Thermophilic Microorganism Survey

Yellowstone National Park

Yellowstone Center for Resources
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Cover photo: Photomicrograph of the pink filament community, Octopus Springs, Yellowstone National Park. Courtesy of Anna-Louise Reysenbach, Indiana University.

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Thermophilic Microorganism Survey

This survey contains a summary of each thermophilic species known to be found in Yellowstone National Park, including a description of the microorganism, its habitat, where it can be found, and any known biotechnological application.

Species Included

Achanthes exiguia
Acidothermus cellulolyticus
Alicyclobacillus acidocaldarius
Anaerobranca horikoshii
Archaeglobus spp.
Bacillus sp.
Bacillus coagulans
Calothrix sp.
Chloroflexus aurantiacus
Chromatium tepidum
Clostridium thermoautotrophicum
EM3, EM17, and EM19 (pink filament community)
Heliobacterium modesticaldum
Mastigocladus laminosus
Methanobacterium thermoautotrophicum
pJp27
Rhodopila globiformis
Synechoccus sp.
Sulfolobus acidocaldarius
Thermoanaerobacter brockii
Thermoanaerobacter ethanolicus
Thermoanaerobacterium thermosulfurigenes
Thermoanaerobacterium xylanolyticum
Thermobacteroides acetoethylicus
Thermodesulfobacterium commune
Thermofilum spp.
Thermoleophilum album
Thermoleophilum minutum
Thermomicrobium roseum
Thermoplasma acidophilium
Thermoplasma volcanium
Thermosphaera aggregans
Thermothrix thiopara
Thermus aquaticus
Thiobacillus thiooxidans

The above list does not represent a complete inventory of the thermophiles that may be found in Yellowstone National Park. It includes only those species brought to our attention whose description in a scientific publication documents their presence in the Park. If you know of a Yellowstone thermophile that is not included in this publication, we encourage you to contribute to our database. See the next page for a sample reporting form. A bibliography of publications related to the Yellowstone geothermal ecosystem appears at the the end of this document.

YELLOWSTONE NATIONAL PARK
THERMOPHILIC MICROORGANISMS

Reporting Form

Scientific Name:

Description:

Habitat Type:

YNP Location:

USGS Quadrangle:

Directions:

Date First Observed:

Other Comments:

Citation: [Please include a reprint of the publication describing the organism.]

Photographs:

Specimens:

Person to Contact:

If you know of a thermophilic organism not included in this document, please contact the Yellowstone Center for Resources, P.O. Box 168, Yellowstone National Park, WY 82190, or call Bob Lindstrom at (307) 344-2234, or e-mail Bob_Lindstrom@NPS.GOV. Thank you for your cooperation.

Collection of any material from a U.S. National Park requires a research/collection permit. Information about permits is available at the preceding address and phone number.

Scientific Name:	***Achnanthes exigua***
Description:	This unialgal diatom was found mixed with flocculent sediments on the surface of a blue-green algal mat which was covered by a shallow layer of water. It reproduces at 12-hour intervals. The maximum metabolism, photosynthetic rate and respiration in this organism occur at thermal temperatures. It is a shade- adapted, phototrophic umbrophile which can also grow in highly intense lighting.
Habitat Type:	Calcium carbonate and neutral chloride Temperature range for growth: 10-44°C Optimum temperature for respiration: 40°C Optimum temperature for photosynthesis: 42°C pH: 8.5
YNP Location:	Alkaline hot spring near Old Faithful; directions not provided.
Abundance:	The population is marginal since it can only grow in low-velocity currents and shallow depressions on bacterial mats.
First Observed:	11/1/72
Other Locations:	Specimens of this diatom have also been collected from Alhambra North Hot Spring in Jefferson County, Montana and from Ohanapecosh Hot Spring No. 6 in Mount Rainier National Park.
Biotech Use:	No known application
Citation:	Fairchild, Eugene and Richard P. Sheridan. 1974. A physiological investigation of the hot spring diatom, *Achnanthes exigua* Grün. Journal of Physiology. 10:1-4.
Photographs:	None
Specimens:	None preserved

Scientific Name:	***Acidothermus cellulolyticus***
Description:	Acidophilic, cellulolytic, phototrophic, thermophilic bacteria. Obligate aerobe that forms gram-variable, non-motile, non-pigmented, non-sporing rods with long slender filaments. It shares several important features with Thermus strains, i.e., aerobic, heterotrophic, and thermophilic mode of growth; morphological features; sensitivity to lysozyme; and presence of catalase. It differs in the carbon sources used for growth, pH and temperature profiles for growth, sensitivity to anti-biotics, resistance to penicillin G, the composition of amino acids in the cell walls, and the structure of the cell walls. It produces the enzyme cellulase, which breaks down cellulose by hydrolysis, an important and unusual characteristic, especially for an acidophilic microorganism.
Habitat Type:	Acid-sulfate Temperature range for growth: 37-65°C Optimum temperature: 55°C pH range: 3.5-7.0 Optimum pH: 5.0
YNP Location:	Upper Norris Geyser Basin; exact locations not provided.
Abundance:	The population appears to be abundant since 12 strains were isolated from various hot springs in the Norris Geyser Basin.
First Observed:	7/1/86
Biotech Use:	This study was supported by the Office of Alcohol Fuels, U.S. Department of Energy, as part of a research program on the production of fuel alcohol from cellulosic biomass materials. It was hypothesized that an acidophilic, cellulolytic, thermophilic bacterium could be grown in culture with other thermotolerant microorganisms to produce ethanol at a high rate from cellulosic wastes; or the cellulytic organism could be used to produce cellulase, which could be added to a cellulose-containing culture of an organism which ferments glucose to alcohol.
Citation:	D.M. Updegraff et al. 1986. Isolation and characterization of *Acidothermus cellulolyticus* gen. nov. species novum, a new genus of thermophilic, acidophilic, cellulolytic bacteria. International Journal of Systematic Bacteriology. 36(3):435-443.
Photographs:	Electron micrograph in citation
Specimens:	Deposited in American Type Culture Collection as ATCC 43068; type strain 11B
YNP Comments:	Acidic hot springs are common in the Norris Geyser Basin and throughout YNP. This bacterium digests cellulose, indicating the presence of wood fiber in the thermal feature, also common in YNP's rapidly changing geothermal ecosystem.

Scientific Name:	***Alicyclobacillus acidocaldarius***
Description:	Acidophilic, heterotrophic, thermophilic. Aerobic, gram-variable, spore-forming rods. It was originally called *Bacillus acidocaldarius*. It is similar to *Bacillus coagulans*, but is considerably more acidophilic.
Habitat Type:	Acid-sulfate, aqueous and terrestrial thermal features Temperature range for growth: 45-70°C Optimum temperature: 60-65°C pH range: 2.0-6.0 Optimum pH: 3.0-4.0
YNP Location:	1) Nymph Creek 2) Unnamed hot springs near Recess Spring, Realgar Spring and Pearl Geyser, all in Norris Geyser Basin
Abundance:	This population appears to be abundant since this is a common habitat type in YNP and 14 cultures of this organism were isolated from a variety of sources.
First Observed:	4/1/71
Other Locations:	This organism also been isolated in soil from an acid fumarole in Hawaii Volcano National Park.
Biotech Use:	None known
Citation:	T.D. Brock and G. Darland. 1971. *Bacillus acidocaldarius* species novum, an acidophilic thermophilic spore-forming bacterium. Journal of General Microbiology. 67:9-15.
Photographs:	Photomicrographs in citation
Specimens:	Deposited in American Type Culture Collection as ATCC 43033, 43034, 43035

Scientific Name: ***Anaerobranca horikshii***

Description: Moderately alkali-tolerant, obligately anaerobic, chemoorganotrophic, gram-positive, heterotrophic, mainly proteolytic, thermophilic bacteria with peritrichous rod-shaped cells that form one to three branches and exhibit only slight tumbling motility. Spores have not been detected.

Habitat Type: Temperature range for growth: 30-66°C
Optimum temperature: 57°C
pH range for growth: 6.5-10.3
Optimum pH: 8.5

YNP Location: Unnamed hot spring pools behind the Old Faithful Hotel and Ranger Station

First Observed: 5/90

Other Locations: No similar isolates have been obtained from other hot springs in YNP or other parts of the U.S., or from hot springs in Iceland, New Zealand, or Italy, or from man-made thermobiotic environments such as sewage sludge, compost, and manure piles.

Biotech Use: Potential industrial applications that require enzymes stable at high pH values (9.5 and above) and at temperatures above 50°C, including the use of proteases and xylaneses for a non-chlorine bleaching process in the pulp and paper industry.

Citation: Engle, Marcella et al. 1995. Isolation and characerization of a novel alkali-tolerant thermophile, *Anaerobranca horikoshii* gen. nov., species novum Journal of Systematic Bacteriology. 45(3):454-461.

Photographs: Electron micrographs in citation

Specimens: NA

Scientific Name: ***Archaeoglobus spp.***

Description: Using in situ 16S RRNA analysis, and specific cell enrichments and cloning with a laser microscope (optical tweezers), this novel hyperthermophilic archaea was isolated from a solfataric hot spring in Yellowstone's Hayden Valley. Originally identified as S10L, it grows anaerobically by fermentation of complex organic material and gains energy by reduction of sulfate. In contrast to other known members of this genus, S10L grows only at low salt concentrations up to 0.7% NaCl and represents the first hyperthermophilic sulfate-reducer from a non-marine environment.

Habitat Type: Mineral spring; temperature range for growth: up to 90°C

YNP Location: Obsidian Pool, about one mile SW of the Mud Volcano Parking area. Exit Board Walk at the Sulfur Caldron, follow trail to Moose Pool. Cross country through woods to an extension of Hayden Valley. The pool is SW of a small muddy lake, and the only black pool among predominantly muddy brown/gray acid features.

First Observed: 1993

Abundance: This is the only known population of these organisms in YNP.

Other Locations: None known.

Biotech Use: No known applications.

Citation: Barns, S.M., Fundyga, R.E., Jeffries, M.W., Pace, N.R. 1964. Remarkable archael diversity detected in a Yellowstone National Park hot spring environment. Proceedings of the National Academy of Science. 91:1609-1631.

Specimens: N/A

YNP Comments: This organism was discovered by Sue Barns and Norm Pace using PCR-based DNA fingerprinting. It was subsequently cultured and named by Stetter, et al of Regensburg, Germany. S10L represents a new archaeoglobus species within the Chrenarchaeota branch of the archaea.

Scientific Name:	***Bacillus sp.***
Description:	Acidophilic, gram-positive, microaerophilic, non-motile, terminal spore-forming thermophilic bacterium growing on hot spring sediments using pullulan as a carbon source. The strain reduced nitrate to nitrite both aerobically and anaerobically. It produced extracellular thermostable pullulanase and saccharidase activities which degraded pullulan and starch into maltrotriose, maltose, and glucose. Gram-positive, non-motile rods with terminal oval spores occur in single cells, pairs or chains of 3 to 4 cells.
Habitat Type:	Acid-sulfate, sediment Temperature range for growth: 40-65°C Optimum temperature: 62°C pH range: 4-6 Optimum pH: 5.5
YNP Location:	Unnamed hot spring
Abundance:	This population is considered marginal since only one isolate was obtained.
First Observed:	10/1/89
Biotech use:	This Bacillus produces three thermostable enzymes: Pullulanase, amylase and saccharidase. These enzymes are capable of hydrolyzing pullulan and starch into products with industrial utility. They can be used to increase starch saccharification and to produce high glucose and high maltose syrups.
Citation:	Shen, Gwo-Jenn et al. 1990. Physiological and enzymatic characterization of a novel pullulan-degrading thermophilic *Bacillus* strain 3183. Applied Microbiology Biotechnology. 33:340-344.
Photographs:	None
Specimens:	Deposited in American Type Culture Collection as ATCC 49341 and 49342

Scientific Name:	***Bacillus coagulans***
Description:	Acidophilic, chemoorganotrophic, spore-forming thermophilic bacillus with gram-variable rods that grows in hot spring effluents. It is found in algal mats consisting of the eukaryotic brown alga, *Cyanidium caldarium* and lives off the algae's extracellular products.
Habitat Type:	Acid-sulfate Temperature range for growth: 30-60°C Optimum temperature: 37-45°C pH range: 2.0-6.0 Optimum pH: 3.0-4.0
Location:	Unnamed hot springs
Abundance:	The organism is probably common in *Cyanidium caldarium* mats since 17 isolates were cultured.
First Observed:	8/1/73
Other Locations:	This organism is abundant in acid hot springs in Yellowstone as well as around the world.
Biotech Use:	Because of its ability to produce acid from certain sugars and to grow at temperatures of 60°C, *B. coagulans* may have relevance as a possible causal organism of flat sour spoilage in acidic food products.
Citation:	Brock, Thomas D. and R.T. Belly. 1974. Widespread occurrence of acidophilic strains of *Bacillus coagulans* in hot springs. J Appl Bact. 37:175-177.
Specimens:	Deposited in American Type Culture Collection as ATCC 7050

Scientific Name: *Calothrix sp.*

Description: Filaments are solitary, in tufts or clumps, or in extended and definite strata, often more or less parallel, mostly erect, unbranched or with false branching, branches usually single, rarely in pairs; filaments and trichomes frequently swollen at bases and tapering into more or less well-developed hairs at apices. Sheaths are mostly firm, never confluent, often lamellate, often pigmented, or homogeneous and colorless. Heterocysts are basal and sometimes also intercalary. Resting cells in some species; basal, single or in rows of a few. Hormogonia often in long rows. Capable of nitrogen fixation.

They are often found associated with *Phormidium*, but in cooler regions. They seem to be of considerable importance in the formation of hot spring terraces and cones. They are the most important components of the Calothrix-Scytonema-Schizothrix formations that cover large areas in the Lower Geyser Basin, and the Calothrix-Diatom associations generally found in the basic, neutral and slightly acid springs. The accurate determination of several species is not easy and many characters are variable and unreliable. Additional study is likely to reveal several other species in the region.

Habitat Type: Neutral chloride and calcium carbonate

YNP Location: Firehole region, Mammoth Hot Springs

Abundance: 12 species have been found in YNP and comprise a very important group. They are characteristic of cooler waters (below 55°C), and are most abundant from 20-40°C. They include active rock-depositing species.

First Observed: 1898 (Tilden)

Biotech Use: None known

Citation: Copeland, Joseph J. Yellowstone Thermal Myxophyceae. Annals of the New York Academy of Sciences. 35:108.

Specimens: N/A

YNP Comments: Common cyanobacteria is responsible for the gray to dark brown mats associated with many thermal features. Possibly second in abundance only to *Phormidia* in Yellowstone thermal features.

Scientific Name: *Chloroflexus aurantiacus*

Description:

Gliding, filamentous, photosynthetic, phototrophic, thermophilic bacterium that forms a mat along the floor and walls of hot spring effluents. The mat which grows from the top, leaving the unhealthy cells in the lower layers to die from light limitation. It can grow either aerobically or anaerobically in association with other organisms, from which organic products are obtained.

- When grown anaerobically: the organism produces bacteriochlorophylls *a* and *c*. It oxidizes sulfide under photoautotrohpic or photoheterotrophic growth conditions and deposits elemental sulfur outside the cell.
- When grown aerobically: the organism acts as a chemoheterotroph. Aerobic chemoheterotrophic growth occurs in darkness or light. Bacteriochlorophyll syntheses cease, but some types of carotenoids continue to be made.

Filament coloration is orange except under anaerobic conditions in low light intensity, where it is dull green. At higher temperatures (above 50°C), it grows in association with the unicellular blue-green alga *Synechococcus lividus*. At lower temperatures (30-40°C), it grows in association with *Phormidium tenue*. In springs rich in sulfide, this organism can grow separately from blue-green algae.

Chloroflexus aurantiacus has characteristics of both green bacteria (light harvesting bacteriochlorophyll and location in chlorosomes) and purple nonsulphur bacteria (photosynethic reaction, elecctron transport components, facultative metabolism, and nutritional versatility), but unlike either group, it is not diazotrophic. And unlike the strictly anaerobic, photoautotrophic naure of green bacteria, Chloroflexus is capable of growing as an aerobic heterotroph or an anaerobic photoheterotroph or photoautotroph. It thereby extends the taxonomic and phylogenetic limits of the "green line" of phototrophic bacteria; it is unique in that there have been no previous reports of filamentous or gliding phototrophic bacteria.

Habitat Type:

Neutral chloride
Temperature range: 50-70°C
Optimum temperature range: 52-60°C
Optimum pH range: 7.6-8.4

YNP Location:

1) Mushroom Spring, on the Howard Eaton trail 0.25km north of Great Fountain Geyser
2) Five Sisters Spring, near Octopus Spring in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
3) Twin Butte Vista Pool, on a rise 0.10km southeast of Great Fountain Geyser

First Observed: 6/1/71

Other Locations: This population is found in several hot springs in YNP and around the world including Oregon, Guatemala, Iceland, Japan and New Zealand.

Biotech Use: No known applications. However, its unique metabolic activity have made it the focus of considerable research in prokaryotic photosynthesis.

Citation:

Brock, Thomas D. and John Bauld. 1973. Eccological studies of *Chloroflexus,* a gliding photosynthetic bacterium. Arch. Mikrobiol. 92:267-284.

Brock, Thomas D. and Michael T. Madigan. 1975. Photosynthetic sulfide oxidation by *Chloroflexus aurantiacus*, a filamentous, photosynthetic, gliding bacterium. Journal of Bacteriology. 122(2):782-784.

Pierson, Beverly K. and richard W. Castenholz. 1974. A phototrophic gliding filamentous bacterium of hot springs, *Chloroflexus aurentiacus,* gen. and species novum Arch Microbiol. 100:5-24.

Madigan, Michael T. and Ghanshyam D. Heda. 1986. Utilization of amino acids and lack of diazotrophy in the thermophilic anoxygenic phototroph *Chloroflexus aurantiacus*. Journal of General Microbiology. 132:2469-2473.

Photographs: Electron micrographs in Pierson and Castenholz

Specimens: Deposited in American Type Culture Collection as ATCC 29362, 29363, 29364; numerous university tissue culture collections

YNP Comments: This is a very well-studied organism. The 55°C mat growing at the outflow channel of Octopus Spring has a 2.5cm layer of *Chloroflexus* which has been studied by Dr. Dave Ward of Montana State University. Using phylogenetic analysis, Dr. Ward and his students have found a guild structure of possibly a hundred organisms comprising this mat. Other researchers working on this organism have altered the site by overharvesting, which has caused concern. The mat vitality is being monitored closely.

Scientific Name: ***Chromatium tepidum***

Description: Obligately phototrophic purple bacterium with gram-negative, motile, rod-shaped cells. It produces bacteriochlorophyll *a* and grows photoautotropically with sulfide as an electron donor. It is also autotrophic in that it can oxidize sulfide to elemental sulfur, which is stored as globules inside the cell. It is not diazotrophic. It forms a reddish bacterial mat in the carbonate sinter of thermal springs containing a high amount of sulfide with neutral to alkaline pH. Its photosynthesis is anoxygenic.

Habitat Type: Calcium-carbonate
Temperature range: 34-57°C
Optimum temperature: 48-50°C
Optimum pH: 7.0

YNP Location: Stygian Springs, located on the top of a ridge in the southwest corner of the Upper Terraces, Mammoth Hot Springs

Abundance: The population of this organism is marginal since only one isolate was obtained in Yellowstone, and one in a hot spring in New Mexico.

First Observed: 2/1/84

Biotech Use: No known application

Citation: Madigan, Michael T. 1984. A novel photosynthetic purple bacterium isolated from a Yellowstone hot spring. Science. 225:313-315.

Madigan, Michael T. 1986. *Chromatium tepidum* species novum a thermophilic photosynthetic bacterium of the family *Chromatiaceae*. International Journal of Systematic Bacteriology. 36(2):222-227.

Photographs: Photomicrograph in Science

Specimens: Deposited in American Type Culture Collection as ATCC 43061 MC

Scientific Name: *Clostridium thermoautotrophicum*

Description: Thermophilic strict anaerobe with round to slightly oval spores formed in terminal positions. Gram-variable, rod-shaped, vegetative cells that are slightly motile by peritrichously inserted flagella. It grows hemolithotrophically with hydrogen and carbon dioxide, and chemoorganotrophically with glucose, fructose, glycerate, or methanol. In both cases, acetate was the only organic fermentation product formed in significant amounts.

Habitat Type: Neutral chloride and acid-sulfate
Temperature range: 36-70°C
Optimum temperature: 56-60°C
pH range: 4.5-7.6
Optimum pH: 5.7

YNP Location:
1) White Creek hot spring (White Creek crosses the Firehole Loop Road, near White Dome Geyser
2) Dragon's Mouth, which is off the boardwalk in the Mud Volcano developed thermal area near Canyon Village

Abundance: The organism is widespread but low in numbers; fourteen isolates were obtained in Yellowstone from two hot springs.

First Observed: 1/1/81

Other Locations: Isolates of this organism have also been found in mud and wet soils from Hawaii, Georgia, Africa, Germany and Italy. It is not restricted to locations with elevated temperature.

Biotech Use: This organism is unique in being able to carry out homoacetate fermentation, in which elemental hydrogen and carbon dioxide are utilized to produce acetate. This ability could lead to biotechnical applications, including the production of road-deicer.

Citation: Wiegel, Jurgen et al. 1981. *Clostridium thermoautotrophicum* species novum, a thermophile producing acetate from molecular hydrogen and carbon dioxide. Current Microbiology. 5:255-260. 1982.

Validation of the publication of new names and new combinations previously effectively published outside the IJSB. International Journal of Systematic Bacteriology. 32(3):384-385.

Photographs: Photomicrographs in Current Microbiology

Specimens: Deposited in American Type Culture Collection as ATCC 33924 (DSM 1974); type strain JW 701/3

Scientific Name:	**EM3, EM17, EM19 (Pink Filament Community)**
Description:	Hyperthermophilic chemotrophic bacteria found in pink filaments attached to rock surfaces in a rapidly flowing hot water. Phylogenetic analysis identified three species: EM3, a unique lineage within the Thermotogales group; EM17, which predominates (26 out of 35 clones) and is closely related to *Aquifex pyrophilus*; and EM19, which is also affiliated with the Aquificales group and is a close relative of another hydrogen-oxidizing bacterium, *Hydrogenobacter thermophilus*.
Habitat Type:	Neutral chloride Temperature range for growth: 84-88°C pH: 7.0
YNP Location:	Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
First Observed:	6/6/66
Abundance:	The population is marginal, since it has been found in the outflow channel of only one hot spring in Yellowstone.
Other Locations:	None known.
Biotech Use:	These extreme thermophiles could not be cultured using traditional culture enrichment techniques. Analysis of the sequences of phylogenetically informative molecules, such as the 16S short sub-unit rRNA, and comparison with a known database of characterized organisms identified the species within a phylogenetic framework.
Citation:	Reysenbach, Anna-Louise. 1994. Phylogenetic Analysis of the Hyper-thermophilic "Pink Filament" Community in Octopus Spring, Yellowstone National Park. Applied and Environmental Microbiology. 60(6):2113-2119.
Photographs:	Photomicrographs in citation
Specimens:	Anna-Louise Reysenbach/Norm Pace Lab, Institute for Molecular and Cellular Biology.
YNP Comments:	Octopus Spring, called "Pool A" by early researchers, is an octopus-shaped pool approximately 15m in size which contains near boiling water at 91°C. It was the site of intense research by T.D. Brock in the 1960s and, due to its thermophilic biodiversity, is the best-studied microbial habitat in YNP. The pink filaments are probably similar to those organisms described by Setchell in 1899 as "filamentous Schizomycetes". The pink filament community, consisting of less than one square meter of habitat, is found no where else in YNP.

Scientific Name: ***Heliobacterium modesticaldum***

Description: Diazotrophic, gram-negative, thermophilic obligate anaerobe found in hot spring microbial mats, motile by flagella or non-motile. The organism fixes nitrogen up to its growth temperature limit and forms heat-resistant cylindrical, subterminal endospores. It can grow phototrophically by photoassimilating pyruvate, lactate, and acetate; or chemotrophically on pyruvate. Sugars and other organic acids are not utilized. The organism contains bacteriochlorophyll *g*, and lacks chlorosomes and intracytoplasmic membranes. Neurosporene is probably the only carotenoid.

Habitat Type: Neutral to alkaline hot springs or volcanic soils
Temperature range: 25-56°C
Optimum temperature: 52°C
Optimum pH: 6.0-7.0

YNP Location: Unnamed thermal springs near the Firehole River and Octopus Spring

First Observed: 1/1/81

Other Locations: Isolates of this organism have also been obtained in from volcanic soils in Iceland.

Biotech Use: None known.

Citation: Kimble, Linda K. et al. 1995. *Heliobacterium modesticaldum,* species novum, a thermophilic heliobacterium of hot springs and volcanic soils. Archives of Microbiology. 163:259-267.

Photographs: Photomicrographs in citation

Specimens: Deposited in American Type Culture Collection as ATCC 51577 (YS6)

Scientific Name: ***Mastigocladus laminosus***

Description: Thermophilic cyanobacteria capable of nitrogen fixation and adaptation to grow at temperatures lower than its normal range; motile by gliding and produces branching filaments. It forms a gelatinous, cartilaginous, or spongy dull blue-green or olive-green mat, doubling about 1.5 times per day. It has little tolerance for hydrogen sulfide and produces spores that are resistant to freezing and drying.

Habitat Type: Calcium-carbonate and neutral chloride
Temperature range for growth: 60-70°C
Optimum temperature: 63-64°C
pH range: 6.2-7.0

YNP Location: Widespread throughout YNP including:
1) Upper Geyser Basin: Bijah Geyser, Mastiff Geyser, Firehole River, Chromatic Spring, and elsewhere
2) Lower Geyser Basin: Jelly Spring
3) Twin Buttes Region: Spray Geyser; West Thumb and Mammoth

Abundance: This cosmopolitan organism can be found in many Yellowstone hot springs, and in alkaline thermal waters throughout the world.

First Observed: 1/1/51

Biotech Use: None known

Citation:

Castenholz, Richard W. 1969. Thermophilic blue-green algae and the thermal environment. Bacteriological Reviews. 33:476-504.

Copeland, Joseph J. 1936. Yellowstone Thermal Myxophyceae. 1936 Annals of the New York Academy of Sciences. 36:1-232.

Fogg, G.E. 1951. Studies on nitrogen fixation by blue-green algae. II. Nitrogen fixation by *Mastigocladus laminosus*. Journal of Experimental Botany. 2:117-120.

Photographs: Drawings in Copeland, p. 88

Specimens: Three strains, none preserved

Scientific Name: ***Methanobacterium thermoautotrophicum***

Description: Anaerobic, asporogenous, gram-positive bacterium which forms long, irregular filaments during growth. It is a non-motile, non-sporing, thermophilic chemolithotroph. Its capable of producing methane and hydrogen during the decomposition of bacterial-algal mat biomass. The 55°C algal-bacterial mat at Octopus Spring is the biomass used in methanogenesis by this organism. Microbial methanogenesis is generally associated with the anaerobic decomposition of organic matter in the absence of electron acceptors, such as oxygen.

Habitat Type: Acid sulfate and calcium carbonate
Temperature range: 42-72°C
Optimum temperature: 65°C
pH range: 6.4-8.4

YNP Location:

1) Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
2) Washburn Pools A and B, several meters NW of Devils Ink Pot in the Washburn Springs area, SW of Mount Washburn
3) Firehole Pool A, located at Midway Geyser Basin next to the Firehole River, halfway between Ojo Caliente Spring and Fountain Freight Road Bridge

Abundance: The population is common since it is found in many springs in Yellowstone. It has also been isolated in sewage sludge.

First Observed: 7/1/80

Biotech Use: This organism, due to the production of ethanol and methanol due to biomass decomposition, could have utility in converting biomass to fuels or chemical feedstock.

Citation: Zeikus, J. G. et al. 1980. Microbiology of methanogenesis in thermal, volcanic environments. Journal of Bacteriology. 143:432-440.

Specimens: Deposited in American Type Culture Collection as ATCC 29183 and 35610

Scientific Name: ***Phormidium laminosum***

Description: Stratum is thin or less often thick, up to 1cm, membranous to grisly, bright blue-green, golden or reddish. Filaments are flexuous to contorted, entangled. Sheaths are colorless, close, of variable thickness, often papery, usually completely or almost completely confluent into an amorphous matrix. Trichomes are 1-2 microns in diameter, not constricted at the cross walls; apices straight, cylindrical except for the apical cell. Cells are longer than broad, 2-5 microns in length, mostly with 2-4 refringent granules on the often inconspicuous cross walls; cell content is pale blue-green. End cells are sharp and pointed, without calyptra. It forms an orange-tan and brownish strata in full sunlight, a blue-green layer when partially shaded, and reddish layers when occurring beneath the surface.

Habitat type: Calcium carbonate and neutral chloride
Temperature: up to 66°C
pH range: 6.0 to 9.0

YNP Location: Numerous hot springs throughout Yellowstone, including the Firehole region and Mammoth Terraces

Abundance: *Phormidium* is a common cyanobacteria found in most non-acidic hot springs throughout Yellowstone and the world. In many springs, *P. laminosum* is the dominant alga over extended areas. Its orange-tan strata have given the name to Orange Mound Spring, on which it is abundant.

First Observed: 1898 (Tilden)

Biotech Use: No known applications

Citation:

Copeland, Joseph J. 1936. Yellowstone Thermal Myxophyceae. 1936 Annals of the New York Academy of Sciences. 36:1-232.

Mann, James E. and Harold E. Schlighting, Jr. Benthic algae of selected thermal springs in Yellowstone National Park. Trans Amer Microsc Soc. 86(1):2-9.

Photographs: Photograph in Copeland, page 169.

Specimens: N/A

YNP Comments: This organism, and possibly many other strains of similar phenotype, is abundant in YNP. It is responsible for many of the beautiful colors associated with hot springs. An organism found in the Firehole region in 1963 and identified as *Phormidum bijahensis* is now considered to be *P. laminosum.*

Scientific Name: *pJP27*

Description: Using in situ 16S RRNA analysis, and specific cell enrichments and cloning with a laser microscope (optical tweezers), this novel hyperthermophilic archaea was isolated from a solfataric hot spring in Yellowstone's Hayden Valley. The organism is rod-shaped, slightly curved, variable in length (between 5 and 10 micrometers) and about 0.5 micrometers in diameter. It grows at 85°C, and is therefore considered a hyperthermophile.

Habitat Type: Mineral spring

YNP Location: Obsidian Pool, about one mile SW of the Mud Volcano Parking area. Exit Board Walk at the Sulfur Caldron, follow trail to Moose Pool. Cross country through woods to an extension of Hayden Valley. The pool is SW of a small muddy lake, and the only black pool among predominantly muddy brown/gray acid features.

First Observed: 1993

Abundance: This is the only known population of these organisms in YNP.

Other Locations: None known.

Biotech Use: No known applications.

Citation: Barns, S.M., Fundyga, R.E., Jeffries, M.W., Pace, N.R. 1964. Remarkable archael diversity detected in a Yellowstone National Park hot spring environment. Proceedings of the National Academy of Science. 91:1609-1631.

Specimens: N/A

YNP Comments: This organism was discovered by Sue Barns and Norm Pace using PCR-based DNA fingerprinting. It was subsequently grown in a mixed culture by Stetter, et al of Regensburg, Germany. PJP27 represents a pivotal new group within the phylogenetic tree that has been named Korarchaeota by Norm Pace. As determined by phylogenetic analysis (evolutionary history), pJP27 is considered the most primitive organism known and the closest known extant relation to the origin of life.

Scientific Name:	***Rhodopila globiformis***
Description:	Gram-negative cells are spherical to avoid, and motile by means of polar flagella, have vesicular intracytoplasmic membranes, and grow only at low pH values. Photoorganotroph that forms purplish-red colonies when grown anaerobically with a light source, and pink colonies when grown microaerophically without light. Discovered by Thomas Brock as a weak red layer of non-mobile, spherical cells from a 3.0 pH spring near the Gibbon River, sample #LIX, 197. The pigments possessed include bacteriochlorophyll a-p and aliphatic methoxylated ketocarotenoids. This organism must have a reduced sulfur source to live because it lacks an assimilatory sulfate reduction system.
Habitat Type:	Acid-sulfate Optimum temperature for growth: 30-35°C pH range: 4.2-6.5 Optimum pH: 4.8-5.6, depending on carbon source
YNP Location:	Gibbon River acid spring, Norris Junction
Abundance:	The population is considered marginal since it was only found in one spring in YNP.
First Observed:	9/1/74
Other Locations:	None known
Biotech Use:	No known application
Citation:	Imhoff, J.F. et al. 1984. Rearrangement of the species and genera of the phototrophic "purple nonsulfur baceria". International Journal of Systematic Bacteriology. 34(3):340-343. Pfennig, Norbert. 1974. *Rhodopila globiformis*, species novum, a new species of the Rhodospirillaceae. Archives of Microbiology. 100:197-206.
Photographs:	Photomicrograph in Pfennig
Specimens:	Deposited in American Type Culture Collection as ATCC# 35887; DSM 161
YNP Comment:	This organism was previously included in the genus *Rhodopseudomonas*.

Scientific Name: ***Sulfolobus acidocaldarius***

Description: Sulfur-oxidizing, facultative autotroph with spherical cells that occurs in the hot acid environments of solfataras. It produces a citrate synthesis resembling those found in gram-positive eubacteria and eukaryotes. A thermostable type II restriction enzyme, *Sau*I, has been isolated from this organism that produces blunt-ends when it cleaves and is an isoschizomer of *Bsp*RI.

Habitat Type: Acid-sulfate
Temperature range for growth: 56-92°C
Optimum temperature: 68-80° depending on strain
pH range for growth: 0.9-5.8
Optimum pH: 2-3

YNP Location:
1) Sulfur Caldron, Moose Pool, Mud Geyser in the Mud Volcano area
2) Evening Primrose in the Sylvan Springs area
3) Vermillion and an unnamed spring (24-2) 450 feet west of Sieve Lake, in the Norris Geyser Basin

Abundance: Common to acidic hot springs and solfataras in the Yellowstone region.

First Observed: 1/1/72

Other Locations: This organism has been found in a variety of aquatic and terrestrial acid thermal areas, including hot springs in Italy, Dominica, and El Salvador.

Biotech Use: This organism is an important geochemical agent because it contributes to high acidity by oxidizing elemental sulfur to sulfuric acid, dissolving rock matrix. It has been used as a bioleaching agent during recovery of gold. Its enzymes are used in molecular biology and genetic engineering.

Citation:

Brock Thomas D. et al. 1972. *Sulfolobus*: A new genus of sulfor-oxidizing bacteria living at low pH and high temperature. Arch Mikrobiol. 84:54-68.

Bohlool, Ben B. and Thomas D. Brock. 1974. Population ecology of *Sulfolobus acidocaldarius*. I. Temperature strains; II. Immunoecological Studies. Archives of Microbiology. 97:169-179; 181-194.

Grossebüter, Wilhem and Helmut Görish. 1985. Partial purification and properties of citrate synthases from the thermoacidophilic archaebacteria *Thermoplasma acidophilum* and *Sulfolobus acidocaldarius*. System Appl Microbiology. 6:119-124.

Prangishvili, D.A. et al. 1985. A restriction endonuclease *Sua*I from the thermoacidophilic archaebacterium *Sulfolobus acidocaldarius*. Federation of European Biochemical Societies. 192(1):57-60.

Photographs: Photomicrographs in Brock, 1972

Specimens: Deposited in American Type Culture Collection as ATCC 33909

Scientific Name: ***Synechococcus sp.***

Description: These organisms can be thermophilic or mesophilic. They are usually obligate photoautotrophs which undergo aerobic photosynthesis. The small cells can be cylindrical, ovoid, or rod-shaped and grow singly, in pairs or in short chains and have no sheaths; they are irregular aggregates united by a slime layer and undergo repeated binary fission in one plane to reproduce. Most of the species are nonmotile; the motile species glide and exhibit a positive phototactic response. 28 species of *Synechococcus* are known.

Habitat Type: Acid-sulfate
Temperature range: 35-53°C, with thermophiles growing above 53°C.

YNP Location: Hot springs throughout YNP

Abundance: These organisms can be found in acidic thermal features throughout Yellowstone National Park.

First Observed: 1/1/71

Other Locations: These organisms have also been isolated from both thermal and non-thermal sources throughout the U.S. and the world.

Biotech Use: No known applications

Citation: Stanier, R.Y. et al. 1971. Purification and properties of unicellular blue-green algae (Order *Chroococcales*). Bacteriological Review. 35(2)171-205.

Rippka, Rosemarie et al. 1979. Generic assignments, strain histories and properties of pure culture of cyanobacteria. Journal of General Microbiology. 111:1-61.

Photographs: Photomicrographs in Rippka

Specimens: Deposited in American Type Culture Collection as ATCC 27149 and 27180

Scientific Name: ***Thermoanaerobacter brockii***

Description: Obligate anaerobic chemoorganotroph with gram-positive, non-motile rods that are frequently uneven in length and occur in chains, pairs or filaments. Forms round terminal endospores. Colonies are uniformly round, mucoid, non-pigmented and flat. The population doubles in about one hour at optimum temperature. It reduces thiosulfate to hydrogen sulfide. It uses a variety of saccharides as energy sources, including starch, maltose, glucose, lactose, sucrose and cellobiose. It does not ferment cellulose. Previously known as *Thermoanaerobium brockii.*

Habitat Type: Acid-sulfate and neutral chloride
Temperature range for growth: 35-85°C
Optimum temperature: 65-70°C
pH range: 5.5-9.5
Optimum pH: 7.5

YNP Location:
1) Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
2) Washburn Pools A and B, several meters NW of Devils Ink Pot in the Washburn Springs area, SW of Mount Washburn
3) Firehole Pool A is located at Midway Geyser Basin next to the Firehole River, halfway between Ojo Caliente Spring and Fountain Freight Road Bridge

Abundance: This population is moderate since it is found in anaerobic decomposing photosynthetic biomass from hot springs throughout Yellowstone.

First Observed: 7/1/80

Other Locations: None known

Biotech Use: The catabolic activity of *Thermoanaerobacter* strains is of industrial interest. It can grow on a variety of sugars, including insoluble starch, and produces largely ethanol and lactic acid as fermentation end products, and therefore may be of use in chemical feedstock production via thermophilic fermentation of biomass. It is used in the perfume industry.

Citation:

Zeikus, J.G. et al. 1979. *Thermoanaerobium brockii* genus novum, species novum; a new chemoorganotrophic, caldoactive, anaerobic bacterium. Archives of Microbiology. 122:41-48.

Lee, Yong-Eok et al. 1993. Taxonimic distinction of saccharolytic thermopilic anaerobes. International Journal of Systematic Bacteriology. 43(1):41-51.

Photographs: Photomicrographs in Zeikus

Specimens: Deposited in American Type Culture Collection as ATCC 33075 (DSM 1457)

Scientific Name: *Thermoanaerobacter ethanolicus*

Description: Extremely thermophilic, gram-variable, non-sporing anaerobic chemoorganotroph found in both alkaline (pH 8.8 and temperature 45-50°C) and slightly acidic (pH 5.5, temperature 55-60°C) hot springs. Peritrichously-flagellated rods in early growth phase; later cell shape varies from chains of coccoid cells one micron in diameter to long filamentous cells which often divide by constriction, forming chains of bacteria with differing cells lengths. Uneven division is common. This bacterium possesses two different alcohol dehydrogenases which enable it to metabolize many alcohols. It ferments glucose into ethanol and carbon dioxide. It reduces thiosulfate to hydrogen sulfide; it does not ferment cellulose.

Habitat Type: Acid-sulfate and calcium-carbonate
Temperature range for growth: 37-78°C
Optimum temperature: 69°C
pH range: 4.4-9.9
Optimum pH: 5.8-8.5

YNP Location:
1) White Creek, where Firehole Loop Road crosses it, on opposite side of road from Great Fountain Geyser
2) Dragons Mouth, in the Sulfur Caldron/Mud Volcano Area, Canyon Village

Abundance: The organism has been found in only two YNP hot springs.

First Observed: 1/1/81

Other Locations: None known outside of YNP.

Biotech Use: This organism releases ethanol and carbon dioxide as fermentation products and has been used in the industrial production of ethanol. U.S. Patent #4,292,406 has been granted for its use in converting cellulose into ethanol.

Citation: Jurgen Wiegel and Lars G. Ljungdahl. 1981. *Thermoanaerobacter ethanolicus* genus novum, species novum; a new extreme thermophilic anaerobic bacterium. Archives of Microbiology. 128:343-348.

Wiegel, Jurgen et al. 1988. Purification and properties of primary and secondary alcohol dehydrogenases from *Thermoanaerobacter ethanolicus*. Applied and Environmental Microbiology. 54(2):460-465.

Photographs: Photomicrographs in Wiegel

Specimens: Deposited in American Type Culture Collection as ATCC 31550

Scientific Name: ***Thermoanaerobacterium thermosulfurigenes***

Description: Obligately anaerobic, phototrophic, and thermophilic chemoorganotroph that grows in the algal-bacterial mat associated with thermal volcanic springs. Gram-negative, motile, peritrichously-flagellated straight rods that form long filaments and swollen, white, refractile, spherical endospores. It reduces thiosulfate to elemental sulfur; it does not ferment cellulose. It produces both ethanol and methanol as fermentation products, and β-amylase, which is extracellular, stable and active at high temperatures and a wide range of pH. Previously known as *Clostridium thermosulfurogenes*.

Habitat Type: Acid sulfate and neutral chloride
Temperature range for growth: 55-75°C
Optimum temperature: 60°C
pH range: 4.0-7.6
Optimum pH: 5.5-6.5

YNP Location: Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek

Abundance: This organism is considered marginal since it has only been found in one Yellowstone hot spring.

First Observed: 5/1/82

Other Locations: None known.

Biotech Use: Due to unique properties of β-amylase, this organism could be used industrially in brewing and starch processing. Food and beverage industries use β-amylase to convert starch into maltose solutions. High value is placed on extreme thermostability and thermoactivity of amylases for use in the bioprocessing of starch.

Citation:

Hyun, H.H. and J.G. Zeikus. 1985. General biochemical characterization of thermostable extracellular β-amylase from Clostridium thermosulfurogenes. Applied and Environmental Microbiology. 49(5)1162-1167.

Lee, Yong-Eok et al. 1993. Taxonimic distinction of saccharolytic thermopilic anaerobes. International Journal of Systematic Bacteriology. 43(1):41-51.

Schink, Bernhard and J.G. Zeikus. 1983. *Clostridium thermosulfurogenes* species novum, a new thermophile that produces elemental sulfur from thiosulfate. Journal of General Microbiology. 129:1149-1158

Photographs: Photomicrographs in Schink and Zeikus, 1983

Specimens: Deposited in American Type Culture Collection as ATCC 33743 (DSM 2229)

Scientific Name:	***Thermoanaerobacterium xylanolyticum***
Description:	Anaerobic, thermophilic bacterium growing chemoorganotrophically in hot springs on xylan. Gram-negative, motile, short rod-shaped cells with spherical terminal spores. Surface colonies are circular with smooth edges cloudy to white. In addition to degrading xylan, it reduces thiosulfate to elemental sulfur, which it deposits on its cells. It does not ferment cellulose.
Habitat Type:	Acid-sulfate Temperature range for growth: 45-70°C Optimum temperature: 60°C pH range: 5.0-7.5 Optimum ph: 6.0
YNP Location:	Frying Pan Springs, which are small, shallow hydrothermal areas located in Sylvan Springs just off the Mammoth-Norris Road on the north side
First Observed:	1992
Abundance:	The population is marginal since it has only been found in Frying-Pan Springs.
Biotech Use:	The xylanolytic enzymes produced by this organism could have applications in the pulp and paper industry.
Citation:	Lee, Yong-Eok et al. 1993. Taxonimic distinction of saccharolytic thermopilic anaerobes. International Journal of Systematic Bacteriology. 43(1):41-51.
Photographs:	Photomicrographs in citation.
Specimens:	Deposited in American Type Culture Collection as ATCC 49914 (DSM 7097)

Scientific Name: ***Thermobacteroides acetoethylicus***

Description: Caldoactive, thermophilic chemoogranotroph with gram-negative, non-sporing, obligately anaerobic rods that exist singly or in pairs and are motile by peritrichous flagellation. Colonies are uniformly round, mucoid, non-pigmented, flat, and grow to a diameter of 3mm in 48 hours. It has a distinctive multiple-layered cell wall architecture without an outer wall membrane. It uses a variety of saccharides as energy sources, including starch, maltose, glucose, lactose, sucrose and cellobiose.

Habitat Type: Acid sulfate and neutral chloride
Temperature range for growth: 40-80°C
Optimum temperature: 65°C
pH range: 5.5-8.5

YNP Location:
1) Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
2) Washburn Springs, SW of Mount Washburn along the trail from the Glacial Eratic in the Canyon area

Abundance: Prevalent in volcanic features where organic matter is being decomposed.

First Observed: 1/1/81

Other Locations: None identified outside of YNP.

Biotech Use: No biotechnical use has been found for this organism. Since it is known to produce ethanol and acetic acid as fermentation products, it is a candidate for future biotechnology research.

Citation:

Zeikus, J.G. et al. 1980. Microbiology of methanogenesis in thermal volcanic environments. Journal of Bacteriology. 143:432-440.

Ben-Bassat, Arie, and J.G. Zeikus. 1981. *Thermobacteroides acetoethylicus* genus novum, species novum; a new chemoorganotrophic anaerobic thermophilic bacterium. Archives of Microbiology. 128:365-370.

Photographs: Photomicrographs in Ben-Bassat

Specimens: Deposited in American Type Culture Collection as ATCC 33265

Scientific Name: ***Thermodesulfobacterium commune***

Description: Thermophilic chemoorganotroph with a small gram-negative, obligate anaerobic, non-motile, non-sporing, straight rod which can reduce sulphate. It uses pyruvate, lactate or hydrogen as electron donors, and sulphate or thiosulphate as electron acceptors for growth and sulphide formation. An outer wall membrane has been found on this organism, as have mesosomes in its interior.

Habitat Type: Acid-sulfate and neutral chloride
Temperature range for growth: 45-85°C
Optimum temperature: 70°C
pH range: 6.0-8.0

YNP Location:
1) Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
2) Washburn Pool A, in the Washburn Springs area, SW of Mount Washburn, along the trail from the Glacial Eratic in the Canyon Area
3) Inkpot Spring in Firehole Pool A, located at Midway Geyser Basin next to the Firehole River, halfway between Ojo Caliente Spring and Fountain Freight Road Bridge

Abundance: This population is considered common since it was found in decomposing biomass from four different locations in Yellowstone.

First Observed: 6/1/82

Other Locations: None known outside of YNP

Biotech Use: No known applications

Citation: Zeikus, J.G. et al. 1983. Microbial ecology of volcanic sulphidogenesis: Isolation and characterization of *Thermodesulfobacterium commune* genus novum and species novum. Journal of General Microbiology. 129:1159-1169.

Photographs: Photomicrographs in Zeikus

Specimens: Deposited in American Type Culture Collection as ATCC 33708

Scientific Name:	***Thermofilum spp.***
Description:	Using in situ 16S RRNA analysis, and specific cell enrichments and cloning with a laser microscope (optical tweezers), this novel hyperthermophilic archaea was isolated from a solfataric hot spring in Yellowstone's Hayden Valley. Originally identified as S10TFL, it s a very thin, filamentous rod that grows anaerobically by fermentation of complex organic material at low salinity.
Habitat Type:	Mineral spring Temperature range for growth: 70-90°C pH: 5.5
YNP Location:	Obsidian Pool, about one mile SW of the Mud Volcano Parking area. Exit Board Walk at the Sulfur Caldron, follow trail to Moose Pool. Cross country through woods to an extension of Hayden Valley. The pool is SW of a small muddy lake, and the only black pool among predominantly muddy brown/gray acid features.
First Observed:	1993
Abundance:	This is the only known population of these organisms in YNP.
Other Locations:	None known.
Biotech Use:	No known applications.
Citation:	Barns, S.M., Fundyga, R.E., Jeffries, M.W., Pace, N.R. 1964. Remarkable archael diversity detected in a Yellowstone National Park hot spring environment. Proceedings of the National Academy of Science. 91:1609-1631.
Specimens:	N/A
YNP Comments:	This organism was discovered by Sue Barns and Norm Pace using PCR-based DNA fingerprinting. It was subsequently cultured and named by Stetter, et al of Regensburg, Germany.

Scientific Name:	***Thermoleophilum album***
Description:	Obligately thermophilic aerobe which grows on hydrocarbons at a narrow range of *n*-alkanes (from 13-20 carbons in length) in a defined mineral salts medium. Small gram-negative, non-motile, non-pigmented non-sporing, rod-shaped cells.
Habitat Type:	Neutral chloride Temperature range for growth: 45-70°C Optimum temperature: 60°C pH range: 6.5-7.5 Optimum pH: 7.0
YNP Location:	Octopus Spring, in Lower Geyser Basin, 300m upstream from where the Firehole Loop Road crosses White Creek
First Observed:	6/15/77
Other Locations:	This organism has also been found in mud and water samples in primarily thermal areas in Arkansas, New Mexico and North Carolina.
Biotech Use:	No known applications. However, its ability to consume hydrocarbons has made it a candidate for further study.
Citation:	Perry, J.J. et al. 1978. Isolation of Thermophilic bacteria capable of growth solely in long-chain hydrocarbons. FEMS Microbiology Letters. 3:81-83. Zarilla, K.A. and J.J. Perry. 1984. *Thermoleophilum album* genus novum and species novum, a bacterium obligate for thermophily and *n*-alkane substrates. Archives of Microbiology. 137:286-290.
Photographs:	SEM photomicrographs in Zarilla
Specimens:	Deposited in American Type Culture Collection as ATCC #35264

Scientific Name:	***Thermoleophilum minutum***
Description:	Obligately thermophilic aerobe which grows on hydrocarbons at a narrow range of *n*-alkanes (from 13-20 carbons in length) in a defined mineral salts medium. Small gram-negative, non-motile, non-pigmented non-sporing, rod-shaped cells.
Habitat Type:	Neutral chloride Temperature range for growth: 45-70°C Optimum temperature: 60°C pH range is 6.0-7.0 Optimum pH: 6.8
YNP Location:	Unidentified hot spring in YNP
Abundance:	It was recovered from only one YNP hot spring.
First Observed:	6/15/85
Biotech Use:	No known application. However, its ability to consume hydrocarbons makes it a candidate for bioremediation processes.
Citation:	Zarilla, K.A. and J.J. Perry. 1986. Deoxyribonucleic acid homology and other comparisons among obligately thermophilic hydrocarbonoclastic bacteria, with a proposal for *Thermoleophilum minutum* species novum. International Journal of Systematic Bacteriology. 36(1):13-16
Specimens:	Deposited in American Type Culture Collection as ATCC #35265

Scientific Name:	***Thermomicrobium roseum***
Description:	Obligately thermophilic and aerobic bacterium with gram-negative, pleomorphic, non-sporing irregularly-shaped rods, occurring singly or in pairs in compact pink colonies. It has an atypical cell wall composed predominantly of a protein with high concentrations of proline, glutamic acid, glycine, and alanine. The organism grows in an orangish-red bacterial mat.
Habitat Type:	Calcium-carbonate Optimum temperature for growth: 70-75°C Maximum temperature: 85°C pH range: 6.0-9.4 Optimum pH: 8.2-8.5
YNP Location:	Toadstool Spring outflow, two miles north of Mushroom Spring in the Lower Geyser Basin
Abundance:	This organism has been found in only a few hot springs in YNP.
First Observed:	6/15/72
Other Locations:	None known outside of YNP
Biotech Use:	No known applications
Citation:	Ramaley, Robert F. et al. 1973. *Thermomicrobium*, a new genus of extremely thermophilic bacteria. International Journal of Systematic Bacteriology. 23(1):28-36. Perry, G.J. et al. 1980. The atypical cell wall comopositoin of *Thermomicorbium roseum*. Can J Microbiol. 25:556-559.
Photographs:	Photomicrographs in Ramaley
Specimens:	Deposited in American Type Culture Collection as ATCC 27502

Scientific Name:	***Thermoplasma acidophilium***
Description:	Saprophytic, obligately heterotrophic and thermoacidophilic archaebacterium found in acidic solfatara sediments. Facultatively anaerobic organotroph which gains energy by sulfur respiration. Gram-negative, motile, flagellate, irregularly-shaped cells lack cell wall and envelope; surrounded by only a cytoplasmic membrane. Closely related to *Thermoplasma volcanium.*
Habitat Type:	Acid-sulfate Temperature range for growth: 45-63°C Optimum temperature: 59°C pH range: 0.5-4.0 Optimum pH: 1.0-2.0
YNP Location:	Nymph Lake, Frying Pan Springs, West Thumb, and Mud Volcano
Abundance:	This organism is abundant; isolates were obtained throughout the YNP acid-sulfate habitat type. (Until this discovery, this organism was believed to exist only in self-heated coal refuse piles; Brock et al.)
First Observed:	11/1/87
Other Locations:	In addition to the sites chosen in YNP, this organism has been found in the Azores, Iceland, Indonesia, Italy, and Java.
Biotech Use:	No known application
Citation:	Segerer, Andreas et al. 1988. *Thermoplasma acidophilum* and *Thermoplasma volcanium* species novum from solfatara fields. Systematic and Applied Microbiology. 10:161-171.
Photographs:	Photomicrographs in citation
Specimens:	Deposited in American Type Culture Collection as ATCC 25905 (DSM 1728)

Scientific Name:	***Thermoplasma volcanium***
Description:	Saprophytic, obligately heterotrophic and thermoacidophilic archaebacterium found in acidic solfatara sediments. Facultatively anaerobic organotroph which gains energy by sulfur respiration. Gram-negative, motile, flagellate, irregularly-shaped cells lack cell wall and envelope; surrounded by only a cytoplasmic membrane. Closely related to *Thermoplasma acidophilum*.
Habitat Type:	Acid-sulfate Temperature for growth: 33-67°C. Optimum temperature: 60°C pH range: 1.0-4.0 Optimum pH: 2.0
YNP Location:	Sulfur Caldron and Mud Volcano in the developed thermal area between Canyon Village and Yellowstone Lake
Abundance:	This organism is abundant; isolates were obtained throughout the YNP acid-sulfate habitat type.
First Observed:	11/1/87
Other Locations:	In addition to the sites chosen in YNP, this organism is found in acid-thermal habitats around the world.
Biotech Use:	No known application
Citation:	Segerer, Andreas et al. 1988. *Thermoplasma acidophilum* and *Thermoplasma volcanium* species novum from solfatara fields. Systematic and Applied Microbiology. 10:161-171.
Photographs:	Photomicrographs in citation
Specimens:	DSM 4299

Scientific Name: *Thermosphaera aggregans*

Description: Using in situ 16S RRNA analysis, and specific cell enrichments and cloning with a laser microscope (optical tweezers), this novel hyperthermophilic archaea was isolated from a solfataric hot spring in Yellowstone's Hayden Valley. Originally identified as M11TL, it grows anaerobically by fermentation of complex organic material at up to 90°C. Hydrogen, carbon dioxide, acetate, and iso-valerate are formed as metabolic products. It is a coccoid archaeum that forms grape-like aggregates and represents a new genus.

Habitat Type: Mineral spring; temperature for growth: up to 90°C

YNP Location: Obsidian Pool, about one mile SW of the Mud Volcano Parking area. Exit Board Walk at the Sulfur Caldron, follow trail to Moose Pool. Cross country through woods to an extension of Hayden Valley. The pool is SW of a small muddy lake, and the only black pool among predominantly muddy brown/gray acid features.

First Observed: 1993

Abundance: This is the only known population of these organisms in YNP.

Other Locations: None known.

Biotech Use: No known applications.

Citation: Barns, S.M., Fundyga, R.E., Jeffries, M.W., Pace, N.R. 1964. Remarkable archael diversity detected in a Yellowstone National Park hot spring environment. Proceedings of the National Academy of Science. 91:1609-1631.

Specimens: N/A

YNP Comments: This organism was discovered by Sue Barns and Norm Pace using PCR-based DNA fingerprinting. It was subsequently cultured and named by Stetter, et al of Regensburg, Germany. M11TL represents a new genus within the Chrenarchaeota branch of the archaea.

Scientific Name:	***Thermothrix thiopara***
Description:	Extremely thermophilic chemosynthetic sulfur autotroph which occurs where geothermal ground waters mix with the oxidizing atmosphere and covers tufa microenvironments with microscopic nets of gram-negative cells. It has a complex life cycle, establishing itself at the sulfide-oxygen interface and forming long (2.5 cm) macroscopic streamers of filamentous cells which grow until they extend to the oxidizing side of the interface, where they fragment into flagellated unicells. This strategy apparently optimizes reproductive success despite the rapid washout of planktonic unicells due to their low specific growth rate relative to the dilution rate of the spring.
Habitat Type:	Calcium-carbonate Temperature at site: 74°C Optimum temperature for growth in lab: 72°C pH: 7.0
YNP Location:	Mammoth Hot Springs
Abundance:	This organism is very abundant, occurring in most calcium-carbonate hot springs in YNP and every spring in Mammoth; it deposits the mineral travertine and is the principal fossil/mineral component of the Mammoth Terraces.
Biotech Use:	No known application. However, it is important in understanding the biogeochemical cycles of Earth's development.
First Observed:	6/15/76
Other Locations:	The organism has also been found in the Jemez hot springs and at Soda Dam in New Mexico.
Citation:	Caldwell, D.E. et al. 1982. *Thermothrix thiopara*: Selection and adaptation of a filamentous sulfur-oxidizing bacterium colonizing hot spring tufa at pH 7.0 and 74°C. Environmental Biogeochemistry. 35:1-6.
Photographs:	Photomicrographs in citation
Specimens:	None preserved

Scientific Name:	***Thermus aquaticus* (Taq)**
Description:	Thermophilic, plagic, obligate aerobic eubacterium. Gram-negative, non-motile non-sporing rods which produce a yellow cellular pigment, probably a carotenoid. Under certain cultural conditions, it forms long filaments and large spherical structures, probably related to spheroplasts. Generation time at optimum temperature is about 50 minutes. Taq was the first hyperthermophile discovered and led to the science of life at high temperature, eventually yielding many other bacteria growing at temperatures above 55°C.
Habitat Type:	Neutral chloride Temperature range for growth: 40-79°C Optimum temperature: 70°C pH range: 7.0-8.0 Optimum pH: 7.5-7.8
YNP Location:	Mushroom Pool, located in the White Creek area of the Lower Geyser Basin, off the Firehole Loop Road, 300m east of White Dome Geyser, just inside the tree line. It is a circular pool approximately 20m in diameter with an L-shaped outflow channel and covered with a dense green/brown bacterial mat.
First Observed:	6/1/65
Other Locations:	Taq is a common thermophilic microorganism with several strains found in hot springs around the world. It is also sometimes found in hot tap water in geographical locations distant from thermal springs.
Biotech Use:	Taq DNA polymerase is the primary enzyme used in polymerase chain reaction (PCR), the enzymatic amplification of DNA for industrial use, which has revolutionized DNA science. The gene producing Taq polymerase has been cloned onto an *E. coli* host for mass production of this enzyme, a process patented by Cetus, Inc. using the original culture collected from Mushroom Pool.
Citation:	Brock, Thomas D. and Hudson Freeze. 1969. *Thermus aquaticus* genus novum and species novum; a non-sporulating extreme thermophile. Journal of Bacteriology. 98(1)289-297.
Photographs:	Photomicrographs in citation
Specimens:	Deposited in American Type Culture Collection as ATCC YT-1 25104

Scientific Name:	***Thiobacillus thiooxidans***
Description:	Chemoautotrophic, rod-shaped, thermophilic, obligately acidophilic bacterium found in solfatara soils. It is responsible for the sulfuric acid production that takes place in solfatara soils. It oxidizes sulfur to sulfuric acid most rapidly at lower temperatures. The habitat generally has little or no vegetation, consists of hydrothermally altered reddish or white soil, with patches of sulfur crystals in the rocks and soil.
Habitat Type:	Acid-sulfate Temperature range: 20-55°C pH range: 0.9-4.5 Optimum pH: 2.5
YNP Location:	A level plain at the southwestern base of Roaring Mountain, a barren white ridge of highly eroded acidic steam vents and solfatara, located north of Norris Junction on the Grand Loop Road.
Abundance:	These organisms are abundant in solfatara habitat types and have also been isolated from other locations within YNP, including Amphitheater Springs.
First Observed:	8/1/72
Other Locations:	This organism is common in solfatara habitats elsewhere in the world.
Biotech Use:	It is used in mine bioleaching operations, and is associated with acid mine pollution.
Citation:	Brock, Thomas D. and Carl Fliermans. 1972. Ecology of sulfur-oxidizing bacteria in hot acid soils. Journal of Bacteriology. 111(2):343-350.
Photographs:	N/A
Specimen:	N/A

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