Geothermal Exploration in India

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In most Precambrian terrains including India, moderate-to-low temperature hot spring systems represent the potential conventional geothermal energy resources. This scenario is in contrast to geothermal fields under production in other parts of the world, which are located in Quaternary volcanic / magmatic settings (Gupta and Roy, 2006). This paper outlines (i) the major hot spring occurrences in India, (ii) the exploration efforts undertaken so far, (iii) possible geothermal models in the light of regional heat flow and heat production datasets, (iv) a few critical information gaps that need to be covered to make realistic assessment of the geothermal energy potential, and (v) perspectives for development and utilisation of geothermal energy in the country, both for electric power generation as well as for direct uses.

Keywords: India, geothermal energy, heat flow, radiogenic heat production

Exploration of Geothermal Energy Resources

The major groups of hot springs in India occur in Manikaran, Puga-Chhumathang valley and Tapoban in the Himalaya, a near N-S trending linear belt in the west coast of Maharashtra, the Son-Narmada-Tapti lineament zone in central India, Tattapani in Chattisgarh, and Rajgir-Monghyr, Surajkund and Bakreshwar in eastern India. The distribution of major groups of hot springs is shown in Figure 1. Rao (1997) provides a brief summary of the historical development of studies on the Indian geothermal resources, starting with the first compilations of 99 hot springs in India and the adjacent countries by Schlagintweit (1865). The locations, geological settings and temperatures of hot springs located in different geologic provinces in India have been compiled by previous workers (for example, Oldham, 1882; Ghosh, 1954; Gupta, 1974; Guha, 1986; GSI, 1991, 2002 and others). A number of those geothermal springs have been used for balneological purposes. However, India is yet to produce electric power from a geothermal field.

Among the most notable achievements during the past five decades have been the assessment of geothermal fields by the Government of India in 1966 and publication of a comprehensive report in 1968 recommending preliminary prospecting of

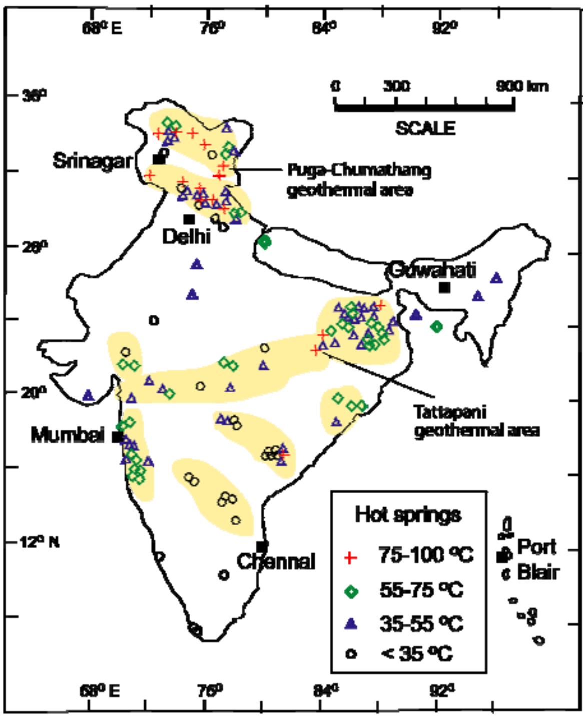

Figure 1. Outline of India showing the distribution of major groups of warm and hot springs (modified after Krishnaswamy, 1975). Temperatures of the hot spring waters are indicated using symbols (see legend). Shaded regions (exaggerated scale) show the major clusters of hot springs.

the Puga and Manikaran geothermal fields in the Himalaya (Hot Springs Committee, 1968). A major, systematic, multi-disciplinary, multi-Institutional programme (including drilling up to 385 m) covering the Puga-Chumathang field in Ladakh was mounted during 1972-74 under the stewardship of V.S. Krishnaswamy of the Geological Survey of India (GSI). The subsurface features were delineated in considerable detail and the results were presented at the Second United Nations Symposium on the Development and Use of Geothermal Resources in 1975. The most significant outcome of the effort was a proposal to set up a 1 MWe binary-cycle power plant on a pilot scale basis, which has not been implemented so far. Attempts to revisit the geothermal exploration in the area include a number of geochemical studies (GSI, 1996) and recent magnetotelluric studies (Abdul Azeez and Harinarayana, 2007). An expert group set up in 2008 by the Ministry of New and Renewable Energy, Government of India made strong recommendations to install pilot-scale plant by drilling exploration cum demonstration wells in the area (MNRE, 2008). This would be useful not only for monitoring the hot water discharge and temperatures over a period of time but also studying the shallow reservoir characteristics. Another major initiative, directed towards the hot springs of the West Coast belt and the Son-Narmada-Tapti belt was taken up by the GSI with UNDP assistance during 1976-77, and was extended for a few years on its own, including deep drilling up to depth of 500 m. The results were published in the Records of the GSI (1987). The Tattapani hot springs of Chattisgarh district was identified for trials with regard to power production using a 300 KW_e binary-cycle power plant. Summaries of various exploration programmes undertaken in the country during the period 1970-1990 are given in Gupta et al. (1973, 1974); Shanker et al. (1976); Singh et al. (1983); Krishnaswamy and Ravi Shanker (1980); GSI (1983, 1991, 1996, 2002); Thussu et al. (1987); Moon and Dharam (1988) and Gupta (1992). The salient results in the case of the two potential geothermal fields, Puga and Tattapani, are summarized below.

Puga Valley Hot Springs

In the case of Puga valley springs, geothermal evidence gathered so far and geochemical indicators including the occurrence of cesium deposits around the springs have suggested the possibility of high temperature hydrothermal circulation in the subsurface (Absar et al., 1996). A shallow reservoir in the top few hundred meters was inferred from geophysical and geothermal investigations carried out during the 1970s. Recent magnetotelluric studies indicate the presence of an anomalous conductive feature (~5 Ohm m) below a depth of ~2 km in the area of the thermal manifestations (Harinarayana et al., 2006; Abdul Azeez and Harinarayana, 2007). Although broad correlations between high electrical conductivity and high temperatures have been observed in some geothermal areas, the calibration of electrical conductivity anomalies to temperature anomalies at depth is not established. Further efforts are necessary to fill existing gaps in knowledge and verify the hypothesis regarding the occurrence of subsurface magma chambers or young intrusive granites in the region. Such heat sources alone can sustain power generation on a reasonable scale (Rao et al., 2003). Determination of background heat flow outside the hot springs zone, helium-isotopic measurements on the thermal waters, detailed petrographic and geochronological studies on young granite intrusives, and tritium dating of the waters would be useful for testing a magmatic heat source.

Tattapani Hot Springs

In the case of the Tattapani hot springs, the temperatures of the issuing waters is ~110 ^oC, the highest recorded so far in the shield. The spring waters are meteoric in origin as indicated by oxygen and helium isotopic data, and the age of these waters indicated by tritium dating is ~40 years (Thussu et al., 1987; Sharma et al., 1996; Minnisale et al., 2000). Repeat well testing carried out by GSI in 1995 and 1999 indicate no significant fall in temperatures and pressures during the intervening period (Sarolkar and Sharma, 2002). Recent magnetotelluric studies in the area have delineated a deep, anomalous conductive zone possibly indicating the subsurface extent of the reservoir (Harinarayana et al., 2004). Lack of evidence for Quaternary magmatism in the region as well as the meteoric nature of the hot spring waters indicate that the hot springs are controlled by forced convection due to peizometric gradient existing between the recharge area and the hot springs, and that the springs could be simply "mining" the normal heat flow (Roy and Rao, 1996; Rao et al., 2003). However, no heat flow measurements outside the localized hot springs zone have been made. There is therefore a clear need to establish the regional thermal conditions by systematic geothermal measurements because they would contain information about subsurface flow and location of recharge area also (Lachenbruch et al., 1976).

Other areas

A large number of warm to hot springs occur in western, central and eastern parts of the Indian shield. The temperatures of these springs are lower than those at Tattapani and vary between 35^o and 80 ^oC. It is likely that a geothermal model similar to that at Tattapani could explain the occurrence of these hot springs.

Heat Flow and Heat Production

Heat flow determinations made through precise temperature measurements in boreholes and thermal conductivity measurements on representative rock formations have been the central theme of the heat flow studies programme at the National Geophysical Research Institute since its inception in 1961. Although boreholes of opportunity have been used for the majority of measurements, a selection has been made on the following criteria to make the heat flow determinations useful for characterizion of the thermal state of the lithosphere: (1) depths greater than 150 m in hard rock areas and several hundred metres in sedimentary basins (2) sites away from hot spring manifestations, tectonically active regions, and rugged topography (3) temperature profiles with no characteristic perturbations such as those of heat refraction and groundwater movement. The principal constraint in the data acquisition programme has been the availability of suitable boreholes for making temperature measurements. This constraint has been addressed, to some extent, through the drilling of 14 dedicated "heat flow" boreholes to depths of up to 500 m at carefully chosen sites in south India. The careful siting of the boreholes in areas of relative lithological homogeneity and low groundwater yields facilitated the acquisition of undisturbed temperature-depth profiles from which gradients could be estimated with a great degree of confidence. In geologic provinces of northern Indian shield, the heat flow coverage is variable and several gaps exist over large segments. In the Himalaya, regional heat flow data are not available. Borehole temperature measurements in close proximity of hot springs exist at a few locations only. However, these measurements are affected by convection due to hydrothermal circulation in the near surface zone and are not representative of deep crustal conditions. Thermal conductivity data for all major rock formations in the southern Indian shield and several rock formations from other parts of India constitute a very extensive database for modelling the thermal structure in the upper few kilometres of the crust.

Heat Flow and Geothermal Gradients

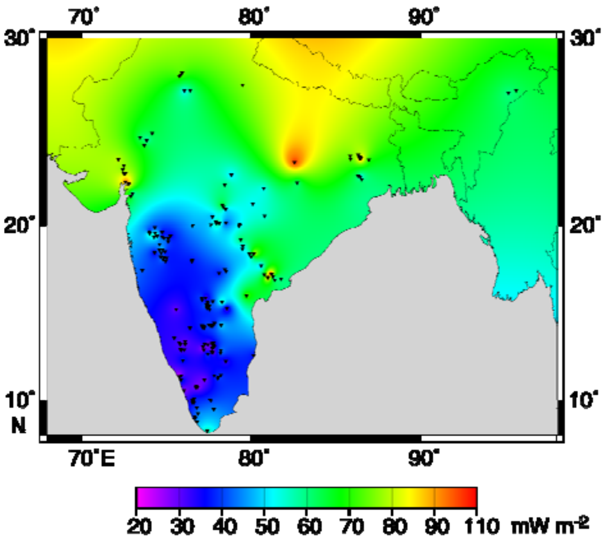

Figure 2. Heat flow map of the Indian Shield. Heat flow sites are shown by filled triangles. Heat flow determinations have been made on the basis of temperature measurements in boreholes and thermal conductivity of rock formations. Over large regions in northern India which are not covered with heat flow measurements, the contours should be treated with caution. [Sources of data: Roy and Rao (2000) and original references therein; Ray et al. (2003); Rao et al. (2003); Roy (2008); Roy et al. (2008)].

A heat flow map for the Indian shield is shown in Figure 2. Heat flow data are now available from measurements made in ~210 boreholes distributed over the major geological provinces in the shield. The dataset shown here is confined to sites where complete information on geothermal gradient and thermal conductivity are available. Heat flow determined using other techniques such as chemical composition of water, and correlations with P-wave velocity and age, are excluded. A detailed discussion of heat flow characteristics of different provinces is given in the papers by Roy and Rao (2000) and Rao et al. (2003). The salient features of the heat flow spectrum in the Indian shield are briefly mentioned below.

1. The southern Indian shield comprising the Archaean Dharwar greenstone-granite-gneiss province and gneiss-granulite province, is characterized by low heat flow, generally ranging from 25 to 50 mW m^{-2}. Geothermal gradients measured in the top few hundred meters in boreholes and up to 2150 m in a deep mine are in the range 12-15 mK m^{-1}.
2. The low heat flow regime of south India extends northward beneath the Deccan Traps in central India, which indicate the absence of thermal transients related to the ~65 Ma Deccan volcanism in the present-day heat flow. Measurements at several localities distributed in Deccan Traps province indicate an average gradient of ~25 mK m^{-1}. However, beneath the Traps which range from a few meters in the east to 2-3 km in the west, the gradient in the Precambrian granitic basement drops to ~15 mK m^{-1} due to higher thermal conductivity of granitic rocks relative to basalts.
3. The Precambrian provinces in northern Indian shield show a contrasting heat flow regime, with values ranging from 50 to 96 mW m^{-2}. Previous studies have attributed the enhanced heat flow to high levels of radiogenic heat production in the upper crust. Temperature gradients vary between 12 and 30 mK m^{-1} across different rock formations.
4. The Gondwana sedimentary basins (Upper Carboniferous to Lower Cretaceous) have a generally high but variable heat flow in the range 46 to 107 mW m^{-2}. Temperature gradients show large variability, and reach peak values of up to ~50 ^{o}Ckm^{-1} in the Damodar Valley basins and ~40 ^{o}Ckm^{-1} in Godavari Valley basin.
5. The Cambay sedimentary basin of Tertiary age in western India shows consistent high heat flow, 75-96 mW m^{-2} in the northern parts and a lower heat flow, 55-67 mW m^{-2}, in the southern parts. Very high gradients in the range 37 to 56 ^{o}C km^{-1} were computed from temperature measurements to depths >1000 m in the northern part.

Radiogenic Heat Production

Heat production due to radioactive decay of long-lived isotopes of U, Th and K (namely, ^{235}U, ^{238}U, ^{232}Th, and ^{40}K) in rock formations constituting the continental crust plays a key role in interpretation of heat flow data. With this primary objective, a low-level counting gamma-ray spectrometric facility using a single-channel analyser was established at the NGRI for analysis of rocks for radioelements U and Th (at ppm levels) and K (Rao, 1974; Rao and Rao, 1979). The facility has been progressively upgraded using a multi-channel analyser and later, a PC-based multi-channel analysing card that provides spectrum stabilization (Roy and Rao, 1999, 2003). Several hundred samples covering major rock types in the Indian shield have been analysed for U, Th and K. The salient features of the dataset are described in Roy (2008).

Over the last two decades, laboratory analyses have been complemented by in-situ gamma-ray spectrometric analysis in several areas in the Indian shield (Roy, 1997; Roy and Rao, 2000, 2003; Ray et al., 2003, 2008). A field-portable, four-channel, spectrum stabilized, gamma-ray spectrometer and a large crystal (6” high and 4” diameter) detector have been used. Analysis for U, Th and K are made by placing the detector directly over fresh rock outcrops. In this case, the detector senses a much larger volume of rock mass, typically a circle of investigation of ~40 cm and a depth of ~12 cm, compared to the laboratory method. In areas abounding with fresh outcrops, this method results in faster coverage.

Significant observations include delineation of pockets of very high heat production in granitic rocks, for example in Tattapani area, and young granite intrusives in northwestern parts of India, detection of granulite facies rocks with lowest heat production reported in literature, and a range of rock formations with intermediate heat production values.

Perspectives for Development of Geothermal Energy

Re-assessment of Energy Potential of Conventional Geothermal Resources

In view of growing energy demands and the emphasis on renewable energy in India, a re-assessment of geothermal energy potential of Puga Valley hot springs in Ladakh and Tattapani hot springs in Chatttisgarh should be carried out by covering some critical gaps in information through acquisition of new data, combined interpretation of geothermal datasets and existing geological, hydrological, geochemical and geophysical datasets to throw light on the nature of the heat source of the hot springs and their sustainability for power production, undertaking drilling and setting up of pilot-scale binary-cycle power plants.

Geothermal resources vary widely from one location to another, depending on the temperature and depth of the resource, the rock chemistry, and the abundance of groundwater. The type of geothermal resource determines the method of its utilization. Variants of binary cycles appropriate to optimum utilization of geothermal heat from hot springs in non-volcanic settings such as those in India need to be developed.

Direct Heat Uses

The heat extracted from warm-to-hot waters emerging from other hot spring systems in the country can be gainfully employed for a number of direct uses such as development of tourist spas for bathing, swimming and balneology, greenhouse cultivation in cold climates, extraction of borax and rare materials such as cesium, and agricultural product processing. The significant economic and environmental benefits of using moderate-to-low enthalpy geothermal waters to replace even small quantities of conventional fuels for direct uses cannot be ignored today in view of the steep increase in costs of fossil fuels and associated greenhouse gas emissions.

Exploration for Enhanced Geothermal Systems

A second category of geothermal resource traditionally referred to as “hot dry rock” and more recently as “enhanced geothermal systems EGS)”, has not yet been explored in India. The primary requirement for such a resource is the occurrence of high temperatures (typically upwards of 150 ^{o}C) at economically viable depths (typically the top 1-4 km of the Earth’s crust). Areas of anomalous high heat flow, high-heat-producing granites and other silicic igneous intrusives having a depth extent of a few kilometers, could be possible targets of future exploration efforts in the country (Roy, 2008). These considerations reinforce the need for carrying out systematic heat flow as well as radiogenic heat production investigations on a country-wide scale.

Geothermal Heat Pumps

The viability of geothermal heat pumps for heating inside buildings should be explored in the states of Jammu and Kashmir, Himachal Pradesh and parts of Uttarakhand which experience severe winter conditions for long periods. Space cooling requirements in most parts of India have grown several fold in the recent years with the growth in economy. There is enormous scope for developing the capabilities in geothermal cooling of buildings by modifying existing technologies to suit Indian conditions. A proper assessment of the technology for application to different climatic environments existing in the region, and its exploitation by integrating it with building designs should be encouraged.

Summary

Moderate-to-low enthalpy hot spring systems primarily represent the known geothermal energy resources in India. These resources are distributed in diverse physiographic and tectonic settings, viz., the Himalayan belt and the Precambrian shield. Detailed geological and geochemical exploration followed by limited geophysical exploration and shallow drilling investigations up to a few hundred meters have resulted in first-order geothermal models for the major hot spring zones in the country. However, development of the geothermal resources has remained at a very low level mainly due to inadequate characterization of the deeper thermal regime leading to low confidence in proposed reservoir models and sustainability of the heat source. There is therefore an urgent need to carry out a reassessment of the geothermal energy potential of hot springs by employing new geophysical probing tools and computational techniques available today, both for electric power generation as well as for direct uses. Efficient exploitation technologies appropriate to non-volcanic areas need to be developed. Systematic heat flow and heat production investigations need to be carried out for the identification of areas where high temperatures in the top few kilometers below the ground surface indicate potential for “hot sedimentary aquifers” as well as “enhanced geothermal systems”. The vast potential for geothermal heat pumps is yet to be tapped. The existing technology must be made accessible to individuals and small communities as a low-cost alternative for their space heating and cooling needs.

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Bihar. systematic geothermal exploration was started by the Geological Survey of India with the launching of the Puga Projecl in J a m m u and Kashmir State. This shallow zone is underlain by varieties of crystalline rocks of Pre-Cambrian to early Paleozoic age. and K. but does not extend towards the western part of the valley. aided by drilling to depths varying between 50 and 225 m. were conducted in other hot spring localities in the NW and NE Himalayas and also extended to parts of Orissa. including preliminary.Â The Puga Project was launched in 1973 and subsequently extended to neighbouring Chumathang area. draft programmes of further exploration and eventual drilling are now being defined. detected a significant resistivity " l o w " in the western part of the shallow Geothermal Exploration and development in Kenya. Cyrus Karingithi cwkaringithi@gmail.com ckaringithi@kengen.co.ke Olkaria Geothermal Power Project, Naivasha, Kenya. Disclaimer: No part of this report may be circulated, quoted, or reproduced for distribution without prior written approval from KenGen. All the information contained herein was prepared for information to the German Parliamentarians visiting Kenya. Overview of power sub-sector today. Geothermal Development Company(GDC) established in 2009 to accelerate Geothermal. Resource Assessment. ~75% Market Share. View Geothermal Exploration Research Papers on Academia.edu for free.Â Parangwedang, Parangtritis, Bantul Regency has potential for the utilization of geothermal energy. Seen the discovery of the geothermal manifestation of hot springs. This study aims to estimate the potential of geothermal energy Parangwedang, as well as create a scheme of utilization of geothermal potential as a recommendation for use in the area. The analysis used in this research is geology analysis and geophysical analysis.