UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-109
May 1968

Mr. Robert Porter
Acting Chief, Earth Resources Survey
Disciplines Program
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-109

GEOTHERMAL STUDIES - YELLOWSTONE

NATIONAL PARK (Test Site 11), WYOMING*

by

D. E. White**
R. O. Fournier**
L. J. P. Muffler**
A. H. Truesdell**

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Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

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*Work performed under NASA transfer funds (FY66), Task 160-75-01-52-10
**U. S. Geological Survey, Menlo Park, California

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NATIONAL PARK (Test Site 11), Wyoming

by

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ABSTRACT

Investigations of thermal areas in Yellowstone National Park include the correlation of subsurface temperatures determined by diamond drilling, surface temperature measurements, and remote sensor data. This report, in two parts, describes 1) the preliminary results of diamond drilling, summarizing lithology, subsurface temperatures and pressures in the drill holes, and 2) a method of using heavy snow fall in calorimetric determinations.

The snow fall method appears applicable to repetitive photographic and infrared observation from space. Passive microwave imaging radiometers might assist such studies but have not yet been tested. The drilling information is to be correlated with analyses of surface monitoring and aircraft remote sensor data.

PREFACE

by

W. D. Carter

Remote sensing investigations of geologic and geothermal features of Yellowstone National Park (Test Site 11), Wyoming, began in 1966 with an increase in transfer funds from the National Aeronautics and Space Administration. It was decided at that time that subsurface data should be obtained in the geyser basins in order to support and fully understand the surface information to be acquired by remote sensors in aircraft. A modest drilling program was recommended, approved and undertaken, with actual drilling operations initiated in April 1967. Drilling continued through October of that year and about 1/4 of the total remains to be completed during the summer of 1968. Although the project is no longer funded by NASA, studies of remote sensor data acquired by three aircraft (H.R.B. Singer, NASA, and University of Michigan) are underway to determine the relationships between surface and subsurface information.

This report, divided in two parts, describes the first results of studies under the Geothermal Investigations Task (160-75-01-52-10). Part I - "A Summary Report of Diamond Drilling in Thermal Areas of Yellowstone National Park' describes the lithology of the cores taken from the drill holes, and the total depth, temperatures and "over pressure" involved in each hole. It will now be possible to make correlations between these data, ground monitoring data collection during aircraft overflights and remote sensor imagery.

Part II - "New Method for Determining Heat Flows of Thermal Areas" uses heavy individual snow fall in calorimetric analysis. Because the ground near prominent thermal features remains bare during such snow falls, such studies appear to be applicable to repetitive photographic and infrared observation from space. Such repetitive observations should enable the investigator to develop isothermal contours of thermal areas. Because the snow pack increases in thickness away from the thermal features the use of passive microwave imaging radiometers may eventually assist studies of this type.

PART I - A SUMMARY REPORT OF DIAMOND DRILLING IN THERMAL AREAS OF YELLOWSTONE NATIONAL PARK

Project time from March through October was devoted almost exclusively to a program of research diamond drilling in the thermal areas of Yellowstone National Park. The drilling was carried out by Sprague and Henwood, Inc., under contract (project 972555); 4,901 feet of 4"x5-1/2", NC, NX, and BX hole were completed with overall core recovery of 87.2 percent. An additional 1,600 feet of drilling will be completed spring and summer of 1968. Summary data follows:

Number	Location	Depth	Maximum Temp.	"Over-pressure"	Lithology
Y-1	Black Sand Basin	215 ft.	171°C	31 psi	Sand, gravel, rhyolite flow
Y-2	Firehole Lake	516	203	57	Sand, rhyolite flow
Y-3	Ojo Caliente	514	196	49	Sand, rhyolite flow
Y-4	Nez Pierce Creek	691	194	87	Rhyolite flow
Y-5	Rabbit Creek	538	170	40	Ash-flow tuff
Y-6	Lone Star	500	181	19	Sand, rhyolite flow
Y-7	Biscuit Basin	242	142	0	Sandstone; rhyolite breccia
Y-8	Biscuit Basin	503	170	34	Sandstone; pumice breccia
Y-9	Norris	812	196	107	Ash-flow tuff
Y-10	Mammoth	370	73	40	Travertine, glacial sediments, Cretaceous sandstone
		4901			

Core from all wells was logged, and intervals selected for detailed laboratory study. Fluid samples were collected at well-head and at depth. Bottom-hole temperature measurements were made as drilling progressed. Initial scientific results include:

1) In six holes temperatures increased nearly linearly with depth until the pressure-corrected theoretical boling point curve was attained.

The temperatures at greater depths were controlled by the boiling point curve until, in 3 holes, temperatures leveled off. In 3 other holes the temperatures were still increasing along the boiling-point curve at the maximum depths drilled (214 feet, 516 feet, and 514 feet).

2) Water pressures measured at the surface exceeded atmospheric in 9 holes. These "artesian" pressures generally became evident at depths of 50 to 200 feet and commonly ranged from 30 to 100 psi, measured at ground level. The high water pressures are related to self-sealing mechanisms in the upper, cooler parts of high temperature hot spring systems. Original high permeabilities of near-surface rocks and sediments have been decreased greatly by deposition of silica, zeolites and/or calcite.

3) The first occurrence of welded ash-flow tuff inside the Yellowstone caldera was encountered in the Rabbit Creek hole from 32 feet to the bottom of the hole at 538 feet. This hole is located on the flank of the structurally high resurgent dome central to the caldera.

4) Core logging provided a preliminary determination of the nature and distribution of hydrothermal minerals. Most of the holes in Upper, Midway, and Lower Geyser Basins are characterized by zeolites (dominant mordenite with subordinate clinoptilolite and analcite), calcite, quartz, pyrite, montmorillonite, and minor pyrrhotite and fluorite. Two of these wells contained abundant earthy hematite. The Norris hole was characterized by white clay, no zeolites, and minor calcite and pyrite. The Mammoth hole encountered abundant secondary pyrite and calcite.

Some geologic mapping and related activities continued concurrently with the drilling, primarily in Lower Geyser Basin, the Norris-Roaring Mountain area, and in the vicinity of the Lone Star drill site.

PART II - NEW METHOD FOR DETERMINING HEAT FLOWS OF THERMAL AREAS

A semiquantitative method has been developed in Yellowstone for measuring the total heat flow through hot ground adjacent to geysers and hot springs. The method utilizes heavy individual snowfalls as calorimeters, extending Wakefield Dort's qualitative observations (Dort, 1966, p. 4439) that ground near prominent thermal features remains bare even during heavy snowfall, and that the thickness of total snowpack increases away from these features.

Optimum conditions for quantitative study are provided by an individual heavy snowfall of short duration, when daily temperature fluctuations are not far from 0°C. Time 0 is when snow first starts to collect on bare ground, and may commonly be fixed with an uncertainty of 1/2 hour or so. A detailed topographic map of the test area is essential; the method has been tested in two areas in Upper Basin, one of which includes Old Faithful. At convenient intervals after a heavy fall has ceased, the lines that demark snow from no-snow are mapped as iso-heat-flow contours.

At the time each contour is mapped, the contour is calibrated. We had observed that snow on boardwalks in the popular thermal areas retained their snow cover much longer than on adjacent hot ground, because of insulation provided by the 2"-thick boards separated from the ground by about 6" of air space. Where a snow-melt contour crossed a boardwalk the snow of a specific area (1 ft^2 used to date) was scraped into a pail;

a pail of hot spring water had been provided in the meantime, and the quantity of water of known temperature and heat content (such as 50°C = 50 cal/ml) just required to melt all of the snow from the measured boardwalk area was determined. The heat per unit area required to melt this boardwalk snow is assumed to be equivalent to the total natural heat flow on the mapped contour of adjacent hot ground. Conducted and probably some convected heat in warm gases are both included without distinction. Each boardwalk control area is assumed to have been influenced by the same gains and losses of heat from solar and atmospheric sources as the adjacent ground that has just lost its snow cover at the mapped contour. Thus, most of the uncertainties concerning these external sources of energy are compensated.

Two reasonably reliable heat-flow contours have been mapped in the Old Faithful test area; these are 1020 and 470 x 10^{-6} cal/cm^2 sec, or roughly 680 and 390 times the "normal" 1-1/2 heat-flow units. These seemingly very high heat flows are consistent with other evidence, including the very high near-surface thermal gradients found in the drill holes.

The method is likely to be most useful in cases of large local differences in heat flow. Under favorable climatic conditions, it can provide much data with minimal time and expense. One important climatic limitation recognized to date is that air temperature should have been near 0°C for a few days prior to the snowfall. Heat-flow contouring was attempted for one snowfall when prior temperatures were considerably above 0°C, and when "steady-state" heat flow had adjusted to a relatively high interface temperature. The snow-fall calorimeter thus was influenced by excess heat stored in near-surface ground.

Reference

Dort, Wakefield, Jr., 1966, Rapid reconnaissance of heat-flow patterns in snow-covered thermal areas: Jour. Geophys. Research, v. 71, p. 4439-4440.

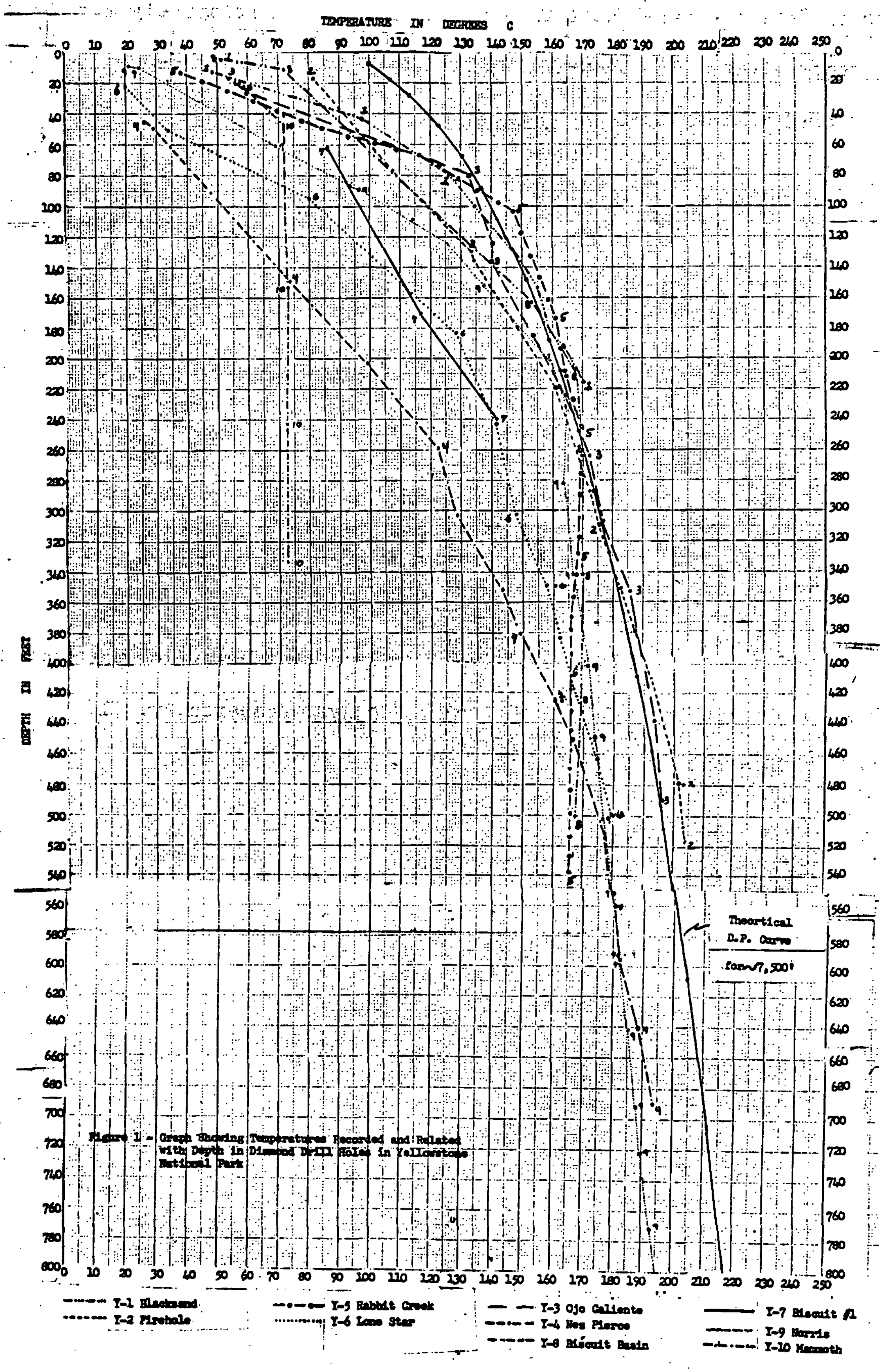
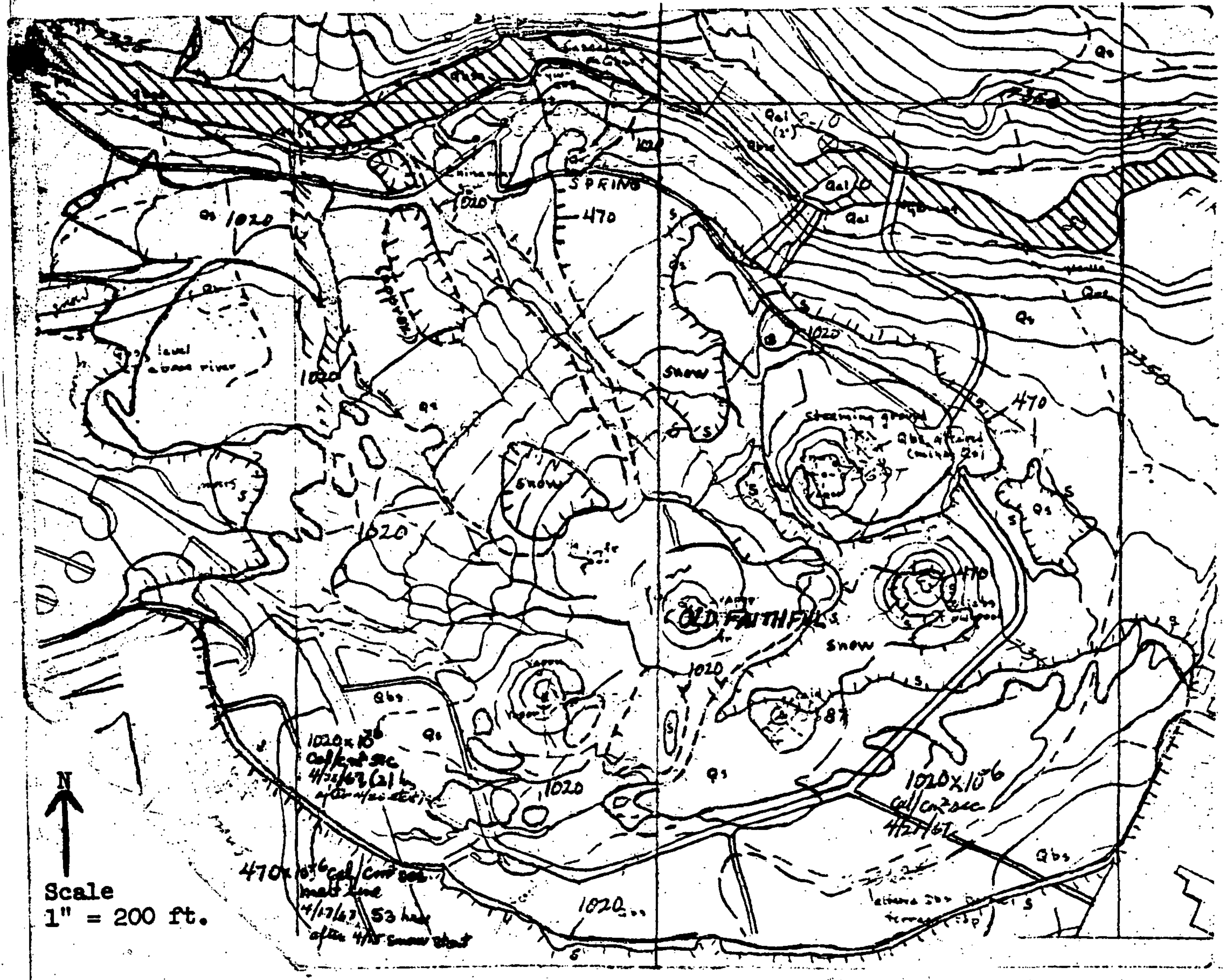


Figure 1 - Graph Showing Temperatures Recorded and Related with Depth in Diamond Drill Holes in Yellowstone National Park

EXPLANATION

470×10^{-6} cal/cm^{2}sec 1020×10^{-6} cal/cm^{2}sec



Scale
1" = 200 ft.

Figure 2 - Preliminary heat flow map of Old Faithful area, Yellowstone National Park, Wyoming, using heavy snowfalls as a calorimetric method.