Exploring and Exploiting Geothermal Resources of India: Case study of Puga Geothermal Field, Ladakh

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Keywords

Heat flow, Resistivity, Temperature gradient, Magneto-telluric surveys, Geothermal potential

Abstract

"Geothermal energy", a renewable source of energy is crucial in the quest for energy transition considering climate change and increasing demand of energy to augment and possibly replace the carbon based fuel sources.

'Geothermal Atlas of India' prepared by the Geological Survey of India (GSI) in 2022 describes over 340 hot spring sites with geothermal potential in a few key geothermal provinces throughout India namely Himalayan belt along Indus Suture Zone (ISZ) in the north to north-east, Western thermal province along west coast and Cambay graben, Son-Narmada-Tapi lineament in central India along with areas in Bengal and Orissa, Andaman-Nicobar region, Godavari & Mahanadi province and Aravalli province. India has an estimated geothermal power potential of ~10,600MWe, but this potential is almost entirely undeveloped.

The paper discusses key provinces in India with an overview of ongoing Geothermal exploration project in Puga Geothermal field, Ladakh. Uses of geothermal resources for power generation, balneology, space heating, cooking etc. are also presented.

The Puga hot spring area, located at the junction of the Indian and Tibetan plates along the Indus Suture Zone, is one of the sites with great potential for geothermal energy. The area exhibits vigorous geothermal activity in the form of hot springs, mud pools, sulphur and borax deposits. Conceptual model of the Puga geothermal system concludes susbsurface temperature would reach to ~160°C at about 450m depth. Magneto-telluric survey carried out by NGRI indicates presence of a conductive structure at 2-8km depth with estimated temperature of ~260°C. The large depth extension of the anomalous conductive structure accounts for a huge volume of the heat source substantiating its long term sustainability.

Success in Puga geothermal field will open up similar areas in Chumathang and Panamik fields, increasing the strategic importance of this area. Ladakh area suffers from an acute shortage of power and development of geothermal potential would provide for baseload needs, especially in the winter months when the region's hydro-power stations are ineffective due to freezing temperatures.

Introduction

Geothermal Energy is the vast reservoir of heat energy in the earth's interior, whose surface manifestations are the volcanoes, fumaroles, geysers, steaming grounds and hot springs. Occurrence of the geothermal resources in India is mostly controlled by tectonic features. The main zone of geothermal resources is located in the Himalayas stretching along the Indus Suture zone (ISZ). Geothermal resources along Son-Narmada lineament at Anhoni-Samoni, Madhya Pradesh and Tatapani, Chhattisgarh form a most promising resource base in Central India. A linear stretch from Koknere in north to Ganeshpuri, Unhavare, Tural and Rajapur in south hosts hot springs along the West Coast of India. Other geothermal springs are located at Bakreshwar in West Bengal, Tarabola in Odisha, Manuguru in Telangana, Unai in Gujarat, Garampani in Assam, Takshing in Arunachal Pradesh, Rajgir in Bihar, mostly formed due to local geological conditions like presence of intrusives, tertiary tectonism and/or neo-tectonics activity. (Sarolkar, 2018 and Singh et al 2016)

Province	Locality	Temperature Gradient	Heat flow
Himalayan	Indus Suture zone Puga-Chumathang Parbati,Satluj, Alaknanda Valleys	100°C/km 60±20°C/km 17±5°C/km	400 mW/m^2 130±30 mW/m^2
Naga Lusai	Garampani, Nambhar & Lumding	Not available	70-100 mW/m^2
Andaman & Nicobar	Mud volcanoes at Hatilevel-Diglipur, Baratang, Barren Islands	Not available	100-180mW/m^2

Exploring and Exploiting Geothermal Resources of India: Case study of Puga Geothermal Field, Ladakh

Province	Locality	Temperature Gradient	Heat flow
West coast	Koknere, Sativali, Ganeshpuri, Akloli, Tural, Rajawadi	55±5°C/km	130±10 mW/m^2
Cambay Graben	Warna, Maktupur, Harsan, Gandhar, Oil &gas wells	25-55°C/km	130±10 mW/m^2
Aravalli	Lalsot-Mandawar-Rindli, Zawar, Khetri	41±10°C/km	100±25 mW/m^2
Son Narmada Tapti	Tattapani, Salbardi, Anhoni-Samoni	40-120°C/km	70-300 mW/m^2
Godavari & Mahanadi	Deuljhari, Taptapani, Manuguru, Pagaderu	39±10°C/km	80±21 mW/m^2
South Indian Craton	Irde, Bandaru, Aranthangi	30°C/km	60-90 mW/m^2

Table-1. Geothermal provinces of India (Geothermal Atlas of India, GSI, 2022)

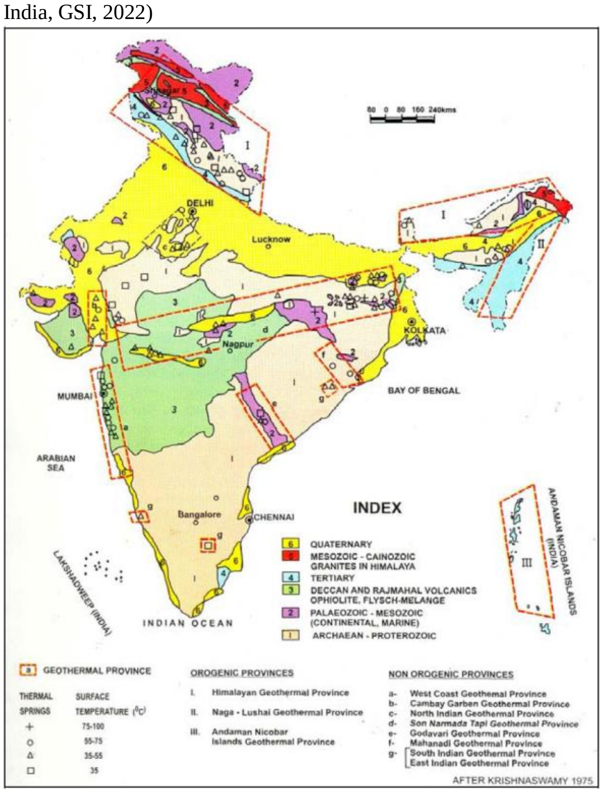

Figure-1: Major Indian Geothermal provinces (From Razdan P N et al, 2008)

Puga Project - Case Study

The Puga valley is a part of the Himalayan Geothermal belt of 1500km which extends from Ladakh in the northwest of India to Assam in the north-east. The Himalayan Geothermal Belt includes more than 150 known places where geothermal manifestations are present. Puga valley is in the Ladakh district of Jammu and Kashmir, India. The geothermal area in Puga valley is located ~3 km south of the Indus Suture Zone (ISZ). The ISZ represents the boundary where the Indian and Asian plates collide in the Himalayan orogeny during the Cenozoic. The bedrock of Puga is composed of Precambrian paragneisses, schists and phyllites interlayered with lenses of limestone and associated amphibolites, eclogite, pegmatite along with Tertiary granitic intrusives. Superficial deposits (~60m thickness) cover the valley floor comprised of talus, glacial moraines, fluvioglacial deposits and borax evaporates These are reconsolidated into hard breccia-like rock by the action of hot geothermal fluid. (Fig.2) (Craig et al 2013 & Azeez and Harinarayana, 2007).

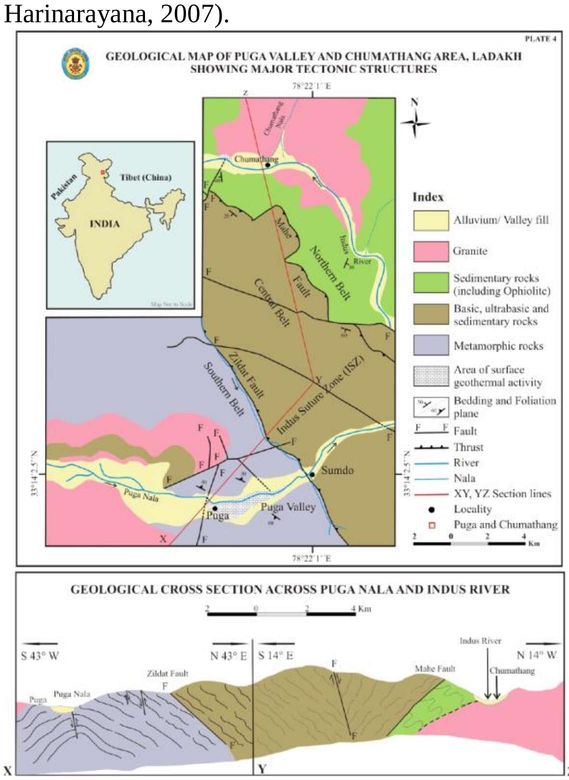

Figure-2: Geological map of Puga Valley and Chumathang area showing major tectonic structures (Geothermal Atlas of India, GSI-2022)

More than hundred hot springs with surface temperatures ranging from 28-84°C are spread over an area of ~5sq.km along the river in Puga Valley forming a marshy zone in the central part. Considerable discharge of steam is also noted from the hot springs in the area as at an elevation of ~4400m above sea level, boiling point of water is ~84°C. Natural discharge of the Puga geothermal field is estimated to be around 30 L/s with the maximum discharge from a single spring being 5 L/s.

Systematic geothermal exploration started in Puga around 1970's through Geological Survey of India (GSI). A total of 34 exploratory boreholes have been drilled in the area since start of exploration activities by GSI. Most of the wells in the area are shallow and only reaching to about 50-150m below surface although the deepest well reached 385m depth. Wellhead measurement of 8 boreholes reported a total discharge of ~50 L/s of steam+water mixture (Max discharge from a single well was ~8 L/s). The steam constitutes 10 to 15% of the total discharge at pressure 2-3 kg/sq.cm with max temperature of 140°C. A conceptual model of the Puga Geothermal system postulates that the subsurface temperature would reach up to 160°C at about 450m depth. (Absar et al. 1996) Several geophysical exploration studies have also been carried out including magnetic, gravity, seismic refraction and resistivity surveys. (Geothermal Atlas, GSI, 2022).

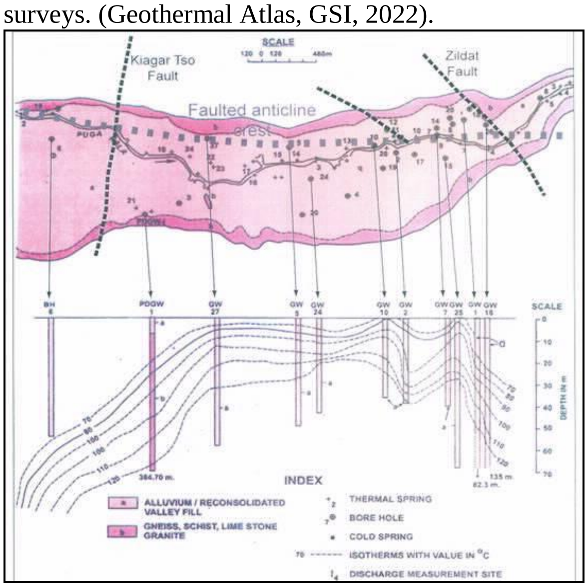

Figure-3: Locations of hot springs and boreholes drilled by GSI at Puga Valley (Geothermal Atlas of India, GSI-2022)

Modelling of the MT data reveals that the area is characterized by a surface low resistive (10–30 ohm-m) layer (~400m thick) correlating with the area of thermal manifestation in the area. The next anomalous conductive structure (~5 ohm-m) in the area commences at 2 km depth. Surface low resistive zone and anomalous conductive structure are separated by a resistive structure. The study also imaged a major fault feature (Kiagar Tso fault) that cuts across the resistive structure and connects the surface low resistive zone and the anomalous conductive structure. The proximal cause of the anomalous conductivity structure could be either the presence of fluid zone associated with partial melting of deep crustal rocks or a hot fluid zone resting over the magma emplaced in the upper crust. Estimated temperature within the conductive structure is ~260°C. The large depth extension (~8 km) of the anomalous conductive structure accounts for a huge volume of the heat source substantiating its long term sustainability (Azeez and Harinarayana, 2007). High temperature conditions at shallow depths make the area highly favorable for thermal resource utilization for power production as well as for other industrial applications of geothermal energy.

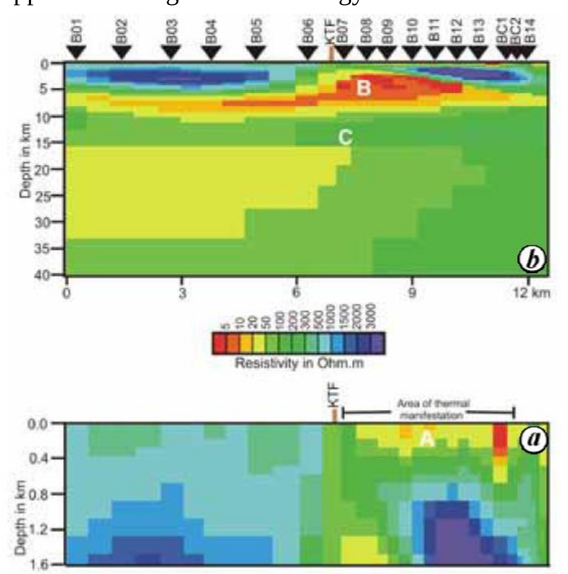

Figure-4: Two-dimensional resistivity model for the Puga geothermal field derived from inversions of MT data.
a. Shallow section;
b. Deeper section. Inverted triangles show the location of MT sites. The area of geothermal manifestation is also marked (From Azeez and Harinarayana, 2007)

Three zones have been demarcated in Puga Geothermal field as illustrated in Table 2.

Bulk Characteristics	**Shallow zone Low resistivity**	**Reservoir/ Aquifer High resistivity**	**Deep structure Conductive**
Depth	0-400m	400-2000m	2-8km
Extent	4sq.km	-	-
Main rock type	Sand + Breccia	Fractured paragneiss	Dense paragneiss & granite
MT resistivity range (Ωm)	10-30	1000	5-10
Rock density range (g/cm^3)	2.2-2.8	2.6-2.9	>2.8
Rock porosity range (%)	5-50	10	<5
Max Temp.(°C)	100-140	240	>200
Conductive phase	Geother. Water + Fresh water	Geother. fluid	Geother fluids + partial melts .(?)

Table 2: Main characteristics of the potential geothermal reservoir in Puga (Hjartarson et al. 2008).

Yangbajing field located NW of Lhasa, Tibet at ~4500m above sea level in Tibetan plateau north of ISZ has characteristics similar to Puga field. Shallow reservoir (180-280m) within unconsolidated Quaternary alluvium and altered Himalayan granite exhibits temperatures ~165°C while deep reservoir (950-1850m) in the slip fault zone of Nyainqentanglha core complex and fractured Himalayan granite shows temperature range of 251-329°C. The zones have been utilized by multiple geothermal wells to generate ~100 GWh annually with installed capacity of 25 MWe since start of exploration in 1976. (Dor Ji & Zhao Ping, 2000)

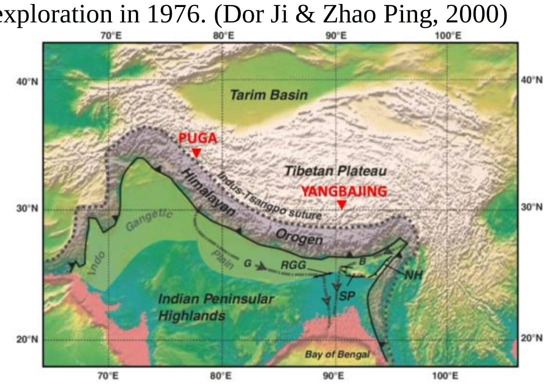

Figure-5: Relative locations of Yangbajing & Puga fields

Pilot stage of the ongoing project at Puga, Ladakh, taken up by ONGC in association with ISOR, Iceland consists of drilling of two wells followed by establishment of power plant up to 1 MW capacity.

Figure-6: Puga valley well site (Aug-2022)

First well was taken up in the central area of known geothermal field with a target depth of 1000m. A shallow kick at 40m with discharge to the tune of 10-15 L/s and steam temperature of 130°C was encountered in the initial phase. Presence of hydrothermally altered high temperature minerals like Epidote, Stibnite crystals and Silica gel with drill cuttings underlined the geothermal potential of the area (Fig 7).

The area is very remote and has a limited fair weather window with multiple associated logistic challenges like limitation on rig size, time of travel, availability of raw material etc.

Further operations with comprehensive planning for a slim hole for better control including deployment of specialized pressure control equipment like Blow out Preventers from the initial phase itself are underway to mitigate the logistical and geological challenges in the remote area.

Studies are also being planned to assess the flow and recharge potential of the reservoirs to gauge and utilize the full potential of Puga field. This utilization may also include nearby geothermally active fields.

Exploring and Exploiting Geothermal Resources of India: Case study of Puga Geothermal Field, Ladakh

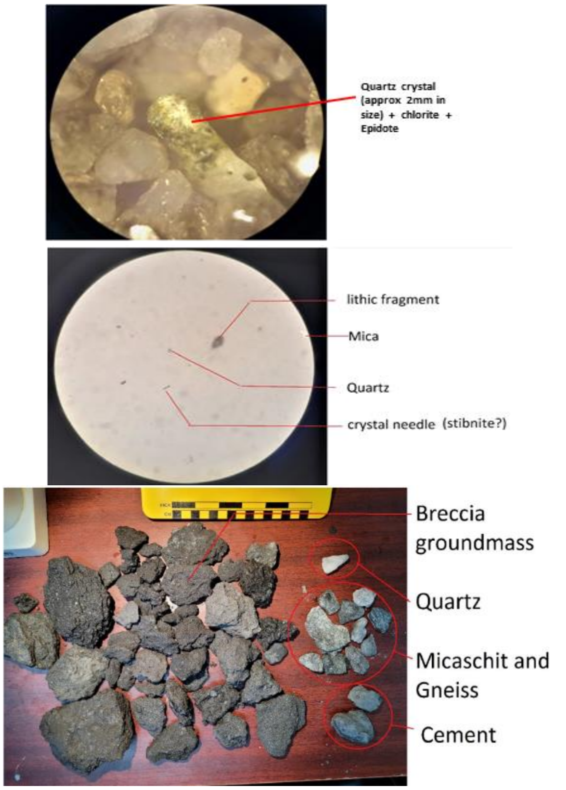

Figure-7: Megascopic and under microscope pictures of cuttings/rock fragments and silica gel from well at Puga valley (2022)

Geothermal Energy: Utility & Development

Geothermal energy is used to heat homes, commercial greenhouses, fish farms, food processing facilities, gold mining, pulp making and in paper mills. Lindal's diagram (Fig 8) lists the uses of geothermal energy according to the surface temperatures available in the field.

Geothermal energy prospects with high enthalpy viz. surface temperatures ~150°C can be utilized for power generation using direct cycle / flash steam plants wherein the steam is seperated and turbines are used for power generation (Fig 9).

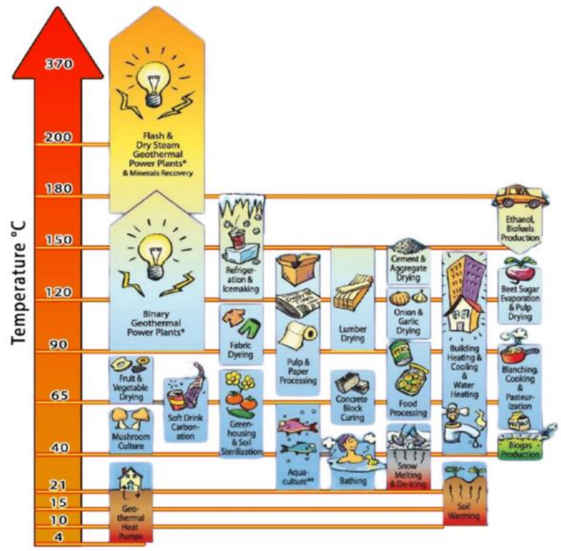

Figure-8: Lindal diagram (after Lindal 1973) showing Geothermal energy utilization as per temperature range

In case of prospects with lower temperatures (100-150°C), binary cycles can be utilized wherein fluid is extracted and circulated through a heat exchanger where the heat is transferred to a low boiling point organic liquid. This gets converted into high pressure vapour, which drives organic fluid turbines to be utilized for power generation (Fig 10).

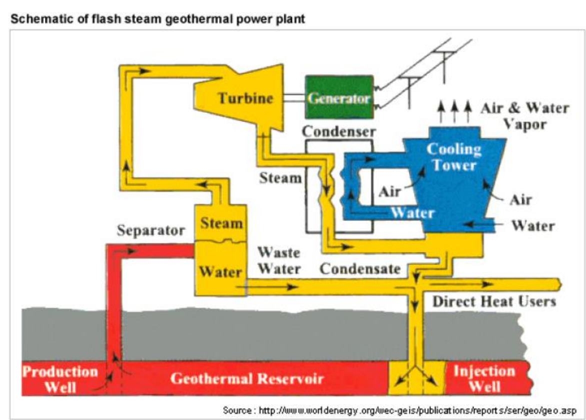

Figure-9: Schematic of flash steam geothermal power plant (from worldenergy.org)

Exploring and Exploiting Geothermal Resources of India: Case study of Puga Geothermal Field, Ladakh

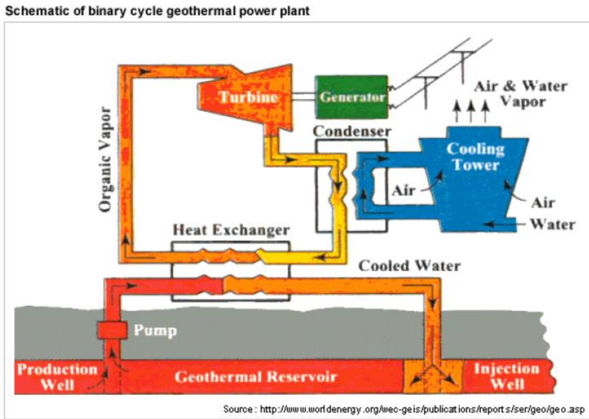

Figure-10: Schematic of binary cycle geothermal power plant (from worldenergy.org)

Studies indicate the geothermal water found in India is of low to medium enthalpy with temperature range between 90°C to 140°C suitable for binary cycle power generation however techno-economic feasiblity assessment for any particular site needs a detailed and focused approach.

Conclusions

- The Puga hot spring area, located at the junction of the Indian and Tibetan plates along the Indus Suture Zone, has perhaps the greatest potential for the development of geothermal energy in the Indian subcontinent considering its similarities to succesful Yangbajing geothermal field of Tibet. Independent studies by experts in the field available with ONGC have indicated a strong probability that the Puga field could sustain a 10-20 MWe power plant.
- The deepest geothermal exploratory boreholes drilled are in Puga (385m), Chhumathang (220m), Manikaran (700m), Tapoban (728m), Tatapani (620m) and West Coast (500m). Thermal discharges are at temperatures of 90°C to 140°C in the promising areas. Thermal fluids issuing from the boreholes have limited output. Electrical power production level can only be enhanced through deeper boreholes and utilization of binary cycle after due techno-economic feasibility studies which requires a multidisciplinary approach with support from experts in the field.
- Success at Puga and replication at other areas like Tatapani-Chattisgarh, Manuguru-Telangana etc. can pave the way towards energy independence of India by contributing to energy basket.

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Acknowledgements

The author would like to express their deep sense of gratitude to Shri Nandan Verma, ED- HoI, KDMIPE, Dehradun for support and guidance during the course of this paper. The author expresses sincere gratitude to Shri Sanjoy Mukherjee, GM (G), Head Unconventional Group, BRG for his guidance and support for writing this paper. Author would also like to thank teams of OEC-ONGC and ISOR, Iceland for their help and guidance during Puga drilling project.