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Aberdeen Section
Accelerating Geothermal Energy
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Integrated Geological-Engineering Framework for Assessing the Heat Extraction Potential from Manuguru Geothermal fields in Godavari Graben, India

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Introduction

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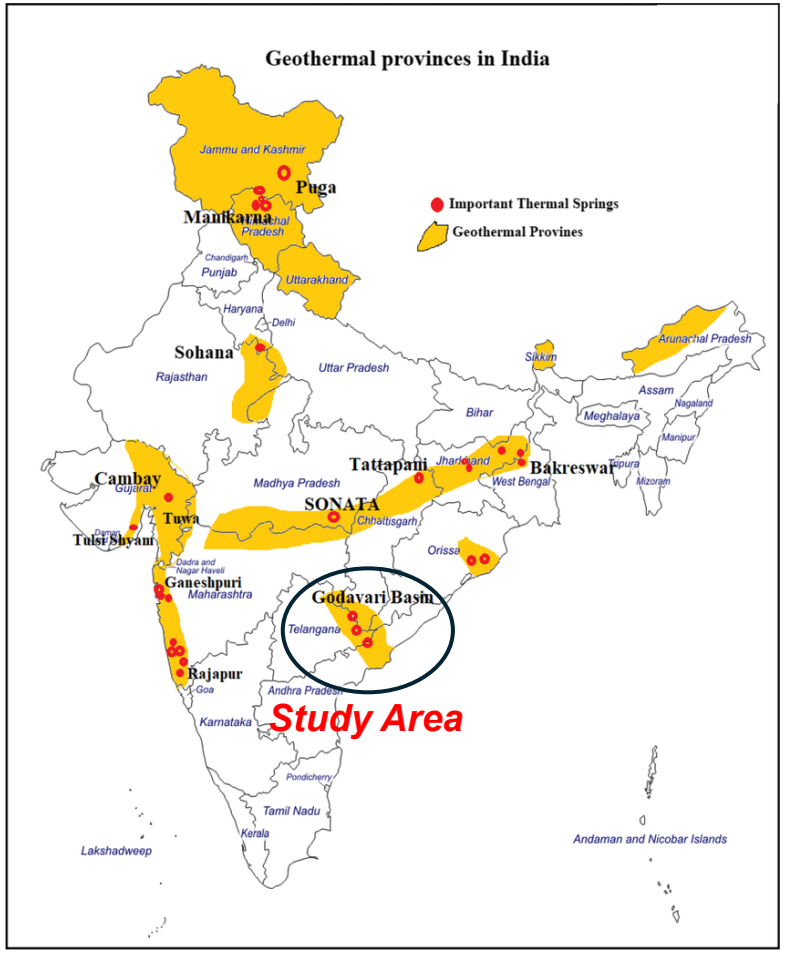
- Increasing demand of energy leads India to switch from fossil fuel to renewable energy sources.
- Geothermal energy is one such source of energy which is getting explored with time.
- Exploration of geothermal survey started long back but exploitation of the same is limited.
- From the energy point of view, **India requires huge thrust in exploration and exploitation in field of geothermal resources**.



Ref: Sharma, O.P. (2017)

India's Geothermal Prospects

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- The geothermal system has been categorized on the basis of resource:
  - ✓Medium enthalpy temperature which ranges from 100 to 200 °C.
    - Himalayan **Puga-Chhumthang**, Parbati, Beas and Satluj.
    - Maharashtra's western coast; along the Son-Narmada-Tapti Lineament Zone at Salbardi, Tatapani in Madhya Pradesh and Rajgir- Monghyr in Bihar and Ghats of Orissa.
    - The rift and grabens of the Gondwana reservoirs which are synonymous with Damodar, Godavari and Mahanadi.
    - The West Coast Cambay Basin consisting of sediments of Quaternary and Tertiary graben.
  - ✓Low enthalpy with temperature less than 100 °C.

Thermal Province	Temperature at Surface (°C)	Temperature at Reservoir (°C)	Heat Flow (mW/m^2)	Thermal Gradient (°C/km)
Himalayan Province	>90	260	468	100
Cambay Province	40–90	150–175	80–93	70
West Coast Province	46–72	102–137	75–129	47–59
Sonata Province	60–95	105–217	120–290	60–90
Godavari Province	50–60	175–215	93–104	60

Ref: Kriti Yadav & Anirbid Sircar (2020)

Pranhita-Godavari Basin

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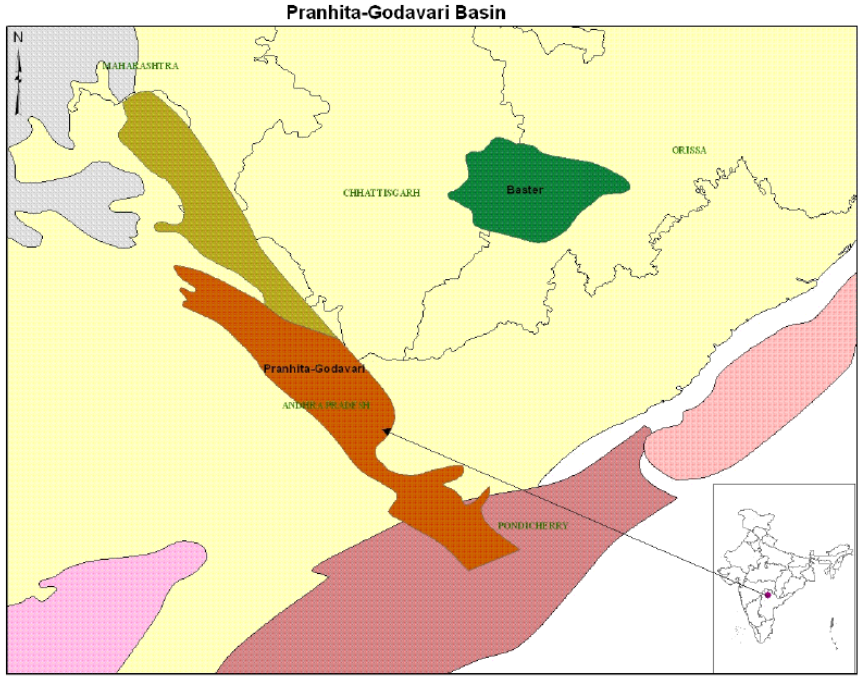
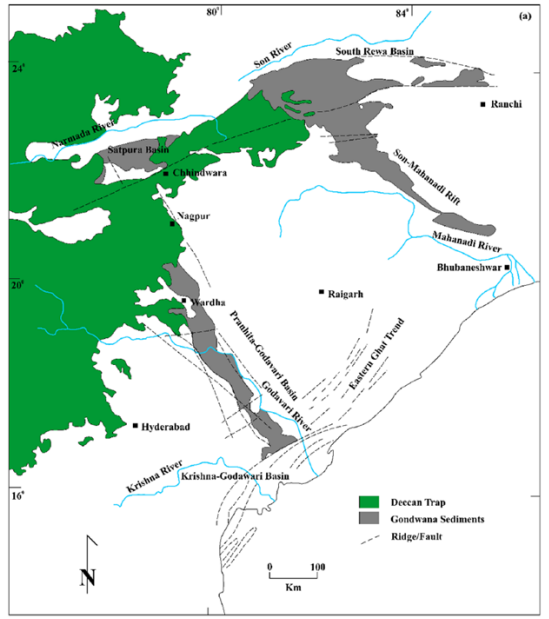


Ref: Pranhita-Godavari Basin, Directorate General of Hydrocarbons, GoI

- The NW-SE trending Pranhita-Godavari Valley is unique as it preserves about 3000 m thick sediments deposited in a time span of 200 Ma from late Carboniferous/early Permian to Cretaceous as it consists of a series of NNW-SSE grabens and half-grabens.
- The PG basin is manifested with numerous geothermal water springs with surface temperatures ranging from 30 to 80ºC.
- High heat flow values ranging from 44 to 180 mW/m2 and a high geothermal gradient of about 60ºC/km are recorded in the geothermal areas.

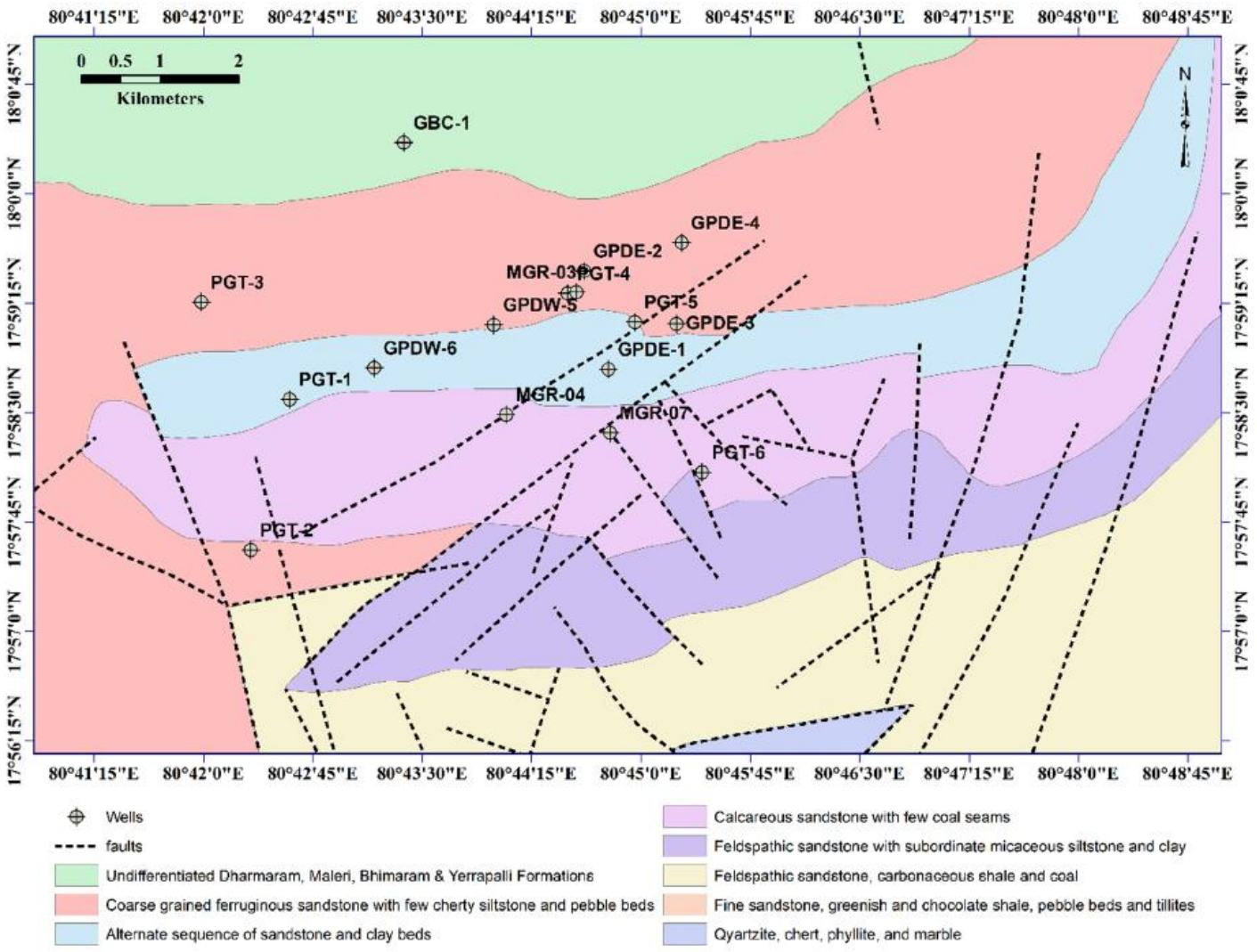


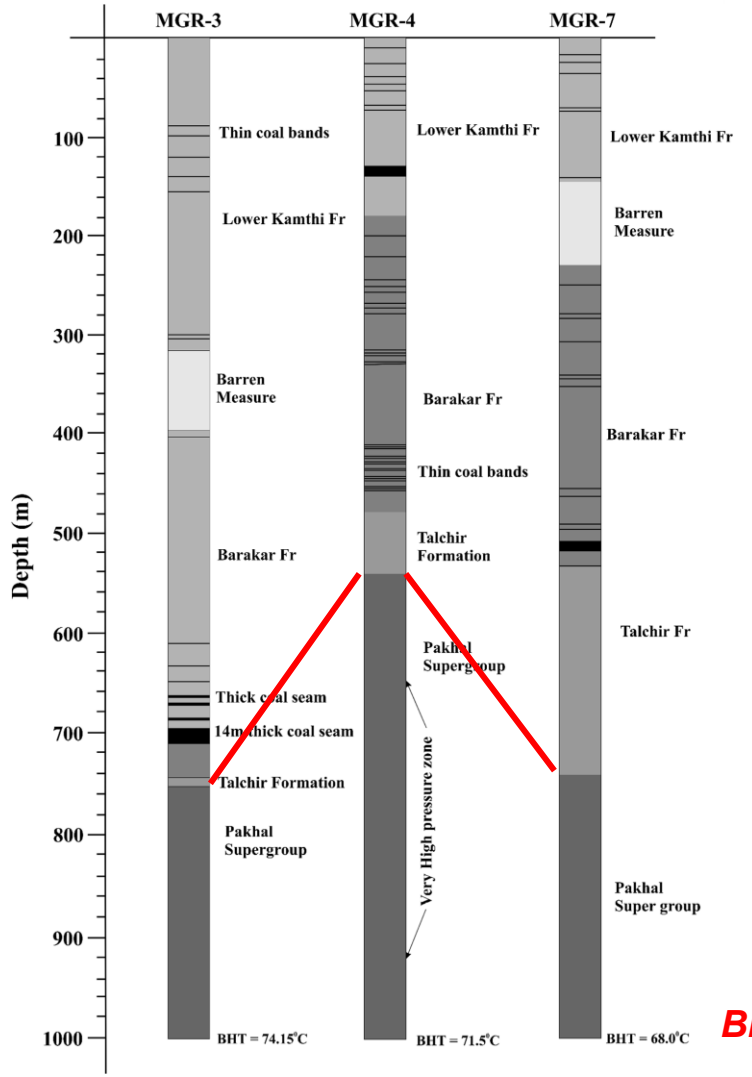
- Numerous hot springs take place here with low to moderate temperatures ranging from 30°C to 62°C.
- The geothermal waters of the area are near neutral (pH: 6.5–7.3) with surface temperature ranging from 30 to 55°C
- High heat flow values ranging from 44 to 180 mW/m2 and a high geothermal gradient of about 60ºC/km in some sections of the graben.
- The reservoir temperature is however projected to be about 100°C to 225°C.

Study Area

Manuguru Province, Godavari Graben

Details of Wells Drilled & Lithology





BHT: 65 - 80°C

Study Area

Manuguru Province, Godavari Graben

Subsurface Temperature Profiles & Gradients

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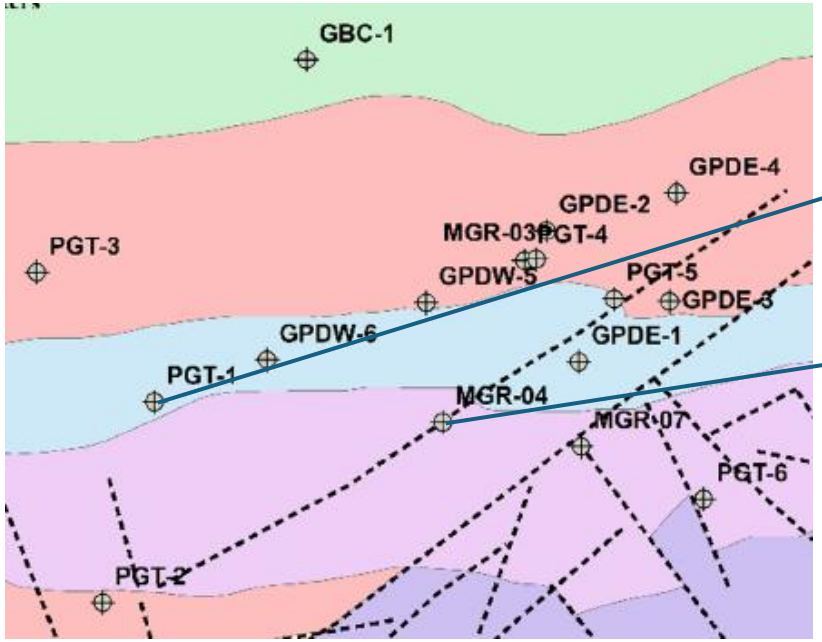

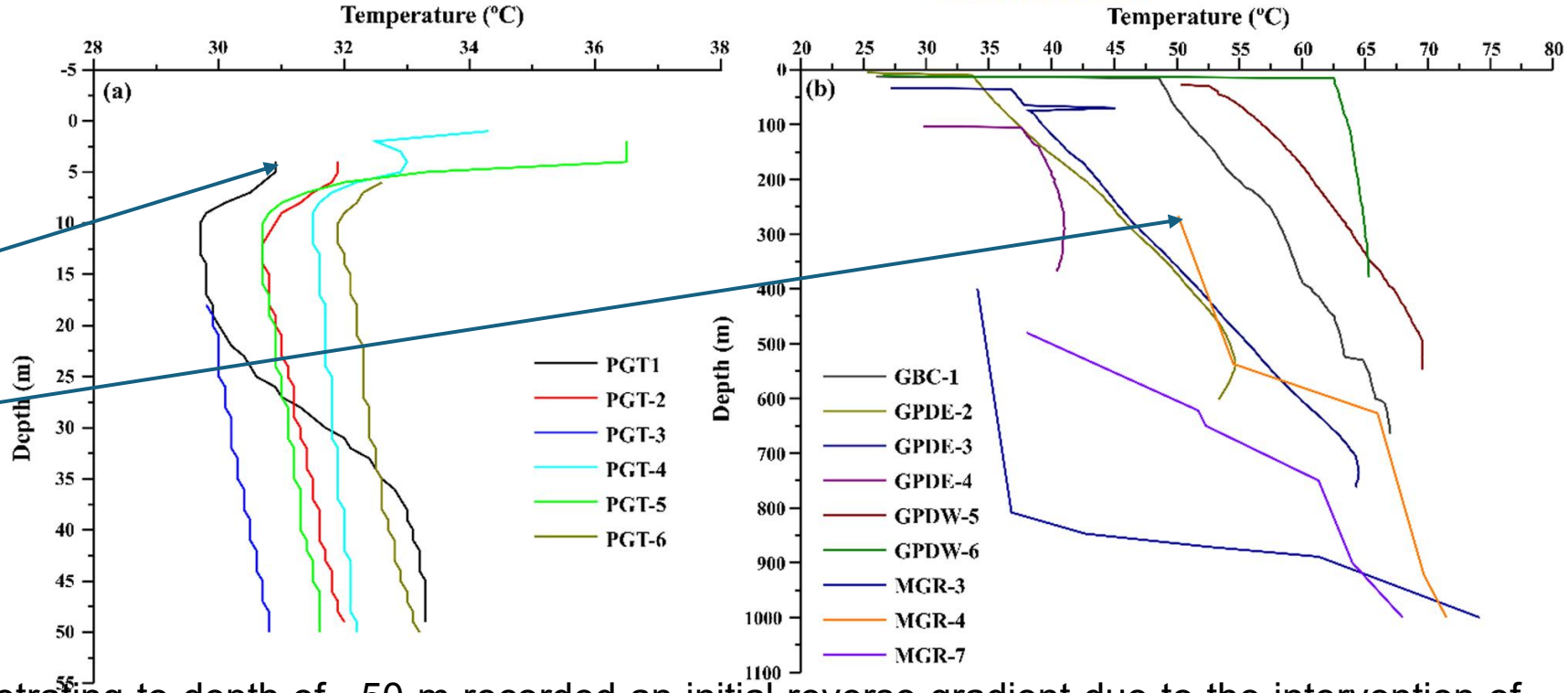

- The shallow bore-wells (PGT 1-6) penetrating to depth of ~50 m recorded an initial reverse gradient due to the intervention of shallow surface groundwater and recorded a bottom hole temperature of ~34ºC.
- The maximum bottom hole temperature recorded from the deep bore wells was 75ºC at 1000 m depth.
- The recorded heat flow values recorded in this region vary from **83 to 388 mW/m2** and are significantly higher than the heat flow value of average continental crust.

Study Area

Manuguru Province, Godavari Graben

Subsurface Temperature Profiles & Gradients

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Thermal logging and heat flow observations in parts of the Manugurua area, Godavari valley.

Sr. No.	Well No.	Longitude	Latitude	Depth m	Bottom hole temperature °C	Thermal gradient °Ckm^{-1}	Thermal conductivity $Wm^{-1}K^{-1}$	Heat flow mWm^{-2}
1	PGT-1	80.70631	17.97650	50	33.4	86.1	3.678	316
2	PGT-2	80.70539	17.95931	50	32.1	34.2	3.678	126
3	PGT-3	80.69972	17.98761	50	30.8	31.3	3.678	115
4	PGT-4	80.74158	17.98861	50	31.6	22.5	3.678	83
5	PGT-5	80.74932	17.98537	50	31.5	23.7	3.678	87
6	PGT-6	80.75699	17.96816	50	33.2	32.5	3.678	120
7	GBC-1	80.72289	18.00583	665	67.2	63.9	3.678	235
8	GPDE-1	80.74628	17.97994	295	47.1	72.1	3.678	265
9	GPDE-2	80.74350	17.99117	601	53.3	47.0	3.678	173
10	GPDE-3	80.75406	17.98511	762	64.3	51.0	3.678	187
11	GPDE-4	80.75464	17.99440	760	64.3	52.8	3.678	194
11	GPDW-6	80.71819	17.97917	379	65.3	105.5	3.678	388
12	GPDW-5	80.73317	17.98502	547	69.6	76.9	3.678	283
13	MGR-03	80.74261	17.98875	1000	74.2	46.7	3.678	172
14	MGR-04	80.73458	17.97478	1000	71.6	44.1	3.678	162
15	MGR-07	80.74647	17.97269	1000	68.4	40.9	3.678	150

- The shallow bore-wells (PGT 1-6) penetrating to depth of ~50 m recorded an initial reverse gradient due to the intervention of shallow surface groundwater and recorded a bottom hole temperature of ~34ºC.
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Study Area

Manuguru Province, Godavari Graben

Other Key Details

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- **Fluid Classification**: Geothermal waters are near-neutral (pH 6.5 - 7.3) with surface temperatures of 30 to 55°C.
- **Water-Rock Interaction**: Enriched SO4 and Cl indicate deep circulation through granitic basement and pyrite-bearing sediments.
- **Gas Geochemistry**: High Helium, CO2, and N2 concentrations suggest deep crustal circulation.
- **Geo-thermometry**: Quartz and Na-K-Ca methods estimate moderate enthalpy reservoir temperatures of 110 to 195°C.
- **Reservoir Dimensions**: Target depth of 2500 to 3000 m over an area of 24 to 26 km².
- **Heat Content**: Estimated recoverable power between 8.92 x 10^8 and 1.24 x 10^9 MJ.
- **Extraction Strategy**: Organic Rankine Cycle (ORC) technology is highly suitable for this temperature range.
- **Power Potential**: Estimated generation capacity of 3584 MWe.

Proposed Geo-Engineering Framework

Phase 1: Structural & Hydrogeochemical Characterization

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Goal: Efficient Sub-surface Characterization with improved Down-hole Formation & Fluid Sampling!!!

- **Stratigraphic Mapping**: Identify the basin-filling sedimentary rocks and basement complexes.
- **Structural Architecture**: Delineate major fault systems that act as conduits for thermal fluids.
- **Fluid Classification**: Analyze the surface discharges to determine water types. The geothermal waters in this area are near neutral (pH 6.5-7.3) and show a Na-Ca-SO4-HCO3 to Ca-HCO3 signature.
- **Water-Rock Interaction**: Evaluate the ionic enrichment processes. The enrichment of SO4 and Cl indicates deep circulation and interaction with pyrite-bearing Gondwana sediments and the granitic gneiss basement.

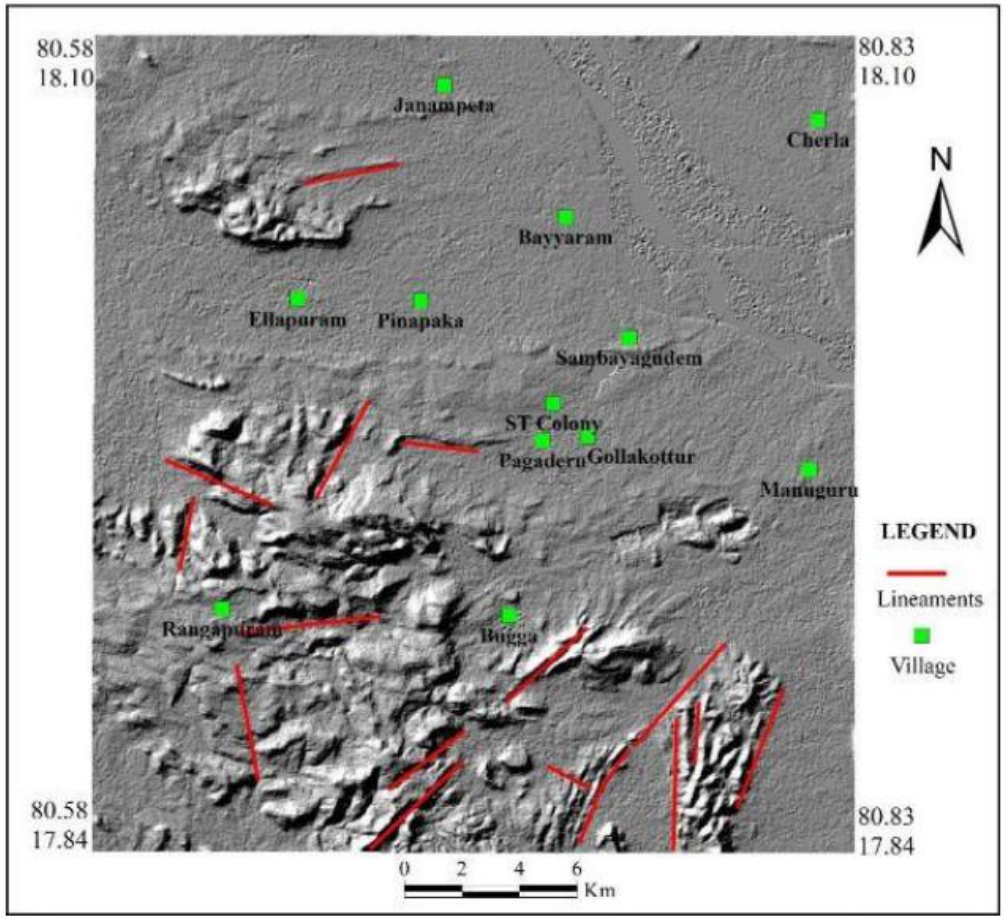

Fig: Interpreted structural lineaments over hill shade map of the Study Area

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Proposed Geo-Engineering Framework

Phase 2: Simulation Modeling (SWPM)

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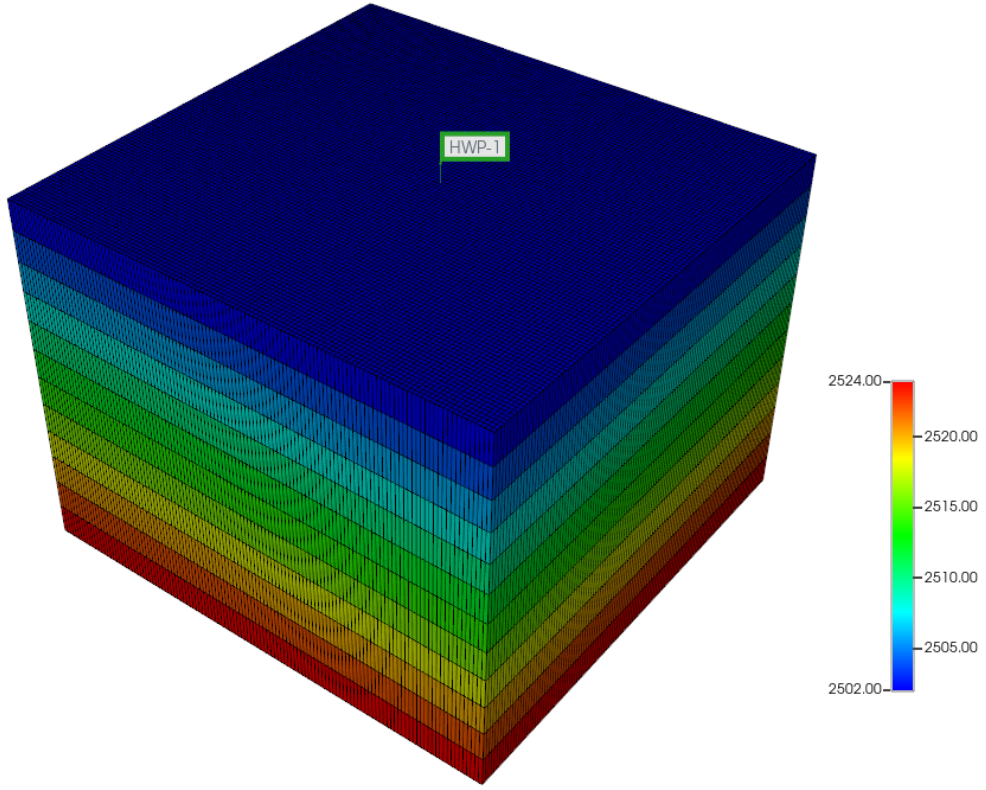
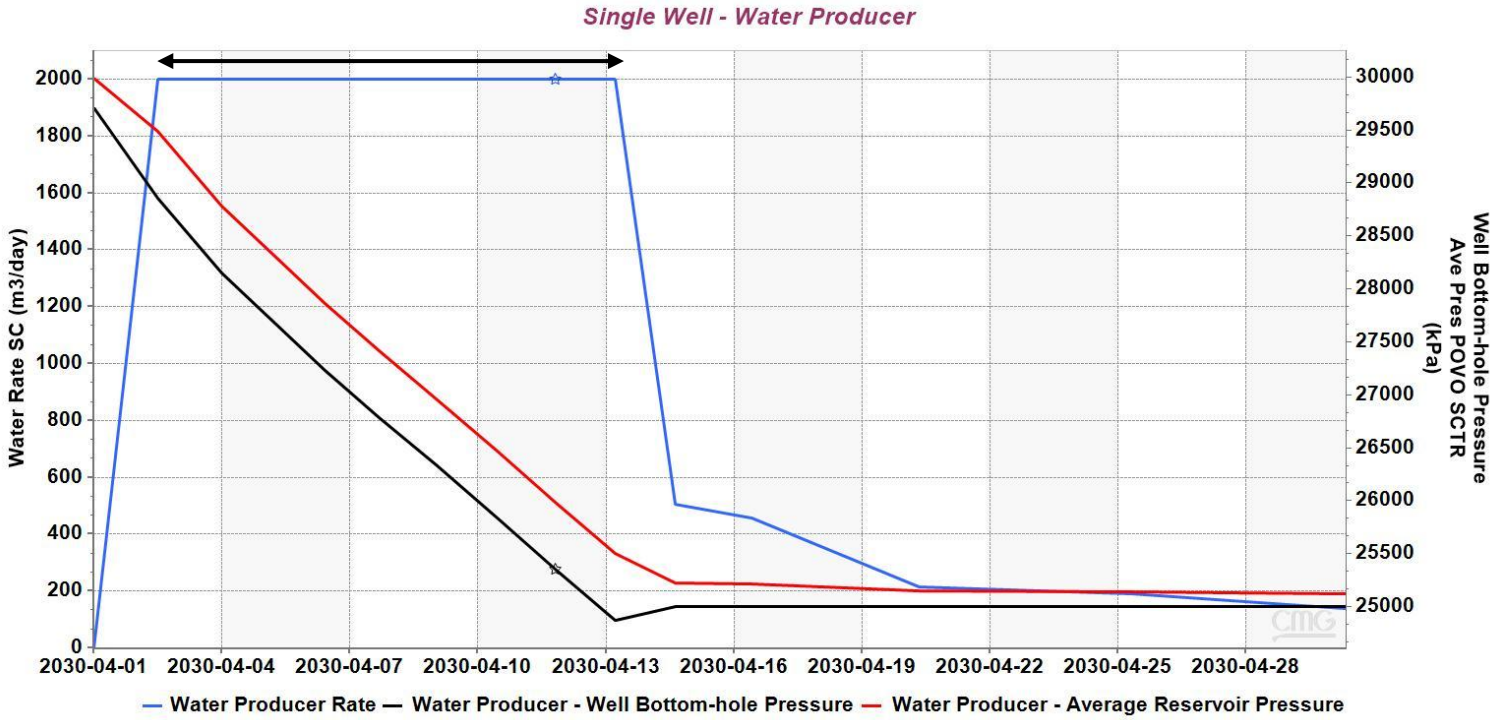


Plateau: 15 days



Constraints:

1. **Max. Water Rate:** 2000m3/day
2. **Min. BHP:** 25000 kPa

Recommendations

Spot Flooding for Pressure Maintenance!!

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Proposed Geo-Engineering Framework

Phase 3: Spot Flooding Framework

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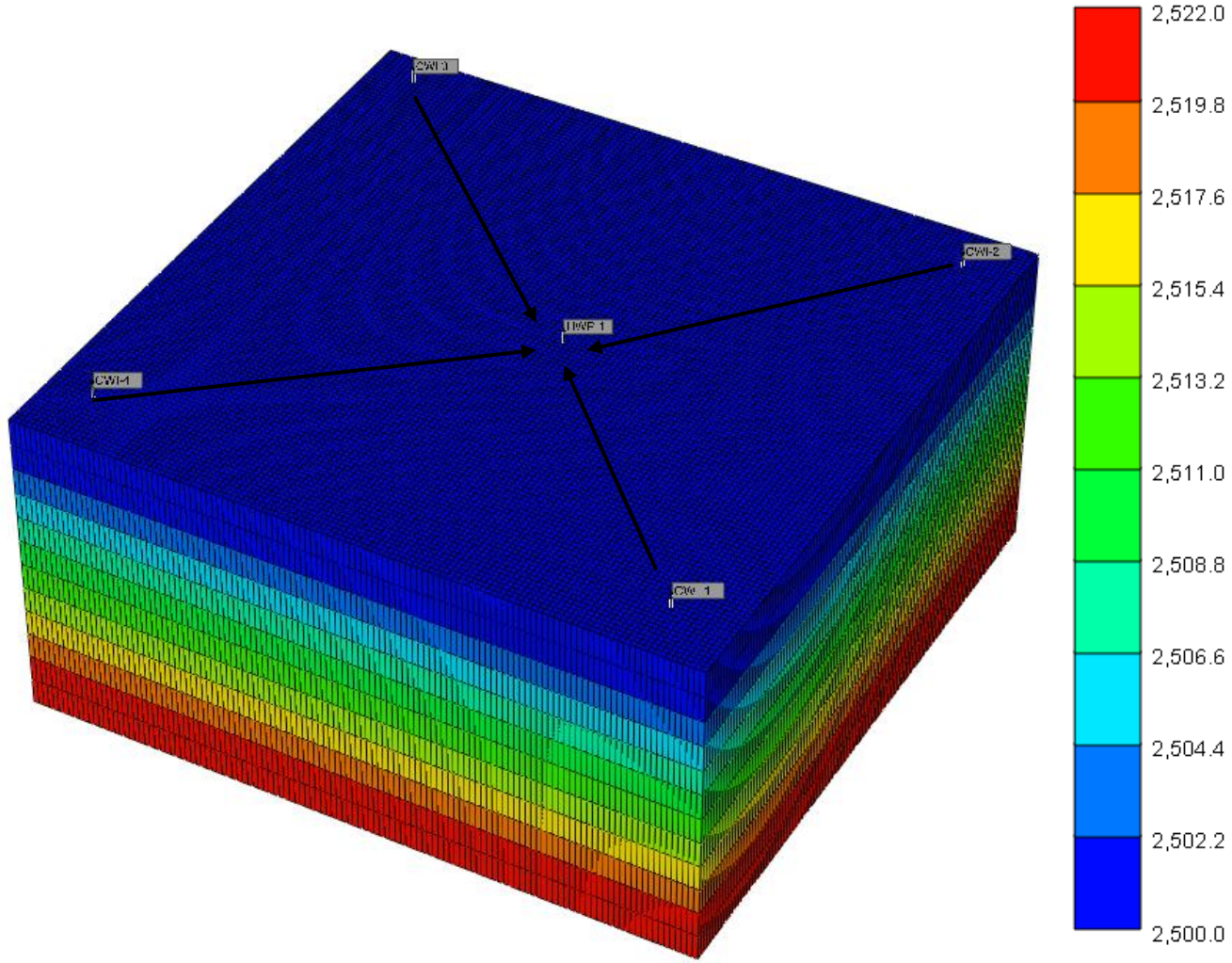

- **Number of Cold-water Injectors:** 4, to set-up a 5-spot pattern flooding.
- **Cold-water Injectors Placement**: Up-dip to Hot-water producer for higher residence time, better heat transfer and efficient pressure maintenance.
- **Voidage Replacement Ratio:** As the primary goal is to enhance water rate from Hot-water producer, instantaneous & cumulative ***VRR > 1*** is recommended.

Ministry of Renewable Energy's Understanding (Govt of India)

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- Since 1973, Geological Survey of India (GSI) has identified 381 hot springs with surface temperatures ranging from 35°C to 89°C.
- Apart from Himalayan regions where reservoir/resource temperatures can reach around 200°C, India

The aforesaid 20 kW pilot geothermal power plant in Manuguru is based on closed loop Binary Organic Rankine Cycle Process technology, which has been successfully demonstrated.

MNRE provides up to 100% financial support to Government/non-profit research organizations and upto 70% to Industry, start-ups, private Institutes, entrepreneur, and manufacturing units under Renewable Energy Research and Technology Development Programme, including for geothermal energy R&D projects.

infrastructure, geothermal fluid collection and disposal systems, and other surface installations; project **development costs**; and grid connection costs; type of power plant (Organic Rankine Cycle, dry steam, flash, or binary), well productivity (the number of wells), and other geothermal field characteristics.

Ministry of Renewable Energy's Understanding (Govt of India)

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Aberdeen Section

- Since 1973, Geological Survey of India (GSI) has identified 381 hot springs with surface temperatures ranging from 35°C to 89°C.
- Apart from Himalayan regions where reservoir/resource temperatures can reach around 200°C, India generally falls within a medium to low heat enthalpy zone, with resource temperatures of 100°C to 180°C.
- This makes it suitable for a range of direct applications such as GSHP for building heating/cooling, greenhouse heating, and cold storage etc.

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