WATER CONTENTS OF YELLOWSTONE MAGMAS ESTIMATED FROM HYDROXYL CONCENTRATIONS IN FELDSPAR PHENOCRYTS

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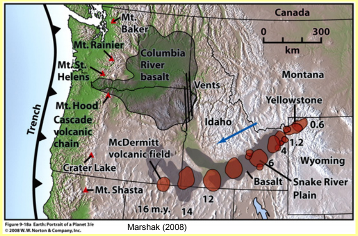
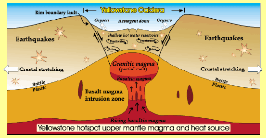
Background

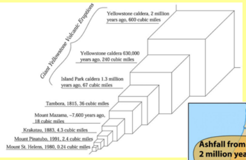
Discovered by Ferdinand V. Hayden, Yellowstone National Park is known for its captivating scenery full of breathtaking geologic features produced by caldera-forming volcanic eruptions over the past 2 million years. Yellowstone was formed by a continental hotspot in the North American Plate about 2 million years ago after the first of three cataclysmic volcanic eruptions. Because the Yellowstone hotspot is under a continental plate, basaltic magma heats silica-rich rock creating viscous rhyolitic magma. Many explosive eruptions (for example, Mount St. Helens) occur in part because magmatic water reduces magma viscosity and forms bubbles during decompression. In this study we evaluate the hypothesis that the mega-eruptions at Yellowstone were caused by magmas with high water concentrations.



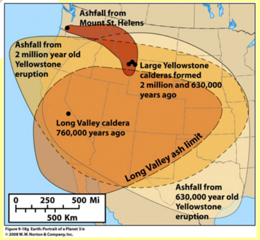
Marshak (2008)



National Park Service website



Smith and Siegel (2000)



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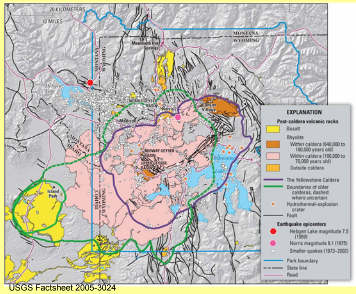


USGS Factsheet 2005-3024

Results

- **Magmatic [OH] in Yellowstone feldspars is low (12-40 ppm H_2O wt.).**
- **Estimated water concentration in Yellowstone magmas: less than 1.5 wt%.**
- **Canyon Flow feldspars: evidence for hydrothermal alteration after eruption.**

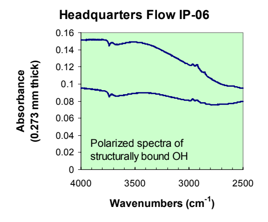
Stratigraphy, Age and OH Concentration Table

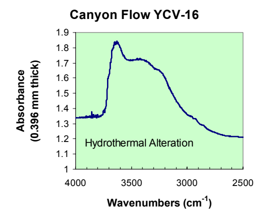
	Unit Name*	Age*	Sample #	[OH] ppm H_20 by weight
First Caldera				
	Huckleberry Ridge Tuff	2.053 Ma		
	Headquarters flow	***1.83 Ma***	***IP-06***	***40***
	Blue Creek flow	***1.77 Ma***	***IP-05***	***47***
	Bishop Mtn flow	1.20 Ma		
	Green Canyon Pass flow	1.17 Ma		
Second Caldera				
	Mesa Falls Tuff	1.292 Ma		
	Osborne Butte dome	1.28 Ma		
Third Caldera				
	Lava Creek Tuff	***640 Ka***	***YCV-19***	***21***
	Biscuit Basin flow	***516 Ka***	***YCV-11***	***12***
	Dunraven flow	486 Ka		
	Canyon flow	***484 Ka***	***YCV-16***	***760(alteration)***
	Tuff of Sulphur Creek	479 Ka		
	Scaup Lake flow	198 Ka		
	Obsidian Cliff flow	183 Ka		
	Dry Creek flow	162 Ka		
	Mallard Lake flow	151 Ka		
	Summit Lake flow	112 Ka		
	Solfatera Plateau flow	110 Ka		
	West Yellowstone flow	108 Ka		
	Hayden Valley flow	102 Ka		
	Gibbon River flow	90 Ka		
	Grants Pass flow	72 Ka		
	Pitchstone Plateau flow	70 Ka		

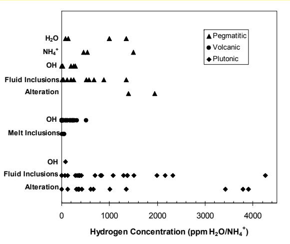
*Age dates and stratigraphy from Christiansen 2001

Bold italics indicates samples tested in this study

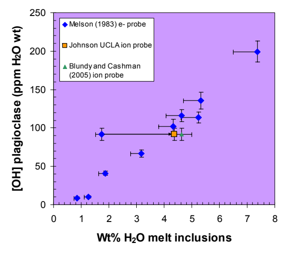
Infrared Spectra of Feldspars







Water species and concentrations in natural feldspars. [OH] in volcanic feldspars ranges from 0-512 ppm H_2O (Johnson 2004)

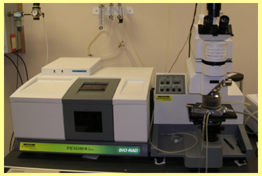


Relationship between [OH] in feldspar and H_2O in magma (Johnson 2005)

Methods

Sample Preparation

Feldspars were separated from the rock matrix by crushing, and were distinguished from quartz grains using cleavage and optical interference figures. The feldspar phenocrysts were prepared for infrared analysis by creating two perpendicular doubly-polished thick sections of each crystal. Individual phenocrysts were attached to a brass plug using Crystalbond™ epoxy. Polishing was done using aluminum oxide polishing film with grit sizes from 30 µm to 1 µm. After polishing, the samples were removed from the brass plug by heating and the remaining Crystalbond™ was removed by dissolving in acetone. Sample thickness was measured using a digital micrometer.



Infrared Analysis

Polarized infrared spectra were obtained at 4 cm^{-1} resolution using the microscope accessory on the Varian Digilab Excalibur FTS3000 Fourier-Transform Infrared (FTIR) spectrometer in the Department of Mineral Sciences at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. A modified form of the Beer-Lambert law was used to determine the concentration of OH from the IR spectra of each feldspar: $\mathbf{A_i = \varepsilon' c t}$ where A_i is the total integrated IR band area in the OH region, **c** is the OH concentration, **t** is the thickness of the polished slab and ε' is the integrated absorption coefficient from Johnson and Rossman (2003).

Abstract

The water contents of five eruptions of Yellowstone Volcano, Wyoming, (Headquarters Flow, Blue Creek Flow, Lava Creek Tuff, Biscuit Basin Flow, and Canyon Flow) were estimated using measurements of structurally incorporated hydroxyl (OH) in feldspar phenocrysts. Hydroxyl concentrations were shown to be related to magmatic water concentrations in a previous study of feldspars from the 1980-81 eruptions of Mount St. Helens (Johnson 2005 GCA 69:A743).

Feldspars from the Yellowstone samples were separated from the rock matrix by crushing and picking individual crystals, and were identified using an optical microscope. The feldspar phenocrysts were prepared for infrared analysis by creating two perpendicular doubly-polished thick sections of each crystal. Polarized infrared spectra were obtained at 4 cm^{-1} resolution using the microscope accessory on the Varian Digilab Excalibur FTS3000 Fourier-Transform Infrared (FTIR) spectrometer in the Department of Mineral Sciences at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. Hydroxyl concentrations were determined using the calibration from Johnson and Rossman (2003; Am Min v.88, 901-911).

The Canyon Flow feldspars contain about 760 ppm of hydrous layer silicates and fluid inclusions indicating that these phenocrysts experienced hydrothermal exchange after eruption. The structural hydroxyl concentrations in the other four Yellowstone samples range from 12 to 47 ppm H_2O by weight. The feldspar from the Lava Creek Tuff, erupted 630,000 years ago, contains 21 ppm H_2O. These hydroxyl concentrations are on the lower end of the range of hydroxyl concentrations reported for feldspar phenocrysts from other volcanoes (0-510 ppm H_2O). Based on these measurements, we estimate that the Yellowstone magmas contained less than 1.5 wt% water.

Conclusions

- **Water concentrations in the magmas were low and probably not a driving factor in the Yellowstone mega-eruptions.**
- **Our research contributes to the process of elimination in finding out what caused these mega-eruptions to be so enormous.**
- **Other techniques are needed to evaluate the role of other gases in the eruptions (Lowenstern and Hurwitz 2008).**

References

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