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Low-Temperature Geothermal Systems in Sedimentary Basin and Their Prospect in Bangladesh

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Keywords:

ABSTRACT

Geothermal systems are distributed throughout the world in various ways on the basis of heat source, heat transfer, reservoir temperature, physical state, utilization and geological settings. Common classification of geothermal systems are: (a) volcanic systems with the heat source being hot intrusions or magma chambers in the crust, (b) convective systems with deep water circulation in tectonically active areas of high geothermal gradient, (c) conductive sedimentary systems with permeable layers at great depth (2-5 km), (d) geopressured systems often in conjunction with oil resources, (e) hot dry rock or EGS systems where abnormally hot masses of low permeability rocks are found at drillable depths, and (f) shallow resources in normal geothermal gradient areas utilized with ground-source heat pump applications. 50 years ago a classification for geothermal systems was proposed in Iceland which were divided into high- and low-temperature geothermal systems or fields based on (arbitrarily) inferred temperature, high temperature fields where a temperature of 200°C is reached at 1 km depth and low temperature fields where temperature is below 150°C in the uppermost km. The high-temperature geothermal fields are all related to volcanism whereas the low-temperature geothermal fields draw heat from the general heat flow of the crust. The geothermal systems are suitable for various applications based on subsurface temperature and fluid. Low-temperature geothermal system is directly related to the sedimentary basin which has thin conductive permeable sedimentary layers. Most of the low-temperature geothermal energy used as heating system in the winter dominant countries around the world. Bangladesh is one of the largest deltas which has a large sedimentary basin. Little prospect of geothermal resources in Bangladesh due to its geo-tectonic settings as well as thick sedimentary covers (130 m -20 km). Bangladesh has no volcanic regions, although in the east it lies close to the Eurasian-Indian plate boundary, which may be associated with high geothermal gradients. It has many abandoned gas wells which temperature is more than 100°C in the depth of 3 km to 4 km. The geothermal prospects, geological mapping of surface geothermal manifestations as well as low-temperature surveys are essential to evaluate the geothermal resources in Bangladesh.

1. INTRODUCTION

The word geothermal comes from Greek words geo (earth) and thermal (heat) meaning heat derived from the earth. It is the thermal energy contained in the fluids of rocks that is filled in the fractures and pore spaces within the upper crust. The heat is generated from several sources. Normally, the heat or temperature created by decay of naturally radioactive elements which increases with depth (Figure 1).The geothermal energy is defined as the temperature energy which stored within the earth where normal or abnormal temperature or geothermal gradient occurred. It refers to all parts of the hydrological system involved, including the recharge zone, all subsurface parts and the outflow of the system. This energy essentially consists of the heat stored beneath the earth's surface and discharging from it. The main sources for geothermal energy are the heat flow from the earth's core and mantle and that generated by the gradual decay of radioactive isotopes in the earth's crust which together result in an average terrestrial heat flow. This energy is found around the world but little in exploitable. The exploitable geothermal areas are associated with the earth's plate boundaries, volcanic regions, warm ground water in sedimentary formations or conductive sedimentary system and hot dry rock. The low-temperature geothermal energy is mainly used in heating purpose but also in industrial uses and little in electricity production. Sedimentary systems are found in many of the major sedimentary basins of the world. These systems owe their existence to the occurrence of permeable sedimentary layers at great depths (> 1 km) and above average geothermal gradients (> 30ºC/km) which are suitable for prospect of low-temperature geothermal system. These systems are conductive in nature rather than convective, even though fractures and faults play a role in some cases. Some convective systems may, however, be embedded in sedimentary rocks. Bangladesh has thick sedimentary covers and considering for the prospect of low-temperature geothermal field. Reservoir rocks of Bangladesh are permeable water bearing sandstone which is a good sign of the low-temperature geothermal system. A geothermal resource mostly depends on reservoir temperature, so Bangladesh needs only temperature. But Bangladesh is a monsoon climatic region where dominant by warm climatic condition and only two or three months covered by winter climate. So, heating system of low-temperature geothermal system is suitable only in winter period for this country but in electricity production it can be used frequently.

2. GEOTHERMAL SYSTEMS

Geothermal systems are classified based on temperature, enthalpy, physical state or their nature of fluid and utilization as well as geological settings (Axelsson et al. 2000). Numerous geothermal systems probably still remains to be discovered, since many systems have no surface activity. The classification of geothermal systems into low-temperature (LT) and high-temperature (HT) on the basis of geothermal field are commonly used in the world.

2.1. Low-Temperature Geothermal Systems

Low-temperature (<150°C) sedimentary geothermal resources are widespread in the continental regions of the earth's crust. They are quite different in nature from the geothermal resources associated with volcanic systems or tectonically active regions of the crust. Low-temperature geothermal energy is the system where geothermal water or subsurface hot water (temperature ranges from 40°C to 150°C) utilized directly as space heating , greenhouse, aquaculture, horticulture, industries and bathing as well as also used

in electricity production (10 to 20 MW power plant). Normally this system is developed out of a volcanic region and is always liquid dominant where water phase controls the pressure (hydro-static) often characterized by hot or boiling springs. Low temperature geothermal activity is spread over most areas of the earth and found in various geological settings. This system depends on the regional geothermal gradient, permeability, porosity and depth of circulation at different types of rocks and their temperature is variable depending on depth of permeable rocks. Water is interstitial water, commonly brine, formerly thought to be of connate origin. Besides volcanic systems all of types (convective, sedimentary, geo-pressure, enhanced and shallow resources types) developed as a low-temperature geothermal system. In convective fractured control systems, the heat source is the hot crust at depth where tectonically active with certain heat-flow. Here the geothermal water has circulated to considerable depth (> 1 km), through mostly vertical fractures, to mine the heat from the rocks (Figure 2). Sedimentary systems are found in many of the major sedimentary basins of the world.

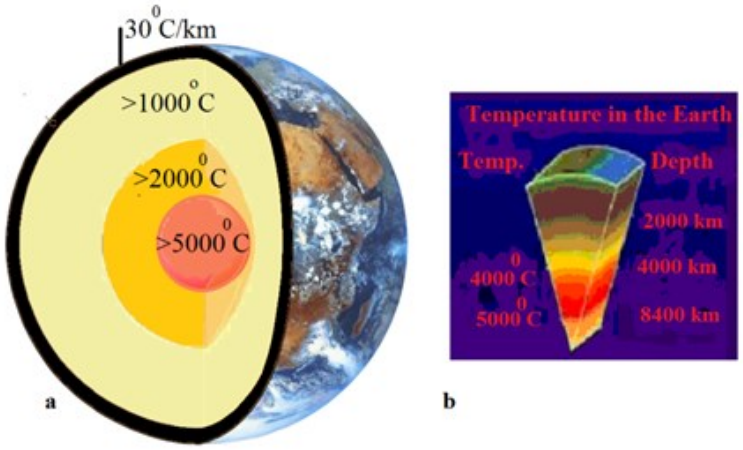


Figure.1: Figure a and b showing the temperature in the Earth which increases with depth.

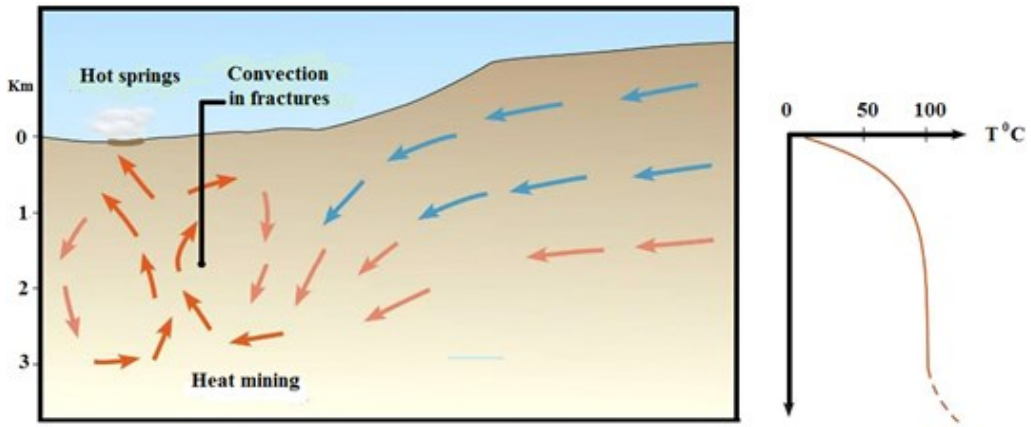


Figure 2: Geothermal systems of the convective fractured control type which are found in tectonically active area (modified from Axelsson 2008).

These systems owe their existence to the occurrence of permeable sedimentary layers (Figure 3) at great depths (> 1 km) and average geothermal gradients (>30ºC/km) which are conductive in nature rather than convective even though fractures and faults play a role in some cases. Some convective systems may, however, be embedded in sedimentary rocks. Geo-pressure system developed in stratigraphic trap at several sedimentary basins that may have pressures close to lithostatic values. Enhanced system developed in created reservoir permeability or Hot Dry Rock (HDR), such types will mostly be used through production/reinjection doublets (Axelsson 2008). Shallow resources developed due to heat pumping from the ground sources. Recent developments in the application of ground source heat pumps have opened up a new dimension in utilizing these resources.

2.2. Low-Temperature Geothermal Energy Utilization Around the World

Low-temperature geothermal energy is widely used in geothermal dominant countries of the world. This energy utilized in various categories' in terms of capacity, energy utilization and capacity factor. Some leading countries who utilize the low-temperature geothermal energy as direct use are mentioning in Table 1, (Lund et. al. 2010).

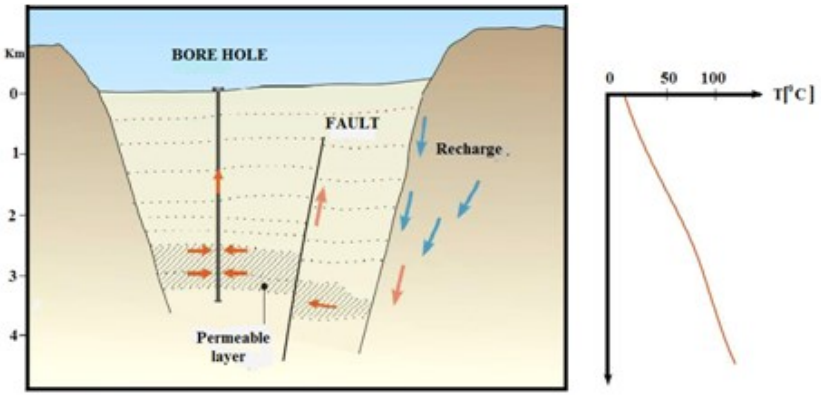


Figure 3: Sedimentary geothermal systems which are found in sedimentary basin (modified from Axelsson. 2008).

Table-01: Low-Temperature energy utilization as direct use around the world (leading 20 countries).

Country	Capacity MWt	Annual use in TJ/yr	Annual use in GWh/yr	Capacity factors
Germany	2,485.4	12,764.5	3,546.0	0.16
France	1,345	12,929	3,591.7	0.30
Canada	1,126	8,873	2,464.9	0.25
China	8,898	75,348.3	2,0931	0.27
Japan	2,099.53	25,697.94	7,138.9	0.39
Norway	1,000	10,800	3,000.2	0.34
Turkey	2,084	36,885.9	10,246.9	0.56
United States	12,611.46	56,551.8	15,710.1	0.14
Switzerland	1,060.9	7,714.6	2,143.1	0.23
Netherlands	1,410.26	10,699.4	2,972.3	0.24
Sweden	4,460	45,301	12,584.6	0.32
Poland	281.05	1,501.1	417.0	0.17
Finland	994	7,966	2213	0.25
Italy	887	9,941	2,761.6	0.36
New Zealand	393.22	9,552	2,653.5	0.77
Austria	662	3727.7	1,035.6	0.18
India	265	2,545	707	0.30
Hungary	664.6	9,767	2,713.3	0.47
Russia	308.2	6,143.5	1,706.7	0.63
Iceland	1,826	24,361	6,767.5	0.47

2.3. High-Temperature Geothermal Systems

These are volcanic/intrusive in origin as regards to occurrence and heat source and associated with the plate boundaries and their temperature are more than 150°C at the depth of 1 km. This system is well suited for the production of electricity and always associated with the volcanic system. The heat sources for such systems are hot intrusions or magma. They are most often situated inside, or close to, volcanic complexes such as calderas, most of them at plate boundaries but some in hot spot areas. Permeable fractures and fault zones mostly control the flow of water in volcanic systems. Aquifers are strata-bound and/or fracture controlled. Many high-temperature geothermal fields are in tectonically disturbed areas such as calderas, rift valleys and block faulted areas.

Particularly favourable are the intersections of regional faults and faults bordering major structural blocks. Characterized by fumaroles, steam vents, mud pools and highly altered ground as well as both of liquid and vapour dominated. This type of field are frequently found in the area of Mid Atlantic ridge (Iceland), Continental Rift (East African rift valley), Ring of Fire (Pacific region) as well as in the area of several kinds of volcanic region (continental margin arc volcanos, micro-continental arc volcanos, young island arc volcanos and inter arc basin, compressional regime, flank zone volcanos, hot spot volcanos etc). USA, Philippine, Iceland, Indonesia, New Zealand, Japan, Italy, Mexico and Costa Rica are the leading countries whose utilized the high – temperature geothermal energy for power generation.

3. SEDIMENTARY BASIN

Basin is the most common term in the earth sciences which is a depressional part in the upper crust filled with different types of rocks. A basin occurs where rock strata tilt toward a common centre. A bowl-shaped vessel usually for holding food or liquids or a bowl-shaped area that forms around a volcano's central vent. Some basins or depressional parts are filled with sedimentary rocks (Sandstone, Shale, Siltstone, Mudstone, Limestone and Claystone, etc) is called a sedimentary basin which form in diverse geological settings usually associated with the plate tectonic activity. Actually this type of basin is created by high sedimentation process in the convergent, divergent, transform and intraplate settings in the plate tectonic settings. Some of them are layered sequences and permeable which is made by the alternation of limestone (fractured limestone) and sandstone; some of them are made by alternation of mudstone and shale which is called impermeable sequences. The general definition of a sedimentary basin is: a low area in the earth's crust, of tectonic origin, in which sediments accumulate (Figure 4). Sedimentary basins range in size from as small as hundreds of meters to large parts of ocean basins. The essential element of the concept is tectonic creation of relief, to provide both a source of sediment and a relatively low place for the deposition of that sediment. It should be mentioned that the term "sedimentary basin" is usually not applied to relatively thin and very extensive deposits of sandstone, limestone, and shale from epicontinental seas on the cratons, many of which have seen no deformation through billions of years, but only to relatively thick deposits in tectonically active areas with negative relief, but intracratonic basins are the exception in this regard (Dickinson 1974).

3.1. Formation of Sedimentary Basin

On a small scale, hundreds to thousands of meters laterally fault movements can created relief of hundreds to thousands of meters, resulting in small but often deep is called a local basin (Figure 4). Some basins are created mechanically on a regional scale in two very important ways: thermally or flexurally, or by a combination of those two effects. In many cases extensional thinning of the lithosphere accompanies the heating and when it is recooling, the elevation of the top of the lithosphere is less than before the heating and extension. Another important way to make the sedimentary basins is to park a large load on some areas of the lithosphere. This new load causes that lithosphere to subside by isostatic adjustment. But the lithosphere has considerable flexural rigidity as well as adjacent lithosphere is bowed down also. The region between the high-standing load and the lithosphere in the far field created depressed to form a sedimentary basin (Balance et al. 1980).

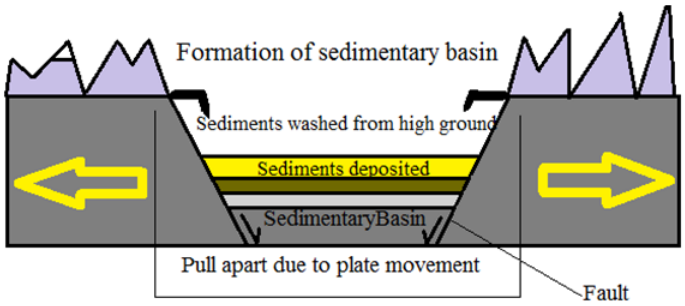


Figure 4: Figure showing the sedimentary basin as well as formation process.

3.2. Description of Some Sedimentary Basins around the World and Their Geothermal Resources

Sedimentary basin and geothermal resources are closely related to each other which are directly influenced by the earth's plate boundaries as well as tectonic settings (Figure 5). Normally, the high-temperature geothermal potential is concentrated in volcanic regions, but low-temperature geothermal energy is associated with the warm ground water in several sedimentary basins around the world. The flux of heat to the surface of some sedimentary formations of the world are sufficiently high to be utilized for house heating using shallow boreholes and ground source heat pumps. The heat of the earth's interior come out to the near surface due to plate movement and store in the fractures zone or some porous layers of sedimentary rocks in the basin which can be utilized as geothermal energy, especially in direct uses.

The formation processes of some sedimentary basin are very favourable for the geothermal energy accumulation due to their crustal displacement. Subsidence is the most common factor for the development of sedimentary basin which may also play to vital role for the heat movement within the Earth. Geothermal energy is found in much sedimentary formation around the world within the sedimentary basin for their interconnection of tectonic settings. Sedimentary geothermal systems are found in many of the major sedimentary basins of the world which are alternate of layered sequences of permeable (limestone, sandstone) and impermeable strata (shale or mudstone). Water is interstitial origin, commonly brine and temperature is variable, depending on depth of permeable rocks in basin. This system occur in permeable sedimentary layers at great depth (>1 km) and above average geothermal gradients (>30°C/km) due to radiogenic heat sources in the shallow crust or tectonic uplifting (folding) in the region or for other reasons (Saemundsson et al. 2009). These systems are conductive in nature rather than convective even though fractures and faults play a role in some cases (Figure 6).

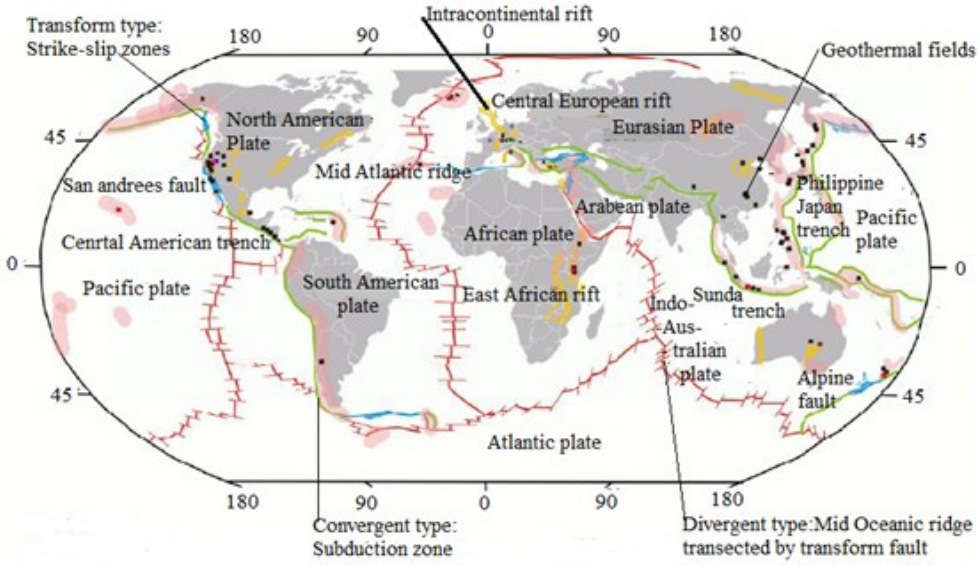


Figure 5: Figure showing the worldwide geothermal fields related to the plate tectonic settings (modified from Moeck, 2014).

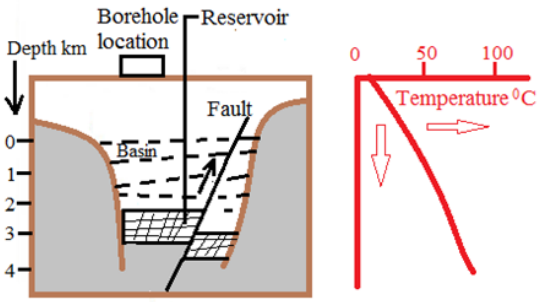


Figure 6: Figure showing the sedimentary basin as well as geothermal reservoir at 2-4 km depth, temperature profile represents a typical sedimentary geothermal gradient.

However, some convective systems may be embedded in sedimentary rocks. Some sedimentary basins contain sedimentary rocks with pore pressure exceeding the normal hydrostatic pressure gradient called geo-pressured geothermal systems. They are confined and analogous to geo-pressured oil and gas reservoirs where fluid caught in stratigraphic traps may have pressures close to lithostatic values. The known geo-pressure systems are found in conjunction with oil exploration. The most intensively explored geo-pressured geothermal sedimentary basin is in the northern part of the Gulf of Mexico and in Europe. Geo-pressured geothermal fields have not yet been exploited (Saemundsson et al. 2009). Typical sedimentary geothermal systems that have been extensively exploited and utilized are mainly found in the Paris Basin in France, the Pannonian Basin in Hungary, the Williston Basin in Montana and North Dakota (USA), the sedimentary system in Texas, the Perth, Otway, Great Artesian Basins in Australia as well as the North China and Wei River Basins in China, to name the most prominent examples. Large numbers of geothermal fields have been observed at different sedimentary basins around the world (Figure 7).

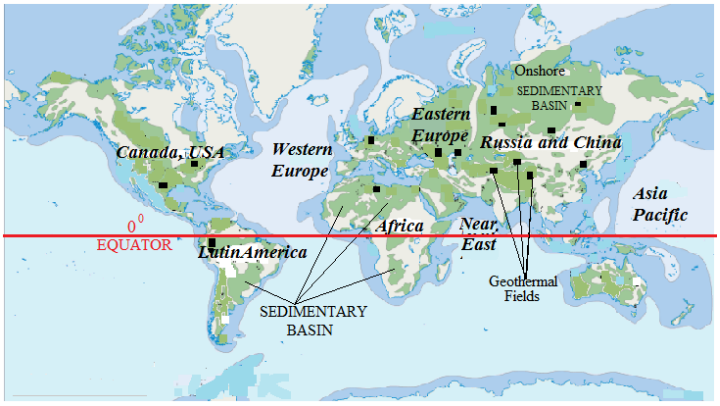


Figure 7: Figure showing the geothermal fields within the sedimentary basins of onshore around the world.

3.2.1. The Paris Basin

France is one of the leading countries in the world who utilized the low-temperature geothermal energy as direct use from the sedimentary geothermal systems. There are several sedimentary basins (Paris Basin, Aquitaine Basin) developed in this country. The Paris Basin is one of them which play a vital role for the development of geothermal energy in this country. Geologically it is the centre of a structural depression that extends between the ancient Armoricain Massif (west), the Massif Central (south), and the Vosges, Ardennes, and Rhineland (east). The area which forms the heartland of France is drained largely by the Seine River and its major tributaries converging on Paris. The natural vegetation of the basin has been almost entirely lost to civilization, except for a few relict forests. The Paris Basin is a large sedimentary basin which occupies a vast part of northern France (110,000 km²) and extends northward below the English Channel, overlying deformed Carboniferous and Permian troughs in between four crystalline basement bodies. The Dogger reservoir (the mid-Jurassic) consisting of carbonate rocks, has been identified as the most promising geothermal development target below the urbanized Paris area. It is recharged along the eastern border of the Paris Basin where the formation outcrops and discharges to the seafloor of the English Channel. In the slow circulation through the basin, the fluid reaches depths of 2,000 m where it acquires its geothermal potential. Geothermal development in the Paris Basin started in the early 1970s. Since then, the main target has been the Dogger Aquifer, and nearly all operations use the "doublet" technology. Of the 55 doublet systems that have been implemented, most of these in the 1980s, 34 are still in operational. Geothermal wells are completed with an open hole through the 100-150 m thick Bathonian deposits where the Dogger reservoir is located. The net total productive thickness is of the order of 20 m on average with the permeability in the range of 2-20 Darcy. Formation temperatures at the top of the productive layers are generally between 55°C and 80°C. The porosity of overall Bathonian is about 15% on average. A temperature simulation was done based on data from the Champigny doublet drilled in 1985. It shows that production well temperature will drop 3°C in 46 or 62 years, due to reinjection, when the distance between doublets is 1,390 m, exploitation flow rate of 270/190 m³/h in the winter/summer and production/winter reinjection/summer reinjection temperature 74/40/60°C (Lopez et al. 2010).

3.2.2. Pannonian Basin in South-East Hungary

Geothermal wells have been used in Hungary for over 140 years. The focus is on medium enthalpy systems that supply energy to large municipal district heating and hot water systems, in addition to spa and wellness establishments. An increasing pressure drawdown in the geothermal systems of the Pannonian Basin shows lack of sustainable management and demonstrates that injection is necessary for the management of the geothermal resources. In Hungary, the earth's continental crust is rather thin (22–26 km) and is covered by low thermal-conductivity formations. These conditions lead to a high geothermal gradient anomaly (approximately 50°C/km) with a heat flow of 90–100 mW/m2. Gravity-driven flow dominates the upper formation and pressure-driven flow dominates the lower sedimentary formations (Jiachao 2012). The porous formations of Pannonian Basin contain water up to 130–150°C; however, the temperature in some karst and fissured carbonated reservoirs in basement rocks is up to 300°C (Szanyi et. al. 2010). Rezessy in 2005 estimated the total geothermal energy of Hungary stored in formations above 5,000 m depth to be approximately 100,000 EJ (1 EJ = 1018 J). To date, over 1,400 registered deep wells in Hungary have found thermal water, among them 950 are in production at present. Only about 20 of these are reinjection wells. Fortunately, recent legislation prohibits new geothermal systems from being established without reinjection; only water used for balneotherapy is allowed to be discharged at the surface. The current estimated total production from thermal wells, which are mostly used about 6 months a year, is 84 million m³ per year, with a heat content of 15.2 PJ per year (Szanyi et al. 2010).

3.2.3. Chinese Basins

Sedimentary geothermal systems are widely spread throughout the vast area of the China mainland. There are more than 3,500 geothermal wells in China (Kang, 2010), most of which are located in sedimentary basins in the north and the east of China. The heat source comes from the natural heat flux. Wellhead water temperature is in the range of 40-60°C in most geothermal wells, but some can reach 95-120°C. The majority of geothermal wells yields 30-60 m³/h while some yield up to 100-300 m³/h. In the inner area of these sedimentary basins, groundwater runoff is mostly slow and stagnant, and very high pressure is often found in boreholes. The reservoir lithology involves either sandstone rock, carbonate rock (limestone or dolomite) or crystallized rock. Most sedimentary geothermal reservoirs can be typically be classified as either porous reservoir with sandstone rock, or fractured karst reservoirs, with carbonate rocks (Wang 2010).

3.2.4. North China Basin

In the North China sedimentary basin fractures, open cavities are widely spread and well developed in the carbonate rock reservoir beneath the upper Tertiary one. Pore-type formations mostly occur in Tertiary sandstones which along with karst-fissure type formations play an important role in geothermal exploitation in the North China basin. In the local extensional stress tectonic environment, tensional fractures and a series of graben structures, of alternate uplifts and depressions, have developed inside the basin. The heat transfer properties of the different formations are distinctly different. The local heat anomaly was formed in the cap rock of the uplift areas, in which the temperature gradient is higher than 4°C/100 m and the heat flow is more than 65 MW/m² (Wang 2010). The North China sedimentary basin is the most important geothermal region in China. Around half of the geothermal wells of China are distributed in it. These are in Beijing, Tianjin, Hebei and Shandong Province which all lie in this basin (Jiachao 2012).

3.2.5. Wei river Basin in China

The Wei River (Guanzhong) sedimentary basin lies in the centre of China. It is estimated to contain about 11X1021 J of exploitable geothermal energy and 130 billion m³ of exploitable geothermal water stored in the basin. The exploitable geothermal water is, furthermore, estimated to be 2 billion m³/year. The exploitation of geothermal energy from the basin started in the 1970s, and by 2007, 346 geothermal wells had already been drilled (Pang et al. 2010). The evidence from δ18O data suggests that the geothermal water, particularly at a distance of 3-5 km from the Qinling Mountain, has a slight connection with shallow groundwater and surface water. A deep geothermal water circulation has also been demonstrated (Qin et al. 2005).

3.2.6. Molasse Basin in Germany

Germany is one of the leading countries in the world with respect to geothermal energy utilization. The Molasse Basin is one of the most important places of source for producing geothermal energy in this country. It is a famous sedimentary basin around the world which has fissure karst aquifers in the Malm or upper jura are large reservoir of geothermal energy. The Malm rocks are located deep below a geological structure known as the South German Molasse Basin. The basin covers an area of 700 km from east to west and 250 km from north to south. Millions of years ago a primeval sea deposited lime, sand and clay here which has subsequently been compacted to fine chalky limestone, carbonates and marl. Tectonic formation of fractures and water erosion has resulted in the so-called karst, which can be extremely water permeable in the regions near the fissures. The layers of most interest for geothermal energy (upper or top Malm) lie at depths between 1,500 and 5,000 m with temperatures ranging between 85 and over 140°C. In the Southern Molasse, thermal water resources above 100°C can be found at depths of approximately 3,000 m which are suitable for geothermal electricity generation (Geology of Molasse Basin).

3.2.7. Great Artesian Basin in Australia

The Great Artesian Basin is a confined multi-layered groundwater system which underlies 1.7 million square km of arid and semi-arid land across Queensland, New South Wales, South Australia and Northern Territory. The aquifer consists of highly permeable sediments, mainly continental quartzose sandstones of horizontal permeability of around one Darcy. Groundwater temperatures at the well heads range from 30°C to 100°C. Spring temperatures range from 20°C to 45°C and the highest temperatures having been measured in the Dalhousie Springs group in northern South Australia. The Great Artesian Basin has significant reserves of warm groundwater suitable for a variety of geothermal applications. Perspective applications include space heating, bathing, aquaculture, air conditioning as well as electric power generation (Habermehi et al. 2001).

3.2.8. Williston Basin in USA

The southern Williston basin, which underlies about 110,000 square miles in North and South Dakota and eastern Montana, is part of a large structural and sedimentary basin. Its surface is a flat to gently rolling plain, standing about 500 to 700 m above sea level and locally studded by a few high buttes. The sedimentary sequence that fills the basin has a maximum thickness of about 6,000 m and rests on Precambrian metamorphic rocks at depths of 160 to 5,000 m below sea level. It contains rocks of every geologic system, from Cambrian to Quaternary. Rocks of Middle Cambrian through Middle Ordovician age are largely shale and sandstone; rocks of Late Ordovician through Pennsylvanian age are largely limestone and dolomite and rocks of Permian through Tertiary age are predominantly shale and siltstone. Pleistocene glacial drift mantles the northern and eastern parts of the area. The thick Upper Cretaceous shale beds as shallow hydraulically fractured shale reservoirs, and the Newcastle Sandstone of Early Cretaceous age as a shallow shale-enclosed sandstone reservoir. Geothermal potential of this basin is very suitable. Some geothermal based power station as well as direct use system developed in this basin. Especially, the Williston basin is a promising target for EGS and co-produced oil field geothermal energy (Research project-The University of North Dakota).

4. GEOTHERMAL PROSPECT IN BANGLADESH

Bangladesh is one of the lowest per capita energy consumption countries in the world. The country is a facing problem with shortage of energy and depended mainly on the natural gas and imported fossil fuel for electricity generation, industries, vehicles etc. Bangladesh has small reserves of oil and coal, but large natural gas resources. Commercial energy consumption is mostly natural gas (around 70%) followed by oil, hydropower and coal. Electricity is the major source of power for country's most of the economic activities. Bangladesh's installed electric generation capacity was more than 10 GW. The country needs to develop alternate energy resources like renewable energy to meet up the demand. Bangladesh has no volcanic region but tectonically lies in the northeastern Indian Plate near the edge of the Indian craton as well as Eurasian-Indian plate boundary which may associate with high geothermal gradients.

4.1. Geothermal Activities in Bangladesh

There is no mentionable work with respect to geothermal energy in this country till now. Herbert Henkel (Sweden) and Prof. D.K. Guha (Bangladesh) under the funding of KTH (The Royal Institute of Technology Stockholm, Sweden) carried out a study on the geothermal energy probability in Bangladesh (Guha et al. 2005 and 2010) which was concentrated mainly on the abandoned deep wells for gas fields. They studied 50 more abandoned wells in Bangladesh and recommended some steps for geothermal energy production from these wells. On the basis of the Herbert Henkel and Guha study and findings the team proposed a project which was coordinated by Prof. Dr. Badrul Imam of Dhaka University. Finally recommended for a pilot study (reopening of the abandoned wells) in at least one of the 3 wells (Singra, Shalbanhat and Sitakund wells) but it was not materialized. Geological Survey of Bangladesh carried out a drilling programme (GDH-65/11) in the area of Thakurgaon district. Drilling concluded at the depth of 586 m and temperature recorded 47°C which is almost normal gradient of Bangladesh (Figure 8).

4.2. Geo-tectonic Settings of Bangladesh

The geology of Bangladesh is affected by the country's location, as Bangladesh is a riverine country. It is the eastern two-thirds of the Ganges and Brahmaputra river delta plain stretching to the north from the Bay of Bengal. While the eastern part of Bangladesh is the continuation of the frontal belt of the Indo-Burma Range. Bengal Delta is one of the largest deltas in the world. Geological evolution of Bengal Delta is related to the uplift of the Himalaya due to collision of Indian and Asian plates. The Bengal Delta is characterized by enormous sediment supply from Himalaya, rapid sedimentation and subsidence resulting in huge thickness of siliciclastic deltaic sediments. Tectonically Bangladesh lies in the northeastern Indian Plate near the edge of the Indian craton. Stable Pre-Cambrian Platform and a huge geosynclinal basin in the southeast are dominating tectonic features of Bangladesh which are separated by a narrow northeast-southwest trending Hinge zone (Figure 9), currently known as palaeo continental slope (Salt et al. 1986). Stable Pre-Cambrian Platform covers the country to the west and northwest of the Hinge zone and is divided into three major zones: Rangpur Saddle, Bogra slope and Dinajpur slope (Figure 9). The thickness of sedimentary column on the stable shelf of Bengal Basin varies from less than 200 m to 10,000 m (Alam 1989). Rangpur Saddle connects the Indian Shield with the Shillong and the Mikir Hills Massif resulting in uplifted basement with thin cover of sedimentary rocks. In Madhyapara area the basement is encountered at 130 m depth and overlain by Plio-Pliestocene sediments. The northern and southern slopes of Rangpur

Saddle are quite gentle and the basement plunges gently from Madhyapara towards the southeast up to the Hinge zone. It separates the Bengal Foredeep and the Himalayan Foredeep. The Northern Slope of Rangpur Saddle is also recognized as Dinajpur Slope, and gently slopes towards the Sub-Himalayan Foredeep. The thick sedimentary basin is subdivided into fold belt in the east and Bengal Foredeep to the west. Bengal Foredeep occupies the vast area between Hinge Line and fold belt of Arakan Yoma Folded System. It comprises a platform region in the west and a folded region in the east. The western platform flank is characterized by several highs and lows namely Faridpur Trough, Barisal-Chandpur High, Hatiya Trough, Madhupur High and Sylhet Trough (Figure 9). The tectonic and geothermal maps of Bangladesh clearly demonstrate a pattern of geothermal conditions in Bangladesh (Figure 8 and 9).

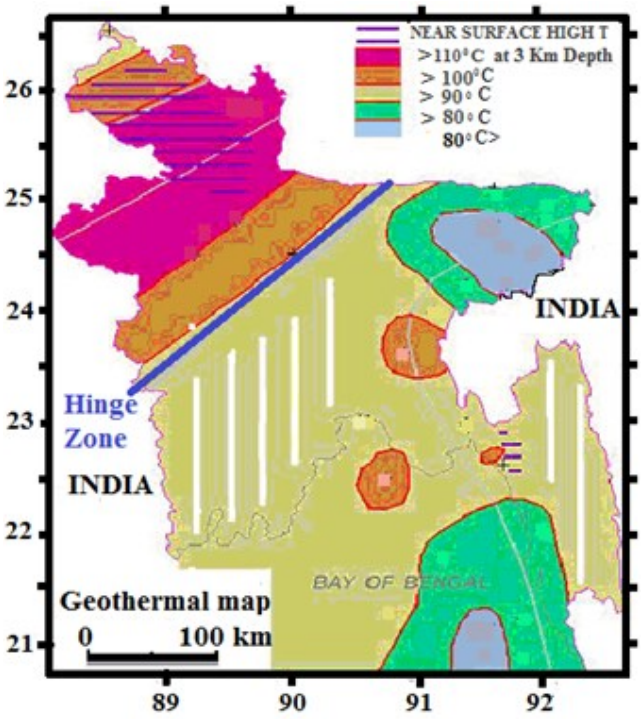


Figure 8: Figure showing the geothermal gradient of Bangladesh at 3 km depth (modified from Guha. 2010).

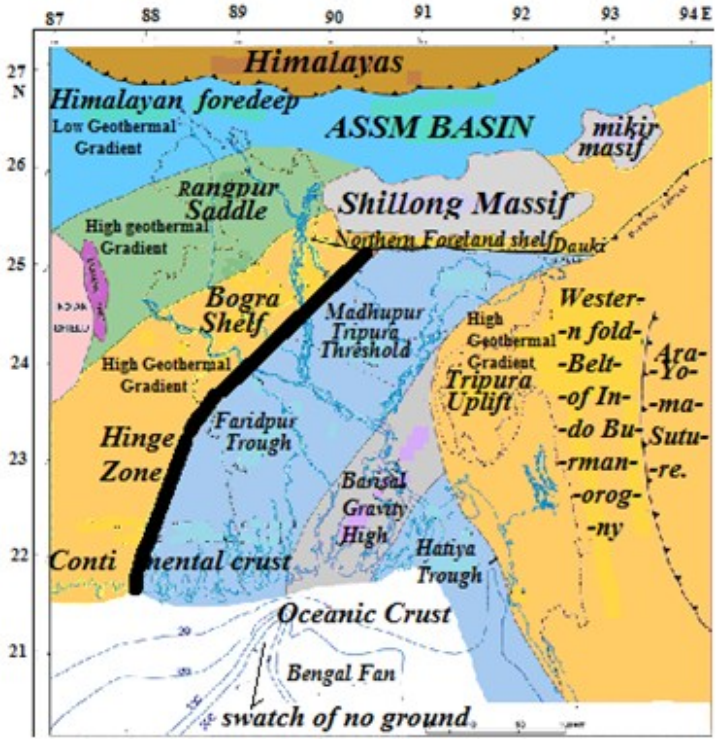


Figure 8: Figure showing the high geothermal gradient area and tectonic settings of Bangladesh (modified from Alam. 1989).

4.3. Sub-Himalayan Foredeep Geothermal Province

The Himalayan Foredeep lies south of the Main Boundary Thrust (MBT) all along the foothills of the Himalayas. In this area at the NW tip of Bangladesh the basement occurs at 2,500 m depth as encountered in Salbanhat-1 well (abandoned gas oil Tetulia, Ponchagarh). At this depth 79^{o}C bottom hole temperature is projected. The Neocene of the Siwalik are well developed in the Himalayan Foredeep. Low geothermal gradient (2.25^{o}C/100 m, Figure 8 and 9), barely feasible to explore geothermal energy. In the well GDH-65/11 recorded 47^{o}C temperatures at the depth of 587 m and Shalbanhat well projected temperature 110^{o}C at the depth of 4,000 m which is shown almost normal gradient in this region (Figure 9).

4.4. Rangpur Saddle Geothermal Province

The Rangpur Saddle represents the Indian Platform and connects the Indian Shield with the Shillong Massif and the Mikir Hills (Figure 8). In the Madhyapara area the basement occurs at only 130 m depth. In the western part of the Rangpur Saddle, a number of graben and half graben structures have been found with Gondwana sediments, some of which contain coal seams. The Gondwana sandstone sequence below the coal seams in Barakupuria coal mine has a temperature of 50^{o}C at a depth of 400 m. The coal seams together have an insulating effect resulting in increased temperature in the basement below. The area is characterized by relatively high surface temperatures reported from some irrigation wells and in coal bearing graben structures and underground hard rocks mine. The geothermal resource is likely located within the uplifted basement and would require hydraulic fracturing methods to create permeability at depth with sufficient high temperature for present technology of electricity generation. Because in the Great Artesian Basin in Australia, the Paris Basin, Molasse Basin in Germany and North China Basin used this energy for power production. Their temperature recorded around 120^{o}C.

4.5. Bogra Shelf Geothermal Province

The Bogra Shelf represents the southern slope of the Rangpur Saddle. It is a regional monocline plunging gently towards the south east towards the Hinge Zone and marks the transition between the Rangpur Saddle and the Bengal Foredeep from depositional as well as structural point of view. Stanvac Oil Company (SVOC) carried out aero-magnetic and seismic surveys in the mid-fifties followed by drilling two wells at Kuchma and Bogra and their geothermal gradient are 27^{o}C/km and 30^{o}C/km respectively. This area is favourable condition for low-temperature geothermal energy production due to slightly high geothermal gradient (Figure 8 and 9). The aquifer of this area is composed of loose water bearing permeable sandstone which is also helpful for geothermal resources. This area maybe suitable for power generation utilizing the geothermal energy of abandoned wells like as that of Texas sedimentary basin and Williston sedimentary basin in USA.

4.6. Potential of Folded Belt Geothermal Province

The Folded Belt (or the folded eastern flank of Bengal Foredeep) represents the most prominent tectonic element of the Bengal Foredeep, with general sub-meridional trending hills parallel to the Arakan Yoma Folded System (Figure 8). The Folded Belt is sub-divided into a Western Zone and an Eastern Zone according to the intensity of folding and other structural features. The Western Zone is the most important and prospective oil and gas province of Bangladesh with 12 fields from Kailas Tila in the north to Semutang in the south. Hot springs have been observed at Barbarkund and Gobaniya Chara in the Sitakund anticline with temperatures of up to 35^{o}C. (Guha et al. 2005). In the Sitakund well, the geothermal gradient is 28^{o}C/km and recorded temperature is 118^{o}C at the depth of 4,000 m. In the sedimentary sequence to 2.3 km depth, consisting of mainly shales, the gradient is slightly higher, indicating a lower thermal conductivity and hence an insulating effect to warmer and deeper formations. In the Bakhrabad well, the geothermal gradient has been found at 30^{o}C/km. The Eastern Zone includes the more steeply folded and faulted anticline structures. The anticline structures can turn out to be of significance also regarding geothermal energy prospects as there are many dry wells penetrated quite deep and thus may have high temperatures. A small power plant maybe set up in this region based on geothermal energy with the help of abandoned gas wells. The geothermal exploration cost can be reduced by using the existing/abandoned on-shore dry wells where the geothermal gradient is sufficiently high (over 30^{o}C/ km) and where porous and permeable reservoir sandstones are penetrated.

5.0. DISSCUSSIONS AND RECOMMENDATIONS

Low-temperature geothermal energy and sedimentary basin are very close to each other due to their interconnection of origin, formation as well as transportation. Large numbers of low-temperature geothermal fields are found in sedimentary basins around the world (The Paris Basin, North China Basin, Molasse Basin in Germany and Great Artesian Basin in Australia, etc.). Geothermal studies so far carried out in Bangladesh indicate that the country is ideally suited for further detailed studies to tap the geothermal energy by carrying out concentrated effort to fully explore the potential of the country. Large part of the sedimentary basin in Bangladesh is quite similar to some geothermal dominant sedimentary basins around the world. There are many abandoned gas wells in the basin part of this country where reservoir rock is water bearing sandstone is good sign for geothermal energy production, here only a suitable temperature is need. Some abandoned gas wells in Texas Basin, USA utilized as geothermal energy production which are quite similar of Bangladesh. They are producing geothermal energy from abandoned gas and oil wells. Low-temperature geothermal energy is producing electricity in Great Artesian Basin in Australia (98°C) and in Bangladesh some abandoned gas wells where temperature is more than 120°C, so, it may be used as geothermal energy for electricity production. It is not out of context to mention that there is immense potential to tap the geothermal energy in Bangladesh in particular in Bogra Shelf and Rangpur Saddle as well as the basin part where abandoned gas wells are available. The country is looking partnership, entrepreneur, agencies, NGO's as well as geothermal developed countries that developing the geothermal energy in this country so that low-temperature are utilized as direct use and power generation. Utilization of deep abandoned oil and gas wells for production of geothermal electricity for meeting the requirements of rural population of Bangladesh so that production cost would be reduced. Accordingly also recommended use of efficient pumps for cooling the buildings and heating for warm water production. It should be needed to detail survey of geothermal provinces (Rangpur Saddle and Bogra Self region) and prepare subsurface geothermal map for utilization of the energy. It is suggested that detail work about more prospective abandoned gas wells around the country. Bangladesh is a new comer country with respect to geothermal activities, so, proper plan, management and evaluation of geothermal energy prospective zone (Rangpur Saddle and Bogra Self region and abandoned gas wells area) should be taken as a

pilot project for the extraction of these resources. In general the geothermal prospects, geological mapping of surface geothermal manifestations as well as low-temperature surveys are essential to evaluate the every geothermal provinces in Bangladesh.

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