2010

Yellowstone! A National Park on a Hot Spot

Judy McIlrath
University of South Florida, jmcilrath@usf.edu

Follow this and additional works at: https://scholarcommons.usf.edu/geo_facpub
Part of the Earth Sciences Commons

Scholar Commons Citation
McIlrath, Judy, "Yellowstone! A National Park on a Hot Spot" (2010). School of Geosciences Faculty and Staff Publications. 1452.
https://scholarcommons.usf.edu/geo_facpub/1452

This Data is brought to you for free and open access by the School of Geosciences at Scholar Commons. It has been accepted for inclusion in School of Geosciences Faculty and Staff Publications by an authorized administrator of Scholar Commons. For more information, please contact scholarcommons@usf.edu.
Yellowstone! A National Park on a Hot Spot

Core Quantitative Literacy Topics
Probability (Recurrence interval)

Supporting Quantitative Literacy Topics
Unit conversion
Percent

Core Geoscience Subject
Volcanism

Judy McIlrath
Department of Geology, University of South Florida, Tampa, FL 33620
© 2010 University of South Florida Libraries. All rights reserved.

This material is based upon work supported by the National Science Foundation under Grant Number NSF DUE-0836566.
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
Getting started

And you should also know where Yellowstone National Park is.

After completing this module, you should be able to:

• Define *recurrence interval*.
• Define *probability*.
• List evidence that Yellowstone is volcanically active.
• Calculate unit conversions.
Yellowstone National Park, WY, located within one of the world’s largest volcanic systems, preserves geologic wonders such as geysers and hot springs sustained by the underlying igneous energy. Yellowstone also supports abundant and diverse wildlife in one of the largest remaining intact wild ecosystems on Earth. Over 3 million visitors visit the park annually, many unaware that they are driving through the caldera of a volcano that has produced several giant, catastrophic eruptions along with many smaller eruptions in the geologically recent past.

As the world’s first National Park, established in 1872, the Yellowstone model has inspired other countries to establish more than a hundred national parks around the world. The park holds the designation of a Biosphere Reserve and World Heritage Site by the United Nations.
Visible evidence of volcanic activity

**Hydrothermal activity** at Yellowstone produces more than 10,000 hydrothermal features (geysers, hot springs, pools, mud pots, and fumaroles), approximately half of the world’s total. With over 300, the park contains the world’s largest concentration of geysers as well as the world’s tallest, Steamboat Geyser with eruptions over 300 feet. Yellowstone is also one of the few places in the world with active travertine terraces. The heat source for the features is a magma chamber a few miles below the surface, and beneath that, a continental hot spot.

Thermophilic bacteria living in the hot water are proving valuable to researchers studying perplexing medical and environmental issues.
Yellowstone: an area of geologic unrest

Far away from an active tectonic boundary, Yellowstone is seismically active. The map below shows epicenters of earthquakes (yellow dots) that occurred between 1973 and 2006. The hexagons indicate epicenters of the two largest historic earthquakes, the 7.5-magnitude Hebgen Lake earthquake (red, 1959) and the 6.1-magnitude Norris earthquake (pink, 1975).

Earthquakes are a major contributor to the hydrothermal system, at times opening pathways (fractures and faults) that bring groundwater to the surface and at times clogging them with debris that shuts off some hydrothermal features on the surface.

Ground motion measurements show periods of uplift and subsidence, indicative of a magma source below the surface.
The Yellowstone hot spot has produced many calderas. One of them, at ~45 mi × 30 mi, is one of the world’s largest and marks one of the largest known volcanic eruptions; that caldera is one of the more recent calderas produced by the hot spot. As hot spots are believed to be relatively stationary, the location and age of the calderas reveal the rate and direction of plate motion. The motion of the North American Plate has been to the southwest. The hot spot is currently under Yellowstone National Park, and the oldest caldera lies to the southwest.

Question 1: At what rate is the North American Plate moving over the hot spot?

This Google Earth image shows approximate caldera locations for the past 12 million years. The measuring tool estimates a distance of 491 km between the oldest caldera and the youngest caldera.

Click on the spreadsheet icon below to access the template for this module. Immediately save the file to your computer, and make the calculations in cm/year and in/year. The formulas you type in the orange cells should return the same answers as seen below.
The huge amount of volcanism

Watch any TV documentary on Yellowstone and you will hear about the cataclysmic eruptions produced by the hot spot. Ash from these eruptions can be traced over large distances of the continent (image below) indicating the violence of the explosive eruptions. While driving through the park, you can see thick walls of tuff formed during these events and in places, see remnants of the calderas themselves.

The volumes of the eruptive material are immense. Most people cannot visualize such large volumes. We will relate them to something that many of us can picture, an Olympic swimming pool.

Question 2: Using the given eruption volumes, how many Olympic-size swimming pools (50m × 25m × 3m) would it take to hold the erupted material for each volcano shown?

<table>
<thead>
<tr>
<th></th>
<th>Olympic Pool Volume</th>
<th>Eruption Volume (miles³)</th>
<th>Eruption Volume (km³)</th>
<th>No. of pools</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3,750 m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mt. St. Helens, WA</td>
<td>1980</td>
<td>0.10</td>
<td>0.4</td>
</tr>
</tbody>
</table>
**Frequency of volcanism**

**Recurrence interval** is a measure (expressed in units of time) related to the frequency of an event. The more frequent the occurrence, the less time between events. The equation to calculate recurrence interval \( T \) is \( T = \frac{N + 1}{n} \), where \( N \) is the number of years in the record and \( n \) is the number of events.

Recurrence intervals are often calculated for geologic events such as earthquakes, floods, and volcanic eruptions.

**Question 3:** What is the recurrence interval for large eruptions at Yellowstone? There were three eruptions in 2.1 million years. Find the eruptions in the previous slide. (With an \( N \) this large, the +1 doesn’t matter to the calculated result.)

Using the figures from the previous slide, what magnitude uncertainty would you associate with the 700,000-year result?

The Yellowstone River carves through volcanic rock to form Grand Canyon of Yellowstone.
Probability is often cast in terms of a forecast. The relationship between probability \((P)\) of an event and its recurrence interval \((T)\) is
\[ P = \frac{1}{T}. \]
Probability is reported as a percentage (%).

Question 4: What is the probability that a large eruption will occur at Yellowstone in any given year?

The probability of Yellowstone producing a caldera-forming eruption within the next year is extremely low! Given the uncertainties mentioned in Slide 8, do you think your conclusion would have been any different if you had made it a thousand years ago? Or a thousand years from now?

The effects of a caldera-forming eruption at Yellowstone, if one occurred, would be worldwide. Large volumes of volcanic gases emitted could drastically change global climate. Vast ash deposits across the United States would destroy life and vegetation.
Recurrence intervals of post-caldera eruptions

Of course the caldera-forming eruptions are not the only eruptions recorded in the rocks of Yellowstone. Around 80 lava flows have occurred in the last 160,000 years. The most recent was around 70,000 years ago.

Question 5: What is the probability that a lava flow eruption will occur at Yellowstone in any given year?

As you can see, the probability of a lava flow occurring on any given day is also very low, but it is much higher than the probability of a cataclysmic eruption occurring.

<table>
<thead>
<tr>
<th>No. of Years</th>
<th>No. of Events</th>
<th>Recurrence Interval (years)</th>
<th>Probability of Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Cataclysmic eruptions</td>
<td>2.1E+06</td>
<td>700,000</td>
</tr>
<tr>
<td>20</td>
<td>Lava Flows</td>
<td>160,000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Columnar jointing in basaltic flows seen between Tower Junction and Canyon.

Eruptions of lava at Yellowstone would create local disturbances within the park in the form of fires and destruction of roads and facilities.
Probability of hazards at Yellowstone

The diagram illustrates that smaller, less-destructive volcanism-related events are more likely than larger cataclysmic events.

Scientists use various methods to monitor volcanic activity in Yellowstone. In 2003, the ground temperature one cm below the surface in the back areas of Norris Geyser Basin was approximately 94 degrees Celsius. Based on scientific data, a management decision was made to close the trails in the back basin. Barefoot visitors were getting burned feet!

Along with the wildlife found in the park, it is the geologic phenomena of the present and past that draws so many visitors to the park!
Establishment of the park

“The headwaters of the Yellowstone River...is hereby reserved and withdrawn from settlement, occupancy, or sale...and dedicated and set apart as a public park or pleasuring-ground for the benefit and enjoyment of the people.” (The Yellowstone National Park Act of 1872)

With the establishment of additional parks, Congress passed the National Park Service Organic Act, on August 25, 1916, creating the National Park Service:

1. to conserve the scenery and the natural and historic objects and the wild life therein and
2. to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Thousands of visitors patiently await the eruption of Old Faithful.

Roosevelt Arch erected with the words “For the benefit and enjoyment of the people”.

Enjoying the solitude in the early morning mist created by the steaming Mammoth Hot Springs.
The allure of volcanism creates a dilemma

In 1883, trains began bringing visitors to the park. Automobiles were allowed in the park in 1915 making visitor access easier and more economical. Park visitation has increased tremendously since the early days of the park. The two fundamental goals stated in the Organic Act—preserving parks in their natural state and making these areas accessible for public use and enjoyment—present difficult management choices.

Visitors of all flavors come to the park. Some come for a wilderness experience. Some come wanting all the comforts of home. How does the park accommodate both?

Many management decisions must be made to find a balance between allowing access to the natural features in the park and protecting the visitors.

Be sure that you can gather information from the visitation graph above. You will be revisiting it in the end-of-module assignment.
To protect visitors from danger, a management decision made it illegal for visitors to soak in ANY thermal feature in the park. The water of the Gardner River is cold and swift. The water of the Boiling River, which flows into the Gardner River, is hot enough to scald. During certain times of the year, bathing is allowed in the Gardner River, where mixing of the waters occur. The timing is determined by the discharge of the Gardner River, which can peak at ~1700 ft³/s. At discharges greater than 300 ft³/s, the volumetric flow rate is too dangerous to allow bathing. Park officials monitor stream gage data. When discharge is less that 300 ft³/s, the Gardner River is open for bathing.
1. Use the Google image on Slide 16 to calculate the rate of motion of the Pacific Plate? What direction is the plate moving?

2. Are the numbers in your calculation for Question 1 exact? Justify your answer.

3. Around 12 large hydrothermal explosions have occurred at Yellowstone in the past 14,000 years. Calculate the recurrence interval of hydrothermal eruptions in the park. What is the probability that a hydrothermal eruption will occur on any given day?

4. Answer the following questions about the visitation graph on Slide 13:
   a. For which years did park visitation reach over 3 million people? (List the years.)
   b. How many years has visitation been over 2.5 million?
   c. What might account for the drop in visitation indicated by the years in the red ellipse?

Inquiry:

5. What are thermophilic bacteria? Why are they important?

Critical thinking:

6. Yellowstone National Park consists of 2.2 million acres. List and discuss the impacts to the park created by park visitors. (Hint: Think of the “comforts of home”.)

7. If a basaltic eruption occurred at Yellowstone, how do you think park visitation would change?
The Hawaiian Island chain was created by a hot spot that currently underlies the Big Island of Hawaii, site of Hawaii Volcanoes National Park. Return to Slide 15

Huckleberry Tuff (2.1 Ma) exposed at Golden Gate, south of Mammoth Hot Springs. The eruption that produced the Huckleberry Tuff, one of the five largest individual eruptions known on Earth, created a caldera more than 60 miles across.
You don’t like crowds? Visit Yellowstone in early March!

Grand Geyser

Hot springs

Crowd at Old Faithful

Survival of the fittest