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# Isotope and chemical compositions of meteoric and thermal waters and snow from the greater Yellowstone National Park region

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# Isotope and chemical Compositions of Meteoric and Thermal Waters and Snow from the Greater Yellowstone National Park Region

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## ABSTRACT

An intensive hydrogeologic investigation, mandated by U.S. Congress and centered on the Norris-Mammoth corridor was conducted by USGS and other scientists during 1988-90 to determine the effects of using thermal water from a private well located in the Corwin Springs Known Geothermal Resources Area, Montana, on the thermal springs of Yellowstone National Park (YNP), especially Mammoth Hot Springs. As part of this investigation, we carried out a detailed study of the isotopic and chemical compositions of meteoric water from cold springs and wells, of thermal water, especially from the Norris-Mammoth corridor and of snow. Additional sampling of meteoric and thermal waters from YNP and surrounding region in northwest Wyoming, southwest Montana and southeast Idaho was carried out in 1991-92 to characterize the distribution of water isotopes in this mountainous region and to determine the origin and possible recharge locations of thermal waters in and adjacent to the Park.

The δD and $\delta^{18}O$ values for 40 snow samples range from –88 to –178‰ and –12.5 to –23.9‰, respectively, and define a well constrained line given by $\delta D = 8.2\ \delta^{18}O + 14.7$ ($r^2$ = 0.99) that is nearly identical to the Global Meteoric Water Line. The δD and $\delta^{18}O$ values of 173 cold water samples range from –115 to –153‰ and –15.2 to –20.2‰, respectively, and exhibit a similar relationship although with more scatter and with some shift to heavier isotopes, most likely due to evaporation effects. The spatial distribution of cold-water isotopes shows a roughly circular pattern with isotopically lightest waters centered on the mountains and high plateau in the northwest corner of Yellowstone National Park and becoming heavier in all directions.

The temperature effect due to altitude is the dominant control on stable water isotopes throughout the region; however, this effect is obscured in narrow 'canyons' and areas of high topographic relief. The effects due to distance (i.e. "continental") and latitude on water isotopes probably are relatively minor and difficult to resolve from the major controls. The data indicate that the groundwater are derived predominantly from cold, isotopically light winter precipitation, and that the isotope values of groundwater from elevations above about 2.5-3.0 km in the Gallatin and northern Absaroka Ranges are light enough (The δD ≥ –149‰) to be the presumed recharge water for the hydrothermal system in the Park. However, estimation of the present-day volume of this recharged, isotopically light water indicates that it is not adequate to supply the high (3-4 $m^3$/s) thermal water discharges from YNP, and cooler temperatures at the time of recharge would be required. The volume of meteoric water with δD values lighter than –145‰ may be adequate for recharging the hydrothermal system, and this may be a more plausible value than the –149‰ originally calculated from data that are subject to moderate uncertainties.

# INTRODUCTION

Yellowstone National Park (YNP) is unrivaled for the abundance and diversity of its hydrothermal features, including geysers, fumaroles, mud pots and thermal springs (e.g., White and others, 1988; Smith and Siegel, 2000). These extraordinary features are distributed throughout the entire 9,000-$km^2$ area of the Park, but are concentrated in several geyser basins located within the 0.6-Ma Yellowstone caldera and in the Norris-Mammoth corridor (figs. 1-3). The Norris-Mammoth corridor (fig. 2) is a complex north-south subsidence structure, extending ~40 km from the Yellowstone caldera to the Corwin Springs Known Geothermal Resources Area (KGRA) located north of the Park in Montana (e.g., Pierce and others, 1991). The Norris-Mammoth corridor contains the only major alignment of volcanic vents and hydrothermally altered areas outside the caldera; the 13 rhyolitic and basaltic vents have ages of 400-80 ka (Hildreth and others, 1991).

The hydrothermal features in YNP are the surface manifestations of very high fluid discharges that include, thermal water, water vapor and gases, especially $CO_2$ (Fournier, 1989; Kharaka and others, 2000; Werner and others, 2000). Thermal water discharges from YNP have been estimated to average a total of about 3-4 $m^3/s$ (Fournier, 1989; Kharaka and others, 2000). The exceptional hydrothermal features of YNP are the result of a favorable combination of climatic and geologic factors, including a huge magmatic heat source that is present at a relatively shallow depth of 4-8 km beneath the 0.6 Ma Yellowstone caldera (Wicks and others, 1998), abundant supplies of recharge water primarily from melting snow and frequent seismic activity that creates new fractures and reopens clogged channels for fluid flow (Fournier, 1989; Kharaka and others, 2000). The shallow magmatic heat driving this hydrothermal system is associated with a deep-mantle plume, a hotspot, that is presently centered beneath the Yellowstone caldera and is responsible, during the last 2.2 Ma, for the huge eruptive volume (~6,000 $km^3$) of rhyolitic ash-flow tuffs and lavas, covering an area of about 17,000 $km^2$ in and adjacent to YNP (e.g. Wicks and others, 1998; Smith and Siegel, 2000; Christiansen, 2001).

An intensive hydrogeologic investigation, mandated by U.S. Congress and centered on the Norris-Mammoth corridor (fig. 2), was conducted by the U.S. Geological Survey (USGS) during 1988-90, in collaboration with the National Park Service and the Argonne, Lawrence Berkeley and Los Alamos National Laboratories, to determine the effects of using thermal water from a private well located in the Corwin Springs, ~3 km north of the Park, on the thermal springs of YNP, especially Mammoth Hot Springs (Sorey, 1991). We have conducted major additional hydrologic and geochemical studies in the corridor and the greater Yellowstone region, especially in the Gallatin and Absaroka Ranges, in order to improve understanding of the origin and evolution of thermal waters in the area. The bulk of the physical, chemical and isotope data for the thermal springs, as well as conclusions and recommendations regarding hydrogeologic connections in the Norris-Mammoth corridor and various thermal features in the Corwin Springs KGRA, are reported in chapters in Sorey (1991), especially in Kharaka and others (1991). Additional results and interpretations regarding the hydrothermal system in the Norris-Mammoth corridor have been reported in Bullen and Kharaka (1992), Mariner and others (1992), Thordsen and others (1992), Sorey and Colvard (1997) and Kharaka and others (1992, 2000).

In this report we present previously unpublished chemical and/or isotope data for 173 water samples from cold springs, shallow cold wells and 40 snow samples collected from the greater Yellowstone National Park area. For this study, we emphasize the sampling of cold wells and cold perennial springs, as opposed to streams, rivers and precipitation favored by Rye and Truesdell (1993). Even though each of the two approaches have limitations, wells and springs were selected, because they yield time-integrated samples of precipitation with relatively uniform isotope values that usually are better representatives of local meteoric water (White and others, 1990; Kharaka and Thordsen, 1992). Samples of freshly precipitated snow were collected, because their isotopes provide better data for establishing the regional meteoric water line (Thordsen and others, 1992; Clark and Fritz, 1997). Although some discussion and interpretation are given for the distribution of cold-water isotopes, the primary purpose is to make the data available to interested researchers and other scientists. Data for all the thermal waters collected by us, including for samples from sites located outside the Norris-Mammoth study area reported in Kharaka, and others (1991) are also presented. Results are used as a basis for discussing the origin and evolution of thermal waters, especially in the Norris-Mammoth corridor.

## Description of Study Area

The study area encompasses about 40,000 $km^2$, mostly in the northwest corner of Wyoming and portions of southwest Montana and east-central Idaho (fig. 1). Most sampling sites are located in YNP, especially the Norris-Mammoth corridor; others extend 50 to 100 km outside the Park boundaries in all directions, except the far southwest (figs. 1-6). The area is characterized by a high volcanic plateau roughly centered on YNP with an average altitude of about 2400 m, which is cut by deep, narrow river canyons and wide valleys. The highest elevation within the Park is Eagle Peak (3500 m) near the southeastern corner, and the lowest elevation is in the northwest corner near Mammoth (1600 m). The volcanic plateau is nearly encircled by prominent mountain ranges, including the Gallatin and Madison Ranges (northwest), the northern Absaroka Range and Beartooth Mountains (north-northeast), the southern Absaroka Range (east-southeast) and the Teton Range (south). All of these ranges have mountains that exceed altitudes of 3000 m; to the southwest, however, the plateau descends gradually onto the Snake River plain to below 2000 m (figs. 1 and 4).

The major watersheds inside the Park are the Snake River (southwest) that drains into the Pacific Ocean, and the Yellowstone (north and east-central), Madison (west), and Gallatin (northwest) rivers that drain into the Atlantic Ocean via the Gulf of Mexico. The Continental Divide defines the boundary between these watersheds. Outside the Park, the Wind River drains the southeast portion of the study area, near Dubois; and the Clarks Fork River, Rock Creek and Stillwater River drain the northeastern portion of the study area (Beartooth Mountains).

## Regional Geology

The Yellowstone Plateau volcanic field (fig. 7) is one of the largest Quaternary and latest Pliocene silicic centers in the world (Christiansen, 2001). During the last 2.2 Ma an eruptive volume of about 6,000 $km^3$ of ash-flow tuffs and rhyolitic lavas have covered an area of about 17,000 $km^2$ (Christiansen, 1984; Hildreth and others, 1991). The igneous rocks of the field consist dominantly of rhyolites and subordinate basalt, with no intermediate compositions. The rhyolites comprise numerous lava flows and three major sheets of welded ash-flow tuff, with eruptions causing large caldera collapses at 2.0, 1.3 and 0.6 Ma (Hildreth and others, 1991). Even younger volcanic rocks are present in the Park, including the 13 rhyolite and several basaltic vents with ages of 400-80 ka, that are present in the Norris-Mammoth corridor (Hildreth and others, 1991).

The youngest rocks in the Park are present in the northwest sector of YNP at Mammoth Hot Springs, which is considered the world's most spectacular thermal area of active travertine precipitation. Massive amounts of travertine, with ages from about 400 ka to present, have and are being precipitated over a large area from nearly 100 hot springs scattered over a score of steplike terraces covering a large area, ~1 km wide and 4 km long (Pierce and others, 1991; Kharaka and others, 1991). A thermal mantle plume hypothesis is currently the preferred model for the origin of the Yellowstone province as well as the eastern Snake River Plain volcanic field (Morgan, 1973; Pierce and Morgan, 1990). In this model a deep mantle hotspot, now centered beneath Yellowstone, was initiated 16 Ma. The track of this hotspot is defined by centers of caldera-forming volcanism that have migrated 700 km northeastward along the Snake River to the Park (Christiansen, 2001).

Volcanic activity in and near YNP was also widespread in the early Eocene (~50 Ma), when several large volcanoes erupted intermittently giving rise to the volcanoclastic and volcanic rocks of the Absaroka Volcanic Supergroup (fig. 7). The Absaroka Volcanics are predominantly andesites, with minor amounts of basalt and they cover most of the Absaroka and Washburn Ranges and part of the Gallatin Range as well as several smaller areas in the Park (Hildreth and others, 1991). The Absaroka Supergroup originated as volcanic arcs related to the westward movement of the North American plate and the subduction of the Pacific and related plates (Christiansen, 2001, and references therein).

The oldest rocks in YNP are the Precambrian basement rocks, about 2.7 billion yr, comprised of gneisses and schists. These rocks are exposed only in the northern part of the Park, where they form the central cores of some mountain ranges such as the Gallatin Range. Precambrian granitoids are also exposed in the Beartooth Mountains (fig. 7) and are present in the Park at relatively shallow depths beneath the sedimentary and volcanic rocks (Pierce and others, 1991). The sedimentary section consists of Cambrian through Cretaceous marine sandstones, shales and limestones, including the Mississippian Mission Canyon Limestone, which is an important regional aquifer (Downey, 1984; Plummer and others, 1990). Glacial and other surficial deposits thinly mantle the bedrock (fig. 7) over large areas in the region (Pierce, 1979).

## Climate

The mountainous terrain of the study area is the main control on its climate. The Park is situated about 600 km from the Pacific Ocean in the mid-latitudes and near the southeast end of the Rocky Mountain chain, which extends far to the northwest through Idaho, Montana and Canada. The study area receives about 75% of its annual precipitation as winter snow from air masses originating in the North Pacific Ocean. Pacific air masses either pass over the high mountains northwest of the Park or move eastward and gradually ascend along the Snake River Plain onto the Yellowstone plateau. The region is also influenced during the winter by Arctic cold air masses and during the summer by warm moist air masses originating in the Gulf of Mexico (Dirks and Martner, 1982, Despain, 1987).

Despain (1987) describes the Yellowstone region as having two principal climatic types: 1) The interior low plateaus and valleys, characterized by a spring peak in precipitation, similar to the Great Plains climate; and 2) the western plateaus and the northern (Gallatin, Madison, and Washburn ranges) and eastern (Absaroka) mountains of the Park, characterized by a winter peak in precipitation, similar to the West coast and mountains of Idaho and northwestern Montana. The largest amounts of precipitation (about 200 cm) fall during winter on the high plateaus located in the southwest part of the Park, because Pacific air masses that approach from the west along the Snake River plain are orographically lifted as they ascend the plateau. This results in large snow accumulations on these regions, whereas the central plateau, situated in the rain shadow of the surrounding mountains, receives lower (about 70 cm) precipitation (fig. 8).

Long-term temperature data from 12 climatic stations show a strong relationship between temperature and elevation. Calculated spring and summer lapse rate from these stations is –9.7°C/km, which is close to the dry adiabatic rate; the winter lapse rate of –5.3°C/km is much lower due probably to temperature inversions (Despain, 1987; Thordsen and others, 1992). During winter months, warmer western air encounters cooler eastern air along the continental divide, resulting in heavy precipitation. Temperature inversions are common, especially in the larger valleys, occurring on more than 40% of the days during seven months of the year. Inversions that persist into the afternoon are most common during the winter months, occurring at ~50% of the days in December.

## METHODS AND PROCEDURES

Field investigations conducted in 1988 through 1992 resulted in a total of close to 300 samples from 228 different sites (figs. 1-6). A total of 173 samples were obtained from 136 different cold springs, seeps and shallow cold wells, 40 samples were obtained as either snow cores or snow grabs, 58 samples were collected from 37 thermal sites (figs. 1-6). Many of the strategically located thermal sites and some of the cold-water sites located in the Norris-Mammoth corridor were sampled several times (up to five) to ascertain the seasonal variability (Kharaka and others, 1991). The methods used in sample collection, preservation and field and laboratory determinations of the chemical components and isotopes are discussed by Kharaka and others (1990, 1991) and by Thordsen and others (1992).

The cold water sampling sites are concentrated in the Gallatin and northern Absaroka Ranges (figs. 1-4) near the northwest corner of the Park (Mammoth-Gardiner area), because that area was postulated by Truesdell and others (1977) as a possible recharge location for the hydrothermal system in the Park. Sample sites also are concentrated in the mountainous areas to the north and northwest, along the Snake River Plain to the west, and at the south end of the Absaroka Range to the southeast. For cold water sites, an effort was made to sample perennial springs having good discharge rates (Ls/min) and, whenever possible, cold water wells. The measured water temperature and conductance and measured or estimated discharge were used to select springs and seeps for sampling. Springs and seeps with obvious contamination and evaporation effects were avoided. Springs and seeps located below lakes and water bodies, that may have been the source for water, were also avoided.

Most of the springs sampled are shown on the 7.5-minute USGS topographic maps. Springs located on private lands often are modified and diverted by pipes to new locations for cattle or domestic use; samples from such sites were obtained as close to the spring source as possible. Where springs and seeps were located close to streams and drainage lines, samples from the main channels were excluded. Most of the sampled groundwater wells are located on public campgrounds or on private lands close to houses and other structures. Inside the YNP boundaries and particularly in the vicinity of thermal areas, care is needed to avoid springs that may contain a thermal water component. These mixed springs usually can be distinguished in the field because they commonly have higher temperature and conductance (Thordsen and others, 1992).

### Snow Samples

Snow samples were collected (figs. 1, 3-4) during May, 1991 from three localities in the study area: 1) the Beehive basin, a small catchment basin (of ~6 $km^2$) in the Madison Range, near the Big Sky ski area (fig. 4); 2) Mt. Washburn, near the center of YNP (fig. 3); and 3) Beartooth Pass area, in the Beartooth Mountains (fig. 5). These localities were selected because: 1) they were easily accessible during the early spring (i.e. roads were open) while still having a substantial winter snow pack; 2) several cold water sites were established at each locality, several of which were sampled before and after the 1991 snowpack; 3) these localities provide a reasonably good west-to-east cross section through the northern portion of the study area. In addition to these 3 localities, a single snow core was obtained near an unnamed spring northeast of the town of Gardiner (site AG-5, fig. 3). Also, a suite of 9 snow samples was collected on 14 September, 1991 from the central part of YNP, between Norris, Mt. Washburn and Grant Village, from a snowstorm that started the previous night and continued into the morning of September 14.

For a particular location, 3 to 5 cores were taken, depending on the snow depth, using a ~4 cm inner diameter PVC pipe. The snow was "double bagged" in resealable plastic bags (~4 L), and allowed to slowly thaw, usually overnight. When completely melted, two 20-ml isotope bottles were filled and sealed with polyseal caps (Thordsen and others, 1992). Additional water was filtered through 0.1 µm

Millipore filters using compressed air. Acidified and unacidified aliquots were collected, as was the case for water samples, for chemical analysis using standard techniques (Kharaka and others, 1991).

### Field Procedures

The methods used in sample collection, preservation and field and laboratory determinations of chemical components and isotopes are detailed in Kharaka and others (1990), Kharaka and others (1991), and Thordsen and others (1992). Water temperatures were usually measured, but discharges usually were only estimated. However, since several field teams were involved in sampling during the study, discharge estimates have high (factor of two) uncertainties. Most field chemistry was performed in a mobile laboratory equipped with pH meters, a spectrophotometer, and filtration, titration and other field equipment. Field determinations, especially on thermal samples included conductance, pH, alkalinity, $H_2S$ and $NH_3$. Raw water samples were usually filtered through a 0.1 µm filter using either compressed nitrogen or compressed air as the pressure source. Filtered samples were stored in high-density polyethylene bottles prerinsed with deionized water for anions, and prerinsed with 5% nitric acid ($HNO_3$) then deionized water for metals and silica. For water isotopes, two 20-ml glass bottles with polyseal caps were filled with raw water. Samples for solute isotopes, organic compounds, silica and other chemical components, when required, were collected and diluted and/or preserved by procedures detailed in Kharaka and others (1991).

### Laboratory Measurements

The water and snow samples were analyzed at USGS Water Resources laboratories in Menlo Park, CA. Concentrations of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and lithium (Li) were determined by flame atomic-absorption spectrometry (AAS) using a double-beam atomic absorption spectrophotometer. Chloride (Cl), bromide (Br), nitrate ($NO_3$), phosphate ($PO_4$), and sulfate ($SO_4$) were determined by ion chromatography (IC). Barium (Ba), boron (B), iron (Fe), manganese (Mn), silica ($SiO_2$) and strontium (Sr) were determined by inductively coupled plasma mass spectrometry (ICP-MS).

The reported concentrations for major cations and anions carry an uncertainty of ±3%. Precision values for minor and trace chemicals are generally ±5%, but could reach ±10% for values close to detection limits (Kharaka and others, 1991).

### Water Isotopes

Water isotopes were determined in the USGS Stable Isotope Laboratory in Menlo Park. Water isotopes are reported in δ–values that are expressed in parts per thousand (per mil, ‰) relative to Standard Mean Ocean Water (SMOW). In the case of oxygen, the equation used is:

$$\delta^{18}\mathrm{O} = \left( \frac{(^{18}\mathrm{O}/^{16}\mathrm{O})\mathrm{sample}}{(^{18}\mathrm{O}/^{16}\mathrm{O})\mathrm{SMOW}} - 1 \right) \mathrm{x}10^{3} ,$$

and in the case of hydrogen, the equation used is:

$$\delta^{2}\mathrm{H} = \left( \frac{(^{2}\mathrm{H}/^{1}\mathrm{H})\mathrm{sample}}{(^{2}\mathrm{H}/^{1}\mathrm{H})\mathrm{SMOW}} - 1 \right) \mathrm{x}10^{3} .$$

The Standard Deviation of reported values for samples are ±0.2‰ for $\delta^{18}O$ and ±2‰ for δD.

## RESULTS AND DISCUSSION

Data are organized into tables of general information (tables 1-3) and physical, chemical and isotopic data (tables 4-6). General information includes location and description of sample sites for cold water (table 1), snow (table 2), and thermal water (table 3). The physical, chemical and isotope data for cold water, snow and thermal water samples are presented in tables 4-6, respectively.

The cold meteoric water sites (tables 1 and 4) are organized into 10 groups, based on geographic region and the local physiography and drainage. This grouping of sample sites is useful for describing and evaluating the relative influences of the climatic and geographic/physiographic controls on the isotopic composition of cold waters. These groups, described below, are assigned a 2-letter abbreviation that expresses the mountain range or other distinguishing physiographic features such as the nearest geographic city/town (e.g. Gallatin Range – Gardiner-Mammoth area = GG). Sample sites in each group are assigned a unique ID in order of the date of first sample at that site. A number of strategically located and easily accessible sites were resampled (16 total), some as many as 4 times during the course of the study, in order to evaluate typical seasonal and annual variations.

The 10 regional groups for the cold-water samples are listed below:

- (GG) Gallatin Range – in vicinity of Gardiner-Mammoth and the Corwin Springs KGRA
- (AG) Absaroka Range – in vicinity of Gardiner, Mammoth and the Corwin Spring KGRA
- (AN) Absaroka Range – northern area
- (AR) Absaroka Range – northeast area (Beartooth Mountains) near Red Lodge, MT
- (AC) Absaroka Range – east of YNP, near Cody, WY
- (AD) Absaroka Range – southern region, near Dubois, WY
- (GN) Gallatin Range – northern portion of Gallatin Range
- (MR) Madison Range – and mountain region northwest of YNP
- (YP) Yellowstone Plateau – (all the high volcanic plateau), includes Washburn range
- (SR) Snake River plain

The snow samples (tables 2 and 5) are subdivided below into three regions:

- (MR) Madison Range (Beehive basin)
- (AR) Absaroka-Beartooth Mountains (most near Beartooth Pass)
- (YP) Washburn Range (Mt Washburn, and Yellowstone Plateau)

Finally, the thermal waters are classified (tables 3 and 6) into sites within and outside Yellowstone National Park

- Sites inside YNP (Norris, Norris-Mammoth corridor, Mammoth, Calcite, Rainbow, Washburn)
- Sites outside YNP (Corwin Springs KGRA; Northern Absarokas – Chico HS, Madison Range – Wolf Cr. HS)

### Chemical Composition of Cold Water and Snow

The specific conductance values for snow samples, as expected for such a pristine setting are low, ranging from 2 to 12 μS/cm (table 5). Only the concentrations of anions, other than bicarbonate, were determined for 4 snow samples, but these indicate that the higher conductance values probably result from dissolution of entrained carbonate minerals (Green and others, 2000).

The specific conductance values for most cold water samples are generally <500 μS/cm, and for many samples are <100 μS/cm (table 4). Such values are typical for uncontaminated springs with shallow circulation paths and shallow ground water (Hem, 1985). A few cold-water samples, however, have specific conductance values greater than 1000 μS/cm, with a maximum of 5200 μS/cm. The samples with higher specific conductance indicate evaporative concentration of solutes and/or significant water-rock interaction in deeper circulation paths.

The chemical composition of water is highly variable reflecting the changes in local and regional geology (fig. 7). In general Ca, Mg and Na are the major cations and $HCO_3$ and $SO_4$ are the major anions (table 4). Concentrations of $SiO_2$ are relatively high, but those of Cl and K are relatively low. Alkalinity values were determined only for a limited number of samples, because the methodology is time consuming and requires field determination. Based on these limited determinations, mass balance of cations and anions (assuming equivalent $HCO_3$ for the excess cations) and the high Ca and Mg values, we conclude that $HCO_3$, mainly from dissolution of carbonate minerals, comprises the bulk of anions.

## Isotope Composition of Cold Water and Snow

The $\delta D$ and $\delta^{18}O$ values for the 173 cold-water samples range from –115 to –153 and –15.2 to –20.2‰, respectively. The $\delta D$ and $\delta^{18}O$ values for the 40 snow samples, as expected, are generally lighter, ranging from –88 to –178 and –12.5 to –23.6‰, respectively. The isotopic composition of snow varies greatly based on the snow events, thaw and freeze cycles, sublimation and evaporation and other complicating factors (Cooper, 1998), but the least-squares line for the snow samples (fig. 9) establishes a well constrained local meteoric water line (LMWL) given by $\delta D = 8.2\ \delta^{18}O + 14.7$ ($r^2 = 0.99$). This line is close to the Global Meteoric Water Line (GMWL) given by $\delta D = 8\delta^{18}O + 10$ (Craig, 1961).

A large number of the $\delta D$ and $\delta^{18}O$ values for cold-water samples plot on or close to the GMWL or the LMWL established by the isotope values for the snow samples (fig. 10). The δ values above the LMWL do not depart significantly from the line, whereas below the LMWL the δ values show a progressive shift away from the line with heavier δ values. The least squares line for the water samples gives the relationship $\delta D = 6.7\ \delta^{18}O – 16.7$ ($r^2 = 0.90$). About 70% of the values fall within 2σ of the LMWL established using the snow data. However, the obvious progressive shift off the LMWL with increasing δ values and the overall slope of 6.7 strongly suggest that systematic evaporation is a major factor modifying the water isotopes (Thordsen and others, 1992).

Evaporation occurs mainly as rain droplets evaporate during descent from the cloud base through unsaturated air (Moser and Stichler, 1971) or during water percolation in the unsaturated rock. The *d*-parameter (Dansgaard, 1964), given by: $d = \delta D – 8\delta^{18}O$, is used to characterize the δD excess resulting from evaporation effects. A *d*-parameter value of 10‰ indicates that the water has not been significantly evaporated as it plots on the GMWL and close to LMWL; evaporated water has progressively lower *d*-parameter values and plots to the right of LMWL, with a variable slope (generally 3-5) that is a strong function of relative humidity, but also depends on temperature and wind speed. About 85% of the δ values that show the larger shifts from the LMWL have *d*-parameter values < 5‰, and are from low altitude samples (<2100 m) that typically were collected in the rain shadow of high mountains (fig. 11).

The relationship between the *d*-parameter and altitude (fig. 11) and *d*-parameter or altitude versus specific conductance or sulfate concentration (figs. 12 and 13) although empirical, suggests that the evaporation trend is in large part caused by the "pseudo-altitude effect," whereby rainfall is enriched in heavy isotopes as droplets evaporate during descent from the cloud base through unsaturated air as well as water evaporation, especially while percolating in the unsaturated rock (Moser and Stichler, 1971; Clark and Fritz, 1997). According to Despain (1987), low altitude areas in the Yellowstone region receive proportionally more annual rainfall than snowfall relative to high altitude areas. The $\delta D$ and $\delta^{18}O$ values for cold-water samples from the nine regions indicate that some areas (e.g., AN, Absaraka Range, north) show the larger shifts from the LMWL, but the values in other areas (e.g., AR, Absaraka Range, northeast) plot close to the LMWL (fig. 14).

The spatial distribution of *d*-parameter (Dansgaard, 1964) is shown in figure 15, using the same grid and contouring methodology described below for the δD and $\delta^{18}O$ values for meteoric water samples depicted in figures 16 and 17. The *d*-parameter values < 5‰ indicating significant evaporation are located at lower altitudes (<2100 m) and rain shadow of high mountains. Values of *d*-parameter greater than 10‰ appear in areas of high precipitation (figs. 8 and 15) in orographic regions and may be explained by precipitation in air with relative humidity close to 100% (Clark and Fritz, 1997).

The spatial distribution of the δD and $\delta^{18}O$ values for cold-water samples are shown in figures 16 and 17, respectively. Delta values are grided and contoured using Arcview (version 3.2a) and Arcview Spatial Analyst module (ESRI), to 0.5 km grid cells, using an inverse distance weighted (IDW) function for 12 nearest neighbors. Delta values for all of the 136 cold-water sample sites are used to generate these contour plots; however for the sample sites (15 sites) that have two or more isotope samples, the lightest delta values are used. For δD distribution (fig. 16) the contour interval was selected to highlight the regions that contain δD values lighter than –149‰, the δD values hypothesized by Truesdell and others (1977), for deep cold water recharge to the major hydrothermal basins in the Yellowstone Park; similarly for $\delta^{18}O$ distribution, the contour intervals highlight values lighter than ~ –20‰ (fig. 17).

The regional spatial distribution of $\delta^{18}O$ and δD values (figs. 16 and 17) shows a roughly circular pattern: isotopically lighter waters ($\delta^{18}O$ < –19.0‰) are centered in the northern part of the Park and extend northwest along the Yellowstone River valley. Notwithstanding the "altitude effect" and other isotopic controls discussed below, the regional pattern appears to reflect the input of precipitation from air masses originating in the North Pacific and moving eastward, and also from cold Arctic air masses moving southward along the Yellowstone River valley. The extent of influence from northbound air masses from the Gulf of Mexico is difficult to interpret because of the sparse distribution of sample sites to the south and southeast of the Park.

The mountainous areas in the northern part of the Park are the likely locations of recharge water (see Origin and Evolution of Thermal Fluids below) for the hydrothermal fluids in Yellowstone. They are the only areas in the region with sufficiently light δD and $\delta^{18}O$ values to match the δD composition of the deep geothermal fluids calculated by Truesdell and others (1977).

### Controls on Cold Water Isotopes

The temperature effect due to altitude apparently is the most important control on the distribution of water isotopes throughout the Yellowstone region. A plot of $\delta^{18}O$ values versus altitude for all the samples, however, indicates a complex relationship as it shows major departures from the expected lighter values with increasing altitude (fig. 18). On the other hand, the altitude relationship is well illustrated in figure 19, on which are plotted *d*-parameter, $\delta^{18}O$ and altitude for water samples located as a function of distance along a SW-to-NE traverse through the region (line A-A', fig. 15). Along the traverse from the Snake River plain to the crest of the Gallatin Range, the altitude gradually increases from 1700 to 2700 m over a distance of ~100 km, and the $\delta^{18}O$ values exhibit a nearly linear decrease from –17 to –20‰ (i.e. –3.0‰ per km increase in altitude). Water samples from the Absaroka Range (fig. 19), also exhibit a $\delta^{18}O$ correlation with altitude of about –3.5‰ per km increase in altitude, although the sampling distribution is sparse and limited to altitudes ranging from 1100 to 1800 m.

Water samples in the Yellowstone River valley, which separates the Gallatin and Absaroka Ranges, were collected at altitudes ranging from ~2700 m near the crest of the Gallatins to ~1500 m near the valley floor, but the $\delta^{18}O$ values mostly remain between –19 and –20‰ (fig. 19). Here, the altitude effect is obscured by what we term the 'canyon' effect. The 'canyon' effect results because the isotopic values of precipitation are controlled primarily by temperatures at the cloud base where phase transformations occur, and the temperatures (altitude) of the cloud base are not significantly affected by the narrow, deep canyons, but are controlled by the altitude of the adjoining mountains (Kharaka and others, 1991; Thordsen and others, 1992).

The $\delta^{18}O$ vs. altitude relations for all of the water samples are shown in figure 20. Superimposed on the plot are estimated winter and summer $\delta^{18}O$-altitude relationships (solid lines) calculated using the Mammoth, Yellowstone Park, WY weather station (altitude = 1902 m) as a reference (Thordsen and others, 1992). The $\delta^{18}O$ values are calculated for winter and summer conditions using: 1) the global temperature $\delta^{18}O$ relationship: $\delta^{18}O = 0.695T - 13.6$, where T is the average annual temperature, in ºC (Dansgaard, 1964); 2) the 30 year average (1941-1970) at Mammoth for January and June (–7.1 and 17.4ºC, respectively); and 3) the local winter and summer lapse rates (–0.53 and –0.97ºC/100 m, respectively), based on climatic and SNOTEL stations in the region (Despain, 1987).

The observed $\delta^{18}O$ values correspond remarkably closely to winter conditions predicted from the temperature-altitude relationships (fig. 20). The sampled ground waters are almost certainly derived predominantly from winter precipitation, with very little influence from summer precipitation. This conclusion appears to be confirmed by isotopic values for 10 cold springs that were sampled in May and September of 1991. The $\delta D$ and $\delta^{18}O$ values for samples from 8 of the springs are constant within analytical error (~2.0‰ $\delta D$ and ~0.2‰ $\delta^{18}O$); the remaining 2 samples have undergone considerable evaporation.

The latitude and distance (i.e. continental) effects on the isotopic distribution probably are relatively minor within the limits of the study area (~200 x 250 km). In addition, these effects may be further obscured because air masses arrive over the Park from almost all directions. However, it is likely that the strong altitude vs. $\delta^{18}O$ relationship along the Snake River Plain-to-Gallatin crest (fig. 19) is enhanced by the distance and latitude effects as North Pacific air masses "rainout" and become depleted in heavy isotopes as they proceed to the northeast over the Yellowstone Plateau and Gallatin Range (Thordsen and others, 1992).

## Hydrothermal Fluid Discharges

The exceptional number of geysers and other hydrothermal features of YNP result from a favorable combination of climatic and geologic factors, including a huge magmatic heat source present at a relatively shallow depth beneath the 0.6 Ma Yellowstone caldera, abundant supplies of recharge water primarily from melting snow and frequent seismic activity that creates new fractures and reopens clogged channels for fluid flow (Fournier, 1989; Wicks and others, 1998; Ball and others, 1998; Kharaka and others, 2000). Thermal water discharges for YNP have been estimated by totaling the measured rates of individual springs or groups of springs (Allen and Day, 1935) or by using the more accurate river chloride inventory method applied to the four major rivers that drain the Park (Fournier and others, 1976; Norton and Friedman, 1985, 1991, 2000; Sorey and Colvard, 1997; Ingebritsen and others, 2001). Results show large seasonal and long-term variations, and yield very high total average discharges of 3-4 $m^3/s$ (Fournier, 1989; Kharaka and others, 2000).

Thermal fluids in the Norris-Mammoth corridor, where our investigations were concentrated, discharge from many springs and thermal areas inside YNP, including Norris Geyser Basin, Roaring Mountain, Clearwater Springs, Sheepeater Canyon Hot Spring, High Bridge Spring, Mammoth Hot Springs and Hot River (figs.1 and 2). Total fluid discharges from these areas average ~0.8 $m^3/s$, with high fluid discharges obtained from the Norris Geyser Basin and Mammoth Hot Springs system. Norris Geyser Basin, located outside the northwest rim of the 0.6 Ma caldera, contains the widest diversity of hydrothermal activity known in the Park, discharging about 150-250 L/s of water, which attains boiling temperature at surface and 360°C at depth (Fournier and others, 1976; White and others, 1988; Kharaka and others, 2000).

The highest thermal water and gas discharges in the corridor are from Mammoth Hot Springs, where travertine-precipitating thermal water issues from ~100 hot springs scattered over a score of step-like travertine terraces, covering a large area, ~1 km wide and 4 km long (figs. 2 and 3). The surface temperatures of the springs (< 73°C) and the calculated reservoir temperature (~100°C) are lower than those of boiling springs encountered at Norris. However, the total thermal-water discharges from the Mammoth system, estimated from long-term flow and chloride flux measurements and extensive application of chemical tracers, are very large averaging 500-600 L/s. The calculated total heat flux from the Mammoth system (220 MW) is comparable to that discharged from the Norris Geyser Basin (Kharaka and others, 1991; Sorey and Colvard, 1997).

The gas concentration in thermal water from the Mammoth system, dominantly $CO_2$, is considerable at ~66 mM/L, and equilibrium gas pressures >5 bar are calculated for samples from the Y-10 well (Kharaka and others, 1991). The total $CO_2$ flux from the Mammoth system amounts to 33-40 M/s. The addition of 17 mM/L of dissolved C, present mainly as $HCO_3^-$ in water samples from the Y-10 well (Kharaka and others, 1991), results in 42-50 M/s calculated total C flux from the Mammoth system.

Extensive tracer tests in 1989-90, using organic and inorganic compounds injected into water in sinkholes, travertine terraces and the Gardner River, established the flow paths, the mixing of thermal and cold surface and ground waters and the hydraulic connections between the thermal features in the Mammoth area (Kharaka and others, 1991; Sorey and others, 1991; Spall and others, 1992). Extensive flow and chloride and sulfate flux measurements and monitoring also were carried out in 1987-95, especially at Hot River, the Gardner River below Hot River and the Mammoth outflow (Sorey and Colvard, 1997). Results show that, despite the visual prominence of the Mammoth terraces, approximately 90% of total thermal water discharging from the Mammoth system is obtained from springs and seeps along the banks of the Gardner River, with the bulk emerging at Hot River. Results also indicate a general decrease of ~15% in total thermal water discharge from ~600 L/s in 1987 to ~500 L/s in 1995 (fig. 21). The decrease in discharge for a longer record (1984-2001) calculated by Friedman and Norton (2002) for the Mammoth system, however, was only 5%. The long-term decrease in discharge is probably related to decreases in regional precipitation rather than to tectonic or anthropogenic factors (Sorey and Colvard, 1997; Kharaka et al., 2000).

## Thermal Water and Gas Compositions

The pristine hydrothermal waters (not modified by boiling and dilution) at the Norris Basin and Clearwater Springs are sinter-precipitating Na-K-Cl type waters (salinity 1,000-2,000 mg/L), high in $SiO_2$, Li and B, and commonly modified by boiling, silica precipitation and mixing with local meteoric water (fig. 2). The thermal waters from Sheepeater Spring and northward in the corridor are markedly different, being travertine-precipitating Ca-Na-Mg-$HCO_3$-$SO_4$-Cl types, with higher salinities (2,000-3,000 mg/L) in the Mammoth Springs (table 6). Chemical geothermometry and $\delta^{34}S$ values (21‰) indicate that the high Ca, Mg and $SO_4$ are obtained from reaction with Paleozoic carbonates at ~100°C. There are differences in the salinity and chemical composition of water among the terrace springs and other sites (e.g., Hot River) in the Mammoth system, but these changes result primarily from dilution with local meteoric water and travertine deposition (Kharaka and others, 1991).

In the Norris-Mammoth corridor, $CO_2$ is the dominant gas, comprising 96% to >99% of the total, with locally significant $H_2S$ and $N_2$. In the Mammoth area, gas discharges are high and there are >50 mM/L of excess $CO_2$ relative to Ca and Mg, indicating a source not related to dissolution of carbonates. The chemical and isotopic compositions of noble gases, especially the $^3He/^4He$ ratios, indicate a mantle origin for the excess $CO_2$. The molar total $C/^3He$ (~$5 \times 10^9$) and $\delta^{13}C$ values of $CO_2$ (–3.4 to –5.2‰) are additional support for the conclusion of a mantle origin for the bulk of the $CO_2$ in the Mammoth system (Kennedy and others, 1985; Kharaka and others, 1991; Trull and others, 1993).

## Origin and Evolution of Thermal Fluids

The δD and $\delta^{18}O$ values of waters, especially when combined with the concentrations of conservative solutes (for example Cl) are the best geochemical indicators of the origins, recharge locations, and flow paths of subsurface waters (for review articles and many references, see Truesdell and Hulston, 1980; Kharaka and Thordsen, 1992). The stable isotopes of water are useful tools because the relations governing their distribution in present-day surface and shallow ground waters of an area (the local meteoric water) as well as their modifications in aquifers are reasonably well known. In aquifers, the isotopes of meteoric water may be modified by evaporation and mixing at low temperatures and by mixing, boiling, and isotopic exchange with minerals at high temperatures.

The δD and $\delta^{18}O$ values of water from 37 thermal springs (total = 58 samples) are listed in table 6 and plotted in figure 22. Many of these samples were not included in Kharaka and others (1991), because they are either located outside the Norris-Mammoth corridor or they represent acid sulfate waters (fig. 22) that were sampled mainly for their gas compositions (Kharaka and others, 1992). Results of δD and $\delta^{18}O$ values shown in table 6 for several samples, including La Duke Hot Spring, Bear Creek-1, the Y-10 well, Narrow Gauge, Opal Terrace and Clearwater-3C are averages of two to four samples collected during 1989-1990 (fig. 2). For these sites, results of replicate sampling are constant within analytical errors of about ± 2‰ for δD and ± 0.2‰ for $\delta^{18}O$ values.

The δD and $\delta^{18}O$ values for selected thermal waters from Yellowstone National Park show significant δD and $\delta^{18}O$ shifts relative to the meteoric water line (fig. 22). The origins of isotopic shifts are complex and likely are different for each area of the Park. Truesdell and others (1977) discussed in detail the isotopic shifts resulting from single-stage or continuous boiling, isotopic exchange between water, dissolved $SO_4$ and geologic materials and mixing between thermal water and shallow cold meteoric water. Although increases in Cl concentrations are similar in single-stage or continuous steam separation, the H isotopic changes differ significantly. Because Cl behaves conservatively in geothermal systems, and water and steam are the only significant sources of H and D, Cl and $SO_4$ concentrations coupled with H isotopes of water can be useful interpretive tools (Truesdell and others, 1977; Fournier, 1989; Kharaka and others, 1991).

Kharaka and others (1991) showed that the isotopic shifts for the waters from Norris Geyser Basin relative to recharge waters with δD and $\delta^{18}O$ values of about –150‰ and –20‰, respectively, result mainly from boiling for the δD values and from boiling and isotopic exchange with aquifer minerals for the $\delta^{18}O$ values. In addition to boiling, the isotopes of water from Clearwater Springs are modified by mixing with dilute local meteoric water with a δD value of about -144‰; this mixing is indicated by examination of the Cl vs. δD relations of the waters. The samples from Mammoth Hot Springs also show moderate isotopic shifts from the meteoric water line (Kharaka and others, 1991, table F-2 and fig. F-5). The three sites shown in figure F-5 (Narrow Gauge, Opal Terrace and the Y-10 well) were selected because the δD and $\delta^{18}O$ values of their waters remained constant for the duration of the study. The sample from the Y-10 well likely is the least modified of the three sites and the most representative of the upflow thermal water for the Mammoth system. This conclusion is reached because the water in the Y-10 well is at high pressure (~4 bars at ground level), is not affected by precipitation of travertine, and water isotope values are the same for water obtained at ground level and by downhole sampler from a depth of 53 m. The δD value of water from the Y-10 well (–149‰) is close to a δD value of –151‰ estimated for the recharge waters for the Mammoth system from the Cl vs. δD relations of thermal waters. The corresponding $\delta^{18}O$ value for the recharge waters is –20.1‰, which would result in a moderate 1.7‰ shift in the $\delta^{18}O$ value of water from the Y-10 well.

There are two possible explanations for the moderate $\delta^{18}O$ shifts for the waters from the Y-10 well and the other sites from Mammoth Hot Springs. The oxygen shift could be the result of isotopic exchange between water and aquifer minerals as the water flows from recharge points in the Gallatin Range to the discharge sites at Mammoth. Oxygen exchange with calcite in Paleozoic limestone resulting in heavier oxygen isotopes in water is a possible explanation because isotopic exchange can take place between water and calcite at relatively low (25º to 100ºC) temperatures (Clayton and others, 1966; Kharaka and Carothers, 1986; Plummer and others, 1990). Alternatively, the oxygen shift also could result from mixing of a Mammoth meteoric water with the deep and unmodified thermal water from Norris Geyser Basin. The minor δD shifts (from a δD value of about –150‰) can be explained by mixing, as in the case of oxygen isotopes, or they could result from minor evaporation of recharge water before it percolates deep into the subsurface. The isotopic shifts also could result from hydrogen exchange with clay minerals in the sedimentary section (Kharaka and Thordsen, 1992).

Using water isotopes of thermal and meteoric water, Craig and others (1956) were the first to conclude that deep-percolating meteoric water was the source of all the thermal water in the Yellowstone National Park, with no or minimal magmatic contribution. This conclusion was supported by subsequent detailed investigations combining water isotopes with enthalpies and chemical compositions of thermal water (e.g. Truesdell and others, 1977; Fournier, 1989; Kharaka and others, 1991). Model calculations by Truesdell and others (1977) indicated that the source meteoric water for Norris, Lower and Shoshone Geyser basins and possibly for all of the other basins in Yellowstone Park has a well constrained δD value of –149‰ and an equivalent $\delta^{18}$O value of –19.9‰.

The isotopic composition of present day precipitation (meteoric water) within and close to the geyser basins in the Park reported in this study and by Truesdell and others (1977), Kharaka and others (1991), Rye and Truesdell (1993) and others are generally heavier than that calculated for the recharge water of the hydrothermal system (Truesdell and others, 1977). The spatial distribution of cold-water samples shows a roughly circular pattern with isotopically lightest waters centered on the mountains and high plateau in the northwest corner of YNP, including the Yellowstone River valley, and becoming heavier in all directions; relatively light water isotopes are also present at high elevations in the southern Absaroka Range, but isotope data for this area are sparse (figs. 16 and 17). Results from this study show that meteoric water with δD and $\delta^{18}$O values lighter than –149‰ and –19.9‰, respectively are present in the Gallatin and northern Absaroka Ranges at 2.5-3.0 km elevations and higher, and in the Yellowstone River valley at elevations of 1500 m and higher. The total land area, shown in figures 16 and 17, with δD and $\delta^{18}$O values lighter than –149‰ and –19.9‰, respectively, is relatively small (~200 km$^2$), and when combined with values for mean annual precipitation (~100 cm/yr, fig. 8) and a reasonable value (5-30%) for the recharged portion of precipitation (Sanford, 2002), yields a volume of this recharge water that is not adequate to supply the high total thermal water discharges (3-4 m$^3$/s) from YNP.

The total land area located in the Gallatin and northern Absaroka Ranges (figs. 16 and 17) with δD values lighter than –145‰ is about 10,000 km$^2$, and precipitation over this area may be adequate for recharging the hydrothermal system in YNP. The value of –149‰ for the δD of recharge water, based on model calculations by Truesdell and others (1977) is generally accepted (e.g., Kharaka and others, 1991). Careful examination of data from Truesdell and others (1977), especially their critical data in figure 8, however could allow for a heavier δD value for the unmodified hydrothermal water, and thus for the recharged meteoric water. Fournier (1989) points out that the bottom hole temperature for the Y-12 well likely was 270ºC rather than the 238ºC used by Truesdell and others (1977), and the Cl concentration in the deep 360ºC water was higher than the 310 mg/L used. Because hydrogen isotopic fractionation between water and steam results in the enrichment of steam with the heavy δD values at temperatures higher than 221ºC (Giggenbach, 1992), the calculated δD value for the unmodified water from the Norris Geyser basin could be 2-4‰ heavier than the –149‰ value calculated by Truesdell and others (1977).

If a δD value lighter than –145‰ is required for the recharge water, it is possible that the hydrothermal water currently discharging from YNP was recharged during an earlier time when the mean annual temperatures were lower. In northern latitudes the δD values become lighter by 5.6‰ per ºC decline in the mean annual temperature (Dansgard, 1964), and a modest lowering of only 0.7ºC will change the δD values of precipitation from current values of ≥ –145‰ to the required values of ≥ –149‰. Climate records for the northern latitudes show significant temperature fluctuations with time (e.g., 1-2ºC lowering during the Little Ice Age) following the Pleistocene, and temperature changes of 5-10ºC are indicated in the last 2 M yrs (Bryant, 1997). It is also possible that the hydrothermal water currently discharging from YNP represents a mixture of meteoric water having relatively heavy isotopes similar to present day precipitation with older meteoric water recharged during cooler periods, including during the Pleistocene when the δD values likely were 30-50‰ lighter that current values. A mixture comprised of about 90% water having present-day isotope values with 10% Pleistocene precipitation would be adequate as the source for the hydrothermal water currently discharging from YNP.

A Pleistocene age for even a small portion of the source meteoric water recharging the present hydrothermal system in YNP is probably unlikely, because the high discharge rates (3-4 $m^3/s$) indicate a relatively short residence time. Radium and radon concentrations in thermal water also indicate that recharge water percolates rapidly (residence time ~500-1000 yrs) in the Norris-Mammoth corridor to the heat source at the Norris Geyser basin (Clark and Turekian, 1990). Model calculations using tritium values in thermal water from many geyser basins also yield low (200-1000 yrs) residence time for the recharge water (Pearson and Truesdell, 1978).

The most logical conclusion from the data discussed above is that the hydrothermal water presently discharging from YNP was recharged in the Gallatin and northern Absaroka Ranges during the Little Ice Age (1250-1900 AD). An acceptable interpretation of the isotope data for the hydrothermal water in YNP would allow the recharge meteoric water to have δD value lighter than –145‰, but keep the temperature and precipitation values in the region similar to their present day values.

## Hydrothermal fluids from the Mammoth system

The pristine water from the Norris Basin has chemical, isotopic and thermal properties similar to those of waters from the caldera basins, which receive their heat and some chemical components from reaction with a relatively shallow magmatic source. The $^3He/^4He$ ratios relative to atmospheric values (R/Ra) yield high values (up to 9 at Norris and 16 inside the caldera), indicating that the magmatic He, $CO_2$ and other volatiles have a "deep" mantle origin (Kennedy and others, 1985; Hearn and others, 1990; Kharaka and others, 1992). The chemical and isotopic compositions of water and solutes, especially the $^3He/^4He$ ratios, in the Mammoth Springs indicate that water also derives its heat and some solutes (e.g., Cl, B, $^3He$ and $CO_2$) from a magmatic source (Kharaka and others, 1991). White and others (1988) postulated that the magmatic source for Norris and the entire Norris-Mammoth corridor is located beneath Roaring Mountain. In this model, the lower concentrations of Cl, Br, B and other conservative solutes in the Mammoth water result from mixing 30-40% Norris-type water with 70-60% meteoric water as fluids flow northward to Mammoth; the much higher values for Ca, Mg, $SO_4$ and $HCO_3$ in the Mammoth water are obtained from reaction with Paleozoic carbonates at ~100°C (e.g., Kharaka and others, 2000).

Kharaka and others (1991) presented an alternative model and postulated that the heat and volatiles for the Mammoth system are provided by a separate magmatic body emplaced near Mammoth ~400 ka. A separate magmatic body is postulated, because (1) gas samples from the Y-10 well and three terrace springs yield R/Ra values of 8.1-8.4, and the sample from Snow Pass gives R/Ra value of 7.5, (2) all the major thermal areas between Norris and Mammoth, including Roaring Mountain, White Rock Springs, Amphitheater Springs, Clearwater Springs, and Horseshoe Hill, have lower R/Ra values of 2-3 (fig. 23). The emplacement of the magmatic system is constrained by model U/Th ages obtained from the extensive travertine deposits in the Mammoth area that indicate five periods of intermittent, but non-overlapping travertine precipitation from about 400 ka to present. The periods of activity could be related to the thickness of glacial ice in the region and/or magmatic injection at depth (Pierce and others, 1991). The $^{87}Sr/^{86}Sr$ ratios and εNd values of most travertines from the Mammoth system are identical, indicating precipitation from thermal fluids derived from the same hydrothermal system (Bullen and Kharaka, 1992). The exact location of the postulated Mammoth magmatic system is not known, but magnetotelluric and other geophysical surveys conducted indicate partial melt conditions (500-600°C) occur south of Bunsen Peak at depths ≥ 6 km (Stanley and others, 1991). Additional evidence for a separate thermal source for the Mammoth system is obtained from satellite radar interferometry imaging for August 24, 2000 to September 13, 2001, that shows areas of significant inflation and surface uplift between the Norris Geyser Basin and Mammoth Springs that are separated from that imaged for the Norris Geyser Basin (W. C. Wicks, written communication, April, 25, 2002).

## CONCLUSIONS

The δD and $\delta^{18}O$ values from snow cores establish a local meteoric water line nearly identical to the GMWL. For cold water samples, δD and $\delta^{18}O$ values plot near the GWML, although many δ values show a progressive shift away from the line with heavier δ values, probably caused by evaporation. The regional distribution of δ values shows a roughly circular pattern with the isotopically lightest waters occurring in the northern part of the Park and extending northward along the Yellowstone River valley.

Overall, the altitude effect appears to be the most important control on the distribution of isotopes. This effect is particularly well defined along a SW-NE traverse ascending the Snake River Plain to the crest of the Gallatin Range. However, on a regional scale the altitude effect is obscured because of several factors, including topographic complexities (i.e. deep canyons and rain shadows) and complex weather patterns.

Spring-water isotopic values are consistent with the major source of ground water originating from cold isotopically light winter precipitation. Seasonal variations are observed, but are difficult to quantify owing to sporadic sampling. Latitude and distance effects are minor within the confines of the study area.

The δD and $\delta^{18}O$ values for the extensive thermal-water discharges from Yellowstone National Park show significant δD and $\delta^{18}O$ shifts relative to the LMWL, but the origins of these isotopic shifts are complex and likely are different for each area of the Park. Isotopic shifts may result from single-stage or continuous boiling, isotopic exchange between water, dissolved $SO_4$ and geologic materials and mixing between thermal water and shallow cold meteoric water. The isotope values for cold water from elevations above about 2.5-3.0 km in the Gallatin and northern Absaroka Ranges (δD and $\delta^{18}O$ values lighter than -149‰ and –19.9‰, respectively) are light enough that such water could be the presumed recharge water for the hydrothermal system in the Park (Truesdell and others, 1977).

Estimations of the volume of present-day recharged water that is isotopically light, indicate that it is not adequate to supply the huge thermal water discharges from YNP. The most logical conclusion from all the chemical and isotope data is that the hydrothermal water presently discharging from YNP was recharged in the Gallatin and northern Absaroka Ranges during the Little Ice Age (1250-1900 AD), when the mean annual temperatures likely were lower by 1-2ºC (Bryant, 1997). An alternative interpretation of the isotope data for the hydrothermal water in YNP would allow the recharge meteoric water to have δD value lighter than –145‰, but keep the temperature and precipitation values in the region similar to their present day values. Detailed investigation of recharge in the region is an important future research topic.

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Table 1. Site name and location of cold springs and wells in and adjacent to Yellowstone National Park
[ Water type - cs, cold spring; ms, cold mineral spring; cw, cold well; n, number of samples
Altitude, in meters above mean sea level]

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| (AN) - Absaroka Range - northern area | | | | | | |
| AN-1 | Unn. spr. | cs | 1 | 45° 19' 56" | 110° 41' 25" | 1682 |
| AN-2 | Unn. spr. | cs | 1 | 45° 29' 45" | 110° 31' 13" | 1719 |
| AN-3 | well | cw | 1 | 45° 44' 9" | 110° 12' 40" | 1323 |
| AN-4 | well | cw | 1 | 45° 32' 51" | 110° 18' 26" | 1689 |
| AN-5 | Unn. spr. | cs | 1 | 45° 33' 4" | 110° 3' 23" | 1811 |
| AN-6 | Unn. spr. | cs | 1 | 45° 40' 29" | 109° 36' 5" | 1326 |
| AN-7 | Unn. spr. | cs | 1 | 45° 34' 57" | 109° 41' 46" | 1559 |
| AN-8 | Unn. spr. | cs | 1 | 45° 34' 11" | 109° 48' 36" | 1673 |
| AN-9 | Unn. spr. | cs | 1 | 45° 35' 54" | 109° 46' 32" | 1494 |
| AN-10 | Unn. spr. | cs | 1 | 45° 22' 42" | 109° 39' 30" | 1642 |
| AN-11 | Unn. spr. | cs | 1 | 45° 40' 11" | 109° 16' 59" | 1141 |
| AN-12 | Unn. spr. | cs | 1 | 45° 28' 11" | 109° 54' 50" | 1829 |
| AN-13 | well | cs | 1 | 45° 21' 12" | 109° 53' 51" | 1579 |
| AN-14 | well | cw | 1 | 45° 40' 15" | 109° 16' 54" | 1131 |
| AN-M | Montanapolis Spring | ms | 3 | 45° 17' 28" | 110° 31' 9" | 1841 |
| (AR) Absaroka Range - northeast of YNP, between northeast gate and Red Lodge, MT | | | | | | |
| AR-1 | Unn. spr. | cs | 1 | 45° 9' 23" | 109° 22' 27" | 2067 |
| AR-2 | well | cw | 1 | 45° 10' 23" | 109° 27' 0" | 2298 |
| AR-3 | well | cw | 1 | 45° 3' 29" | 109° 24' 42" | 2195 |
| AR-4 | Unn. spr. | cs | 4 | 45° 1' 35.2" | 109° 53' 36.1" | 2451 |
| AR-5 | well | cw | 1 | 45° 1' 27" | 109° 54' 42" | 2377 |
| AR-6 | Unn. spr. | cs | 1 | 44° 55' 37.7" | 109° 32' 8.7" | 2987 |
| AR-7 | Unn. spr. | cs | 1 | 44° 58' 9.2" | 109° 28' 55.3" | 3249 |
| AR-8 | Unn. spr. | cs | 1 | 44° 57' 50.2" | 109° 28' 44.7" | 3191 |
| AR-9 | Unn. spr. | cs | 1 | 44° 57' 53.7" | 109° 28' 44.7" | 3191 |
| AR-10 | Unn. spr. | cs | 1 | 44° 59' 53.7" | 109° 25' 13.4" | 3170 |
| AR-11 | Unn. spr. | cs | 1 | 44° 58' 37.7" | 109° 26' 54.9" | 3200 |
| AR-12 | well | cw | 1 | 44° 56' 47" | 109° 35' 9.4" | 2719 |
| AR-13 | well | cw | 1 | 45° 0' 27.7" | 109° 59' 22.6" | 2217 |
| (AC) Absaroka Range - east of YNP eastgate, between east gate and Cody, WY | | | | | | |
| AC-1 | Unn. spr. | cs | 1 | 44° 36' 43" | 109° 7' 54" | 1713 |
| AC-2 | well | cw | 1 | 44° 27' 56" | 109° 37' 18" | 1807 |
| AC-3 | Newton Spring | cs | 1 | 44° 27' 22" | 109° 45' 16" | 1926 |
| AC-4 | Unn. spr. | cs | 1 | 44° 29' 59" | 109° 55' 50" | 2079 |
| (AD) Absaroka Range - southern area, near Dubois WY | | | | | | |
| AD-1 | Unn. spr. | cs | 1 | 43° 43' 10" | 109° 58' 31" | 2585 |
| AD-2 | well | cw | 1 | 43° 42' 17" | 109° 58' 5" | 2548 |
| AD-3 | Unn. spr. | cs | 1 | 43° 36' 15" | 109° 57' 19" | 2761 |
| AD-4 | Unn. spr. | cs | 1 | 43° 34' 5" | 109° 52' 59" | 2640 |
| AD-5 | Unn. spr. | cs | 1 | 43° 30' 28" | 109° 50' 38" | 2960 |
| AD-6 | well | cw | 1 | 43° 40' 18" | 109° 38' 27" | 2377 |
| AD-7 | Bartrand Spring | cs | 1 | 43° 41' 59" | 109° 36' 41" | 2499 |
| AD-8 | Unn. spr. | cs | 1 | 43° 40' 1" | 109° 38' 5" | 2341 |
| AD-9 | Unn. spr. | cs | 1 | 43° 42' 2" | 109° 41' 41" | 2865 |

Table 1. Site name and location of cold springs and wells in and adjacent to YNP - continued

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| AD-10 | Unn. spr. | cs | 1 | 43° 41' 5" | 109° 45' 47" | 2548 |
| AD-11 | Unn. spr. | cs | 1 | 43° 41' 5" | 109° 45' 47" | 2548 |
| AD-12 | Unn. spr. | cs | 1 | 43° 41' 6" | 109° 22' 18" | 2566 |
| AD-13 | Unn. spr. | cs | 1 | 43° 41' 51" | 109° 26' 3" | 2804 |
| AD-14 | well | cw | 1 | 43° 38' 45" | 109° 29' 57" | 2256 |
| (AG) Absaroka Range - Gardiner-Mammoth area | | | | | | |
| AG-1 | well (CUT) | cw | 2 | 45° 5' 20.5" | 110° 46' 36.2" | 1579 |
| AG-2 | well | cw | 1 | 45° 3' 10.4" | 110° 42' 7.9" | 1899 |
| AG-3 | well | cw | 1 | 45° 2' 4.6" | 110° 41' 8.7" | 1713 |
| AG-4 | Unn. spr. | cs | 1 | 45° 2' 14.4" | 110° 41' 56.9" | 1682 |
| AG-5 | Unn. spr. | cs | 3 | 45° 3' 9.6" | 110° 35' 9.3" | 2633 |
| AG-6 | Unn. spr. | cs | 2 | 45° 4' 11" | 110° 38' 38" | 2073 |
| AG-7 | Unn. spr. | cs | 1 | 45° 2' 43" | 110° 35' 40" | 2646 |
| AG-8 | Unn. spr. | cs | 1 | 45° 2' 35" | 110° 35' 55" | 2560 |
| AG-9 | Unn. spr. | cs | 3 | 45° 3' 33" | 110° 37' 58" | 2073 |
| AG-10 | Unn. spr. | cs | 3 | 45° 2' 8.9" | 110° 40' 39.7" | 1792 |
| AG-11 | Unn. spr. | cs | 3 | 45° 5' 54" | 110° 46' 22" | 1804 |
| AG-12 | Unn. spr. | cs | 1 | 45° 7' 15.3" | 110° 44' 34.4" | 2243 |
| AG-13 | Unn. spr. | cs | 1 | 45° 7' 47.8" | 110° 44' 47.2" | 2499 |
| AG-14 | well | cs | 1 | 45° 4' 58" | 110° 46' 34.7" | 1573 |
| AG-15 | well (Hoppe) | cw | 1 | 45° 2' 4.2" | 110° 40' 49.6" | 1783 |
| (YP) Yellowstone Plateau - including interior volcanic plateaus, and Washburn Range | | | | | | |
| YP-1 | Unn. spr. | cs | 3 | 44° 42' 29" | 111° 5' 57" | 2012 |
| YP-2 | well | cw | 1 | 44° 56' 54" | 110° 18' 29" | 1905 |
| YP-3 | Unn. spr. | cs | 5 | 44° 53' 20.7" | 110° 23' 24" | 2009 |
| YP-4 | Unn. spr. | cs | 2 | 44° 32' 8" | 110° 26' 12" | 2362 |
| YP-5 | Iron Spring | cs | 1 | 44° 39' 36" | 110° 46' 7" | 2176 |
| YP-6 | Unn. spr. | cs | 4 | 44° 38' 14.5" | 110° 51' 45.4" | 2051 |
| YP-7 | well | cw | 1 | 44° 44' 23" | 110° 41' 30" | 2281 |
| YP-8 | well | cw | 1 | 44° 16' 53" | 110° 37' 36" | 2380 |
| YP-9 | well | cw | 1 | 44° 55' 2" | 110° 6' 45" | 2104 |
| (GG) Gallatin Range - Gardiner-Mammoth area | | | | | | |
| GG-1 | Unn. spr. | cs | 4 | 44° 59' 18.8" | 110° 42' 58.9" | 2035 |
| GG-2 | well (NPS-1) | cw | 1 | 45° 3' 15.3" | 110° 45' 54.9" | 1579 |
| GG-3 | Unn. spr. | cs | 1 | 44° 59' 5.6" | 110° 48' 55" | 2512 |
| GG-4 | Unn. spr. | cs | 1 | 44° 59' 7.4" | 110° 48' 19.1" | 2451 |
| GG-5 | Unn. spr. | cs | 1 | 44° 58' 17.2" | 110° 46' 13.5" | 2390 |
| GG-6 | Unn. spr. | cs | 1 | 44° 57' 40.6" | 110° 44' 22.5" | 2316 |
| GG-7 | Unn. spr. | cs | 1 | 44° 56' 37" | 110° 49' 51" | 2505 |
| GG-8 | Unn. spr. | cs | 1 | 44° 56' 58" | 110° 46' 41" | 2353 |
| GG-9 | Unn. spr. | cs | 1 | 45° 3' 5.9" | 110° 48' 12.1" | 2505 |
| GG-10 | Unn. spr. (Sawmill Cr. Spr.) | cs | 2 | 45° 2' 44" | 110° 48' 11.4" | 2036 |
| GG-11 | Unn. spr. | cs | 1 | 45° 2' 7.7" | 110° 46' 14.3" | 1728 |
| GG-12 | Apollinaris Spring | cs | 1 | 44° 50' 33" | 110° 43' 54" | 2243 |
| GG-13 | well | cw | 1 | 44° 53' 9" | 110° 44' 7" | 2231 |
| GG-14 | Unn. spr. | cs | 3 | 44° 59' 19.6" | 110° 42' 58.9" | 2035 |
| GG-15 | Unn. spr. | cs | 1 | 44° 57' 31.6" | 110° 43' 60" | 2286 |

Table 1. Site name and location of cold springs and wells in and adjacent to YNP - continued

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| (GN) Gallatin Range - northern area | | | | | | |
| GN-1 | Unn. spr. | cs | 1 | 45° 12' 57" | 110° 56' 26" | 1838 |
| GN-2 | Unn. spr. | cs | 1 | 45° 14' 1" | 110° 58' 9" | 2140 |
| GN-3 | Unn. spr. | cs | 1 | 45° 14' 1" | 110° 58' 9" | 2140 |
| GN-4 | Unn. spr. | cs | 1 | 45° 14' 1" | 110° 58' 9" | 2140 |
| GN-5 | Unn. spr. | cs | 1 | 45° 13' 49" | 110° 57' 11" | 2060 |
| GN-6 | Unn. spr. | cs | 1 | 45° 3' 28" | 110° 56' 20.2" | 2682 |
| GN-7 | Unn. spr. | cs | 1 | 45° 5' 23.2" | 110° 58' 19" | 2591 |
| GN-8 | Unn. spr. | cs | 1 | 45° 3' 29" | 110° 56' 17.3" | 2682 |
| GN-9 | Unn. spr. | cs | 1 | 45° 19' 3" | 111° 10' 21" | 1951 |
| GN-10 | well | cw | 1 | 45° 22' 18" | 111° 9' 9" | 1774 |
| GN-11 | Unn. spr. | cs | 1 | 45° 26' 24" | 111° 11' 29" | 1707 |
| GN-12 | Unn. spr. | cs | 1 | 45° 25' 33" | 111° 8' 21" | 1835 |
| GN-13 | Unn. spr. | cs | 1 | 45° 26' 11" | 111° 10' 40" | 1747 |
| GN-14 | Unn. spr. | cs | 1 | 45° 31' 39" | 111° 1' 8" | 1914 |
| GN-15 | Unn. spr. | cs | 1 | 45° 31' 25" | 111° 1' 5" | 1902 |
| GN-16 | Unn. spr. | cs | 1 | 45° 38' 23" | 110° 42' 24" | 1588 |
| (MR) Madison Range - northwest of YNP, including sites in south Gravelly Range | | | | | | |
| MR-1 | Unn. spr. | cs | 1 | 45° 33' 3" | 111° 26' 22" | 1682 |
| MR-2 | Unn. spr. | cs | 1 | 45° 29' 42" | 111° 25' 13" | 1811 |
| MR-3 | well | cw | 1 | 45° 26' 50" | 111° 22' 34" | 1865 |
| MR-4 | well | cw | 1 | 45° 36' 24.8" | 111° 34' 10.9" | 1366 |
| MR-5 | Unn. spr. | cs | 1 | 45° 34' 45.1" | 111° 40' 41.9" | 1487 |
| MR-6 | Unn. spr. | cs | 1 | 45° 27' 15.8" | 111° 37' 18.1" | 1823 |
| MR-7 | Unn. spr. | cs | 1 | 45° 21' 5" | 111° 24' 9" | 2987 |
| MR-8 | Unn. spr. | cs | 2 | 45° 20' 19" | 111° 23' 49" | 2761 |
| MR-9 | Unn. spr. | cs | 1 | 45° 19' 37" | 111° 23' 12" | 2621 |
| MR-10 | Unn. spr. | cs | 1 | 44° 53' 7" | 111° 3' 11" | 2164 |
| MR-11 | Unn. spr. | cs | 1 | 44° 53' 52" | 111° 3' 21" | 2195 |
| MR-12 | Unn. spr. | cs | 1 | 44° 49' 46.9" | 111° 31' 4.1" | 1850 |
| MR-13 | Unn. spr. | cs | 1 | 44° 48' 14" | 111° 33' 40" | 1914 |
| MR-14 | Unn. spr. | cs | 1 | 44° 48' 13" | 111° 33' 32" | 1914 |
| MR-15 | well | cw | 1 | 44° 47' 49.9" | 111° 33' 36" | 2012 |
| MR-16 | Unn. spr. | cs | 1 | 44° 46' 4.1" | 111° 29' 53.2" | 1963 |
| MR-17 | Unn. spr. | cs | 1 | 45° 21' 6.5" | 111° 24' 8.9" | 3005 |
| MR-18 | Unn. spr. | cs | 1 | 45° 21' 6.9" | 111° 24' 5.2" | 3011 |
| MR-19 | Unn. spr. | cs | 1 | 45° 20' 47.2" | 111° 23' 43.6" | 2853 |
| Snake River Plain - southwest of YNP | | | | | | |
| SR-1 | Unn. spr. | cs | 1 | 44° 11' 28" | 111° 33' 53" | 1695 |
| SR-2 | Unn. spr. | cs | 1 | 44° 13' 10" | 111° 37' 51" | 1792 |
| SR-3 | Elk Wallow well | cw | 1 | 44° 13' 16" | 111° 29' 37" | 1901 |
| SR-4 | Unn. spr. | cs | 1 | 44° 17' 4" | 111° 30' 59" | 1897 |
| SR-5 | North Antelope Spring | cs | 1 | 44° 18' 36" | 111° 36' 19" | 2079 |
| SR-6 | Lyle Spring | cs | 1 | 44° 18' 2" | 111° 32' 40" | 1957 |
| SR-7 | Osborne Springs | cs | 1 | 44° 18' 32" | 111° 24' 26" | 1868 |
| SR-8 | Unn. spr. | cs | 1 | 44° 17' 2" | 111° 18' 54" | 1870 |
| SR-9 | Unn. spr. | cs | 1 | 44° 26' 19" | 111° 15' 30" | 1939 |

Table 1. Site name and location of cold springs and wells in and adjacent to YNP - continued

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| SR-10 | Latham Spring | cs | 1 | 44° 27' 34" | 111° 8' 34" | 2323 |
| SR-11 | Big Springs (southern) | cs | 4 | 44° 29' 56" | 111° 15' 14" | 1951 |
| SR-12 | Big Springs (northern) | cs | 3 | 44° 30' 2" | 111° 15' 14" | 1951 |
| SR-13 | Unn. spr. | cs | 1 | 44° 32' 13" | 111° 15' 27" | 1957 |
| SR-14 | Unn. spr. | cs | 1 | 44° 35' 35" | 111° 16' 27" | 2091 |
| SR-15 | Black Sand Spring | cs | 1 | 44° 39' 33" | 111° 9' 35" | 2018 |
| SR-16 | Howard Spring | cs | 1 | 44° 40' 8" | 111° 17' 10" | 2140 |

Table 2. Site name and location for snow samples in and adjacent to Yellowstone National Park
[sfc, surface sample; n, number of samples; Altitude, in meters above mean sea level]

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| Absaroka Range - northeast of YNP, between northeast gate and Red Lodge, MT along Highway 212 | | | | | | |
| AR-S1 | Beartooth Pass | sfc | 1 | 45° 0' 28.2" | 109° 24' 30" | 3109 |
| AR-S2 | Beartooth Pass, nr ski resort | core | 1 | 44° 58' 31" | 109° 26' 0.6" | 3328 |
| AR-S3 | Beartooth Pass, at saddle | core | 1 | 44° 58' 27.7" | 109° 27' 17" | 3210 |
| AR-S4 | Beartooth Pass - West Summit rest area | core | 2 | 44° 58' 10.9" | 109° 28' 15.8" | 3335 |
| AR-S5 | Beartooth Pass - snow 10300' | core | 2 | 44° 57' 48.1" | 109° 28' 55.6" | 3164 |
| AR-S6 | near Long Lake | core | 1 | 44° 56' 27" | 109° 30' 21.8" | 2943 |
| AR-S7 | Beartooth Lake campground | core | 2 | 44° 56' 31.4" | 109° 35' 44.7" | 2720 |
| AR-S8 | Chief Joseph campground | core | 2 | 45° 1' 7.8" | 109° 52' 17.9" | 2448 |
| Yellowstone Plateau - including interior volcanic plateaus and Washburn Range | | | | | | |
| YP-S1 | Dunraven Pass | core | 3 | 44° 47' 5.9" | 110° 27' 10.6" | 2697 |
| YP-S2 | Mt Washburn, near summit at 10220' | core | 1 | 44° 47' 53" | 110° 25' 59.2" | 3115 |
| YP-S3 | Mt Washburn, north ridge at 9860' | core | 2 | 44° 48' 4" | 110° 26' 5.6" | 3005 |
| YP-S4 | Mt Washburn, north ridge at 9620' | core | 1 | 44° 48' 24.2" | 110° 26' 1.1" | 2932 |
| YP-S5 | Mt Washburn, north ridge at 9150' | core | 1 | 44° 48' 49.2" | 110° 26' 24.4" | 2789 |
| YP-S6 | Mt Washburn, north ridge at 8820' | core | 1 | 44° 49' 22.4" | 110° 26' 39.4" | 2688 |
| YP-S7 | Cascade Lake picnic area | core | 1 | 44° 44' 32.7" | 110° 29' 37.5" | 2426 |
| YP-S8 | near Palmer Creek, near AG-5 cold spring | core | 1 | 45° 3' 4.6" | 110° 35' 9.3" | 2633 |
| YP-S9 | Norris Basin, at parking lot | sfc | 1 | 44° 43' 35.1" | 110° 42' 2.3" | 2312 |
| YP-S10 | Ice Lake Trail | sfc | 1 | 44° 43' 0" | 110° 38' 4.9" | 2402 |
| YP-S11 | Canyon Junction | sfc | 1 | 44° 44' 8.7" | 110° 29' 32.3" | 2409 |
| YP-S12 | Mt. Washburn, parking lot near summit | sfc | 1 | 44° 49' 26" | 110° 26' 41.1" | 2667 |
| YP-S13 | Mt. Washburn, north road to summit | sfc | 1 | 44° 50' 25.7" | 110° 26' 16.1" | 2499 |
| YP-S14 | Dunraven picnic area | sfc | 1 | 44° 45' 45.4" | 110° 28' 16.7" | 2545 |
| YP-S15 | Continental Divide nr Grant Village | sfc | 2 | 44° 21' 26.4" | 110° 34' 53.9" | 2437 |
| Madison Range - Beehive basin, near Lone Mountian ski area, MT | | | | | | |
| MR-S1 | Beehive Basin @ 2621 m | core | 1 | 45° 19' 37.3" | 111° 23' 12.5" | 2621 |
| MR-S2 | Beehive Basin @ 2682 m | core | 1 | 45° 19' 39.3" | 111° 23' 4.6" | 2682 |
| MR-S3 | Beehive Basin, trailhead @ 2554 m | core | 1 | 45° 18' 56.7" | 111° 23' 3.2" | 2554 |
| MR-S4 | Beehive Basin @ 2493 m | core | 1 | 45° 18' 42.9" | 111° 23' 2.2" | 2493 |
| MR-S5 | Beehive Basin @ 2432 m | core | 1 | 45° 18' 26.4" | 111° 22' 56.2" | 2432 |
| MR-S6 | Beehive Basin, 2m profile (0.5m intervals) | profile | 4 | 45° 19' 25.5" | 111° 23' 6.4" | 2627 |

Table 3. Site name and location for thermal and mineral waters in and adjacent to Yellowstone National Park
[Water type - ts, thermal spring; tw, thermal well; n = number of samples;
Altitude, in meters above mean sea level]

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| *Sites inside Yellowstone National Park boundary* | | | | | | |
| Mammoth Area | | | | | | |
| M-NG | Narrow Gauge | ts | 3 | 44° 58' 11.1" | 110° 42' 32.2" | 2012 |
| M-OT | Opal Terrace | ts | 1 | 44° 58' 23.4" | 110° 42' 8.5" | 1913 |
| M-PP | Painted Pool | ts | 1 | 44° 57' 55.3" | 110° 42' 48.8" | 2054 |
| M-PS | Poison Spring | ts | 1 | 44° 57' 53.4" | 110° 42' 55.8" | 2062 |
| M-SP | Unn. spr. (Snow Pass) | ts | 2 | 44° 57' 30.5" | 110° 44' 7.8" | 2274 |
| M-Y10 | well (Y-10) | tw | 5 | 44° 57' 57.7" | 110° 42' 47.3" | 2055 |
| Norris-Mammoth Corridor | | | | | | |
| NM-AS1 | Amphitheater Springs (#1) | ts | 1 | 44° 47' 42.9" | 110° 43' 26.9" | 2301 |
| NM-AS2 | Amphitheater Springs (#2) | ts | 1 | 44° 47' 48.9" | 110° 43' 24.2" | 2298 |
| NM-CW1 | Clearwater Springs (CW-1) | ts | 1 | 44° 47' 9.3" | 110° 44' 21.1" | 2295 |
| NM-CW2 | Clearwater Springs (CW-2) | ts | 1 | 44° 47' 17.5" | 110° 44' 18.4" | 2292 |
| NM-CW3 | Clearwater Springs (CW-3) | ts | 4 | 44° 47' 20.2" | 110° 44' 19.5" | 2292 |
| NM-HB | Unn. wm. spr. (High Bridge) | ts | 1 | 44° 57' 0.3" | 110° 40' 53.8" | 1821 |
| NM-S | Sheepeater Hot Springs | ts | 2 | 44° 54' 31.9" | 110° 42' 24" | 2131 |
| NW-W | Whiterock Springs | ts | 1 | 44° 46' 47.8" | 110° 41' 58.4" | 2310 |
| Norris Basin | | | | | | |
| N-C | Cistern Spring | ts | 1 | 44° 43' 23.1" | 110° 42' 11.7" | 2291 |
| N-G | Growler | ts | 1 | 44° 43' 48.2" | 110° 41' 57.9" | 2295 |
| N-PG | Porkchop Geyser | ts | 2 | 44° 43' 20" | 110° 42' 26.6" | 2288 |
| N-NP | Unn. acid spr. (nr. Porkchop Geyser) | ts | 1 | 44° 43' 20.6" | 110° 42' 26.6" | 2287 |
| Calcite Springs thermal Area (near Tower Junction) | | | | | | |
| YP-C1 | Unn. spr. (Calcite Spr.) | ts | 3 | 44° 54' 18.9" | 110° 23' 40.1" | 1856 |
| YP-C2 | Unn. spr. (Calcite Spr.) | ts | 1 | 44° 54' 22.8" | 110° 23' 39" | 1856 |
| Rainbow Springs thermal area (Wrong Creek- southwest side of Mirror Plateau) | | | | | | |
| YP-R2 | Rainbow Springs (YRS-2) | ts | 1 | 44° 46' 8.5" | 110° 16' 11.1" | 2490 |
| YP-R33 | Rainbow Springs (#33) | ts | 1 | 44° 46' 8.5" | 110° 16' 11.1" | 2490 |
| YP-R4 | Rainbow Springs (#4) | ts | 1 | 44° 46' 8.5" | 110° 16' 11.1" | 2490 |
| YP-ROS | Rainbow Springs (oil seep) | ts | 1 | 44° 46' 8.5" | 110° 16' 11.1" | 2490 |
| Washburn Hot Springs thermal area (Washburn Range, east flank) | | | | | | |
| YP-W1 | Washburn Hot Springs (#1) | ts | 1 | 44° 46' 0.6" | 110° 25' 37.8" | 2527 |
| YP-W2 | Washburn Hot Springs (#2) | ts | 1 | 44° 45' 58.3" | 110° 25' 44.3" | 2512 |
| *Thermal waters- Outside Yellowstone National Park* | | | | | | |
| Corwin Springs Known Geothermal Resources Area | | | | | | |
| CS-BC1 | Bear Creek Hot Springs (BC-1) | ts | 1 | 45° 1' 57.8" | 110° 41' 1.8" | 1634 |
| CS-BC2 | Bear Creek Hot Springs (BC-2) | ts | 2 | 45° 1' 50.9" | 110° 41' 1.5" | 1622 |
| CS-BC3 | Bear Creek Hot Springs (BC-3) | ts | 1 | 45° 1' 50.1" | 110° 41' 15.9" | 1609 |
| CS-BCG | Bear Creek Hot Springs, at gauge | ts | 1 | 45° 1' 54.6" | 110° 41' 1.7" | 1625 |
| CS-LD | La Duke Hot Springs | ts | 4 | 45° 5' 25.8" | 110° 46' 27.9" | 1567 |
| CS-MS | Unn. spr., near Miller Well | ts | 1 | 45° 4' 58" | 110° 46' 36.2" | 1564 |
| CS-NL | Unn. spr. (near La Duke HS) | ts | 1 | 45° 5' 13.3" | 110° 46' 29" | 1567 |
| CS-MW | well (Miller) | tw | 3 | 45° 4' 57.7" | 110° 46' 35.6" | 1564 |
| CS-CUT1 | well (CUT-1) | tw | 1 | 45° 5' 21.1" | 110° 46' 33.4" | 1576 |

Table 3. Site name and location for thermal and mineral waters in and adjacent to YNP - continued

| Site name | Local site name | Water type | n | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| Absaroka Range - northern area | | | | | | |
| AN-C | Chico Hot Springs | ts | 2 | 45° 20' 12" | 110° 41' 29.3" | 1615 |
| Madison Range | | | | | | |
| MR-WC | Wolf Creek Hot Springs | ts | 1 | 44° 59' 3" | 111° 36' 54" | 1850 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area

[Deg C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, not determined; <, less than]

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (μS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (AN) Absaroka Range - northern area | | | | | | | | | | | | | | |
| AN-1 | 89YNP-212 | 06-24-89 | 8 | 166 | -- | 17.5 | 23.3 | 3.81 | 5.7 | 0.79 | -- | 3.2 | 1.1 | 56 |
| AN-2 | 90YNP-224 | 06-06-90 | 4 | 139 | -- | 12.8 | 16.3 | 4.63 | 2.2 | -- | -- | 9.6 | 0.9 | 48 |
| AN-3 | 90YNP-226 | 06-06-90 | 11 | 252 | -- | 10.3 | 5.49 | 0.15 | 53.8 | 0.06 | -- | 39.4 | 3.9 | 114 |
| AN-4 | 90YNP-227 | 06-06-90 | 11 | 410 | -- | 7.0 | 56.8 | 12.2 | 10.8 | -- | -- | 73.3 | 0.5 | 162 |
| AN-5 | 90YNP-228 | 06-06-90 | 6 | 495 | -- | 10.1 | 75.0 | 16.9 | 6.6 | -- | -- | 15.7 | 2.6 | 130 |
| AN-6 | 90YNP-229 | 06-07-90 | 8 | 630 | -- | 6.3 | 59.3 | 26.8 | 43.3 | 2.10 | -- | 63.9 | 2.7 | 207 |
| AN-7 | 90YNP-230 | 06-07-90 | 10 | 380 | -- | 6.7 | 43.3 | 15.1 | 16.1 | -- | -- | 11.7 | 1.5 | 97 |
| AN-8 | 90YNP-231 | 06-07-90 | 7 | 240 | -- | 19.6 | 37.3 | 4.06 | 6.7 | -- | -- | 7.8 | 0.7 | 77 |
| AN-9 | 90YNP-232 | 06-07-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AN-10 | 90YNP-235 | 06-07-90 | 12 | 620 | -- | 8.8 | 70.0 | 26.9 | 8.0 | -- | -- | 16.8 | 2.5 | 139 |
| AN-11 | 90YNP-236 | 06-07-90 | 9 | 970 | -- | 8.5 | 36.0 | 16.4 | 177 | 2.12 | -- | 107 | 9.1 | 358 |
| AN-12 | 90YNP-233 | 06-08-90 | 8 | 670 | -- | 11.4 | 97.2 | 28.4 | 6.2 | -- | -- | 173 | 0.9 | 319 |
| AN-13 | 90YNP-234 | 06-08-90 | 8 | 65 | -- | 10.6 | 6.43 | 1.72 | 2.1 | -- | -- | 4.8 | 0.3 | 27 |
| AN-14 | 90YNP-237 | 06-08-90 | 10.5 | 890 | -- | 8.3 | 21.7 | 11.9 | 180 | 1.84 | -- | 69.6 | 11.3 | 307 |
| AN-M.1 | 89YNP-213 | 06-24-89 | 9 | 5200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AN-M.2 | 90YNP-225 | 06-06-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AN-M.3 | 90YNP-319 | 08-15-90 | 10 | 5200 | -- | 23.8 | 393 | 87.5 | 968 | 60.9 | 2960 | 678 | 243 | 5434 |
| (AR) Absaroka Range - northeast of YNP, between northeast gate and Red Lodge, MT | | | | | | | | | | | | | | |
| AR-1 | 90YNP-238 | 06-09-90 | 6 | 66 | -- | 8.9 | 6.27 | 2.66 | 1.5 | -- | -- | 3.0 | 0.3 | 23 |
| AR-2 | 90YNP-239 | 06-09-90 | 3 | 100 | -- | 8.2 | 9.37 | 4.88 | 2.4 | -- | -- | 2.6 | 0.2 | 29 |
| AR-3 | 90YNP-240 | 06-09-90 | 5 | 130 | -- | 9.2 | 14.1 | 6.06 | 1.9 | -- | -- | 5.9 | 0.4 | 39 |
| AR-4.1 | 90YNP-246 | 06-11-90 | 2 | 105 | -- | 10.9 | 14.8 | 3.65 | 1.0 | -- | -- | 3.1 | 0.4 | 35 |
| AR-4.2 | 90YNP-318 | 08-14-90 | 5 | 130 | -- | 12.8 | 17.2 | 4.21 | 1.7 | -- | -- | 3.0 | 0.3 | 40 |
| AR-4.3 | 91YNP-8 | 05-26-91 | -- | 106 | -- | 10.7 | 14.6 | 3.45 | 1.4 | 0.41 | -- | 3.0 | 0.4 | 35 |
| AR-4.4 | 91YNP-116 | 09-02-91 | 3 | 121 | -- | -- | -- | -- | -- | -- | -- | 2.8 | 0.3 | -- |
| AR-5 | 90YNP-247 | 06-11-90 | 8 | 265 | -- | 8.9 | 42.7 | 8.32 | 0.9 | -- | -- | 8.4 | 0.8 | 73 |
| AR-6 | 91YNP-109 | 09-02-91 | 4 | 17 | -- | -- | -- | -- | -- | -- | -- | 0.68 | 0.4 | -- |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued
[mg/L, milligrams per liter; --, not determined; <, less than]

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (AN) Absaroka Range - northern area | | | | | | | | | | | | | | |
| AN-1 | -- | 0.040 | <0.05 | <0.03 | 0.08 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.172 | -19.0 | -140 | 11.9 |
| AN-2 | -- | 0.031 | <0.05 | <0.2 | <0.1 | 0.01 | -- | <0.002 | 1.2 | <0.30 | 0.029 | -17.9 | -136 | 7.2 |
| AN-3 | -- | <0.002 | <0.05 | <0.2 | 0.34 | 0.01 | -- | <0.002 | 0.2 | <0.30 | 0.019 | -15.2 | -122 | -0.5 |
| AN-4 | -- | 0.093 | <0.05 | <0.2 | 0.12 | <0.01 | -- | 0.005 | 0.6 | <0.30 | 0.169 | -18.7 | -141 | 8.4 |
| AN-5 | -- | 0.13 | <0.05 | <0.2 | 0.13 | <0.01 | -- | <0.002 | 2.1 | <0.30 | 0.349 | -17.9 | -137 | 5.5 |
| AN-6 | -- | 0.12 | 0.22 | <0.2 | 0.28 | <0.01 | -- | <0.002 | 1.0 | <0.30 | 1.67 | -17.5 | -137 | 2.4 |
| AN-7 | -- | 0.13 | 0.11 | <0.2 | 0.20 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 1.53 | -16.7 | -132 | 2.1 |
| AN-8 | -- | <0.002 | <0.05 | <0.2 | 0.11 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.121 | -17.5 | -135 | 4.6 |
| AN-9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.2 | -131 | 6.8 |
| AN-10 | -- | 0.074 | <0.05 | <0.2 | 0.19 | <0.01 | -- | 0.003 | 4.51 | <0.30 | 0.433 | -16.7 | -131 | 2.4 |
| AN-11 | -- | 0.052 | 0.37 | <0.2 | 0.32 | <0.01 | -- | <0.002 | 0.76 | <0.30 | 1.13 | -16.9 | -135 | -0.3 |
| AN-12 | -- | 0.026 | <0.05 | <0.2 | 0.19 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 1.42 | -18.3 | -139 | 7.1 |
| AN-13 | -- | 0.007 | <0.05 | <0.2 | <0.1 | 0.02 | -- | 0.032 | 0.39 | <0.30 | 0.046 | -18.7 | -139 | 10.3 |
| AN-14 | -- | 0.20 | 0.54 | <0.2 | 1.0 | 0.03 | -- | 0.011 | <0.1 | <0.30 | 0.717 | -17.1 | -137 | 0.2 |
| AN-M.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.7 | -150 | 7.6 |
| AN-M.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -153 | 3.6 |
| AN-M.3 | -- | 0.012 | 0.82 | 0.89 | <0.2 | 3.9 | 1.23 | 0.29 | <0.1 | <0.30 | 5.20 | -19.5 | -153 | 3.1 |
| (AR) Absaroka Range - northeast of YNP, between northeast gate and Red Lodge, MT | | | | | | | | | | | | | | |
| AR-1 | -- | 0.014 | <0.05 | <0.2 | <0.1 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.052 | -19.0 | -143 | 8.9 |
| AR-2 | -- | 0.015 | <0.05 | <0.2 | <0.1 | 0.12 | -- | 0.15 | <0.1 | <0.30 | 0.059 | -19.3 | -142 | 11.8 |
| AR-3 | -- | 0.022 | <0.05 | <0.2 | <0.1 | 0.02 | -- | 0.027 | 0.53 | <0.30 | 0.175 | -19.2 | -145 | 8.2 |
| AR-4.1 | -- | 0.021 | <0.05 | <0.2 | <0.1 | 0.01 | -- | <0.002 | <0.1 | <0.30 | 0.070 | -18.9 | -143 | 8.3 |
| AR-4.2 | -- | 0.025 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.086 | -19.0 | -142 | 9.5 |
| AR-4.3 | -- | 0.020 | 0.05 | <0.03 | <0.05 | <0.01 | 0.001 | <0.002 | 0.36 | <0.05 | 0.065 | -18.8 | -140 | 10.5 |
| AR-4.4 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | <0.02 | 0.05 | -- | -18.6 | -141 | 7.8 |
| AR-5 | -- | 0.059 | <0.05 | <0.2 | <0.1 | <0.01 | -- | <0.002 | 2.6 | <0.30 | 0.122 | -19.3 | -147 | 7.2 |
| AR-6 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | 0.41 | <0.05 | -- | -19.1 | -142 | 10.2 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (µS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AR-7 | 91YNP-110 | 09-02-91 | 0 | 14 | -- | -- | -- | -- | -- | -- | -- | 0.45 | 0.1 | -- |
| AR-8 | 91YNP-111 | 09-02-91 | 5 | 32 | -- | -- | -- | -- | -- | -- | -- | 1.3 | 0.1 | -- |
| AR-9 | 91YNP-112 | 09-02-91 | 4 | 43 | -- | -- | -- | -- | -- | -- | -- | 2.3 | 0.2 | -- |
| AR-10 | 91YNP-113 | 09-02-91 | -- | 40 | -- | -- | -- | -- | -- | -- | -- | 2.6 | 0.2 | -- |
| AR-11 | 91YNP-114 | 09-02-91 | 3.5 | 69 | -- | -- | -- | -- | -- | -- | -- | 1.5 | 0.4 | -- |
| AR-12 | 91YNP-115 | 09-02-91 | 3 | 235 | -- | -- | -- | -- | -- | -- | -- | 11.5 | 0.3 | -- |
| AR-13 | 91YNP-136 | 09-11-91 | -- | 351 | -- | -- | -- | -- | -- | -- | -- | 14.7 | 0.4 | |
| (AC) Absaroka Range - east of YNP eastgate, between east gate and Cody, WY | | | | | | | | | | | | | | |
| AC-1 | 90YNP-241 | 06-09-90 | 10.5 | 1220 | -- | 19.8 | 111 | 41.8 | 128 | -- | -- | 360 | 9.9 | 674 |
| AC-2 | 90YNP-242 | 06-10-90 | 13.5 | 141 | -- | 27.9 | 10.9 | 3.90 | 13.6 | -- | -- | 8.2 | 0.5 | 66 |
| AC-3 | 90YNP-243 | 06-10-90 | 14 | 190 | -- | 18.6 | 8.92 | 0.94 | 32.9 | 0.16 | -- | 8.7 | 0.7 | 71 |
| AC-4 | 90YNP-244 | 06-10-90 | 8.5 | 200 | -- | 32.5 | 15.3 | 7.12 | 17.3 | -- | -- | 12.5 | 1.0 | 86 |
| (AD) Absaroka Range - southern area, near Dubois, WY | | | | | | | | | | | | | | |
| AD-1 | 90YNP-301 | 08-11-90 | 5 | 205 | -- | 31.1 | 17.0 | 3.77 | 23.2 | -- | -- | 10.0 | 0.6 | 87 |
| AD-2 | 90YNP-302 | 08-11-90 | 11 | 190 | -- | 40.4 | 28.6 | 4.22 | 5.9 | -- | -- | 3.3 | 0.8 | 84 |
| AD-3 | 90YNP-303 | 08-11-90 | -- | 250 | -- | 12.6 | 28.7 | 10.7 | 6.1 | -- | -- | 1.9 | 0.5 | 62 |
| AD-4 | 90YNP-304 | 08-11-90 | 4 | 320 | -- | 10.1 | 37.4 | 16.7 | 7.4 | -- | -- | 10.9 | 0.6 | 85 |
| AD-5 | 90YNP-305 | 08-11-90 | 5 | 15 | -- | 9.5 | 1.65 | 0.41 | 1.6 | -- | -- | 0.58 | 0.4 | 15 |
| AD-6 | 90YNP-306 | 08-12-90 | 5 | 208 | -- | 31.4 | 29.4 | 6.44 | 4.0 | -- | -- | 2.2 | 0.2 | 74 |
| AD-7 | 90YNP-307 | 08-12-90 | 5 | 360 | -- | 45.7 | 33.3 | 15.2 | 23.7 | -- | -- | 5.9 | 1.6 | 126 |
| AD-8 | 90YNP-308 | 08-12-90 | 5.5 | 280 | -- | 30.4 | 40.6 | 8.08 | 7.7 | -- | -- | 2.7 | 0.5 | 91 |
| AD-9 | 90YNP-309 | 08-12-90 | 5 | 65 | -- | 45.1 | 10.1 | 3.75 | 3.1 | -- | -- | 1.7 | 0.4 | 65 |
| AD-10 | 90YNP-310 | 08-12-90 | 5 | 175 | -- | 28.9 | 13.8 | 3.88 | 21.3 | 0.69 | -- | 4.9 | 0.4 | 74 |
| AD-11 | 90YNP-310A | 08-12-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AD-12 | 90YNP-311 | 08-13-90 | 4 | 325 | -- | 17.1 | 24.4 | 16.2 | 30.1 | -- | -- | 15.9 | 1.0 | 106 |
| AD-13 | 90YNP-312 | 08-13-90 | 7 | 335 | -- | 20.6 | 32.5 | 21.4 | 5.2 | -- | -- | 3.7 | 0.4 | 85 |
| AD-14 | 90YNP-313 | 08-13-90 | 8 | 430 | -- | 16.2 | 51.2 | 18.2 | 13.5 | -- | -- | 4.5 | 1.1 | 106 |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/O-16, stable isotope ratio (permil) | H-2/H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AR-7 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | <0.02 | <0.05 | -- | -19.7 | -146 | 11.6 |
| AR-8 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | <0.02 | <0.05 | -- | -17.2 | -125 | 12.8 |
| AR-9 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | 0.48 | <0.05 | -- | -17.2 | -126 | 11.4 |
| AR-10 | -- | -- | -- | <0.03 | 0.13 | -- | -- | -- | 1.1 | <0.05 | -- | -15.5 | -115 | 8.8 |
| AR-11 | -- | -- | -- | <0.03 | 0.08 | -- | -- | -- | <0.01 | <0.05 | -- | -15.5 | -115 | 8.9 |
| AR-12 | -- | -- | -- | <0.03 | 0.85 | -- | -- | -- | <0.01 | <0.05 | -- | -20.2 | -150 | 11.8 |
| AR-13 | -- | -- | -- | <0.03 | 0.12 | -- | -- | -- | 0.10 | <0.05 | -- | -18.9 | -141 | 9.7 |
| (AC) Absaroka Range - east of YNP eastgate, between east gate and Cody, WY | | | | | | | | | | | | | | |
| AC-1 | -- | 0.015 | 0.17 | <0.2 | 0.33 | 0.07 | -- | 0.006 | <0.1 | <0.30 | 0.864 | -19.1 | -147 | 5.5 |
| AC-2 | -- | <0.002 | <0.05 | <0.2 | 0.13 | 0.04 | -- | <0.002 | <0.1 | <0.30 | 0.070 | -19.0 | -146 | 5.7 |
| AC-3 | -- | 0.006 | <0.05 | <0.2 | 0.22 | 0.06 | -- | <0.002 | <0.1 | <0.30 | 0.093 | -18.3 | -145 | 1.3 |
| AC-4 | -- | <0.002 | <0.05 | <0.2 | 0.14 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.048 | -17.7 | -140 | 1.1 |
| (AD) Absaroka Range - southern area, near Dubois, WY | | | | | | | | | | | | | | |
| AD-1 | -- | 0.026 | <0.05 | <0.2 | 0.20 | 0.07 | <0.01 | 0.015 | <0.1 | <0.30 | 0.098 | -19.2 | -145 | 8.8 |
| AD-2 | -- | 0.084 | <0.05 | <0.2 | <0.1 | 0.02 | <0.01 | <0.002 | <0.1 | <0.30 | 0.152 | -18.9 | -144 | 6.8 |
| AD-3 | -- | 0.13 | <0.05 | <0.2 | <0.1 | 0.05 | <0.01 | 0.009 | <0.1 | <0.30 | 0.350 | -19.3 | -145 | 9.2 |
| AD-4 | -- | 0.11 | <0.05 | <0.2 | 0.18 | <0.01 | <0.01 | <0.002 | 0.70 | <0.30 | 0.289 | -19.3 | -146 | 9.2 |
| AD-5 | -- | 0.004 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | 0.55 | <0.30 | 0.010 | -18.3 | -137 | 9.7 |
| AD-6 | -- | 0.097 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.096 | -18.6 | -139 | 9.2 |
| AD-7 | -- | 0.17 | <0.05 | <0.2 | 0.18 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.339 | -19.0 | -149 | 3.2 |
| AD-8 | -- | 0.11 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.115 | -18.5 | -142 | 5.8 |
| AD-9 | -- | 0.091 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.063 | -19.2 | -144 | 9.1 |
| AD-10 | -- | 0.031 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.092 | -17.9 | -136 | 7.1 |
| AD-11 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.1 | -136 | 8.9 |
| AD-12 | -- | 0.070 | <0.05 | <0.2 | 0.16 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.486 | -19.0 | -148 | 3.3 |
| AD-13 | -- | 0.19 | <0.05 | <0.2 | 0.11 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.339 | -19.3 | -149 | 4.8 |
| AD-14 | -- | 0.12 | <0.05 | <0.2 | 0.17 | 0.12 | 0.042 | 0.010 | <0.1 | <0.30 | 0.325 | -18.8 | -145 | 5.3 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temper-ature, water (Deg C) | Specific conduct-ductance (µS/cm) | pH (stand-ard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magne-sium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potas-sium, dissolved (mg/L as K) | Alka-linity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chlo-ride, dissolved (mg/L as Cl) | Solids, sum of consti-tuents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (AG) Absaroka Range - Gardiner-Mammoth area | | | | | | | | | | | | | | |
| AG-1.1 | 89YNP-34 | 05-20-89 | -- | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-1.2 | 90YNP-120 | 06-16-90 | -- | 390 | 6.35 | 23.6 | 39.2 | 11.2 | 21.2 | 4.45 | 111 | 87.7 | 6.9 | 309 |
| AG-2 | 89YNP-29 | 05-22-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-3 | 89YNP-21 | 05-23-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-4 | 89YNP-24 | 05-23-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-5.1 | 89YNP-201 | 06-20-89 | 3 | 42 | -- | 16.3 | 4.81 | 0.58 | 3.0 | 0.42 | -- | 1.4 | 1.1 | 28 |
| AG-5.2 | 91YNP-25 | 05-28-91 | 2.5 | 39 | -- | 13.8 | 4.57 | 0.55 | 2.2 | 0.36 | -- | 1.2 | 0.3 | 25 |
| AG-5.3 | 91YNP-117 | 09-03-91 | 3 | 39 | -- | -- | -- | -- | -- | -- | -- | 1.3 | 0.3 | -- |
| AG-6.1 | 89YNP-202 | 06-21-89 | 14 | 173 | -- | 25.1 | 20.3 | 5.46 | 5.7 | 3.33 | -- | 8.0 | 1.9 | 72 |
| AG-6.2 | 89YNP-335 | 09-10-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-7 | 89YNP-203 | 06-21-89 | 1 | 26 | -- | 12.5 | 2.19 | 0.68 | 1.8 | 1.01 | -- | 2.3 | 0.9 | 22 |
| AG-8 | 89YNP-204 | 06-21-89 | 3 | 40 | -- | 11.3 | 2.71 | 1.73 | 1.7 | 1.58 | -- | 3.1 | 0.6 | 23 |
| AG-9.1 | 89YNP-205 | 06-21-89 | 6 | 261 | -- | 20.0 | 26.3 | 14.0 | 5.8 | 4.42 | -- | 17.4 | 1.1 | 90 |
| AG-9.2 | 89YNP-334 | 09-10-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-9.3 | 91YNP-26 | 05-28-91 | 2.5 | 270 | -- | 16.2 | 26.4 | 14.0 | 6.7 | 4.43 | -- | 15.7 | 2.1 | 86 |
| AG-10.1 | 89YNP-251 | 06-23-89 | 9.5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-10.2 | 89YNP-117 | 06-26-89 | -- | 496 | 7.85 | 20.3 | 34.2 | 25.4 | 41.1 | 4.64 | 294 | 38.4 | 5.54 | 465 |
| AG-10.3 | 89YNP-344 | 09-10-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-11.1 | 89YNP-214 | 06-26-89 | 10 | 454 | -- | 13.1 | 35.9 | 34.2 | 13.0 | 3.07 | -- | 34.7 | 3.3 | 140 |
| AG-11.2 | 91YNP-27 | 05-28-91 | 10 | 454 | -- | 11.7 | 34.5 | 31.6 | 13.7 | 2.84 | -- | 33.0 | 2.8 | 134 |
| AG-11.3 | 91YNP-118 | 09-03-91 | 9 | 453 | -- | -- | -- | -- | -- | -- | -- | 32.3 | 2.8 | -- |
| AG-12 | 89YNP-266 | 07-17-89 | 8 | 318 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-13 | 89YNP-268 | 07-17-89 | 7 | 137 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-14 | 89YNP-306 | 09-09-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| AG-15 | 89YNP-331 | 09-10-89 | -- | 2800 | -- | 25.1 | 494 | 167 | 72.0 | 22.0 | -- | 1520 | 24.2 | 2335 |
| (YP) Yellowstone Plateau - including interior volcanic plateaus and Washburn Range | | | | | | | | | | | | | | |
| YP-1.1 | 89YNP-206 | 06-22-89 | 16.5 | 432 | 6.69 | 88.3 | 15.5 | 8.97 | 65.1 | 9.15 | 243 | 10.0 | 15.7 | 459 |
| YP-1.2 | 89YNP-333 | 09-10-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/O-16, stable isotope ratio (permil) | H-2/H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (AG) Absaroka Range - Gardiner-Mammoth area | | | | | | | | | | | | | | |
| AG-1.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.1 | -142 | 3.4 |
| AG-1.2 | 0.12 | 0.025 | 0.21 | 0.03 | 0.43 | <0.01 | 0.053 | <0.002 | 1.9 | <0.05 | 0.355 | -17.4 | -140 | -0.9 |
| AG-2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -152 | 4.8 |
| AG-3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.0 | -143 | 9.5 |
| AG-4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.9 | -144 | 6.9 |
| AG-5.1 | -- | 0.017 | <0.05 | <0.03 | <0.05 | 0.05 | -- | <0.002 | 0.05 | <0.05 | 0.052 | -19.1 | -142 | 10.3 |
| AG-5.2 | -- | 0.011 | <0.05 | <0.03 | <0.05 | 0.02 | <0.001 | <0.002 | 1.2 | 0.08 | 0.046 | -19.1 | -142 | 10.3 |
| AG-5.3 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | <0.02 | 0.05 | -- | -17.1 | -138 | -1.3 |
| AG-6.1 | -- | 0.068 | <0.05 | <0.03 | 0.71 | <0.01 | -- | 0.004 | 1.06 | <0.05 | 0.124 | -20.2 | -152 | 9.7 |
| AG-6.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -20.0 | -147 | 12.6 |
| AG-7 | -- | 0.015 | <0.05 | <0.03 | <0.05 | 0.13 | -- | 0.003 | <0.02 | <0.05 | 0.015 | -19.1 | -142 | 10.7 |
| AG-8 | -- | 0.020 | <0.05 | <0.03 | <0.05 | 0.02 | -- | <0.002 | 0.06 | <0.05 | 0.016 | -19.7 | -146 | 12.0 |
| AG-9.1 | -- | 0.063 | <0.05 | <0.03 | 0.14 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.231 | -19.6 | -150 | 7.2 |
| AG-9.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.7 | -149 | 8.3 |
| AG-9.3 | -- | 0.035 | <0.05 | <0.03 | 0.12 | <0.01 | 0.013 | <0.002 | 0.05 | <0.05 | 0.200 | -19.1 | -147 | 5.5 |
| AG-10.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -152 | 5.5 |
| AG-10.2 | 0.10 | 0.053 | <0.05 | 0.04 | 0.55 | <0.01 | 0.058 | <0.002 | 0.25 | <0.05 | 0.323 | -19.2 | -152 | 1.9 |
| AG-10.3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.8 | -152 | 6.4 |
| AG-11.1 | -- | 0.066 | <0.05 | <0.03 | 0.16 | <0.01 | -- | <0.002 | 1.2 | <0.05 | 1.32 | -19.1 | -148 | 4.6 |
| AG-11.2 | -- | 0.059 | <0.05 | 0.04 | 0.14 | <0.01 | 0.011 | <0.002 | 1.5 | <0.05 | 1.24 | -19.1 | -149 | 3.9 |
| AG-11.3 | -- | -- | -- | <0.03 | 0.15 | -- | -- | -- | 1.4 | <0.05 | -- | -18.9 | -147 | 3.7 |
| AG-12 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -150 | 6.6 |
| AG-13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.8 | -152 | 6.9 |
| AG-14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.1 | -144 | 9.6 |
| AG-15 | -- | 0.014 | 0.29 | 0.12 | 3.3 | 0.05 | 0.24 | 0.31 | 1.2 | <0.05 | 2.11 | -18.8 | -146 | 5.1 |
| (YP) Yellowstone Plateau - including interior volcanic plateaus and Washburn Range | | | | | | | | | | | | | | |
| YP-1.1 | -- | 0.016 | 0.07 | 0.03 | 3.3 | 0.04 | -- | 0.016 | <0.02 | <0.05 | 0.039 | -19.6 | -148 | 8.4 |
| YP-1.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -149 | 7.2 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (µS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YP-1.3 | 90YNP-215 | 06-04-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| YP-2 | 90YNP-245 | 06-11-90 | 8 | 230 | -- | 14.8 | 30.4 | 8.38 | 3.3 | 1.54 | -- | 7.3 | 1.4 | 66 |
| YP-3.1 | 90YNP-248 | 06-11-90 | 10 | 160 | -- | 31.3 | 10.4 | 3.21 | 19.6 | 1.22 | -- | 5.0 | 1.1 | 72 |
| YP-3.2 | 90YNP-316 | 08-14-90 | 12 | 130 | -- | 29.7 | 11.1 | 3.82 | 11.5 | 1.59 | -- | 5.6 | 2.4 | 66 |
| YP-3.3 | 91YNP-17 | 05-27-91 | 8 | 171 | 7.71 | 33.8 | 11.2 | 3.34 | 20.6 | 1.27 | -- | 5.1 | 2.0 | 80 |
| YP-3.4 | 91YNP-137 | 09-11-91 | 12 | 168 | -- | -- | -- | -- | -- | -- | -- | 4.5 | 2.0 | -- |
| YP-3.5 | 92YNP-5 | 07-12-92 | -- | 155 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| YP-4.1 | 90YNP-250 | 06-11-90 | 8.5 | 70 | -- | 37.8 | 6.13 | 1.41 | 3.0 | 2.08 | -- | 1.3 | 0.6 | 54 |
| YP-4.2 | 91YNP-24 | 05-27-91 | 3 | 72 | 7.23 | 38.0 | 6.57 | 1.42 | 3.4 | 2.09 | -- | 1.4 | 1.1 | 59 |
| YP-5 | 90YNP-251 | 06-11-90 | 16 | 240 | -- | 98.6 | 11.4 | 1.84 | 30.0 | -- | -- | 32.4 | 2.4 | 185 |
| YP-6.1 | 90YNP-255 | 06-12-90 | 12 | 195 | -- | 51.8 | 7.33 | 1.02 | 30.1 | 3.30 | -- | 3.7 | 16.2 | 117 |
| YP-6.2 | 91YNP-29 | 05-29-91 | -- | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| YP-6.3 | 91YNP-140 | 09-13-91 | -- | 206 | -- | -- | -- | -- | -- | -- | -- | 3.6 | 16.8 | -- |
| YP-6.4 | 92YNP-1 | 07-11-92 | -- | 198 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| YP-7 | 90YNP-256 | 06-12-90 | 15 | 570 | -- | 80.0 | 29.8 | 7.05 | 90.2 | 11.0 | -- | 11.2 | 16.9 | 240 |
| YP-8 | 90YNP-314 | 08-14-90 | 12 | 45 | -- | 24.4 | 3.44 | 0.56 | 2.8 | 1.49 | -- | 1.3 | 3.2 | 38 |
| YP-9 | 90YNP-317 | 08-14-90 | 11 | 180 | -- | 25.6 | 23.4 | 7.36 | 2.1 | 1.85 | -- | 1.9 | 0.3 | 61 |
| (GG) Gallatin Range - Gardiner-Mammoth area | | | | | | | | | | | | | | |
| GG-1.1 | 89YNP-265 | 06-23-89 | -- | 596 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-1.2 | 91YNP-32 | 05-30-91 | -- | 508 | -- | 17.9 | 59.5 | 16.01 | 28.9 | 2.44 | -- | 16.9 | 2.3 | 145 |
| GG-1.3 | 91YNP-138 | 09-13-91 | 5 | 496 | -- | -- | -- | -- | -- | -- | -- | 14.8 | 2.4 | -- |
| GG-1.4 | 92YNP-3 | 07-11-92 | -- | 455 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-2 | 89YNP-33 | 05-20-89 | -- | 459 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-3 | 89YNP-254 | 06-25-89 | -- | 337 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-4 | 89YNP-255 | 06-25-89 | -- | 203 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-5 | 89YNP-256 | 06-25-89 | -- | 203 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-6 | 89YNP-264 | 06-25-89 | -- | 295 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-7 | 89YNP-216 | 06-27-89 | 6 | 306 | -- | 6.0 | 54.1 | 8.03 | 1.3 | 0.45 | -- | 4.1 | 1.0 | 76 |
| GG-8 | 89YNP-218 | 06-27-89 | -- | 218 | -- | 30.7 | 30.8 | 8.52 | 3.4 | 0.45 | -- | 1.9 | 0.8 | 77 |
| GG-9 | 89YNP-257 | 06-27-89 | -- | 203 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YP-1.3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.6 | -150 | 7.3 |
| YP-2 | -- | 0.037 | <0.05 | <0.2 | <0.1 | <0.01 | -- | 0.007 | <0.1 | <0.30 | 0.099 | -18.5 | -143 | 4.2 |
| YP-3.1 | -- | 0.008 | <0.05 | <0.2 | 0.54 | 0.02 | -- | <0.002 | <0.1 | <0.30 | 0.045 | -19.8 | -150 | 8.0 |
| YP-3.2 | -- | 0.025 | <0.05 | <0.2 | 0.49 | 0.03 | <0.01 | <0.002 | 0.94 | <0.30 | 0.085 | -18.9 | -147 | 3.8 |
| YP-3.3 | -- | 0.008 | <0.05 | <0.03 | 0.63 | <0.01 | 0.004 | <0.002 | 1.7 | <0.08 | 0.048 | -19.9 | -150 | 8.8 |
| YP-3.4 | -- | -- | -- | <0.03 | 0.65 | -- | -- | -- | 1.4 | 0.13 | -- | -19.9 | -150 | 9.1 |
| YP-3.5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.7 | -148 | 9.5 |
| YP-4.1 | -- | 0.002 | <0.05 | <0.2 | 3.2 | 0.06 | -- | <0.002 | 0.18 | <0.30 | 0.013 | -19.2 | -148 | 5.6 |
| YP-4.2 | -- | 0.002 | <0.05 | <0.03 | 4.3 | 0.03 | 0.017 | <0.002 | 0.23 | <0.05 | 0.015 | -19.8 | -148 | 10.4 |
| YP-5 | -- | 0.041 | <0.05 | <0.2 | 3.8 | 4.2 | -- | 0.29 | <0.1 | <0.30 | 0.027 | -19.6 | -147 | 9.3 |
| YP-6.1 | -- | 0.002 | 0.21 | <0.2 | 5.2 | <0.01 | -- | <0.002 | 0.75 | <0.30 | 0.007 | -19.4 | -149 | 6.3 |
| YP-6.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.4 | -148 | 7.0 |
| YP-6.3 | -- | -- | -- | 0.04 | 7.1 | -- | -- | -- | 0.80 | <0.05 | -- | -19.5 | -150 | 6.1 |
| YP-6.4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.5 | -149 | 6.6 |
| YP-7 | -- | 0.009 | 0.31 | <0.2 | 3.0 | 0.04 | -- | 0.008 | 0.37 | <0.30 | 0.073 | -19.1 | -147 | 5.9 |
| YP-8 | -- | 0.003 | <0.05 | <0.2 | 1.4 | 0.05 | <0.01 | <0.002 | 0.82 | <0.30 | 0.013 | -18.3 | -139 | 7.7 |
| YP-9 | -- | 0.026 | <0.05 | <0.2 | <0.1 | 0.01 | <0.01 | <0.002 | 0.20 | <0.30 | 0.067 | -19.1 | -146 | 6.5 |
| (GG) Gallatin Range - Gardiner-Mammoth area | | | | | | | | | | | | | | |
| GG-1.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.8 | -142 | 0.7 |
| GG-1.2 | -- | 0.084 | <0.05 | <0.03 | 0.27 | 0.02 | 0.011 | 0.010 | <0.02 | 0.12 | 0.563 | -18.3 | -142 | 4.5 |
| GG-1.3 | -- | -- | -- | <0.03 | 0.29 | -- | -- | -- | <0.02 | 0.06 | -- | -18.1 | -141 | 3.9 |
| GG-1.4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.9 | -138 | 4.7 |
| GG-2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.2 | -142 | 3.3 |
| GG-3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.7 | -146 | 11.6 |
| GG-4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.1 | -146 | 6.6 |
| GG-5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -20.3 | -152 | 9.7 |
| GG-6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.7 | -149 | 8.7 |
| GG-7 | -- | 0.22 | <0.05 | <0.03 | 0.05 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.100 | -19.3 | -147 | 7.8 |
| GG-8 | -- | 0.043 | <0.05 | <0.03 | 0.05 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.082 | -19.6 | -147 | 10.1 |
| GG-9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.3 | -144 | 10.4 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temper-ature, water (Deg C) | Specific conduct-ductance (μS/cm) | pH (stand-ard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magne-sium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potas-sium, dissolved (mg/L as K) | Alka-linity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chlo-ride, dissolved (mg/L as Cl) | Solids, sum of consti-tuents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GG-10.1 | 89YNP-267 | 07-13-89 | 10 | 1020 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-10.2 | 90YNP-119 | 06-16-90 | 9 | 870 | 8.52 | 12.7 | 1.06 | 0.27 | 216 | 0.72 | 575 | 25.7 | 1.1 | 838 |
| GG-11 | 89YNP-269 | 07-24-89 | -- | 259 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-12 | 90YNP-252 | 06-11-90 | 8.5 | 181 | -- | 62.1 | 18.6 | 4.58 | 8.4 | -- | -- | 6.1 | 0.7 | 106 |
| GG-13 | 90YNP-254 | 06-12-90 | 8.5 | 290 | -- | 22.7 | 37.2 | 8.76 | 4.4 | 1.49 | -- | 4.8 | 2.1 | 83 |
| GG-14.1 | 91YNP-33 | 05-30-91 | -- | 436 | -- | 20.1 | 54.6 | 15.4 | 13.9 | 2.22 | -- | 15.0 | 2.5 | 125 |
| GG-14.2 | 91YNP-139 | 09-13-91 | 5 | 491 | -- | -- | -- | -- | -- | -- | -- | 14.5 | 2.3 | -- |
| GG-14.3 | 92YNP-4 | 07-11-92 | -- | 475 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GG-15 | 91YNP-34 | 05-30-91 | -- | 153 | -- | 23.8 | 25.9 | 1.41 | 1.6 | 1.41 | -- | 4.1 | 0.9 | 60 |
| (GN) Gallatin Range - northern area | | | | | | | | | | | | | | |
| GN-1 | 89YNP-208 | 06-23-89 | 6.5 | 447 | -- | 36.4 | 56.5 | 19.6 | 8.6 | 5.33 | -- | 15.8 | 4.2 | 148 |
| GN-2 | 89YNP-209 | 06-23-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-3 | 89YNP-209A | 06-23-89 | 7 | 164 | -- | 40.3 | 23.0 | 3.31 | 5.8 | 0.94 | -- | 2.8 | 0.9 | 78 |
| GN-4 | 89YNP-209B | 06-23-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-5 | 89YNP-210 | 06-23-89 | 8 | 256 | -- | 40.6 | 39.7 | 6.51 | 5.4 | 1.07 | -- | 3.3 | 1.1 | 99 |
| GN-6 | 89YNP-258 | 06-27-89 | -- | 76 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-7 | 89YNP-259 | 06-27-89 | -- | 134 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-8 | 89YNP-263 | 06-27-89 | -- | 249 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-9 | 90YNP-216 | 06-05-90 | 4 | 100 | -- | 20.3 | 9.36 | 4.24 | 3.5 | 2.35 | -- | 5.8 | 1.2 | 46 |
| GN-10 | 90YNP-217 | 06-05-90 | 7 | 270 | -- | 16.4 | 26.5 | 8.67 | 16.0 | -- | -- | 7.2 | 10.5 | 86 |
| GN-11 | 90YNP-218 | 06-05-90 | 5 | 291 | -- | 7.9 | 32.9 | 18.2 | 0.9 | -- | -- | 4.8 | 0.7 | 66 |
| GN-12 | 90YNP-219 | 06-05-90 | 7 | 310 | -- | 38.5 | 46.5 | 9.80 | 4.9 | -- | -- | 5.8 | 0.9 | 107 |
| GN-13 | 90YNP-220 | 06-05-90 | 6 | 212 | -- | 16.7 | 26.4 | 9.53 | 2.3 | -- | -- | 5.3 | 0.7 | 62 |
| GN-14 | 90YNP-221 | 06-05-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GN-15 | 90YNP-222 | 06-05-90 | 5 | 105 | -- | 44.5 | 11.9 | 2.80 | 3.1 | -- | -- | 2.6 | 0.4 | 66 |
| GN-16 | 90YNP-223 | 06-05-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| (MR) Madison Range - northwest of YNP | | | | | | | | | | | | | | |
| MR-1 | 90YNP-320 | 08-16-90 | 9 | 235 | -- | 11.4 | 26.1 | 11.8 | 2.9 | 1.42 | -- | 4.2 | 0.9 | 58 |
| MR-2 | 90YNP-321 | 08-16-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GG-10.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.9 | -149 | 10.0 |
| GG-10.2 | 0.12 | 0.018 | 0.31 | <0.03 | 3.0 | 0.14 | 0.20 | 0.015 | <0.02 | <0.05 | 0.037 | -18.8 | -148 | 2.5 |
| GG-11 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.0 | -146 | 5.3 |
| GG-12 | -- | 0.005 | <0.05 | <0.2 | 4.8 | <0.01 | -- | 0.011 | 0.12 | <0.30 | 0.061 | -18.5 | -146 | 1.9 |
| GG-13 | -- | 0.018 | <0.05 | <0.2 | 0.80 | <0.01 | -- | 0.004 | 1.3 | <0.30 | 0.105 | -19.0 | -144 | 8.4 |
| GG-14.1 | -- | 0.092 | <0.05 | <0.03 | 0.23 | <0.01 | 0.010 | <0.002 | <0.02 | 0.10 | 0.449 | -17.9 | -140 | 3.6 |
| GG-14.2 | -- | -- | -- | <0.03 | 0.25 | -- | -- | -- | <0.01 | 0.13 | -- | -18.1 | -140 | 4.8 |
| GG-14.3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.6 | -137 | 3.6 |
| GG-15 | -- | 0.076 | <0.05 | <0.03 | 0.07 | <0.01 | 0.003 | 0.004 | 0.18 | <0.05 | 0.088 | -18.5 | -141 | 7.5 |
| (GN) Gallatin Range - northern area | | | | | | | | | | | | | | |
| GN-1 | -- | 0.17 | <0.05 | <0.03 | 0.33 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.286 | -19.5 | -145 | 11.1 |
| GN-2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.4 | -149 | 6.1 |
| GN-3 | -- | 0.010 | <0.05 | <0.03 | 0.10 | <0.01 | -- | <0.002 | <0.02 | <0.05 | 0.098 | -19.5 | -149 | 6.3 |
| GN-4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.3 | -149 | 5.4 |
| GN-5 | -- | 0.050 | <0.05 | <0.03 | 0.16 | <0.01 | -- | <0.002 | <0.02 | 0.33 | 0.241 | -19.3 | -148 | 6.7 |
| GN-6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.9 | -143 | 8.4 |
| GN-7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.2 | -145 | 8.5 |
| GN-8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.0 | -142 | 10.5 |
| GN-9 | -- | 0.027 | <0.05 | <0.2 | 0.11 | 1.0 | -- | 0.007 | 0.14 | <0.30 | 0.033 | -18.5 | -142 | 6.2 |
| GN-10 | -- | 0.022 | <0.05 | <0.2 | 0.13 | 0.03 | -- | 0.053 | 0.33 | <0.30 | 0.183 | -19.3 | -148 | 6.7 |
| GN-11 | -- | 0.027 | <0.05 | <0.2 | <0.1 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.043 | -19.3 | -145 | 9.5 |
| GN-12 | -- | 0.014 | <0.05 | <0.2 | 0.12 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.254 | -19.0 | -148 | 3.7 |
| GN-13 | -- | 0.037 | <0.05 | <0.2 | <0.1 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.104 | -19.3 | -147 | 7.1 |
| GN-14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.1 | -142 | 3.2 |
| GN-15 | -- | 0.027 | <0.05 | <0.2 | 0.10 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.065 | -18.7 | -143 | 6.4 |
| GN-16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.9 | -143 | 0.3 |
| (MR) Madison Range - northwest of YNP | | | | | | | | | | | | | | |
| MR-1 | -- | 0.037 | <0.05 | <0.2 | <0.1 | <0.01 | 0.01 | <0.002 | 0.69 | <0.30 | 0.073 | -18.6 | -144 | 5.1 |
| MR-2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.0 | -135 | 1.3 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (µS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MR-3 | 90YNP-322 | 08-16-90 | 5 | 52 | -- | 9.2 | 8.16 | 2.09 | 2.1 | -- | -- | 3.9 | 0.3 | 27 |
| MR-4 | 90YNP-323 | 08-17-90 | 10 | 350 | -- | 27.9 | 35.4 | 12.3 | 22.1 | -- | -- | 17.3 | 13.6 | 132 |
| MR-5 | 90YNP-324 | 08-17-90 | 15 | 340 | -- | 31.6 | 34.4 | 11.1 | 19.0 | -- | -- | 29.9 | 9.1 | 139 |
| MR-6 | 90YNP-325 | 08-17-90 | 9 | 75 | -- | 21.3 | 10.3 | 2.83 | 3.2 | -- | -- | 4.0 | 1.0 | 44 |
| MR-7 | 90YNP-326 | 08-18-90 | 1 | 22 | -- | 2.8 | 3.13 | 0.43 | 0.4 | -- | -- | 0.6 | 0.2 | 9 |
| MR-8.1 | 90YNP-327 | 08-18-90 | 2 | 30 | -- | 4.7 | 4.89 | 0.67 | 0.6 | -- | -- | 1.1 | 0.1 | 13 |
| MR-8.2 | 91YNP-103 | 09-01-91 | 4 | 37 | -- | -- | -- | -- | -- | -- | -- | 1.2 | 0.1 | -- |
| MR-9 | 90YNP-328 | 08-18-90 | 4 | 232 | -- | 4.7 | 37.8 | 6.88 | 0.5 | -- | -- | 5.1 | 0.4 | 57 |
| MR-10 | 90YNP-329 | 08-19-90 | 6 | 130 | -- | 14.3 | 20.4 | 4.30 | 1.8 | -- | -- | 2.6 | 0.5 | 44 |
| MR-11 | 90YNP-330 | 08-19-90 | 7 | 250 | -- | 9.7 | 40.3 | 7.99 | 1.1 | -- | -- | 5.2 | 0.4 | 65 |
| MR-12 | 90YNP-331 | 08-19-90 | 10 | 320 | -- | 13.2 | 31.0 | 17.3 | 8.0 | 2.09 | -- | 3.8 | 3.1 | 79 |
| MR-13 | 90YNP-332 | 08-19-90 | 8 | 220 | -- | 11.1 | 25.3 | 11.9 | 5.0 | 1.83 | -- | 2.2 | 2.4 | 59 |
| MR-14 | 90YNP-333 | 08-19-90 | 5 | 225 | -- | 11.7 | 24.2 | 11.9 | 5.3 | -- | -- | 2.2 | 2.4 | 59 |
| MR-15 | 90YNP-335 | 08-19-90 | 13 | 230 | -- | 12.0 | 24.1 | 11.8 | 5.3 | -- | -- | 2.1 | 2.3 | 59 |
| MR-16 | 90YNP-336 | 08-19-90 | 9 | 240 | -- | 17.6 | 26.4 | 14.9 | 8.7 | -- | -- | 2.8 | 2.2 | 74 |
| MR-17 | 91YNP-104 | 09-01-91 | 0 | 29 | -- | -- | -- | -- | -- | -- | -- | 1.0 | 0.2 | -- |
| MR-18 | 91YNP-105 | 09-01-91 | 4 | 44 | -- | -- | -- | -- | -- | -- | -- | 3.1 | 0.2 | -- |
| MR-19 | 91YNP-107 | 09-01-91 | 8 | 33 | -- | -- | -- | -- | -- | -- | -- | 2.0 | 0.2 | -- |
| (SR) Snake River Plain - southwest of YNP | | | | | | | | | | | | | | |
| SR-1 | 90YNP-201 | 06-02-90 | 8 | 170 | -- | 37.0 | 19.3 | 4.83 | 7.4 | -- | -- | 3.6 | 5.1 | 78 |
| SR-2 | 90YNP-202 | 06-02-90 | 9 | 59 | -- | 28.9 | 5.40 | 1.29 | 3.4 | 1.11 | -- | 2.5 | 1.4 | 49 |
| SR-3 | 90YNP-203 | 06-03-90 | 6 | 56 | -- | 6.6 | 4.68 | 1.26 | 2.9 | -- | -- | 1.3 | 2.3 | 20 |
| SR-4 | 90YNP-204 | 06-03-90 | 6 | 85 | -- | 25.2 | 9.36 | 2.76 | 3.3 | -- | -- | 2.1 | 0.9 | 44 |
| SR-5 | 90YNP-205 | 06-03-90 | 5 | 46 | -- | 16.8 | 4.89 | 1.12 | 2.2 | -- | -- | 1.4 | 0.4 | 27 |
| SR-6 | 90YNP-206 | 06-03-90 | -- | 49 | -- | 18.5 | 4.48 | 1.26 | 2.7 | -- | -- | 2.0 | 1.0 | 31 |
| SR-7 | 90YNP-207 | 06-03-90 | 6 | 99 | -- | 39.1 | 7.34 | 3.23 | 5.8 | -- | -- | 1.5 | 1.1 | 60 |
| SR-8 | 90YNP-208 | 06-03-90 | 5.5 | 86 | -- | 36.8 | 6.80 | 3.36 | 3.4 | -- | -- | 1.5 | 1.0 | 54 |
| SR-9 | 90YNP-209 | 06-03-90 | 10.5 | 95 | -- | 40.6 | 4.19 | 0.66 | 12.5 | -- | -- | 2.2 | 2.1 | 66 |
| SR-10 | 90YNP-210 | 06-04-90 | 5 | 29 | -- | 22.8 | 1.57 | 0.43 | 1.3 | -- | -- | 1.5 | 1.1 | 32 |
| SR-11.1 | 90YNP-211 | 06-04-90 | 14 | 130 | -- | 49.9 | 5.29 | 0.76 | 18.8 | -- | -- | 2.8 | 3.8 | 86 |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MR-3 | -- | 0.010 | <0.05 | <0.2 | <0.1 | 0.08 | <0.01 | 0.088 | 0.53 | <0.30 | 0.040 | -18.2 | -138 | 8.1 |
| MR-4 | -- | 0.043 | 0.13 | <0.2 | 1.3 | 0.02 | 0.13 | 0.010 | 1.0 | <0.30 | 0.119 | -17.4 | -135 | 4.1 |
| MR-5 | -- | 0.025 | <0.05 | <0.2 | 0.58 | <0.01 | 0.016 | <0.002 | 2.6 | <0.30 | 0.235 | -18.5 | -146 | 2.4 |
| MR-6 | -- | 0.037 | <0.05 | <0.2 | <0.1 | 0.39 | <0.01 | 0.005 | <0.1 | <0.30 | 0.039 | -18.7 | -142 | 7.5 |
| MR-7 | -- | 0.003 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | 0.90 | <0.30 | 0.011 | -19.1 | -140 | 13.2 |
| MR-8.1 | -- | 0.008 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | 0.42 | <0.30 | 0.026 | -19.7 | -147 | 11.0 |
| MR-8.2 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | 0.64 | <0.05 | -- | -19.0 | -143 | 9.1 |
| MR-9 | -- | 0.14 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | 0.83 | <0.30 | 0.069 | -19.3 | -147 | 7.9 |
| MR-10 | -- | 0.024 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.033 | -18.3 | -135 | 10.8 |
| MR-11 | -- | 0.052 | <0.05 | <0.2 | <0.1 | <0.01 | <0.01 | <0.002 | <0.1 | <0.30 | 0.059 | -18.8 | -139 | 11.7 |
| MR-12 | -- | 0.023 | <0.05 | <0.2 | 0.11 | <0.01 | <0.01 | <0.002 | 1.6 | <0.30 | 0.057 | -19.3 | -147 | 7.6 |
| MR-13 | -- | 0.014 | <0.05 | <0.2 | 0.23 | <0.01 | <0.01 | <0.002 | 0.43 | <0.30 | 0.058 | -17.2 | -136 | 1.8 |
| MR-14 | -- | 0.014 | <0.05 | <0.2 | 0.29 | <0.01 | <0.01 | <0.002 | 0.41 | <0.30 | 0.055 | -17.2 | -136 | 1.8 |
| MR-15 | -- | 0.015 | <0.05 | <0.2 | 0.27 | <0.01 | <0.01 | <0.002 | 0.55 | <0.30 | 0.057 | -17.1 | -131 | 6.1 |
| MR-16 | -- | 0.008 | <0.05 | <0.2 | 0.18 | <0.01 | <0.01 | <0.002 | 1.1 | <0.30 | 0.058 | -19.4 | -148 | 7.0 |
| MR-17 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | 2.1 | <0.05 | -- | -18.0 | -134 | 10.0 |
| MR-18 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | 0.25 | <0.05 | -- | -18.4 | -136 | 11.0 |
| MR-19 | -- | -- | -- | <0.03 | <0.05 | -- | -- | -- | <0.01 | <0.05 | -- | -18.0 | -134 | 10.4 |
| (SR) Snake River Plain - southwest of YNP | | | | | | | | | | | | | | |
| SR-1 | -- | 0.018 | 0.08 | <0.2 | 0.2 | 0.03 | -- | 0.003 | 0.31 | <0.30 | 0.051 | -17.7 | -136 | 5.3 |
| SR-2 | -- | 0.016 | 0.05 | <0.2 | <0.1 | 0.26 | -- | 0.008 | 4.2 | <0.30 | 0.019 | -17.4 | -134 | 5.5 |
| SR-3 | -- | 0.012 | <0.05 | <0.2 | <0.1 | 0.15 | -- | 0.045 | 0.80 | <0.30 | 0.032 | -17.1 | -130 | 6.8 |
| SR-4 | -- | 0.004 | <0.05 | <0.2 | <0.1 | 0.22 | -- | <0.002 | <0.1 | <0.30 | 0.036 | -17.4 | -130 | 9.3 |
| SR-5 | -- | 0.009 | <0.05 | <0.2 | <0.1 | 0.10 | -- | <0.002 | <0.1 | <0.30 | 0.029 | -17.6 | -130 | 10.7 |
| SR-6 | -- | 0.005 | <0.05 | <0.2 | <0.1 | 0.15 | -- | <0.002 | <0.1 | <0.30 | 0.024 | -17.8 | -129 | 13.4 |
| SR-7 | -- | 0.008 | 0.06 | <0.2 | 1.3 | 0.20 | -- | <0.002 | 0.2 | <0.30 | 0.022 | -18.2 | -133 | 12.1 |
| SR-8 | -- | 0.004 | <0.05 | <0.2 | <0.1 | 0.12 | -- | <0.002 | <0.1 | <0.30 | 0.022 | -18.1 | -132 | 12.8 |
| SR-9 | -- | <0.002 | 0.07 | <0.2 | 2.6 | 0.02 | -- | <0.002 | 0.31 | <0.30 | 0.006 | -18.5 | -135 | 12.8 |
| SR-10 | -- | <0.002 | <0.05 | <0.2 | <0.1 | <0.01 | -- | <0.002 | 2.7 | <0.30 | 0.011 | -18.7 | -137 | 13.1 |
| SR-11.1 | -- | <0.002 | 0.09 | <0.2 | 3.4 | <0.01 | -- | <0.002 | <0.1 | <0.30 | 0.006 | -18.5 | -137 | 11.6 |

Table 4.--Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (μS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SR-11.2 | 90YNP-337 | 08-20-90 | 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| SR-11.3 | 91YNP-1 | 05-24-91 | -- | 128 | -- | 52.5 | 5.32 | 0.74 | 20.2 | 3.49 | -- | 2.8 | 4.0 | 95 |
| SR-11.4 | 91YNP-101 | 08-31-91 | -- | 122 | -- | -- | -- | -- | -- | -- | -- | 2.7 | 3.9 | -- |
| SR-12.1 | 90YNP-211A | 06-04-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| SR-12.2 | 91YNP-2 | 05-24-91 | -- | 104 | -- | 45.4 | 5.12 | 0.73 | 13.9 | 3.01 | -- | 2.3 | 3.1 | 78 |
| SR-12.3 | 91YNP-102 | 08-31-91 | -- | 103 | -- | -- | -- | -- | -- | -- | -- | 2.3 | 3.0 | -- |
| SR-13 | 90YNP-212 | 06-04-90 | 9 | 75 | -- | 35.6 | 4.63 | 0.86 | 7.9 | -- | -- | 1.8 | 1.6 | 55 |
| SR-14 | 90YNP-213 | 06-04-90 | -- | 103 | -- | 21.3 | 11.8 | 3.75 | 3.0 | -- | -- | 2.2 | 0.7 | 43 |
| SR-15 | 90YNP-214 | 06-04-90 | -- | 95 | -- | 36.2 | 5.81 | 0.98 | 11.2 | -- | -- | 1.3 | 3.7 | 63 |
| SR-16 | 90YNP-257 | 06-12-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table 4. Physical and chemical analyses of cold water samples from the greater Yellowstone National Park area - continued

| Site Name | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SR-11.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.6 | -138 | 10.8 |
| SR-11.3 | -- | <0.002 | 0.08 | <0.03 | 4.6 | <0.01 | 0.080 | <0.002 | 0.15 | <0.05 | 0.006 | -18.5 | -137 | 10.4 |
| SR-11.4 | -- | -- | -- | <0.03 | 4.9 | -- | -- | -- | <0.02 | <0.05 | -- | -18.2 | -139 | 6.8 |
| SR-12.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.5 | -136 | 12.2 |
| SR-12.2 | -- | <0.002 | 0.06 | <0.03 | 4.0 | <0.01 | 0.060 | <0.002 | 0.16 | <0.05 | 0.006 | -18.4 | -137 | 10.5 |
| SR-12.3 | -- | -- | -- | <0.03 | 4.2 | -- | -- | -- | <0.02 | <0.05 | -- | -18.2 | -138 | 8.1 |
| SR-13 | -- | <0.002 | <0.05 | <0.2 | 2.1 | 0.02 | -- | <0.002 | <0.1 | <0.30 | 0.006 | -18.5 | -135 | 12.8 |
| SR-14 | -- | 0.003 | <0.05 | <0.2 | <0.1 | 0.08 | -- | <0.002 | <0.1 | <0.30 | 0.106 | -18.2 | -130 | 15.1 |
| SR-15 | -- | <0.002 | 0.08 | <0.2 | 2.9 | 0.02 | -- | <0.002 | <0.1 | <0.30 | 0.008 | -18.8 | -141 | 8.9 |
| SR-16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -17.6 | -137 | 4.5 |

Table 5.--Physical and chemical analyses of snow samples from the greater Yellowstone National Park area
[Deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, not determined; <, less than]

| Site Name | Field Sample ID | Date | Specific conductance (µS/cm) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | O-18/O-16, stable isotope ratio (permil) | H-2/H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (AR-S) Absaroka Range - northeast of YNP, between northeast gate and Red Lodge, MT | | | | | | | | | | | | |
| AR-S1 | 90YNP-258 | 06-09-90 | -- | -- | -- | -- | -- | -- | -- | -21.5 | -162 | 10.4 |
| AR-S2 | 91YNP-9 | 05-26-91 | 2 | -- | -- | -- | -- | -- | -- | -22.2 | -167 | 10.9 |
| AR-S3 | 91YNP-10 | 05-26-91 | 2 | -- | -- | -- | -- | -- | -- | -19.6 | -145 | 11.9 |
| AR-S4.1 | 91YNP-11 | 05-26-91 | 3 | -- | -- | -- | -- | -- | -- | -19.1 | -141 | 11.7 |
| AR-S4.2 | 91YNP-11A | 05-26-91 | -- | -- | -- | -- | -- | -- | -- | -22.6 | -170 | 10.3 |
| AR-S5.1 | 91YNP-12 | 05-26-91 | 2 | -- | -- | -- | -- | -- | -- | -19.9 | -146 | 13.1 |
| AR-S5.2 | 91YNP-12A | 05-26-91 | -- | -- | -- | -- | -- | -- | -- | -23.6 | -178 | 10.8 |
| AR-S6 | 91YNP-13 | 05-26-91 | 3 | -- | -- | -- | -- | -- | -- | -21.2 | -160 | 9.8 |
| AR-S7.1 | 91YNP-14 | 05-26-91 | 2 | -- | -- | -- | -- | -- | -- | -20.9 | -158 | 9.3 |
| AR-S7.2 | 91YNP-14A | 05-26-91 | -- | -- | -- | -- | -- | -- | -- | -22.2 | -169 | 8.7 |
| AR-S8.1 | 91YNP-15 | 05-26-91 | 3 | -- | -- | -- | -- | -- | -- | -20.8 | -157 | 9.8 |
| AR-S8.2 | 91YNP-15A | 05-26-91 | -- | -- | -- | -- | -- | -- | -- | -20.3 | -153 | 9.3 |
| (YP-S) Yellowstone Plateau - including interior volcanic plateaus and Washburn Range | | | | | | | | | | | | |
| YP-S1.1 | 91YNP-16 | 05-26-91 | 3 | -- | -- | -- | -- | -- | -- | -17.8 | -133 | 8.9 |
| YP-S1.2 | 91YNP-16A | 05-26-91 | -- | -- | -- | -- | -- | -- | -- | -16.6 | -121 | 12.0 |
| YP-S1.3 | 91YNP-145 | 09-14-91 | 4.5 | 0.08 | 0.3 | <0.03 | <0.05 | 0.10 | <0.05 | -19.1 | -140 | 13.1 |
| YP-S2 | 91YNP-18 | 05-27-91 | 4 | -- | -- | -- | -- | -- | -- | -18.5 | -137 | 10.9 |
| YP-S3.1 | 91YNP-19 | 05-27-91 | 4 | -- | -- | -- | -- | -- | -- | -18.7 | -138 | 11.5 |
| YP-S3.2 | 91YNP-19A | 05-27-91 | -- | -- | -- | -- | -- | -- | -- | -12.5 | -88 | 11.8 |
| YP-S4 | 91YNP-20 | 05-27-91 | 4 | -- | -- | -- | -- | -- | -- | -18.2 | -136 | 9.8 |
| YP-S5 | 91YNP-21 | 05-27-91 | 5 | -- | -- | -- | -- | -- | -- | -23.9 | -175 | 16.0 |
| YP-S6 | 91YNP-22 | 05-27-91 | 3 | -- | -- | -- | -- | -- | -- | -22.3 | -167 | 11.3 |
| YP-S7 | 91YNP-23 | 05-27-91 | 3 | -- | -- | -- | -- | -- | -- | -19.9 | -147 | 11.5 |
| YP-S8 | 91YNP-25A | 05-28-91 | 6 | -- | -- | -- | -- | -- | -- | -21.7 | -164 | 9.3 |
| YP-S9 | 91YNP-142 | 09-14-91 | 12 | 0.56 | 0.4 | <0.03 | <0.05 | <0.02 | <0.05 | -17.9 | -128 | 15.2 |
| YP-S10 | 91YNP-143 | 09-14-91 | 7 | -- | -- | -- | -- | -- | -- | -18.1 | -130 | 14.5 |

Table 5.--Physical and chemical analyses of snow samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Specific conductance (µS/cm) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YP-S11 | 91YNP-144 | 09-14-91 | 3 | -- | -- | -- | -- | -- | -- | -19.1 | -143 | 9.7 |
| YP-S12 | 91YNP-146 | 09-14-91 | 2.0 | 0.06 | 0.1 | <0.03 | <0.05 | 0.06 | <0.05 | -19.2 | -141 | 12.6 |
| YP-S13 | 91YNP-147 | 09-14-91 | 7 | -- | -- | -- | -- | -- | -- | -19.4 | -141 | 14.6 |
| YP-S14 | 91YNP-148 | 09-14-91 | 9 | -- | -- | -- | -- | -- | -- | -19.6 | -143 | 13.8 |
| YP-S15.1 | 91YNP-149 | 09-14-91 | 8 | -- | -- | -- | -- | -- | -- | -17.2 | -122 | 15.3 |
| YP-S15.2 | 91YNP-150 | 09-14-91 | 7.5 | 0.9 | 0.3 | <0.03 | <0.05 | 0.21 | <0.05 | -18.2 | -133 | 12.6 |
| (MR-S) Madison Range - Beehive basin, near Lone Mountian ski area, MT | | | | | | | | | | | | |
| MR-S1 | 91YNP-3 | 05-25-91 | 8 | -- | -- | -- | -- | -- | -- | -19.4 | -146 | 8.6 |
| MR-S2 | 91YNP-4 | 05-25-91 | 3 | -- | -- | -- | -- | -- | -- | -19.4 | -146 | 9.3 |
| MR-S3 | 91YNP-5 | 05-25-91 | 3 | -- | -- | -- | -- | -- | -- | -20.3 | -152 | 10.4 |
| MR-S4 | 91YNP-6 | 05-25-91 | 5 | -- | -- | -- | -- | -- | -- | -17.9 | -134 | 9.1 |
| MR-S5 | 91YNP-7 | 05-25-91 | 2 | -- | -- | -- | -- | -- | -- | -19.8 | -148 | 10.5 |
| MR-S6-A | 91YNP-35A | 05-25-91 | -- | -- | -- | -- | -- | -- | -- | -19.1 | -140 | 12.3 |
| MR-S6-B | 91YNP-35B | 05-25-91 | -- | -- | -- | -- | -- | -- | -- | -23.2 | -175 | 10.7 |
| MR-S6-C | 91YNP-35C | 05-25-91 | -- | -- | -- | -- | -- | -- | -- | -18.4 | -136 | 10.7 |
| MR-S6-D | 91YNP-35D | 05-25-91 | -- | -- | -- | -- | -- | -- | -- | -18.6 | -134 | 14.2 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area

[Deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, not determined; <, less than]

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (µS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sites inside Yellowstone National Park boundary* | | | | | | | | | | | | | | |
| (M) Mammoth Area | | | | | | | | | | | | | | |
| M-NG.1 | 89YNP-101 | 06-20-89 | 72 | 2440 | 6.51 | 57.4 | 384 | 70.3 | 130 | 56.3 | 897 | 573 | 164 | 2361 |
| M-NG.2 | 89YNP-301 | 09-08-89 | 68 | 2450 | 6.5 | 58.9 | 347 | 70.6 | 129 | 56.1 | 816 | 583 | 164 | 2252 |
| M-NG.3 | 90YNP-101 | 06-11-90 | 59 | 2400 | 6.42 | 53.0 | 313 | 77.7 | 126 | 56.6 | 720 | 581 | 166 | 2121 |
| M-OT | 89YNP-302 | 09-08-89 | 71 | 2380 | 6.45 | 57.0 | 328 | 72.7 | 126 | 54.9 | 746 | 582 | 161 | 2154 |
| M-PP | 90YNP-103 | 06-11-90 | -- | 2500 | 6.76 | 55.0 | 337 | 76.7 | 124 | 54.9 | 747 | 640 | 163 | 2224 |
| M-PS | 90YNP-104 | 06-11-90 | 44 | 2450 | 6.08 | 49.3 | 337 | 69.1 | 125 | 55.2 | 595 | 711 | 162 | 2130 |
| M-SP.1 | 89YNP-253 | 06-25-89 | 8 | 541 | 5.77 | 20.3 | 102 | 8.25 | 1.0 | 1.23 | -- | 23.7 | 1.1 | 159 |
| M-SP.2 | 90YNP-107 | 06-12-90 | -- | 585 | -- | 17.8 | 115 | 9.07 | 1.1 | 1.08 | 378 | 19.9 | 0.9 | 543 |
| M-Y10.1 | 89YNP-102 | 06-20-89 | 53 | 3030 | 6.21 | 94.6 | 492 | 76.1 | 156 | 64.5 | 1040 | 808 | 174 | 2938 |
| M-Y10.2 | 89YNP-304 | 09-09-89 | 60 | 3020 | 6.34 | 95.9 | 504 | 78.7 | 158 | 64.6 | 1040 | 815 | 174 | 2961 |
| M-Y10.3 | 90YNP-4 | 05-18-90 | 70 | 3160 | -- | 91.7 | 490 | 84.0 | 159 | 63.3 | 1160 | 802 | 183 | 3076 |
| M-Y10.4 | 90YNP-5 | 05-18-90 | 70 | 3060 | -- | 92.4 | 471 | 84.9 | 160 | 64.1 | 1040 | 808 | 180 | 2942 |
| M-Y10.5 | 90YNP-102 | 06-11-90 | 52 | 3010 | 6.3 | 88.8 | 466 | 85.4 | 156 | 63.3 | 1030 | 810 | 175 | 2911 |
| (NM) Norris-Mammoth Corridor | | | | | | | | | | | | | | |
| NM-AS1 | 91YNP-56 | 05-28-91 | 82 | 2680 | 2.09 | 101 | 1.82 | 0.25 | 13.8 | 5.73 | -- | 427 | 2.2 | 566 |
| NM-AS2 | 91YNP-57 | 05-28-91 | 93 | 3900 | 2.09 | 207 | 1.26 | 0.48 | 22.3 | 11.6 | -- | 719 | 0.5 | 972 |
| NM-CW1 | 89YNP-336 | 09-13-89 | 85 | 1210 | -- | 243 | 21.4 | 5.19 | 167 | 47.6 | -- | 92.0 | 286 | 893 |
| NM-CW2 | 89YNP-337 | 09-13-89 | 86 | 929 | -- | 250 | 13.5 | 3.36 | 122 | 49.2 | -- | 108 | 184 | 752 |
| NM-CW3.1 | 89YNP-28 | 05-18-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| NM-CW3.2 | 89YNP-106 | 06-22-89 | 92.6 | 1470 | 6.75 | 304 | 13.6 | 0.12 | 278 | 64.0 | 33 | 64.8 | 467 | 1278 |
| NM-CW3.3 | 89YNP-338 | 09-13-89 | 94 | 1710 | -- | 294 | 12.3 | 0.07 | 272 | 62.7 | -- | 70.5 | 443 | 1203 |
| NM-CW3.4 | 90YNP-118 | 06-15-90 | 94.8 | 1600 | 6.88 | 284 | 11.5 | 0.10 | 258 | 60.0 | 42 | 69.8 | 425 | 1198 |
| NM-HB | 89YNP-116 | 06-24-89 | 33.5 | 2760 | 6.34 | 18.5 | 156 | 44.1 | 458 | 34.5 | 1500 | 218 | 140 | 2605 |
| NM-S.1 | 89YNP-118 | 06-26-89 | -- | 1260 | 6.51 | 83.6 | 141 | 12.9 | 93.5 | 36.4 | 570 | 84.5 | 97.0 | 1137 |
| NM-S.2 | 89YNP-215 | 06-26-89 | 73 | | 6.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| NM-W | 91YNP-28 | 05-29-91 | 92.7 | 1310 | 2.53 | 79.0 | 2.63 | 0.60 | 2.9 | 4.49 | -- | 361 | 0.6 | 520 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area - continued
[mg/L, milligrams per liter; µg/L, micrograms per liter; --, not determined; <, less than]

| Site Name | Aluminium, dissolved (µg/L as Al) | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sites inside Yellowstone National Park boundary* | | | | | | | | | | | | | | | |
| (M) Mammoth Area | | | | | | | | | | | | | | | |
| M-NG.1 | 5.6 | 0.61 | 0.066 | 3.76 | 0.51 | 2.3 | 0.21 | 1.59 | 0.028 | 0.03 | 0.06 | 1.84 | -18.3 | -146 | 0.7 |
| M-NG.2 | -- | -- | 0.062 | 3.63 | 0.49 | 1.5 | 0.04 | 1.57 | 0.023 | <0.1 | <0.05 | 1.64 | -18.1 | -152 | -7.6 |
| M-NG.3 | -- | 0.93 | 0.063 | 3.58 | 0.51 | 1.5 | 0.03 | 1.56 | 0.022 | 0.04 | <0.05 | 1.63 | -18.2 | -145 | 0.5 |
| M-OT | -- | -- | 0.060 | 3.58 | 0.48 | 1.4 | 0.15 | 1.55 | 0.021 | <0.02 | 0.12 | 1.58 | -18.2 | -149 | -3.3 |
| M-PP | -- | 0.22 | 0.049 | 3.51 | 0.50 | 2.0 | <0.01 | 1.59 | 0.006 | <0.02 | <0.05 | 2.19 | -17.2 | -146 | -8.6 |
| M-PS | -- | 0.12 | 0.056 | 3.63 | 0.51 | 2.1 | 0.08 | 1.61 | 0.076 | <0.02 | <0.05 | 1.90 | -17.8 | -145 | -3.0 |
| M-SP.1 | -- | -- | 0.26 | <0.05 | <0.03 | 0.21 | 0.53 | -- | 0.039 | <0.02 | <0.05 | 0.107 | -18.4 | -141 | 6.5 |
| M-SP.2 | -- | -- | 0.26 | 0.02 | <0.03 | 0.12 | 0.21 | <0.002 | 0.025 | <0.02 | <0.05 | 0.110 | -18.1 | -138 | 6.5 |
| M-Y10.1 | 3.9 | 1.0 | 0.055 | 4.17 | 0.54 | 2.3 | 2.1 | -- | 0.037 | 0.03 | <0.05 | 3.56 | -18.4 | -149 | -2.1 |
| M-Y10.2 | -- | -- | 0.055 | 4.00 | 0.54 | 1.7 | 0.75 | 1.69 | 0.040 | <0.2 | <0.05 | 3.49 | -18.3 | -148 | -1.4 |
| M-Y10.3 | -- | -- | 0.10 | 4.13 | 0.57 | 1.4 | 5.9 | 1.71 | 0.45 | 1.59 | <0.05 | 3.44 | -18.2 | -150 | -4.4 |
| M-Y10.4 | -- | -- | 0.14 | 4.14 | 0.55 | 1.6 | 7.8 | 1.74 | 0.30 | 0.11 | <0.05 | 3.74 | -18.2 | -149 | -3.2 |
| M-Y10.5 | -- | 0.72 | 0.052 | 4.06 | 0.55 | 1.6 | 0.05 | 1.73 | 0.033 | <0.02 | <0.05 | 3.71 | -17.9 | -152 | -8.8 |
| (NM) Norris-Mammoth Corridor | | | | | | | | | | | | | | | |
| NM-AS1 | -- | 8.1 | 0.064 | 0.12 | <0.03 | 0.11 | 0.40 | 0.002 | 0.047 | <0.02 | <0.05 | 0.011 | -11.7 | -129 | -35.9 |
| NM-AS2 | -- | 5.8 | 0.029 | <0.05 | <0.03 | 0.35 | 1.4 | 0.033 | 0.045 | <0.02 | <0.05 | 0.006 | -12.3 | -127 | -28.4 |
| NM-CW1 | -- | -- | 0.022 | 4.46 | 0.87 | 1.3 | 0.67 | 1.70 | 0.41 | <0.1 | <0.05 | 0.095 | -17.1 | -143 | -6.7 |
| NM-CW2 | -- | -- | 0.008 | 3.13 | 0.56 | 1.1 | 0.51 | 1.13 | 0.44 | <0.1 | <0.05 | 0.054 | -17.7 | -143 | -1.8 |
| NM-CW3.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -16.8 | -146 | -11.9 |
| NM-CW3.2 | -- | 0.77 | 0.038 | 7.60 | 1.39 | 3.1 | <0.01 | 4.17 | 0.037 | 0.02 | <0.05 | 0.083 | -15.7 | -142 | -16.4 |
| NM-CW3.3 | -- | -- | 0.036 | 7.12 | 1.35 | 2.9 | <0.01 | 4.01 | 0.037 | <0.2 | <0.05 | 0.073 | -15.3 | -143 | -19.8 |
| NM-CW3.4 | -- | 0.52 | 0.028 | 6.68 | 1.28 | 3.1 | <0.01 | 3.95 | 0.029 | <0.02 | <0.05 | 0.067 | -15.0 | -142 | -21.3 |
| NM-HB | -- | 1.8 | 0.079 | 5.15 | 0.49 | 0.7 | 0.09 | 0.74 | 0.38 | <0.02 | <0.05 | 2.15 | -18.6 | -150 | -0.4 |
| NM-S.1 | -- | -- | 0.22 | 2.37 | 0.32 | 2.2 | <0.01 | 1.13 | 0.11 | <0.02 | <0.05 | 0.511 | -18.8 | -148 | 1.8 |
| NM-S.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.8 | -150 | -0.2 |
| NM-W | -- | 18 | 0.077 | <0.05 | <0.03 | <0.05 | 49.9 | 0.014 | 0.12 | <0.02 | <0.05 | 0.032 | -5.3 | -114 | -71.2 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temper-ature, water (Deg C) | Specific conduct-ductance (µS/cm) | pH (stand-ard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magne-sium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potas-sium, dissolved (mg/L as K) | Alka-linity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chlo-ride, dissolved (mg/L as Cl) | Solids, sum of consti-tuents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (N) Norris Basin | | | | | | | | | | | | | | |
| N-C | 90YNP-114 | 06-15-90 | 83 | 1800 | 6.29 | 535 | 3.62 | 0.08 | 313 | 62.4 | 38 | 70.6 | 511 | 1586 |
| N-G | 90YNP-117 | 06-15-90 | 87 | 2400 | 6.8 | 602 | 2.42 | 0.01 | 394 | 103 | 32 | 41.2 | 695 | 1943 |
| N-PG.1 | 89YNP-109 | 06-22-89 | >86 | 2340 | 8.5 | 741 | 3.49 | 0.06 | 388 | 91.1 | 62 | 23.2 | 687 | 2066 |
| N-PG.2 | 90YNP-116 | 06-15-90 | 87 | 2350 | 8.0 | 504 | 3.39 | 0.02 | 400 | 92.7 | 55 | 24.0 | 700 | 1850 |
| N-NP | 89YNP-108 | 06-22-89 | -- | 2140 | -- | 369 | 3.84 | 0.15 | 348 | 75.3 | -- | 81.3 | 595 | 1536 |
| Calcite Springs thermal Area (near Tower Junction) | | | | | | | | | | | | | | |
| YP-C1.1 | 89YNP-252 | 06-24-89 | 94 | 1670 | 7.5 | 191 | 31.5 | 13.0 | 197 | 95.0 | 200 | 250 | 238 | 1408 |
| YP-C1.2 | 90YNP-111 | 06-14-90 | 94 | 1610 | 7.35 | 166 | 35.8 | 12.8 | 199 | 92.7 | 198 | 264 | 233 | 1414 |
| YP-C1.3 | 90YNP-115 | 06-15-90 | -- | 1380 | -- | 172 | 29.7 | 5.10 | 202 | 86.5 | 142 | 258 | 240 | 1362 |
| YP-C2 | 90YNP-110 | 06-14-90 | 94 | 1680 | -- | 158 | 41.3 | 10.2 | 202 | 97.0 | 134 | 333 | 239 | 1427 |
| Rainbow Springs thermal area (Wrong Creek- southwest side of Mirror Plateau) | | | | | | | | | | | | | | |
| YP-R2 | 89YNP-260 | 06-27-89 | 76.1 | 1650 | 6.68 | 337 | 26.4 | 15.3 | 270 | 51.3 | 506 | 153 | 198 | 1671 |
| YP-R33 | 90YNP-133 | 06-18-90 | 81 | 1700 | -- | 315 | 22.0 | 9.03 | 285 | 62.2 | 381 | 281 | 170 | 1639 |
| YP-R4 | 90YNP-132 | 06-18-90 | 78 | 1660 | -- | 323 | 27.9 | 17.2 | 275 | 51.2 | 501 | 154 | 199 | 1664 |
| YP-ROS | 90YNP-134 | 06-18-90 | 30 | 435 | -- | 46.2 | 6.29 | 4.37 | 34.3 | 7.43 | 59 | 24.7 | 64.0 | 283 |
| Washburn Hot Springs thermal area (Washburn Range - between Mt. Washburn and Grand Canyon of Yellowstone) | | | | | | | | | | | | | | |
| YP-W1 | 90YNP-112 | 06-14-90 | 80 | 3490 | -- | 58.7 | 3.97 | 0.23 | 1.0 | 1.58 | 216 | 1200 | 0.8 | 2064 |
| YP-W2 | 90YNP-113 | 06-14-90 | -- | 4300 | 3.15 | 280 | 18.8 | 9.07 | 14.5 | 4.44 | -- | 1790 | 0.9 | 2741 |
| *Thermal waters- Outside Yellowstone National Park* | | | | | | | | | | | | | | |
| (CS) Corwin Springs Known Geothermal Resources Area | | | | | | | | | | | | | | |
| CS-BC1 | 89YNP-105 | 06-21-89 | 31.6 | 2880 | 5.8 | 34.9 | 507 | 91.4 | 113 | 48.8 | 1240 | 869 | 42.8 | 2961 |
| CS-BC2.1 | 89YNP-308 | 09-11-89 | 32 | 2650 | 6.08 | 32.7 | 477 | 89.7 | 112 | 47.3 | 1250 | 824 | 42.4 | 2888 |
| CS-BC2.2 | 90YNP-105 | 06-12-90 | 32 | 2920 | 6.15 | 35.2 | 503 | 98.4 | 121 | 50.0 | 1240 | 878 | 42.7 | 2986 |
| CS-BC3 | 89YNP-309 | 09-11-89 | 14 | 4290 | 7.34 | 24.0 | 10.0 | 2.57 | 1220 | 5.52 | 3260 | 14.1 | 43.4 | 4590 |
| CS-BCG | 91YNP-124 | 09-04-91 | 29 | 2930 | -- | -- | -- | -- | -- | 47.4 | -- | 907 | 40.2 | -- |
| CS-LD.1 | 89YNP-110 | 06-23-89 | 68 | 2580 | 6.46 | 56.7 | 333 | 64.1 | 240 | 24.5 | 295 | 1250 | 44.8 | 2318 |
| CS-LD.2 | 89YNP-307 | 09-09-89 | -- | 2570 | 7.5 | 51.6 | 328 | 59.6 | 236 | 23.7 | 289 | 1250 | 43.9 | 2297 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area - continued

| Site Name | Aluminium, dissolved ($\mu$g/L as Al) | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (N) Norris Basin | | | | | | | | | | | | | | | |
| N-C | -- | 0.80 | 0.013 | 7.25 | 1.49 | 4.9 | 0.04 | 4.61 | 0.018 | <0.02 | <0.05 | 0.017 | -19.4 | -145 | 10.2 |
| N-G | -- | 0.67 | 0.009 | 9.92 | 2.07 | 5.9 | <0.01 | 6.74 | 0.003 | 0.04 | <0.05 | 0.012 | -13.5 | -140 | -32.0 |
| N-PG.1 | -- | 0.14 | 0.004 | 9.89 | 2.12 | 5.8 | 0.02 | 6.55 | 0.004 | 0.03 | <0.05 | 0.017 | -15.7 | -144 | -18.2 |
| N-PG.2 | -- | 0.18 | 0.009 | 9.85 | 2.07 | 6.2 | <0.01 | 6.72 | <0.002 | <0.02 | <0.05 | 0.014 | -14.8 | -143 | -24.1 |
| N-NP | -- | 0.84 | 0.051 | 8.58 | 1.84 | 4.8 | 1.2 | 5.65 | 0.057 | 0.03 | <0.05 | 0.016 | -14.7 | -140 | -22.0 |
| Calcite Springs thermal Area (near Tower Junction) | | | | | | | | | | | | | | | |
| YP-C1.1 | -- | -- | 0.16 | 32.4 | 0.90 | 3.9 | 0.12 | 2.17 | 0.036 | 0.07 | <0.05 | 1.36 | -14.4 | -146 | -30.6 |
| YP-C1.2 | -- | 28 | 0.11 | 31.2 | 0.87 | 3.2 | 0.25 | 2.11 | 0.053 | 0.09 | <0.05 | 1.11 | -14.4 | -146 | -31.1 |
| YP-C1.3 | -- | 28 | 0.050 | 32.4 | 0.96 | 3.5 | 0.04 | 2.11 | 0.032 | 0.06 | <0.05 | 0.447 | -13.7 | -146 | -36.8 |
| YP-C2 | -- | 26 | 0.12 | 31.4 | 0.90 | 2.9 | 0.04 | 2.22 | 0.028 | 0.04 | <0.05 | 1.38 | -14.1 | -145 | -32.8 |
| Rainbow Springs thermal area (Wrong Creek- southwest side of Mirror Plateau) | | | | | | | | | | | | | | | |
| YP-R2 | -- | -- | 0.13 | 19.2 | 0.59 | 2.8 | 0.20 | 0.52 | 0.094 | 0.03 | 0.04 | 0.196 | -16.2 | -147 | -16.9 |
| YP-R33 | -- | 11 | 0.086 | 17.3 | 0.53 | 1.6 | <0.01 | 0.62 | 0.19 | <0.02 | <0.05 | 0.124 | -15.6 | -142 | -17.1 |
| YP-R4 | -- | 8.4 | 0.13 | 18.2 | 0.60 | 1.8 | 0.19 | 0.52 | 0.099 | 0.03 | <0.05 | 0.195 | -14.9 | -143 | -24.3 |
| YP-ROS | -- | 2.1 | 0.040 | 2.64 | 0.10 | 0.38 | 3.0 | 0.069 | 0.15 | 0.04 | <0.05 | 22.0 | -14.8 | -125 | -6.9 |
| Washburn Hot Springs thermal area (Washburn Range - between Mt. Washburn and Grand Canyon of Yellowstone) | | | | | | | | | | | | | | | |
| YP-W1 | -- | 567 | 0.035 | 0.20 | <0.03 | <0.05 | 0.01 | 0.008 | 0.006 | 0.2 | <0.25 | 0.125 | -3.3 | -118 | -91.8 |
| YP-W2 | -- | 560 | 0.011 | 6.87 | <0.03 | <0.05 | 21.5 | <0.002 | 0.29 | <0.02 | <0.25 | 0.060 | -6.8 | -116 | -61.1 |
| *Thermal waters- Outside Yellowstone National Park* | | | | | | | | | | | | | | | |
| (CS) Corwin Springs Known Geothermal Resources Area | | | | | | | | | | | | | | | |
| CS-BC1 | -- | -- | 0.029 | 1.05 | 0.13 | 2.5 | 1.2 | 0.42 | 0.064 | 0.02 | <0.05 | 3.55 | -19.4 | -146 | 9.6 |
| CS-BC2.1 | -- | -- | 0.029 | 1.09 | 0.13 | 1.4 | 0.06 | 0.39 | 0.065 | <0.02 | <0.05 | 3.23 | -19.4 | -148 | 7.7 |
| CS-BC2.2 | -- | 0.27 | 0.029 | 1.30 | 0.14 | 1.5 | 1.2 | 0.43 | 0.071 | <0.02 | <0.05 | 3.49 | -19.5 | -148 | 8.1 |
| CS-BC3 | -- | -- | 1.2 | 1.13 | 0.34 | 2.2 | <0.01 | 1.16 | 0.064 | 0.26 | <0.05 | 1.26 | -18.8 | -146 | 5.1 |
| CS-BCG | -- | -- | -- | -- | 0.13 | 3.2 | -- | 0.43 | -- | <0.02 | <0.05 | -- | -19.4 | -148 | 6.8 |
| CS-LD.1 | 0.43 | 0.19 | 0.035 | 0.46 | 0.21 | 3.5 | 0.05 | 0.28 | 0.021 | 0.08 | <0.05 | 4.22 | -19.3 | -144 | 10.7 |
| CS-LD.2 | -- | -- | 0.035 | 0.58 | 0.20 | 3.5 | 0.21 | 0.27 | 0.021 | <0.2 | <0.05 | 4.15 | -19.4 | -146 | 9.6 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area - continued

| Site Name | Field Sample ID | Date | Temperature, water (Deg C) | Specific conductance (µS/cm) | pH (standard units) | Silica, dissolved (mg/L as $SiO_2$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Alkalinity, lab (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, sum of constituents, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CS-LD.3 | 90YNP-109 | 06-12-90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| CS-LD.4 | 92YNP-2 | 07-11-92 | -- | 2570 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| CS-MS | 89YNP-27 | 05-21-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| CS-NL | 89YNP-112 | 06-23-89 | 58 | 2490 | 6.37 | 73.6 | 331 | 60.8 | 236 | 25.2 | 345 | 1170 | 43.2 | 2291 |
| CS-MW.1 | 89YNP-30 | 05-21-89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| CS-MW.2 | 89YNP-114 | 06-23-89 | 23.5 | 2300 | 7.68 | 64.3 | 97.1 | 92.2 | 307 | 28.7 | 274 | 1000 | 36.1 | 1909 |
| CS-MW.3 | 89YNP-305 | 09-09-89 | -- | 2290 | 7.8 | 60.2 | 95.5 | 89.6 | 311 | 28.2 | 265 | 990 | 35.2 | 1882 |
| CS-CUT1 | 89YNP-113 | 06-23-89 | 54.1 | 2440 | 6.67 | 76.1 | 334 | 73.2 | 210 | 25.7 | 243 | 1230 | 37.5 | 2238 |
| (AN) Absaroka Range - northern area | | | | | | | | | | | | | | |
| AN-C.1 | 89YNP-115 | 06-24-89 | 44 | 383 | 7.52 | 38.1 | 34.5 | 8.19 | 35.4 | 6.78 | 173 | 43.8 | 10.1 | 352 |
| AN-C.2 | 90YNP-121 | 06-16-90 | -- | 409 | -- | 36.8 | 35.3 | 8.76 | 36.0 | 7.32 | 177 | 46.6 | 10.9 | 361 |
| (MR) Madison Range | | | | | | | | | | | | | | |
| MR-WC | 89YNP-207 | 06-22-89 | 64 | 473 | 8.62 | 54.9 | 6.86 | 1.16 | 101 | 2.06 | 164 | 42.3 | 19.2 | 410 |

Table 6.--Physical and chemical analyses of thermal and mineral water samples from the greater Yellowstone National Park area - continued

| Site Name | Aluminium, dissolved (µg/L as Al) | Ammonium, dissolved (mg/L as $NH_4$) | Barium, dissolved (mg/L as Ba) | Boron, dissolved (mg/L as B | Bromide, dissolved (mg/L as Br) | Fluoride, dissolved (mg/L as F) | Iron, dissolved (mg/L as Fe) | Lithium, dissolved (mg/L as Li) | Manganese, dissolved (mg/L as Mn) | Nitrate, dissolved (mg/L as $NO_3$) | Phosphate, dissolved (mg/L as $PO_4$) | Strontium, dissolved (mg/L as Sr) | O-18/ O-16, stable isotope ratio (permil) | H-2/ H-1, stable isotope ratio (permil) | d-parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CS-LD.3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.0 | -145 | 6.2 |
| CS-LD.4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.3 | -146 | 8.2 |
| CS-MS | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -19.5 | -148 | 8.6 |
| CS-NL | -- | 0.13 | 0.046 | 0.46 | 0.20 | 3.0 | 0.03 | 0.28 | 0.064 | 0.42 | <0.05 | 4.22 | -19.2 | -146 | 8.0 |
| CS-MW.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -18.8 | -146 | 4.9 |
| CS-MW.2 | 0.79 | 0.71 | 0.019 | 0.63 | 0.19 | 1.9 | 0.32 | 0.12 | 0.21 | <0.02 | <0.05 | 1.63 | -19.5 | -147 | 8.7 |
| CS-MW.3 | -- | -- | 0.018 | 0.61 | 0.16 | 1.5 | 0.36 | 0.12 | 0.19 | <0.02 | <0.05 | 1.55 | -19.4 | -147 | 8.1 |
| CS-CUT1 | 0.55 | 0.23 | 0.029 | 0.54 | 0.19 | 2.8 | 0.75 | 0.21 | 0.16 | 0.02 | <0.05 | 4.48 | -19.4 | -145 | 10.2 |
| (AN) Absaroka Range - northern area | | | | | | | | | | | | | | | |
| AN-C.1 | -- | 0.10 | 0.10 | 0.05 | 0.04 | 0.9 | <0.01 | 0.028 | 0.002 | 0.64 | <0.05 | 0.383 | -19.3 | -147 | 6.9 |
| AN-C.2 | -- | 0.12 | 0.11 | 0.08 | 0.06 | 0.97 | <0.01 | 0.031 | 0.008 | 0.74 | <0.05 | 0.373 | -19.0 | -148 | 4.2 |
| (MR) Madison Range | | | | | | | | | | | | | | | |
| MR-WC | -- | -- | 0.017 | <0.05 | 0.09 | 17.7 | <0.01 | 0.067 | <0.002 | 0.28 | <0.05 | 0.041 | -20.2 | -146 | 15.4 |

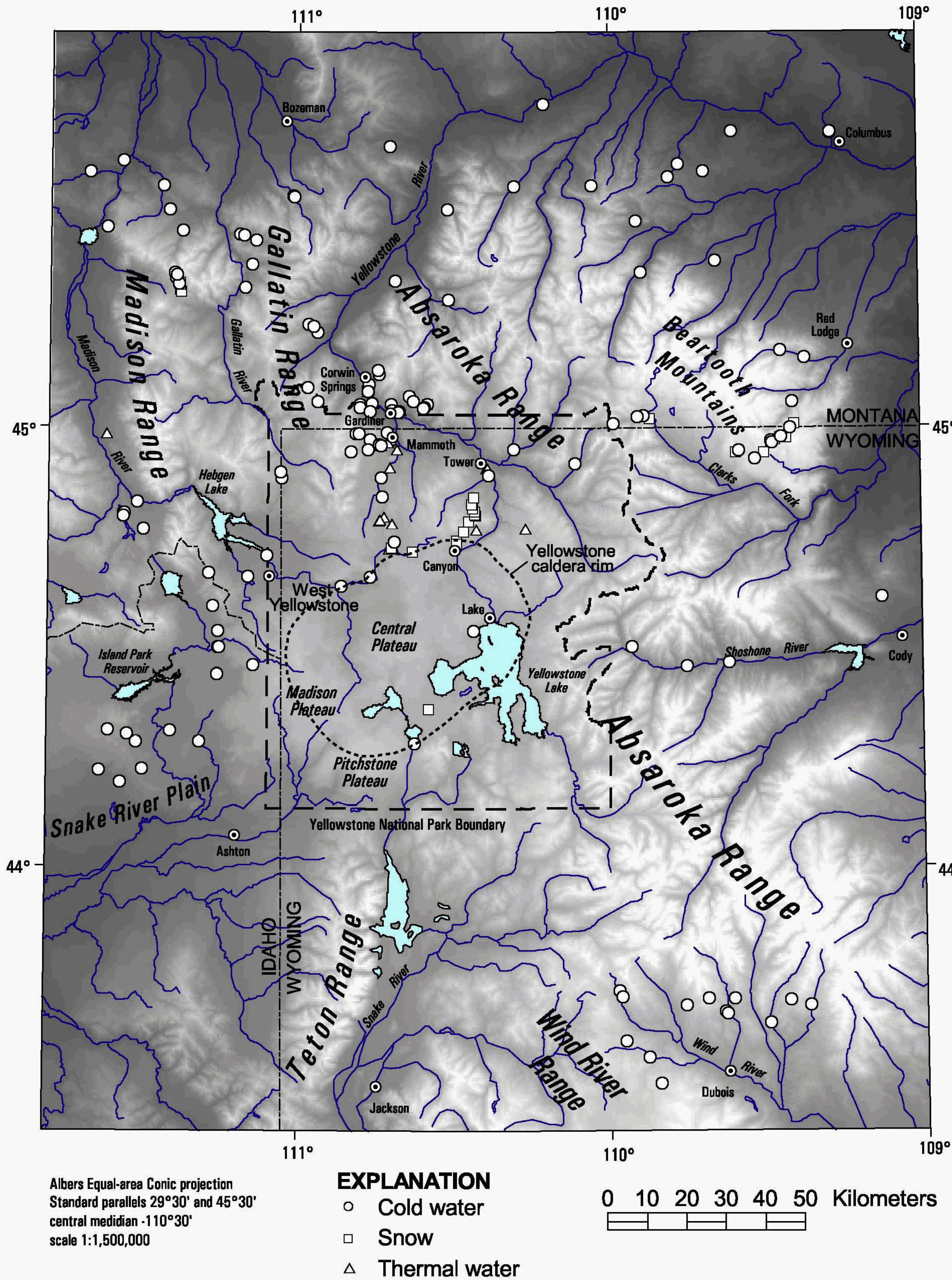


Figure 1. Location of sampling sites for cold water, snow, and thermal water, in the greater Yellowstone National Park area.

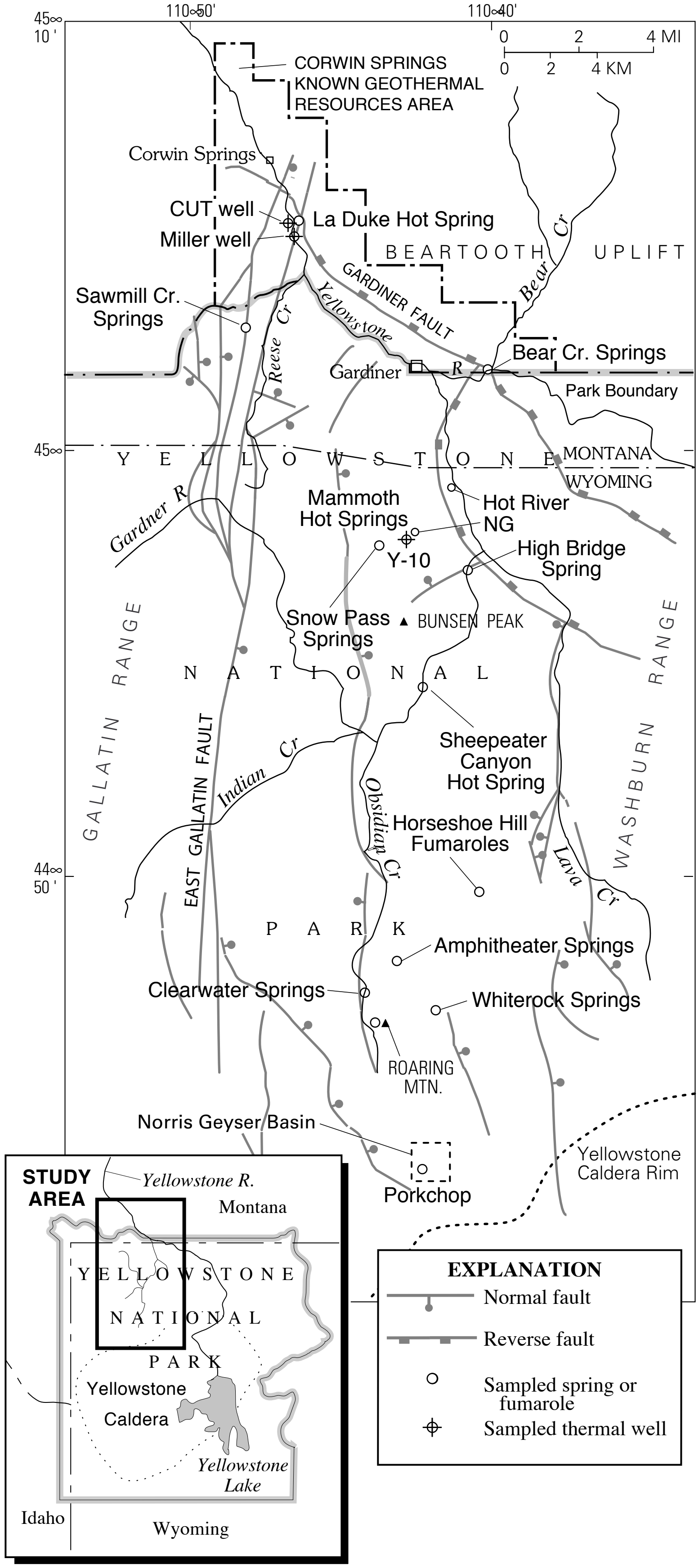


Figure 2. Regional setting for the Norris-Mammoth corridor that extends from Yellowstone caldera through Mammoth Hot Springs to Corwin Springs Known Geothermal Resources Area. The thermal springs, including Narrow Gauge spring (NG) and wells, including Y-10 sampled are indicated (modified from Kharaka and others, 1991).

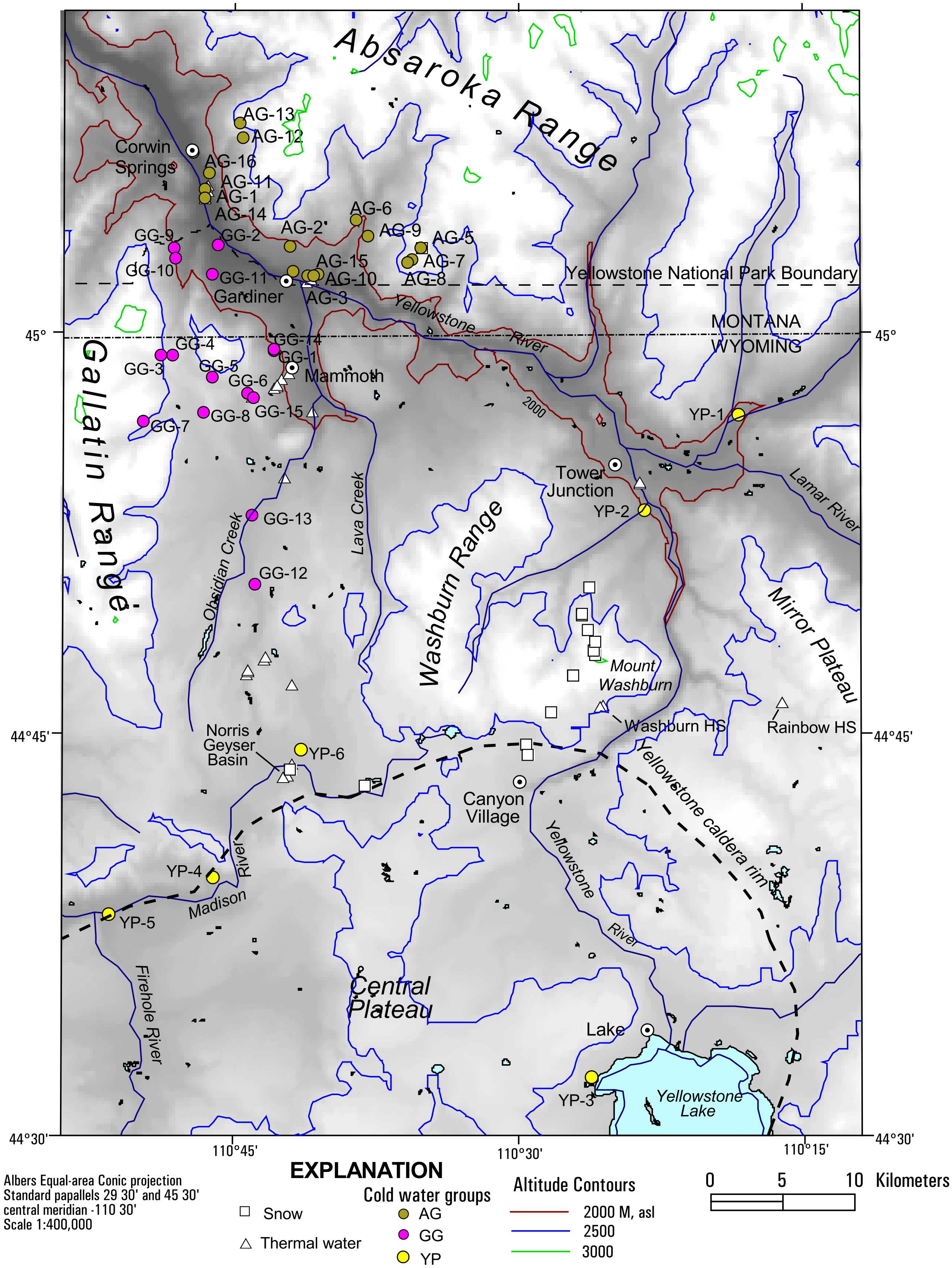


Figure 3. Location of sampling sites for cold water (groups AG, GG, and YP), snow and thermal water in the Gardiner-Mammoth area and northern portion of Yellowstone National Park.

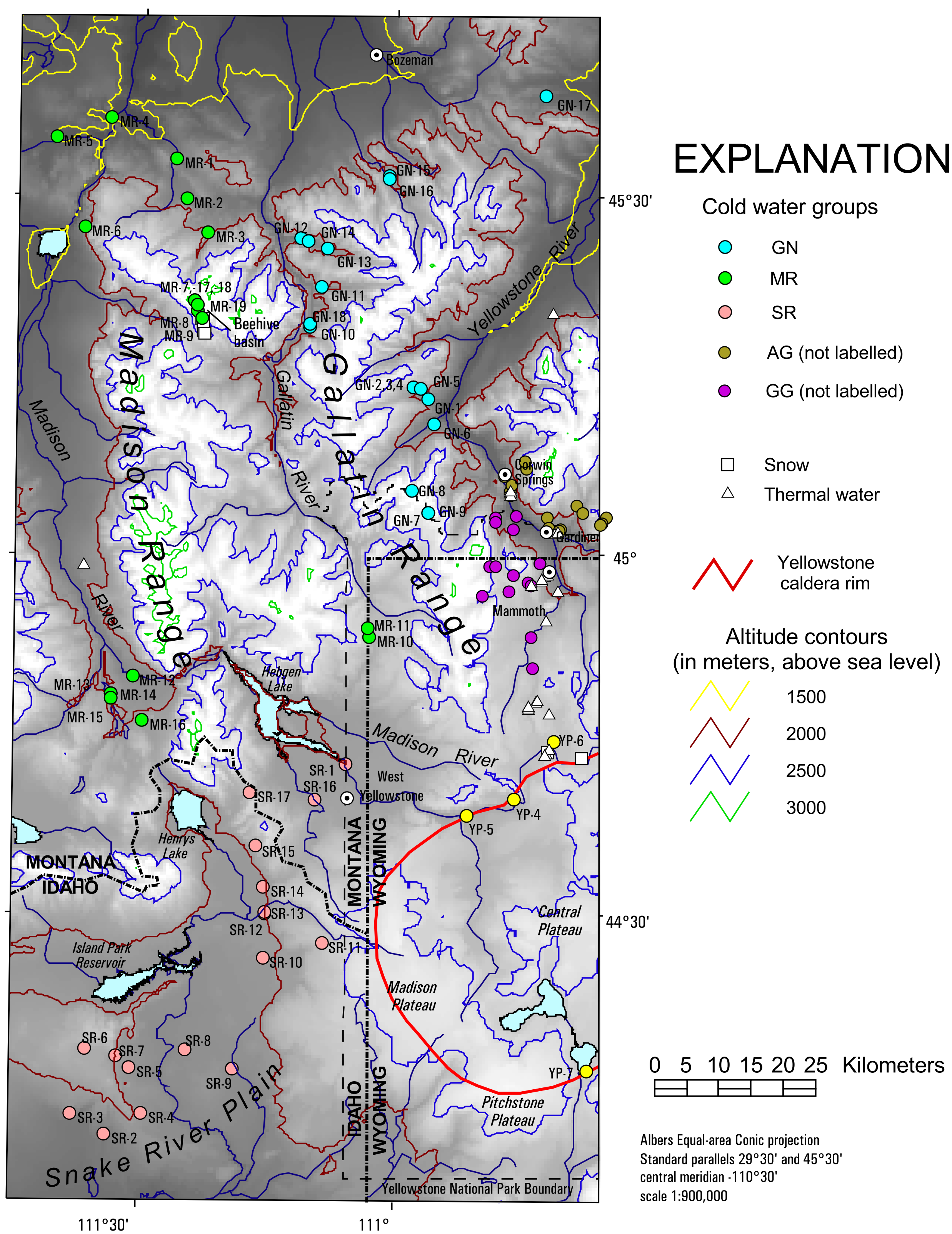


Figure 4. Location of sampling sites for cold water (groups GN, MR, SR, and YP), snow, and thermal water in the western portion of the study area (Gallatin Range, Madison Range, Snake River Plain and Yellowstone volcanic plateaus).

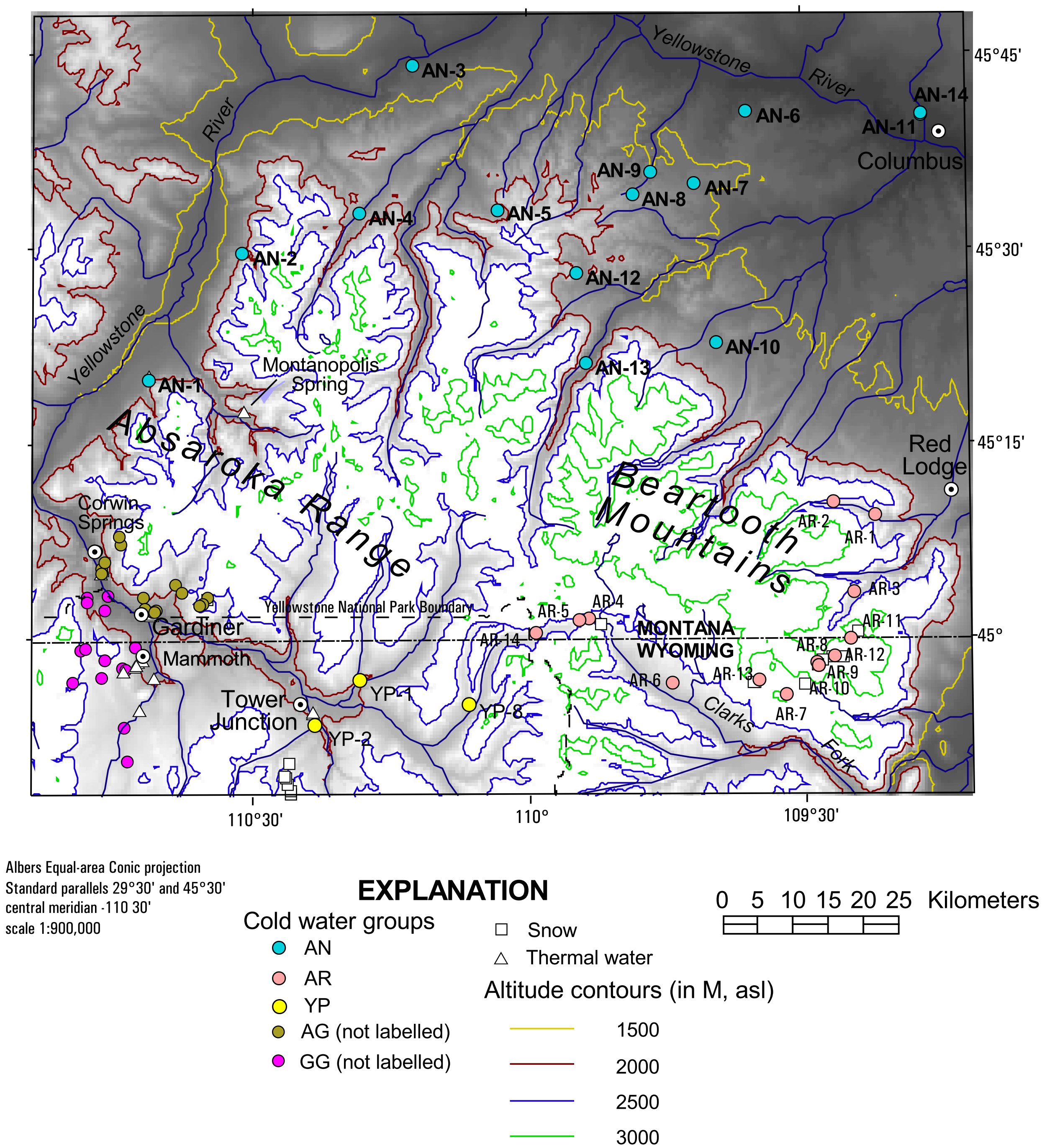


Figure 5. Location of sampling sites for cold water (groups AN, AR, and YP), snow, and thermal water in the northeast portion of the study area.

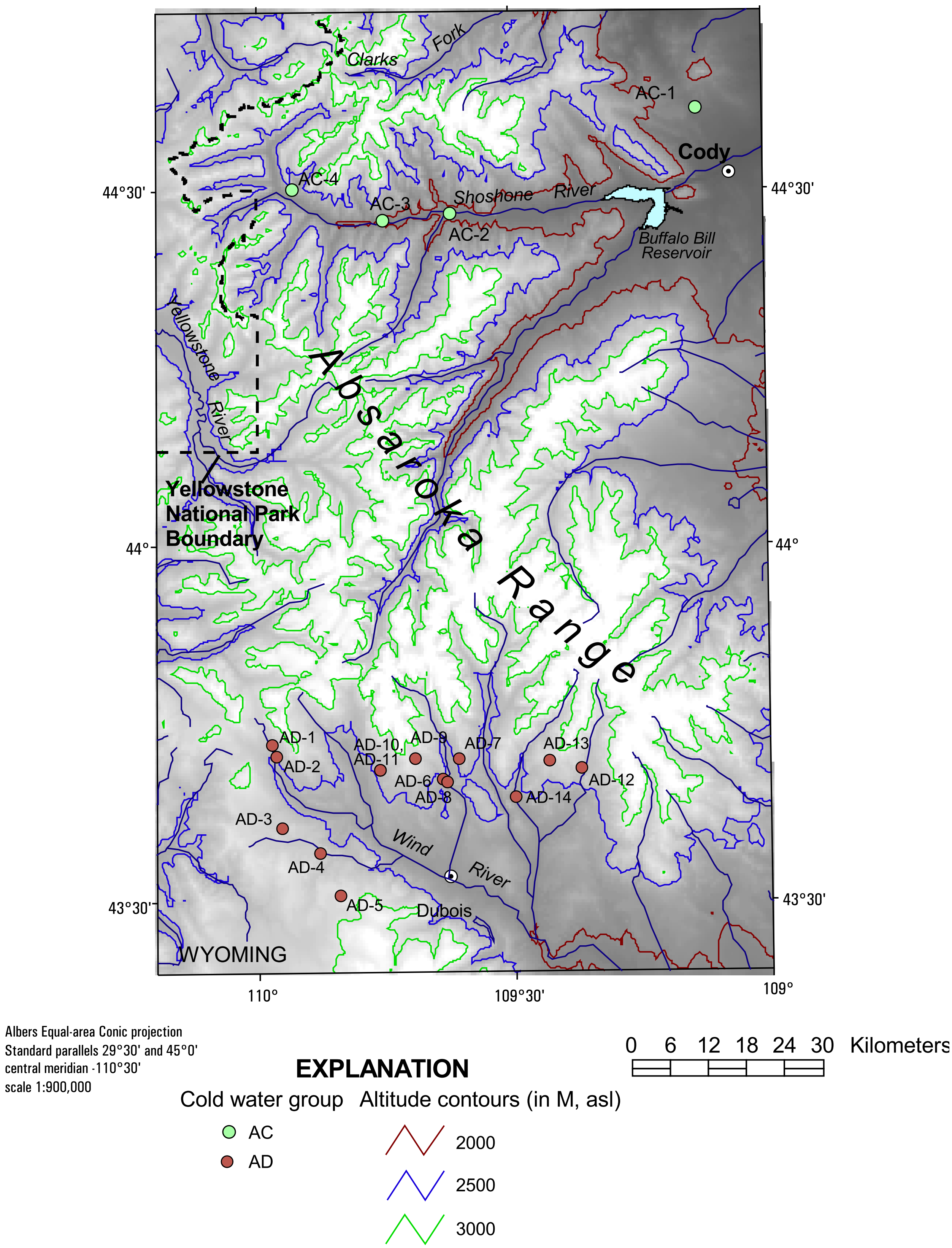


Figure 6. Location of sampling sites for cold water groups AC and AD, in the southeast portion of the study area.

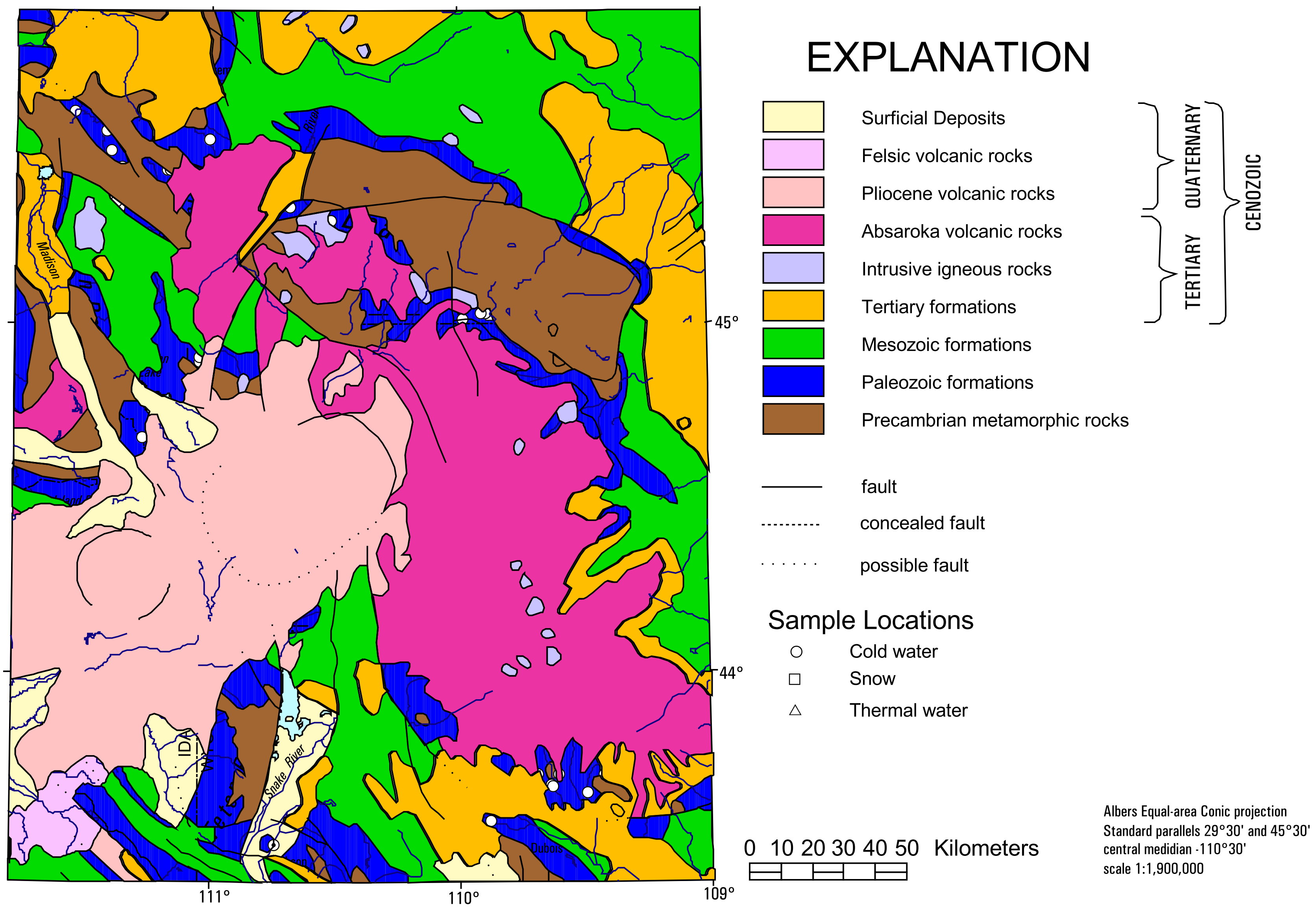


Figure 7. Generalized geologic map of the greater Yellowstone National Park area. Modified from digital representation of the 1974 King-Biekman map by Schruben et al.(1997).

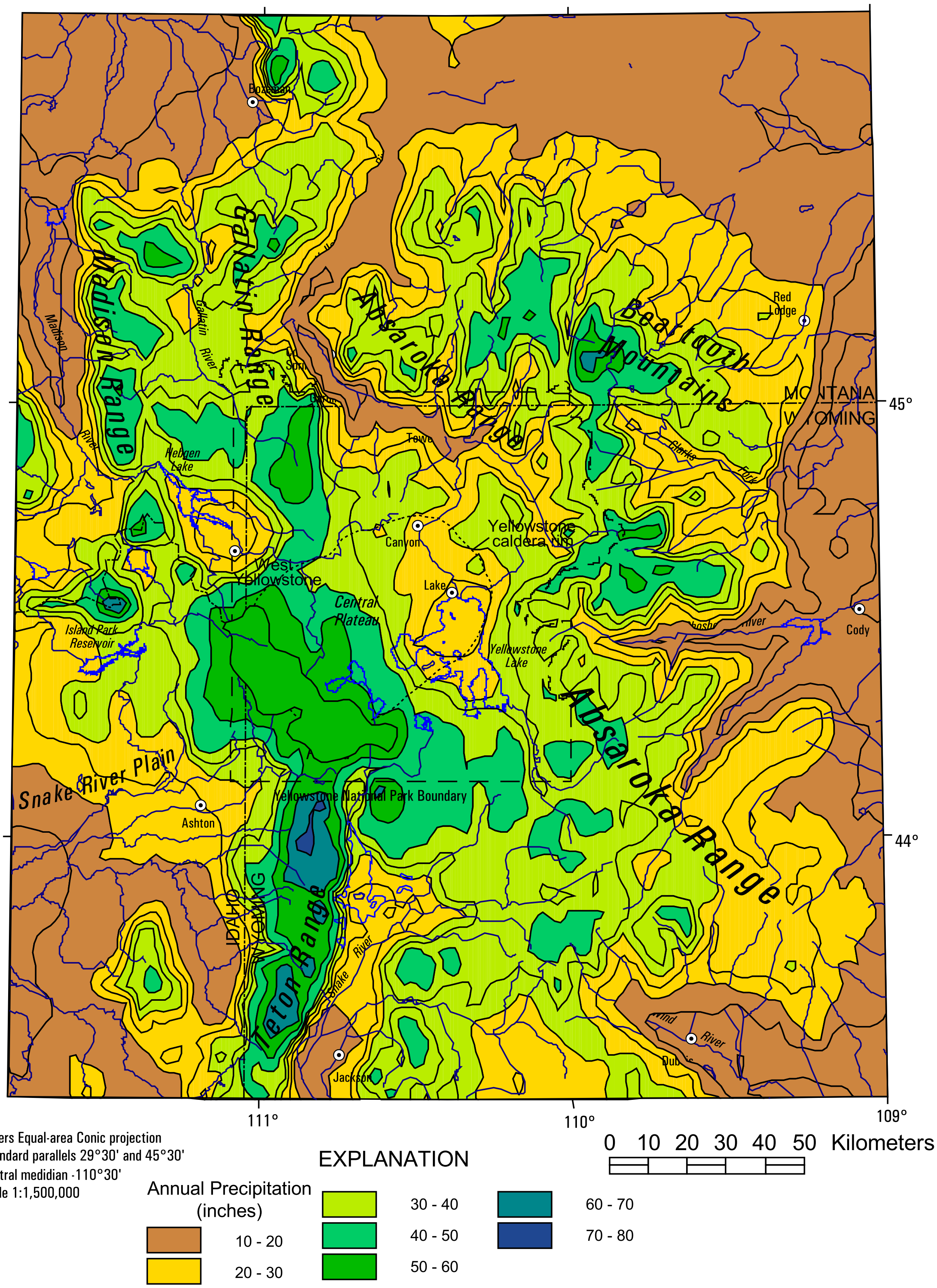


Figure 8. Mean annual precipitation for the greater Yellowstone National Park area (National Atlas, 2002).

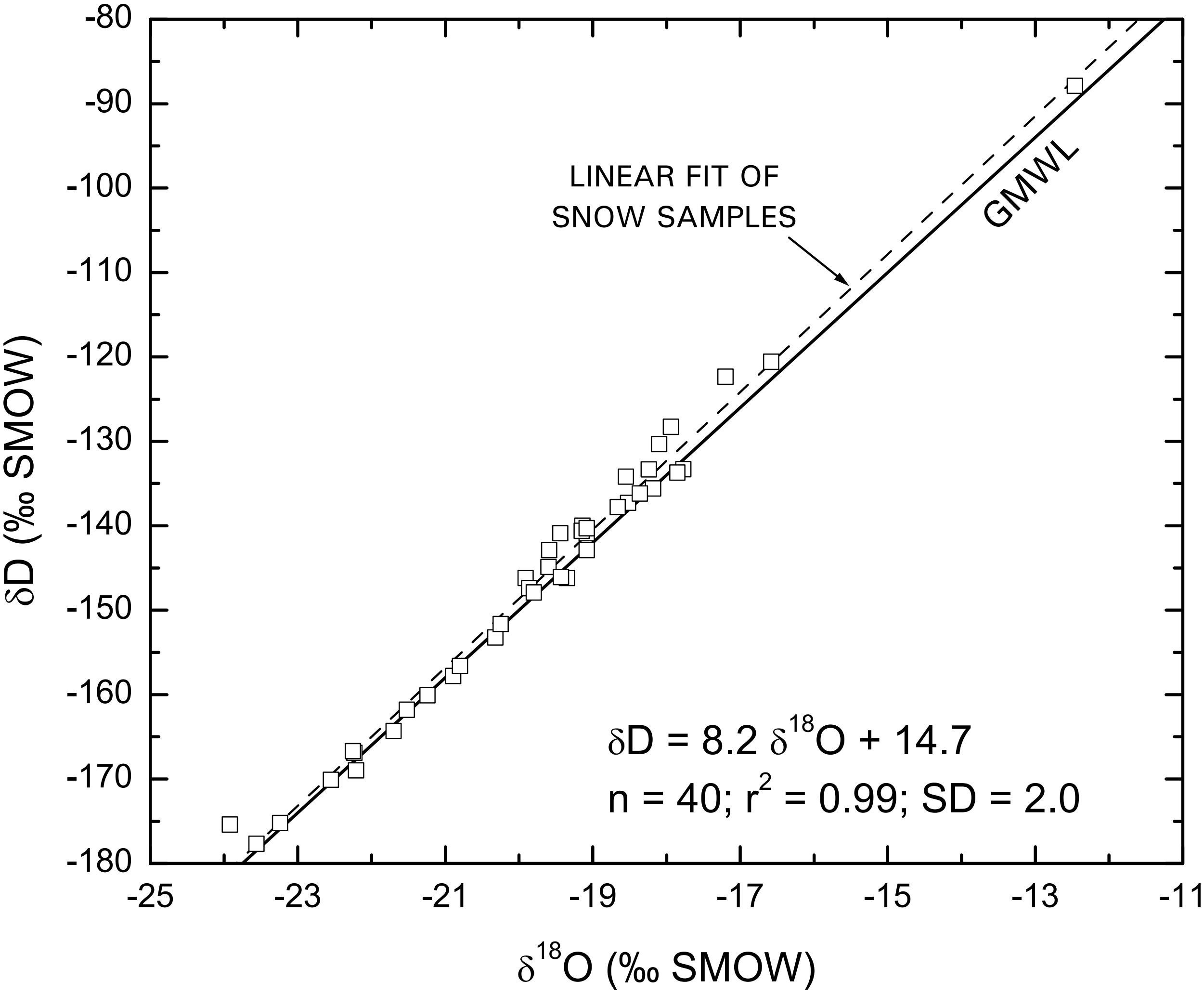


Figure 9. The stable isotope composition of 40 snow samples collected from the study area and their resultant Local Meteoric Water Line (LMWL) of $\delta D = 8.2\ \delta^{18}O + 14.7$, which approximates the GMWL.

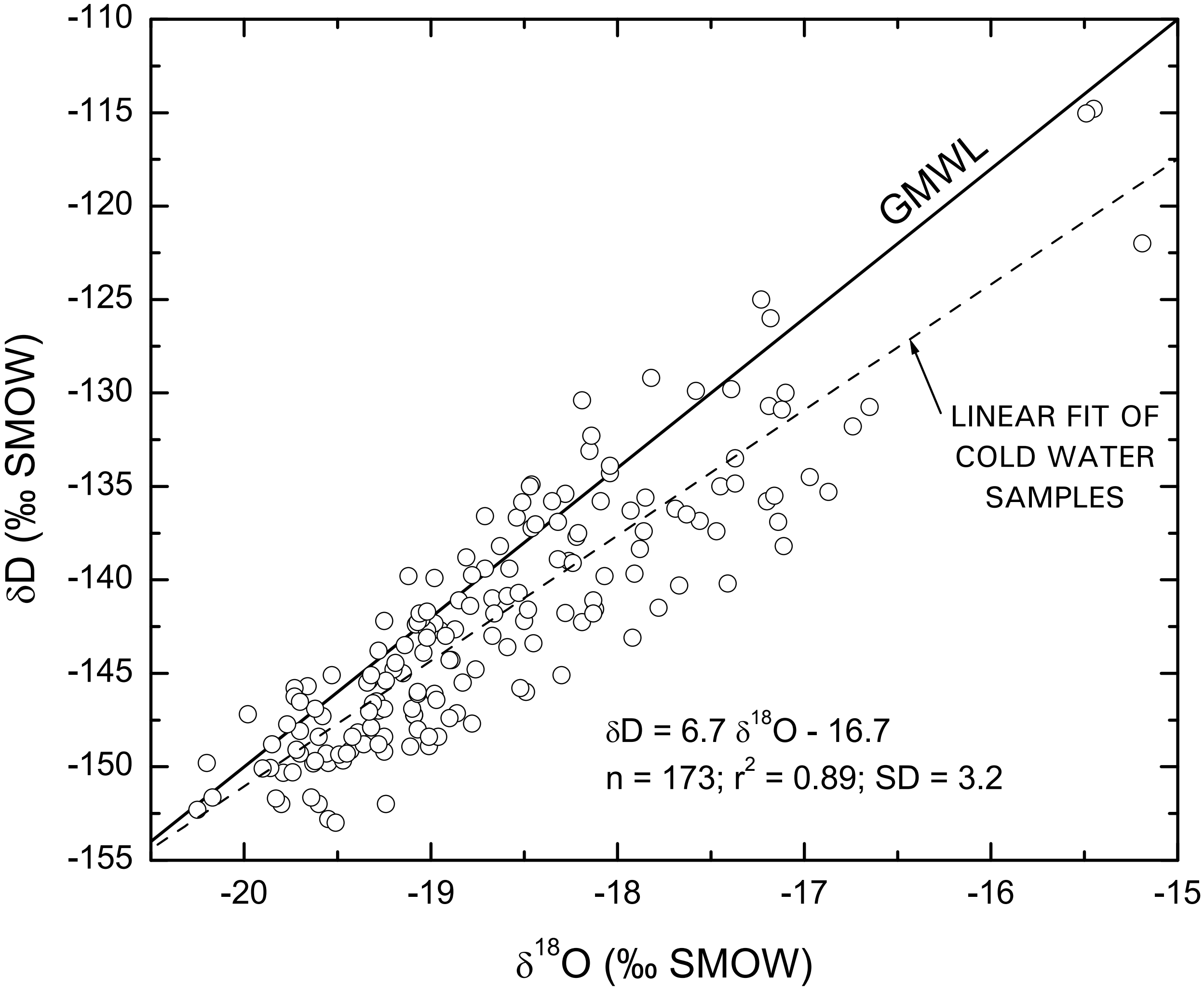


Figure 10. The stable isotope composition of cold-water samples collected in the study area. Note the departure of the linear fit from the GMWL, especially in samples with heavy isotopes.

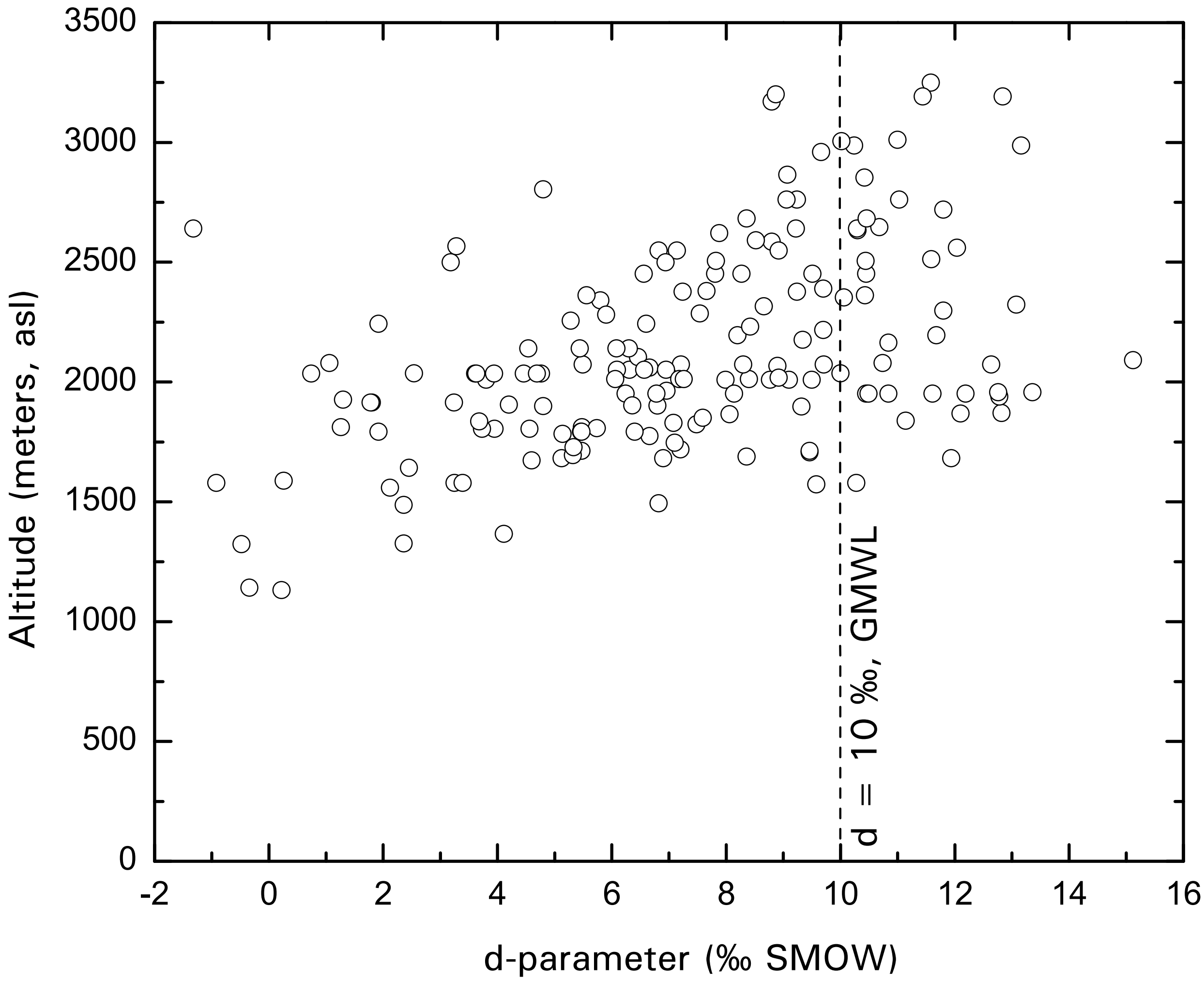


Figure 11. Variation of *d*-parameter (see text) with altitude for the cold water samples. Note that the samples with *d*-parameter values <5, indicating significant evaporation, are mainly from low altitude areas.

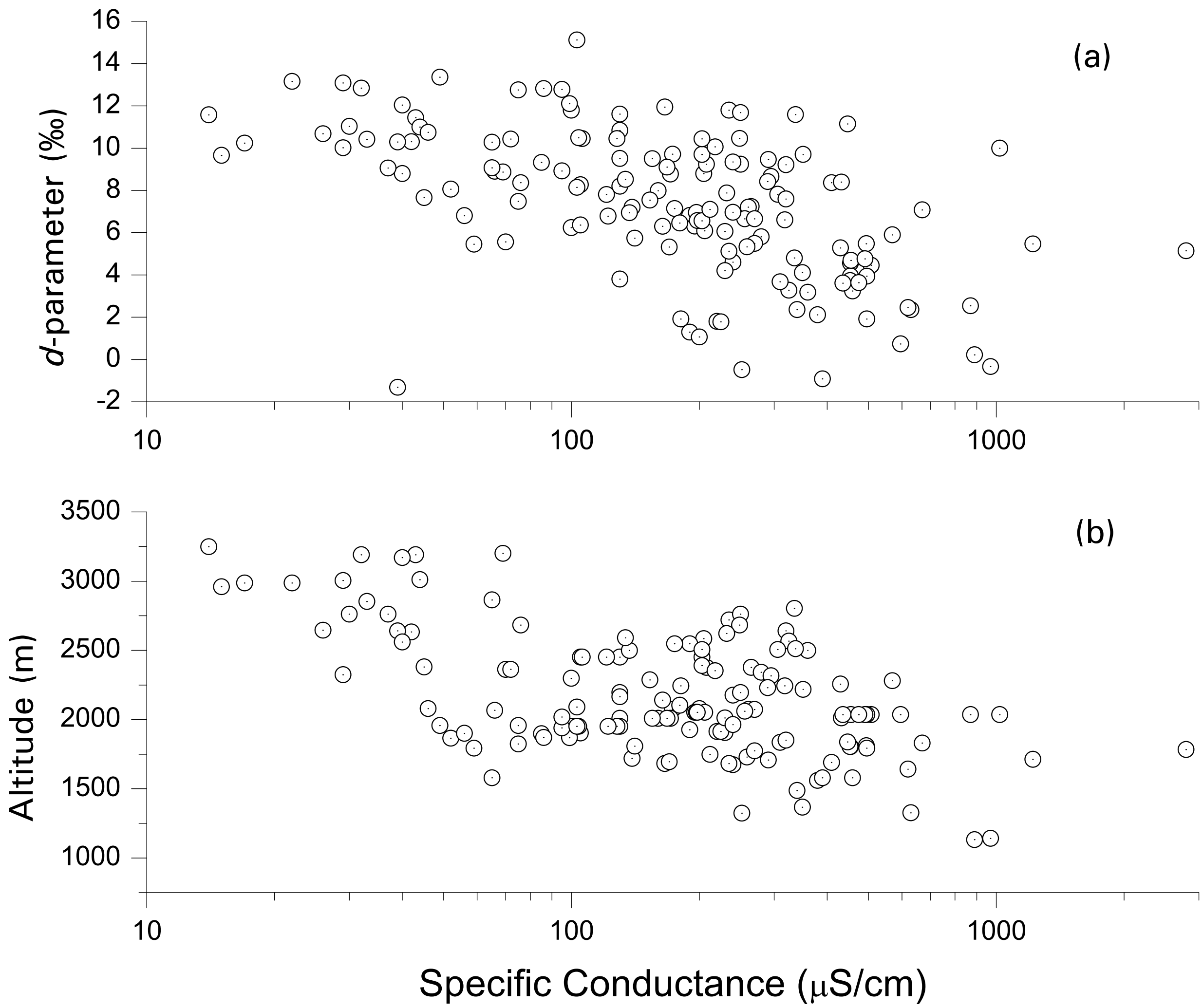


Figure 12. Scatter plot of *d*-parameter (a) and altitude (b) vs. specific conductance (log scale) for cold water samples.

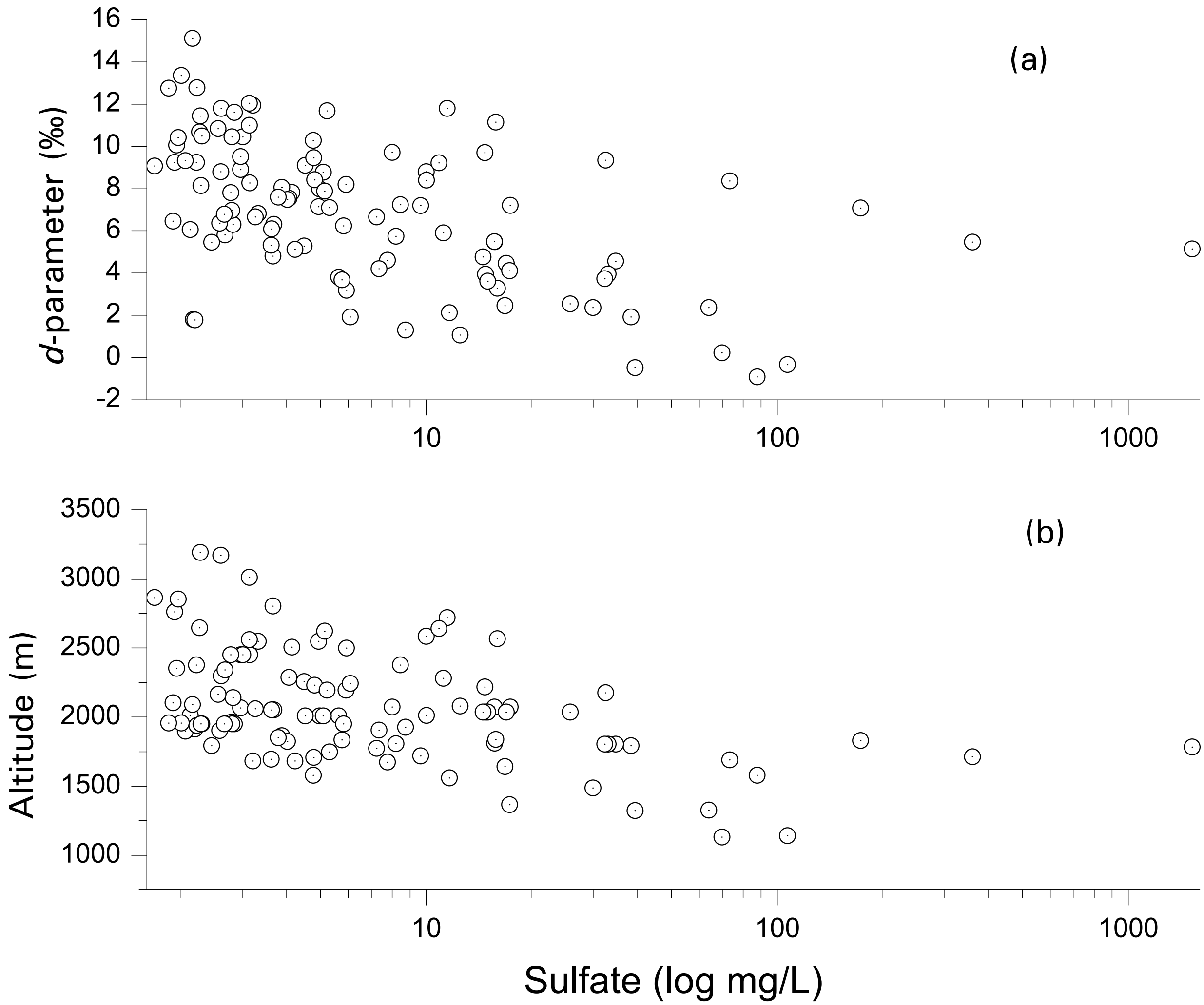


Figure 13. Scatter plot of *d*-parameter (a) and altitude (b) vs sulfate concentrations (log scale) for cold water samples.

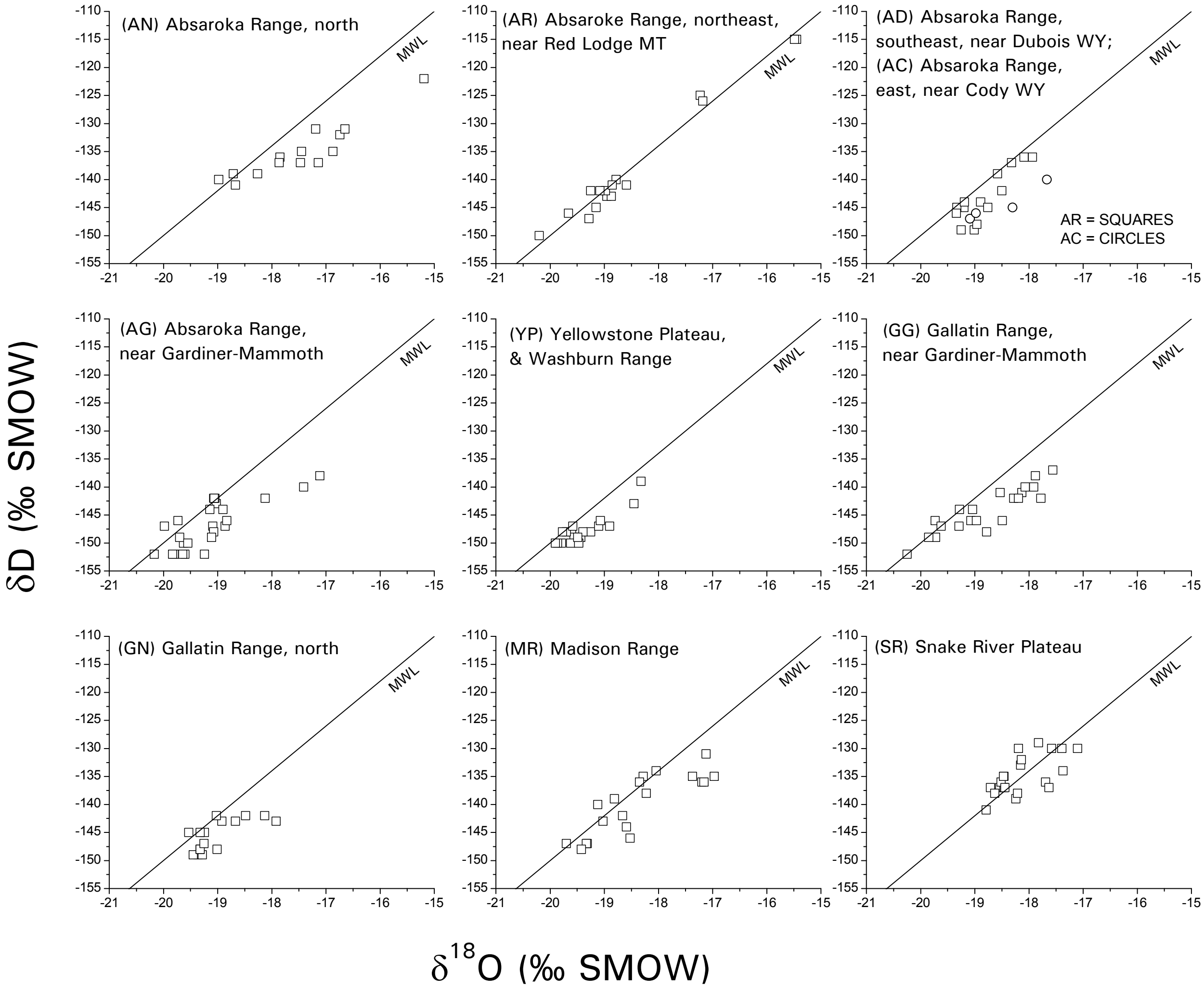


Figure 14. The stable isotope composition for cold-water samples obtained from the nine (AD and AC samples are plotted together in top right) from geographic/physiographic regions.

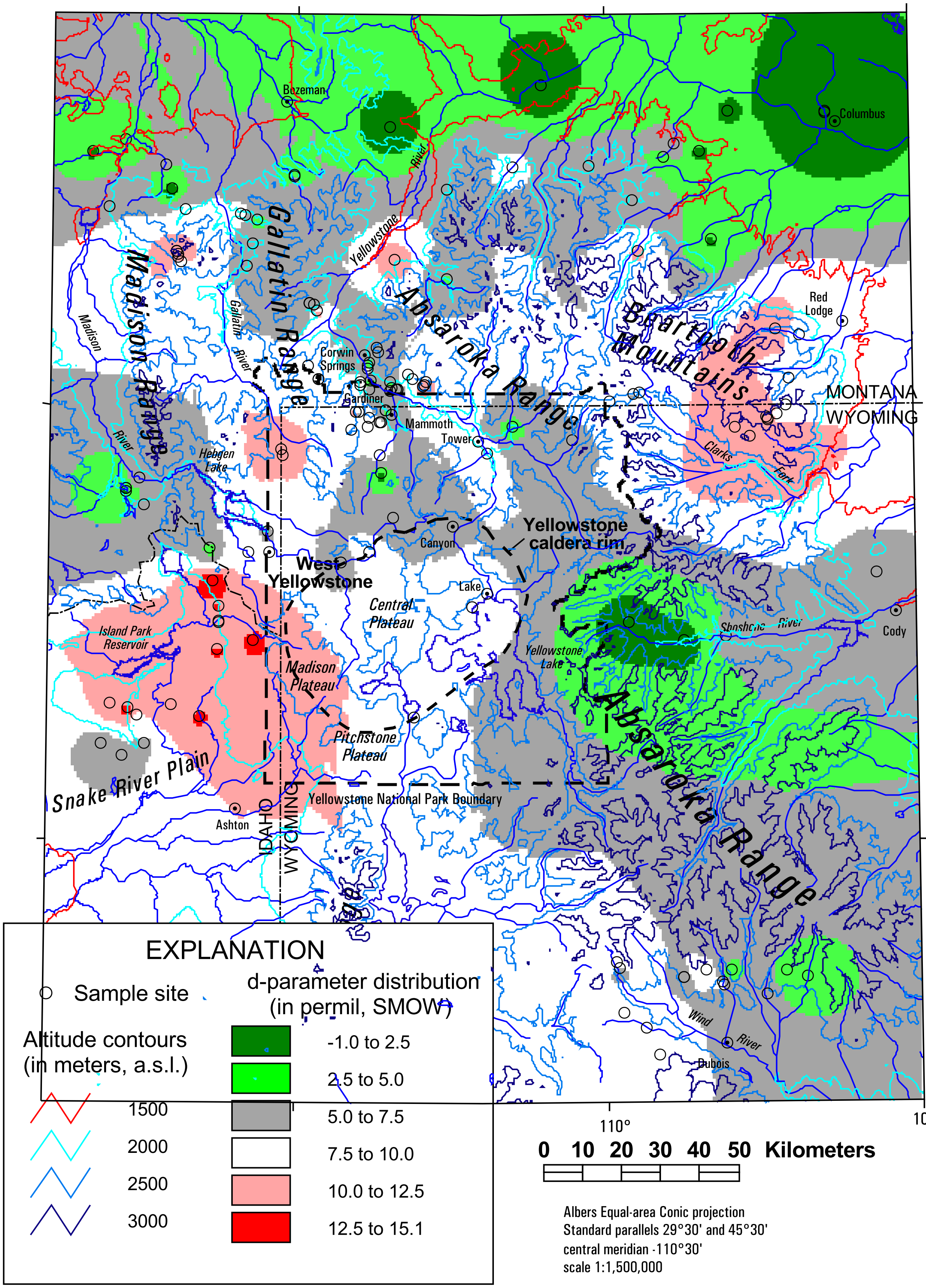


Figure 15. d-parameter distribution for cold waters in the study area.

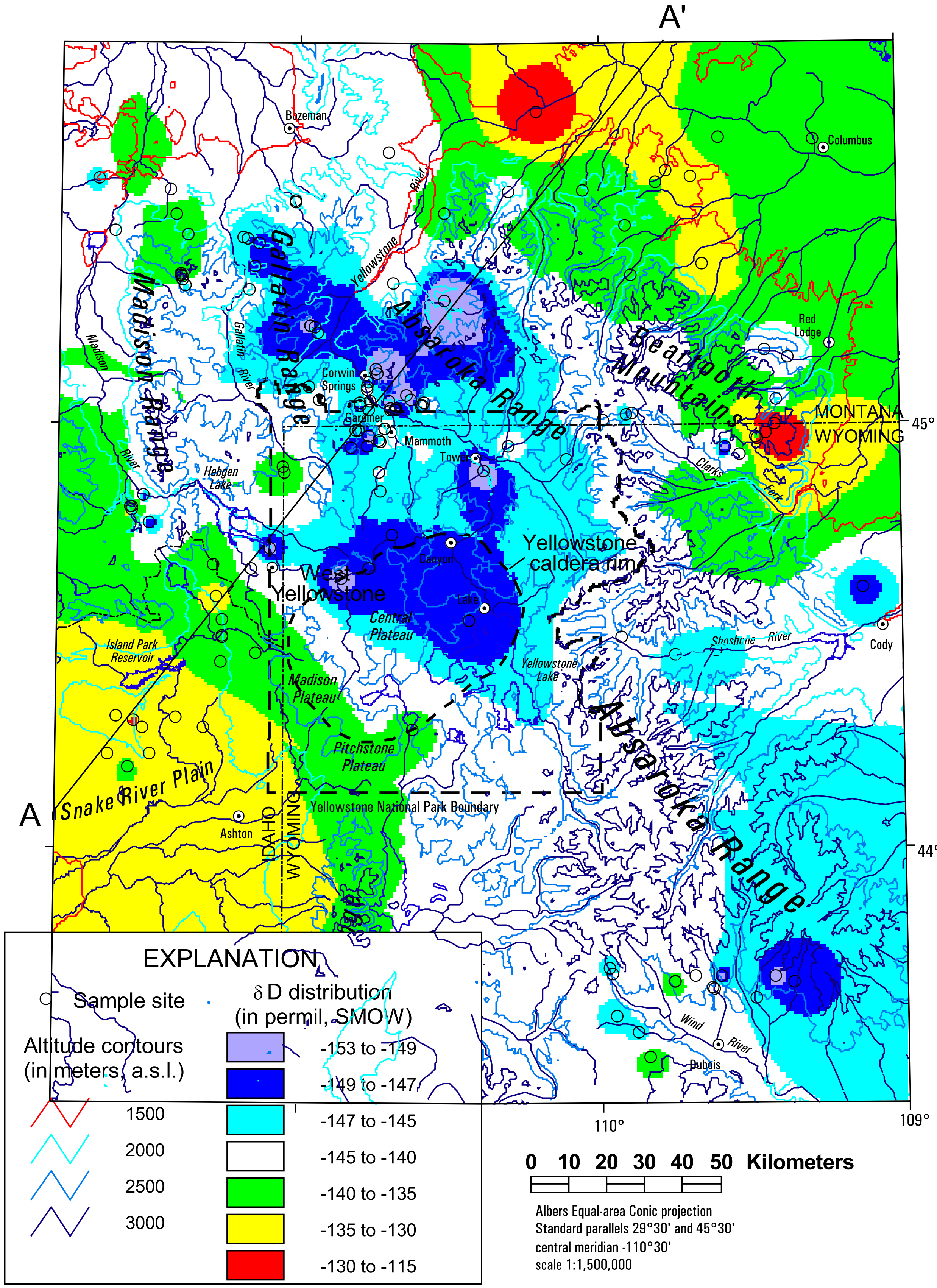


Figure 16. δD distribution for cold waters in the study area. Line A-A' is traverse in figure 19.

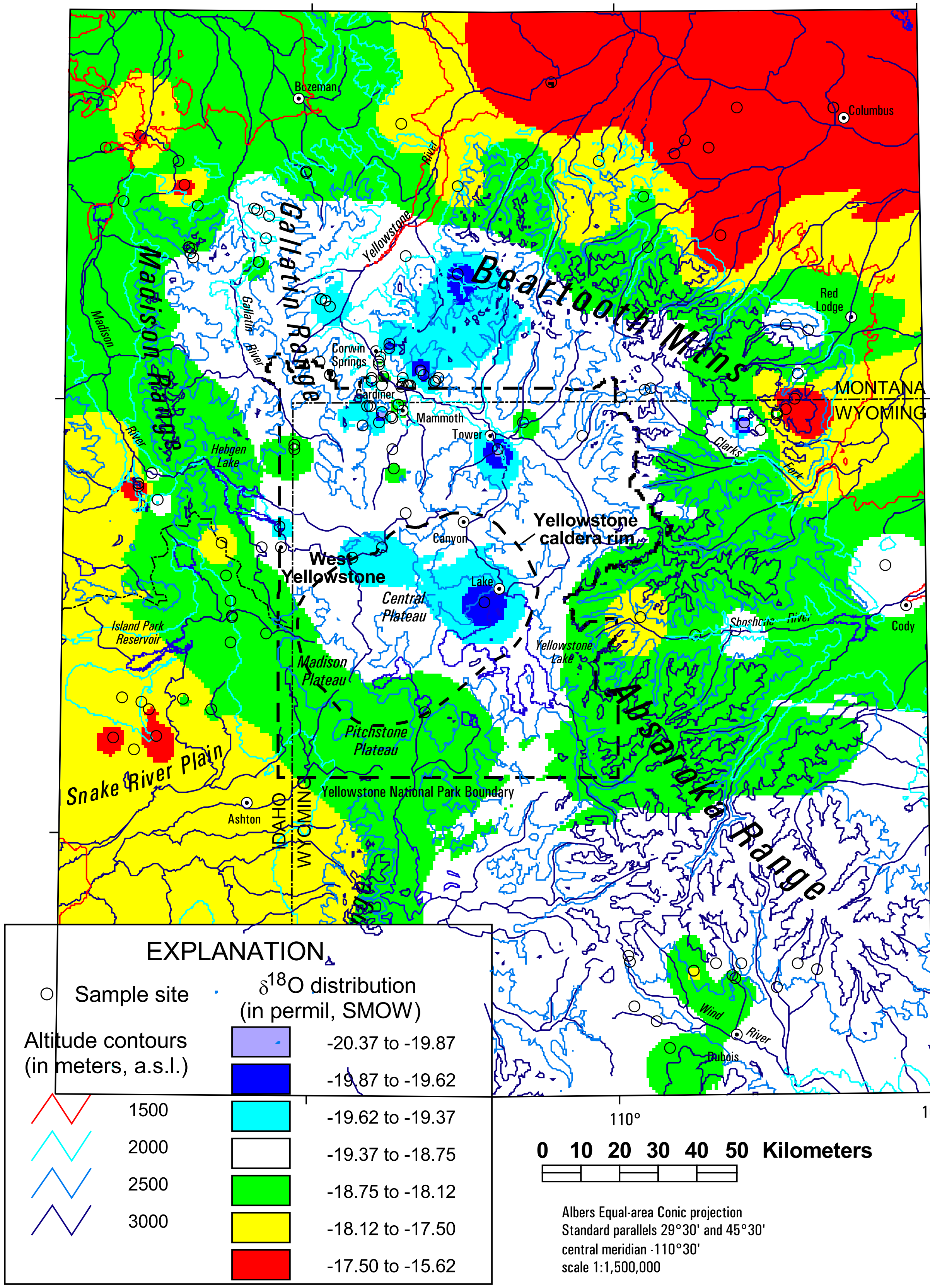


Figure 17. $\delta^{18}O$ distribution for cold waters in the study area.

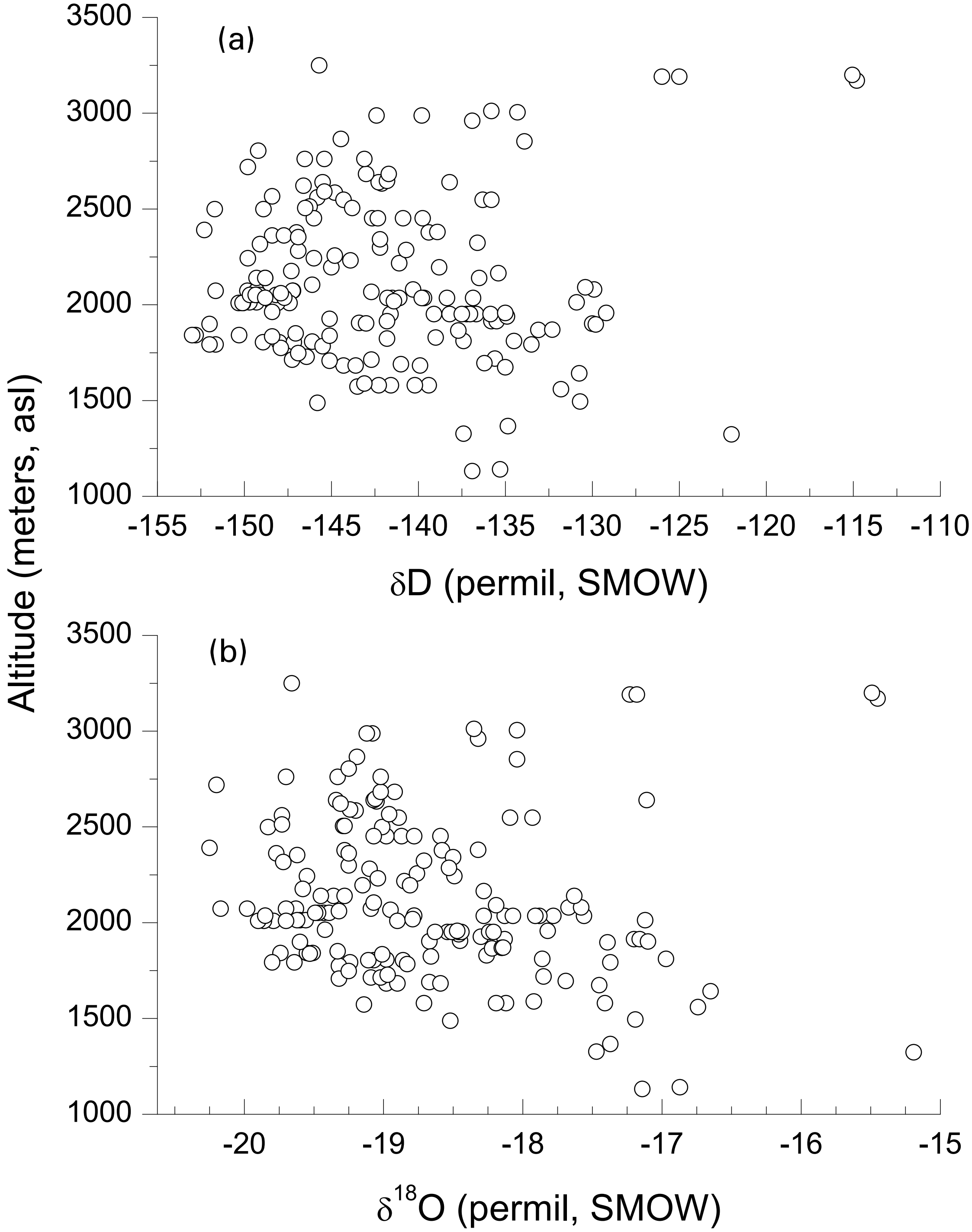


Figure 18. Scatter plot of altitude vs. δD and $\delta^{18}$O values for cold-water samples in the study area. Note the large scatter in the data points indicating complex relationship between altitude and water isotopes.

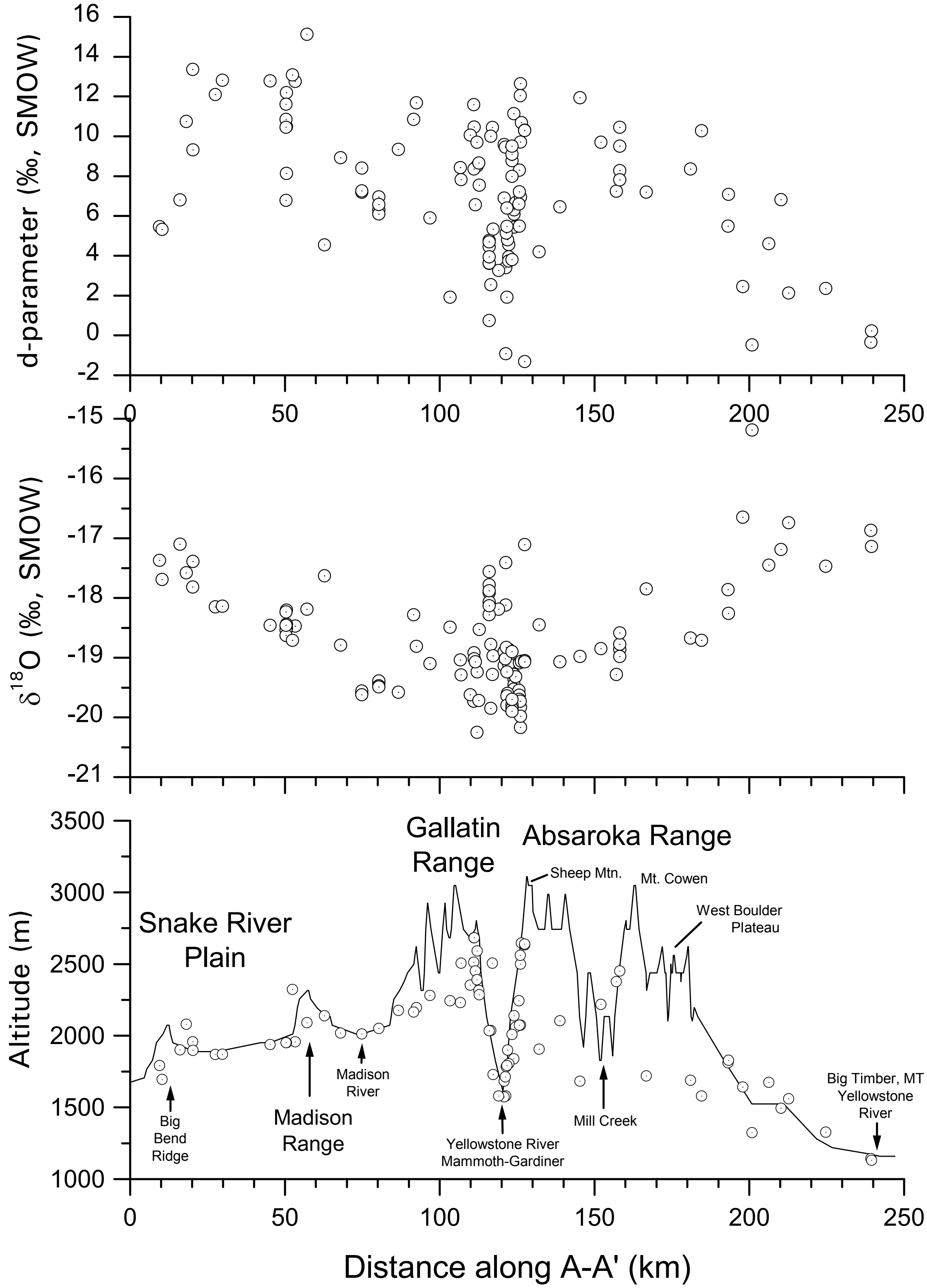


Figure 19. Cross section through study area showing altitude of sample sites, and δD and *d*-parameter values of cold-water samples vs. distance along line A-A' (fig. 16).

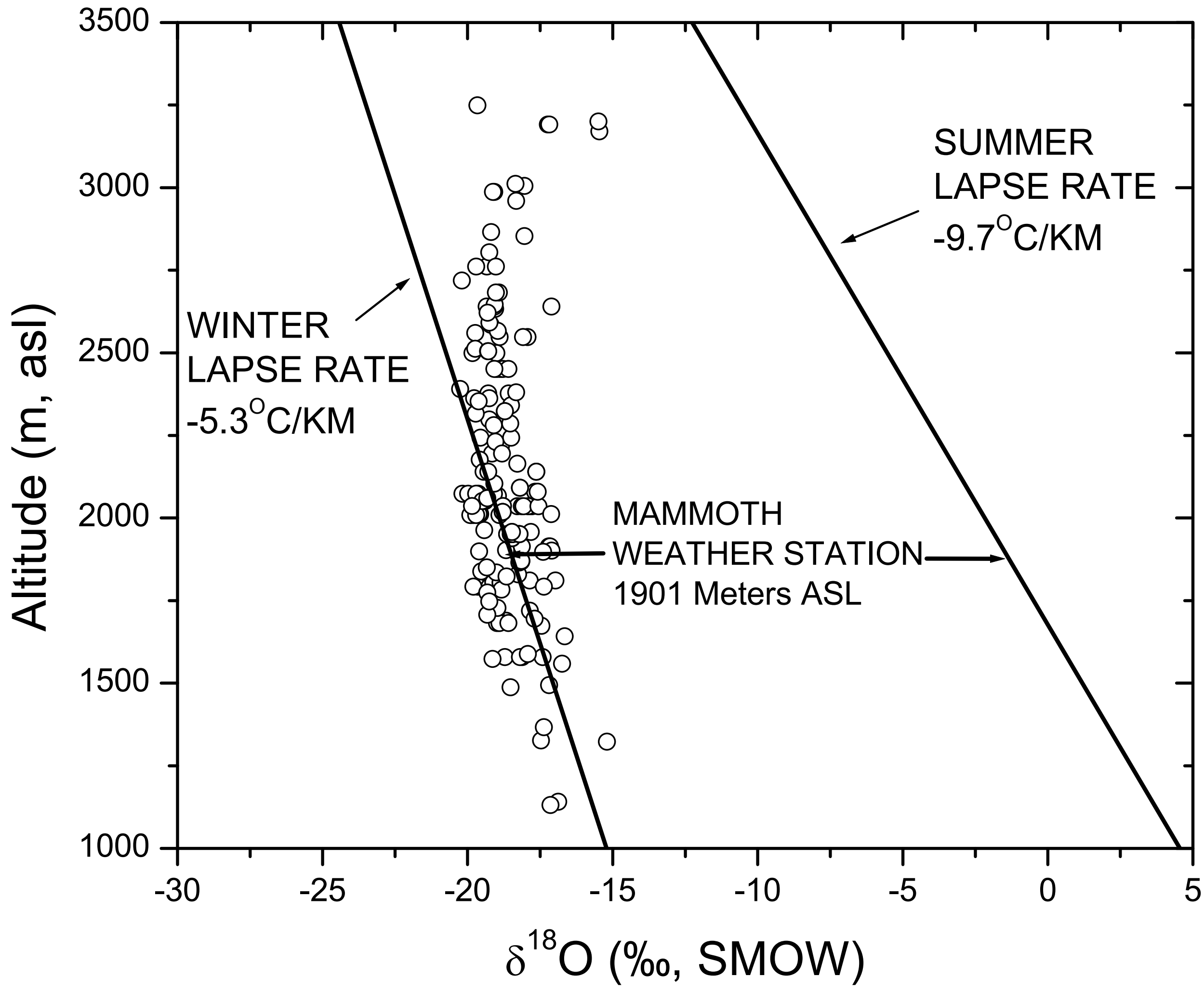


Figure 20. Scatter plot of altitude vs. $\delta^{18}O$ values for cold-water samples in the study area, compared to the predicted $\delta^{18}O$ values for winter and summer conditions at (see text for full explanation) Mammoth weather station (modified from Thordsen and others, 1992).

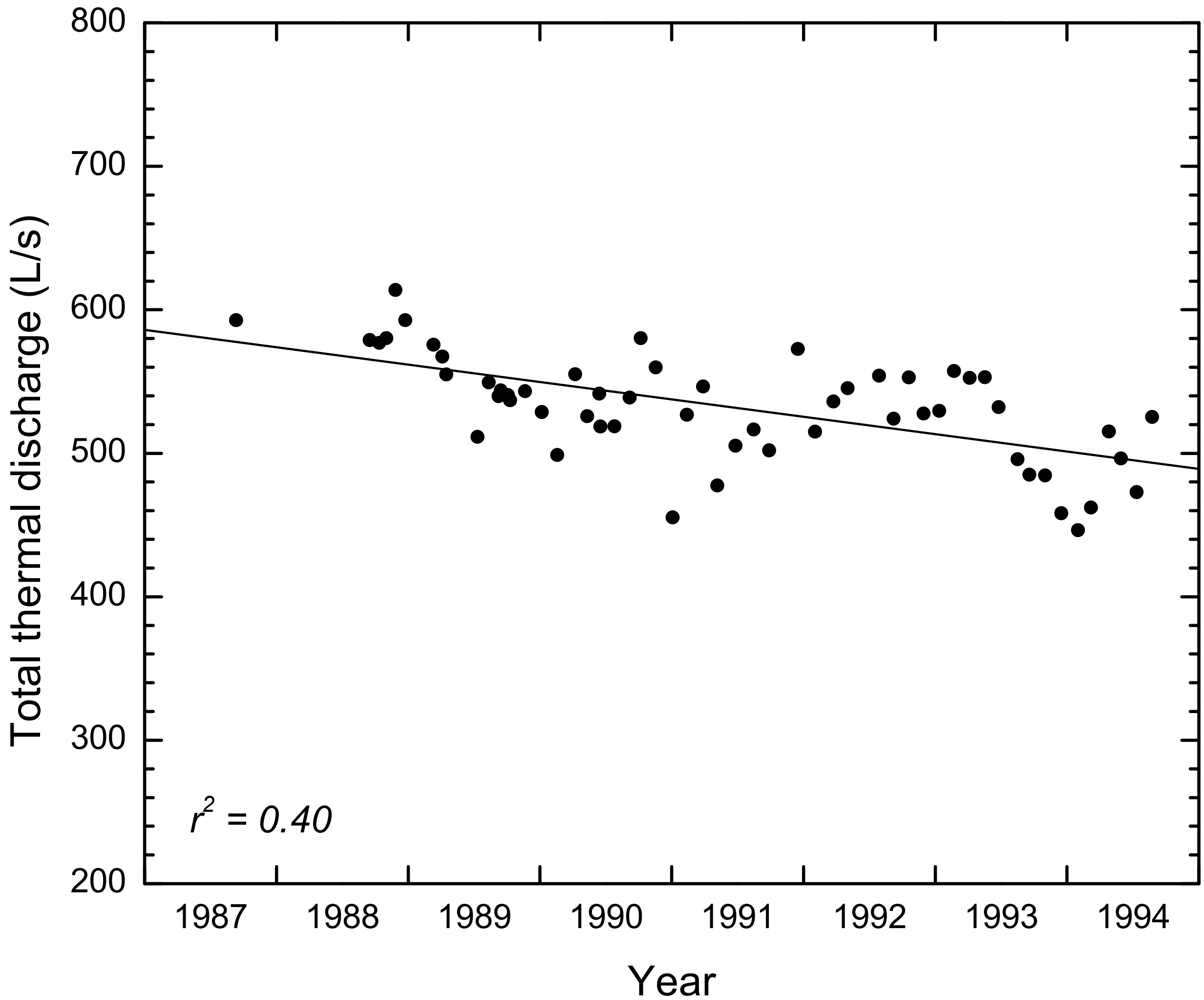


Figure 21. Total thermal water discharges from the Mammoth Hot Springs system for 1987-1994 (from Kharaka and others, 2000).

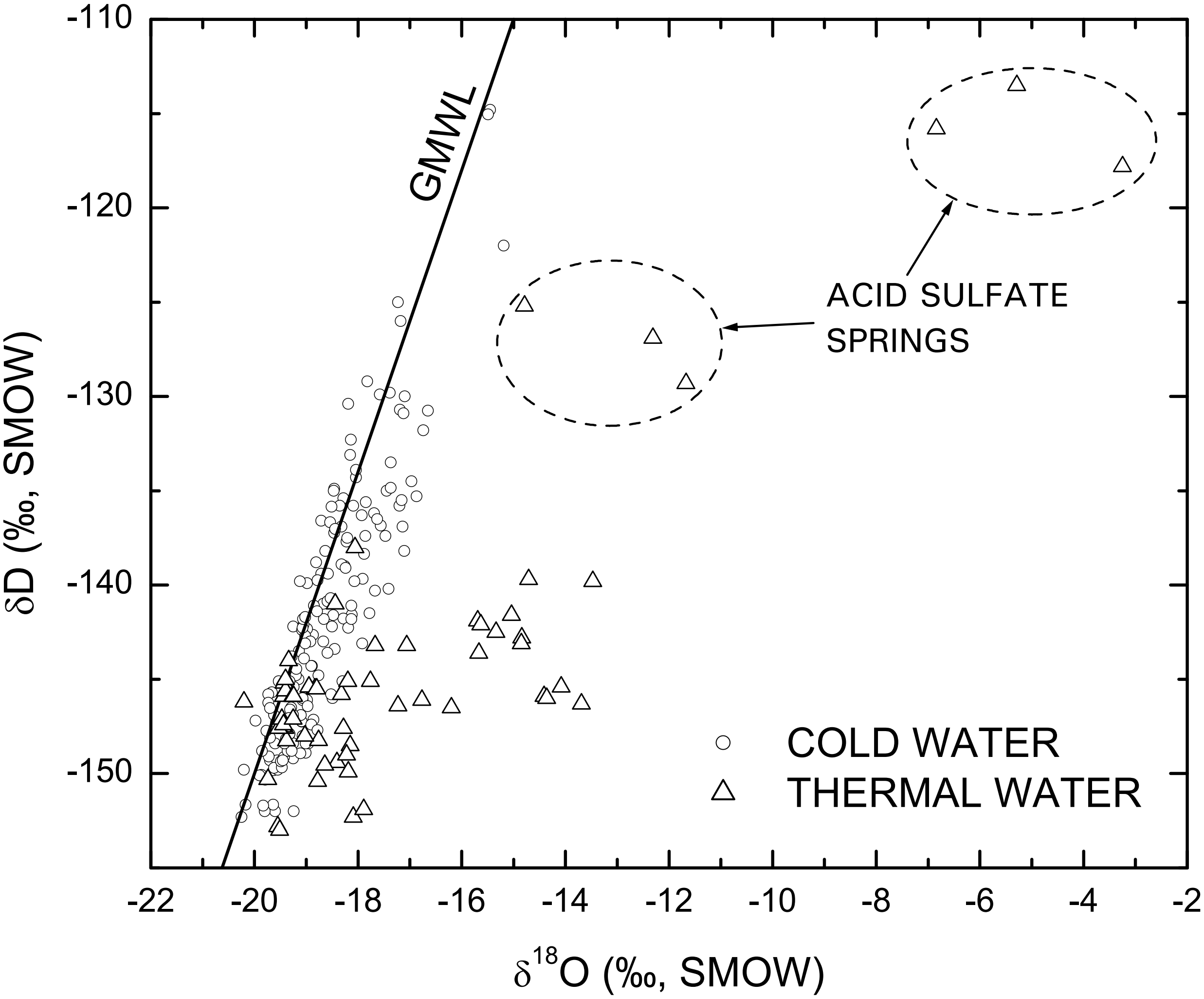


Figure 22. Scatter plot of δD vs. $\delta^{18}$O values for thermal- and cold-water samples in the study area. Samples from acid sulfate springs controlled by boiling and condensation are delineated.

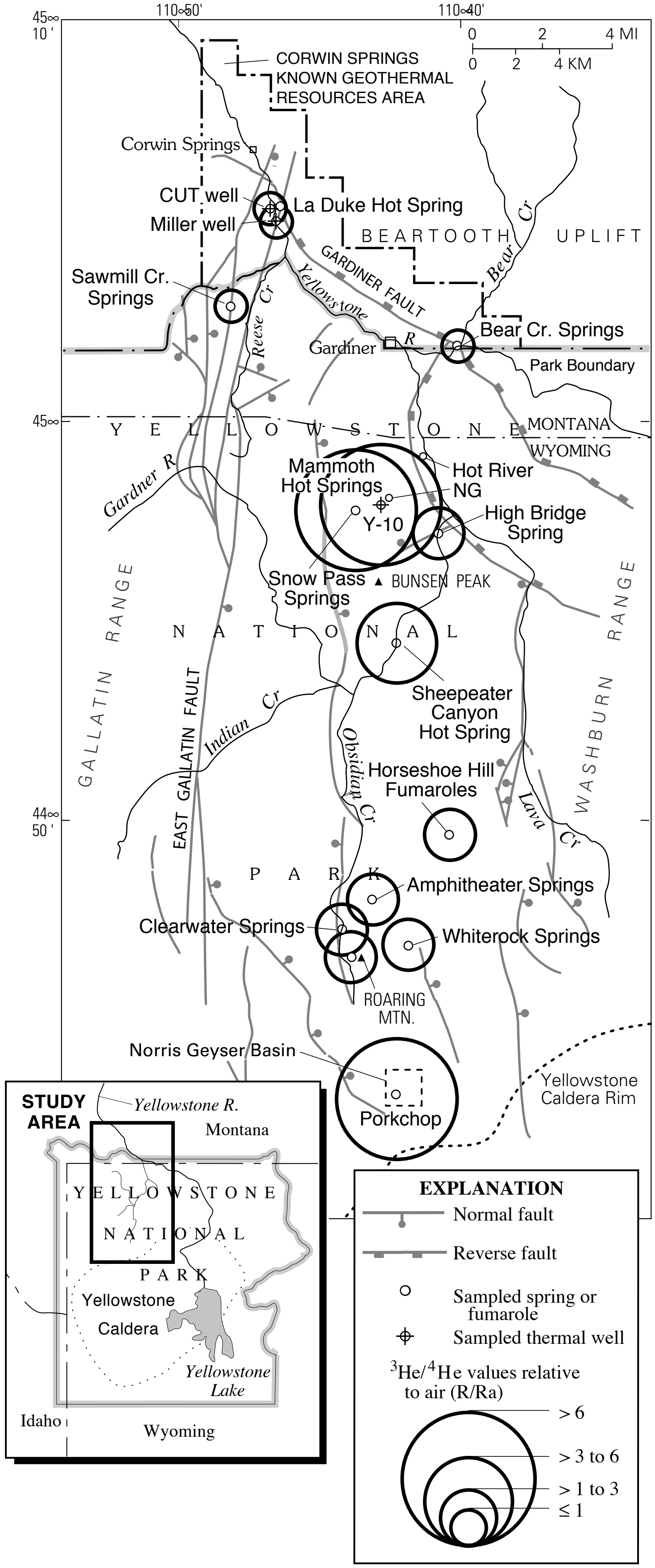


Figure 23. Distribution of the 3He/4He values relative to air (R/Ra) in thermal fluids from the Norris-Mammoth corridor. Note the high values for the Mammoth system and Norris Geyser Basin and the relatively low values in the intervening thermal areas (from Kharaka and others, 2000).