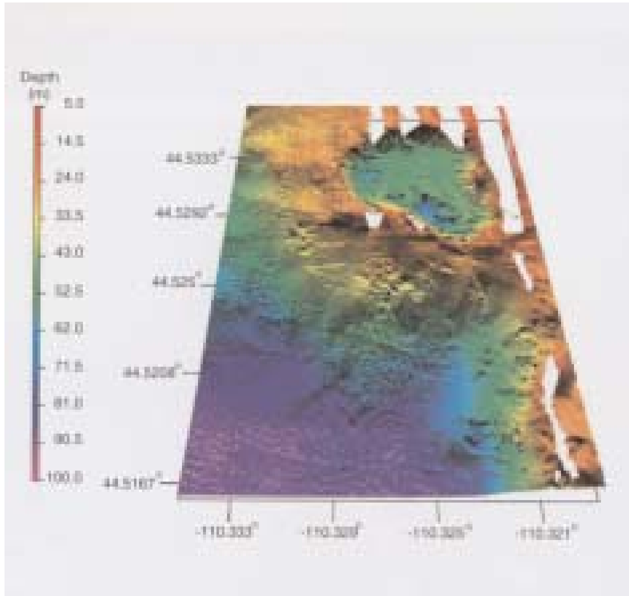
alteration or, in places, alteration due to emplacement of lava flows into water, such as ancestral Yellowstone Lake. For example, the West Thumb rhyolite flow due west of the Yellowstone River is glassy, flow-banded, and fresh; the magnetic intensity values in this area generally are high (Figures 1B, 1C, 2C). In contrast, in areas where flows were emplaced into water, such as the West Thumb rhyolite flow exposed on the northeast shore of West Thumb basin (Figures 1B, 2B), magnetic intensity values are low (Figure 1C). The low magnetic values of flows emplaced into water may be primarily carried by the fine-grained and altered matrix in the massive rhyolitic breccias, highly fractured perlitic vitrophyre, clastic dikes, and entrained stream, beach, and lake sediments in an altered matrix.



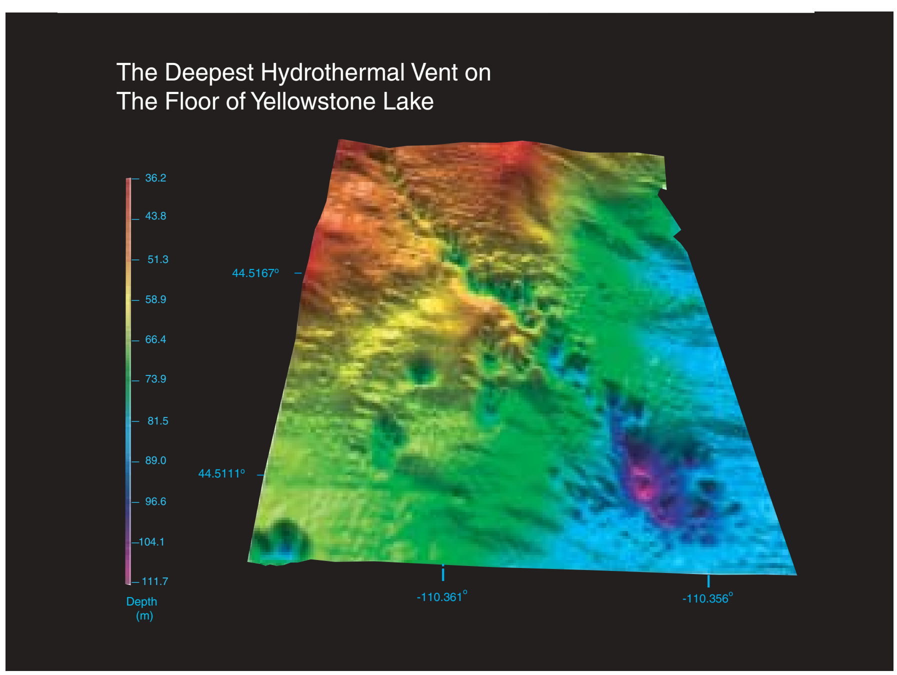


Plate 3. (A) High-resolution bathymetric image of hydrothermal siliceous spires on the lake floor. (B) High-resolution bathymetric image of hydrothermal vent craters along a northwest-trending fissure east of Stevenson Island. The deep hole at the southeastern end of the trend is one of the largest hydrothermal vent areas in the lake, and is also the deepest point in the lake at 133 m.

Large hydrothermal explosion craters.

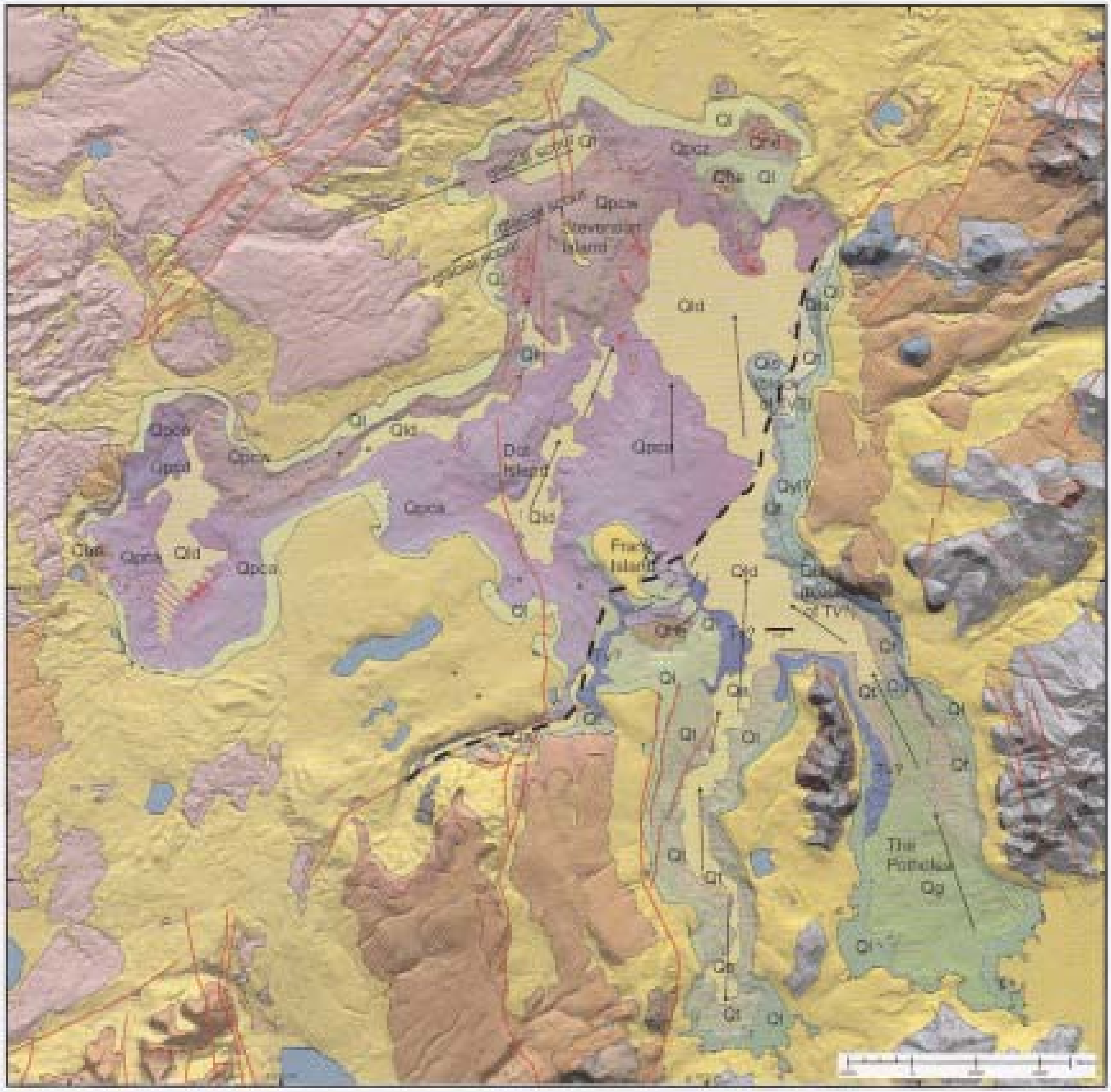
Subaerial hydrothermal explosions have occurred repeatedly in YNP over the past 12 ka, and are confined primarily within the boundaries of the Yellowstone caldera (Figure 1). Large (>500 m), circular, steep-walled, flat-bottomed depressions are mapped at several sites in Yellowstone Lake in the West Thumb, central, and northern basins (Figure 2). These are interpreted as large composite hydrothermal explosion craters similar in origin to those on land, such as Duck Lake, Pocket Basin, the Turbid Lake crater, and the Indian Pond crater (Figures 1B, 2B, 2C).

A newly-discovered, 500-m-diameter, sublacustrine explosion crater in the western part of West Thumb basin, near the currently active West Thumb Geyser Basin, is only 300 m northeast of Duck Lake (Figures 2A, 2B), a postglacial (<12 ka) hydrothermal explosion crater. Here, heat-flow values are as high as 1500mW/m^2, reflecting the hydrothermal activity that contributed to the formation of the offshore explosion crater. The 500-m-wide West Thumb explosion crater is surrounded by 12– 20 m high, nearly vertical walls, and has several smaller nested craters along its eastern edge. These nested craters are as deep as 40 m, and are younger than the main crater. Temperatures of hydrothermal fluids emanating from the smaller northeast nested crater have been measured by ROV at 72°C.

Another newly-discovered, large, subaqueous hydrothermal explosion crater is the >600-m-wide elongate, steep-walled, flat-floored crater south of Frank Island (Figure 2D). Muted topography suggests that this explosion crater is one of the oldest still recognizable in Yellowstone Lake. Further, this crater occurs in an area where heat flow values are at present relatively low. Submersible investigations do not indicate hydrothermal activity within the crater.

In the northern basin of Yellowstone Lake, Mary Bay contains a roughly 1-km by 2-km area of coalesced explosion craters (Figures 2A, 2C), thus making it the world's largest known hydrothermal explosion system. Boiling temperature in the deep part of Mary Bay is about 160ºC. Submersible investigations show that fluids from a 35-m-deep hydrothermal vent have temperatures near the 120ºC limit of the temperature probes used, reflecting extremely high-heat flow values in this

Plate 2. Preliminary geological map of Yellowstone Lake.



Ql: Quaternary shallow lake sediments (shallow water deposits and submerged shoreline deposits)

Qhe: Quaternary hydrothermal explosion deposits

Qa: Quaternary alluvium (deltaic sediments)

Qld: Quaternary deep lake sediments (laminated deep-basin deposits)

Qls: Quaternary land slide deposits and blocks

Qt: Quaternary talus and slope deposits

Qg: Quaternary glacial deposits

Qpcz: Quartemary Pelican Creek flow

Qpce: Quaternary Elephant Back flow

Qpcw: Quaternary West Thumb flow

Qpca: Quaternary Aster Creek flow

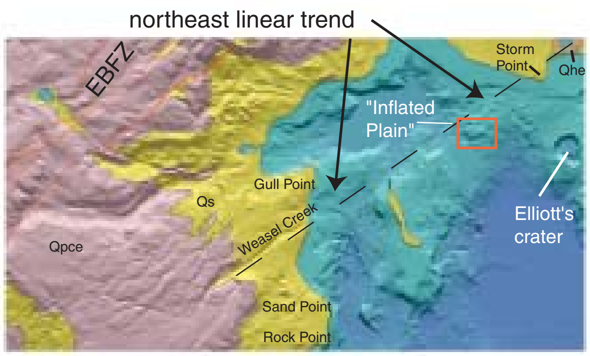
Qpcl: Quaternary tuff of Bluff Point

Qpcd: Quaternary Dry Creek flow

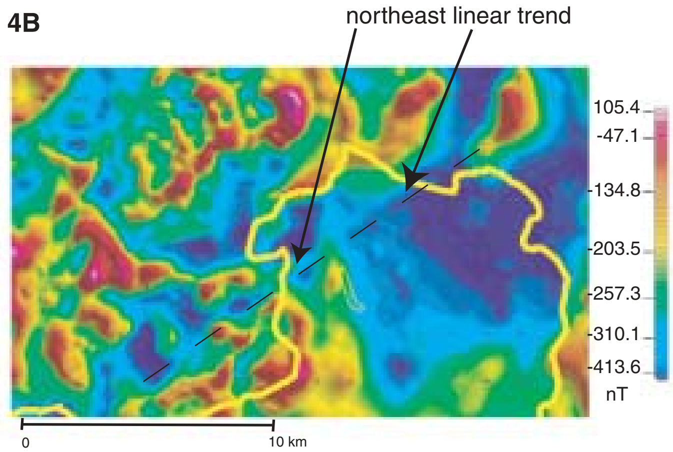
Tv: Tertiary volcanic rocks (undifferentiated)

Figure 4. (right facing page) **(A)** High-resolution blue shaded-relief bathymetric map of the northern basin of Yellowstone Lake highlighting the location of the "Inflated Plain," Storm Point, Elliott's hydrothermal explosion crater, the Elephant Back Fault Zone (EBFZ), and a northeast linear trend. **(B)** High-resolution aeromagnetic map (Finn and Morgan, 2002) of the area shown in Figure 4A. The shoreline of Yellowstone Lake is represented by a solid yellow line. Stevenson Island is shown as a thin solid yellow line. Note the location of the "Weasel Creek lineament." **(C)** Grey-shaded bathymetric close-up image of the "Inflated Plain." Illumination is from due north with a sun-angle of 45°. **(D)** Grey-scale amplitude map of the same area shown in Figure 4C. Bright areas are reflective due to their relative hardness and degree of silicification. Dark areas are sites of active hydrothermal vents. The range of reflectivity is from 26–20 dB. **(E)** Two-dimensional color bathymetric map of the "Inflated Plain." Area shown in black box is the area shown in Figures 4D and E. Total depth ranges from 5.56–49.76 m. **(F)** Three-dimensional color-shaded relief image of the "Inflated Plain." Area shown is same as area in Figure 4E; the image is rotated so that north is at 340° and is tilted 20°. Total depth ranges from 5.56–49.76 m. Data shown in Figure 4 are from 2002 mapping, when the "Inflated Plain" was resurveyed.

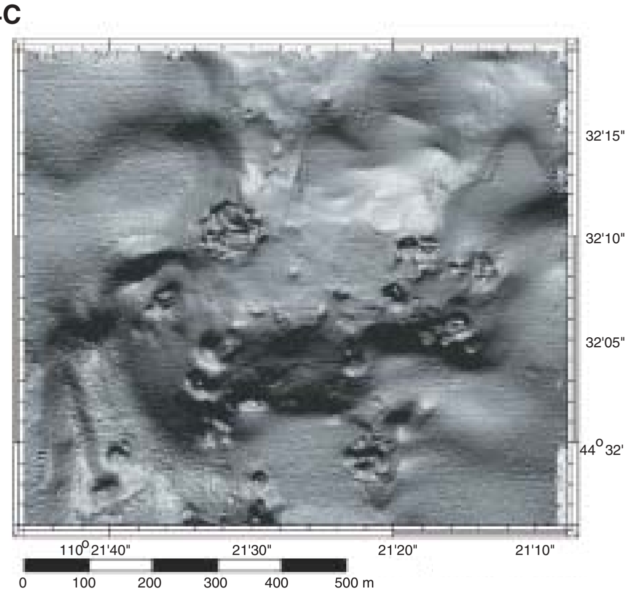
4A



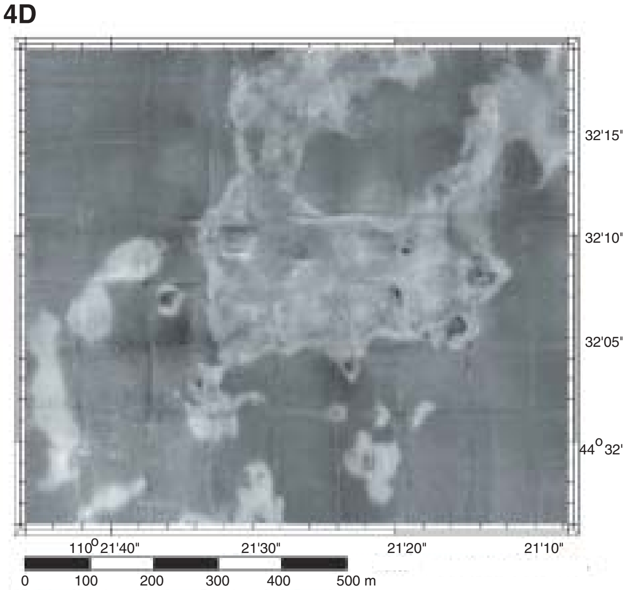
4B



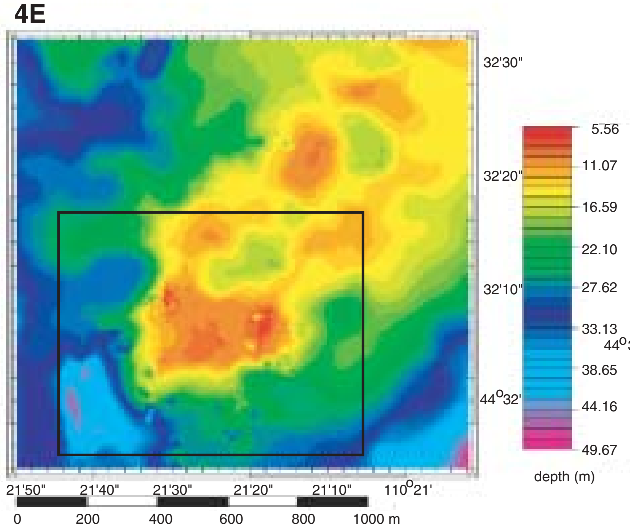
4C



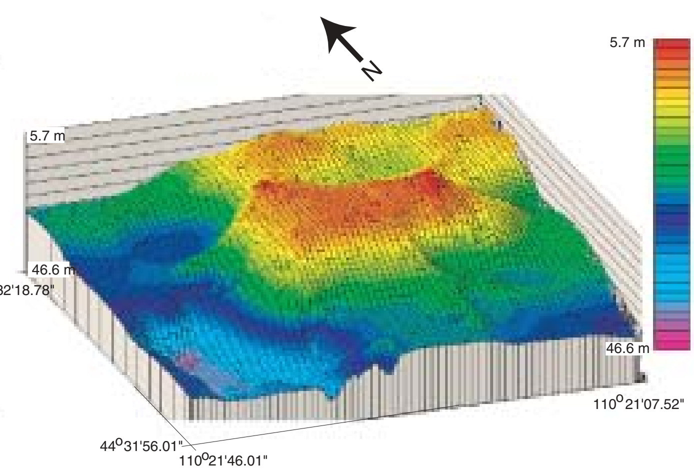
4D



4E



4F



area. Radiocarbon dates from charcoal in breccia deposits and underlying soils exposed in the wave-cut cliffs along the Mary Bay shore indicate that eruption of this crater occurred at 13.4 ka. Detailed stratigraphic measurements of the breccia deposit indicate that multiple explosions and emplacements occurred during formation of this large and complex feature.

A dark, clean, well sorted, cross- to planar-bedded, generally fine-grained sand overlying varved lake sediments occurs as a sedimentary interbed between breccia deposits within the Mary Bay breccia deposit. These types of deposits are likely ephemeral, and the likelihood of their preservation in the stratigraphic record is slight. The sand unit below the Mary Bay breccia is 1.5 to > 2 m thick and contains numerous small en echelon faults. These deposits are similar to other paleoseismites. We conclude that this sand unit represents a deposit from a possible earthquake-generated tsunami-like wave, which may be related to triggering the explosion of the Mary Bay crater complex.

One kilometer southwest of the Mary Bay crater complex is another newly-discovered, large (~800-m-diameter), composite depression informally referred to as Elliott's crater (Figure 2C, Plate 3A), named after Henry Elliott who helped map Yellowstone Lake in the 1871 Hayden survey. Development of Elliott's hydrothermal explosion crater is best illustrated in a north–south seismic reflection profile (Figure 3B). Zones of non-reflectivity in the seismic profile on the floor and flanks of the large crater probably represent hydrothermally altered, and possibly heterolithic explosion-breccia deposits, similar in character to those exposed on land and associated with subaerial explosion craters. Seismic profiles in the hummocky area southeast of Elliott's crater are also non-reflective, and may represent a layer of heterolithic and/or hydrothermally altered material erupted from this crater. In contrast to the subaerial craters, which have radial aprons of explosion-breccia deposits that rim the crater, many of the sublacustrine circular depressions lack an obvious apron. This may indicate either more widespread dispersal of ejection deposits in the lake water or that some other process, such as catastrophic collapse of sealed cap rock, created the depressions.

Following the initial major explosive event of Elliott's crater, lacustrine sediments accumulated in the floor of the crater and on its south flank. Based on sedimentation rates in the lake, post-eruptive sediment thickness of ~8 m indicates the main hydrothermal explosion occurred between 8 and 13 ka. Opaque zones within the stratified sedimentary fill of the crater indicate the presence of hydrothermal fluids and/or gases. The presence of two younger craters at the south end of the main crater floor further indicates more recent hydrothermal activity, and possibly younger explosions. A north-south seismic profile across Elliott's crater shows about 10 m of vertical difference in height between the rims. This difference may result from doming associated with hydrothermal activity prior to initial explosion.

Hydrothermal vents on the floor of Yellowstone Lake.

Geochemical studies of the vents indicate that ~10% of the total deep thermal water flux in Yellowstone National Park occurs on the lake bottom. Hydrothermal fluids containing potentially toxic elements (arsenic, antimony, mercury, molybdenum, tungsten, and thallium) significantly influence lake chemistry, and possibly the lake ecosystem. ROV observations indicate that shallow hydrothermal vents are home to abundant bacteria and amphipods that form the base of the local food chain that includes indigenous cutthroat trout, grizzly bears, bald eagles, and otters that feed on the potamodromous cutthroat trout during spawning in streams around the lake.

In seismic reflection profiles (Figure 3B), hydrothermal vent features are typically imaged as V-shaped structures associated with reflective layers that are deformed or have sediments draped across their edges. Areas of high opacity or no reflection occur directly beneath them, and are interpreted as gas pockets, gas-charged fluids, or hydrothermally-altered zones. Evidence for lateral movement of hydrothermal fluids is seen beneath and adjacent to hydrothermal vents identified in the seismic reflection profiles. The areas of opacity in the seismic data, and of low values of magnetic intensity in the aeromagnetic data, represent larger zones of hydrothermal alteration than seen in the surficial hydrothermal vents.

Seismic reflection profiles of the surveyed areas in the northern, central, and West Thumb basins of Yellowstone Lake reveal a lake floor covered with laminated, diatomaceous, lacustrine muds, many of which are deformed, disturbed, and altered. High-resolution bathymetric mapping reveals that many areas contain small (<20 m) depressions pockmarking the lake bottom (Plate 2, cover).

Many vent areas are associated with smaller domal structures in which the laminated, diatomaceous, lacustrine sediments have been domed upward as much as several meters by underlying pockets of gas or gas-charged fluids, presumably rich in steam and possibly CO_2. Hydrothermal activity beneath the domes silicifies the sediments causing them to become sealed, impermeable, and weakly lithified so that their resultant compaction is minimal. The unaltered zones of muds surrounding these domes become more compacted over time and contribute to the overall domal morphology. These domal structures may be precursors to small hydrothermal explosions, collapse zones, and areas where active hydrothermal venting may develop in the future.

An active domal structure informally referred to as the "Inflated Plain" was originally recognized in the 1999 bathymetric survey of the northern basin as a relatively large "bulge-like feature". The "Inflated Plain" covers a roughly circular area with a diameter of ~1 km, and rises several 10s of meters above the surrounding lake floor. This area hosts numerous active and vigorous hydrothermal vents, smaller domal structures, and vent deeps.

As seen in Figure 4A, the "Inflated Plain" lies along a northeast linear trend in line with Storm Point and Indian Pond, both areas of hydrothermal explosion origin, to the northeast; an unnamed trough to the southwest; and Weasel Creek farther southwest, west of the lake (Figure 2B, 4A). We informally refer to the northeast linear trend as the "Weasel Creek lineament." Weasel Creek is an unusually straight drainage, as are two smaller subparallel drainages due north of it, and may represent a linear zone of weakness. The "Weasel Creek lineament" also is reflected as a linear zone of low magnetic intensity in the high-resolution magnetic map of the area (Figure 4B), and may reflect a zone of upwelling hydrothermal fluids that have contributed significantly to the demagnetization of the rocks present. This structure appears to left-laterally offset to the "outlet graben" to the north from an incipient graben to the south associated with the "fissures."

In summer 2002, while traversing the "Inflated Plain" area in the boat, *RV Cutthroat*, we noted a strong scent of H^2S, a 10–30-m diameter plume of fine sediments, and large concentrations of bubbles, many of them quite vigorous, at the lake surface. The fine sediment plume was detected by the fathometer as a strong reflector, concentrated ~3 m below the lake surface. For Dave Lovalvo, this was the first time in 18 years of working in this area that any of these phenomena have been observed. The depth of the lake floor here is ~28 m.

A close-up, bathymetric image of the "Inflated Plain" (Figure 4C) shows a bulging, domal structure, pockmarked with numerous hydrothermal vents and craters. Clear evidence of hydrothermal alteration is seen in the amplitude map (Figure 4D), where bright areas are reflective due to their relative hardness and degree of silicification. Figures 4E and F show the "Inflated Plain" in 2-dimensional and 3-dimensional perspectives, respectively, and plainly demonstrate how this feature rises as much as 30 m from the lake floor.

Siliceous spires.

Siliceous spires in Bridge Bay (Figure 2B), in the northern basin of Yellowstone Lake, were discovered by Dave Lovalvo in 1997, and are described here because they represent an end-member of hydrothermal deposit development in the lake, clearly imaged by multibeam sonar studies. Approximately 12–15 spires are identified in water depths of 15 m. These roughly conical structures (Figure 5A) are up to 8 m in height and up to 10 m wide at the base. A small, 1.4-m-tall spire collected from Bridge Bay in cooperation with the National Park Service in 1999 shows the spire base to be shallow (~0.5 m below the sediment-water interface), irregular, and rounded; spire material above the lake floor constitutes about 75% of the entire structure. The lake floor level is recorded on the spire as a zone of banded ferromanganese, oxide-stained, clay-rich, and diatomaceous sediments. Below the lake floor, the spire is not oxidized, whereas above it, the spire has a dark, reddish-brown, oxide coating (Figure 5B). The interior of the collected spire is white, finely porous, and has thin (from 0.3 cm to <3 cm diameter), anastomozing vertical channels through which hydrothermal fluids flowed. Little oxide occurs in the interior of the spire structure, but oxidation surfaces are present on former growth fronts (Figure 5B). Chemical and oxygen-isotope analyses and scanning electron microscope (SEM) studies of spire samples show them to be composed of silicified bacteria, diatom tests, and amorphous sil-

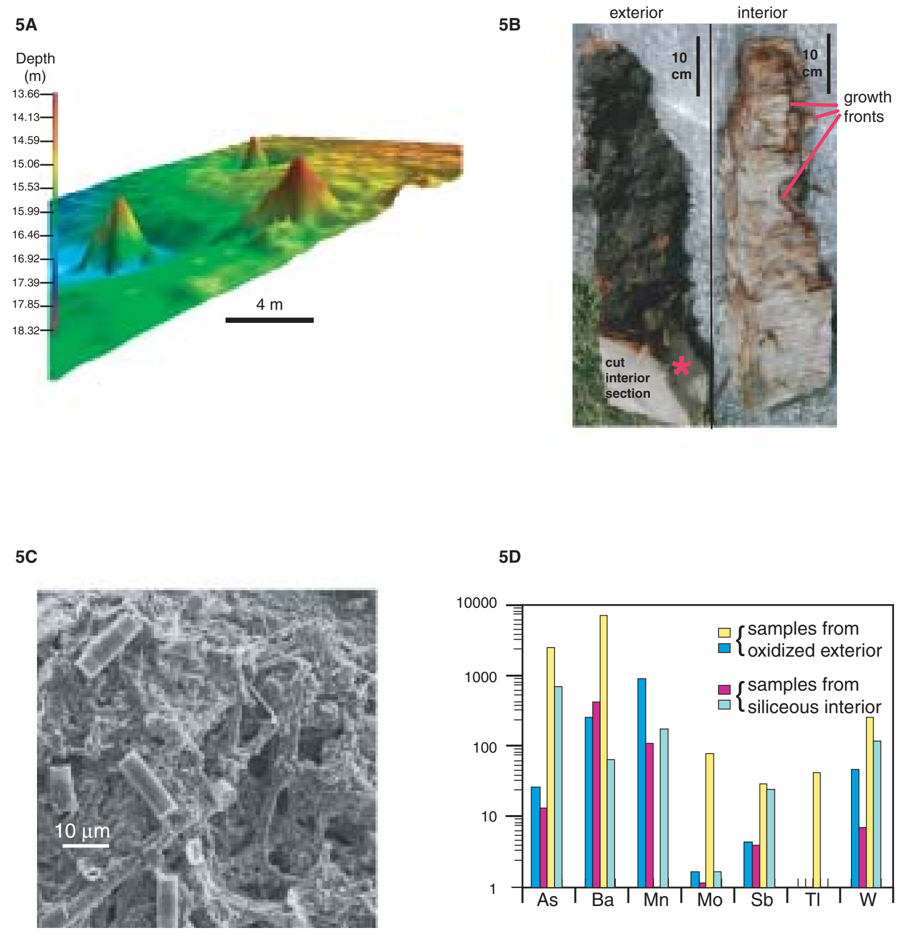


Figure 5. (A) Bathymetric image of spires in Bridge Bay, showing roughly conical shapes. About a dozen such siliceous sinter spires occur near Bridge Bay, some as tall as 8m. Many of the spires occupy lake-bottom depressions (possible former explosion or collapse craters). (B) Photographs of the exterior and interior of a 1.4-m-tall spire sample recovered from Bridge Bay by NPS divers. The sediment-water interface of this spire is apparent near the base of the exterior section, as seen in the dramatic change in color in the outer rind of red-brown ferromanganese oxide to the light gray interior. (The red asterisk on the photograph showing the exterior is on a natural external surface of the spire below the sediment-water interface.) Former growth fronts on the spire can be seen as shown in the photograph of the interior section. (C) SEM image of diatoms, silicified filamentous bacteria, and amorphous silica from a spire sample. (D) Summary bar graph of chemical analyses of spire samples showing substantial concentrations of potentially toxic elements arsenic, barium, manganese, molybdenum, antimony, thallium, and tungsten.

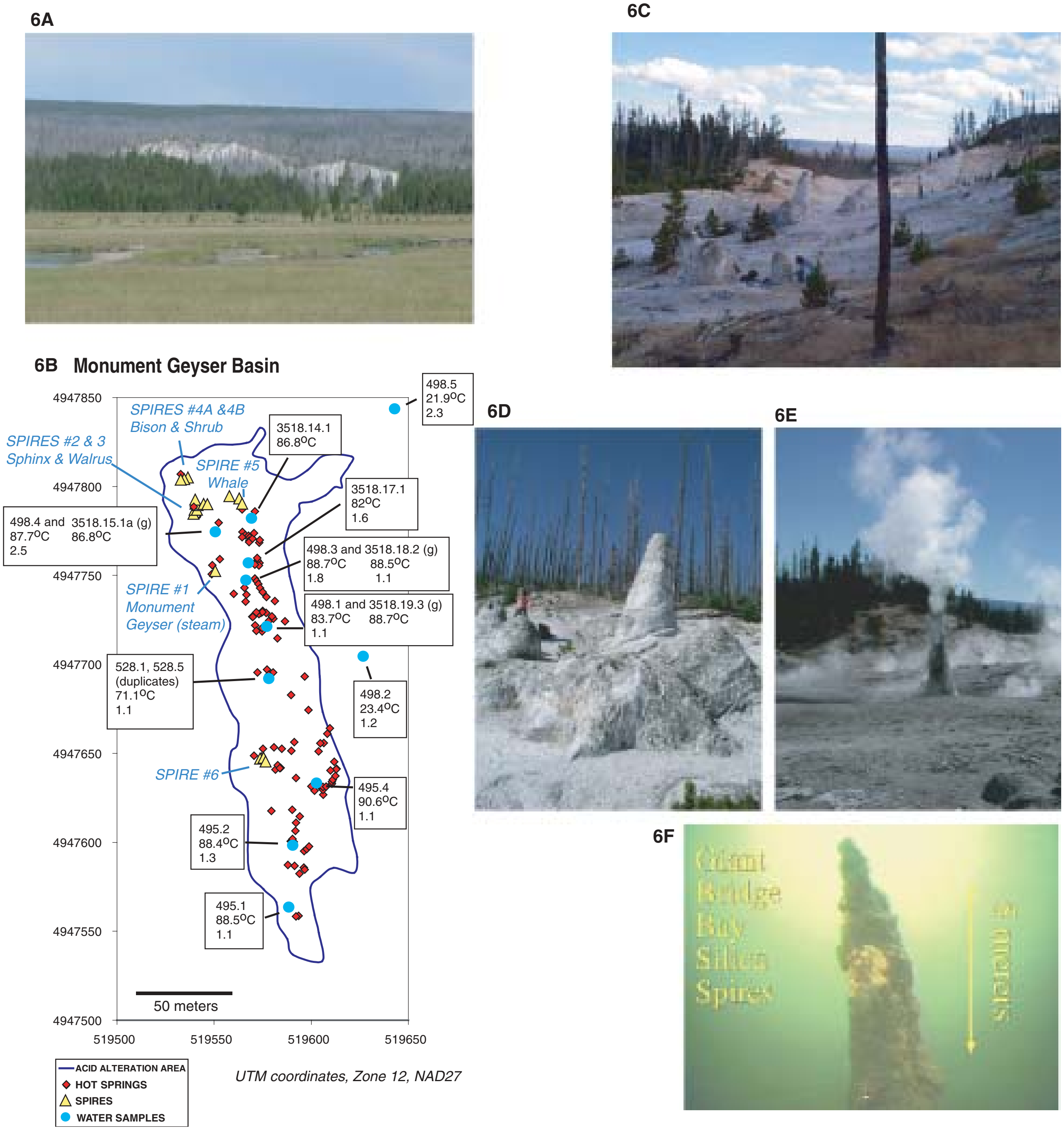


Figure 6. (A) Monument Geyser Basin caps a larger hydrothermal system along a north–northwest-trending fissure. The area in white is composed of hydrothermally-altered Lava Creek Tuff. (B) Index map of Monument Geyser Basin showing the extent of hydrothermal alteration and distribution of the spire-like structures, hot springs, and water-sample localities. The values in the boxes represent individual sample numbers, temperatures, and pH. (C) Looking south into Monument Geyser Basin. Note that the basin has a central trough and contains as many as seven spire-like siliceous structures. (D) Spire-like structure on the northern edge of the basin, informally referred to as the Walrus. (E) Another spire-like structure actively venting steam and $H^{2}S$. This structure is ~2m tall. (F) Underwater photograph of a large (~8 m) spire structure in Bridge Bay in the northern basin of Yellowstone Lake. The subaerial structures at Monument Geyser Basin are very similar to the spires in Bridge Bay (in terms of size, scale, distribution) and are irregular in form.

ica produced by sublacustrine hydrothermal vent processes (Figure 5C).

Geochemical studies of lake waters, hydrothermal vent fluids, and waters in tributary streams show that Yellowstone Lake waters and vent fluids are enriched in As, Mo, Tl, Sb, and W. Similarly, the Bridge Bay spires are strongly enriched in As, Ba, Mn, Mo, Tl, Sb, and W (Figure 5D). Oxygen isotopic values suggest formation of the spires at about 70–90°C. U-series disequilibrium dating of two samples from one spire yields dates of about 11 ka; thus, the spire analyzed is immediately postglacial. Spires may be analogous in formation to “black-smoker chimneys;” well-documented hydrothermal features associated with deep-seated hydrothermal processes at oceanic plate boundaries. They precipitate on the lake floor due to mixing between hydrothermal fluids and cold bottom waters.

Subaerial features analogous to the spires in Bridge Bay may be found at Monument Geyser Basin, located along the western edge of the Yellowstone caldera (Figure 1A), on a ridgetop along a northwest-trending fault in altered Lava Creek Tuff (Figure 6A). As Figure 6B shows, the number and distribution of the siliceous, spire-like structures at Monument Basin are similar to what is seen in Bridge Bay. In Bridge Bay, the spires are cold and inactive. The structures at Monument, like the spires in Bridge Bay, have irregular forms, and similar dimensions (Figures 6C, D, E, F). Currently, Monument Geyser Basin sits about 250 m above the water table, and emits highly acidic steam consistent with the intense alteration of the Lava Creek Tuff host rock. It is unlikely that the monuments formed from an acid-steam system, because steam has a very limited carrying capacity for SiO_2. We hypothesize these deposits also formed from a hot water system in an aqueous environment, probably related to a glacially-dammed lake during the waning stages of the Pinedale glaciation about 12–15 ka.

Fissures and faults.

Features identified in the western area of the northern and central basins (Figures 2A, C, D) include a set of sub-parallel, elongate, north-northeast-trending fissures west of Stevenson Island extending southward toward Dot Island (Figure 2A); a series of en echelon, linear, northwest-trending, fissure-controlled, small depressions east and southeast of Stevenson Island; and a graben north of Stevenson Island, nearly on strike with Lake Village (Figure 1B).

The subparallel fissures west of Stevenson Island (Figures 2A, C) cut as much as 10–20 m into the soft-sediment lake floor 0.5-km southeast of Sand Point. These fissures represent extension fractures whose orientation is controlled by regional north–south structural trends, recognized both north and south of Yellowstone Lake. Active hydrothermal activity is localized along the fissures as shown by dark oxide precipitates and warm shimmering fluids upwelling from them. The fissures, inspected with the submersible ROV for about 160 m along their NNE trend are narrow (<2 m wide), and cut vertically into soft laminated sediments. No displacement is observed. A parallel set of N–S-trending fissures also occurs 1.3-km northeast of Sand Point (Figure 2C). Farther south along this trend, the fissures appear to have well-developed hydrothermal vent craters, although investigations with the submersible show only weak or inactive vent fields in the central basin. Examination of the high-resolution magnetic intensity map of this area shows a linear zone of relatively lower magnetic intensities that spatially coincides with the fissures and graben (Figures 1C, 2B, 2D).

Observation of the features east of Stevenson Island (Figure 2C), using the submersible ROV, indicates that small, well-developed hydrothermal vents coalesce along northwest-trending fissures. A large hydrothermal vent at the south end of the northernmost set of aligned vents, in the deepest part of Yellowstone Lake, at 133 m (Plate 3B), emits hydrothermal fluids as hot as 120°C.

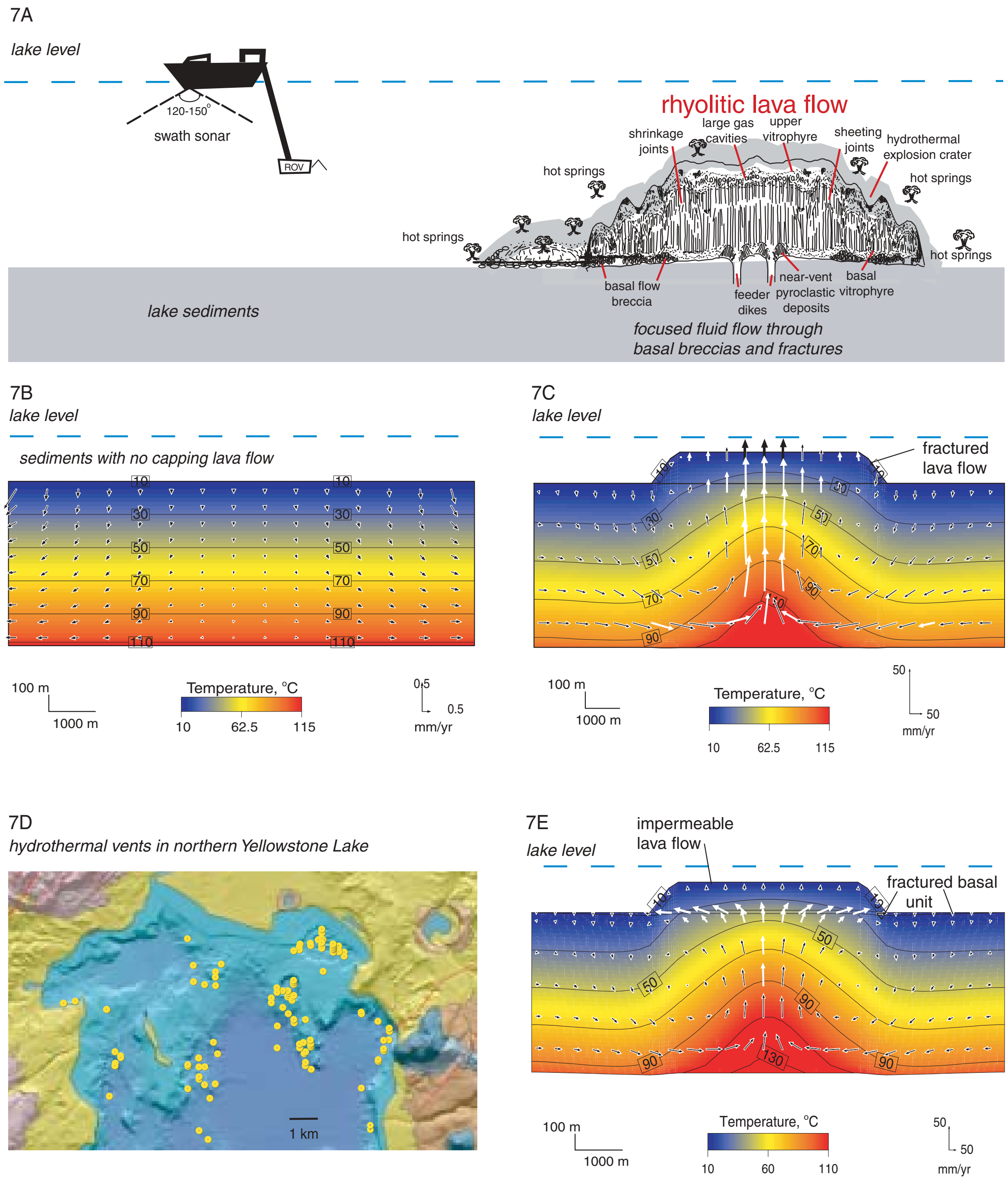
Finally, east–west seismic reflection profiles across the down-dropped block north of Stevenson Island reveal a north-northwest-trending graben structure bounded by normal faults. This graben, referred to as the Outlet graben, was identified by previous investigations, but our studies, using differential GPS navigation and high-resolution seismic and bathymetric data, provide the first accurate information on location and displacement of this important structure. Measured displacements along the two bounding faults are variable, but displacement along the western boundary is generally ~6 m, whereas that along the eastern normal fault is ~2 m. The eastern bounding fault cuts Holocene lake sediments, indicating recent movement. Seismic profiles across the graben indicate that it projects (or strikes) toward Lake Village (Figures 1B, 2C), posing a potential seismic hazard in that area.

Another incipient graben may be offset from and forming to the south-southwest of the Outlet graben, where the north-northeast fissures are identified. This structure is on trend with the Eagle Bay fault system.

The sublacustrine fissures and faults revealed by the high-resolution bathymetry are related to the regional tectonic framework of the northern Rocky Mountains, variable depths to the brittle-ductile transition zone, and the subcaldera magma chamber and play important roles in shaping the morphology of the floor of Yellowstone Lake. Many recently-identified features along the western margin of the northern and central basins, such as the active fissures west of Stevenson Island and the active graben north of it, are oriented roughly north–south, and are probably related to a regional structural feature in western Yellowstone Lake on strike with the Neogene Eagle Bay fault zone (Figure 1B). Seismicity maps of the Yellowstone region show concentrations of epicenters along linear north–south trends in the northwestern portion of the lake.

Landslide deposits.

Multibeam bathymetric data reveal hummocky, lobate terrain at the base of slopes along the margins, especially along the northeast and east of the lake basin (Figure 2A, Plate 2). Seismic reflection data indicate that the deposits range in thickness from $\geq$10 m at the eastern edge of the lake, and are recognizable as thin (<1m) units extending up to 500 m into the interior of the lake basin. We interpret these as landslide deposits. The thickness



of the lacustrine-sediment cap deposited above the landslide deposits is variable, and suggests that the landslides were generated by multiple events. We suggest the landslides were triggered by ground shaking associated with earthquakes and (or) hydrothermal explosions. The eastern shore of Yellowstone Lake, near where many of these landslide deposits occur, marks the margin of the Yellowstone caldera and abuts steep terrain of the Absaroka Mountains to the east, both possible factors contributing to landslide events. The volume of material identified in these deposits would result in a significant displacement of water in the lake, and may pose a potential hazard on shore.

Submerged shorelines.

Several submerged former lake shorelines form underwater benches in the West Thumb and northern basins of Yellowstone Lake (Figures 2A, B, and C). The submerged, shallow margins (depth <15-20 m) of the northern basin are generally underlain by one-to-three relatively flat, discontinuous, postglacial terraces that record the history of former lake levels. Correlation of these submerged shoreline terraces around the lake is based primarily on continuity inferred from multi-beam bathymetric data and shore-parallel seismic reflection profiles. These data indicate that lake levels were significantly lower in the past. An extensive bench occurs south of Steamboat Point and along the western shore of the northern basin south of Gull Point (Figure 2C). In Bridge Bay, submerged-beach pebbly sand 5.5 m below

Figure 7. (facing page). (A) Schematic diagram showing physical features of a rhyolitic lava flow. (B) Two-dimensional fluid-flow model with simple glaciolacustrine sedimentary aquifer (no cap rock), which results in low flow velocities, recharge at the surface, and lateral flow out of both ends of the model aquifer. Subsurface temperatures never exceed 114°C, as indicated by contours and color map. Fluid flow rates are low (<0.7 mm/y), as indicated by velocity vectors. (C) Fluid-flow model with a fully-cooled rhyolitic lava flow acting as cap rock. The underlying sedimentary aquifer and heat flow are exactly the same as in the previous model. The addition of a 200-m-thick fractured crystalline rock cap strongly focuses the upward limb of an intense convection cell under the cap rock. In this model, fluid temperatures reach 140°C, and flow velocities are as high as 150 mm/yr. (D) Locations of hydrothermal vents on the lake floor mapped using seismic reflection. Lava flow boundaries are based on high-resolution bathymetry and aeromagnetic data. (E) Fluid flow model that includes a basal breccia zone beneath an impermeable lava flow. In this case, the lower sedimentary unit is overlain by a thin, fractured lava flow unit (20-m-thick) that extends the entire width of the sedimentary prism. Above the more permeable basal unit is a 170-m-thick, low-permeability, unfractured lava flow. Flow vectors indicate strong upflow under the lava flow, with maximum subsurface temperatures of ~150°C and flow rates up to 160 mm/y. Upflow is deflected laterally within the 20-m-thick "basal" fractured zone toward the flow edges, resulting in hydrothermal venting on the lake floor near the margins of lava flows.

the present lake level yielded a carbon-14 date of 3,835 years. Well-developed submerged shoreline terraces are present in West Thumb basin, especially along its southern and northern edges.

Relief on these terraces is as much as 2–3 m, a measure of post-depositional vertical deformation. Documentation of the submerged terraces adds to a database of as many as nine separate emergent terraces around the lake. Changes in lake level over the last 9,500 radiocarbon years have occurred primarily in response to episodic uplift and subsidence (inflation and deflation) of the central part of the Yellowstone caldera. Holocene changes in lake level recorded by these terraces have been variably attributed to intra-caldera magmatic processes, hydrothermal processes, climate change, regional extension, and (or) glacioisostatic rebound.

Discussion

Do the newly discovered features in Yellowstone Lake pose potential geologic hazards?

The bathymetric, seismic, and submersible surveys of Yellowstone Lake reveal significant potential hazards existing on the lake floor. Hazards range from potential seismic activity along the western edge of the lake, to hydrothermal explosions, to landsliding associated with explosion and seismic events, to sudden collapse of the lake floor through fragmentation of hydrothermally-altered cap rocks. Any of these events could result in a sudden shift in lake level, generating large waves that could cause catastrophic local flooding. Ejecta from past hydrothermal explosions that formed craters in the floor of Yellowstone Lake extend several kilometers from their crater rims and include rock fragments in excess of several meters in diameter. Deposits from the Indian Pond hydrothermal explosion event extend as much as 3 km from its crater and are as thick as 3–4 m. In addition, the threat of another large explosion event may exist, as indicated by the abundance of hydrothermal venting and domal structures observed, especially in the northern basin, where heat-flow values and temperatures are extremely high. The area covered by the "Inflated Plain" is very comparable in scale to its neighboring feature to the east, the 800-m-diameter, 8.3-ka Elliott's hydrothermal explosion crater (Figure 2B, 4A).

The combination of active and vigorous hydrothermal vents, the plume of fine sediments in the lake subsurface, the strong, locally-sourced H^2S scent, and the evidence for silicification of lake sediments merit detailed monitoring of the "Inflated Plain" as a potential and serious hazard and possible precursor to a large hydrothermal explosion event. The "Inflated Plain" area was resurveyed in 2002 in order to compare any changes from the 1999 survey; these analyses currently are under investigation. In addition to hazards affecting humans, hydrothermal explosions are likely to be associated with the rapid release into the lake of steam and hot water, possibly affecting water chemistry by the release of potentially toxic trace metals. Such changes could have significant impact on the fragile ecosystem of Yellowstone Lake and vicinity.

Do rhyolitic lava flows control hydrothermal activity?

One of the basic observations from our surveys is that a close spatial relationship exists between the distribution of hydrothermal vents, explosion craters, and sublacustrine rhyolitic lava flows. Does the presence of fully-cooled lava flows in a subaqueous environment affect the distribution of hydrothermal vents? Could the identification of rhyolitic lava flows be used as a tool to help predict where some hydrothermal activity may occur in the future?

The relationship between sublacustrine hydrothermal features and the areas of high relief, interpreted here as rhyolitic lava flows, can be seen in Figures 1B, 2A, and 7D. Based on our observations of the abundant, present-day distribution of hydrothermal vents, we infer that fully-cooled rhyolitic lava flows exert a fundamental influence on subsurface hydrology and hydrothermal vent locations. We speculate that upwelling hydrothermal fluids are focused preferentially through rhyolitic lava flows, whereas hydrothermal fluids conducted through lake and glacial sediments tend to be more diffuse (Figure 7). In addition, convective flow moves laterally away from thicker, more impermeable segments of the rhyolite flow toward the fractured flow margin, where the majority of hydrothermal activity is observed (Figure 7E).

Summary and conclusions

This mapping of Yellowstone Lake allows the lake basin to be understood in the geologic context of the rest of the Yellowstone region. Rhyolitic lava flows contribute greatly to the geology and morphology of Yellowstone Lake, as they do to the subaerial morphology of the Yellowstone Plateau. We infer from our high-resolution bathymetry and aeromagnetic data that Stevenson, Dot, and Frank Islands are underlain by large-volume rhyolitic lava flows (Figure 2A). Mapped late Pleistocene glaciolacustrine sediment deposits on these islands merely mantle or blanket the flows. Similarly, the hydrothermally-cemented beach deposits exposed on Pelican Roost, located ~1 km southwest of Steamboat Point (Figure 2C), blanket another submerged large-volume rhyolite flow. The margin of the Yellowstone caldera passes through the central part of the lake and northward along the lake's eastern edge (Figure 1). Similar to most of the rest of the topographic margin of the Yellowstone caldera (Figure 1A), we suggest that post-collapse rhyolitic lava flows are present along much of the caldera margin beneath Yellowstone Lake and control much of the distribution of the sublacustrine hydrothermal vents. Many potential hazards have been identified in our mapping effort. Next steps will include hazard assessments and methodologies to be employed in monitoring these potentially dangerous features under the aegis of the Yellowstone Volcano Observatory.

Lisa Morgan (foreground) is a research geologist for the USGS. Her focus for the past 23 years has been the geology and geophysics of volcanic terrains, including that of the eastern Snake River Plain and Yellowstone Plateau, Cascades, Hawaii, Japan, and other areas. With Ken Pierce, Morgan developed major concepts and a model for the Yellowstone hot spot. Her current research focuses on the Yellowstone Plateau, mapping and interpretation of the geology and potential geologic hazards in Yellowstone Lake, and physical processes associated with large-volume caldera-forming eruptions and hydrothermal explosions.

Pat Shanks (right) is a research geochemist with the USGS. He has extensively studied seafloor and sublacustrine hydrothermal vents and mineral deposits on the mid-ocean ridges and in Yellowstone Lake, using stable isotopes and aqueous geochemistry as primary tools. His current research includes hot spring geochemistry, hydrothermal explosion deposits, hydrothermal alteration processes in volcanic rocks, and the geochemistry of metals in the environment related to sites of past mining activities.

Dave Lovalvo (left) is the founder and owner of Eastern Oceanics. For 30 years, He has filmed and supported underwater research projects in just about every major ocean and many of the world's major inland lakes. Dave has spent 15 years exploring, filming and now mapping Yellowstone Lake, and continues to support projects in Yellowstone and many other locations around the world. He has been a manned submersible pilot of the Deep Submergence Vehicle (DSV), Alvin, and a pilot and member of the design team for the unmanned DSV, Jason 2. He currently operates Eastern's unmanned DSV Oceanic Explorer. His latest projects have been the search and discovery of the PT-109 with Bob Ballard and the National Geographic Society, and the government-sponsored exploration of the new underwater volcano off Grenada called "Kick-em Jenny." Dave resides in Redding, Connecticut.

Acknowledgments

We thank Kate Johnson, Ed duBray, Geoff Plumlee, Pat Leahy, Steve Bohlen, Tom Casadevall, Linda Gundersen, Denny Fenn, Elliott Spiker, Dick Jachowski, Mike Finley, John Varley, Tom Olliff, and Paul Doss for supporting this work. We thank Dan Reinhart, Lloyd Kortge, Paul Doss, Rick Fey, John Lounsbury, Ann Deutch, Jeff Alt, Julie Friedman, Brenda Beitler, Charles Ginsburg, Pam Gemery, Rick Sanzolone, Dave Hill, Bree Burdick, Eric White, Jim Bruckner, Jim Waples, Bob Evanoff, Wes Miles, Rick Mossman, Gary Nelson, Christie Hendrix, and Tim Morzel and many others for assistance with field studies. We thank Bob Christiansen, Karl Kellogg, and Geoff Plumlee for constructive reviews that substantially improved the manuscript. We are grateful to Coleen Chaney, Debi Dale, Joan Luce, Marlene Merrill, Mary Miller, Vicky Stricker, Sandie Williamson, and Robert Valdez for their skillful assistance with project logistics. This research was supported by the U.S. Geological Survey, the National Park Service, and the Yellowstone Foundation.

Sources

Space constraints prevent us from listing the numerous citations and sources included in this article as originally submitted. For a complete list, please contact alice_wondrak@nps.gov.

Predators and Prey at Fishing Bridge

by Paul Schullery

For more than thirty years now, I've watched Yellowstone cutthroat trout rise in the slow waters at the outlet of Yellowstone Lake. Their reliable presence, their abundance, and their easy familiarity with gawkers like me, all made it seem like this was something I could get around to photographing someday, but didn't have to do right now. After all, the only thing I really wanted was some beautiful overhead shots of these golden fish, sinuously distorted and glowing against the mottled greens of the river bottom.

Last summer, I finally started taking the pictures. About noon on a very hot, bright early July day, I walked out on Fishing Bridge and discovered that quite a few fish were feeding steadily on small mayflies and stoneflies. Eagerly rising trout are as exciting to me as the sight of a grizzly bear, and I was immediately caught up in the scene. Rather than looking for a fish tastefully holding over just the right color of bottom so I could get my artful trout picture, I spent the next hour on the bridge or along the shore, banging away at these eager risers. Even as I was taking the pictures, I wondered if my autofocus camera and 300 mm lens were up to the challenge of stopping the action, and what I might find when I could finally examine the pictures.

What I found was as exciting as watching the risers. In that first hundred or so images, a surprising number of which weren't just blurry splashes, the camera stopped the action at many distinct stages of the rise and take. What was just a quick flash of action when I watched it was revealed as much, much more. The more I looked, the more I saw. The more I saw, the more I needed to go back and take more pictures.

Each subsequent visit to the bridge led me back into the angling literature and (more fruitfully) into the scientific literature on the physiology of feeding fish. I would look through each new batch of pictures, notice something new, think about it until I wondered about something else, then look through the pictures again, and again, and again. I'm

ALL PHOTOS PAUL SCHULLERY

1. A Yellowstone cutthroat trout with one of the many thousands of mayflies it will eat each summer. In all these photographs, wild Yellowstone cutthroat trout were photographed feeding naturally; neither trout nor flies were interfered with or manipulated in any way.

2. Something about an individual mayfly has sparked something in the brain of an individual trout, which turns to investigate. The fly has tipped over and a wing is pinned against the water surface. Perhaps the trout's interest was triggered by the panicky motion of the insect's struggles.

still not done looking, and the more I find the more I realize I'm a long way from being done taking pictures, too.

If you've watched many nature films on television, there's a powerful image you will almost certainly remember. The scene is a tropical reef—some colorful submerged landscape replete with coral forests, sponges, and other exotica. The whole thing is near enough to the surface for sunlight to dapple its happy, travel-poster community of plants and animals. But off to the side (sinister soundtrack here), you see the snout, or even the whole head, of some darkly porcine, heavy-jawed fish, shadowed patiently amidst the undulating vegetation.

Then a new camera angle reveals an innocent little creature—a tiny fish, a crusteacean, some other tidbit of biological mobility—going about its day (peppy, cheerful soundtrack here, to evoke additional sympathy).

You know what's going to happen, but it's always startling anyway, because it happens so fast. The innocent little tiddler comes doodling along until it's directly in front of the big fish, then it's suddenly gone and the fish, which hasn't left its place, is closing its mouth (only the tackiest of producers put a small burp on the soundtrack at this point, but some do succumb to a little ascending pennywhistle toot, to signify the hasty sucking in of the prey).

It's a great nature film gimmick, always good for a startled chuckle. It's also terrifically interesting predatory behavior. It's evolution making the most

3. Even in the cleanest, clearest water, the trout must pick its food from a distracting assortment of flotsam in the surface film, caught here when the camera chose to focus on it rather than on the trout below.

4. The trout has a kind of visual lock on this drifting mayfly. The fly is now well within the range of the fish's suction. The tiny "lens" of distorted surface just above the trout's head indicates that the trout has already begun to create a "rise form," though whether or not the fish will take the fly is uncertain.

of the animal's tools and environment. It's predation without the chase. It's always dramatic, and for all its staginess and comic effect it's also a little scary. It looks almost like magic.

We don't hear much about this sort of thing with trout, especially trout rising to feed near or on the surface. Their fastidious little "rise forms" (the spreading rings of ripples that follow each feeding episode) hint of a greater refinement, as if trout have better table manners than to go around acting like a starship with an overactive tractor beam.

In fact, fishing writers have tended to describe the trout's feeding behavior as quite passive, more or less like this: When the trout

5. The same stage of the process as the previous pictures, but with a different fish photographed from a different angle. The trout's mouth is slightly open, with the fly perfectly suspended across the gap. The lower jaw, seeming a bit underslung, appears to be filling out already as the fish begins to create the suction that will pull the fly in.

6. The decision to take the fly has been made. The fly, this time a mayfly "spinner," has barely begun to tip into the opening mouth of the trout (the spinner, with its wings extended flat across the surface, is the last life stage of the mayfly). Suction has also begun; the beginning of the suction trough is passing over the head of the trout.

sees a fly gliding toward it, the fish simply rises to the surface, opens its mouth and gills, and lets the river run through its head, carrying the fly in. The fish keeps the fly and lets the extra water flow on, right out the gills.

But trout use precisely the same suction forces as the big reef fish described earlier. In a process that is likewise too quick for us to observe from the bank, or even from a few feet away, they take their food in by means of a complex and forceful series of valve-like motions of surprising power and elegant efficiency.

Let's follow a mayfly to its doom in a trout's mouth, starting with the fly, poised on the surface, riding the current downstream. The trout sees it, and moves in to investigate. Forget for the moment that in that one sentence is a world of engaging wonders to do with the trout's visual acuity, its ability to identify prey, the refraction of light in a stream and how that affects the trout's "window," and a host of other subjects that many writers have capably explored. Right now we're only concerned with the challenges the fish faces in eating this fly.

Anglers have spent centuries watching fish feed. Vincent Marinaro's beautiful book *In the Ring of the Rise* (1976), with its series of photographs of trout rising, gave anglers their first close look at the ways in which trout conduct their inspection of a prospective meal. Water is a much thicker and potentially clumsier "atmosphere" than

7. The mouth is now as open as it gets. A mayfly is in it, and two more drift by to the left.

8. It isn't enough to get the fly over the lip. It must be pulled deep into the fish's mouth, and the powerful suction is now doing that. The suction trough is clearly visible around the fish's head as down-curving distortion lines. The trough is likewise revealed in its shadow on the river bottom—a twin-lobed circle encompassing the trout's head.

air. A fish that simply charges up to its prey is likely to push it away with its own "bow wave." But depending upon the speed of the trout as it approaches the fly, and the care it exercises, it may approach quite closely. Fish routinely get their little faces right up close to the insect, and seem to lock it in place right there in front of them as it drifts long.

I wonder about this stage in the process. Marinaro showed us, in his photographic series depicting what he called the "compound rise" and the "complex rise," the way a trout noses right up to a fly, then drifts backwards along with the fly as it continues on its way downstream. The trout concentrates on the fly, and keeps it right there, just off the end of its snout.

9. The same process, with another fish viewed from another angle. Again the trough is revealed in the surface distortion around the mouth, and again the two-lobed shadow stands out on the river bottom. The twin-lobed shape is probably the result of the trout's "chin" dividing the suction trough. At this stage, though the gills may be partly open, they are not fully expelling water.

10. Though the fish is somewhat obscured by the distortion of the water, this is the busiest of the pictures in the sequence. The lower jaw is still distended; notice how the cutthroat markings stand out. Both gills are now open wide, and the trout's right gill is clearly expelling a strong current of water. Water is almost certainly also exiting the left gill, but the light is from the right (as the off-center shadow of the suction trough, on the river bottom, shows), and the distortion of light on that side is probably lost under the fish.

This behavior is certainly agonizing for the angler, and who knows what the fly must make of it?

But here is what I find most curious about it. The whole time this is going on, often for several feet or even yards of drift, the fly is well within the suction range of the fish (rainbow trout in one study, feeding under the surface, rarely applied suction toward food that was much more than a head-length away). I wonder if while the trout is eyeing the fly from this close, if it isn't also applying some subtle little outward or inward currents to the fly, testing it in some way? Animals take every evolutionary advantage that comes along. Maybe the trout is only toying with the fly a little (trout are known to "play" with their food more toward the end of an insect hatch, when they are presumably sated, than at the beginning). Or maybe such manipulation, jostling the fly around a little, would somehow help in the decision of whether or not to eat it. Imagine being the fly at this point.

That's all speculation, of course. What happens next is vividly real. If all goes well with the inspection, it's time to feed.

The goal of the trout is to create enough suction to ensure that the fly is drawn well into the mouth. To increase the force of that flow beyond its own physical capacity to create suction, the trout will often move forward as it takes, its speed adding a little more *umph* to the current flow it is creating with suction. As it does that, it creates suction with its mouth. There are now three distinct forces speeding the fly into the trout's mouth: the downstream flow of the current, the upstream movement of the trout, and the suction of the trout's mouth.

The trout creates the suction by enlarging its mouth capacity, which it does by opening and extending its jaws, and dropping the floor of the lower jaw, deepening the mouth cavity. This is facilitated by those pleatlike structures that run the length of the bottom of the lower jaw (a cutthroat trout's "cutthroat" marks are partly hidden in those pleats until they stretch open).

The photographs capture the effect of this suction clearly. The surface-feeding fish, in sucking down the fly, actually pulls a shallow hole in the water surface—a little feeding depression, or trough. The insightful British angling writer G.E.M. Skues recognized the evidence of this process eighty years ago in *The Way of a Trout with a Fly*. He described the initial stage of the take as "a faint hump on the surface, often accompanied by a tiny central eddy caused by the suction with which the trout has drawn in the fly."

Now the fish's mouth has opened, the oral cavity has deepened, and the fly is either in or on its way into the mouth.

11. In this revealing photograph, the trout has closed its mouth, and the suction trough is sliding back over its head. Most important, the rapid closing of the mouth and the contraction of the floor of the mouth is expelling water from the gills with such force that some of it also escapes in strong little spurts from the sides of the fish's mouth. This startling process occurred with more than one of the photographed trout.

12. The trout inadvertently inhales air along with any fly taken from the water's surface. This air is then expelled out the gills with the water. Here, the first bubble of air emerges from the trout's gill and reaches the surface as the fish turns down from its take.

The gills are already in play, as some water is moving out of them, but the fish is dealing with some involved physics at this point. If it simply drops the floor of its lower jaw and opens its mouth and gills all with equal force and at the same time, there will still be a lot of suction, but water may be pulled in from both ends—into the mouth and in through the gills (the latter, if it happens too dramatically, is apparently not an especially pleasant experience for the trout). This could defeat the real goal of the suction. The trout needs to keep the suction going mostly one way, into the mouth, to have the best chance of capturing the fly. That said, even when the trout does this right, there may be a modest back-

fly. It closes its mouth (a good bit more quickly than it opened it), flushes the water out the gills, and the fly is retained, presumably either in the throat or against the gill rakers—those hard arching structures to which the gills are attached.

There is one lovely lingering aftereffect in the take of a trout, first noted by the angling writer Skues. Perplexed by rising trout whose prey he could not see, Skues needed a way to determine if a fish was rising to floating flies, or feeding right under the surface. He reasoned that a fish feeding beneath the surface would inhale only water when taking a fly, but a fish feeding on the surface, especially if taking an upwinged insect like an adult

13. More bubbles have appeared, and are drifting back over the trout as the fish settles back into its holding position. But one last fine stream of small bubbles can be seen, still underwater, as they emerge from the trout's right gill.

14. The serendipitous beauty of a complete rise: as the trout turns down from a successful take, another mayfly eases past, caught by the camera as it passes over the pectoral fin.

wash into the gills, but not enough to interfere with the capture of the fly.

Now that the suction has been successful, the trout has the fly in its mouth. But recall what anglers dread at this stage: that the fish will reject, or “spit out” the fly. They actually do this—*ptui!*—and the reason they can do it so quickly and so forcefully is that they just reverse the process that pulled the fly in. They can just contract that lower jaw expansion, collapse the large oral cavity, and the fly spurts back out. If the trout was operating only a passive, flow-through system, it would have no capacity for such abrupt and decisive changes of plan, and we’d catch a lot more of them.

But let’s assume that the trout approves of the

mayfly, would necessarily engulf a fair amount of air with the water and the fly. That air would be expelled out the gills with the water, and would be evident as bubbles in the resultant rise form. A fish feeding on insects that were under the surface of the water, such as mayfly nymphs or drowned adults, might cause a surface disturbance that looked like any other rise form, but it couldn’t have bubbles in it because the fish had no air to eject. The photographs show this too.

Setting aside what all this observation and photography and reading has taught me about fishing, it has given me a deepened respect for trout—creatures I already thought I admired pretty thoroughly. Perhaps most important, I admire them much more as individuals than I used to. The feeding process is so full of opportunities for variation, not only in one fish but from fish to fish, that I am much less likely than before to make assumptions about one fish based on what the fish next to it has been doing. We fishermen have joked for so long about how we're made fools of by these simple little creatures that we have begun to believe not only that we're fools but that trout really are simple. They may not be as individual as humans, but I'm now convinced they're a lot closer to it than I used to think.

I also admire them more as predators. I don't know what's going on when a trout is nosing up against a fly, doing its equivalent of judging and deciding. But the more I stare at these pictures of fish staring at insects, the more I respect whatever it is that the trout is going through (so far, I try not to think much about what the insect is going through). Like its physiological attainments, which result from millions of years of evolutionary engineering, the trout's cognition seems to me a spectacularly successful tool.

Over the years, I've spent a huge amount of time watching Yellowstone predators go about their work, making their assessments, passing their fateful judgments, making their perfect moves. Trout are unmistakably members of the same guild. Whatever rarified sphere of consciousness or even wisdom these creatures may inhabit, and whatever we may eventually conclude about the primitiveness or sophistication of their brains, I am infinitely more aware of their superiorities than I am of their limitations. ✪

MARSHA KARLE

Paul Schullery, a former editor of *Yellowstone Science,* is the author of many books, including *American Fly Fishing: A History* (1987) and *Lewis and Clark Among the Grizzlies* (2002). This essay appeared in different form in the May 2003 issue of *Fly Fisherman* magazine.

NEWS & notes

USFWS Reclassifies Some Wolves from Endangered to Threatened

The U.S. Fish and Wildlife Service has changed the status of gray wolves in the western Great Lakes states and northern Rocky Mountains from "endangered" to the less serious "threatened" designation under the Endangered Species Act.

The reclassification rule also establishes three "Distinct Population Segments" (DPS) for gray wolves under the Endangered Species Act. The three DPSs encompass the entire historic range of the gray wolf in the lower 48 states and Mexico, and correspond to the three areas of the country where there are wolf populations and ongoing recovery activities.

Wolf populations in the Eastern and Western DPSs have achieved population goals for recovery, and Advance Notices of Proposed Rulemaking are being published concurrent with this reclassification rule to give the public notice that the Service will soon begin work to propose delisting these populations.

The threatened designation, which now applies to all gray wolves in the lower 48 states except for those in the Southwest, is accompanied by special rules to allow some take of wolves outside the experimental population areas in the northern Rocky Mountains. These rules provide options for removing wolves that cause problems for livestock owners and other people affected by wolf populations. Wolves in experimental population areas in the northern Rocky Mountains are already covered by similar rules that remain in effect.

The USFWS will now begin the process of proposing to remove gray wolves in the western and eastern United States from the endangered and threatened species list, once the agency has determined that all recovery criteria for wolf populations in those areas have been met and sufficient protections remain in place to ensure sustainable populations.

To delist the wolf, various recovery criteria must be met, in addition to reaching population goals. Among those criteria are requirements to ensure continued survival of the gray wolf after delisting. This will be accomplished through management plans developed by the states and tribes. Once delisted, the species will no longer be protected by the Endangered Species Act. At that point, individual states and tribes will resume management of gray wolf populations, although the Service will conduct monitoring for five years after delisting to ensure that populations remain secure.

The final rule reclassifying the gray wolf will be published in the Federal Register. For more information on the gray wolf, visit the Service's wolf website at http://midwest.fws.gov/wolf.

Bison Capture Operations Outside North Entrance

During the first week of March, bison migrated near Stephens Creek along the park's northern boundary, and capture operations began at the Stephens Creek capture facility outside the North Entrance for the first time since 1996. Under the final state and federal Records of Decision (ROD) for the Interagency Bison Management Plan (IBMP) that were signed in December 2000, and the December 2002 IBMP Operating Procedures, when the bison population in late winter/early spring is over 3,000 animals, and they are moving onto lands where cattle are being grazed near the North Entrance, they will be captured in the Stephens Creek facility and sent to slaughter facilities. The November population estimate was approximately 3,800. About 25 bison have died this year either by management actions west of the park, natural mortality, or motor vehicle accidents.

The IBMP and the IBMP Operating Procedures use a variety of methods along the north and west boundaries of the park to limit the distribution of bison and to maintain separation of bison and cattle on public and private lands. It also allows some bison on certain public lands where cattle are not grazed.

The first response to bison approaching the north boundary is to haze them to keep them inside the park. However, after attempts at hazing the bison become ineffective and unsafe, it may become necessary to begin capturing the animals. Hazing occurred during the previous few weeks on numerous occasions.

A total of 231 bison were captured at the Stephens Creek facility and sent to slaughter facilities. Meat, heads and hides will be donated to Native American groups/individuals and other social service organizations.

Spring Bear Emergence Reminder

The park's Bear Management Office has started receiving reports of bear activity within Yellowstone, indicating that bears are beginning to emerge from their winter dens.

Soon after bears emerge from their dens, they search for winter-killed wildlife and winter-weakened elk and bison, the primary sources of much-needed food during spring for both grizzlies and black bears. Visitors are asked to be especially cautious of wildlife carcasses that may attract bears, and to take the necessary precautions to avoid an encounter. Do not approach a bear under any circumstances. An encounter with a bear feeding on a carcass increases the risk of personal injury. Bears will aggressively defend a food source, especially when surprised.

The National Park Service is continuing the seasonal "Bear Management Area" closures in Yellowstone's backcountry. The program regulates human entry in specific areas to prevent human/bear conflicts and to provide areas where bears can range free from human disturbances.

Visitors are asked to report any sightings or signs of bears to the nearest visitor center or ranger station as soon as possible. Permits for backcountry camping and information on day hikes are available at visitor centers and ranger stations.

For further information on spring conditions in Yellowstone National Park, call park headquarters at (307) 344-7381.

NPS PHOTO

NPS and Montana Department of Livestock personnel meet at the Stephens Creek capture facility.

Winter Use FSEIS Released for Grand Teton and Yellowstone National Parks

The Final Supplemental Environmental Impact Statement for winter use was made available to the public on February 20, 2003. There will not be a public comment period. National Park Service and National Environmental Policy Act (NEPA) regulations call for a 30-day waiting period, but public comment is not customary on a final environmental impact statement. A Record of Decision was expected to be signed near the end of March 2003.

Five alternatives for winter visitor use in the three park units are evaluated in the FSEIS. Three of the alternatives, including the preferred alternative, are limited specifically to actions that allow snowmobile recreation to continue in the parks. The other alternatives include a no action alternative that would implement the

Recent aerial photos taken in Hayden and Pelican Valleys (left and below, respectively) show that bears have begun their spring emergence.

NPS PHOTOS

November 2000 Record of Decision to ban snowmobiles from the parks beginning the 2003-2004 winter use season, and a second that would delay implementation of the November 2000 Record of Decision until the 2004-2005 winter use season.

The preferred alternative strikes a balance between phasing out all snowmobile use—as required under the November 2000 Record of Decision—and allowing for the unlimited snowmobile use of the past. Critical elements of the preferred alternative include: reduced numbers of snowmobiles through daily limits; implementing best available technology requirements for snowmobiles; implementation of an adaptive management program; guided access for both snowmobiles and snowcoaches; a reasonable phase-in period; a new generation of snowcoaches; and funding to effectively manage the winter use program. Implementation of all the critical elements will address the adverse impacts identified in the November 2000 Record of Decision.

Hard copies and CDs of the document are available by writing: FSEIS, Planning Office, P.O. Box 168, Yellowstone National Park, Wyoming 82190. The document can also be found by accessing www.nps.gov/grte/winteruse/winteruse.htm. The FSEIS is loaded in two volumes. Volume 1 is the main document and the appendices. Volume 2 is the public comments and their responses.

Happy 10th Anniversary, YCR!

The Yellowstone Center for Resources celebrated its 10th anniversary on March 13, 2003. Created with the goal of centralizing resource research and management, YCR now includes the park's Branches of Natural and Cultural Resources, its Spatial Analysis Center (GIS lab), and YCR's own support branch (including the Resource Information and Publications Team, AKA the people who bring you Yellowstone Science!). Although all major undertakings, such as wolf restoration, represent cooperative efforts among the park's divisions, many such projects have been primarily directed out of the YCR. Highlights of the past ten years include wolf restoration; the lake trout eradication program; initiation of thermophile surveys; successful bald eagle and peregrine falcon recovery programs; meeting target goals for grizzly bear recovery; six biennial science conferences (planning for the seventh is underway!); the halting of the New World Mine; initiation of a new Heritage and Research Center to house the park's library, archives, and photo and museum collections; strengthening of tribal relations through the consultation process; completion of the interagency bison management plan and EIS; and acquisition of the Jack and Susan Davis collection. Yellowstone Science also celebrates 11 years this year, with a mailing list that has grown to include more than 2,100 individuals interested in Yellowstone's research and resources.

Above, YCR Director John Varley cuts the NPS arrowhead-shaped YCR birthday cake.

Below, Here from the start: original YCR employees Wayne Brewster, Kerry Gunther, Mary Hektner, Mark Biel, Jennifer Whipple, Ann Rodman, Paul Schullery, Sue Consolo Murphy, John Varley, Joy Perius, and Melissa McAdam.

NPS PHOTOS

Lake Conference Proceedings Available

The proceedings from the Sixth Biennial Scientific Conference on the Greater Yellowstone, *Yellowstone Lake: Hotbed of Chaos or Reservoir of Resilience?* are now available. Conference participants will receive their copies in the near future. Others who would like a copy, please contact Virginia Warner at virginia_warner@nps.gov or (307) 344-2233.

NPS PHOTO

Yellowstone Science
Yellowstone Center for Resources
P.O. Box 168
Yellowstone National Park, WY 82190

CHANGE SERVICE REQUESTED

PRSRT STD AUTO
US POSTAGE PAID
National Park Service
Dept. of the Interior
Permit No. G-83