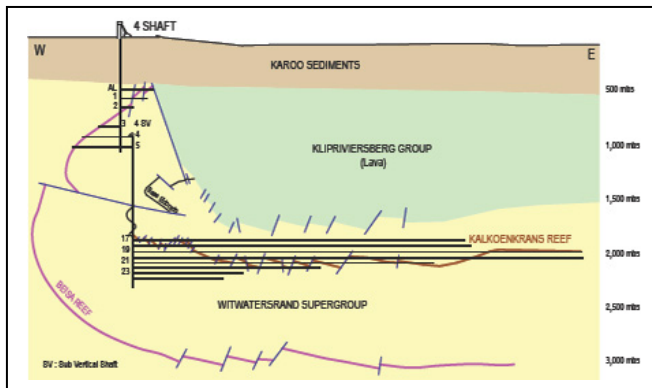




As miners on Earth dig deeper mines, they have noticed that the temperature of rocks gets higher. This tells scientists that the interior of Earth is much hotter than its surface. Exactly how much hotter depends on how deep into Earth you travel.

The Beatrix Mine is located in the extreme southern Witwatersrand Basin in South Africa. The basin, created by an ancient asteroid impact over 3 billion years ago, is the world's largest gold deposit. To get to the richest veins of gold, miners have to dig 2,200 meters below ground level.

A measure of how fast the temperature increases for a given depth is called the geothermal gradient. Gradient is a mathematical term that just means how fast one number (temperature in degrees) changes as you move a certain distance (depth in meters). The geothermal gradient for the Beatrix Gold Mine is about $+29^{\circ}\text{C}/\text{km}$. This means that for every kilometer of depth, the temperature of the rock increases by 29° Celsius ($+52^{\circ}\text{F}$).

Problem 1 – On a summer day at the mine's surface, the temperature is about 90°F (32°C). What temperature in Celsius and Fahrenheit will a miner experience at the bottom of Shaft 4 at a depth of 2,200 meters?

Problem 2 – A geologist measures the geothermal gradient of $+0.02^{\circ}\text{C}/\text{meter}$ at one location in Africa, and $+29^{\circ}\text{C}/\text{km}$ at another location in Texas. Which location has the fastest temperature change with depth?

Problem 3 – You want to dig a basement floor to your home so that the lowest floor is always at a temperature of 60°F . It is known that at a depth of 3 meters, the ground is always at a temperature of 13°C (55°F) year-round because the soil above acts as an insulator. How deep must you excavate to reach the proper depth if you are in a volcanically-active area where the geothermal gradient is $+35^{\circ}\text{C}/\text{km}$?

Problem 4 - One of the deepest laboratories in the world is in the small town of Soudan, Minnesota. It is a physics research facility and is at a depth of 690 meters (2,263 feet) below the surface. It is operated by the University of Minnesota. If the geothermal gradient is $+25^{\circ}\text{C}/\text{km}$, how warm are the walls of this laboratory if the average surface temperature is $+55^{\circ}\text{F}$ ($+13^{\circ}\text{C}$)?

The temperature gradient in the Beatrix Mine is given by T. C. Onstott, D. P. Moser, M. F. DeFlaun, L. M. Pratt, and B. Sherwood Lollar, Abstr. 101st Gen. Meet. Am. Soc. Microbiol., p. 515, 2001 in their study of bacteria living in the crust at high temperatures. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC93369>)

*"The geothermal gradients were found to vary among the four mines and appeared to be correlated with the amounts of water moving through fractures or along dyke contacts. At East Driefontein only a few slowly flowing boreholes were noted at the time of this study and the geothermal gradient is $9^{\circ}\text{C km}^{-1}$, whereas at West Driefontein, Kloof, and **Beatrix fissure** water emanating from boreholes is common and the geothermal gradients are 13, 16, and $29^{\circ}\text{C km}^{-1}$, respectively"*

Problem 1 – On a summer day at the mine's surface, the temperature is about 90°F (32°C). What temperature in Celsius and Fahrenheit will a miner experience at the bottom of Shaft 4 at a depth of 2,200 meters?

Answer: The gradient is $+29^{\circ}\text{C/km}$ so the increase in temperature will be $+29^{\circ}\text{C/km} \times (2.2\text{km}) = +64^{\circ}\text{C}$, and so adding this to the surface temperature you get $+32^{\circ}\text{C} + 64^{\circ}\text{C} = +96^{\circ}\text{C}$. In terms of Fahrenheit we have $(+96^{\circ}\text{C} \times 9/5) + 32^{\circ}\text{F} = +205^{\circ}\text{F}$. That means you can use the mined rocks to boil water, and that makes them very dangerous to the miners.

Problem 2 – A geologist measures the geothermal gradient of $+0.02^{\circ}\text{C/meter}$ at one location in Africa, and $+29^{\circ}\text{C/km}$ at another location in Texas. Which location has the fastest temperature change with depth?

Answer: $1\text{ km} = 1000\text{ meters}$ so we can convert to the same units: $+0.02^{\circ}\text{C/meter} \times (1000\text{ meters/1km}) = +20^{\circ}\text{C/km}$. The location in Africa has a faster increase of temperature with depth than Texas.

Problem 3 – You want to dig a basement floor to your home so that the lowest floor is always at a temperature of 60°F (16°C). It is known that at a depth of 3 meters, the ground is always at a temperature of 13°C (55°F) year-round because the soil above acts as an insulator. How deep must you excavate to reach the proper depth if you are in a volcanically-active area where the geothermal gradient is $+35^{\circ}\text{C/km}$?

Answer: First you need to excavate to 3 meters depth (about 9 feet) where you start with a temperature of 13°C . You need an additional 3°C of warming. The geothermal gradient is $+35^{\circ}\text{C/km}$ or $+0.35^{\circ}\text{C/meter}$. To get an additional 3°C of heating you need to dig an additional $+3^{\circ}\text{C}/(+0.35^{\circ}\text{C/m}) = 8.6\text{ meters}$ for a total depth of 11.6 meters (or 35 feet).

Problem 4 - One of the deepest laboratories in the world is in the small town of Soudan, Minnesota. It is a physics research facility and is at a depth of 690 meters (2,263 feet) below the surface. It is operated by the University of Minnesota. If the geothermal gradient is $+25^{\circ}\text{C/km}$, how warm are the walls of this laboratory if the average surface temperature is $+55^{\circ}\text{F}$ ($+13^{\circ}\text{C}$)?

Answer: $T = +13^{\circ}\text{C} + 0.69\text{km} \times (+25^{\circ}\text{C/km}) = +30^{\circ}\text{C}$ (or $+86^{\circ}\text{F}$)