DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Moving particles (bacteria?) in fluid inclusions from Yellowstone National Park, Wyoming

By

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PREFACE

The video tape comprising this report was shown at the Third Biennial Pan-American Conference on Research on Fluid Inclusions held in Toronto, Canada, from May 20-22, 1990. Requests for copies of the tape prompted its publication as a U.S. Geological Survey open-file report. Much of the fluid inclusion data included in the video tape previously has been published; references to the prior publications are included following this printed version of the video tape text. A few pertinent references consulted during preparation of the video tape section on thermophilic microorganisms and the geologic setting of Yellowstone National Park also are listed. Most illustrations utilized in the video tape were copied from other publications; some of the figures and tables are not compatible with the video tape medium and are reproduced in this report for the convenience of the viewer. These illustrations are labeled with the same video tape counter value, time and section number as that given in the text outline.

INTRODUCTION

1. VIDEO TAPE SEGMENT SHOWING THE TWO MAIN FLUID INCLUSIONS THAT CONTAIN MOVING PARTICLES. (counter value 0153, time 01:33)

a. These two liquid-rich fluid inclusions contain hundreds of tiny moving particles.
b. The fluid inclusion on the right is about 30 micrometers in width.
c. Most of the particles are egg-shaped and are about 1 micrometer in length. Many of the particles appear to be tadpole-shaped; however, the "tail" always points downward even though orientation of the particles changes continuously. The appearance of a "tail" probably is a shadow effect.
d. The fluid inclusion on the right contains at least two moving particles that are rod-shaped and are about 2 micrometers in length. Another particle, briefly seen moving in and out of focus, has a dumbell shape and appears to consist of 2 smaller joined segments.
e. The fluid inclusions formed in hydrothermal quartz crystals that were deposited on fractures in rhyolite flows of U.S. Geological Survey research drill hole Y-13 from Yellowstone National Park.
f. Moving particles shown in this video tape segment were photographed at room temperature; however, fluid inclusion homogenization temperatures (T_h) for these quartz crystals range between 190 ° and 286 °C. Homogenization temperatures are the approximate temperatures at which the fluid was trapped.

GEOLOGIC SETTING

2. LOCATION MAP OF YELLOWSTONE NATIONAL PARK IN RELATION TO THE NORTHWESTERN UNITED STATES. (counter value 0285, time 03:01)

a. Yellowstone National Park is located in the northwestern part of the United States within portions of the states of Wyoming, Montana, and Idaho.

3. MAP OF THE YELLOWSTONE CALDERAS. (counter value 0307, time 03:16)

a. The Yellowstone plateau region has been a center of rhyolitic volcanism during the past 2 m.y.
b. Major explosive caldera-forming pyroclastic eruptions occurred at about 2.0, 1.3, and 0.6 m.y. ago, and each of these climactic events was preceded and followed by episodic eruptions of rhyolitic lava.

4. MAP OF THE YOUNGEST YELLOWSTONE CALDERA AND HYDROTHERMAL FEATURES WITHIN YELLOWSTONE NATIONAL PARK. (counter value 0348, time 3:44)

a. Shortly after the formation of the 0.6 m.y. old Yellowstone caldera, two resurgent domes emerged.
b. In this map:
   (1) The Yellowstone caldera is shown by the northwest slanting hatched lines.
   (2) The location of the ring-fracture system is denoted by light stippling.
   (3) The resurgent domes have northeast slanting hatched lines.
   (4) And the active and recently active hydrothermal areas are shown in black.
c. Note: This map and a few other figures that are difficult to see in the videotape are reproduced in the printed section of this report.

5. TABLE: CHRONOLOGY OF PERTINENT GEOLOGIC EVENTS IN THE YELLOWSTONE REGION. (counter value 0405, time 4:24)

a. During the past 150,000 years, the caldera has been flooded by rhyolitic lavas that were erupted in three short episodes at about 150,000, 110,000, and 70,000 years ago.
b. Two major periods of glaciation are recognized, intersperced with the late volcanism, in the Yellowstone National Park region.
   (1) The first, known as the Bull Lake glaciation, lasted from about 155,000 to 130,000 years ago.
   (2) The second, called the Pinedale glaciation, lasted from about 45,000 to 14,000 years ago.
c. There is some evidence to suggest that hydrothermal activity in the Yellowstone region has been continuous at least since early in the Pinedale glaciation and may possibly date back to about 265,000 years ago.

6. MAP SHOWING THE LOCATION OF U.S. GEOLOGICAL SURVEY RESEARCH DRILL HOLES COMPLETED IN 1967 AND 1968. (counter value 0481, time 05:18)

a. This map shows the location of 13 research drill holes completed by the U.S. Geological Survey in 1967 and 1968 for the purpose of obtaining detailed physical and chemical data on the shallow parts of active high-temperature geothermal systems. The majority of the drill holes are clustered in the Upper and Lower Geyser Basins (two of the most accessable thermal areas in the park).

7. MAP OF LOWER GEYSER BASIN. (counter value 0524, time 05:48)

a. Drill hole Y-13, in the northeastern corner of Lower Geyser Basin, yielded the quartz crystals that contain the tiny moving particles.

8. CROSS SECTION SHOWING STRATIGRAPHY AND TEMEPERATURE DATA FOR DRILL HOLE Y-13. (counter value 0546, time 06:04)

a. A cross section drawn between two of the research drill holes shows the units penetrated by the Y-13 drill hole. The upper 16 m of drill core consists mostly of late Pleistocene glacial sediment with a thin mantle of hot spring sinter. Between 16 m and the hole bottom, at 142-m depth, the drill core consists of 2 rhyolite lava flows both of which have a K-Ar age of about 150,000 years B. P.
b. Y-13 was drilled in a zone of major upflow of thermal water (shown by arrows leading to hot springs) with a maximum temperature of about 203° C measured near the bottom of the drill hole. Isothermal contours shown in the cross section are in 50° C intervals.

9. PHOTOGRAPH OF HOT SPRING NEAR Y-13 DRILL HOLE. (counter value 0614, time 06:54)

a. Hot springs near the Y-13 drill hole discharge water that is slightly above the boiling point for water at this elevation.

10. PHOTOGRAPH OF PORCUPINE HILLS. (counter value 0628, time 07:05)

a. Nearby hydrothermally cemented kame deposits (known as Porcupine Hills) suggest that hydrothermal activity in this area has been continuous at least since the early part of the Pinedale glacial period (45,000 years ago).

11. PHOTOGRAPH OF ALTERED Y-13 DRILL CORE. (counter value 0646, time 07:18)

a. The Y-13 drill core is extremely altered, and 1-2 mm-long quartz crystals, as well as numerous other hydrothermal minerals, coat most fractures and vugs.
b. Quartz crystals that host the fluid inclusions exhibit crystal faces, and precipitated in open fractures from hydrothermal solutions that flowed through altered rhyolitic volcanic rocks.

DATA ON FLUID INCLUSIONS

12. VIDEO TAPE OF MOVING PARTICLES. (counter value 0674, time 07:40)

a. The fluid inclusions that contain moving particles are found only in the central interior parts of 1-2-mm-long quartz crystals.
b. Some of these fluid inclusions appear to have been trapped on crystal faces during crystal growth and are primary inclusions; most appear to have been trapped in small fractures that may have formed within the crystals as a result of thermal cracking during periods of rapidly changing temperature.
c. After entrapment of these fluid inclusions, additional growth (as much as 0.15 mm thick) of quartz on exterior crystal faces sealed off the fractured zones and left quartz rims almost free of fluid inclusions.
d. Therefore, most inclusions in the fractures are thought to be pseudosecondary.

e. Altogether about 20 quartz crystals from depths of 59.5, 102.1, and 102.5 m in the Y-13 drill core have fluid inclusions containing between one and several hundred similar moving particles that are noticeable because of their continuous Brownian-like motion.
f. This motion did not appear to vary during heating and freezing of the fluid inclusions (except when the water was frozen to ice). Also, the motion does not change in response to raising or lowering the intensity of light in the microscope.
g. Through the use of a confocal laser scanning microscope we are able to view the moving particles in real time at magnifications up to about 10,000 times their actual size. At these magnifications most of the particles are nearly uniform in size (about 1 micrometer) and are egg-shaped.

13.SEM OF A RODLIKE PARTICLE. (counter value 0847, time 09:53)

a. A 1 micrometer long rodlike particle found on the side of a breached fluid inclusion cavity is shown in this scanning electron microscope (SEM) photograph. The scale bar, shown in the lower left corner of the photograph, is about 1/2 micron long.

14.VIDEO TAPE OF VERY TINY MOVING PARTICLES. (counter value 0867, time 10:11)

a. The shapes of very small particles (less than 1 micrometer) in a few fluid inclusions are difficult to discern even at the highest possible magnification.

15.DIAGRAM SHOWING HOMOGENIZATION TEMPERATURE MEASUREMENTS FOR DRILL HOLE Y-13. (counter value 0897, time 10:33)

a. This diagram shows the relation of fluid-inclusion T_h values with measured temperatures and a theoretical reference boiling-point curve for drill hole Y-13.
b. The theoretical boiling-point curve, shown as a solid line with the water table at the present land surface (0-m depth), assumes that hydrostatic pressure is controlled by the weight of an overlying column of cold recharge water.
c. Circles joined by dashed lines denote the measured temperatures as drilling progressed.
d. X's are the observed T_h of individual fluid inclusions at the given depths.
e. Most of the moving particles are found at 102.1-m depth, where the measured temperature and pressure are about 190° C and 1.24 MPa, respectively.
f. Melting-point temperatures of the Y-13 fluid inclusions (-0.1° to 0.0 ° C) indicate that the salinity is very low.
g. Homogenization temperatures of the liquid-rich fluid inclusions at 102.1-m depth range from about 190° to 280° C and mostly exceed the measured temperature and present theoretical reference boiling-point curve.
h. These high T_h require that the boiling-point curve be adjusted to a much higher altitude (i.e., a much higher water table) at the time of formation of the fluid inclusions than at present.
i. For the boiling-point curve to attain 280 °C at 102.1-m depth, an increase of about 425 m in the altitude of the water table at the time of entrapment of the fluid inclusion is required.
j. The dashed curve shows a reference boiling-point curve for estimated thickness of glacial ice required to account for the fluid inclusion T_h.

16.TABLE SHOWING ESTIMATED THICKNESS OF PINEDALE GLACIAL ICE FROM GLACIAL GEOLOGY AND FROM FLUID INCLUSION MEASUREMENTS. (counter value 1046, time 12:35)

a. The only way to increase the altitude of the water table while maintaining hydrothermal convection is to cover the Lower Geyser Basin with a deep lake or a thick cover of glacial ice.
b. Glacial geology studies of the Yellowstone region indicate that at least 550 m of glacial ice covered the Y-13 area during the Pinedale glaciation.
c. A conservative estimate of 425 m of glacial ice covering the Y-13 area based on the fluid inclusion studies is a very reasonable figure.
d. Even a liberal estimate of 730 m of glacial ice cover, which includes the highest temperature data points, may be possible due to evidence for a much greater ice thickness - 1070 m in the Mud Volcano Area of Yellowstone Park.

17. DIAGRAM SHOWING FLUID INCLUSION HOMOGENIZATION TEMPERATURES AND REFERENCE BOILING POINT CURVES FOR DRILL HOLE Y-13. (counter value 1116, time 13:27)

a. The ice sheet is likely to have caused the effective altitude of the water table to rise much more than 425 m during maximum glaciation.
b. During the period of glacial decline, the water table would again decrease, and the boiling-point curve would simultaneously be lowered.
c. The lowering water table and decreasing temperatures at given depths could induce thermal cracking of the quartz crystals.
d. Decreasing temperature also causes a decrease in the solubility of quartz, which would result in overgrowths of silica on previously deposited quartz crystals.
e. Thus, the range in observed fluid-inclusion homogenization temperatures may reflect changing conditions during waning stages of glacial periods. If this is so, the hydrologic conditions required to create the high-temperature fluid inclusions that contain moving particles must have occurred during late Pinedale or, possibly, early Pinedale glaciation (45,000-14,000 y. B.P.).

DISCUSSION

18. VIDEO TAPE OF MOVING PARTICLES. (counter value 1184, time 14:33)

a. If the moving particles are microorganisms, they were present within an active hydrothermal system at a significant depth below the surface at the time of their entrapment.
b. It is not inconceivable that living microogranisms have been trapped in a fluid inclusion at a temperature of more than 190 °C.
c. Thermophilic microorganisms, largely bacteria and blue-green algae, are reported living in superheated hot springs where the 94-95 °C temperatures are above the 92 °C boiling point of water at the 2200-m altitude of Yellowstone Park.
d. Thermophilic bacteria and other microorganisms have been discovered in submarine hot springs in several areas. The most notable of which was a 350 °C black smoker on the East Pacific Rise; however, that study has been disputed.

19. SIMILAR MOVING PARTICLES IN FLUID INCLUSIONS FROM OTHER AREAS. (counter value 1250, time 15:31)

a. Similar moving particles have been found in fluid inclusions from other geothermal areas at The Geysers and Long Valley areas of California, and the Miravalles geothermal area of Costa Rica.
b. Fluid inclusions from two fossil geothermal areas near Mount Hood, Oregon and Detroit, Oregon also contain a few similar moving particles.

c. Homogenization temperatures of fluid inclusions containing moving particles from these areas generally range between 190° and 286° C.
d. Melting point temperatures for the fluid inclusions mostly range between 0.0 ° and -0.3 °C and indicate that the salinity is low.
e. The moving particles have only been observed in hydrothermal quartz crystals.
f. No moving particles have been located in fluorite or calcite fluid inclusions of the above studies. Also, moving particles were not found in more saline/higher temperature fluid inclusions in anhydrite, epidote, sphalerite, calcite, or quartz from the 3.2-km deep Salton Sea Scientific Drilling Program State 2-14 well.

20.CONCLUDING REMARKS (counter value 1335, time 16:46)

a. At the present time, it has not been definately proven that the moving particles in fluid inclusions from drill hole Y-13 in Yellowstone National Park are microorganisms.
b. The fluid inclusions containing the moving particles or a video tape of the moving particles have been shown to several microbiologists who indicated that the particles might be bacteria. However, many of these scientists emphatically state that if the moving particles are bacteria they are not presently living.
c. If the moving particles are eventually proven to be thermophilic microorganisms, they probably lived underground at temperatures above 190 °C in Yellowstone's hot-spring systems during the Pinedale glaciation (45,000-14,000 years B.P.).

ACKNOWLEDGMENTS

(counter value 1387, time 17:33)

We thank Richard C. Ayers and Makoto Yonezawa of Lasertec U.S.A., Inc. for permiting us to utilize the tremendous capabilities of the Lasertec confocal scanning laser microscope in order to obtain the high magnification views of the moving particles. We are also greatful to Robert L. Oscarson for assistance in the scanning electron microscope studies, Michael M. Moore for his help and advice in producing this video tape and Ted G. Theodore for advice and use of his laboratory facilities. Background information pertaining to the volcanic geology, glacial geology and geothermal systems of Yellowstone National Park was summarized from publications of Robert L. Christainsen, Kenneth L. Pierce, Donald E. White and their many coworkers. Constructive reviews of this report by Terry E. C. Keith and Melvin H. Beeson are greatly appreciated.

End of video tape (counter value 1461, time 18:42)

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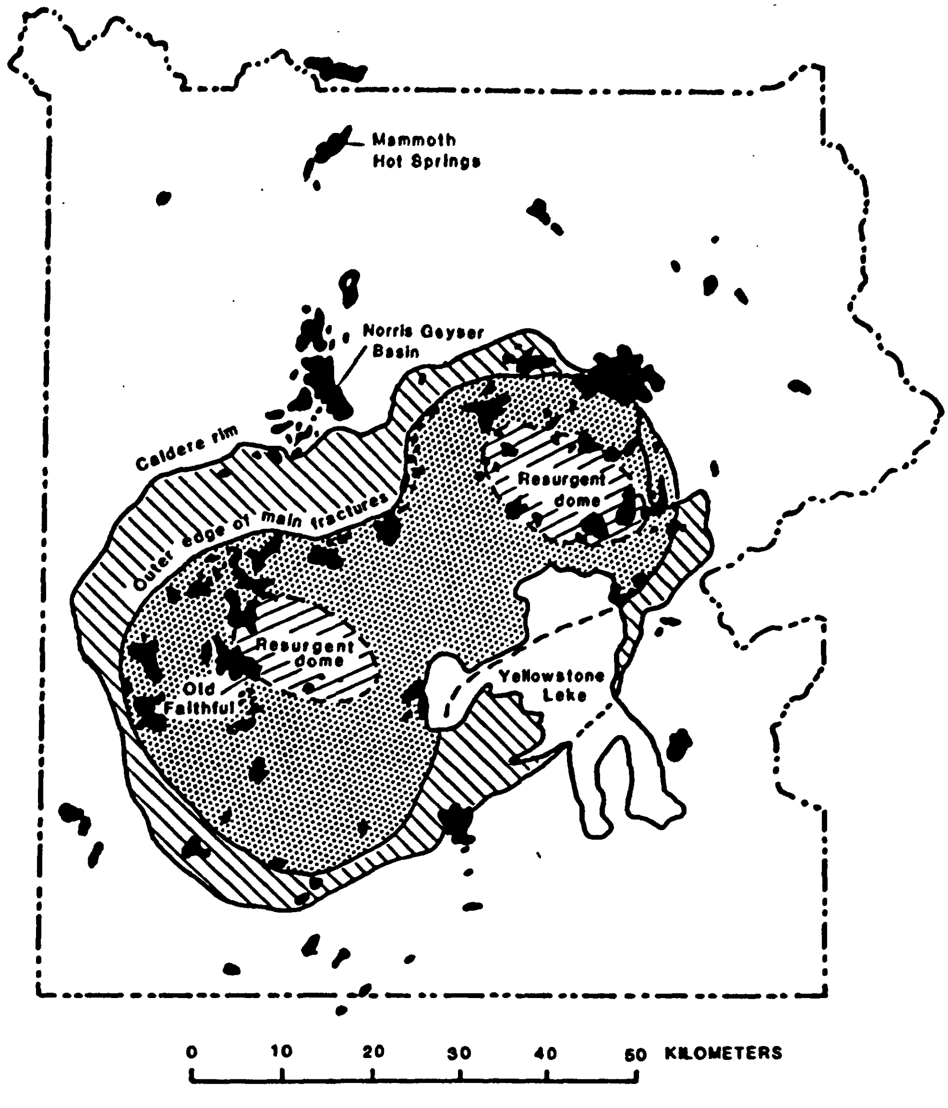
ILLUSTRATIONS

Section 4. (counter value 0348, time 03:44)



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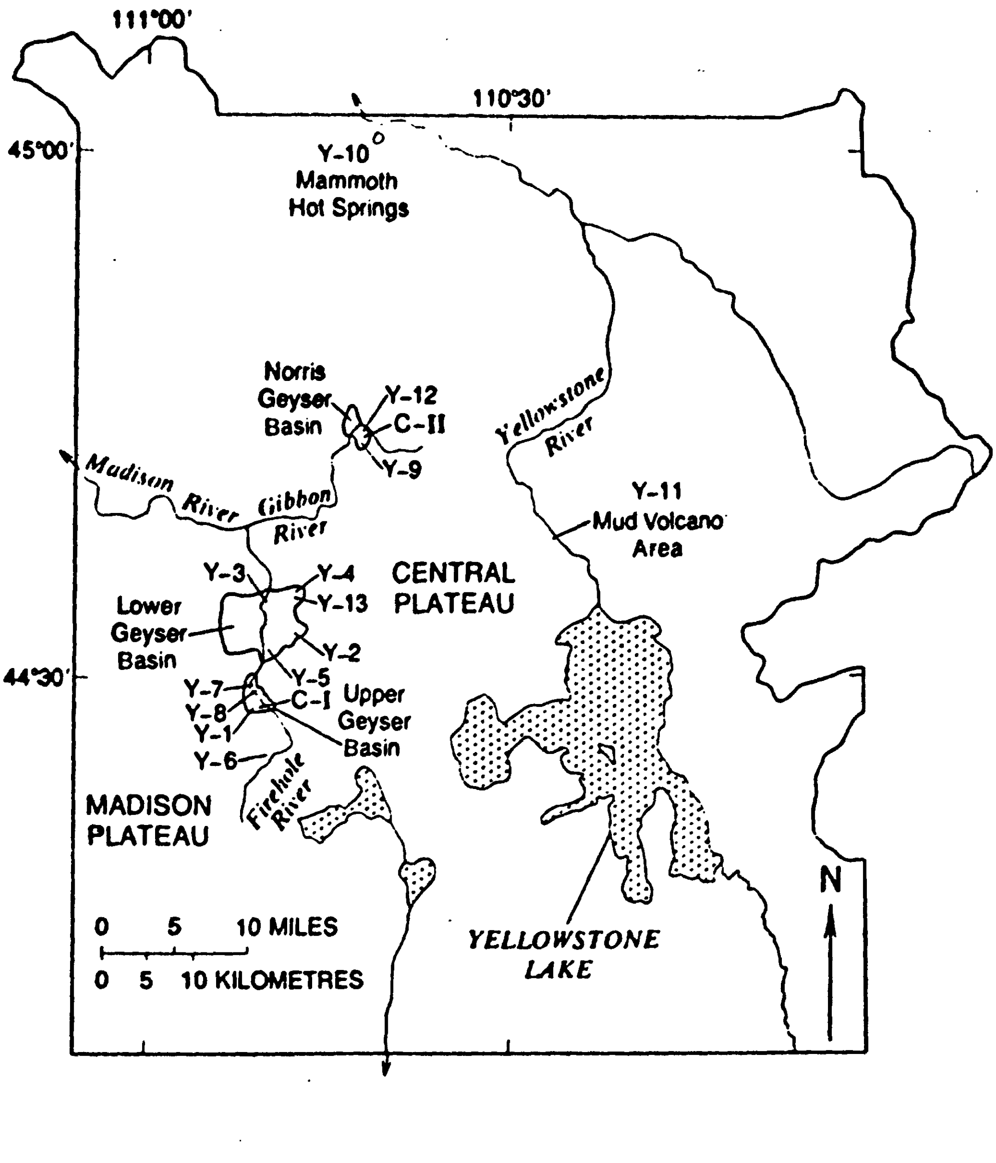

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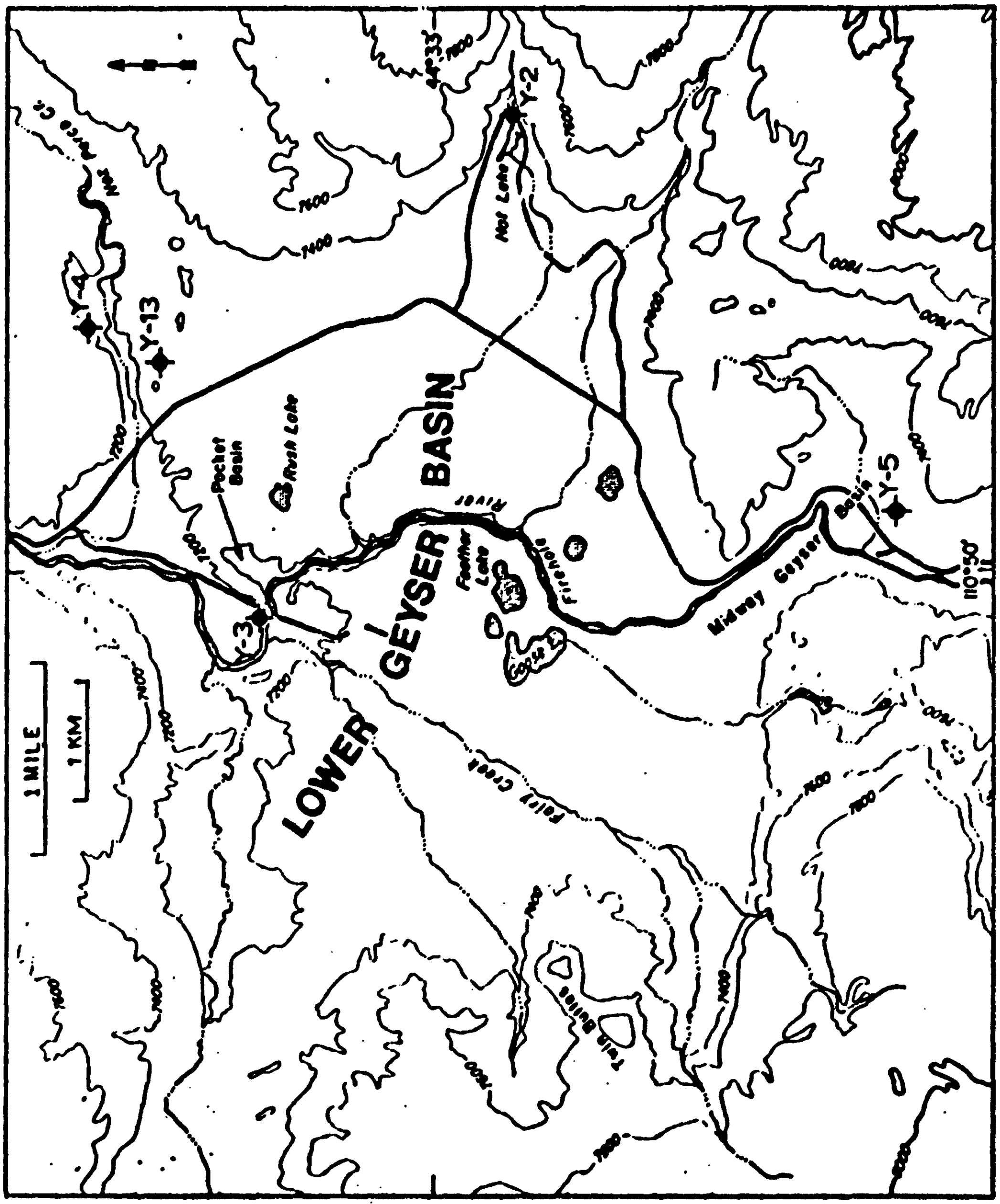

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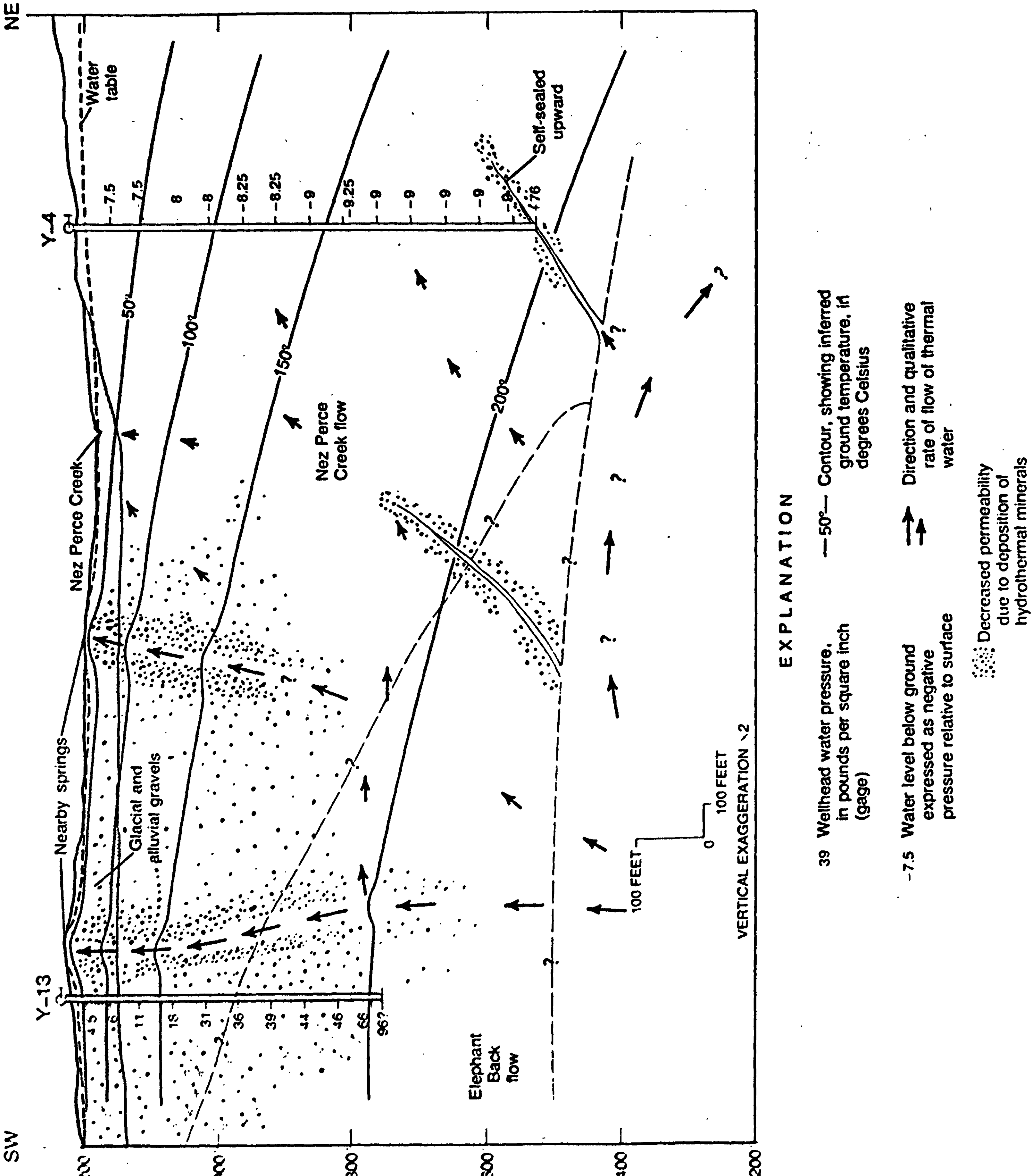

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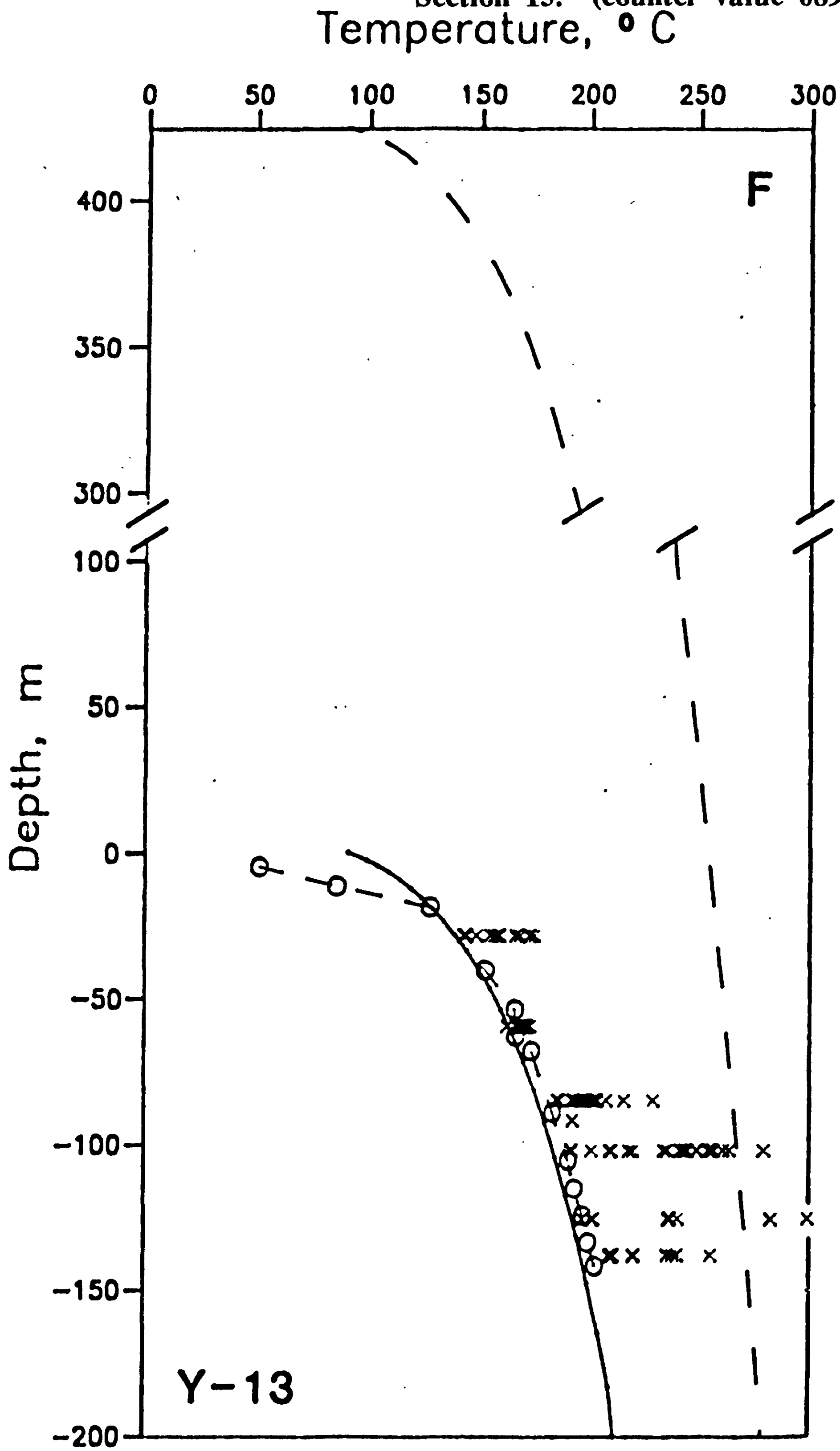

ESTIMATED THICKNESS OF PINEDALE GLACIAL ICE FROM GLACIAL GEOLOGY AND FROM FLUID INCLUSION MEASUREMENTS

Drill hole	Estimate from glacial geology* (m)	Estimate from fluid inclusions: Conservative estimate† (m)	Estimate from fluid inclusions: Liberal estimate** (m)
Lower Geyser Basin			
Y-2	550	50	75
Y-3	460	170	245
Y-4	550	0	0
Y-13	550	425	730††
Midway Geyser Basin			
Y-5	540	125	440
Upper Firehole River area near Lone Star Geyser			
Y-6	570	160	720††
Norris Geyser Basin			
Y-9	740	0	0
Mud Volcano area			
Y-11	1070	50	105

* Data from glacial geology studies of K. L. Pierce and J. D. Good (1988, written commun.).

† Excluding isolated highest temperature data points.

**Including highest temperature data points.

††Values exceed estimates of glacial ice thickness and corresponding T_h might be erroneous; however, the implied ice thicknesses could be valid because evidence for even greater thicknesses of glacial ice was found near Norris Geyser Basin and the Mud Volcano area (K. L. Pierce, 1988, written commun.).

Section 17. (counter value 1116, time 13:27)