Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Possible Enhanced Geothermal System Potential of High Heat Producing Radioactive Bundelkhand Granite

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Keywords: Bundelkhand granite, EGS

ABSTRACT

Uniaxial Compressive Strength (UCS) was carried out on high heat generating Bundelkhand granites in Madhya Pradesh. The heat generation varies from 1.4 to 5.4 μW/m^3. These granites hosts high temperature geothermal system at Tattapani. UCS shows strong relationship with strain rate at higher temperatures. These granites are under NE-SW compression regime and are well suited at candidates for EGS power projects.

1. INTRODUCTION

The Bundelkhand craton is one of the four Archean shields in India occupying nearly 29,000 km^2 in the central part of the Indian peninsula. Bundelkhand craton is bounded by Son-Narmada lineament on south, the Great Boundary fault of Aravali in the west and Himalayas in the North (Fig.1). These granites are characterized by their ability to generate high heat due to the high content of radioactive elements like uranium, thorium and potassium. Thermal springs issuing through these granites have chloride content and register high surface temperatures. These granites are potential sites for generating future EGS based power plants (Chandrasekharam and Chandrasekhar, 2010, Chandrasekharam and Chandrasekhar, 2008). Geological, structural and physico-mechanicaal properties of these granites have been assessed as a part of a joint collaboration between IIT Bombay and Monash University, Australia. This paper present certain salient features of this investigation.

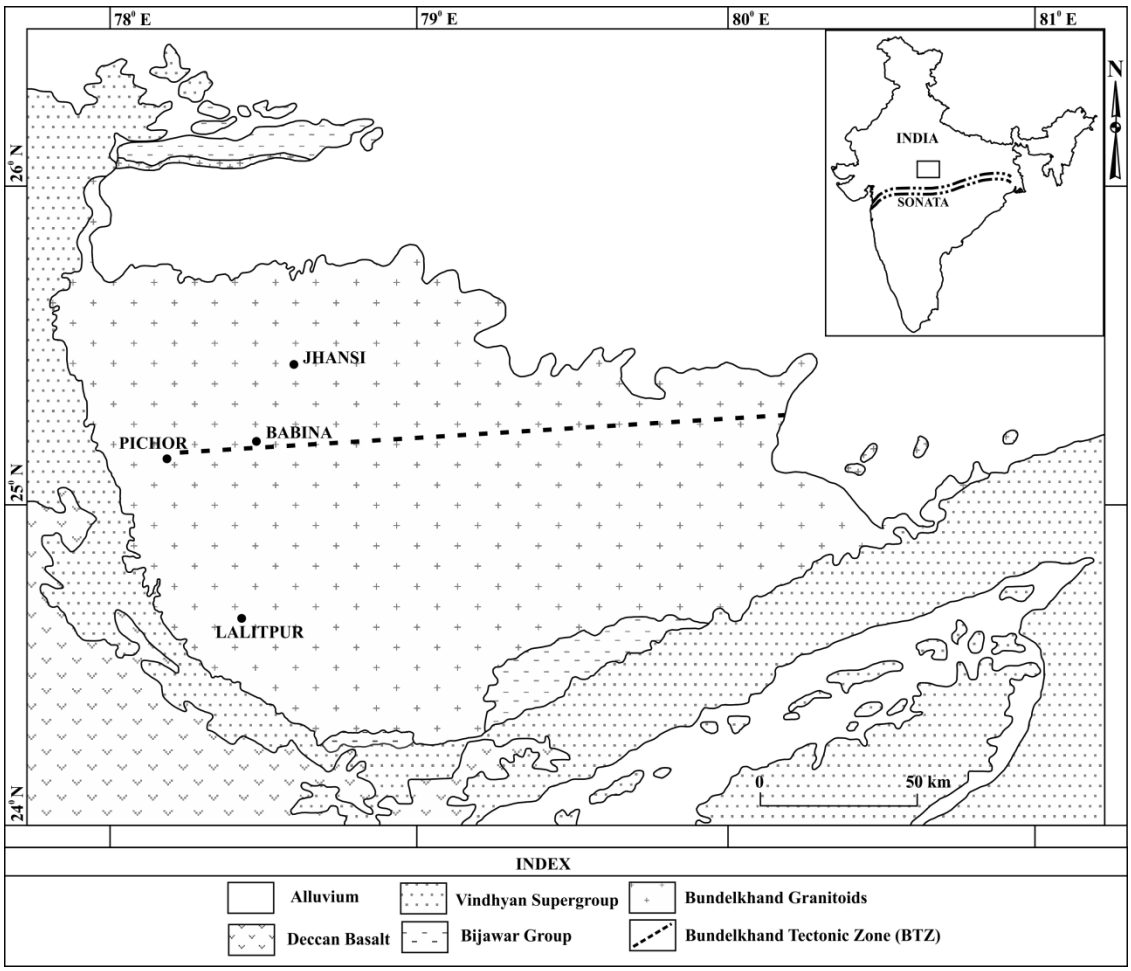

Figure 1: Geological map of Bundelkhand Craton (modified after Pati et al., 2007)

2. GEOLOGY

The Bundelkhand craton consist of supracrustral gneisses with or without tonalite-trondjhemite granodiorite and granite (TTG of 3.3 Ga, Mondal et al., 2002). Several phases of compositionally different felsic intrusive rock, felsic volcanic rocks, giant quartz veins (GQVs) (Pati et al., 2007) and mafic ultramafic intrusive rocks (Basu, 1986; Mondal et al., 2002; Malviya et al., 2006) are also associated with the craton. The GQVs are older than 2.0 Ga and shows NW trend (Pati et al., 2007). The supracrustal gneisses show three phases of folding and the imprint of a crustal-scale brittle ductile shearing (~E-W trending) episode that affected all major lithology except the mafic dikes (Malviya et al., 2006; Pati et al., 2007). The Bundelkhand rocks are metamorphosed to amphibolite facies (Basu, 1986) and possibly to granulite facies. The extension of Bundelkhand Tectonic Zone (BTZ) is around 200 km (Fig 1).

3. METHOD

The study area consists of several locations within the Jhansi district of Uttar Pradesh, India. Boulder size oriented rock samples were collected in the field (Fig 2) and transported to the laboratory and 30 cm length 45 cm diameter cores were cut from these bounders. These cores were transported to Monash University to carryout uniaxial compressive strength (UCS) on the cores at different temperature pressure conditions.

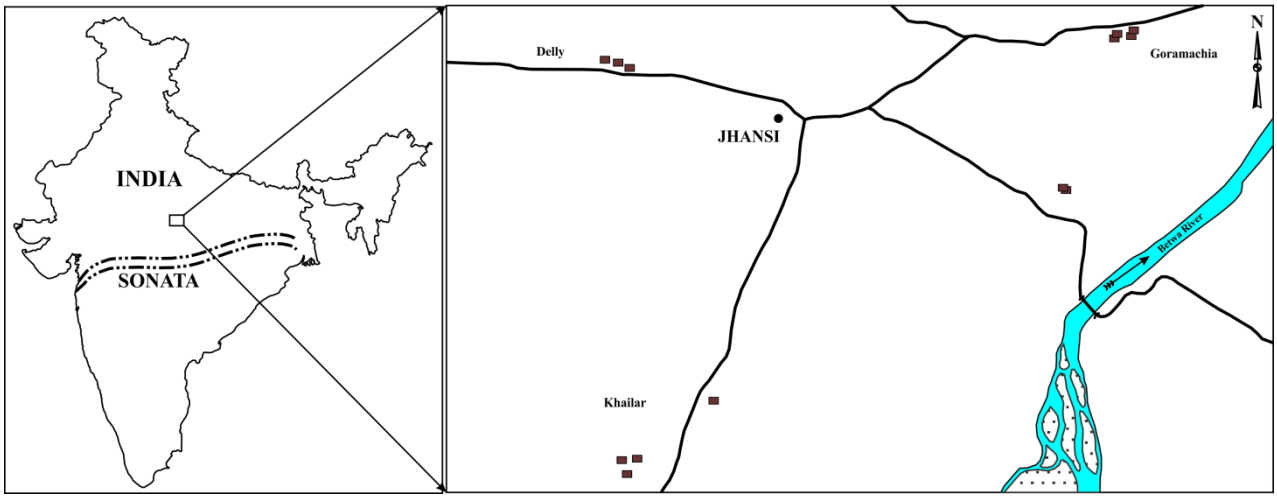

Figure 2: Granite sample location at various parts of Jhansi; square box indicates the sample locations.

4. RESULT AND DISCUSSION

4.1 High heat producing granite

The Bundelkhand granites host geothermal system at Tattapani area (Minissale et al., 2000) and the heat generation capacity of these granites varies from 1.4-5.4 $\mu W/m^3$ (Menon et al., 2003). These are fertile granites with high Th (6.9 - 42.5 ppm), U (3 - 8.8 ppm) and K (1.4 - 4.6 wt. %) contents, and are best suited to initiate EGS projects (Table 1). These granites are under NE-SW compressive regime (Chandrasekharam and Chandrasekhar, 2008, Chandrasekharam and Chandrasekhar, 2010).

Table 1. Radioactive element content in Bundelkhand granites (Data source Menon et al., 2003)

U (ppm)	Th (ppm)	K (%)	RHP ($\mu W/m^3$)
3	6.9	1.4	1.4
8	42.5	4.3	5.4
8.8	38.1	4.6	5.3
5.9	31.4	4.4	4.1

4.2 Uniaxial Compressive Strength (UCS)

The granites samples collected from the study area (Fig. 2) are of two types: alkali granite and plagioclase granite. Both the granites possess different compressive strength when subjected to different temperature and strain rate conditions. Compressive strengths of Alkali granite at various temperature and strain rate condition are listed below in Table 2 and that of plagioclase granite are listed in Table 3.

Table 2: Average compressive strength of Alkali granite of Bundelkhand craton at different temperature and strain rate condition (strength in MPa)

Avg. Compressive Strength of Alkali granite (MPa)			
Strain rate (mm/min)	**At temperature**		
	25 °C	**200 °C**	**400 °C**
0.05	202.9	190.2	153.1
0.5	223.8	209.3	160.0
5	232.5	222.1	174.6

Experimental results shows that with a strain rate of 0.05 mm/min, the compressive strength of alkali granites at room temperature (25 °C) is 202.9 MPa which decreased to 190.2 MPa at 200 °C i.e. by 6%, and further decreased to 153.1 MPa i.e. by 19% at 400 °C. With a strain rate of 0.5 mm/min, the compressive strength at room temperature (25 °C) is 223.8 MPa which decreased to 209.3 MPa i.e. by 6% at 200 °C and it further decreased to 160 MPa i.e. by 24 % at 400 °C. With a strain rate of 5.00 mm/min, the compressive strength of rock at room temperature (25 °C) is 232.5 MPa which decreased to 222.1 MPa at 200 °C i.e. by 5% and further decreased to 174.6 MPa i.e. by 21% at 400 °C.

Table 3: Average compressive strength of Plagioclase granite of Bundelkhand craton at different temperature and strain rate condition (strength in MPa)

Avg. Compressive Strength of Plagioclase granite (MPa)			
Strain rate (mm/min)	**At temperature**		
	25 °C	**200 °C**	**400 °C**
0.05	220.9	215.9	157.5
0.5	225.0	220.0	160.1
5.0	325.9	254.0	161.7

It is observed that with a strain rate of 0.05 mm/min, the compressive strength at room temperature (25 °C) is 220.9 MPa which decreased to 215.9 at 200 °C i.e. by 2% and further decreased to 157.5 MPa i.e. by 27% at 400 °C. With a strain rate of 0.5 mm/min, the compressive strength at room temperature is 225 MPa which decreased to 220 MPa at 200 °C i.e. by 2% and further decreased to 160.1 MPa i.e. 27% at 400 °C. With a strain rate of 5.0 mm/min, the compressive strength of rock at room temperature is 325.9 MPa which decreased to 254 MPa at 200 °C i.e. by 22% and further decreased to 161.7 MPa i.e. by 36% at 400 °C.

5. CONCLUSIONS

Bundelkhand granites are high heat producing granites and the heat generation ranges from 1.4 to 5.4 $\mu W/m^3$. It was observed that the strength of the rock varies with different strain rate. The UCS test results on the alkali granite and plagioclase granite do not show significant variation from 25 °C to 200 °C, but at temperatures > 400 the compressive strength decreases. The effect of strain rate on the uniaxial compressive strength has also been demonstrated from the result. Both Alkali granites and Plagioclase granites show the trend of increase in uniaxial compressive strength with increase in strain rate. But in Plagioclase granites, increase in compressive strength is insignificant from low strain rate (0.05 mm/min) to standard strain rate (0.5 mm/min). However, higher strain rate (5.0 mm/min) studies shows a significant increase in UCS with a very wide range of distribution from room temperature to 400 °C which is probably due to the formation of micro-cracks at higher temperature. Further work is being carried out to understand the propagation of fractures at elevated temperatures.

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