Isostacy

- Isostacy is about the interactions between the lithosphere layer and the asthenosphere layer. Remember that the lithosphere is a rigid solid and the asthenosphere is a plastic zone in the mantle. The asthenosphere is mostly solid, but it can flow and it is higher in density. Thus, we think of the lithosphere above as "floating" on this lower layer.

- Definition: Isostacy- condition of equilibrium, comparable to floating, of the lithosphere above the asthenosphere.

- The reason the asthenosphere is plastic is because it is close to the melting temperature of peridotite rock.

- Through the lithosphere layer, temperatures are well below the melting temperature of the rocks and this layer is rigid. At the asthenosphere layer, temperature rises to the point were it approaches melting and the rocks become plastic in nature, like hot asphalt or warm silly putty. Its still essentially a solid, but it can slowly flow. Below the asthenosphere, the increase in pressure overcomes the affects of high temperature, and the mantle becomes more rigid again.

So how do we know the isostacy condition exists?

Today we have evidence of what the Earth’s interior is like from earthquake energy wave data that image inside the Earth. We don’t have the background yet to understand that. But, there are other types of evidence that support the idea of isostacy.

- These lines of evidence were discovered as scientists worked to explain the:

A) Great Survey of India problem and

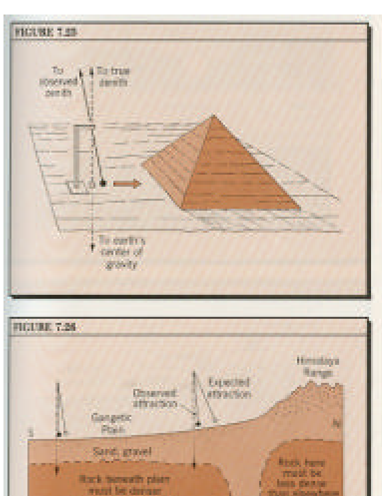
B) the erosion of mountain ranges problem

C) shorelines of Lake Bonneville problem

The Great Survey of India problem - gravitational attraction of mountain belts

From Newton’s Law of Gravity- every object exerts a force on every other object. The gravitational pull of one object on another increases with the mass of the objects. The more massive the object, the more the pull.

From Strahler



In the top diagram, there is a ball suspended vertically from a string. This is called a plumb bob and its suppose to show you a true vertical line that is created as the ball is gravitationally attracted to the center of the Earth.

However, when a plumb bob is located next to another large object, the mass of this other large object also creates a gravitational attraction on the ball. This causes the ball to move toward the other object, in this case a pyramid. See top of figure, ignore bottom.

The amount of pull indicated on the ball is a gross exaggeration of the real amount. But the pull is detectable.

This little fact became critical during the Great Land Surveys of India. One method determined distance between towns by conventional triangulation, which uses plumb bobs as part of the technique. To be accurate, the plumb bobs must show a true vertical line. The other method used astronomical techniques that didn't depend on plumb bobs. The two methods didn't agree and the problem was determined to be with gravitational attraction by the massive Himalayas on the plumb bobs. The closer to the Himalayas the survey went, the greater the error in the plumb bob method.

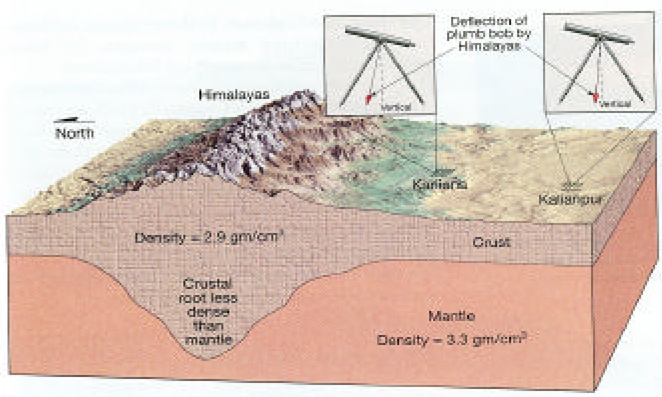


Figure 20.5 During the first survey of India an error in measurement occurred because the plumb bob on an instrument was deflected by the massive Himalayas. Later work by George Airy predicted that the mountains have roots of light crustal rocks. Airy's model explained why the plumb bob was deflected much less than expected.

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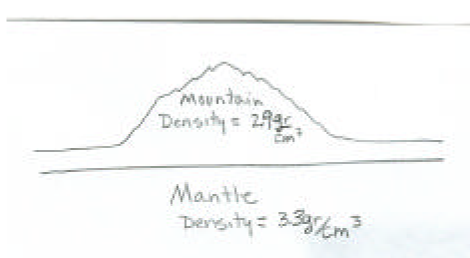
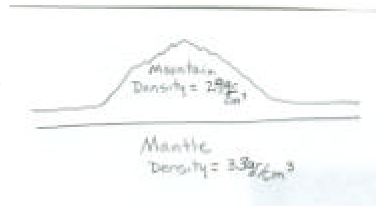
- Once it was determined that the mass of the mountains was creating a gravitational attraction on the suspended balls, attempts were made to factor this attraction in and make a correction.
- To do this they assumed the visible volume of the mountain range was low density crustal rock. Then they assumed this mound of low density rock was resting directly on high density mantle. The diagram below shows how they were envisioning the crust and mantle looked like at the mountains.
- To calculate the gravitational pull of the mountain range and mantle below on the plumb bob, the mass of the mountain range and the mantle rocks must be determined (gravitational pull is proportional to mass)



- To calculate mass of the rocks pulling on plumb bob we use the density equation. Density = mass/volume We reorganize the equation to solve for mass, Mass = density x volume



- We know the volume of the mountain range because we can determine average values of length, width, and height from maps. We guess at the volume of mantle that is pulling on the plumb bob (see diagram to right)
- We know the density of the rocks of the mountain and of the mantle because we can measure that in the lab

- So, mass of mountains is calculated (density of crustal rocks in mountains x volume of mountains) and mass of mantle is calculated (density of mantle x volume of mantle). These two masses are added together. This total mass is then used to calculate gravitational pull on plumb bob.

- The calculations overestimated the amount of plumb bob movement. This means the model overestimated the amount of mass pulling on the plumb bob. So, the model had to be changed.
- How could you change the model so that the amount of mass is decreased?

- So the scientific method required a new explanation that involved less mass. This new explanation proposed that the low density crustal material extended deep into the Earth. This greater volume of low density material would decrease the overall mass attracting the plumb. The calculations were done so that the astronomical method and the plumb bob method gave the same result. It ended up that a deep root of low density crustal material was needed below the Himalayas. Note the root in the diagram below.

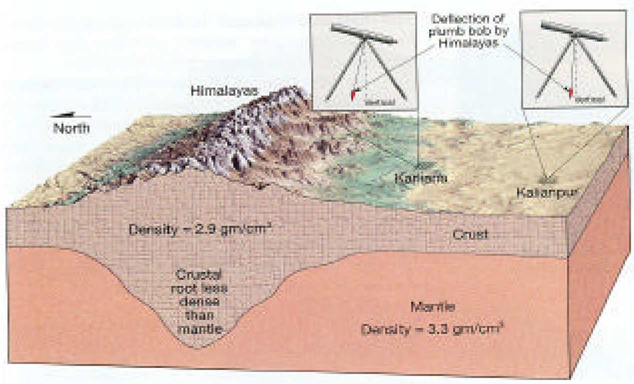


Figure 20.5 During the first survey of India an error in measurement occurred because the plumb bob on an instrument was deflected by the massive Himalayas. Later work by George Airy predicted that the mountains have roots of light crustal rocks. Airy's model explained why the plumb bob was deflected much less than expected.

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The solution to the survey problem also provided an answer to a another problem that geologists had been working on:

The Time of erosion of mountain ranges

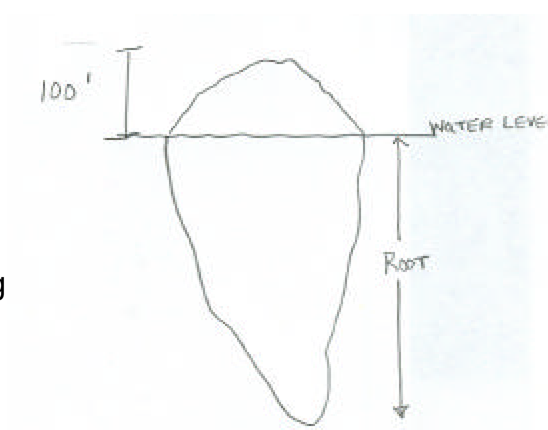
- The problem: Erosion of mountain ranges takes much longer to occur than is predicted based on erosion rates.
- At typical rates of erosion, it was predicted that the area of mountains above sea level would erode away in a time frame of tens of millions of years. Yet, mountains could be shown to exist for sometimes hundreds of millions of years.
- The idea that mountains have roots and the idea that lithosphere floats in the asthenosphere would explain this observation.
- In this explanation, we will compare mountains with deep crustal roots “floating” on the asthenosphere to an ice bergs floating in the ocean.

This iceberg is comparable to the mountain range. Both are a low density solid that is floating in a higher density material.

Most of the low density, solid material is below the surface. The visible part of the iceberg is like the part of the mountain range that extends above the surrounding lowlands.

From The Blue Planet-Skinner et al. 2nd edition

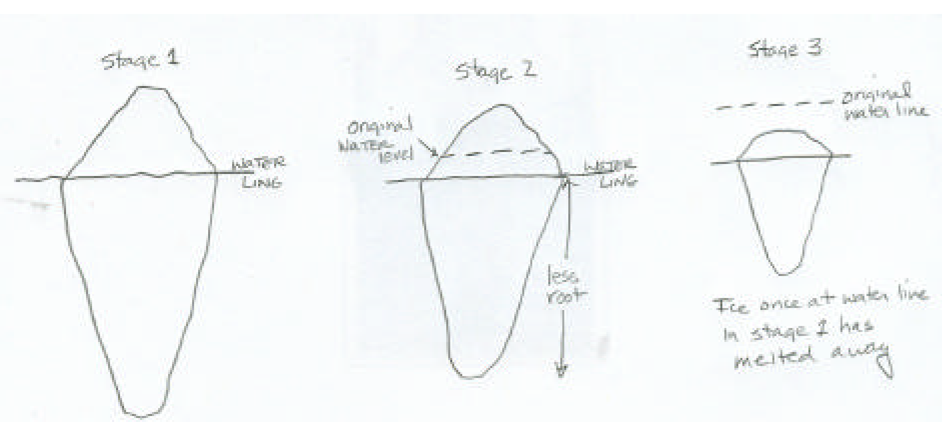
- We can model the melting of the ice berg as analogous to the erosion of a mountain range.
- So, consider an ice berg that has 100 feet of ice above sea level (see below). What happens to the ice berg when the top 20 feet of ice is melted from the top? Estimate the height above sea level that the ice berg has after melting.



- The iceberg is not now at a level of 80 feet above sea level. Its new height is actually something between 80 feet and 100 feet. Why?

- As melting removes material from above sea level, the buoyancy of the ice in the water causes part of the root zone to rise above the water. So even though 20 feet of ice has been removed from the top, the rise of the entire ice berg as the weight is removed keeps the height greater than 80 feet.

- Over time, as more melting occurs, more and more of the root zone will be elevated above sea level and also melt. Eventually all the ice exposed above the water level will be ice that had formerly been below the water in the root zone.



- Once the survey method provided evidence for the idea that mountains have low density roots, the erosion problem of mountains could be explained.
- With a deep crustal root, the mountains could be considered as floating in the mantle. As erosion took material off the top of the mountain, the root began to rise up. Over time rocks that were once in the root were elevated above sea level, where they too were eroded. Thus, mountains took so long to erode because not only were the rocks originally above sea level being eroded away, but the rocks of the roots would also rise up and be eroded as well.

The higher the elevation of the Earth's surface, the deeper the root

Note how the mountains (below) extend for a height of 8 kilometers above the rest of the Earth's surface and that the crust below extends downwards for a depth of 80 kilometers. In places where the mountain range is not as high, the root is not as deep.

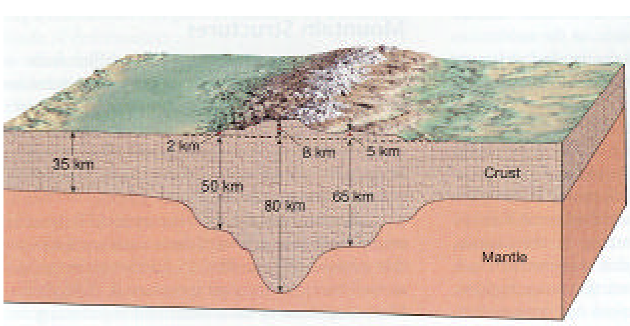


Figure 20.6 Mountains are supported by the buoyancy of light crustal roots floating in the denser mantle (like icebergs floating in seawater). (Modified after Peter Molnar)

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Summary

- The idea that mountains have roots supports the idea of isostacy. If the rigid, low density lithosphere is floating in the plastic, higher density asthensophere, then it makes sense that thickening the crust to make mountains above sea level requires a thick crustal root to support the weight of those mountains. This is like the ice berg. The higher the tip of the ice berg above the water, the deeper the root of ice below the water line that is required to support the tip. The same with mountains, the higher the elevation above sea level, the deeper the crustal root that supports it.

- The long time to erode a mountain range, as the root rises buoyantly during erosion, is also consistent with a plastic, asthenosphere layer supporting the lithosphere.

Further evidence for isostacy
The shorelines of Lake Bonneville Problem
and Isostatic Rebound of the Earth's Surface

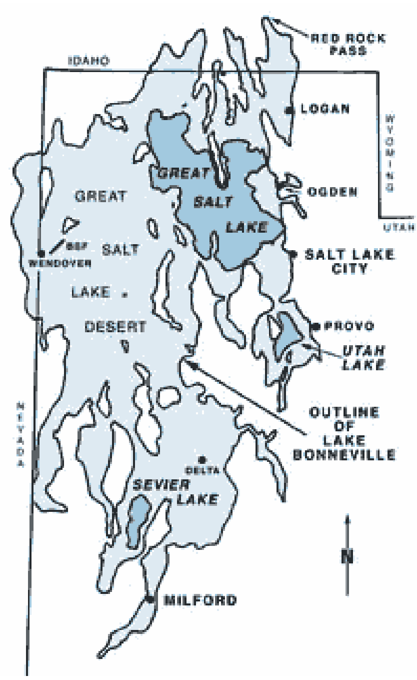
- Although we haven't directly discussed it, implied in the previous explanations on isostacy is the idea that the asthenosphere is plastic and it flows. Thus, as mountain root zones rise when erosion removes weight at the surface, the plastic mantle must flow to fill in the space created by the rising root. (Water does the same thing under a melting ice berg).

- Its hard to measure this rising in mountains, where erosion is stripping away rocky material at the same time. But, we can measure rebounding of the Earth's surface as a weight is removed in other places. One of those places is in northern Utah.
- In the late 1880's, another survey resulted in some unexpected results that needed explanation. This survey was measuring the elevation of beach deposits from Lake Bonneville, a huge lake that existed in much of northern and central Utah during the last Ice Age. It was at its peak about 10,000 years ago. The amount of water was immense, the lake was over 1000 feet deep in places. Gilbert went all over the state, measuring the elevation of these shorelines. He concentrated on the elevation of the highest shoreline that represented the lake at its deepest and largest.

- When Gilbert measured the elevations of the shorelines at the various mountain ranges that had been in the lake (they were islands when the lake existed), he expected that all the shorelines would have the same elevation.
- But, what we found was that the shorelines occurred at different elevations in different mountain ranges. For instance, he found that the shoreline was at 5,200 feet along the Wasatch Mountains, but it was at 5,300 feet at mountains ranges west of the current Great Salt Lake. Here is another problem that needed an explanation. How could a lake have different elevations at different places?

- The map to the right is from the Utah Geological Survey http://www.ugs.state.ut.us/online/PI-39/pi39pg01.htm

Lake Bonneville is shown in light blue, lakes that exist today are shown in dark blue.



- Gilbert thought of several ideas, or hypotheses, that might explain the surprising beach elevation data he had collected. He then worked to test each idea and kept or discarded his ideas according to his results. This approach is call multiple working hypotheses.

- For anyone not familiar with Utah, the Wasatch Mountains are due east of the current Great Salt Lake and Utah Lake (see previous map)

Gilbert's ideas and tests

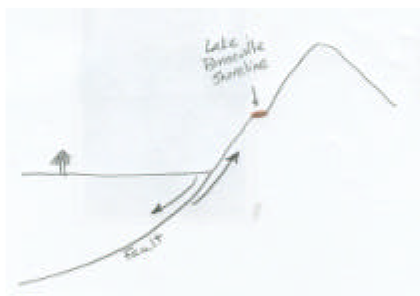
- Idea 1- Although Gilbert was careful to look only at the highest shoreline at each location, which are likely to be the same age, he considered the idea that the shorelines were actually from different time periods. This would mean that the Wasatch Mountain shorelines were created at one time, when the lake was at 5200 feet, and the shorelines to the west were created at a different time when the lake was higher, at 5300 feet.

- Test- Gilbert mapped all the shoreline areas to see what evidence he could find to support this idea. What he found is that the lake had natural outlet at 5200 feet (located at Red Rock Pass-see prior map). Thus, if the water tried to rise higher than this level, it would just flow through the outlet. So, Gilbert discovered that the lake could not rise above 5200 feet!!!

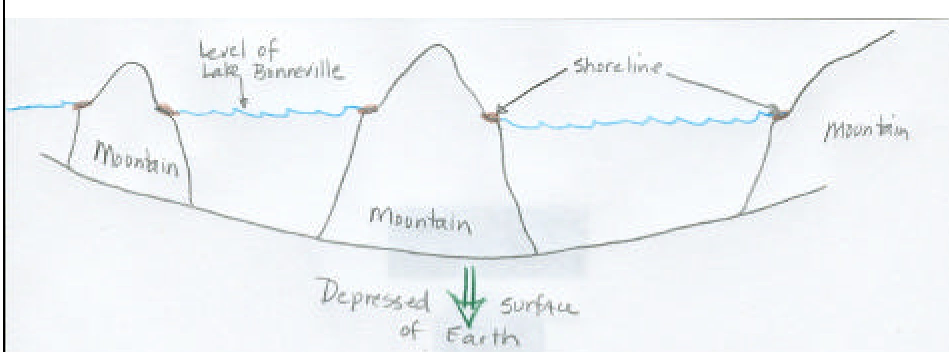
Gilbert then reasoned that if the lake level could not rise to 5300 feet, than the only other way to get shorelines at 5300 feet, is to somehow change the elevations of the shoreline AFTER the lake made them.

- Idea 2 The Wasatch Fault has lowered the elevation of the shoreline along the Wasatch Mountains. As the blocks of rock slide along the fault during an earthquake, the shoreline drops down with the block of rock that moves down.

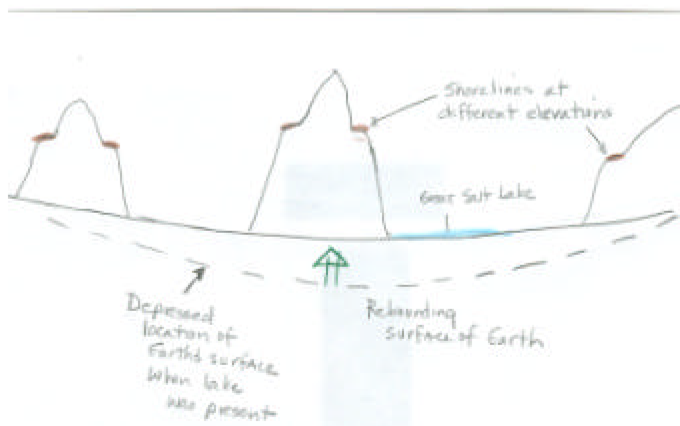
- Test- To study the fault along the Wasatch Mountains and see how it would change the shoreline elevations. Gilbert discovered the shorelines are on the side of the fault that <u>rises</u> when earthquakes shift the Earth. In the diagram below, see how the block of rock on the right side of the fault contains the mountain range and note the shorelines are deposited onto the side of the mountain range. During an earthquake, the mountain and shoreline rise together. So movement on the Wasatch Fault could not explain why the shorelines on the Wasatch Mountains are lower than those to the west.



Idea 3 – The weight of Lake Bonneville water had depressed the surface of the Earth at the time the shorelines were being created. As the water load built up on the Earth's surface, the plastic mantle flowed out from underneath and the Earth's surface lowered in elevation. So the shorelines all formed at the same time and at the same elevation after the Earth's surface had been lowered by the weight of the water.



As climate conditions changed and the water evaporated, the removal of the weight caused the plastic mantle to flow back underneath the area and the Earth's surface rebounded back to original position. This rebounding would change the elevation of the shorelines. Areas with the highest shoreline elevations would be the areas where the most rebound occurred.



Test- Gilbert determined where the greatest amount of rebound has occurred to see if they match where the lake was deepest. They do (see homework). This idea is still accepted as correct today.

- Northern Utah is not the only place where rebounding of the Earth's surface is occurring after a load has been removed. This phenomenon, called isostatic rebound, is also occurring in the Great Lakes area and in parts of Scandinavia, where the Earth's surface was depressed by the weight of massive glaciers thousands of feet thick. In the time since the ice has melted, the Earth's surface has been rebounding upwards as the mantle flows back underneath. The process continues today and is being measured by GPS technology.