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Hot Dry Rock Potential in India: Future Road Map to Make India Energy Independent

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ABSTRACT

Several magmatic activities occurred in India during the Precambrian and Post Carboniferous Eras, as represented by granites, basalts and pegmatites. Northern parts of India including Ladakh, Zanskar, Uttarkhand, Himachal Pradesh, and Madhya Pradesh were loci of intense intrusive activity. This is represented by granites of different ages varying from 5-477 Ma. Meanwhile, Precambrian igneous activities were widespread across the country. The Precambrian gneiss invariably forms the stratigraphic basement unit in India. A variety of older granites have intruded into this basement. Although the granite outcrop is discrete, gravity and aeromagnetic anomaly maps indicate that these granites occupy a large area below the sediment and Deccan volcanic cover. In certain areas, they form the basement of Paleozoic (e.g. Gondwana) and Cenozoic (e.g Deccan basalt) formations. These granites occupy an area of about 150,000 km^2, extend to great depths, and sometimes form large batholiths several kilometers thick. The most significant feature of these granites is that they drive all the hydrothermal systems in the country. The heat production capacity of these granites varies from about 3-5 $\mu W/m^3$. Prolonged circulation and intense water-rock interaction processes are indicated by high ^4He content, low $^4He/^3He$ ratio, and high fluoride content in the thermal water. Even though the west coast thermal circulation is thought to be in the Deccan volcanic flows, recent reports on the presence of 140 Ma granite below the Deccan volcanic flows does not preclude major thermal fluid circulation in a granite reservoir. Even in places where natural fluid circulation is not present, these high heat generating granites can be considered hot dry rocks with a high potential to generate electricity. Considerable EGS potential exists even in regions where hydrothermal systems do not exist (e.g. Tamil Nadu). Assessment has been carried out on the power producing capacity of thee granites using U, Th and K content. For example, estimates on a small volume of granite from northern India indicate that there is potential to generate a minimum of 61,160 x 10^{12} kWh. Perhaps in the future, EGS may help to make India energy independent and to eliminate its 78,577 MWe deficit.

1. INTRODUCTION

With population growth accelerating, demand for power will increase world the over. This demand will be high in non-OECD (Organization for Economic Cooperation and Development) countries like India, where the population growth is greater that 17% per year, and the and the electricity demand will grow by 3.5 % annually (Chandrasekharam and Bundschuh, 2008). The 2004-2030 energy forecasts indicate that coal and gas will continue to dominate energy use and will remain the single dominant contributor to CO_2 emissions (IEA,2007). India is no different from the global scene. The demand for electric power will grow to 1,41,080 MWe from the current production of 1,23,668 MWe. India will try to approach this target by using easily available coal reserves. It is estimated that an additional 263 tonnes of coal will be burnt to achieve this target, thereby releasing 870 million tonnes of CO_2 (Chandrasekharam and Chandrasekhar, 2010). With the UNFCC cap on emission rates, developing countries like India must depend on low carbon emission energy sources like renewable energy sources. The renewable energy sources should be large enough to sustain the demand for longer periods of time, should be commercially and technically accessible and should emit low amounts carbon dioxide. India has sufficiently large EGS sites that, if exploited, may fulfill India's ambition of increasing the per capita electricity consumption to 1000 kWh from the present 631 kWh (MOP, 2008). As discussed earlier, all hydrothermal systems in the country are driven by high heat generating granites whose volumes are large enough to make India energy independent and reduce electricity demand to zero. With current and developing drilling technologies and breakthrough research in heat extraction technology, India will become a major producer of electric power from EGS.

2. GRANITES AND GRANITES

India is one of the few countries that contain geological formations extending from Archean to recent. The country has excellent exposures of rocks belonging to the entire geological age spectrum, and a major volume is represented by volcanic and plutonic rocks. Volcanic flows and sedimentary formations provide excellent heat insulation to these plutonic intrusions.. The role of plutonic granite in the stratigraphic evolution in India is shown in Figure 1. Granites, representing the continental crust, occur as intrusions in early and late stratigraphic units, as shown in Table 1.

As shown in Table 1, granites of age varying from the Precambrian to recent (1 Ma) occur in the Indian stratigraphy. The area of outcropping of granite over the continent is about 150,000 km^2 (Chandrasekharam and Chandrasekhar, 2008, Chandrasekhar and Chandrasekharam, 2008). These granites are covered by sedimentary sequences of varying ages or by Deccan flood basalts. Post Carboniferous igneous activities were generally concentrated towards Central and Northern parts of India, such as along the Indus Suture Zone, which is shown in Figure 1. On the other hand, Precambrian igneous activities were widespread across the continent. Unlike other countries, India has a stratigraphic basement unit invariably composed of Precambrian granite gneisses.

Table 1. Plutonic granite activities (vertical Bars) in the Indian stratigraphic sequence. For the sake of simplicity, the formations representing each Era are omitted (modified from Chandrasekharam and Chandrasekhar, 2008).

ERA	Ma	System	
CENOZOIC (CZ)	<65		█
		Quaternary	█
		Neogene	█
		Paleogene	█
MESOZOIC (MZ)	250-65		█
		Cretaceous	
		Jurassic	
		Triassic	
PALEOZOIC (PZ)	540-250		
		Permian	
		Carboniferous	█
		Devonian	
		Silurian	
		Ordovician	
		Cambrian	
PRECAMBRIAN (PE)	>540		█
		Proterozoic	█
		Archean	

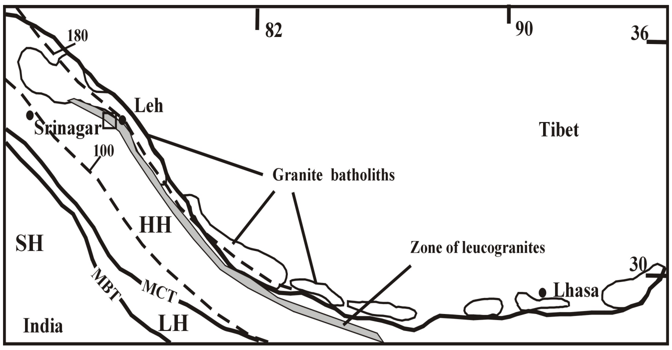

Figure 1. Post Carboniferous granite activity along the Himalayan Geothermal Belt (HGB, modified after Chandrasekharam and Bundschuh, 2008).

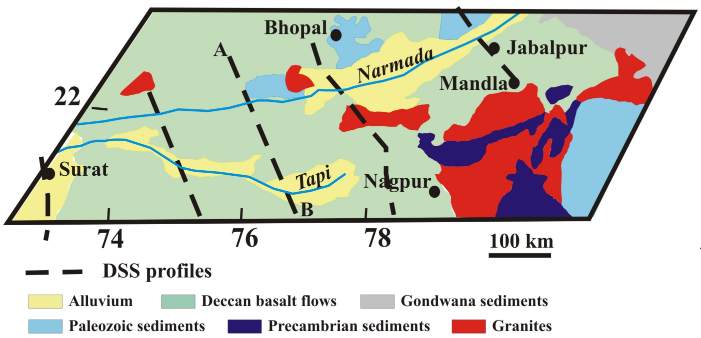

Figure 2. Surface lithology showing the granite outcrop across SONATA (modified after GSI, 1993; CRUMANSONATA, 1995). The granites belong to the Bundelkhand and Bastar cratons

In order to evaluate the subsurface extension of the granites, a small region between 72 and 82 °E longitude and along the 22 °N latitude was chosen. The geological surface and drainage features of this region were taken from published maps and are shown in Figure 2 (GSI,1993, CRUMANSONATA, 1995, Srivastava et al., 2009). Several DSS profiles were carried out across the Narmada river, as shown in Figure 2 (Kaila et a., 1981). Gravity, magnetic, magnetotelluric, and heat flow investigations were also carried out in this region (Rao et al., 1970, Kail et al., 1981, Singh and Meissener, 1995). The subsurface lithology across the DSS profile A-B (from Figure 2) is shown in Figure 3. The subsurface lithological features were modeled to 1 and 2 km depths using the above geological and geophysical data set. This is shown in Figure 4. The Narmada lineament controlling the river Narmada becomes a tight fracture at crustal levels although it is presumed to extend to mantle depths (Kaila e al, 1981). This inference is supported by the absence of mantle signatures in the thermal gases (low $^3He/^4He$ ratios) sampled along this fracture in the SONATA geothermal province (Minissale et al, 2000).

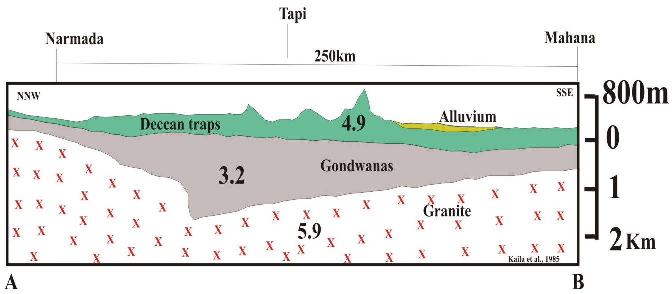

Fig. 3. Subsurface lithology based on DSS profile. The granites that outcrop as discrete bodies towards SE and NW corners in Figure 2 form a continuum below the depth of 1.5 km. Numbers denote seismic velocities in km/s (modified after Kaila et al., 1981).

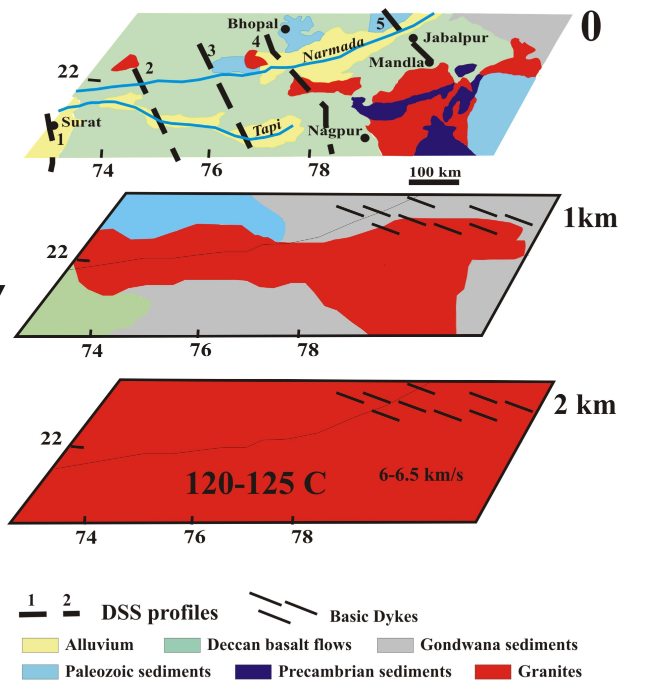

Figure 4. Subsurface lithological features projected to 1 and 2 km depths using DSS, gravity, heat flow, magnetic and MT data set across Narmada lineament.

The Bundelkhand and Bastar granite shown in Figure 4 hosts geothermal circulation at Tattapani (SONATA, Minissale et al., 2000) and Tuwa (Minissale et al 2003), and the reported heat generating capacity of these granites varies from 3-8 μW/m^3 (Chandrasekharam and Chandrasekhar, 2008 and the references therein). These are fertile granites with high Th (3-101 ppm), U (5-14 ppm) and K contents, indicating that they are high heat generating granites. The occurrence of such fertile granite is becoming a common feature in the Indian subcontinent (Senthilkumar and Sethuraman, 2003). Thus, at depths of 2-3 km, the area occupied by this fertile granite is several times greater than 150,000 km^2 and comprises a huge volume of potentially exploitable granite bodies for EGS. In the case of HGB, the temperatures of the granites at a 2 km depth are twice that estimated for the central India (Chandrasekharam and Bundschuh, 2008).

The power generating capacity of these granites in relation to the electricity requirements of the states where these granites occur has been estimated by M/s GeoSyndicate Power Pvt. Ltd (Chandrasekharam and Chandrasekhar, 2008). The estimate for a small area of about 1000 km^2 in Ladakh in the HGB indicate geothermal reserves of about 61,160 x 10^{12} kWh in this area. Meanwhile, Ladakh is currently generating ~ *4 x 10^8* kWh using diesel generators, and the reported demand is 310 x 10^6 kWh (Chandrasekharam and Chandrasekhar, 2008). Thus, geothermal reserves are greater than the current electricity demand in Ladakh by several factors. Similarly, it was estimated that a small part of these granites (1000 km^2) in Madhya Pradesh (shown in Figure 4) has a reserve of about 24,464 x 10^{12} kWh (Chandrasekharam and Chandrasekhar, 2008), while the present consumption of electricity in the entire state of Madhya Pradesh is about 33 x 10^9 kWh. (CEA, 2006). The Bundelkhand and the Baster granites shown in Figure 4 extend southward, forming the basement in Andhra Pradesh, including the Godavari rift (Senthil Kumar et al., 2007). Similar granites of equivalent age are also exposed in and around Hyderabad. The estimated reserve of Andhra Pradesh granites is 111,200 x 10^{12} kWh, while the current electricity deficit of the state is ~ 25 x 10^9 kWh (Chandrasekharam and Chandrasekhar, 2008). Even states like Tamil Nadu, which has no known hydrothermal systems, has potential sites to initiate EGS projects. Thus, the granites of varying ages in the Indian stratigraphy (shown in Table 1) are potential candidates for exploitation to meet India's growing electricity demand and reduce its dependence on coal and oil. Thus, geothermal energy can help to make India energy independent and to wipe out its 78,577 MWe deficit. Further, it aids in India's compliance with the UNFCCC mandate of reducing the CO_2 emissions by more than 5% and reducing carbon trade activity with European countries in the future. In fact, the hydrothermal systems that have a potential of generating 80 x 10^9 kWh are driven by these high heat generating granites (Chandrasekhar and Chandrasekharam, 2009).

3. DISCUSSIONS

All hydrothermal systems in India located along major rift zones (West coast, Cambay, SONATA and Godavari) and those associated with subduction related tectonics (such as the Himalayan Geothermal Province) are driven by high heat generating granites (Chandrasekhar and Chandrasekharam, 2009). Although a small mantle helium component is present in the thermal gases, this component could have been an artifact of mantle material entrapped during the evolution of the crust, as is the case of the ^{3}He/^{4}He ratio in the Himalayan granites (Hoke et al., 2000). This is also true in the case of the Cambay and SONATA geothermal provinces, where this small mantle helium component may be due to leakage of helium from the mantle through the major fractures and faults that extend to mantle depths. This shows that all the hydrothermal systems in India are in fact naturally enhanced geothermal systems and they provide considerable amounts of information for selecting sites and initiating EGS projects in India (Chandrasekhar and Chandrasekharam, 2009 GRC). In addition to this, as described above, almost all states in India have potentially high heat generating granite. The observed heat flow and thermal gradients within these hydrothermal systems (Chandrasekharam, 2005) is inherent in granites present in these regions. Considering the total surface exposure of such high heat generating granite over the Indian subcontinent (150,000 km^2), their depth of occurrence, and the stress regime of the Indian plate (Chandrasekharam, 2001), Indian granites are future warehouses of geothermal energy. It is estimated that these granites have the capacity to generate a quantity of energy equivalent to 3.133 x 10^{22} BTU. As new data regarding the radioactive element content in these granites are flooding the literature, the future of granites in supporting the electricity demand of this country is looking brighter. In fact, new uranium mines are being opened based on the high concentration of radioactivity in the Cuddppah district in Andhra Pradesh (Dr Achar, Atomic Minerals Division, India, Personal communication). Perhaps in the next decade, India may become one of the hot spots for EGS in southeast Asia.

4. CONCLUSIONS

India appears to be a warehouse of high heat generating granites and has the potential to generate electricity greater than projected requirements by the year 2030 and make India more energy independent. In fact, the earning accumulating through CDM is substantial that it can trade carbon, like European countries, in the near future. The location of EGS sites, considering the local logistic support of ports, water, and surface transport facilities, is conducive to foreign direct investments in the power sector. The Indian government has realized this potential and is making efforts, albeit slowly, to bring geothermal into the primary energy source mix. In the future, India may disprove the IEA's 2007 report that it will be a major coal importer in 2030 if its geothermal resources are judiciously utilized not only for power generation but also in the building and food processing sectors (Chandrasekhar and Chandrasekharam 2010, this volume).

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