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GEOTHERMAL ENERGY RESOURCES OF INDIA: COUNTRY UPDATE

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ABSTRACT

All the geothermal provinces of India are located in areas with high heat flow and geothermal gradients. The heat flow and thermal gradient values vary from 75–468 mW/m^2 and 59–234°C respectively. Additional exploration studies and reservoir modelling have been carried out between 1995 and 1998 to understand the reservoir characteristics. Thermal gas discharges from several thermal provinces recorded high helium concentration varying from 0.5–6.9%. Gas data, together with heat flow and thermal gradient data, suggests the presence of granites and related intrusives with high U concentration (0.19–10.7%) in these provinces. Many such provinces are also best suited for HDR projects. High ^{4}He content in the thermal gases is obliterating the presence of primordial helium. Pilot power plants, commissioned at certain thermal discharge sites, proved the power generating capacity of these provinces. The estimated power generating capacity of the thermal discharges is about 10,600 MW. The available geophysical and geochemical data are sufficient to identify sites for undertaking deep drilling projects, and to commission binary power plants. Many independent power producers are keen to collaborate with foreign financial institutions to develop geothermal energy sources in rural India. With the existing environmental problems associated with coal based mega power projects, and with incentives given to develop non-conventional energy sources, the future of the Indian geothermal energy program is bright.

1. INTRODUCTION

The seven major geothermal provinces of India, enclosing nearly 400 thermal springs, are associated with mid-continental rifts, subduction, sedimentary basins and Cretaceous-Tertiary volcanism (Fig. 1). These provinces include i) The Himalayas, ii) Sohana, iii) Cambay, iv) Son-Narmada-Tapi rift zone (SONATA), v) West coast, vi) Godavari, and vii) Mahanadi. With the recent volcanic eruption, the Barren island has become one the most important geothermal provinces in the Indian subcontinent. The estimated energy from one third of these springs is of the order of 40.9x10^{18} calories. This is equivalent to the energy that can be obtained from 5.7 billion tonnes of coal or 28 million barrels of oil. If these energy resources are developed for a medium to low temperature application it will substitute about 10,600 MW of power (Ravi Shanker, 1996). The estimated power shortfall in India at present is about 5000 MW and it could rise to about 43,000 MW in the next five years. To decrease this supply-demand gap, renewable energy sources have been given increased importance during the last few years. Thus, wind energy is expected to generate about 1000 MW, biomass about 140 MW, small hydro power about 172 MW and solar about 810 MW of power. Though geothermal energy sources can potentially generate 10,600 MW of power, they have not been exploited to date. Additional exploration studies on thermal gases from these geothermal provinces have been carried out since 1996 in order to understand the reservoir characteristics. In addition, Deep Seismic Sounding (DSS) profiles were carried out across several geothermal provinces (Son-Narmada-Tapi; West coast and Cambay) to understand the crustal structure below these thermal provinces. Several potential sites were identified for further exploration through deep drilling. Private power producers are keen to develop this source with financial partners from other countries.

2. EXPLORATION ACTIVITIES

Exploration activities in terms of geochemical studies on thermal gases, computer simulations and geophysical data acquisition, are being carried out in some of the most promising geothermal fields, like the Puga, Manikaran, Tattapani, Cambay, and the West coast. Work on other thermal provinces is yet to make a beginning.

2.1 Geochemical studies on thermal gases and waters

After the oil crisis in the 70's, a reconnaissance survey by the U.N. organization and the Geological Survey of India, on a majority of thermal springs were carried out, the results of which are reported in the "Geothermal Atlas of India" (G.S.I., 1991). Since then, focussed studies on the geological, tectonic and geochemical characteristics of the springs suggest that some of them can be exploited for power generation and for direct utilization by industries (Ravi Shanker, 1991; Chandrasekharam, et al., 1992; Chandrasekharam and Antu, 1995; Chandrasekharam et.al., 1996; Chandrasekharam and Prasad, 1998; Pitale and Padhi, 1996). Although several authors have reported chemical and isotopic data on the thermal springs (Giggenbach, 1976; Giggenbach et al., 1983; Gonfianti, 1977; Nevada and Rao, 1991; Chandrasekharam et al., 1989, 1997), studies on the associated gas phase can be considered practically missing. In order to fill this gap, as a part of a collaborative project between the Department of Sciences and Technology, Govt. India and the Ministry of Foreign Affairs, Italy , two extensive sampling campaigns on thermal waters and associated gas emissions were carried out in 1997 and 1998, in three of the most promising geothermal provinces, i.e. i) the West coast, ii) the eastern boundary of the Cambay basin, and iii) along the Son-Narmada-Tapi lineament (SONATA), which represents the most important E-W mid-continental structure. The gases from these provinces are rich in N_2 and Ar, which are apparently atmospheric in origin. The most remarkable finding is the high ^{4}He concentration in these gases which range from 0.5–6.9%. Such a high ^{4}He concentration in the thermal gases is suppressing the mantle ^3He, thereby registering a low R/R_A ratio. Deep and prolonged circulation of thermal waters, and the presence of anomalous geothermal gradients, have been recorded in the above three provinces (Chandrasekharam et al., 1997; Casiglia et al., 1999). Such a high ^4He is apparently due to the presence of a large reservoir of He in the Precambrian rocks lying below the Deccan trap cover. Similar He concentration (1.4–2.77%) in the thermal waters from the Bakreswar geothermal province in West Bengal has been reported by the Atomic Minerals Division (Nagar et al., 1996). Even the soils around this geothermal province have registered anomalously high He concentration (46.6–82.8 ppm). Like in the above three geothermal provinces, high helium concentrationin thermal waters in Bakreswar, is obviously being produced by decaying U and Th in the Precambrian crystallines. This is further supported by heat flow value of 145–200 mW/m^2 for this province, a value which is greater than twice the average global value, and is similar to the value reported for young spreading ocean ridges, such as the Red Sea ridge axis (Gettings et al., 1986). Similar heat flow values have been reported for the Godavari geothermal province. Geochemical exploration carried out in the Godavari geothermal province indicates two promising areas, i) the Bugga, and ii) Manuguru, for geothermal energy development. The thermal reservoir here appears to be the Talchir sandstone (Gondwana Super group), a secondary reservoir with storage capacity of 35 million cubic meters. With surface flow rate of 1000 l/min, the reservoir, with power generating capacity of about 38 MW, should yield thermal waters for 75 years (Chandrasekharam and Jayaprakash, 1996).

The geothermal province which is unexplored is the Barren Island volcano. This volcano, located over a trench in the Andaman sea (12^o 17' 30" N; 93^o 52' 30" E) is the only active volcano on the Indian subcontinent. Captain Blair, the founder of the harbour (Port Blair) in the Andamans, reported violent activity of the volcano in 1789. Barren is a tiny island, 7.8 km^2, in an area with a maximum elevation of 350 m. It is located 116 km ENE of Port Blair. This volcano erupted in 1991 after lying dormant for two centuries. Olivine basalts erupted during the first phase of eruption and the second phase was dominated by high alumina basalts (Haldar et al., 1992). Its eruption coincided with that of Mt. Pinatubo of Philippines and Mt. Unzen of Japan. Super heated steam and gas started emanating from the volcano since 1950s (Raina, 1987). A number of centres with fumerolic activity and thermal manifestation are seen around the volcano as well as within the crater (Bandyopadhyaya et al., 1973). Detailed geothermal exploration activity is being planned with CNR, Italy and ETH, Switzerland.

2.2 Geophysical activities

Two dimensional resistivity structure of Puga, one of the potential geothermal fields of Ladakh district of Jammu and Kashmir State, has been delineated using magnetotelluric recordings and geoelectromagnetic induction tomography (GEMIT). Puga valley is located at 4000 m elevation, lies towards the southern margin of the Tsangpo suture zone and is well known for its numerous thermal springs with temperatures up to 90°C (boiling of water at that elevation). Sulphur and borax deposits have been reported from this area. The results indicate that the low resistivity zone, representing the geothermal reservoir, extends between 1 and 3 km (Singh and Nabetani, 1995). This shallow reservoir has a power potential of 45 MW (Ravi Shanker et.al., 1977). It may be mentioned that the Yangbajing geothermal field in China, which is located about 1200 km ESE of Puga, is already producing 25 MW of power (Ravi Shanker, 1996). In fact, a pilot binary geothermal energy plant to generate 5 kW of power, was installed at Manikaran (located in Parbati valley, SW of Puga) in Himachal Pradesh, by the Geological Survey of India, in collaboration with National Aeronautical Laboratory in the eighties, using R113 as a secondary fluid. This pilot plant, which was later abandoned due to landslides, proved the capability of some of the geothermal provinces of the Himalayan region in generating power. With the present available technology, it should be possible to generate more power using the thermal water and steam in this region.

Deep Seismic Sounding (DSS) experiments across major structures like the Godavari rift, Son-Narmada-Tapi lineament, Cambay rift and the Himalayas, have been conducted to delineate the subsurface tectonic fabric and to decipher information related to the crust-mantle boundary (Kaila and Krishna, 1992).

Along the SE part of the Godavari thermal province, the P wave velocity increases from 5.3 km/s to 6.5 km/s indicating upwarp of the lower crust at a depth of 3.5 km. Several deep seated faults have been recorded within the sedimentary formation which are intruded by several irregularly shaped, branching basic and ultrabsic bodies (Chaterji and Gosh, 1970). The thermal reservoir at Bugga and Manuguru in this province is reported to be at a depth of 2.5 km (Chandrasekharam and Jayaprakash, 1996).

Across SONATA, which encloses the famous Tattapani geothermal province, DSS results indicate deep seated faults extending down to mantle depths. However, primordial ^3He has not been detected in the gases from this province (Casiglia et al., 1999). Therefore these "deep seated faults" may be sealed, thus preventing escape of ^3He from the mantle or they may represent other structures. Detailed geological, gravity, magnetic and seismic investigation conducted by several institutes in collaboration with the Geological Survey of India (CRUMANSONATA, 1995) delineate these deep seated faults to be paleo-suture zones developed during collision of the Deccan protocontinent with the Bundalkhand protocontinent (Jain et al., 1995). The Tattapani geothermal province falls north of this paleo-suture zone. The R/R_A ratio in the thermal gases also support the presence of such structure in this region (Casiglia et al., 1999). Several other faults which are sympathetic to the main suture are channeling thermal waters to the surface and these faults have been activated periodically during the geological history and some of them are still active (Ravi Shanker, 1987). Borehole logs in this province indicate the presence of Gondwana sedimentary formations lying over the

Proterozoic basement intruded by younger granites and pegmatites.

Cambay basin is enclosed by failed arms of the triple junction related to the Deccan volcanism (Sheth and Chandrasekharam, 1997). Shallow and deep section delineated from DSS along this basin, extending from Mehmadabad to Billimora (Fig. 1), reveals that the basin is bounded by step faults on the eastern and western margins of the basin with several deep seated faults extending to mantle depths (Kaila and Krishna, 1992). Towards the southern part of the basin (at Billimora) the Moho is encountered at a depth of about 18 km (Kaila and Krishna, 1992; Singh et.al., 1991) and the 1250°C isotherm is located at a depth of about 40 km. The presence of high density material at shallow depth in this area is further supported by positive gravity anomaly (+35 mgals). Granite intrusives, like the Godhra granite, with radiometric age of about 955 Ma, outcrop within the basin near Tuwa. These geological and tectonic features are contributing to the high heat flow value in this region, which ranges from 67–93 mW/m^2, with thermal gradient as high as 70°C/km. (Gupta, 1981; Ravi Shanker, 1988). Mantle degassing through such deep seated faults is indicated by relatively high R/R_A ratio (0.3) and higher CO_2 content (3%) in gases from the Tuwa thermal province (Casiglia et al., 1999).

Magnetotelluric investigation across Tapi basin, which encloses the Jalgaon geothermal province, indicates the presence of a granite intrusive between 2 and 10 km depth, covered by thick Gondwana sedimentary formation (Rao et al., 1995; Chandrasekharam and Prasad, 1998). Thus, the geothermal province (heat flow: 120 mW/m^2; thermal gradient: 60°C/km; Ravi Shanker, 1988) in this basin is related to the above magmatic body.

The NW Himalayan region, enclosing nearly 100 thermal springs, includes the well known Puga, Manikaran and Chummathang geothermal provinces. A conceptual 2D computer model for the Puga geothermal province using the MULCOM computer programme (using SHAFT 79; O'Sullivan, 1985) has been developed, to assess the potential of the reservoir for electrical power generation, at the Geothermal Institute, University of Auckland (Mishra et al., 1996). This model is based on the existing geological, borehole logs, thermal gradient, heat flow, rate of the thermal discharge and other hydrological parameters of the aquifer. The results indicate that Puga geothermal province can generate 2 MW power for 30 years.

3. DRILLING ACTIVITIES

All the exploratory boreholes drilled by the Geological Survey of India and Atomic Minerals Division in some of the geothermal provinces are shallow, reaching maximum depth of about 600 m. About 26 boreholes were drilled in Tattapani geothermal province between 1981 and 1993. In addition, in order to assess the possibility of commissioning a pilot binary cycle power generation plant, five production wells have been drilled to a maximum depth of 350 m. These boreholes lie in an area of anomalously high thermal gradient and high heat flow (~90°C/km and 290 mW/m^2, respectively). Free flowing and geyseric conditions were encountered in these boreholes. Isotherms and thermal gradient contours at 100 and 300 m depths indicate upflow zones have an area of 1 to 2 km^2. These wells are yielding 1800 l/min of hot water at 112°C. With this flow rate and at 6% plant efficiency, electrical energy potential calculated is about 11 MWe for twenty years. Temperature of the order of 160°C is envisaged at a depth of 1.5 km (Sharma et al., 1996). Earlier, reservoir temperature of 217°C has been estimated at 3 km depth for this thermal province, based on experimental results and geochemical thermometers (Chandrasekharam and Antu, 1995).

Based on magnetic, electrical, and resistivity surveys over the Bakreswar-Tantloi geothermal province of West Bengal and Bihar, which registered heat flow value and geothermal gradient of 200 mW/m^2 and 90°C/km respectively, (Ravi Shanker,1988), two exploratory boreholes to a depth of 200 m at Tantloi in Bihar were drilled by the AMD. Thermal gases and waters with high concentration of He (1.4–2.77%) have been encountered in these boreholes. The rate of flow of gas and that of water vary between 0.02-0.06 l/min and 900 l/min respectively (Nagar et.al., 1996). High heat flow coupled with very high He concentration in the gases and thermal waters apparently indicate that the granites and gneisses through which the thermal waters are circulating, are enriched in uranium minerals. A pilot helium extraction plant has been commissioned by the above organization to recover He from thermal gases and water.

About 34 boreholes were drilled to a depth of 400 m in the Puga valley, which encloses both the Puga and Chumathang geothermal fields. The bottom hole temperature recorded at this depth is 140°C, with pressures ranging from 2–3 kg/cm^2. Of these, 17 are flowing wells with a total discharge of 190 tonnes/h and maximum discharge measured for a single well is 30 tonnes/h. Geothermal gradients greater than 200°C/km and heat flow varying from 140–468 mW/m^2 have been recorded from these wells (Ravi Shanker, 1988). A large number of granite, granitoid and pegmatite intrusives with radiometric ages ranging from 3.4 Ma to 495 Ma, and with U_2O_3 content varying from 0.19–10.7%, which appear to be the main source of heat, have been reported from several localities in these geothermal provinces (Ravi Shanker et al., 1977; Srikantia and Bhargava, 1998). Space heating experiments using hot water from the wells have been conducted by the Geological Survey of India (G.S.I., 1991). These space heated huts have been used to extract and refine borax and sulphur which occur in large quantities there.

The West coast thermal province, located within the Deccan volcanic terrain, is a narrow stretch of 300 km, aligned parallel to the coast. About 60 thermal springs clustered in 16 localities, with surface temperatures varying from 47 to 71°C, lie within this province. Six boreholes drilled to a depth of 500 m recorded temperature gradients of 47–59°C/km and heat flow value of 75–129 mW/m^2 (Ravi Shanker, 1987). Though the surface flow rates of some of the thermal springs are low (48 l/min; Ravi Shanker, 1987), measured discharge through the boreholes is 24 tonnes/h (Muthuraman, 1986). The continental crust is attenuated and foundered at several places along the west coast during the

Deccan volcanic episode (Chandrasekharam, 1985), thereby recording positive gravity anomalies along the coast. Geophysical investigation along the coast and off-shore of Bombay recorded thin lithosphere (~18 km) and the 1250°C isotherm in this region is expected at a depth of 20 km (Pande et al., 1984).

4. OTHER DEVELOPMENTAL ACTIVITIES

In order to assess the potential of non-conventional energy resources and collate the existing data on geothermal energy resources from various research institutes, the Geological Survey of India organized a seminar on Geothermal Energy in India during October 1996. The developmental activities reported by various workers at this seminar are quite encouraging.

In order to eleminate the effect of conventional binary fluids, such as CFC's, on the ozone layer, experimental and thermodynamic analyses have been carried out to asseses the performance of a new binary fluid, commercially known as HFC-134a. The advantages of using this fluid are, the irreversibility of the flashing binary cycles are much lower and hence the utilisation factors are substancially higher as compared to the conventional cycles (Tyagi and Bhave, 1996).

A heat exchanger has been designed to dehydrate onions using the thermal waters of Bugga and Manuguru located in the Godavari basin geothermal province of Andhra Pradesh. The estimated reservoir temperature, based on geochemical thermometers, is greater than 173°C. This 1-6 tube shell and tube exchanger is cost effective and more suitable for this province and can dehydrate 10,000 lb/h of onions with an air volume of 20,000 m^3/h (Chandrasekharam and Jayaprakash, 1996; Chandrasekharam et al., 1996).

The Puga thermal waters contain 10 ppm of cesium. It is estimated that for a natural discharge of 30 l/s, about 10 tonnes of cesium is being discharged annually from the thermal waters. Experiments have been conducted to recover Cs by absorption on ammonium 12-molybdophosphate (AMP) at pH 6-7 in the presence of Al^{+3} ion. In all the five experiments conducted, 70% cesium has been recovered from the thermal waters. It is estimated that about 1.5 tonnes of cesium worth about \$400,000 can be produced annually from the thermal waters of Puga (Srivastav et.al., 1996).

5. CONCLUSIONS

Exploration and pre-feasibility studies on promising geothermal provinces have clearly demonstrated that the geothermal energy resources programme in India has come to a stage where commericial exploitation of the reserves has to be initiated on a large scale. The high heat flow and geothermal gradients in most of the thermal fields, supported by anomalously high ^{4}He concentration, is related to the magmatic intrusives with high U and Th contents. Gamma-ray spectrometer analysis on several rock samples, collected from high heat flow regions, reveal that high heat flow is closely related to high heat generation of the formations, which in turn is related to high concentrations of U and Th in the rocks (Rao et. al., 1976). Thus, many of the geothermal provinces discussed above are excellent sites for hot dry rock (HDR) programme as well (Chandrasekharam 1996). In all the geothermal provinces investigated so far, the geothermal reservoir is estimated to be at depth varying from 1–3 km. The present scenario in India is similar to that of Australia, where burried granites with sedimentary blankets, at depths varying from 2–5 km, with temperature exceeding 250°C are identified as the prime sites for HDR programme. The high heat flow here is attributed to high heat generation in these granites (Burns et.al.,1995). Experimental programmes, like those conducted at Fenton Hill, New Mexico (Jelacic and Hooper, 1996), and like those proposed to be taken for the Muswellbrook site, Australia, to generate 20 MWe power from 1 cubic kilometer of hot rock (250°C) at a depth of 5 km (Somervillie et al. 1994), should be initiated at some of the geothermal provinces in India. Deep drill hole to a depth of 2 km in the geothermal provinces discussed above should be able to generate substantial power and also support several industries. The present mood of the Indian industries is upbeat with many private power companies prepared to invest in geothermal energy resources with foreign collaboration.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICTY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specifiy)*		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in January 2000	Nil	Nil	50524	224603	19576	69870	2005	6726	224	162	72329	301361
Under construction in January 2000	Nil	Nil	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Funds committed, but not yet under construction in January 2000	Nil	Nil	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total projected use by 2005	Nil	Nil	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd

*Diesel+wind; Nd: Data not available

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999

1) I = Industrial process heat; C = Air conditioning (cooling); A = Agricultural drying (grain, fruit, vegetables); F = Fish and animal farming; S = Snow melting; H = Space heating & district heating (other than heat pumps); B = Bathing and swimming (including balneology); G = Greenhouse and soil heating; O = Other (please specify by footnote)

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (° C) - outlet temp. (° C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (° C) - outlet temp. (° C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual energy use (TJ/yr) x 0.03171]/Capacity (MWt)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Locality	Type 1)	Maximum Utilization					Capacity 3)	Annual Utilization		
		Flow Rate	Temperature (° C)		Enthalpy 2) (kJ/kg)			Ave. Flow	Energy 4)	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor 5)
Himalaya@	B	60	>90*	15			19	60	593	0.98
Cambay	B	100	90	25			27	100	857	1
West Coast	B	60	72	30			10	60	332	1
SONATA	B	66	95	25			19	66	609	1
Bakreswar	B	15#	66	30			3	15	71	0.75
Godavari	B	15#	58	30			2	15	55	0.872
Barren Island	unused	Nd	500**							
TOTAL										

Nd: do data; @ includes several springs; * surface temp; # natural discharge; ** fumerolic discharge

Note: please report all numbers to three significant figures.

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 1999

1) *Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (° C) - outlet temp. (° C)] x 0.004184*
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalphy (kJ/kg)] x 0.001

2) *Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (° C) - outlet temp. (° C)] x 0.1319* *(TJ = 10^{12} J)*
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) *Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171* *(MW = 10^6 W)*
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Use	Installed Capacity 1) (MWt)	Annual Energy Use 2) (TJ/yr = 10^{12} J/yr)	Capacity Factor 3)
Space Heating 4)			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish and Animal Farming			
Agricultural Drying 5)			
Industrial Process Heat 6)			
Snow Melting			
Bathing and Swimming 7)	9	277	0.975
Other Uses (specify)			
Subtotal	9	277	0.975
Geothermal Heat Pumps			
TOTAL	9	277	0.975

4) *Includes district heating (if individual space heating is significant, please report separately)*
5) *Includes drying or dehydration of grains, fruits and vegetables*
6) *Excludes agricultural drying and dehydration*
7) *Includes balneology*

Note: *please report all numbers to three significant figures.*

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1995 TO DECEMBER 31, 1999

[1] *Include thermal gradient wells, but not ones less than 100 m deep*

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration [1]	(all)	31		73		0.2-0.6
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total		31		73		0.2-0.6

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with a University degress)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributied Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1995			1+			
1996			1+			
1997			1+		3	
1998			1+		3	
1999			1+		3	
Total			5+		9	

+number varies from 0-2(students involved in geothermal projects)

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (1999) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1985-1989	Nd	Nd	Nd	Nd		100
1990-1994	Nd	Nd	Nd	Nd		100
1995-1999	Nd	Nd	Nd	Nd		100

Nd:Data not available

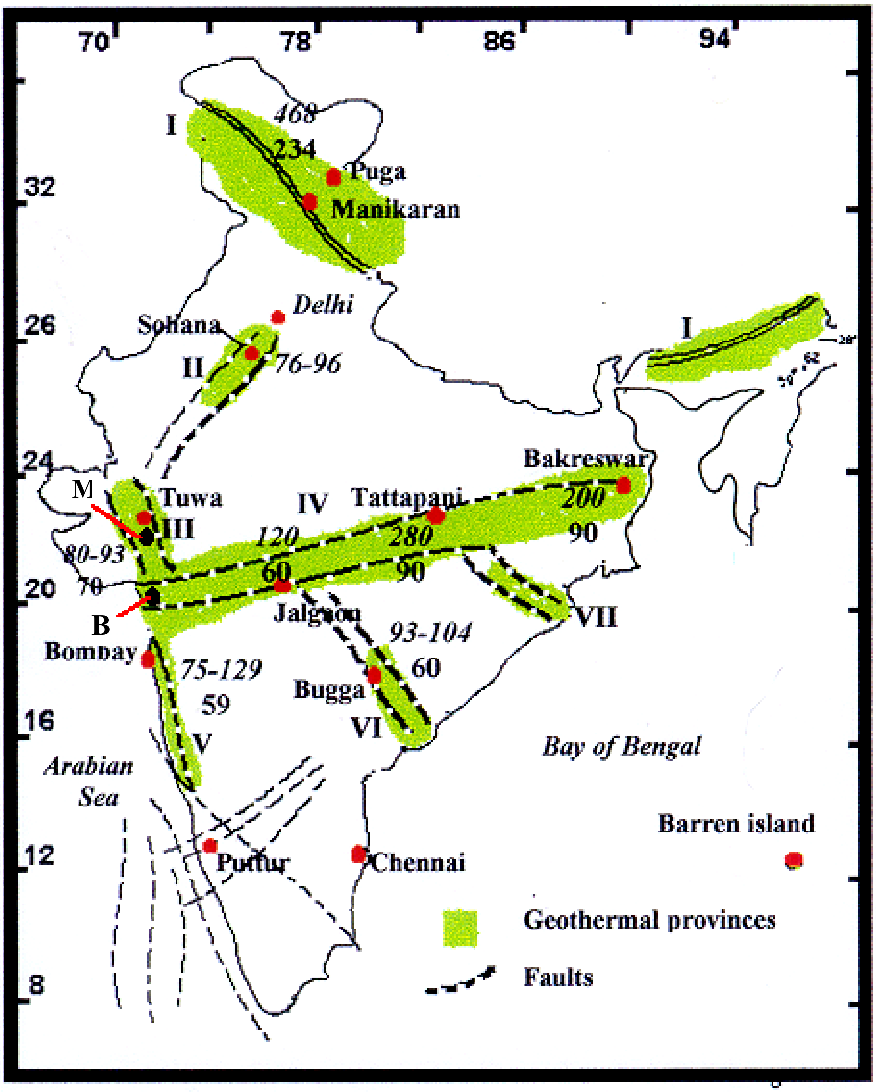

Fig. 1. Map of India showing the geothermal provinces, heat flow values (mW/m^2: *in italics*) and geothermal gradients ($^oC/km$). I: Himalaya; II: Sohana; III: Cambay; IV: SONATA; V: West coast; VI: Godavari; VII: Mahanadi. M: Mehmadabad; B: Billimora.