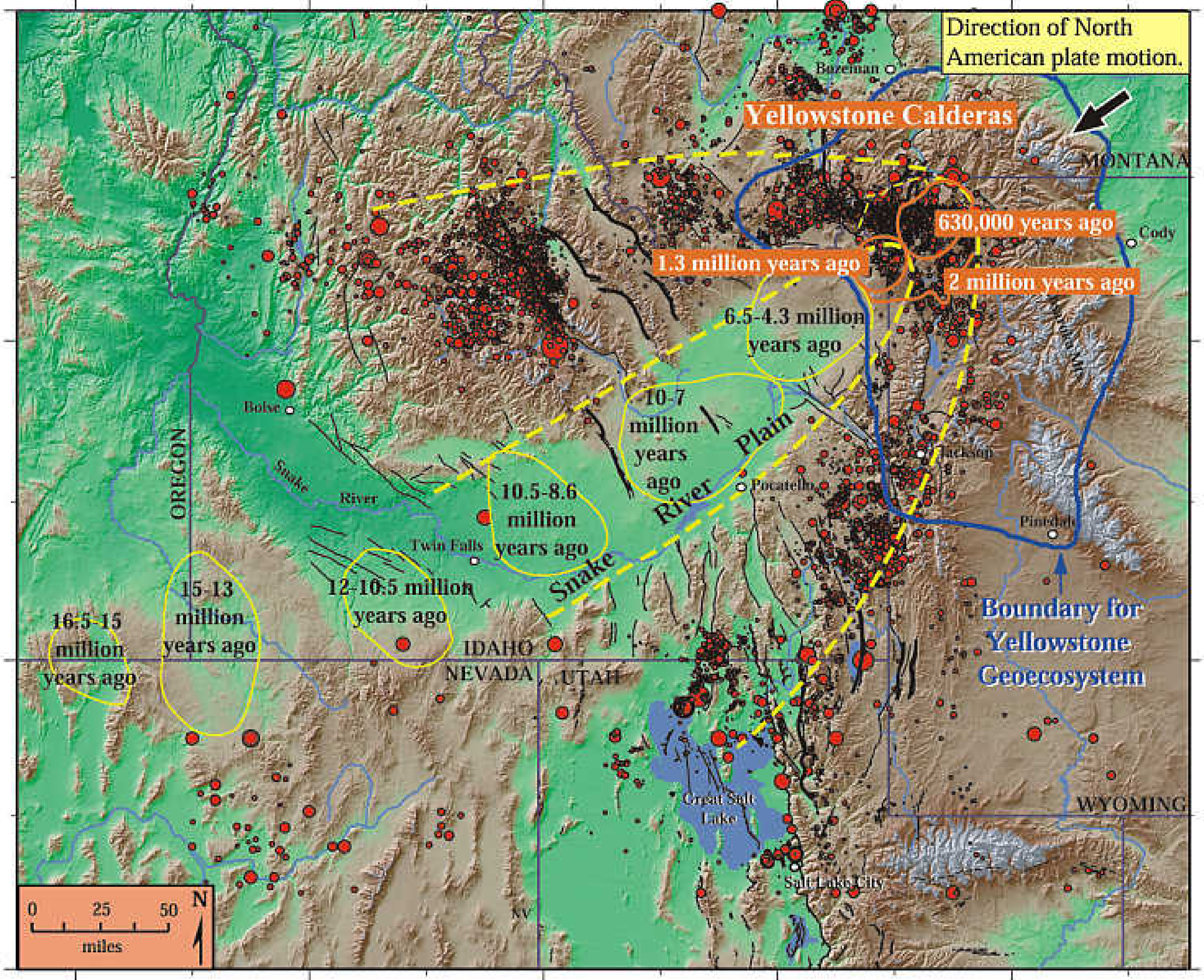
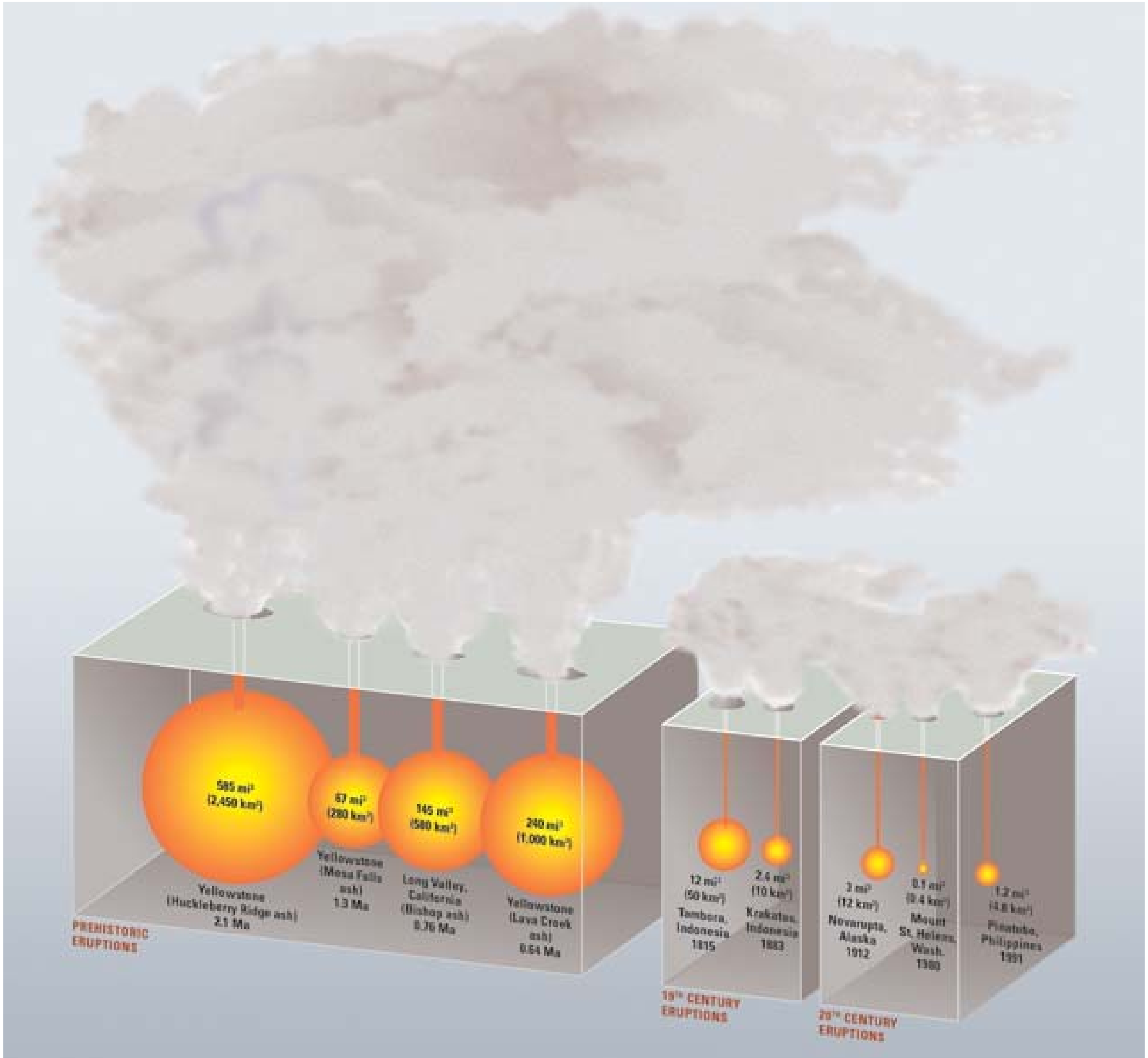
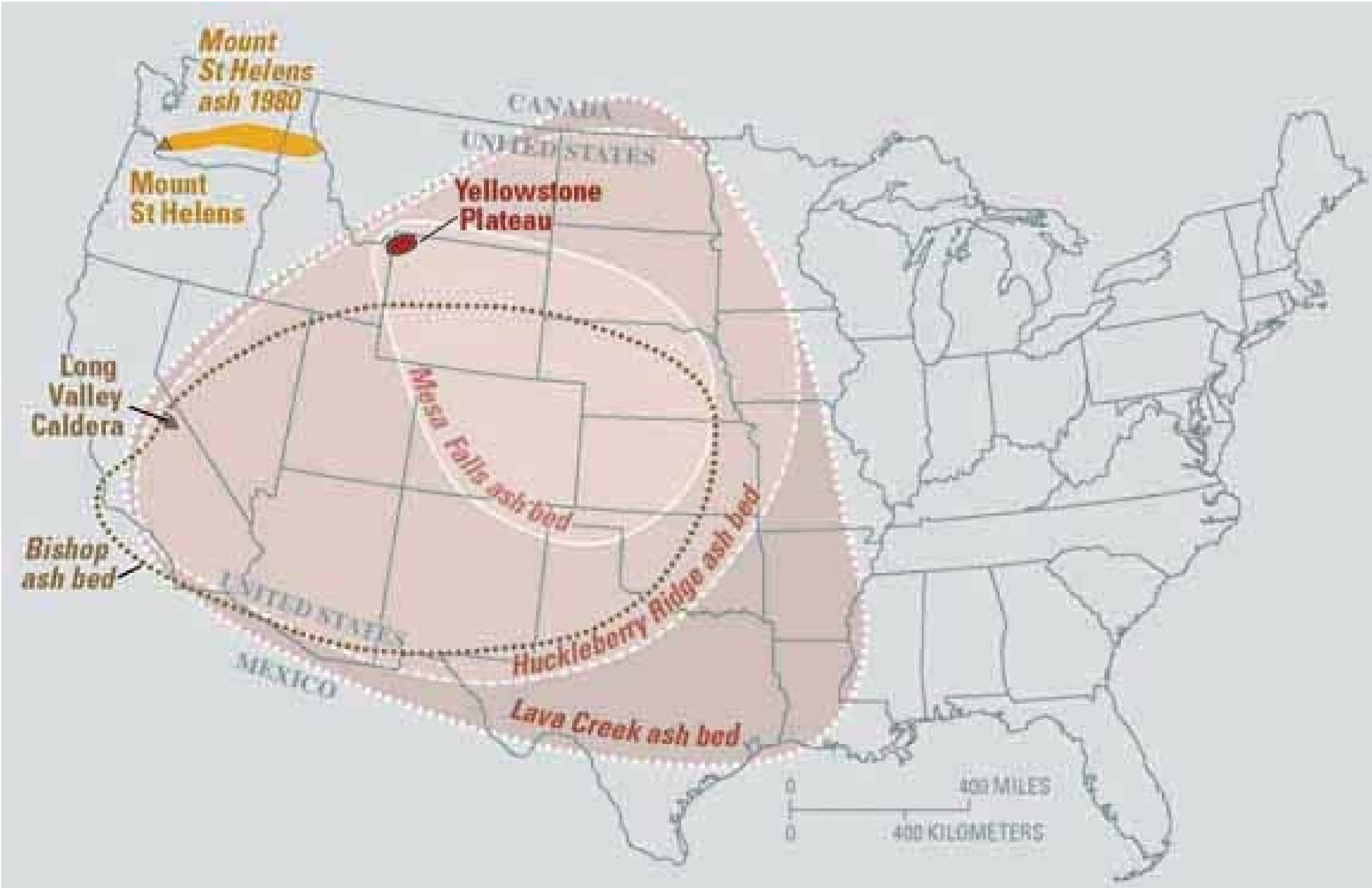
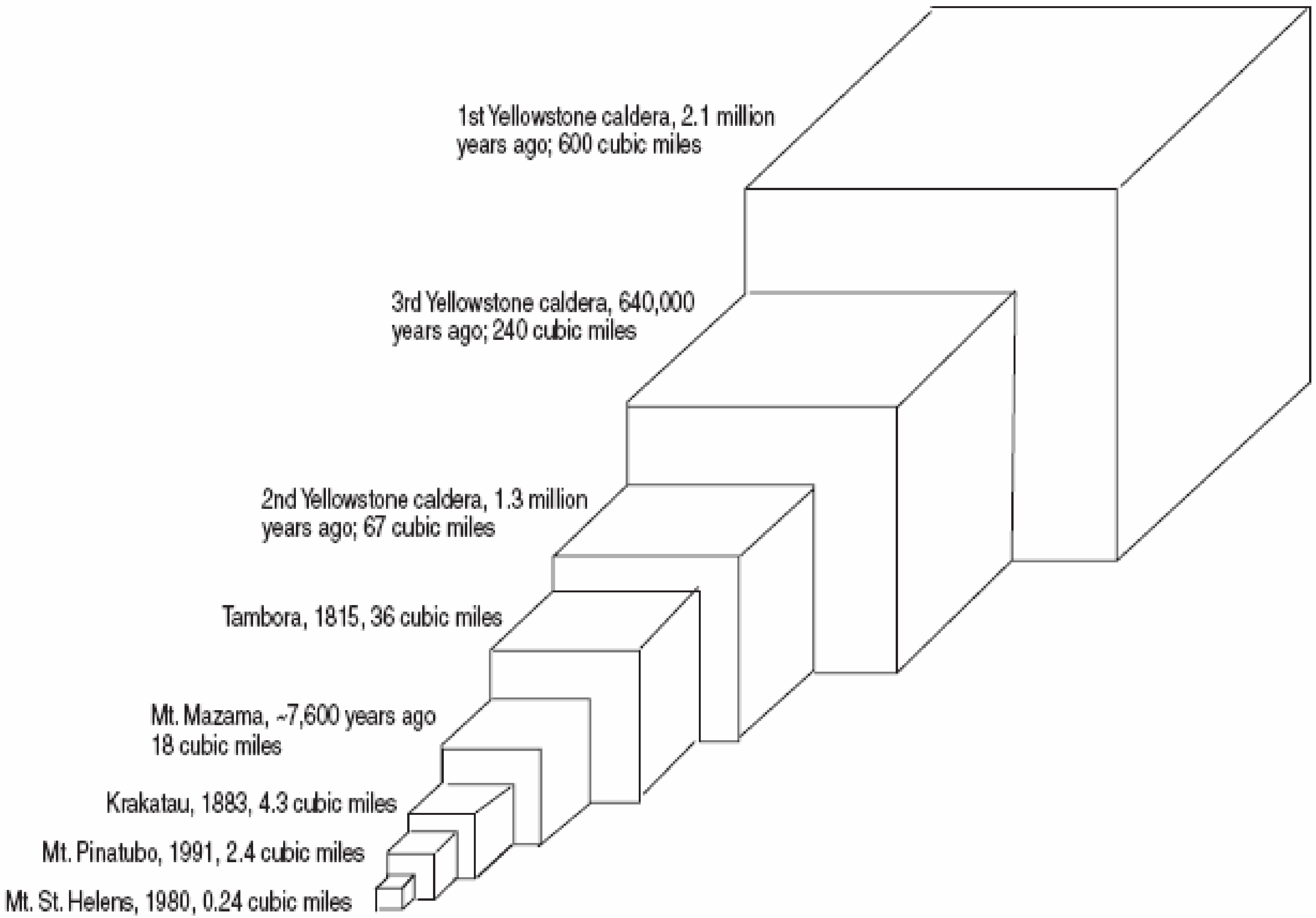


46ûN
44ûN
42ûN
40ûN
Direction of North American plate motion.
Bozeman
Yellowstone Calderas
MONTANA
630,000 years ago
Cody
1.3 million years ago
2 million years ago
6.5-4.3 million years ago
10-7 million years ago
Boise
Snake River Plain
Jackson
OREGON
Snake River
Pocatello
10.5-8.6 million years ago
Twin Falls
Pinedale
15-13 million years ago
12-10.5 million years ago
16.5-15 million years ago
Boundary for Yellowstone Geoecosystem
IDAHO
NEVADA
UTAH
Great Salt Lake
WYOMING
Salt Lake City
0 25 50
miles
N


585 mi³
(2,450 km³)
Yellowstone
(Huckleberry Ridge ash)
2.1 Ma
67 mi³
(280 km³)
Yellowstone
(Mesa Falls
ash)
1.3 Ma
145 mi³
(580 km³)
Long Valley,
California
(Bishop ash)
0.76 Ma
240 mi³
(1,000 km³)
Yellowstone
(Lava Creek
ash)
0.64 Ma
PREHISTORIC
ERUPTIONS
12 mi³
(50 km³)
Tambora,
Indonesia
1815
2.4 mi³
(10 km³)
Krakatau,
Indonesia
1883
19TH CENTURY
ERUPTIONS
3 mi³
(12 km³)
Novarupta,
Alaska
1912
0.1 mi³
(0.4 km³)
Mount
St. Helens,
Wash.
1.2 mi³
(4.8 km³)
Pinatubo,
Philippines
1991
20TH CENTURY
ERUPTIONS


Mount
St Helens
ash 1980
Mount
St Helens
CANADA
UNITED STATES
Yellowstone
Plateau
Long
Valley
Caldera
Mesa Falls ash bed
Huckleberry Ridge ash bed
Bishop
ash bed
UNITED STATES
MEXICO
Lava Creek ash bed
0
400 MILES
0
400 KILOMETERS



1st Yellowstone caldera, 2.1 million years ago; 600 cubic miles
3rd Yellowstone caldera, 640,000 years ago; 240 cubic miles
2nd Yellowstone caldera, 1.3 million years ago; 67 cubic miles
Tambora, 1815, 36 cubic miles
Mt. Mazama, ~7,600 years ago 18 cubic miles
Krakatau, 1883, 4.3 cubic miles
Mt. Pinatubo, 1991, 2.4 cubic miles
Mt. St. Helens, 1980, 0.24 cubic miles

# The Quaternary and Pliocene Yellowstone Plateau Volcanic Field of Wyoming, Idaho and Montana

Robert L. Christenson,
USGS PP 729-G

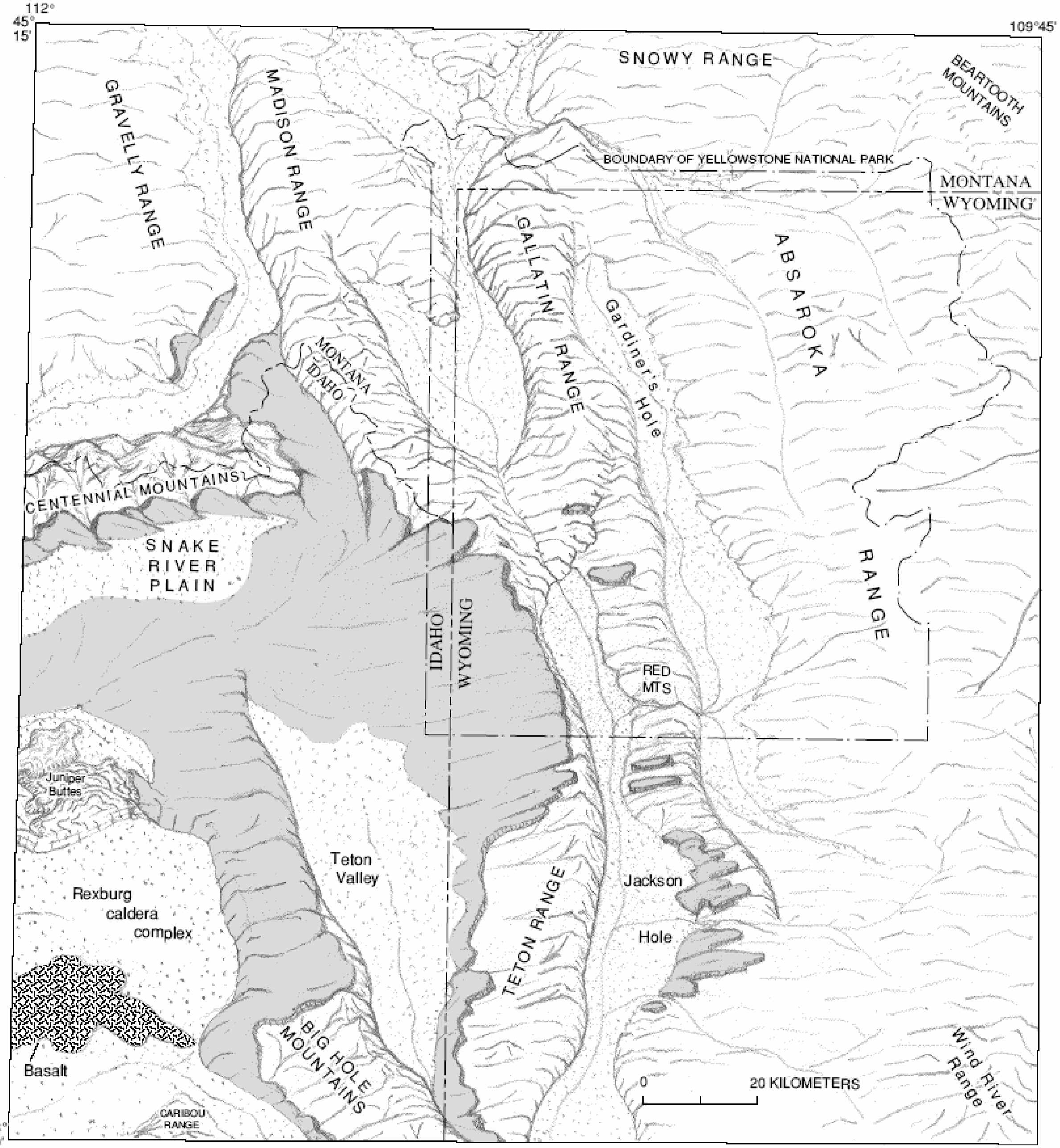
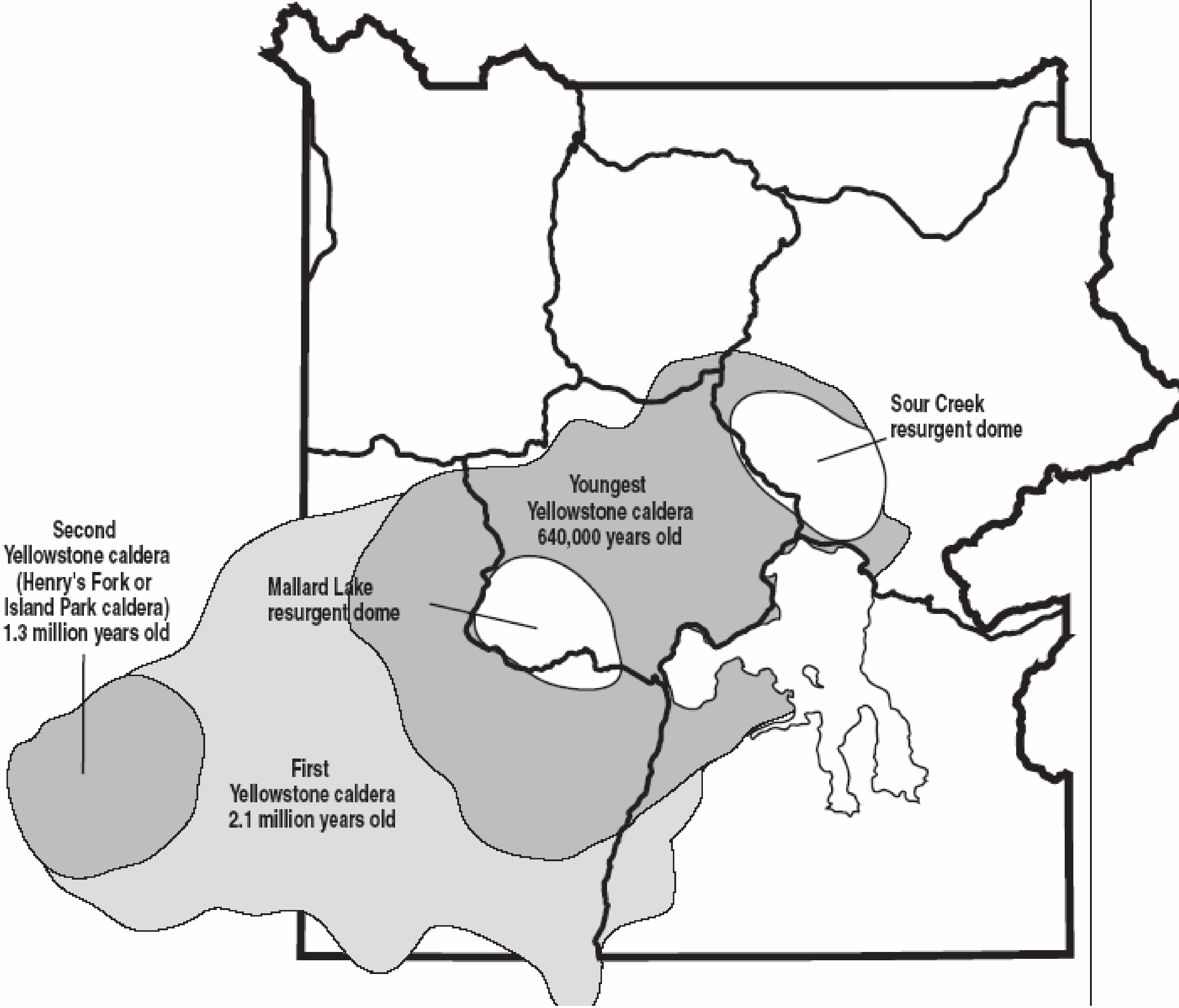



Figure 6.—Interpretive reconstruction of the Yellowstone Plateau region before initial plateau volcanism (a little before 2 Ma). The region was entirely an elevated and faulted mountainous terrain with no basin in the present plateau area. Gray areas are underlain by the tuff of Kilgore, Conant Creek Tuff, and older ash-flow tuffs of the eastern Snake River Plain.

# Three Volcanic Cycles of Yellowstone

- Three extraordinarily large explosive eruptions in the past 2.1 million years each created a giant caldera within or west of Yellowstone National Park with the spread of enormous volumes of hot, fragmented volcanic rocks as pyroclastic flows over vast areas within times as short as a few days or weeks.


Sour Creek
resurgent dome
Youngest
Yellowstone caldera
640,000 years old
Second
Yellowstone caldera
(Henry's Fork or
Island Park caldera)
1.3 million years old
Mallard Lake
resurgent dome
First
Yellowstone caldera
2.1 million years old

# Three Volcanic Cycles of Yellowstone

- The accumulated hot ash, pumice, and other rock fragments welded together from their heat and the weight of overlying material to form extensive sheets of hard lava-like rock
- In some sections, these welded ash-flow tuffs are more than 400 m thick!
- These ash-flow sheets—from oldest to youngest, the Huckleberry Ridge, Mesa Falls, and Lava Creek Tuffs—account for more than half the material erupted from Yellowstone

# Three Volcanic Cycles of Yellowstone

- The enormous outpouring of magma, 280 to 2,450 km3 during each explosive event, led to the collapse of magma-chamber roofs, causing the ground above to subside by many hundreds of meters to form the calderas.
- These ash-flow sheets—from oldest to youngest, the Huckleberry Ridge, Mesa Falls, and Lava Creek Tuffs—account for more than half the material erupted from Yellowstone

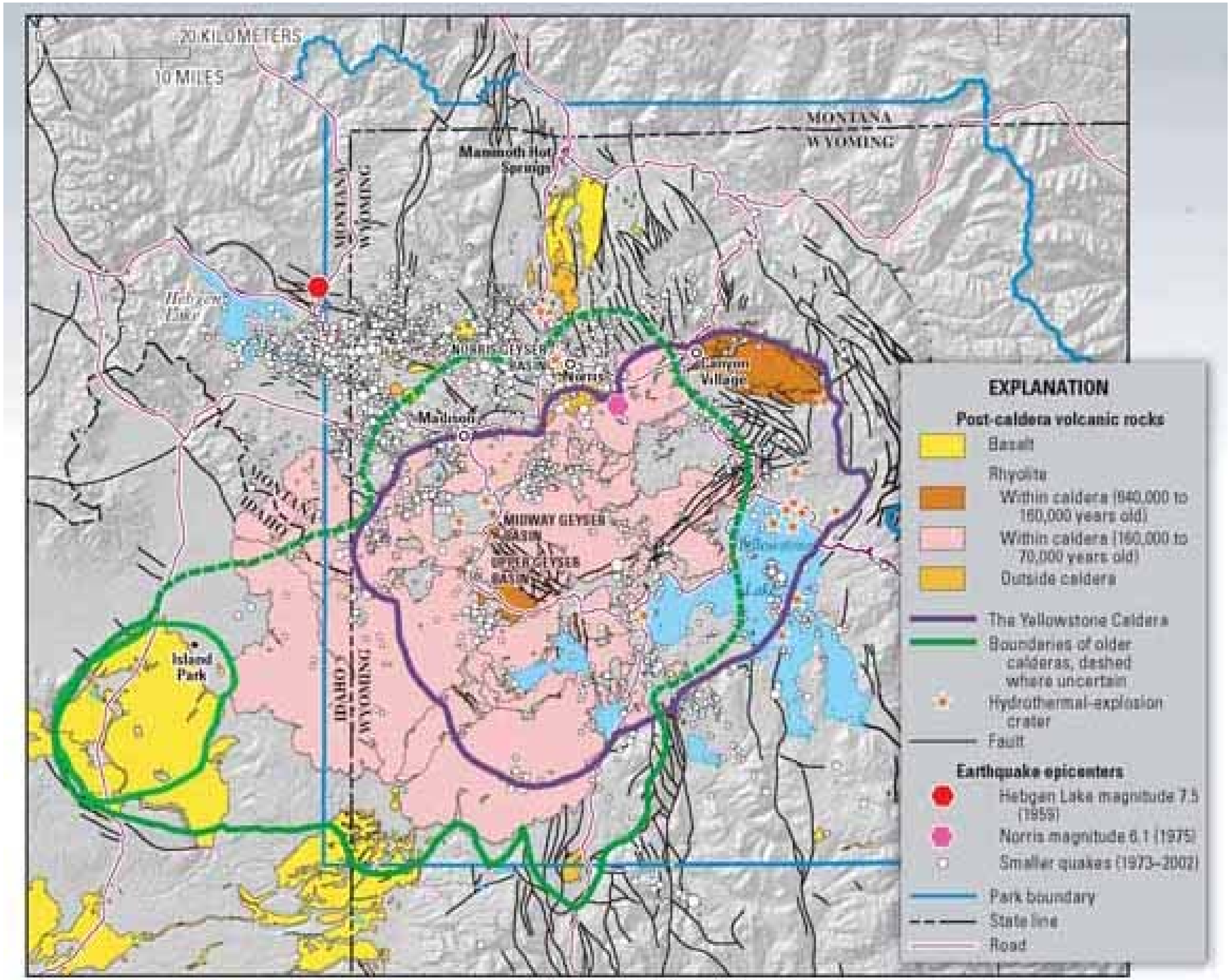
# Three Volcanic Cycles of Yellowstone

- The enormous outpouring of magma, 280 to 2,450 km3 during each explosive event, led to the collapse of magma-chamber roofs, causing the ground above to subside by many hundreds of meters to form the calderas.
- Before and after these caldera-forming events, eruptions in the Yellowstone area produced rhyolitic and basaltic rocks
- Large rhyolite lava flows and some smaller pyroclastic flows in and near where the calderas collapsed and basalt lava flows around the margins of the calderas.

| Caldera-forming ash-flow tuff | Age (millions of years) | Volume erupted ($km^3$) | Area covered ($km^2$) | Caldera dimensions (km) | Caldera name |
|---|---|---|---|---|---|
| Lava Creek Tuff | - 0.640 | 1,000 | 7,500 | 85 x 45 | Yellowstone caldera |
| Mesa Falls Tuff | -1.3 | 280 | 2,700 | 16 km in diameter | Henry's Fork caldera |
| Huckleberry Ridge Tuff | -2.1 | 2,450 | 15,500 | 75-95 x 40-60[1] | Big Bend Ridge, Snake River, and Red Mountains caldera segments |

# Stratigraphic units of the Yellowstone Plateau volcanic field

| Volcanic Cycle | Precaldera Rhyolite | Caldera-forming ash-flow tuff | Postcaldera rhyolite | Contemporaneous plateau-marginal basalts[1] |
|---|---|---|---|---|
| Third | Mount Jackson Rhyolite<br>Lewis Canyon Rhyolite | Lava Creek Tuff<br>(0.64 Ma) | Plateau Rhyolite[2] | Basalts of Snake River Group<br>Osprey Basalt<br>Madison River Basalt<br>Basalt of Geode Creek<br>Swan Lake Flat Basalt<br>Basalt of Mariposa Lake<br>Undine Falls Basalt<br>Basalt of Warm River<br>Basalt of Shotgun Valley |
| Second | Big Bend Ridge Rhyolite[3] | Mesa Falls Tuff<br>(1.3 Ma) | Island Park Rhyolite | Basalt of the Narrows |
| First | Rhyolite of Snake River Butte | Huckleberry Ridge Tuff<br>(2.2-2.1 Ma) | Big Bend Ridge Rhyolite[3] | Junction Butte Basalt |



20 KILOMETERS
10 MILES
MONTANA
WYOMING
Mammoth Hot Springs
Hebgen Lake
NORRIS GEYSER BASIN
Norris
Canyon Village
Madison
MONTANA
IDAHO
MIDWAY GEYSER BASIN
UPPER GEYSER BASIN
Island Park
IDAHO
WYOMING
EXPLANATION
Post-caldera volcanic rocks
Basalt
Rhyolite
Within caldera (940,000 to 160,000 years old)
Within caldera (160,000 to 70,000 years old)
Outside caldera
The Yellowstone Caldera
Boundaries of older calderas, dashed where uncertain
Hydrothermal-explosion crater
Fault
Earthquake epicenters
Hebgen Lake magnitude 7.5 (1959)
Norris magnitude 6.1 (1975)
Smaller quakes (1973–2002)
Park boundary
State line
Road

# A general sequence of events was repeated in the evolution of each of Yellowstone's three volcanic cycles:

- A broad area, larger than that which will become the caldera is slowly uplifted. This uplift reflects the development and rise of large volumes of rhyolite to form a magma chamber at shallow depths in the Earth's crust.
- Stretching of the crust above the inflating magma chamber leads to concentric and radial fracturing and faulting at the surface, typically accompanied by the extrusion of lava flows from these fractures.

# A general sequence of events was repeated in the evolution of each of Yellowstone's three volcanic cycles:

- At a critical stage in the evolution of the magma chamber, enormous volumes of the pressurized rhyolite magma erupt explosively through the ring-fracture zone created above the magma chamber during inflation and uplift, producing extensive ash-flow sheets.
- As the eruptions partly empty the chamber of its magma, the roof of the magma chamber collapses along the same ring fractures to produce a large caldera.

# Aerial view of the NW rim of the Yellowstone caldera and intracaldera rhyolite lava flows at Madison Junction in Yellowstone National Park


Yellowstone Caldera rim
Nez Perce
Creek flow
West
Yellowstone
flow

# NE Side of Yellowstone Caldera

# Huckleberry Ridge Tuff on Mt. Everts

# Huckleberry Ridge Tuff on Mt. Everts

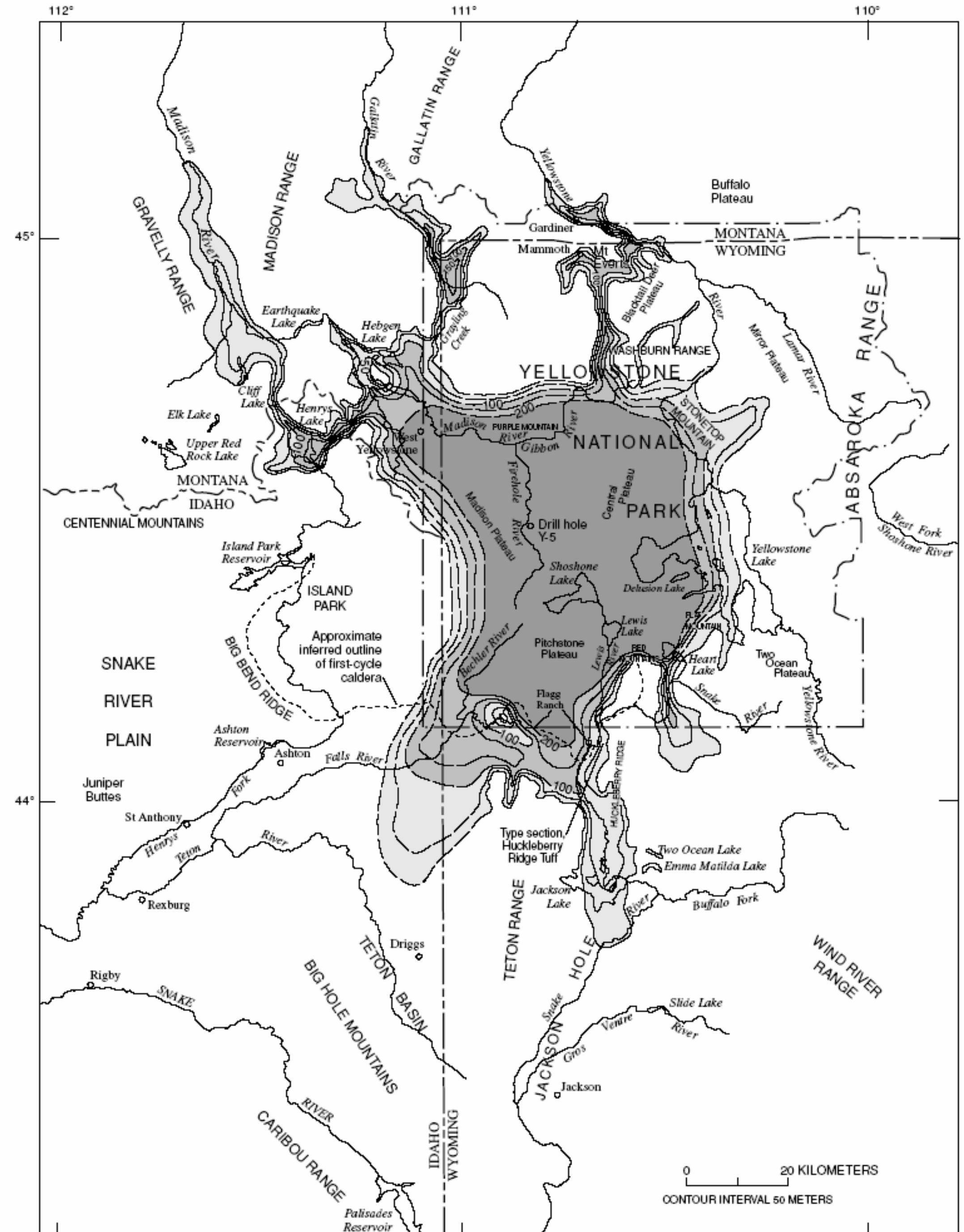



Figure 32.—Areal distribution and thickness of member A, Huckleberry Ridge Tuff, in relation to topographic features in the Yellowsto

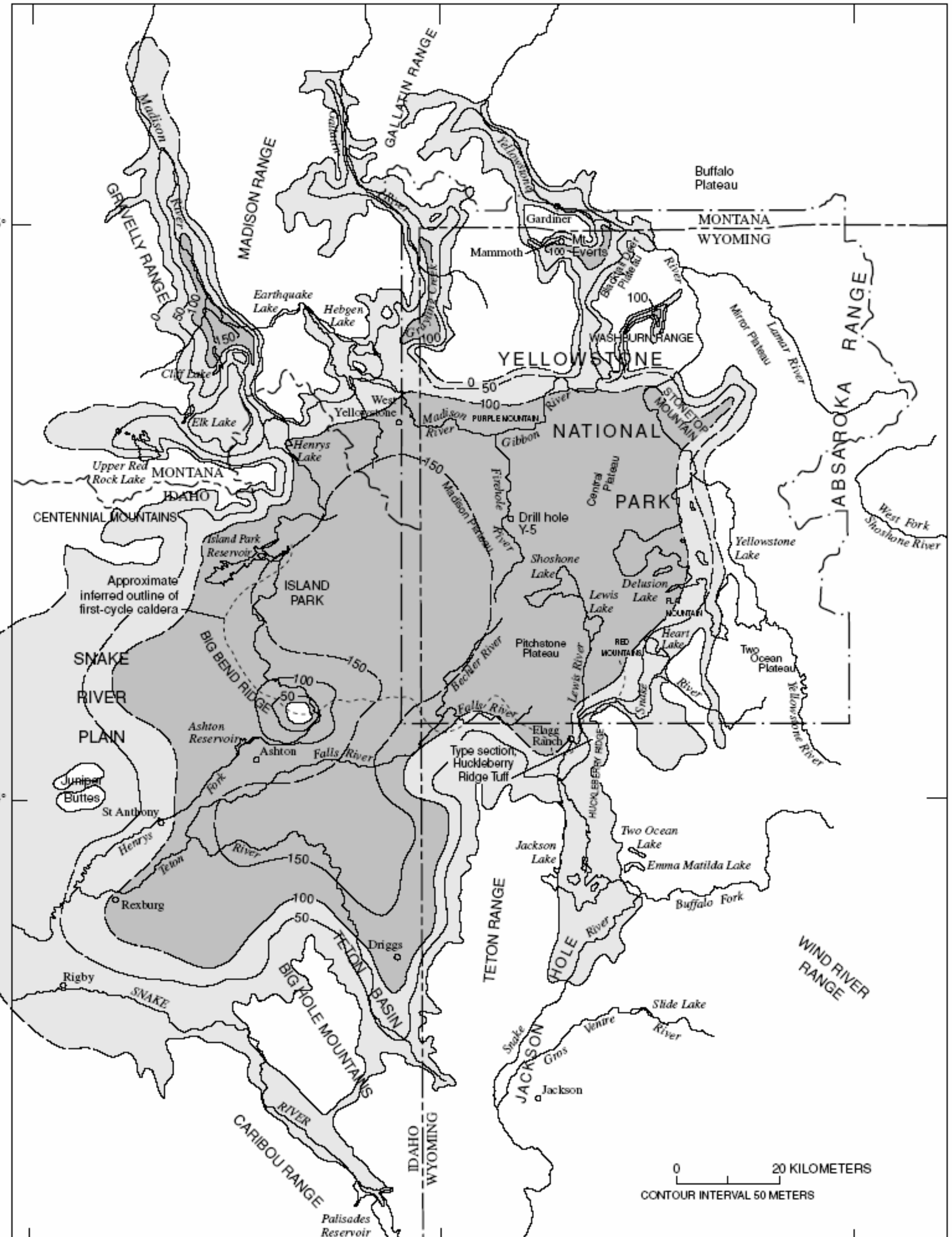



Figure 33.—Areal distribution and thickness of member B, Huckleberry Ridge Tuff, in relation to topographic features in the Yellowstone Plateau volcanic field that affected its distribution. Member B spread widely on surfaces blanketed by older ash flows. The calculated initial area is 15,400 km² and initial volume is 1,340 km³. Shading is darker for thicker sections. Isopachs in meters, dashed where inferred.

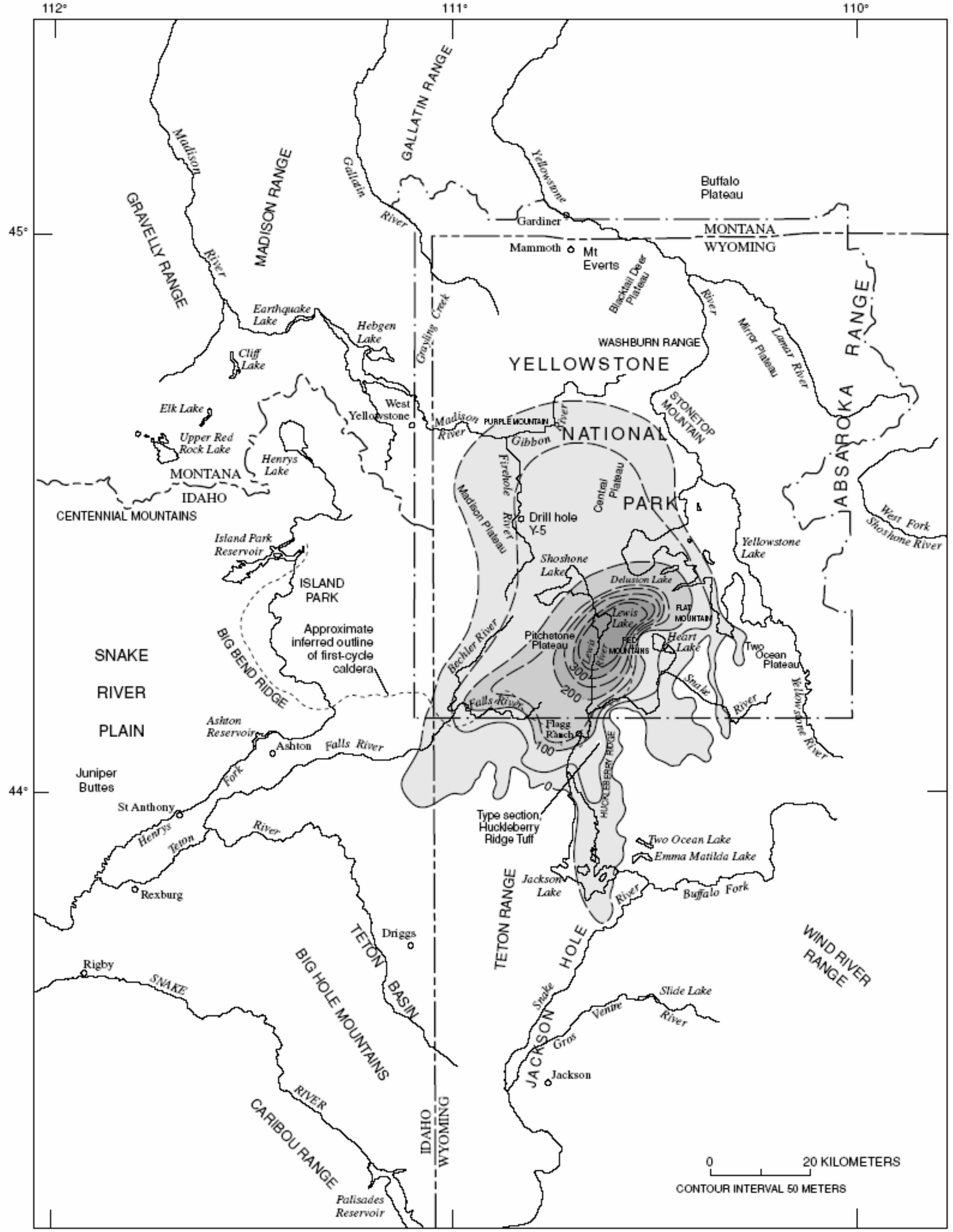
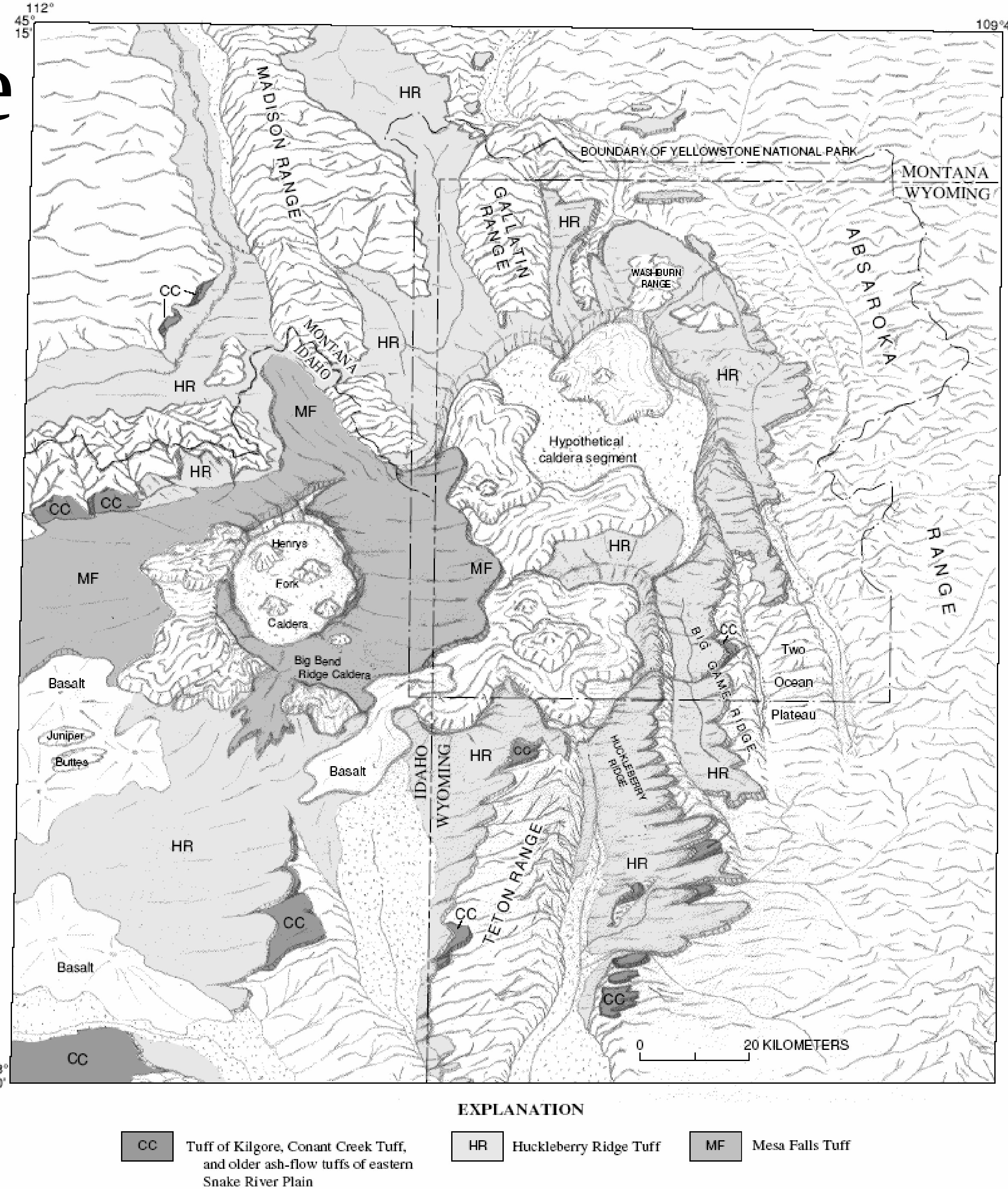



Figure 34.—Areal distribution and thickness of member C, Huckleberry Ridge Tuff, in relation to topographic features in the Yellowsto Plateau volcanic field that affected its distribution. Member C is exposed only near the south margin of the Yellowstone Plateau. The calcula initial area is 3,690 km² and initial volume is 290 km³. Shading is darker for thicker sections. Isopachs in meters, dashed where inferred.

# Yellowstone 1.2 million years ago



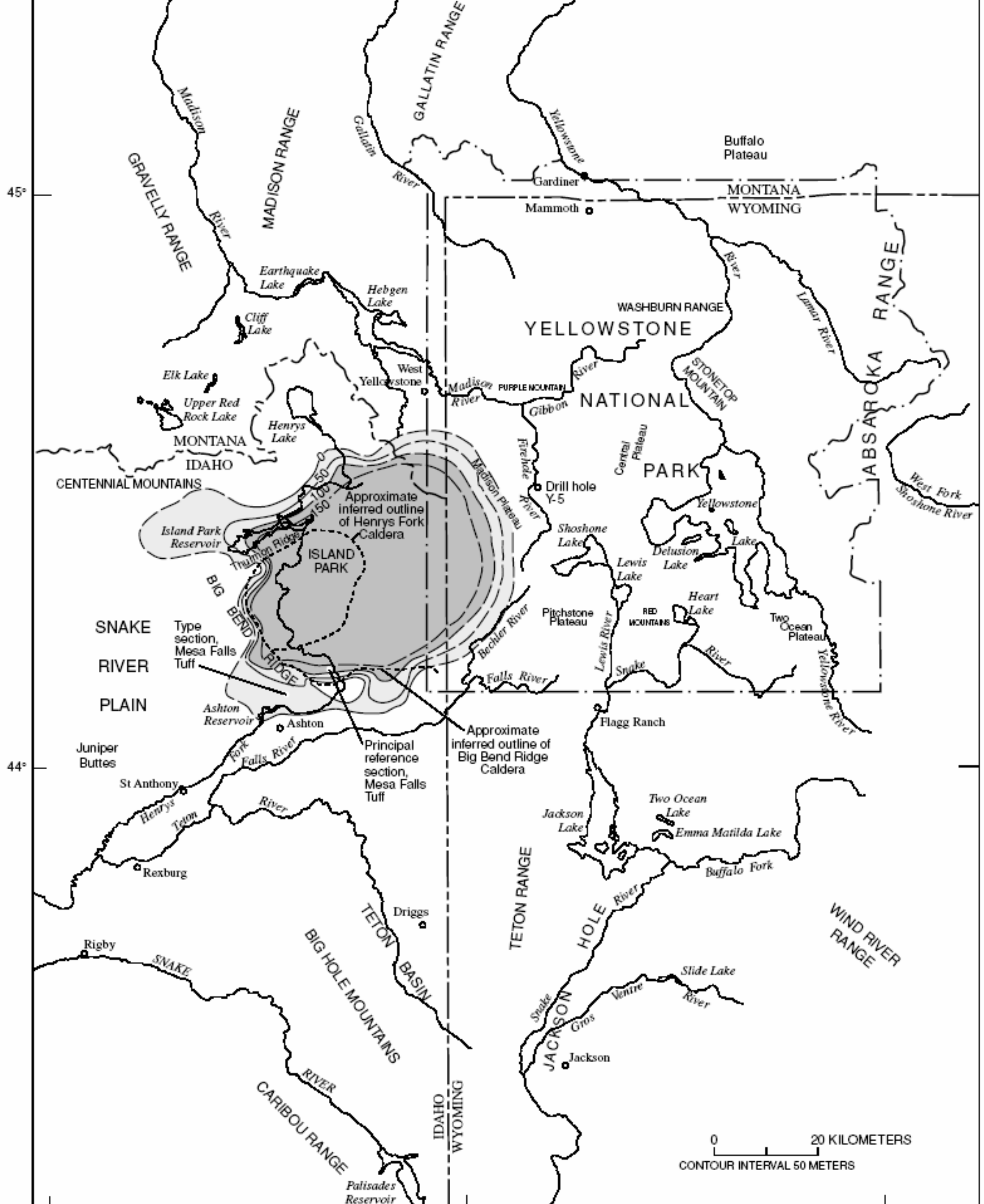



Figure 37.—Areal distribution and thickness of the Mesa Falls Tuff, in relation to topographic features in the Yellowstone Plateau volcani field that affected its distribution. Exposure is limited to the Island Park area, but buried thickness in the first-cycle caldera may b considerable. The calculated initial area is nearly 2,700 km² and initial volume is 280 km³. Shading is darker for thicker sections. Isopach in meters, dashed where inferred.

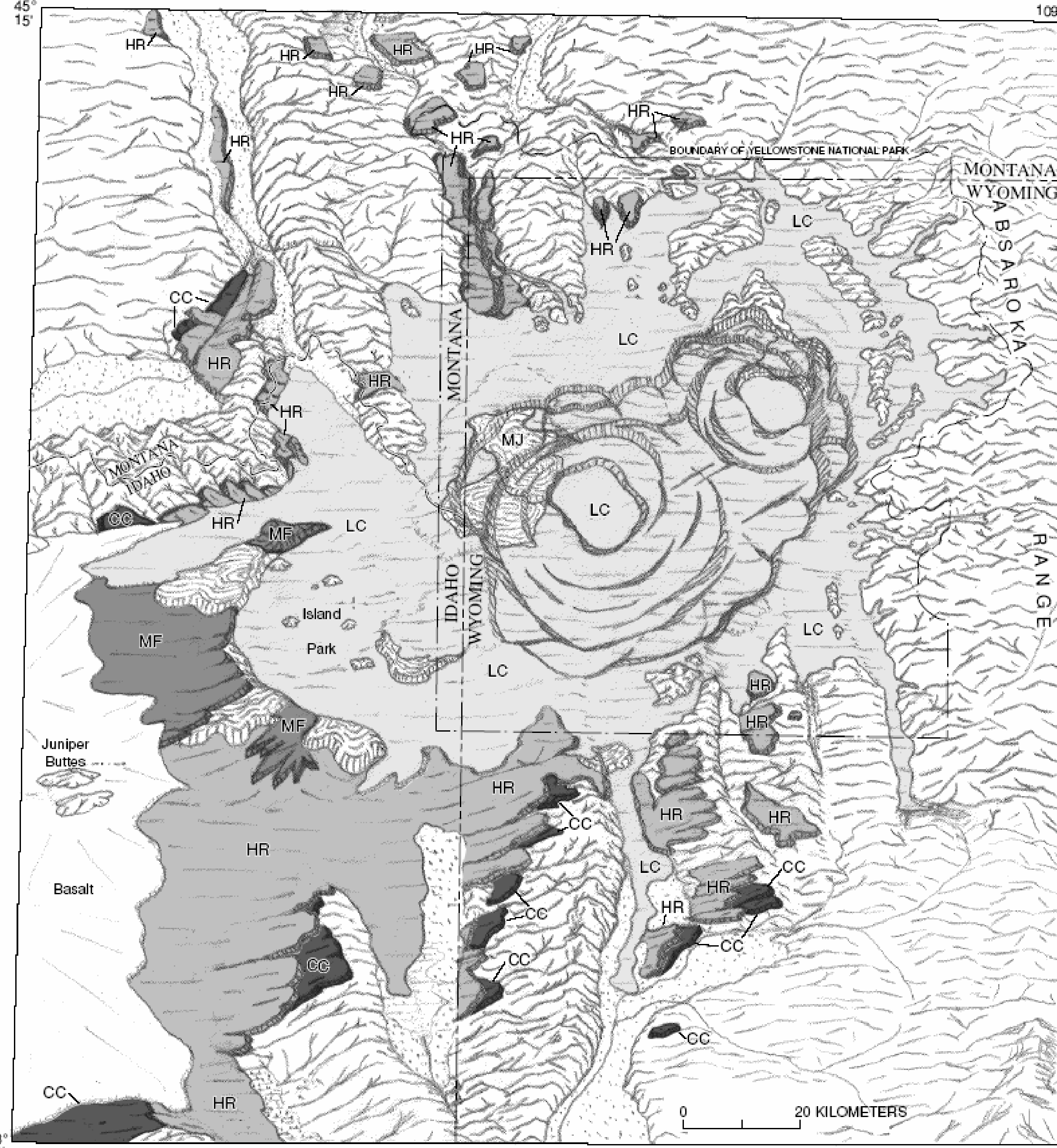



Figure 20.—Interpretive reconstruction of the Lava Creek Tuff ash-flow sheet and the Yellowstone caldera before resurgence. CC, Kilgore Tuff and Conant Creek Tuff; HR, Huckleberry Ridge Tuff; MF, Mesa Falls Tuff; MJ, lava flows of Mount Jackson Rhyolite; LC, Lava Creek Tuff.

# A general sequence of events was repeated in the evolution of each of Yellowstone's three volcanic cycles:

- Postcollapse volcanism includes the extrusion of rhyolite lavas and smaller explosive eruptions of pyroclastic flows within or adjacent to the the caldera.
- In the present-day Yellowstone caldera, lakes formed where streams draining into or along the margin of the caldera were dammed by these thick intracaldera rhyolite flows, including Shoshone, Lewis, Heart, and Yellowstone Lakes.

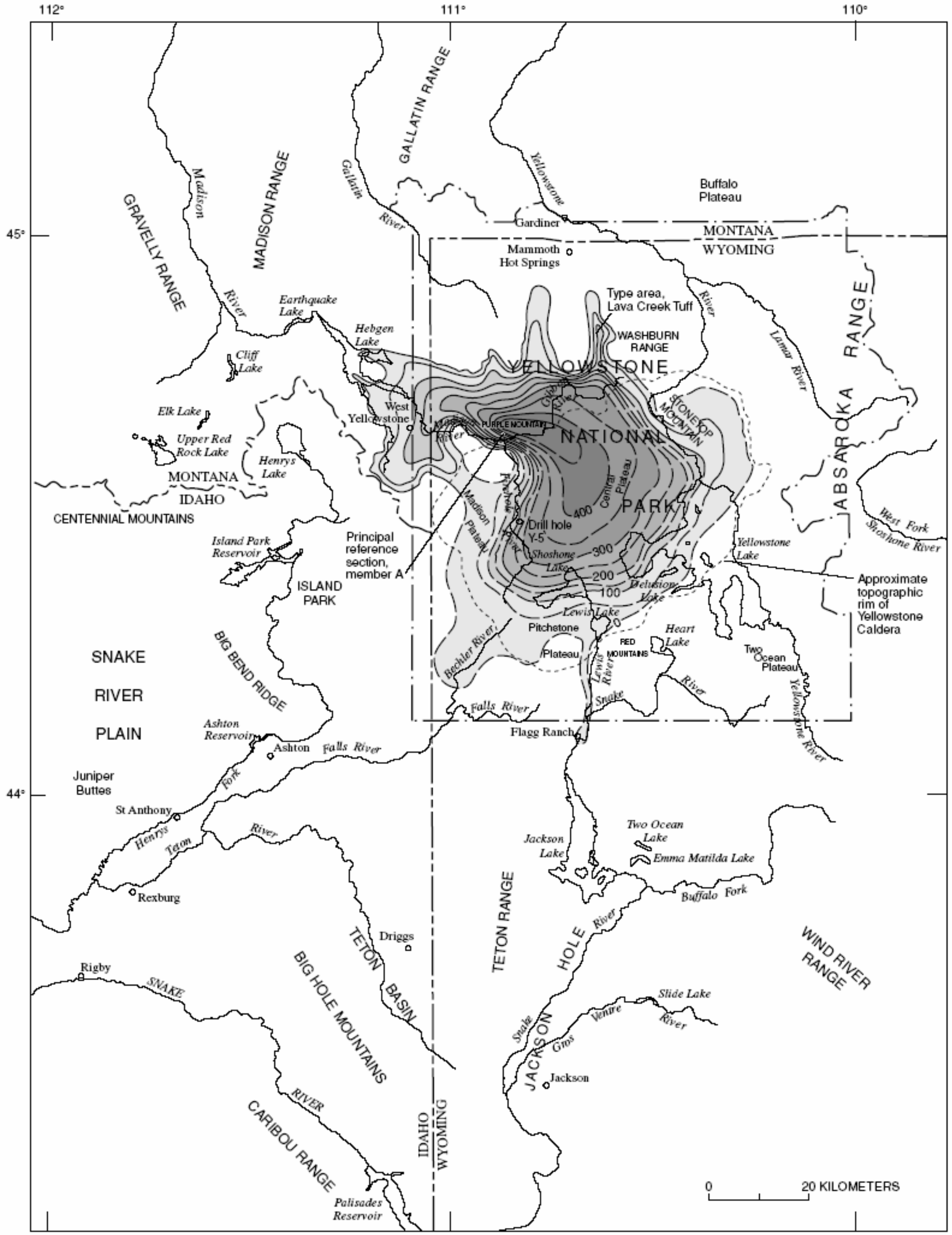
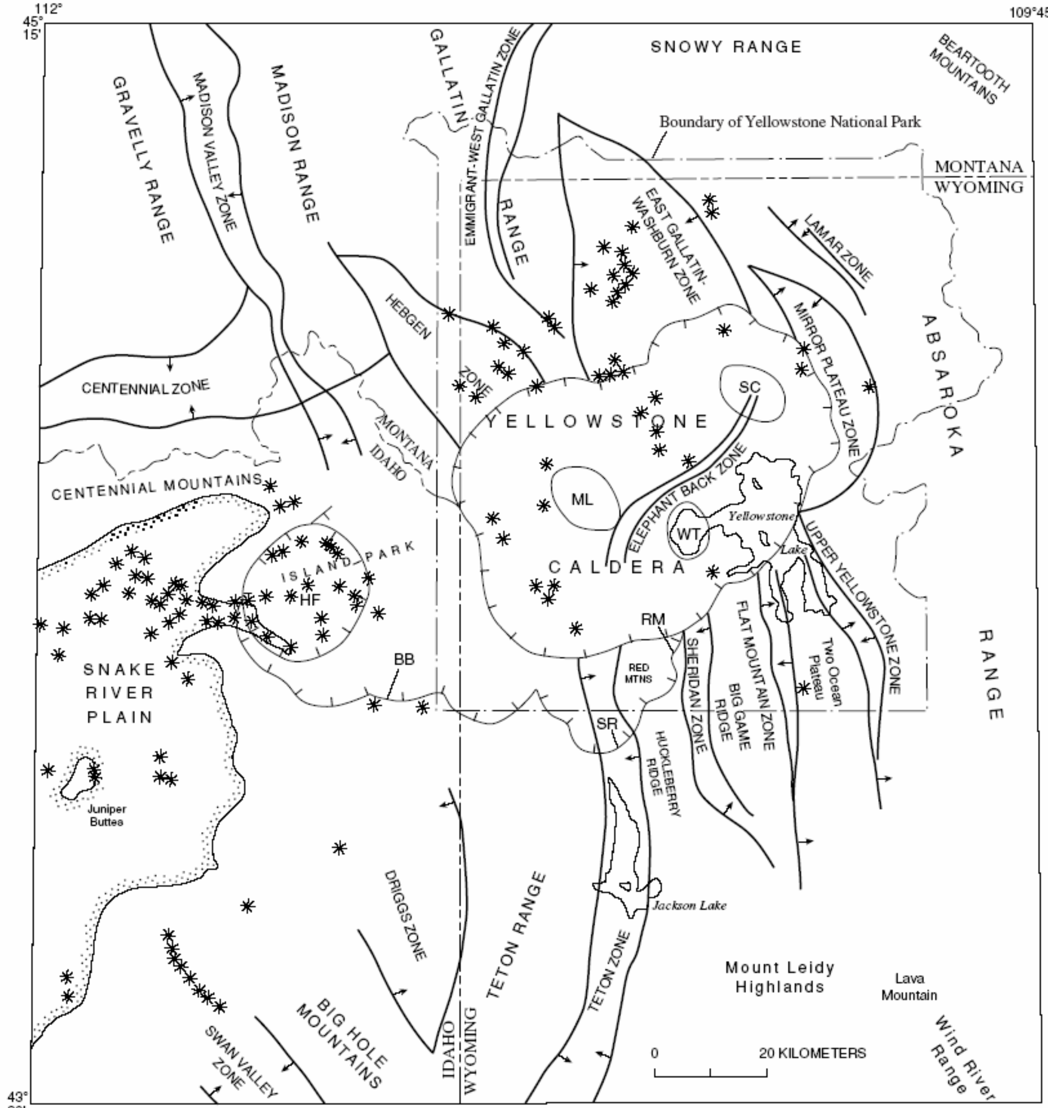



Figure 18.—Areal distribution and thickness of member A, Lava Creek Tuff, in relation to topographic features in the Yellowstone Plateau volcanic field that affected its distribution. Member A was emplaced on erosional topography of high relief from a source area southeast of Purple Mountain. The calculated initial area is 3,240 km² and initial volume is 510 km³. Shading is darker for thicker sections. Isopachs in meters, dashed where inferred.




**EXPLANATION**

HF — Caldera rim—Hachures toward collapse. HF, Henrys Fork caldera; BB, Big Bend Ridge caldera segment; SR, Snake River caldera segment; RM, Red Mountains caldera segment; WT, West Thumb caldera.

SC — Resurgent dome—ML, Mallard Lake; SC, Sour Creek

Major late Cenozoic fault zone—Arrows toward structurally lowest part

* Known volcanic vents—All others whose general locations are known lie in the same zones as those above.

Table 3.—Members of the Plateau Rhyolite in relation to caldera events.

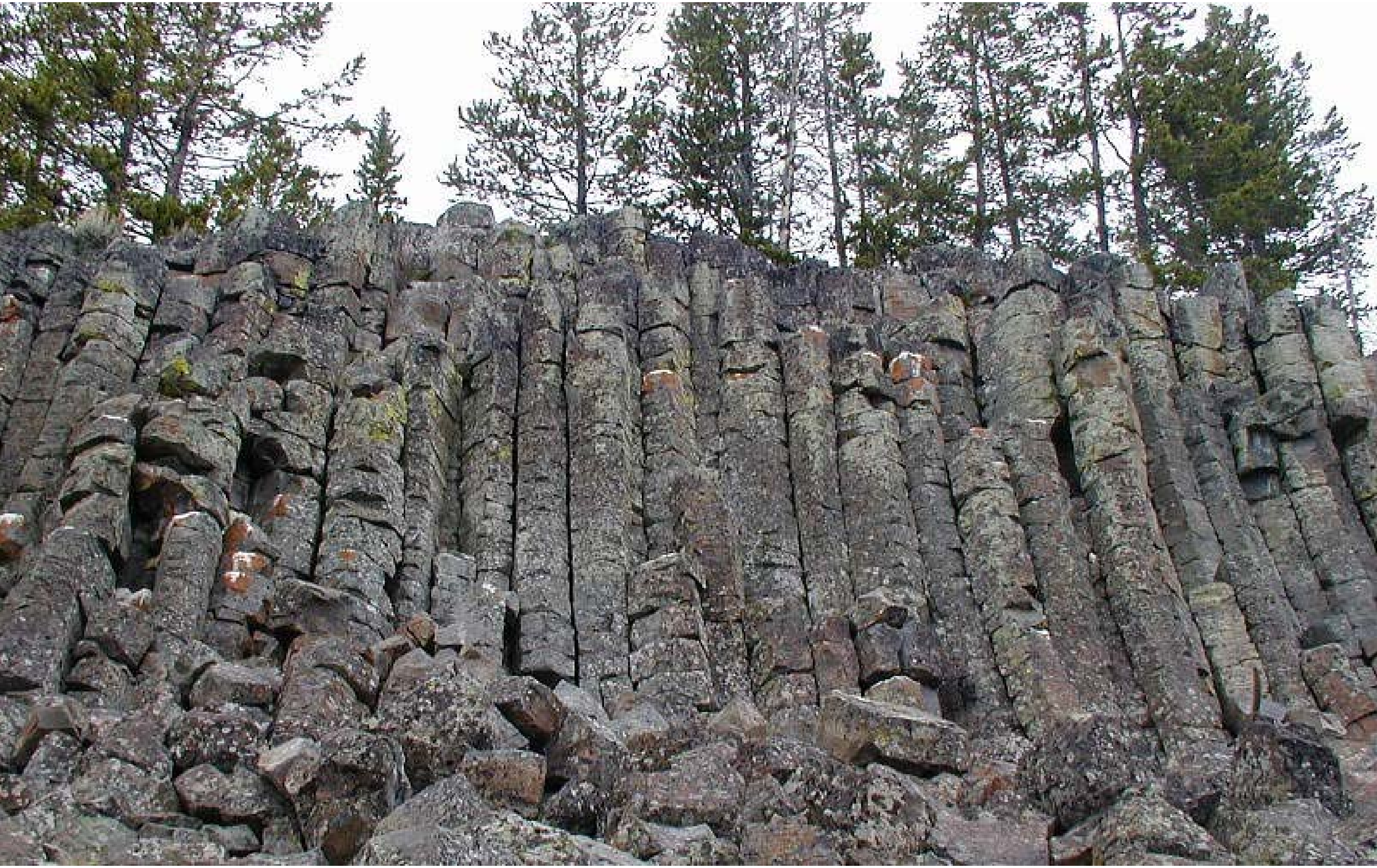
<table>
<tr><th>Plateau Rhyolite age group</th><th>Caldera event</th><th>Intracaldera flows and minor related pyroclastics</th><th colspan="2">Extracaldera flows and minor related pyroclastics</th></tr>
<tr><td rowspan="3">Younger postcollapse rhyolites</td><td></td><td>Central Plateau Member</td><td rowspan="4">Obsidian Creek Member</td><td rowspan="4">Roaring Mountain Member</td></tr>
<tr><td>Late doming</td><td></td></tr>
<tr><td rowspan="2"></td><td>Mallard Lake Member</td></tr>
<tr><td>Older postresurgence rhyolites</td><td>Upper Basin Member</td></tr>
<tr><td></td><td>Early resurgent doming</td><td></td><td colspan="2"></td></tr>
</table>

# A general sequence of events was repeated in the evolution of each of Yellowstone's three volcanic cycles:

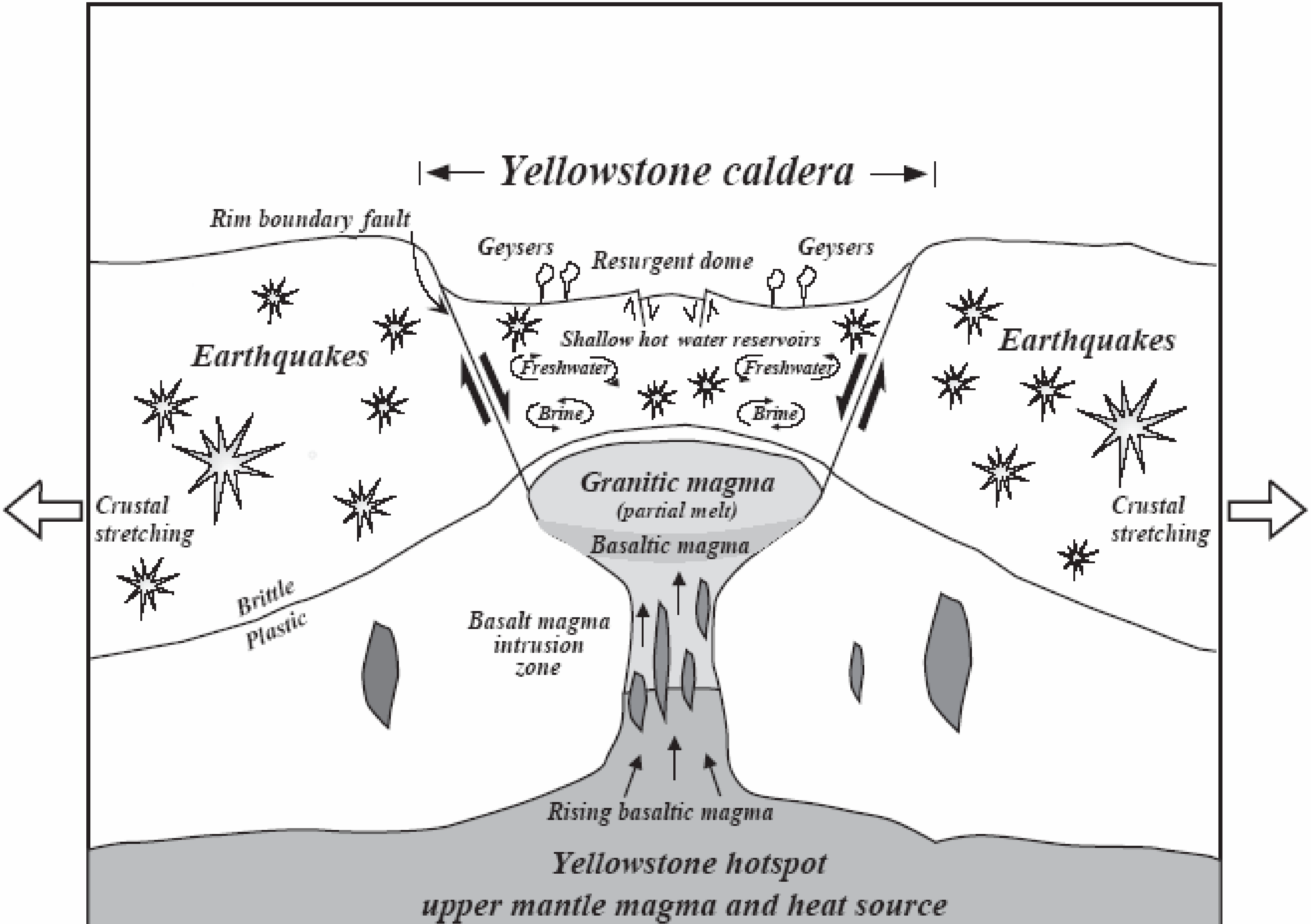
- Shortly following collapse, the caldera floor may be uplifted by hundreds of meters in a process known as resurgent doming; this uplift reflects renewed pressure as magma rises again into the magma chamber.
- Hydrothermal activity (such as hot springs and geysers) occurs during all three stages but, in the third stage, it becomes the dominant or only visible sign at the surface of magmatic activity below.

# Lava Creek spills over the surface of a basalt lava flow that was emplaced about 700,000 years ago

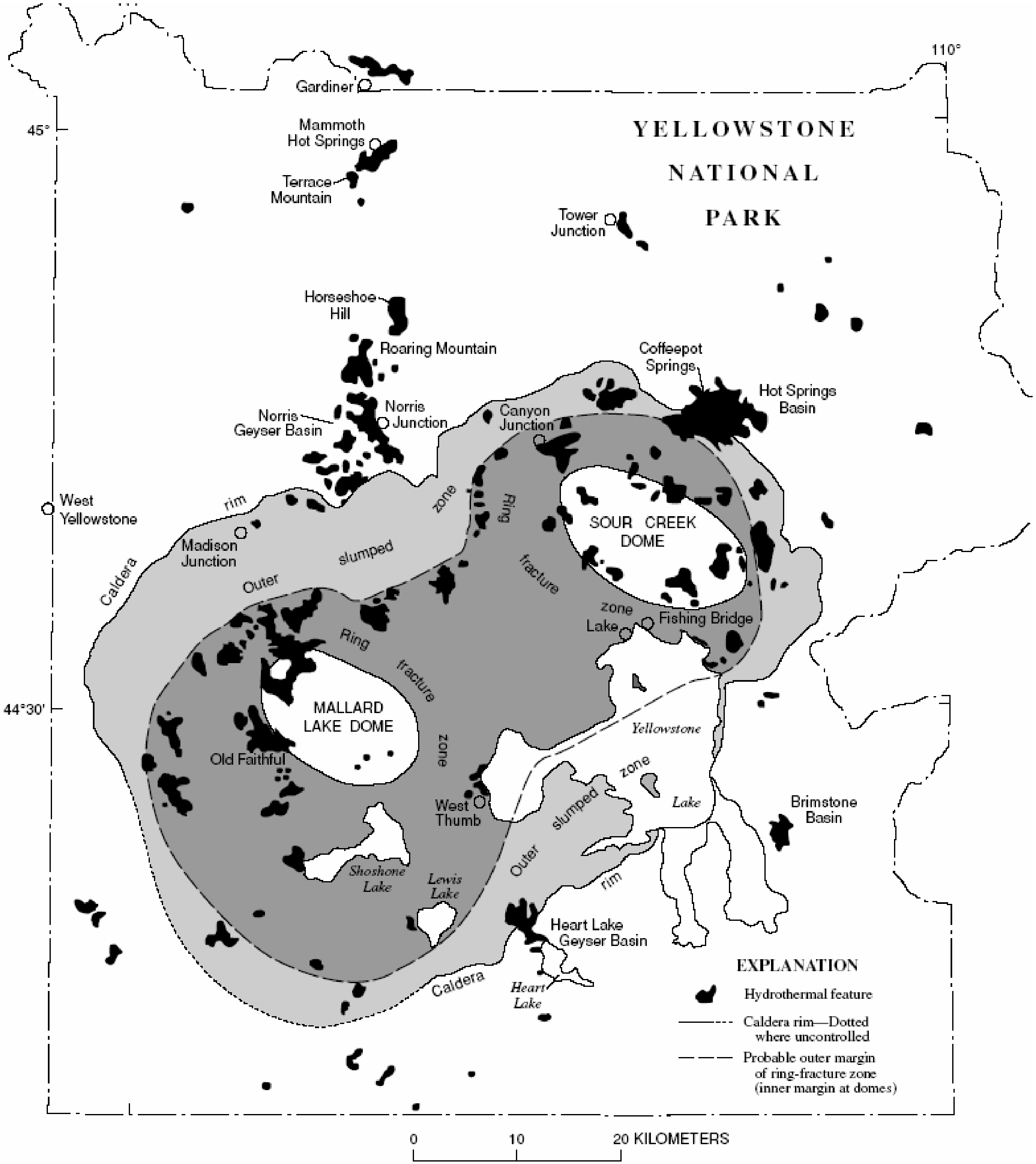
# Intracaldera rhyolite lava flows of the forested Madison and Pitchstone Plateaus



# Obsidian Cliff

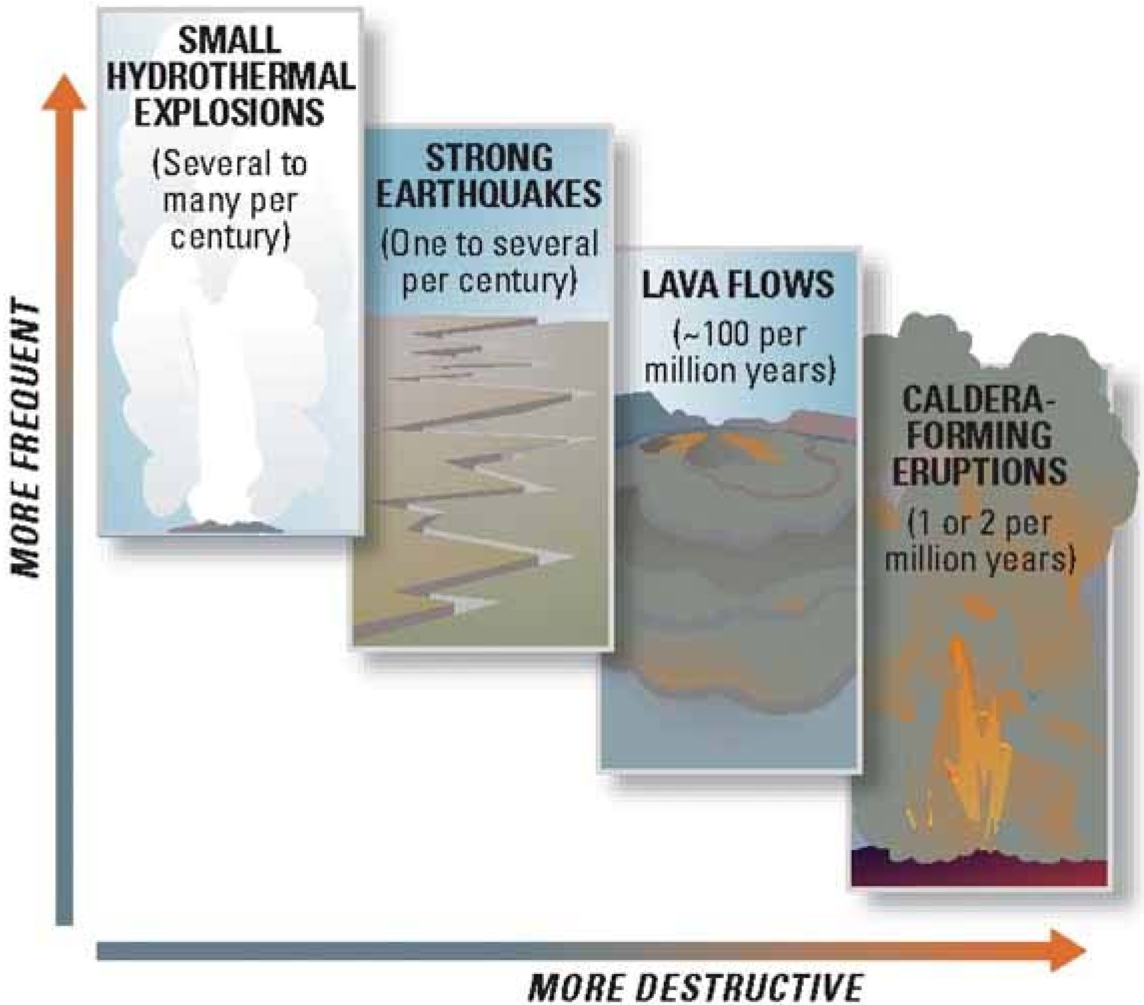


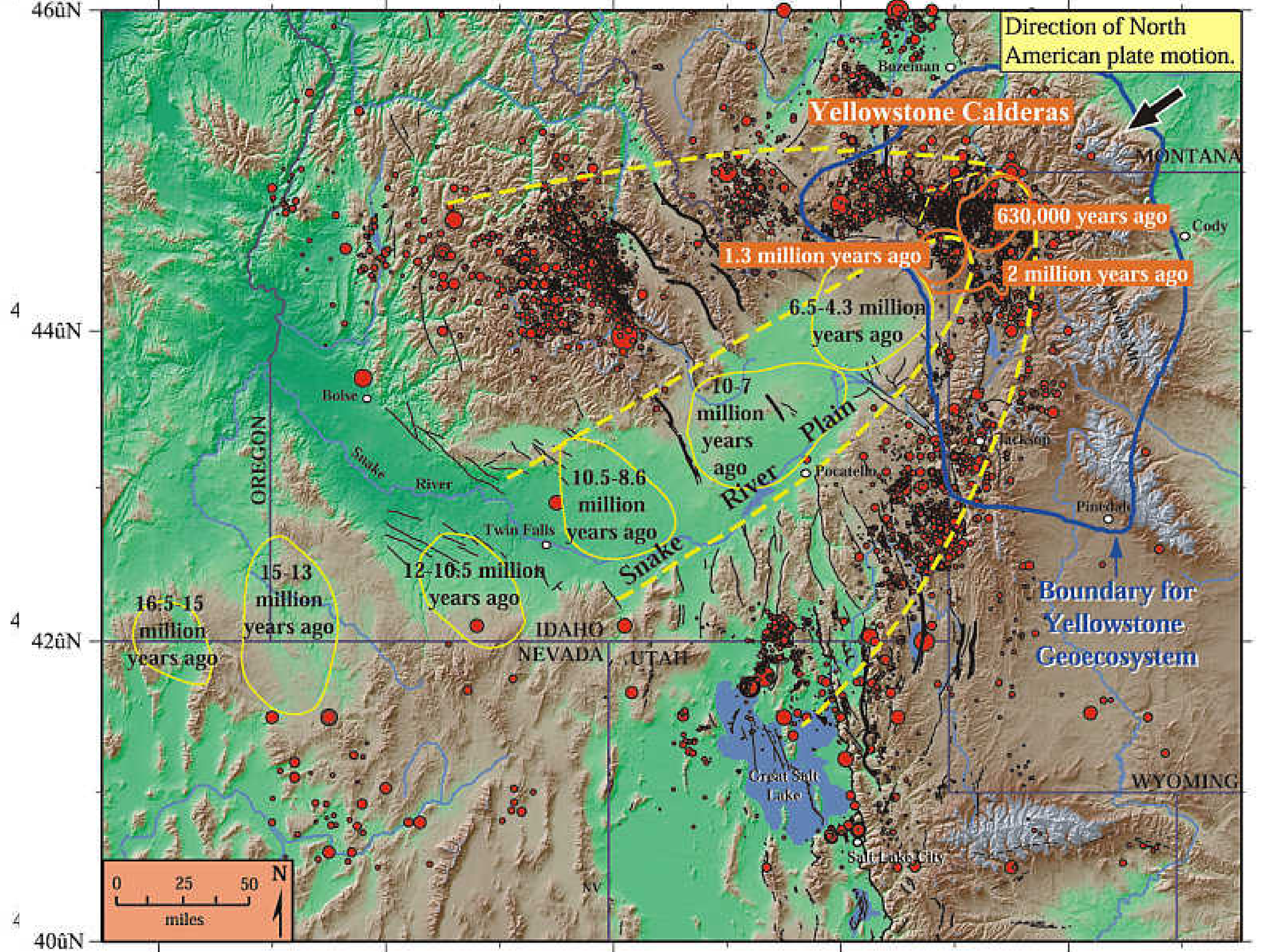
Yellowstone caldera
Rim boundary fault
Geysers
Resurgent dome
Geysers
Earthquakes
Shallow hot water reservoirs
Earthquakes
Freshwater
Freshwater
Brine
Brine
Granitic magma
(partial melt)
Basaltic magma
Crustal stretching
Crustal stretching
Brittle
Plastic
Basalt magma intrusion zone
Rising basaltic magma
Yellowstone hotspot
upper mantle magma and heat source



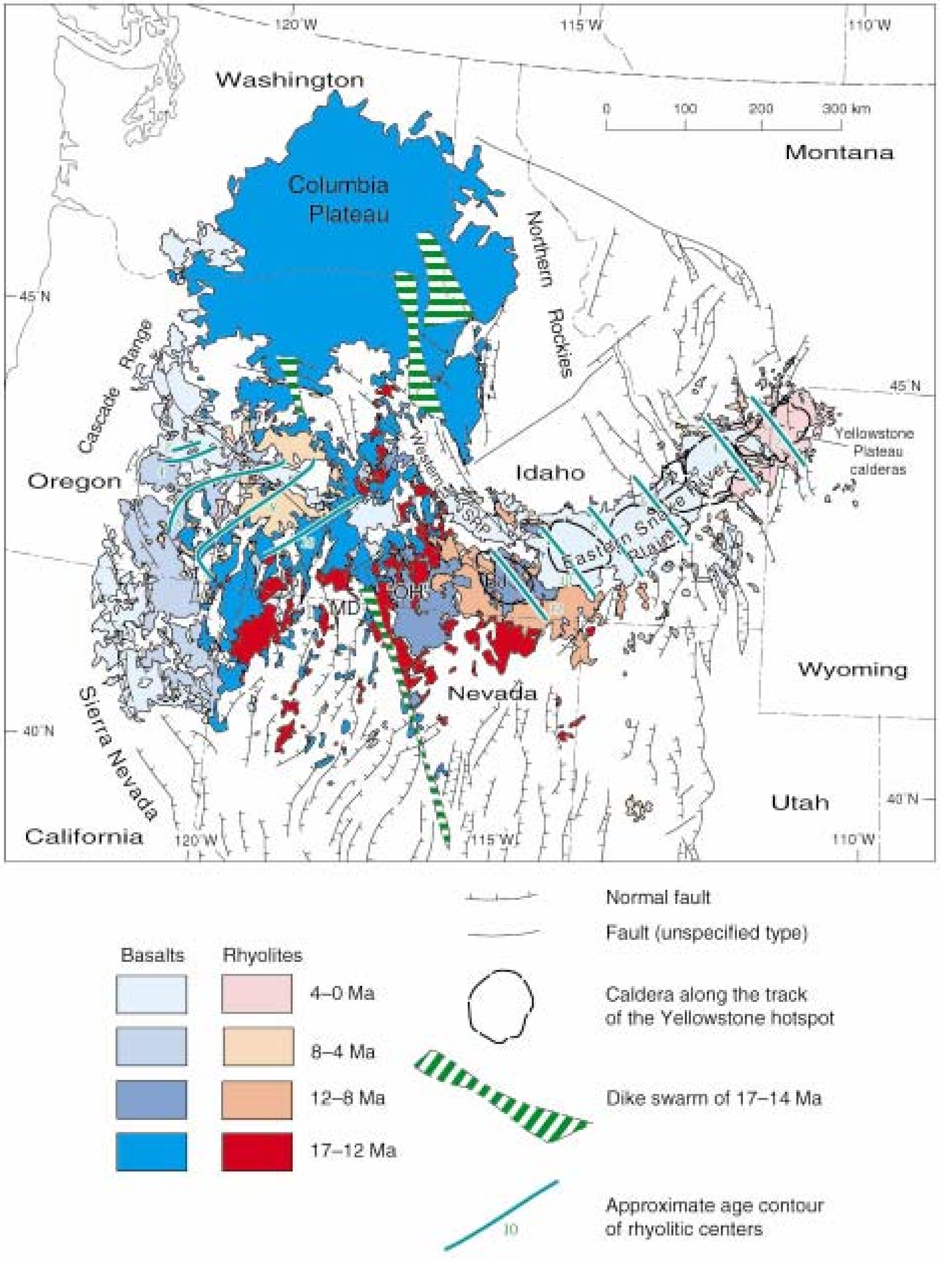
YELLOWSTONE
NATIONAL
PARK
110°
45°
44°30'
Gardiner
Mammoth Hot Springs
Terrace Mountain
Tower Junction
Horseshoe Hill
Roaring Mountain
Coffeepot Springs
Hot Springs Basin
Norris Geyser Basin
Norris Junction
Canyon Junction
West Yellowstone
Madison Junction
SOUR CREEK DOME
MALLARD LAKE DOME
Old Faithful
Lake
Fishing Bridge
West Thumb
Yellowstone Lake
Shoshone Lake
Lewis Lake
Brimstone Basin
Heart Lake Geyser Basin
Heart Lake
Caldera rim
Outer slumped zone
Ring fracture zone
EXPLANATION
Hydrothermal feature
Caldera rim—Dotted where uncontrolled
Probable outer margin of ring-fracture zone (inner margin at domes)
0
10
20 KILOMETERS

# How Dangerous is Yellowstone?





46ûN
44ûN
42ûN
40ûN
Direction of North American plate motion.
Yellowstone Calderas
MONTANA
Bozeman
630,000 years ago
Cody
1.3 million years ago
2 million years ago
6.5-4.3 million years ago
10-7 million years ago
Boise
Snake River Plain
Jackson
Pocatello
10.5-8.6 million years ago
Pinedale
Twin Falls
OREGON
Snake River
12-10.5 million years ago
15-13 million years ago
16.5-15 million years ago
IDAHO
NEVADA
UTAH
Boundary for Yellowstone Geoecosystem
Great Salt Lake
Salt Lake City
WYOMING
0 25 50
miles
N



120°W
115°W
110°W
Washington
0 100 200 300 km
Montana
Columbia Plateau
Northern Rockies
45°N
45°N
Cascade Range
Yellowstone Plateau calderas
Oregon
Idaho
Western Snake River
Eastern Snake River Plain
MD
OH
BJ
Wyoming
Nevada
40°N
40°N
Sierra Nevada
Utah
California
120°W
115°W
110°W
Normal fault
Fault (unspecified type)
Basalts
Rhyolites
4–0 Ma
8–4 Ma
12–8 Ma
17–12 Ma
Caldera along the track of the Yellowstone hotspot
Dike swarm of 17–14 Ma
Approximate age contour of rhyolitic centers
10

# Future Eruptions of Yellowstone

- The long-term nature of volcanism in this part of North America suggests that more eruptions will occur as the Yellowstone National Park continues to evolve.
- The most recent series of eruptions, 160,000 to 70,000 years ago, extruded more than 20 thick rhyolite lava flows and domes, most of them within the youngest caldera.
- Other postcaldera lavas are basalts, erupted around the margins of the rhyolitic calderas.

# Future Eruptions of Yellowstone

- Based on Yellowstone's history, the next eruptions are likely to expel lavas, which might be either rhyolites or basalts, possibly accompanied by moderate explosive activity.
- Far less likely would be another enormous outpouring of material that could lead to a fourth caldera.

**2,375 Earthquakes in 2002, Yellowstone Area**

*Anyone can access real-time data about earthquakes in Yellowstone from a website maintained by the University of Utah Seismograph Stations: www.seis.utah.edu*