CHAPTER 15

TEMPERATURE LOGGING OF BOREHOLES IN THE GONDWANA BASINS OF BIHAR AND WEST BENGAL

by

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Introduction

Temperature logging of boreholes in the coalfields of Bihar and West Bengal was introduced by the Geological Survey of India for the first time in 1964. The application of the method was extended to base-metal exploration in parts of Purulia district, West Bengal; Singhbhum district, Bihar; Dariba-Rajpura and Saladipura areas, Rajasthan; Agnigundala, Andhra Pradesh and a few other areas where electrical and radiometric logging were also in progress. Fig. I shows the areas where temperature logging is in progress.

Temperature logs provide information on thermal gradient, which can be utilised for heat flow determinations. This aspect of studies on thermal logging is included in the Upper Mantle Research Programme of the Survey.

The present paper deals with the results of temperature logging in a few deep boreholes in the coalfields of Bihar and West Bengal; and it presents mainly the calculated temperature gradients in the different rock formations encountered in these boreholes. An apparatus for the measurement of thermal conductivity of rock-core is in the process of development in the Well Logging Division of the Survey. When this apparatus is ready the heat-flow calculations will be completed.

The writer is grateful to S. Dutta and J. K. Chatterjee for their valuable assistance in the preparation of the plates.

Temperature Logging and Thermal Gradient

Temperature within the earth rises with increasing depth. The rate of increase varies considerably. This variation is primarily due to differences in thermal conductivity. Studies from different parts of the world, however, have shown that heat flow, i.e. the product of temperature gradient and thermal conductivity is generally constant.

Temperature gradient measurements in a borehole will therefore reflect the lithological changes. The gradients are generally low in formations having high thermal conductivity and high when thermal conductivity is low. Temperatures encountered in boreholes are not only dependent on the natural condition of the rocks but also on the circulating mud. When the well is allowed to stand, the mud in the hole at each point gradually comes to the temperature of the formation around it. The mud temperature at each level changes at a rate which depends on the thermal conductivity of the surrounding formations and on the volume of the mud, which itself is a direct function of the hole diameter. Measurement of temperature of this static mud gives the temperature of rocks in the adjoining wall.

The temperature gradient in any formation is constant and inversely proportional to the thermal conductivity. Thermal conductivity of the formation depends upon,—(1) conductivity of the solid particles, (2) geometry of the solid particles and (3) conductivity of the fluid in the pores and interstices. It increases with compactness ; and, therefore, igneous and metamorphic rocks are better conductors than sediments. In dry and porous rocks the thermal conductivity is considerably less that those with pore fluid. Sandstones usually are better conductors than shales, because of high conductivity of quartz. Thermal conductivity of quartz is greater than that of calcite ; and the latter is greater than those of silicates. Conductivities of shales or sandstones are much greater than that of coal. A coal seam with shaly matter or with considerable moisture and ash will have a comparatively higher heat conductivity than good quality coal.

Method of Study and Instruments Used

Temperature measurements in boreholes are made with a thermistor or a thermometer whose sensing element is a temperature sensitive resistance. The 'thermometer', enclosed in a suitable case, is gradually lowered in the borehole by a cable from the cable drum of the logging instrument. As the device is lowered, a voltage corresponding to the value of the temperature sensitive resistance is transmitted by means of of the cable to the recording instrument where it is recorded on a calibrated chart roll. The multi-purpose loggers with an additional attachment, a surface module, and the borehole temperature probe are used for this purpose. When measuring temperature gradients in boreholes, it is desirable that the hole should be full of water or drilling mud. The borehole is allowed to stand undisturbed for a period of minimum 24 hours, so that the fluid at each level can attain the temperature of the adjoining borehole wall. When several types of logging of a borehole is done, temperature logging is always made the first, and is done during the first downward journey of the electrode in the borehole.

In the Geological Survey of India two types of loggers having provisions for temperature surveys were used. These are,—(1) WIDCO, and (2) LOGMASTER, both manufactured in the U.S.A. The temperature sensing element in the WIDCO probe is a resistance thermometer in a metal case, while that in the logmaster is a 'thermistor' insulated by special type of varnish. In both the instruments, the readable sensitivity is ·005°C.

Results of Investigations

Following paragraphs discuss the salient features of the results of thermal logging of nine boreholes in the coalfielde of Bihar and West Bengal. The boreholes logged are enumerated below :

Borehole No.	*Location*		
R 29	Kaitha	Block,	Ramgarh C. F., Bihar
NOAR 95	Argada	,,	S. Karanpura C. F. ,,
WBK 2	Kashikhap	,,	W. Bokaro C. F. . ,,
NOWBK 80	Kedla	,,	W. Bokaro C. F. ,,
KBM 17	Badam	,,	N. Karanpura C.F. ,,
NOWBT 32	Taping	,,	Bokaro C. F. ,,
KB 12	Barkagaon	,,	Karanpura C. F. ,,
JFT 2	Talgharia	,,	Central Jharia C.F. ,,
NORD 4	Surajnagar	,,	Raniganj C. F., W. Bengal

These boreholes were drilled in the Lower Gondwana formations to which majority of coal occurences are restricted. The most extensive coal occurrences are in the lower part of the Damuda Series, i.e. the Barakar Stage and the Raniganj Stage. The Damuda Series comprises four stages,—viz. Karharbari, Barakar, Ironstone Shales and Raniganj. The Karharbari Stage consists of pebbly grits and sandstones. The Barakar Stage is the main coal-bearing group and consists of sandstones and grits with occassional conglomerates and beds of shales. The Ironstone Shales are entirely barren of coal seams, excepting a few streaks of carbonaceous matter. They consist of shales and fine grained sandstones. The Raniganj Stage consists of sandstones, shales and coal seams,—the sandstones being more fine-grained than those of the Barakar Stage.

Geothermal Gradients

It is well known that geothermal gradients vary according to the nature of formations. The average geothermal gradient in the earth's crust is generally taken to be 1°C for every 55 metres of depth. This is, however, tempered by the fact that thermal conductivity of rocks vary within wide range.

Each temperature log, presented in this paper, has been studied in detail along with electrical and gamma-ray logs wherever these logs were also recorded. Temperature gradients against individual formations in each borehole have been computed and presented as gradient profiles alongside other log traces of each borehole.

Figs. 2 to 9 are the log traces. The computed temperature gradients for the major rock formations in each borehole are presented in accompanying table.

None of the boreholes penetrated much into the basement crystallines. As such, temperature gradients in the crystallines could not be computed. The table, however, shows the temperture in the crystallines wherever they have been touched.

The top 60 to 70 metres in almost every borehole exhibit erratic temperature gradients. This is because of the influence of atmospheric temperature and unsuitable thermal conditions due to flow of shallow subsurface water in the boreholes.

Excepting for minor fluctuations, the temperature gradient in shales and sandstones are more or less linear showing a uniform increase in temperature with depth. There are, however, exceptions in this smoothness of the temperature logs near the coal seams, where the subsurface temperature increases abruptly with a sharp gradient ; and the curve assumes a step-like shape both above and below the coal seams.

Temperature gradients against thick shale and sandstone horizons are noted to vary within reasonable limits from one borehole to another. Where the horizons are thinner and are overlain or underlain by coal and carbonaceous shale horizons, thermal gradients are higher.

The computations for determining average temperature gradients in rocks of different types were made after giving due consideration to the

Table Showing Temperature Gradients in Different Formations

Borehole No. & Location	Depth of borehole (metres)	Depth logged (metres)	Surface Temperature °C	Bottom Temperature °C	Temperature Gradients in °Centigrade per Metre			
					Shale	Sandstone	Carbonaceous Shales	Coal
B 29 Kaitha Block	601.0	600.0	30°	41°.6	.006—.011	.022—.030	.026—.033	.055—.068
NOAR—95 Argada Block	448.0	447.0	26°.6	37°.5 (Crystallines)	.011—.014	.016—.020	.037—.044	.055—.077
NCWBT—32 Taping Block	206.5	205.0	27°.0	34°.0	.009—.013	.030—.032	.042—.046	.070—.118
KBM—17 Badam Block	543.8	543.0	25°.0	37°.0	.010—020	.019—.027	.034—.056	.080—.084
WBK—2 Kashikhap Block	444.3	442.0	29°.5	36°.6 (Crystallines)	.008—.010	.024—.027	.022—.030	.066—.099
KB—12 Barkagaon Block	471.2	436.0	50°.0	56°.1	.035	.024	.042—.044	.066
JFT—2 Talgaria Block	1135.7	1110.0	24°.6	46°.6 (Crystallines)	.013—.015	.026—.027	.040—.043	.080—.085
NCRD—4 Surajnagar	1382	1377	24°.4	49°.4 (Crystallines)	.003	.011—.018	.018	.033

factors stated in the preceeding lines. The computed values are as follows :

Nature of formation	*Temperature gradients* (°Centigrade/Metre)
Shale	.010 to .015
Sandstones	.020 to .027
Carbonaceous Shales	.030 to .043
Coal with shale	.055 to .065
Coal	.070 to .098

However, the determination of the heat-flow rates remains incomplete because the instrumentation for measuring thermal conductivity of rock-cores is in the process of development. The cores from boreholes which have been subjected to temperature logging have been preserved carefully, and it is expected that the investigation will be completed within a few months. The present opportunity has been taken to present the interpreted information on the thermal gradients, which can provide some approximate idea as to heat-flow rates in the areas studied.

AREA India Kulu

Geothermal Exploration of the Parbati Valley Geothermal Field, Kulu District, Himachal Pradesh, India

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ABSTRACT

The Parbati Valley geothermal field is divided into five sectors, and out of these a geothermal exploration program has been launched in two sectors—Manikaran and Kasol. This field lies to the southwest of the central crystalline axis where profuse igneous activity has taken place during Tertiary times. This activity appears to be the main source of the heat supply to the field, although contribution of some heat through radioactive disintegration cannot be ruled out. A tear fault with 1-km displacement, picked up in the Parbati Valley, and fractures related to it may provide the ultimate major channels for the upward movement of the hot fluids, while joints in the country rock serve as immediate channels for these fluids.

Spontaneous polarization and resistivity geophysical surveys pointed to the presence of some significant zones of thermal activity and possible shallow subsurface channels for movement of thermal fluids at Manikaran, whereas resistivity surveys pointed to the existence of a shallow hot zone at Kasol.

Surface manifestations of thermal activity at Manikaran and Kasol are in the form of hot springs recording temperatures from 37 to 96°C. The base temperatures of thermal fluids of Manikaran sector as calculated from Na-K-Ca and silica thermometry comes to 197 to 203°C and 131 to 138°C respectively.

The average geothermal gradients in the drill holes at Manikaran vary from +0.12 to +0.14°C/m in the depth range 0 to 76 m, and at Kasol from +0.16 to +1.25°C/m in the depth ranges of 0 to 40 m. Beyond these depths a reversal of gradients is noticed.

INTRODUCTION

The Parbati Valley geothermal field lies in the Inner Himalayan Range at altitudes ranging between 1300 and 3000 m above mean sea level (m.s.l.) and is divisible into five sectors, namely Jan, Kasol, Manikaran, Pulga, and Khirganga (Fig. 1). Hot springs in this field have been known for over a century and a quarter and were first recorded by W. Moorcroft (1841). Subsequently these springs were examined by several workers, but their interest was limited to assessing their therapeutic value and of utilizing this to promote tourism. In 1966, the Government of India constituted a Hot Spring Committee with a view to examining the possibility of development of some of the geothermal fields in the country for generation of power. In 1968 the field party of this Committee, led by Krishnaswamy, examined the hot-spring areas in Parbati Valley and recommended a detailed investigation in order to evaluate the prospects for power generation and to establish the potentialities of this field as a prospective geothermal energy resource.

As a follow-up action on the recommendations made by this Committee, preliminary geophysical studies were initiated at Manikaran-Kasol by the National Geophysical Institute in 1970 and geochemical studies were initiated by the Indian Institute of Technology in 1973. Acting on another recommendation of this Committee, the Government of India approached the United Nations in 1971 for the formulation a United Nations Development Project (UNDP) to help in conducting geothermal studies. Consequently two United Nations experts, Dr. T. Meidav and Mr. J. J. Bradbury, visited some Indian hot spring regions and prepared a project proposal document for undertaking intensified geothermal studies in Parbati Valley and the west coast region. This proposal was accepted in 1973 and the Geological Survey of India, as a chief counterpart Agency during the exploratory phase, launched an integrated geothermal exploration program involving geological, geophysical, geochemical, and drilling techniques in early 1974. This paper presents the results of this exploration conducted at the Manikaran, Kasol, and Jan sectors of the Parbati Valley geothermal field.

GEOLOGY

The Parbati Valley geothermal field lies to the southwest of the central crystalline axis, which runs along the Great Himalayan Range and comprises predominantly foliated gneiss intruded by younger granite (Pascoe, 1973), where profuse igneous activity has taken place during Tertiary times. Stratigraphic succession in a part of the Parbati Valley between Manikaran and Jan (Fig. 2) is given in the Table 1.

The hot springs at Manikaran, Kasol, and Jan are located in the Manikaran quartzite (Devonian) underlying the main central thrust, while those at Pulga and Khirganga are in the overthrust sheet comprised of rocks of Precambrian

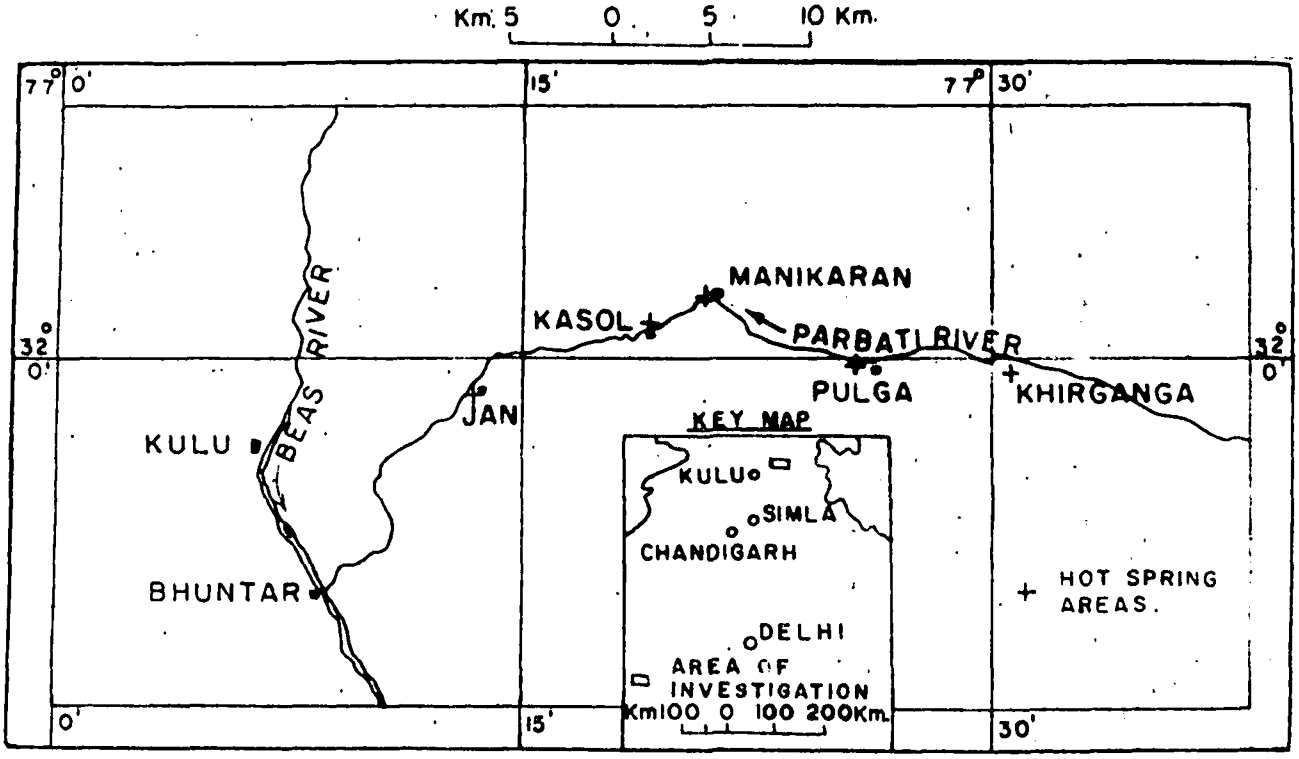

Figure 1. Map showing location of hot spring areas in the Parbati Valley, Kulu District, Himachal Pradesh, India.

Table 1. Stratigraphic succession in a part of Parbati Valley.

Age	Lithology
Recent and Pleistocene	Valley fill and terrace deposits.
Tertiary (?)	Granite
Devonian(?)	Manikaran quartzite: white, grey, greenish, and pinkish quartzite with lenticular bands of greensih chlorite phyllite and a thick unit of carbonaceous phyllite and schist: green chlorite phyllite; lenticular bands of limestone and quartzite.
Lower Paleozoic(?)	Green bed: green basic schist and phyllite; massive trap with amygdaloidal and vesicular structure.
Precambrian (?)	Carbonaceous phyllite and schist with lenticular bands of limestone.

age intruded by younger granitic rocks, some of which may be of possible Tertiary age. The granites of the central crystalline axis of the Himalayas, as well as the granites intruding the Manikaran quartzite, are possibly the source for the heat of the hot-spring waters in the Parbati field.

The Manikaran quartzite is highly jointed, and these joints hold great significance as far as the movement of hot waters at shallow depths at Manikaran, Kasol, and Jan is concerned.

A sinistral tear fault (Fig. 2) along the Parbati River, which displaces Manikaran quartzite and schistose rocks by about 1 km is noticed in the area 6 km downstream of Kasol. Another fault also running along Parbati River is suspected near Jan hot spring.

On geological and structural considerations it could be postulated that the main central thrust and the faults mentioned above as well as the fractures related to these structural features may provide the ultimate major channels for the movement of hot fluids from the deep-seated regions to the surface.

GEOTHERMAL ACTIVITY

Surface Manifestations

Geothermal activity manifests itself in the form of hot springs at Manikaran, Kasol, and Jan with surface temperature varying between 21 and 96°C and the hottest springs being at Manikaran. There are as many as 35 hot springs at Manikaran (Fig. 3 with 27 springs) distributed over a distance of 1.25 km, 13 springs at Kasol (Fig. 4) over a distance of 300 m, and one spring at Jan.

At Manikaran, hot springs generally emerge either from joints in quartzites or through the overburden of the terrace gravel deposit. However, one spring issues near the exposure of the Carbonaceous phyllite tectonically overlying the Manikaran quartzite. The three springs (Nos. 6, 9, and 10) are in the form of spouts with water rising to heights of 30 cm to 1 m, their temperature being 94 to 96°C. Bubbling activity is also noticeable in some springs. Around most of the springs, deposits of aragonite coated with iron oxide have formed. Discharge of water from hot springs varies from a few liters to as much as 600 liters/minute, the total discharge having been estimated at about 1800 liters/minute.

At Kasol, too, the hot springs emerge from quartzite and overburden. The temperature of water from the hottest spring is 76°C. Individual discharge of water from hot springs varies from a few liters to about 100 liters/minute whereas the total discharge is about 175 liters/minute. Encrustations of calcium carbonate and ferruginous staining of the joints in the bed rock are noticeable around some of the springs.

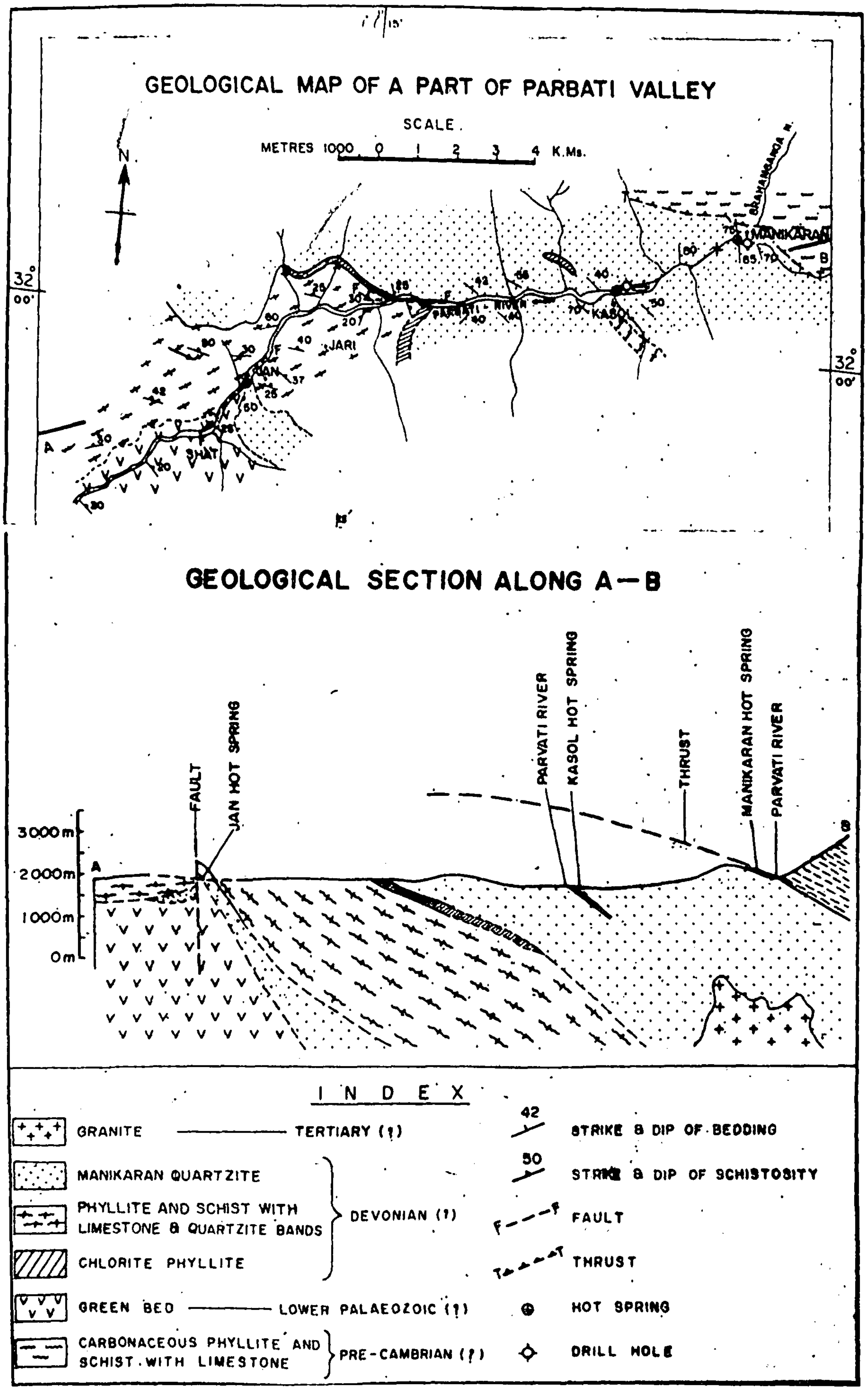

Figure 2. Geological map of a part of the Parbati valley.

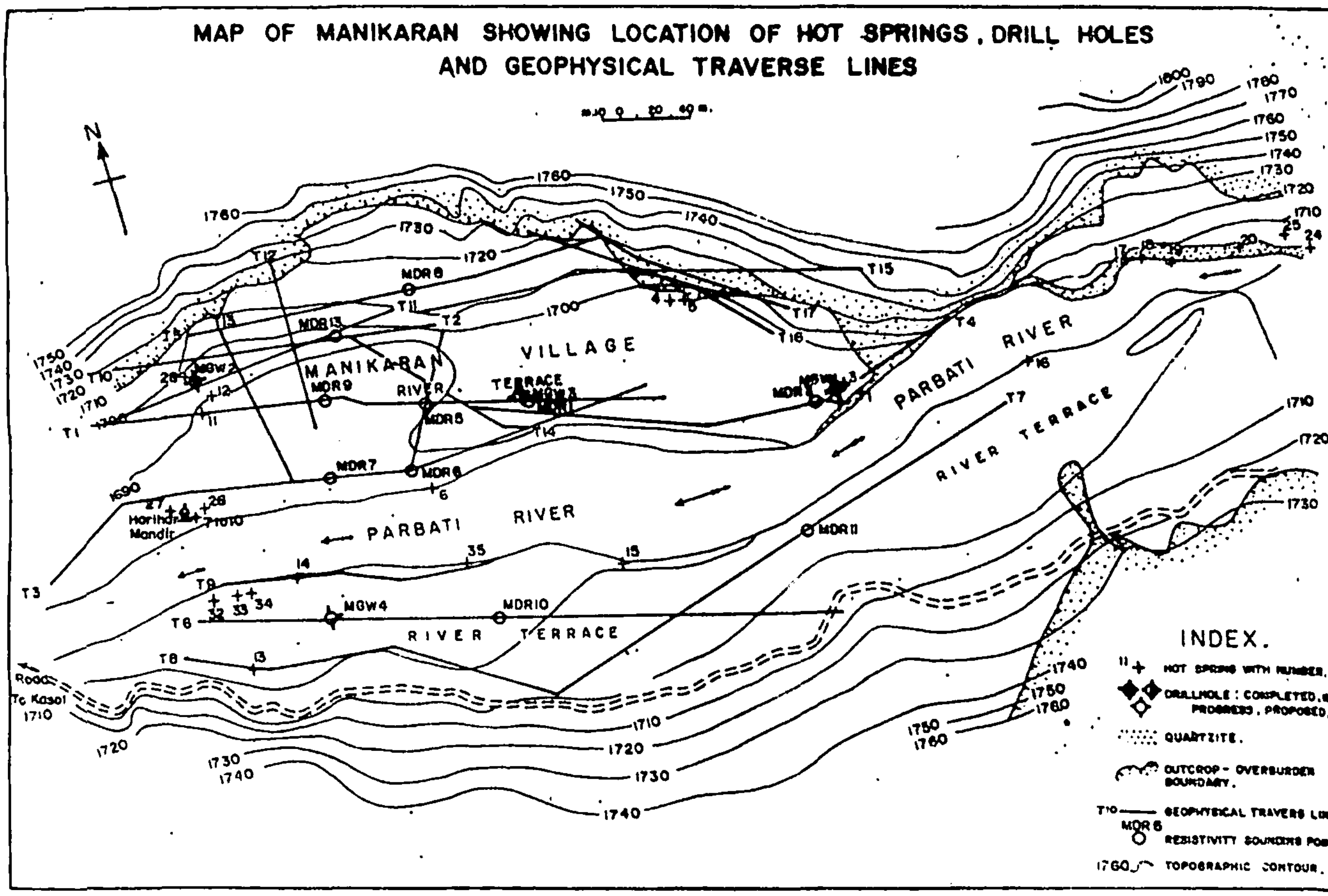

Figure 3. Map of Manikaran showing location of hot springs, drill holes, and geophysical traverse lines.

At Jan only one hot spring is seen emerging from jointed quartzite with 34°C temperature and 300 liters/minute discharge. There is vigorous gas activity in the spring. Deposits of ferruginous matter are noticed in and around the spring.

Subsurface Evaluation

Information on the subsurface geothermal conditions at Manikaran and Kasol is based on the results of the geophysical surveys and exploratory drilling.

Geophysical surveys. The scope of the geophysical surveys was restricted, especially at Manikaran, by the limited working space, rugged topography, and proximity of the turbulent Parbati River, which flows through the hot-spring area.

The spontaneous polarization surveys at Manikaran brought to light five zones of positive 'high', their closures having peak values of +414 mV, +236 mV, +311 mV, +170 mV, and +200 mV on the traverse T10, T10, T17, T3, and T6 (Fig. 5) respectively. On the basis of experience gained at Puga, Ladakh, all such closures could be inferred to indicate the existence of relatively hot ground underneath. Some of these positive self-potential (SP) closures are associated with low resistivity (10 to 50 ohm·m) and a substantial electromagnetic anomaly.

Twelve vertical electrical soundings were conducted which employed a Schlumberger electrode configuration with a maximum electrode separation (AB/2) of 100 m, and these indicated the presence of a low-resistivity layer (5 to 20 ohm·m) varying in thickness from 5 to 30 m overlying the resistive basement (quartzite). This low-resistivity layer may represent the unconsolidated valley fill material, possibly saturated with hot fluids. Some typical sounding curves are reproduced in Figure 6. The results of resistivity profilings with 40 m electrode separation (Wenner configuration) indicate certain north-south trending low-resistivity zones, which could be interpreted as representing the channels of hot water at shallow depths. These findings are in agreement with the results of resistivity surveys carried out by National Geophysical Research Institute. Magnetic surveys carried out at Manikaran did not bring to light any significant anomaly associated with thermal activity.

On the basis of the electrical resistivity surveys carried out at Kasol, a low-resistivity zone of 40 to 100 ohm·m in the overburden was demarcated (Figs. 4 and 6). This zone of low resistivity is associated with comparatively lower values of 700 to 1120 ohm·m for the bed rock, which otherwise indicates a resistivity varying from 300 ohm·m to infinity, the normal overburden resistivity being of the order of 170 to 60 000 ohm·m. The thickness of the zone of low resistivity in the overburden varies from 15 to 40 m. The upper and lower limits of the depth range of this zone are 1 m and 48 m respectively. It is likely that the low-resistivity zone demarcated represents a part of the probable hot zone.

Refraction seismic and electrical resistivity surveys revealed that the depth of bed rock at Kasol varies, in general, between 12 and 115 m. The overburden thickness contours (Fig. 4) brought to light a depression in the bed rock towards

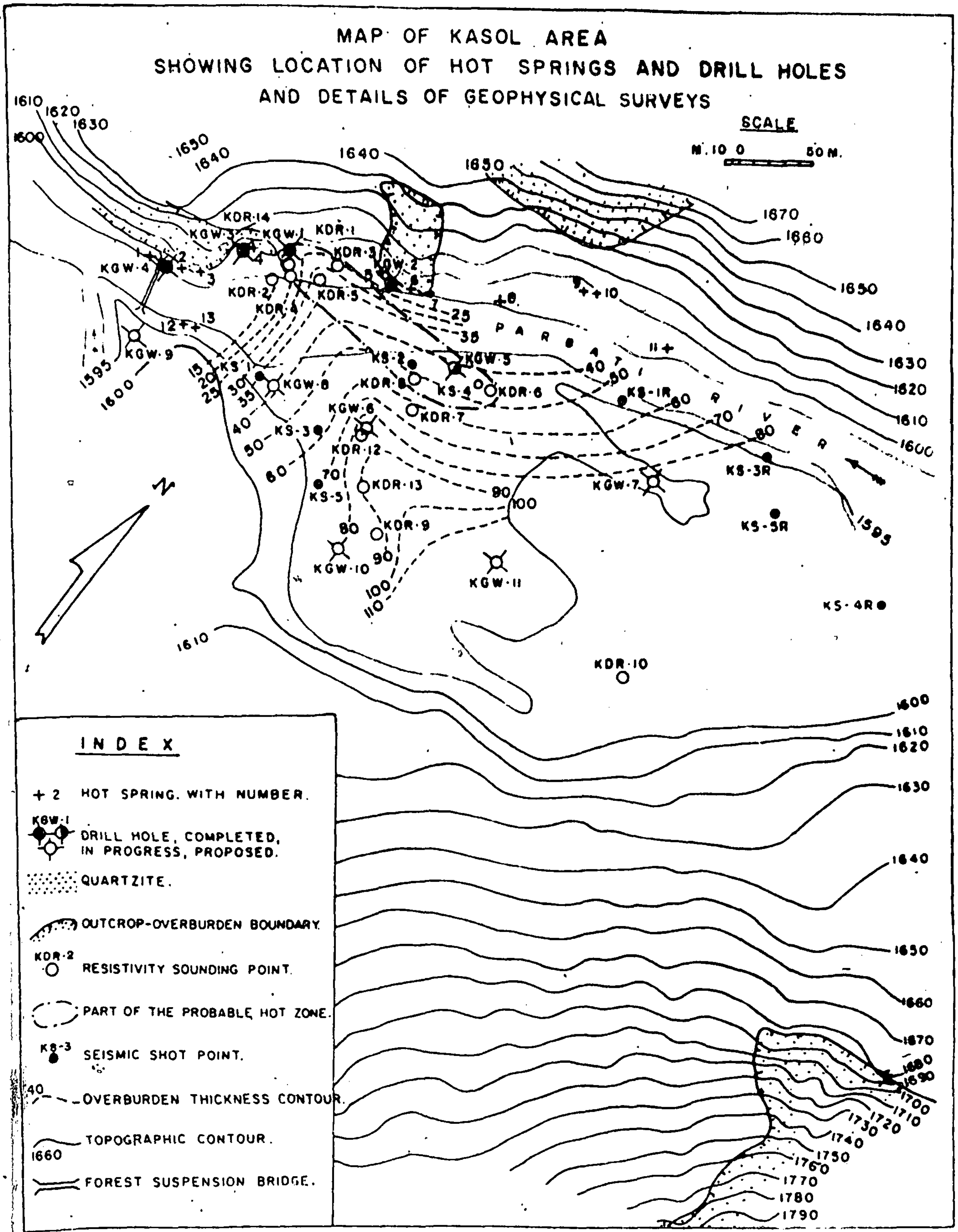

Figure 4. Map of Kasol area showing location of hot springs and drill holes and details of geophysical surveys.

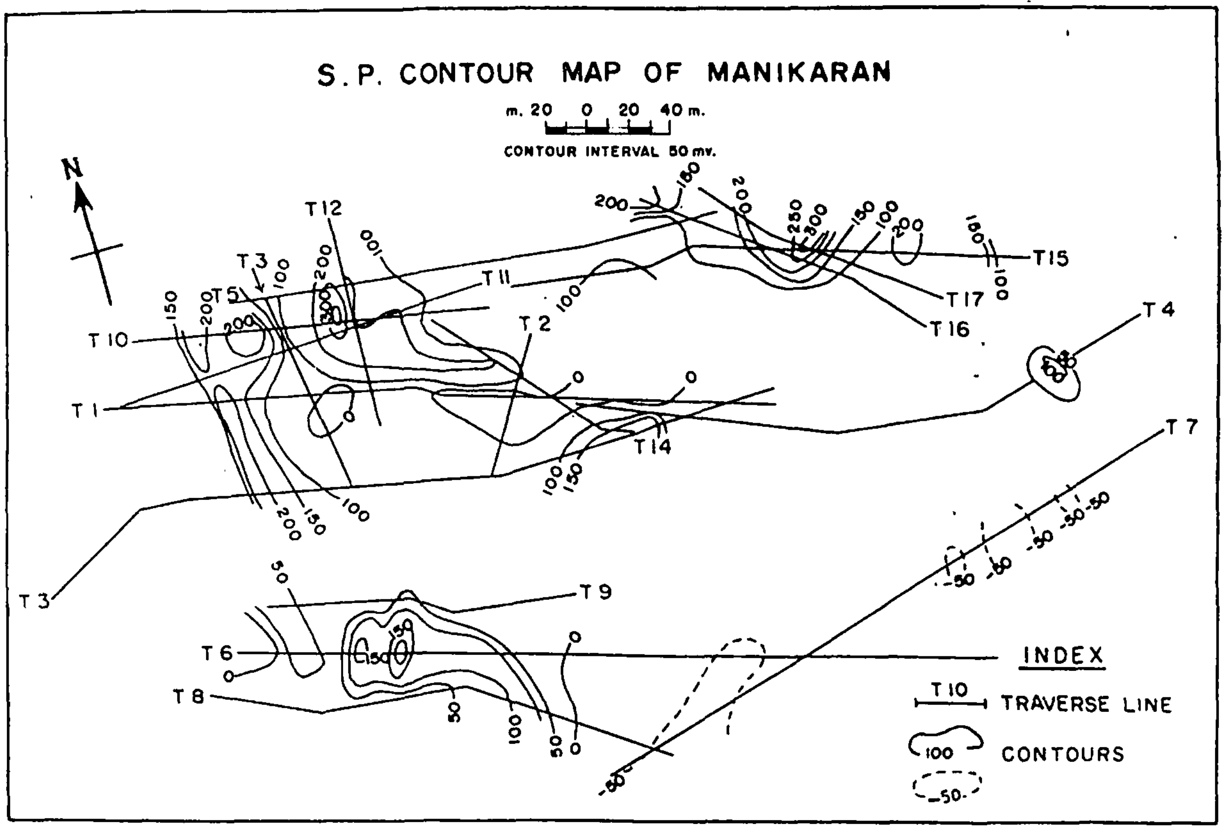

Figure 5. Self-potential contour map of Manikaran.

the eastern part of the area, the plunge in the contours coinciding with the low resistivity zone.

Exploratory drilling. Exploratory drilling was undertaken at Manikaran and Kasol for making a geothermal gradient evaluation, exploring the structural control for geothermal activity, and testing the zones of promising geophysical anomalies. Two holes at Manikaran and four holes at Kasol have been completed up to the end of March, 1975.

Out of the six holes drilled, hot water under artesian conditions was struck in four, the details of which are given in Table 2.

The artesian flow of hot water from some of the drill holes appears to have resulted from piercing of the joint-controlled, confined hot-water channel or channels existing at shallow depths. The increase in the discharge of hot water in some of the holes may be attributed to the interception in the drill hole of some other hot water channel or channels at greater depths.

The average geothermal gradients as well as the actual temperatures recorded in the drill holes in Manikaran and Kasol are presented in Table 3. It may be mentioned here that due to lack of measuring equipment, the temperature measurements on the holes in which hot water was struck under artesian conditions were taken after the hot water started flowing out of these holes.

Table 3, as well as the temperature-depth curves for the drill holes (Fig. 7) indicate that the geothermal gradients in all the drill holes showed a negative trend beyond certain depths, probably because of having crossed the zones conducting hot water. The drill hole MGW-2 showed positive gradients in two different depth ranges with a zone of negative gradient in-between, indicating thereby that a channel or channels bearing hot water were intercepted in this hole at two different levels.

HYDROLOGICAL CONDITIONS

In the Manikaran and Kasol thermal areas two distinct hydrological units can be recognized. The first unit, comprising river terraces, valley fill material, and alluvial cones, contains water under unconfined conditions. This unit at Manikaran has a thickness of about 30 m, and at Kasol about 40 m to 120 m. The second hydrological unit comprises hard rock, that is, quartzite and associated phyllites. The quartzite is highly jointed and fractured, and forms the base for the first water-bearing unit. This hydrological unit, on account of being thousands of meters thick and having a network of interconnected joints and fissures, forms the main potential ground-water reservoir and permits deep circulation of meteoric water. Both the aquifer units receive recharge from surface precipitation as well as from melting snow at high altitudes. The area receives good snow and rainfall, the annual average rainfall being of the order of 100 to 120 cm. The thermal areas get their recharge mainly from the second unit. The possibility that the water from Parbati River may to some extent recharge the thermal-water system is not ruled out.

The model of the hydrothermal system in the Manikaran-Kasol area envisages that cold meteoric water from high catchment areas descends underground through joints and structurally weak zones. This water gets heated by coming into contact and mixing with ascending magmatic fluids at depth and also by conductive heat flow in bed rock and moves upward along the available channels to the reservoir

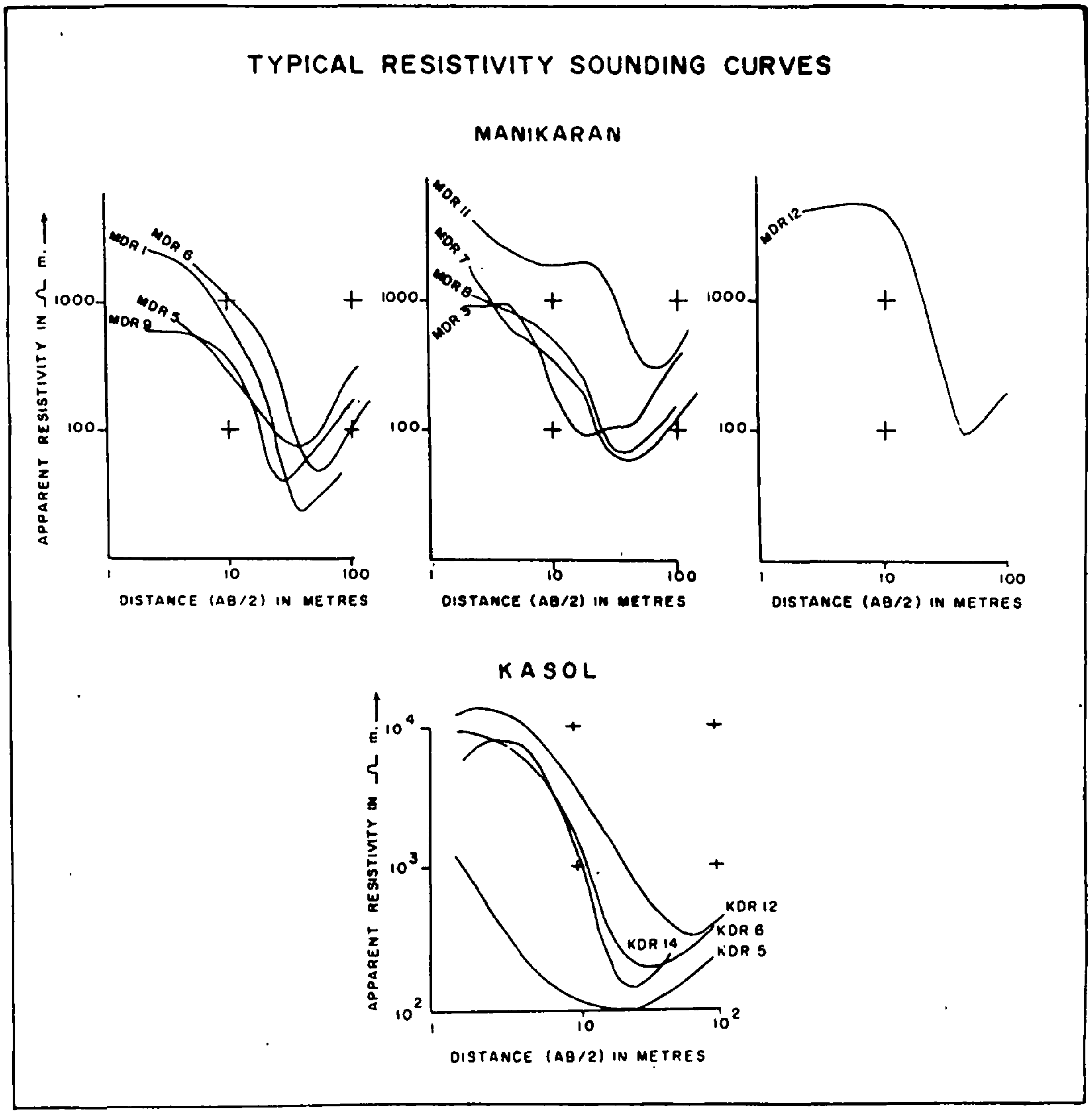

Figure 6. Typical resistivity sounding curves, Manikaran and Kasol.

Table 2. Details of artesian conditions struck in the drill holes.

Hole No.	MGW-1	MGW-2	KGW-1	KGW-2	KGW-3	KGW-4
Depth drilled (m)	126.45	122.45	136.15	120.15	72.67	120.00
Depth at which artesian conditions were struck (m)	36.66	56.85	–	21.00	–	24.00
Depth to bed rock (m)	5.30	2.45	20.00	5.48	6.75	8.95
Temperature* (°C)	83	92	–	62	–	72
Discharge* (liters/minute)	40	150	–	10	–	5
Variation in discharge (liters/minute)	40–90	150–160	–	10–200	–	5–10

*Measurements taken when artesian conditions were struck.

of hot fluid which is feeding the springs and well discharges under favorable conditions.

GEOCHEMISTRY

The results of the chemical analysis of the water samples collected by the authors from the hot springs in Manikaran, Kasol, and Jan and also from drill hole MGW-1 have yielded information about the composition and type of thermal waters, their likely source of heat, and their base temperatures. Water samples from the Parbati River were also analyzed for a comparative study of river water with thermal water. A few representative analyses are tabulated in the Table 4.

Table 3. Average geothermal gradients in drill holes.

Hole No.	Depth range (m)	Gradient (°C/m)	Temperature (°C)
MGW-1	0–34	+0.12	77–81.10
	34–38	0	81.10
	38–112	−0.21	81.10–65
MGW-2	0–76	+0.14	92–103
	76–84	0	103
	84–96	−0.04	103–102.5
	96–100	+0.13	102.5–103.0
KGW-1	2–40	+1.25	24–71.6
	40–43	0	71.6
	43–100	−0.44	71.6–46.6
KGW-2	0–30	+0.16	72–76.75
	30–54	0	76.75
	54–78	−0.18	76.75–72.5
KGW-3	2–26	+0.91	51–72.80
	26–45.50	−0.51	72.80–62.75
KGW-4	0–22	+0.2	52–56.60
	22–68	−0.22	56.50–46.50
	68–80	0	46.50
	80–90	−0.12	46.50–45.30

Waters from all but one hot spring at Manikaran are near neutral to weakly alkaline, with a pH value ranging from 7.5 to 8.1, the lone exception being spring No. 7 (pH 6.1), which is weakly acidic. In general, the chemical constituents in the thermal water in decreasing order of concentration are: cations—Na, Ca, K, and Mg; and anions—HCO_3, Cl, SiO_2, SO_4, and F. On the basis of dominant cations and anions the Manikaran thermal water is generally of the sodium-calcium-bicarbonate-chloride type. Special mention may here be made of spring Nos. 13 and 29, in which the water is of calcium-bicarbonate type and calcium-magnesium-bicarbonate type, respectively.

Waters from Kasol hot springs are near neutral to alkaline with pH values ranging from 7.2 to 7.9. The concentration of chemical constituents in decreasing order of predominance is cations—Ca, Na, Mg, and K; and anions—HCO_3, SiO_2, SO_4, Cl, and F. On the basis of the dominant radicals present the thermal water is of calcium-sodium-magnesium-bicarbonate type. Thermal water at Jan is acidic with a pH value of 5.8. The concentration of constituents present in the water indicates that it is of the sodium-chloride type. Water from Parbati River is near neutral with a pH value of 6.8. It is of the calcium-bicarbonate type.

A comparative study of the results of chemical analysis indicates that the concentration of Na, K, Cl, SiO_2, B, and F progressively decreases in thermal waters from Manikaran to Kasol to the Parbati River. This observation is interpreted as indicative of a greater admixture of surface water with original hot fluid in Kasol than at Manikaran. Compared to Manikaran and Kasol hot-spring waters, the Jan thermal water is characterized by the dominance of Na, Ca, K, Mg, SO_4, Cl, and total dissolved solids. Of particular significance is the predominance of Na, Cl, and total dissolved solids, which in all likelihood points to the nearness of some major hot-water channel.

Critical weight ratios and constituent concentrations in the three hot spring regions examined are tabulated in Tables 5 and 6 respectively. The corresponding values for typical volcanic hot-spring waters as obtained by White (1966) are also given for comparison.

A study of Tables 5 and 6 indicates that by and large these hot spring waters resemble the volcanic type of thermal water, this resemblance being greatest in the case of Jan, followed by Manikaran and Kasol. Higher values of Ca+Mg/NA+K and HCO_3/Cl, and a lower concentration of total dissolved solids is attributed to the admixture of

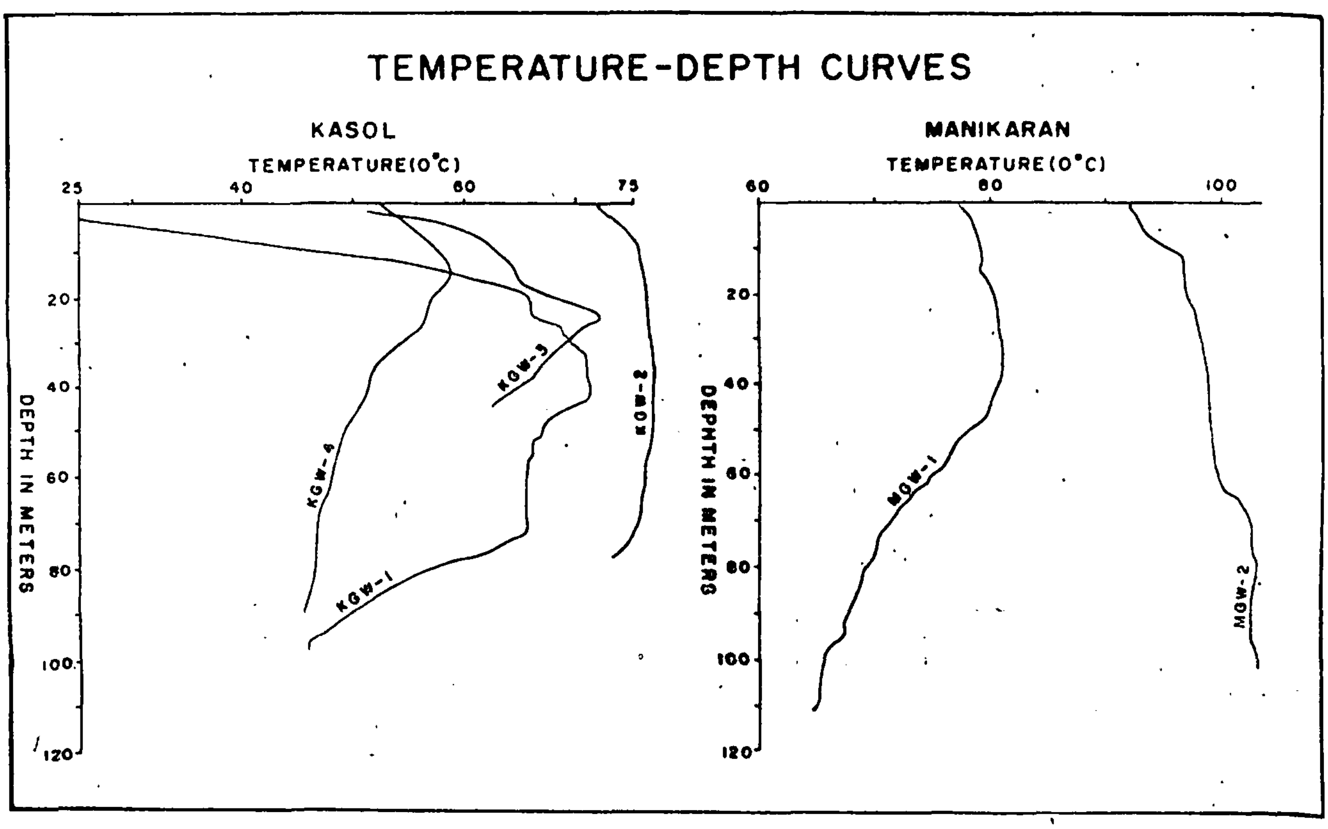

Figure 7. Temperature-depth curves, Kasol and Manikaran.

Table 4. Results of the chemical analysis of water samples.

	Manikaran									Kasol				
	Hot springs 1	4	7	10	11	13	20	29	Drill hole MGW-1	Hot springs 2	2a*	3	Jan hot spring	Parbati River
Temperature (°C)	87	87.5	96	96	82	37	77	45	77	75	70	76	34	8
pH	7.5	7.6	6.1	7.5	7.7	8.1	7.5	7.5	7.9	7.4	7.2	7.9	5.8	6.8
Specific conductivity at 25°C in μ mho/cm	678	735	839	850	850	413	597	517	551	586	597	586	2110	63
CO_3	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
HCO_3	235	235	246	287	258	199	205	258	129	246	246	246	284	23
Cl	74	84	90	90	105	18	67	7	53	46	46	46	418	6
Total hardness as $CaCO_3$	134	144	172	172	152	171	134	210	116	225	225	235	363	39
Ca^{2+}	47	47	51	56	53	56	47	55	36	54	58	56	70	9
Mg^{2+}	4	6	10	9	5	8	4	17	6	22	19	23	45	4
Fe	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
SiO_2	90	100	90	90	90	30	100	45	60	55	60	60	24	6
F	0.8	1.0	0.8	0.8	0.8	0.2	0.6	1.0	0.6	0.4	0.3	0.3	—	<0.2
B	2.6	2.4	3.0	226	3.0	0.7	2.4	1.9	2.0	2.5	1.8	2.4	—	1.3
NO_3	0.5	0.5	Trace	0.25	0.25	0.25	0.25	Trace	<0.25	Trace	0.25	<0.25	<0.25	Trace
NO_2	0.008	0.032	Trace	Trace	0.08	Trace	0.001	Trace	<0.009	0.004	Trace	0.001	0.003	Trace
NH_3	0.16	0.24	0.28	0.40	0.24	Trace	0.16	0.05	—	0.06	Trace	0.06	0.36	Trace
SO_4	31	30	38	34	34	56	39	41	28	50	53	50	67	Trace
Na	90	94	95	96	100	12	64	16	40	37	58	40	210	2
K	18	18	19	19	18	5	14	6	12	10	11	10	28	2
Total dissolved solids	448	470	548	565	552	290	406	322	351	386	410	395	1038	48
Uranium in ppb†	—	—	2.1	0.7	1.0	—	—	—	0.7	4.9	—	4.9	—	—

Note: All values in ppm except when mentioned otherwise.
*Spring 2a is very close to spring 2.
†Data supplied by Shri T. M. Mahadevan, Atomic Minerals Division, Dept. of Atomic Energy.

Table 5. Weight ratios of chemical constituents in hot-spring waters.

Ratios of constituents	White's range for volcanic hot spring	Manikaran hot spring	Kasol hot spring	Jan hot spring
SO_4:Cl	0.01–0.5	0.32–0.58	1.15	0.16
HCO_3:Cl	0.01–3	2.37–3.18	5.34	0.68
B:Cl	0.01–0.1	0.0286–0.0389	0.0391–0.0343	—
F:Cl	0.0005–0.1	0.007–0.012	0.006–0.008	—
K:Na	0.03–0.3	0.18–0.2	0.25	0.13
$\frac{Ca + Mg}{Na + K}$	0.001–0.2	0.47–0.65	1.6	0.48

Table 6. Constituent concentration in hot spring waters.

Chemical constituents	White's range	Manikaran	Kasol	Jan
Ca	1–100	47.56	54.58	70
Mg	0.1–10	4–10	19–23	45
SiO_2	100–700	90–100	55–60	24
Total dissolved solids	1000–5000	448–565	386–410	1038

cold river water at shallower levels. Thus on geochemical considerations, it could be concluded that thermal waters of Jan, Manikaran, and Kasol receive significant contributions from magmatic sources, and the dilution by surface water is maximum at Kasol, followed by Manikaran and Jan. Krishnaswamy (1965) also suspected a magmatic source for the Parbati valley thermal springs. Chemical studies conducted by the National Geophysical Research Institute also indicated the association of magmatic components with thermal springs at Manikaran.

Sodium-potassium-calcium thermometry and silica thermometry have been applied to estimate the base temperatures of the thermal fluids at Manikaran, Kasol, and Jan, and the ranges of the base temperatures arrived at are given below:

	Manikaran	Kasol	Jan
Na-K-Ca thermometry	197–203°C	182–207°C	194°C
Silica thermometry	131–138°C	106–110°C	72°C

Alkali thermometry is not applicable for estimating base temperatures for the ratio $\sqrt{MCa}/MNa$ is greater than one.

Silica thermometry has yielded a correspondingly much lower base temperature, but Na-K-Ca thermometry is considered to be much more reliable than silica thermometry. High base temperatures as indicated above indirectly support the conclusion drawn earlier that the heat is partly derived from magmatic sources.

The uranium content in the thermal waters of Manikaran and Kasol is 0.7 to 2.1 ppb and 4.9 ppb (T. M. Mahadevan, personal commun.) respectively. Such a low concentration of uranium in the thermal waters suggests that the contribution of heat to the thermal system from disintegration of radioactive minerals is not significant, although radioactive mineralization is known to occur in the nearby area.

FUTURE PLAN OF WORK

Six more shallow exploratory drill holes at Kasol (Fig. 4) and one at Manikaran (Fig. 3) are proposed to be drilled for geothermal gradient evaluation, testing of some geophysical anomaly zones, and delimiting the thermal areas.

Geophysical and drilling work for establishing thermal gradients has to be taken up at Jan for evaluation of geothermal conditions. Preliminary geological, geophysical, and geochemical studies have to be carried out at Pulga and Khirganga. Subsequent drilling to deeper levels for exploring the major channels for the migration of thermal fluids, as well as for possible geothermal reservoirs, has to be taken up at Kasol and Manikaran.

UTILIZATION

A quantitative assessment of the discharge of thermal fluids from the drill holes and hot springs at Manikaran and Kasol is currently under way. It is likely that the thermal discharges, if proved to be in sufficient quantity, may be utilized for installing a freon-based geothermal power plant and also for setting up a refrigeration plant on the ammonia-water absorption system.

CONCLUSION

The acid igneous activity of Tertiary age associated with the central crystalline axis and with the Manikaran quartzite is believed to be the main source of heat for the thermal fluids in the Parbati field. Concentration of chemical constituents in the hot waters and high base temperatures deduced from Na-K-Ca thermometry are indicative of a partly magmatic origin for the heat of these fluids.

On the basis of the exploration carried out so far, it has not been possible to pick out any major channel which is controlling the upward migration of thermal fluids from the deeper levels. However, it is likely that the three structural features, namely, the tectonic contact between Manikaran quartzite and carbonaceous phyllite/schist, the tear fault detected 6 km downstream of Kasol, and the fault suspected near Jan hot spring, as well as the fractures associated with these features, may be acting as the ultimate channels for the movement of thermal fluids. Further exploration may throw light on this aspect of the geothermal field.

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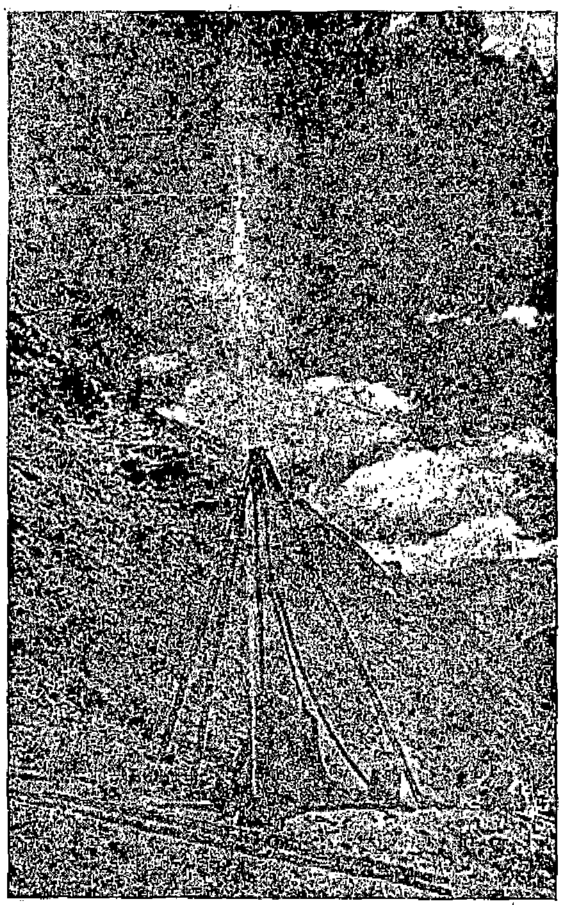
Geothermal Resources Development
GSI Leads Expedition to Puga Valley, Ladakh

The Hot Springs Committee, set up by the Govt. of India in 1966 for investigating



Gusher of steam and hot water, 15 m. high, from a shallow borehole, drilled by GSI in 1970-71.

into the possibilities of the utilisation of geothermal energy, examined the data of about 250 known hot springs in India for evaluating their potentiality as a possible source of geothermal power and based on the available data assigned a high priority to the detailed investigation of the Puga Valley in the Ladakh district of Jammu & Kashmir and Manikaran in the Parvati Valley of Himachal Pradesh, the most prospective hot spring regions in the north-western Himalayas. More recently, the National Committee on Science and Technology, through its Sub-Committee on Geothermal Resources, endorsed the opinion of the Hot Springs Committee and proposed a few long term and short term projects for the exploration of the geothermal resources of the country, in which the Puga area had the highest priority.

Puga Geothermal Field

The Puga Valley, located at an altitude of 4,600 m., is well known for over a century for its thermal manifestation in the form of a series of hot springs and sulphur and borax occurrences. The surface temperature of the springs varies from 50° to 83°C, the latter being the boiling point of water at stated altitude. A maximum temperature of 110°C was recorded in 1970-71 in one of the 17 boreholes drilled by the Survey to a depth of 22 - 50 m., under its programme of exploration of sulphur and borax in the valley, carried out under the guidance of Dr. M. K. Roy Chowdhury, the present Director General of the Survey. A pressure exceeding 7 atmospheres was also recorded in one of the boreholes at shallow depth.

Encouraged by the above findings and also in pursuance of the recommendations of the Hot Springs Committee (1968) and of the Geothermal Resources Exploration Sub-Committee of the National Committee on Science and Technology (1972), the Geological Survey of India has taken the lead in resources development activity by formulating a well defined project of short duration for 3—5 years for establishing the power and other mineral potentialities of the Puga area. The Survey has put into action a multi-disciplinary multipurpose project utilising the latest techniques and expertise available in the country, both in the Survey and in the other leading scientific organisations, like the Atomic Minerals Division of the Department of Atomic Energy, the National Geophysical Research Institute, Hyderabad, the Earthquake Engineering School, Roorkee and the Indian Institute of Technology, Kanpur.

Objectives

The project has been taken up with the following objectives.

1. To study the potential of the area for generation of geothermal power by carrying out detailed geological, geotechnical, geophysical and geochemical surveys and prospecting, drilling *etc.*

2. To analyse the data obtained from the above for the preparation of a project report for geothermal power generation and define the quantum of work required in the second phase of operation.

3. To study the potential of the geothermal field for chemical industries, green house cultivation and heating purposes.

4. To study the Quaternary geology and geohydrology of the Puga basin from the point of view of possible geothermal application.

5. To study in depth the sulphur and borax occurrences, evidences of base metal mineralisation and radioactivity in the area, for an assessment of their potential for development.

[*Continued on page 8*]

Expediton to Puga

from page 3

6. To study the related geological aspects for facilitating regional assessment in not only this area but also in other Himalayan areas.

Operational Plan

In order to achieve the above objectives, the Survey has organised the work on expedition basis to a difficult terrain at a high altitude with the active support and help of the Ministry of Defence, the Border Roads Organisation and the various agencies of the State Govt. Base camps and transit camps have already been established at Chashma Shahi, Kangan, Sonamarg, Kargil and Leh. The expedition commenced its operation, with the opening of the Zogila pass in the first week of June, 1973, under the overall guidance and co-ordination of Shri V. S. Krishnaswamy, Deputy Director General, ably supported by Shri G. M. Banerjea, Director, Kashmir Circle as the Dy. Co-ordinator.

The team comprises 55 earth scientists, engineers and technicians and about 60 supporting staff of the Survey. 15 scientists and technicians of the collaborating organisations will also be working with the project for different periods. The team will work in 14 parties representing different disciplines of the geosciences.

The *fundamental geological studies* will engage four parties carrying out field checking of the photo-geological maps and systematic geological mapping on scale 1 : 50,000, besides studying the Himalayan granites, the rocks of the Indus-Ophiolite suite, the reported carbonatites and also the major thrusts and faults.

The *applied geological studies* will include (a) evaluation of geothermal resources and (b) evaluation of mineral resources.

The evaluation of the geothermal resources will be carried out by 7 parties representing the seven disciplines of the Earth Sciences, *viz.*, Geotechnics, Quaternary Geology & Geohydrology, Geothermics, Radiometrics, Geoseismics, Geophysics and Geochemistry. Excepting the Geothermics party of the National Geophysical Research Institute, the Radiometrics party of the Atomic Minerals Division and the Geoseismics party of the Earthquake Engineering School, the other four parties will be manned by the officers of the Survey. The Geochemistry party of the Survey will have a Mobile Chemical Laboratory and will be supported by two geochemists from the Indian Institute of Technology, Kanpur who will conduct studies on special aspects of geothermal thermometry and isotopy as related to geothermal development.

The Drilling party of the Survey, includes a mobile workshop and two truck-mounted drilling machines. An experienced Drilling Engineer has been trained in Italy for carrying out work in high temperature and high pressure conditions, as obtains in the present area. About 500 m. of exploratory drilling are planned for the 1972-73 season, ending in mid-October, 1973.

The evaluation of the mineral resources will be carried out by 2 parties from the Survey for the study of sulphur and borax occurrences of Puga, potash and other evaporites of the adjacent lakes and for the study of the prospects of base metal and radioactive minerals in the area.

Outlook

The data proposed to be collected during the operation of the Puga multi-disciplinary and multipurpose project are expected to cover all the important facets of Earth Sciences. On completion of the first phase of the work planned for 1973, sufficient background information is expected to be available for planning the second phase of the geothermal and mineral evaluation studies of the area.

If this concerted effort bears fruit and if it is established that power can be produced and transmitted economically to Leh, the project would have made a positive contribution to the fuel requirement of the Defence personnel in the area, which have now to be transported over a long distance of 400 km. by road in the absence of fossil-fuels in the area and due to the high cost of hydro-power generation.

In addition, the recent development in the fields of plate tectonics, continental drift and mineral genesis have suggested the possibility of encountering base metal and other mineralisation in and around the Puga valley, as the area is located at the junction of two continental plates, with a zone of subduction represented by the Indus Suture line. Besides, the reported occurrence of suspected carbonate plugs have suggested the possible occurrence of other minerals of great utility.

The Puga multi-disciplinary multi-purpose project is, thus, truly a National exploration endeavour and if favourable results are obtained, would go a long way towards providing a sound base for sustaining the development of a very important but economically backward region of our country.