U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
NATIONAL PARK SERVICE

SCIENTIFIC INVESTIGATIONS MAP 2973
SHEET 2 OF 2

LAKE HOTEL GRABEN

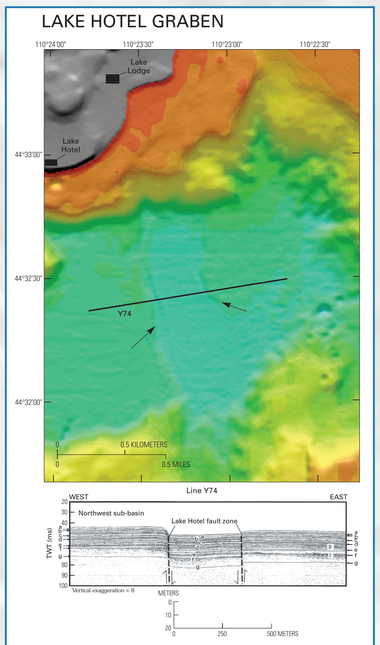


Figure 1. The Lake Hotel graben is an active structure in the northern basin of Yellowstone Lake with initial movement occurring between 15,000 to 12,000 years ago and most recently between 3,000 to 100 years ago. The Lake Hotel graben is a northern extension of the Eagle Bay fault (see geologic map; Morgan and others, 2003; Johnson and others, 2003). The line, Y74, represents a seismic reflection profile (see inset) across the Lake Hotel graben. Arrows indicate edges of graben.

SILICEOUS SPIRES IN BRIDGE BAY

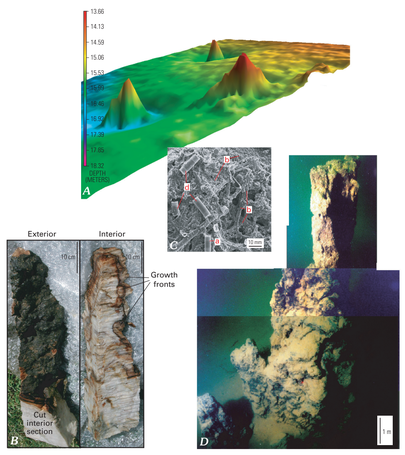


Figure 2. *A*, Oblique bathymetric image of siliceous spires in the Bridge Bay area showing their conical forms occupying hydrothermal vent depressions; *B*, photographs of the interior and exterior of a 1.4-m spire; *C*, scanning electron microscopic image of a spire sample showing silicified filamentous bacteria (b), diatoms (d), and amorphous silica (a); and *D*, photomosaic of spire in Bridge Bay (photograph by David A. Lovalvo, Eastern Oceanics).

WEST THUMB BASIN

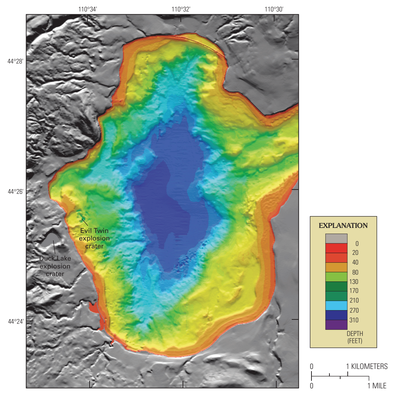


Figure 3. High-resolution, multi-colored bathymetric map of West Thumb basin surrounded by a gray-shaded topographic-relief map. Sediment-veneered, post-caldera rhyolitic lava flows partly fill the interior of the <200,000-year-old West Thumb caldera within the larger 640,000-year-old Yellowstone caldera. Rhyolitic lava flows contribute significantly to the morphology of the northern two-thirds of Yellowstone Lake (see geologic map).

VIEW OF YELLOWSTONE LAKE FROM SOUTH

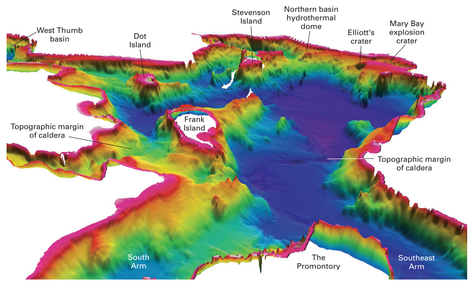
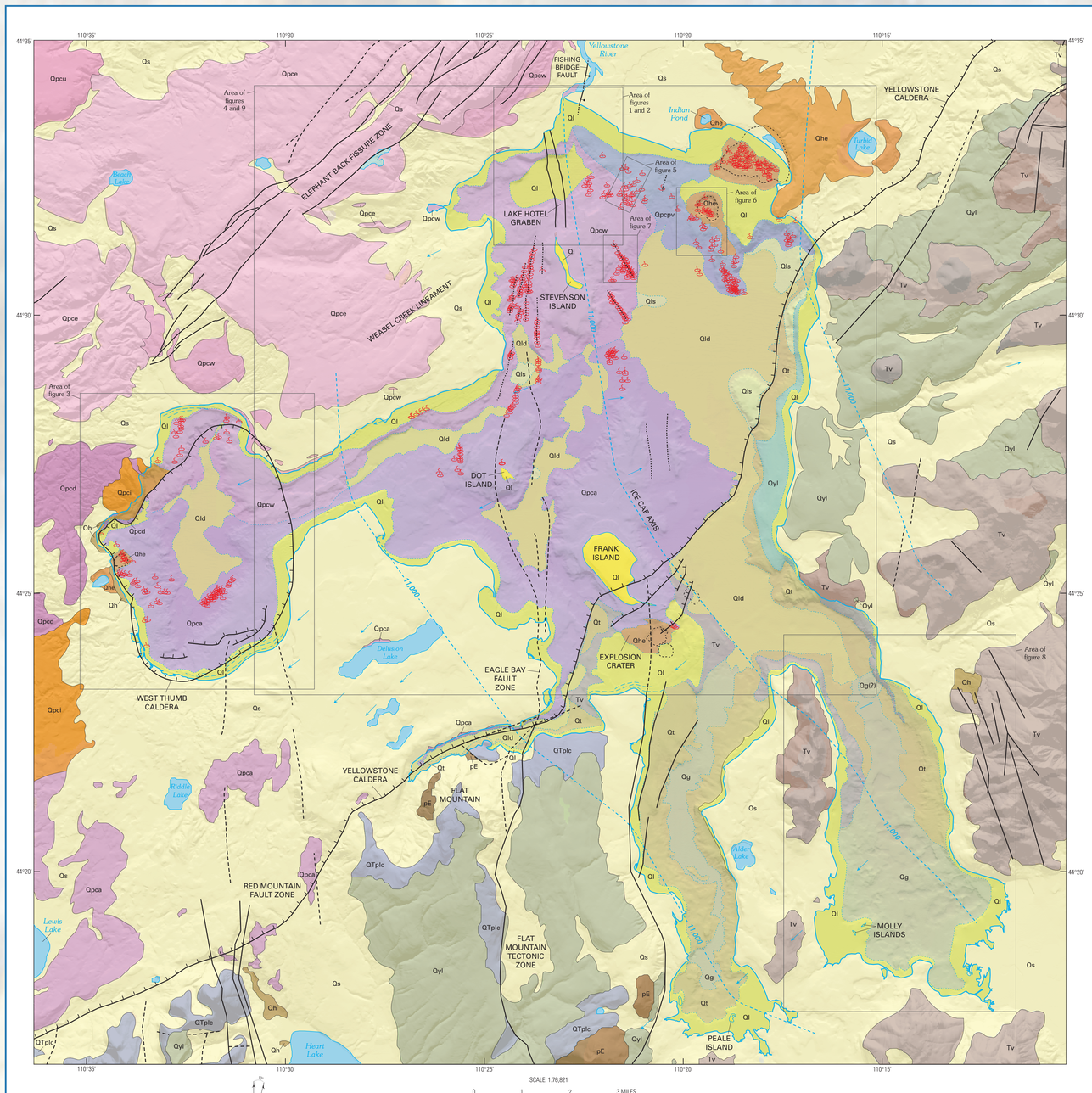


Figure 4. Oblique bathymetric image of Yellowstone Lake viewed from The Promontory northward into the 640,000-year-old Yellowstone caldera.



EXPLANATION

QUATERNARY UNITS

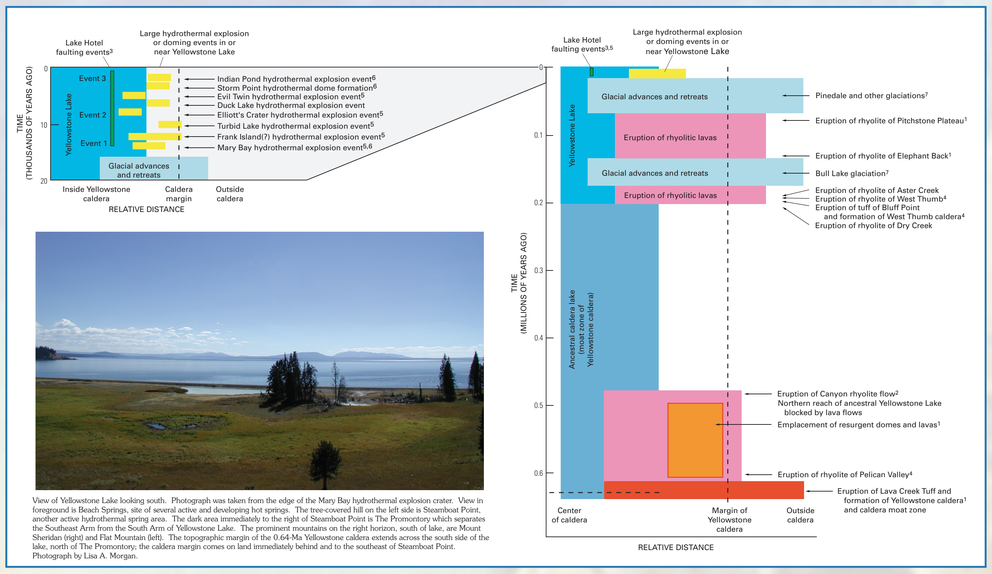
- Qs — Sediments
- Ql — Shallow-lake sediments—Shallow water deposits and submerged shoreline deposits
- Qld — Deep-lake sediments—Laminated deep-basin deposits
- Qhe — Hydrothermal-explosion deposits
- Qh — Hydrothermal deposits
- Qls — Landslide deposits
- Qt — Talus and slope deposits
- Qg — Glacial(?) deposits
- Qpcu — Spruce Creek rhyolite flow
- Qpce — Elephant Back rhyolite flow
- Qpcw — West Thumb rhyolite flow
- Qpca — Aster Creek rhyolite flow
- Qpci — Tuff of Bluff Point
- Qpcd — Dry Creek rhyolite flow
- Qpcpv — Pelican Creek rhyolite flow
- Qyl — Lava Creek Tuff

OLDER UNITS

- QTplc — Quaternary and Tertiary pre-Lava Creek Yellowstone Group rhyolites, undifferentiated
- Tv — Tertiary volcanic rocks, undifferentiated
- pE — Pre-Eocene rocks, undifferentiated

- Contact
- Fracture, fault—Dashed where approximately located or inferred; dotted where concealed; bar and ball on downthrown side
- Caldera margin and related structures
- Hydrothermal explosion crater
- Hydrothermal vent
- Direction of 16-ka ice flow
- Underwater contact
- ~ 11,000 ~ Contour on upper surface of 16-ka ice cap
- Yellowstone Lake shoreline
- Submerged shoreline
- Water

GEOLOGIC MAP OF YELLOWSTONE LAKE



View of Yellowstone Lake looking south. Photograph was taken from the edge of the Mary Bay hydrothermal explosion crater. View in foreground is Beach Springs, site of several active and developing hot springs. The tree-covered hill on the left side is Steamboat Point, another active hydrothermal spring area. The dark area immediately to the right of Steamboat Point is The Promontory which separates the Southeast Arm from the South Arm of Yellowstone Lake. The prominent mountains on the right horizon, south of lake, are Mount Sheridan (right) and Flat Mountain (left). The topographic margin of the 0.64-Ma Yellowstone caldera extends across the south side of the lake, north of The Promontory; the caldera margin comes on land immediately behind and to the southeast of Steamboat Point. Photograph by Lisa A. Morgan.

SCHEMATIC DIAGRAM SHOWING MAJOR GEOLOGICAL EVENTS CONTRIBUTING TO FORMATION OF YELLOWSTONE LAKE AND SURROUNDING VICINITY OVER TIME

NORTHERN BASIN HYDROTHERMAL DOME

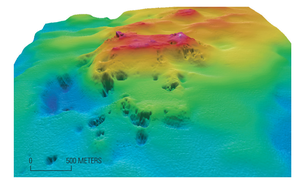


Figure 5. Oblique bathymetric image of the "northern basin hydrothermal dome" of Yellowstone Lake showing its domal structure and pockmarks indicating dozens of active hydrothermal vents. Note areas to the northeast have similar dome morphologies and may represent formerly active hydrothermal fields.

ELLIOTT'S CRATER

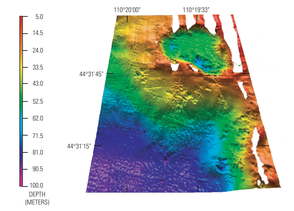


Figure 6. Oblique, shaded-relief, high-resolution bathymetric image of the 5,000- to 8,000-year-old Elliott's hydrothermal explosion crater, showing small vents and domes in the lacustrine sediments that overlie the crater flank. Younger explosions in the southern part of the large crater have created new, smaller craters and associated hydrothermal vents.

THE DEEPEST HYDROTHERMAL VENT ON THE FLOOR OF YELLOWSTONE LAKE

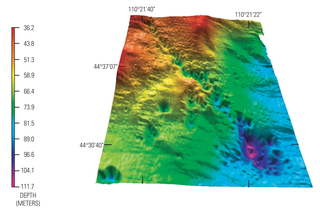


Figure 7. Oblique, shaded-relief, high-resolution bathymetric image of hydrothermal vent craters along a northwest-trending fissure east of Stevenson Island. In the deepest part of Yellowstone Lake, at 130-m depth, vigorous hydrothermal vents with T > 120° C occur in a 200-m-wide hydrothermal crater.

SOUTHEAST ARM

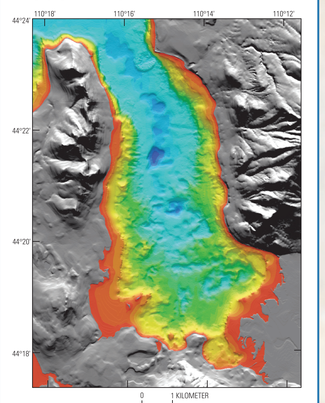


Figure 8. High-resolution bathymetric map of the Southeast Arm of Yellowstone Lake surrounded by gray-shade topographic-relief map. The floor of the lake, at this locality, has been shaped primarily by glacial processes as seen in the many kettle and glacial meltwater features present.

TOPOGRAPHIC MARGIN OF YELLOWSTONE CALDERA

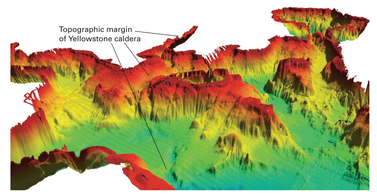


Figure 9. View of Yellowstone Lake from the northeast, looking south along the topographic margin of Yellowstone caldera.

METHOD

High-resolution, multi-beam sonar mapping of Yellowstone Lake was conducted by the U.S. Geological Survey in conjunction with the National Park Service from 1999 to 2002. Yellowstone Lake is the largest high-altitude lake in North America, at an altitude of 2,357 m with a surface area of 341 km^2 (sheet 1). More than 140 rivers and streams flow into Yellowstone Lake. The Yellowstone River, which enters at the southern end of the lake into the Southeast Arm (sheet 1), dominates the inflow of water and sediment (Shanks and others, 2005). The only outlet from the lake is at Fishing Bridge where the Yellowstone River flows northward discharging 375 to 4,600 cubic feet per second.

The multi-beam sonar mapping occurred over a four-year period beginning in 1999 with mapping of the northern basin, continued in 2000 in West Thumb basin, in 2001 in the central basin, and in 2002 in the southern part of the lake including the Flat Mountain, South, and Southeast Arms (sheet 1, index map). The multi-beam swath-bathymetric surveys employed a SeaBeam 1180 (180 kHz) instrument with a depth resolution of <1 percent of the water depth. Water depth in the survey areas varied from approximately 4 to 133 m. The multi-beam instrument used 126 beams arrayed over a 150° ensonification angle to map a swath width of 7.4 times water depth (sheet 1, index map). The new survey, with locations controlled within <1 m both horizontally and vertically using differential GPS, utilized more than 244 million soundings to produce high-resolution continuous-overlapping coverage of the lake's bathymetry (sheet 1).

Seismic-reflection records of the upper 25 m of the lake bottom also were obtained in 1999, 2000, 2001, and 2003. The seismic-reflection profiling utilized an EdgeTech SB-216S, that sweeps a frequency range from 2 to 10 kHz and has a beam angle of 15°–20°. Both the swath-unit transducer and the sub-bottom seismic unit were rigidly mounted to the transom of the National Park Service RV "Cutthroat," an 8-m-long aluminum boat.

Using the bathymetric and seismic data in addition to the high-resolution aeromagnetic data acquired in 1996 (Finn and Morgan, 2002) and previous on-land geologic mapping (U.S. Geological Survey, 1972; Christiansen, 2001; Good and Pierce, 1996), a geologic map has been prepared and is included as sheet 2. Various bathymetric perspectives of the lake floor have been prepared by Boris Schulze of Sea Beam, L-3 Communications (written commun., 2001) and are included in sheet 2. The reader is referred to Morgan and others (2003), Johnson and others (2003), Morgan and others (2007), and Morgan and Shanks (2005) for further information on interpretation of the high-resolution surveys collected by the U.S. Geological Survey from 1999 to 2003.

ACKNOWLEDGMENTS

Special acknowledgment is given to David A. Lovalvo of Eastern Oceanics, LLC who helped organize and coordinate mapping operations and designed, built, and piloted the remotely operated submersible used for sampling and observations. Special thanks are given to Boris Schulze, Jurg Dühn, Peter Gimpel, and Elak-L3 Communications for multi-beam system operation, data acquisition, and preliminary data processing. We also specifically thank and acknowledge Boris Schulze for the creation of the bathymetric images shown on sheet 2. We acknowledge the following for their various contributions to the success of this project: John Varley, Mike Finley, Paul Doss, Pat Leahy, Kate Johnson, Steve Bohlen, Christie Hendrix, Ann Duetsch, Geoff Plumlee, Ed duBray, Linda Gunderson, Dick Jahouski, Ken Pierce, Bill Stevenson, Tom Oliff, Hank Heasler, Carol Finn, Sam Johnson, Tom Casadevall, Erica Jo Thompson, Denny Fenn, Steve Harlan, John Lonsbury, Rick Fey, Lloyd Kortge, Suzanne Lewis, Frank Walker, Todd Koel, Harlan Kredit, Pat Bigelow, and Bill McIntosh. The authors thank and acknowledge Ken Pierce, Bob Christiansen, Hank Heasler, and Cheryl Jaworoski for their thorough and insightful reviews of the geologic map and many productive discussions. The authors are very grateful to Gayle Dumonceaux, Laurie Morath, and Greg Green for their assistance in ArcGIS and graphics on the maps.

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GEOLOGIC MAP AND BATHYMETRIC PERSPECTIVE VIEWS OF THE FLOOR OF YELLOWSTONE LAKE

BATHYMETRY AND GEOLOGY OF THE FLOOR OF YELLOWSTONE LAKE, YELLOWSTONE NATIONAL PARK, WYOMING, IDAHO, AND MONTANA

By

Lisa A. Morgan, W.C. Pat Shanks, Gregory K. Lee, and Michael W. Webring

2007

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