Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Brazil: Country Update

Hamza, V.M., Cardoso, R.R., Gomes, A.J.L. and Alexandrino, C.H.

Observatório Nacional, Rio de Janeiro, Brazil

hamza@on.br; rrc@on.br; ajlgomes@on.br; chalex@on.br

Keywords: Geothermal Resources, Brazil, 2010

ABSTRACT

We present an updated assessment of geothermal resources of Brazil and discus its implications in the context of the current national energy matrix and its projections for the next few decades. The data base employed in resource assessment consists of results of geothermal measurements at over 500 sites and hydrothermal and energy use data on thermal fluid discharge systems at over 100 localities. The total resource base, referred to the accessible depth limit of 3km, is estimated at 2400 TJ of which more than 50% is located in areas of sedimentary basins. A significant number of low temperature geothermal resources (with temperatures <90^{0}C) have been identified in the continental area, but the potential for high temperature geothermal systems appears to be restricted to the Atlantic islands of Fernando de Noronha and Trindade. The available part of the resources, calculated on the basis of regionally averaged values of porosity and permeability, is estimated to be of the order of 5 TJ, but only a small fraction is being currently exploited. The total capacity of low temperature geothermal systems under economic exploitation is estimated at 365 MWt, while the annual energy use is estimated to be of the order of 6540 TJ. About a dozen of the spring systems account for the bulk of this capacity. Most of them are located in west central Brazil (in the states of Goiás and Mato Grosso) and in the south (in the state of Santa Catarina). The potential for large scale exploitation of low temperature geothermal water for industrial use and space heating is considered to be significant in the central parts of the Paraná basin (situated at southern and southeastern Brazil), where cold winter seasons prevail under subtropical climate conditions.

1. INTRODUCTION

The National Council for Energy Policies (CNPE), presided by Ministry of Mines and Energy (MME) and operating under the Presidency of Brazil acts as the advisory body for formal policies and recommendations concerning development of energy sources in Brazil. This Council has set up technical committees, which draw guidelines for the development and use of different types of energy resources. A specific Committee has not yet been set up exclusively for geothermal energy resources. However the Committee CT5 has the task of examining alternate and renewable energy resources, which potentially include also geothermal energy. Alternate energy resources currently contribute less than 1% of the total energy production.

According to the recent estimates (MME, 2009) the total energy generation in Brazil is estimated at about 251.52 million TOE (tones of oil equivalent). Systems based on the use of hydrocarbon resources, hydroelectric power generation and biomass systems account for nearly 96.6% of this total. Table (1) provides a summary of the main systems that make up the energy matrix of Brazil. Geothermal energy sources are not directly used for electrical power generation and hence not formally recognized by CNPE. However, according to recent compilations of information on energy use geothermal contribution is estimated to be over 360MWt and ranks as one of the important in the group of alternative energy sources.

Table (1) Energy Matrix of Brazil. The energy generation is given in units of 10^6 tons of oil equivalent (TOE)

Energy System	2004		2009	
	(10^6 TOE)	(%)	(10^6 TOE)	(%)
Petroleum	85.51	42.9	93.71	37.26
Biomass	53.57	26.9	70.54	28.05
Hydro Electricity	27.78	13.9	35.01	13.92
Natural Gas	14.88	7.5	25.63	10.19
Coal	13.10	6.6	14.29	5.68
Uranium	3.57	1.8	3.70	1.47
Others	<1.00	<1.0	8.64	3.44
Total	198.41	100.0	251.52	100.00

2. GEOLOGY BACKGROUND

We provide here a brief description of geological background of the Brazilian territory that is relevant to the problem of assessment of geothermal resources. The continental segment of the Brazilian territory is situated within the eastern part of the South American Platform. This region is characterized by Precambrian igneous rock formations, which cover 36 percent of the territory. Metamorphic rocks of amphibolite to granulite facies and granitoids of Archean age are also found in large parts of the basement of the South American Platform. There are also Proterozoic units, which are folded strips of green schist facies and several granitoids. The basement is widely exposed in great shields of which the prominent ones are the Guyana, the Central Brazil and the Atlantic.

During Paleozoic times the Brazilian platform was affected by considerable vertical movements of crustal blocks, leading to the formation of large sedimentary basins in its interior parts. The prominent ones are the Amazon, the Parnaiba and the Parana basins. There is evidence for occurrence of extensive magmatic activity during Mesozoic periods in some of these basins. During Mesozoic times, horizontal movements associated with plate tectonic activity contributed to the formation of rift basins, mainly along the coastal areas. These basins are characterized by active tectonics and sediment deposition during Tertiary periods. Some significant thermal anomalies have been identified in these rift basins. Nevertheless, with the exception of the large number of alkaline intrusions in southern and south-eastern Brazil, these basins also have been practically free of any significant tectonic activity since the beginning of the Tertiary period. The main geologic features of Brazil are illustrated in the map of Figure (1).

Such characteristics of geologic history imply that the thermal regime at shallow depths is characterized by temperatures less than 100^{0}C at depths less than 3km. Also, the depth ranges of medium to high enthalpy geothermal systems are likely to be 5 to 10km.

3. REGIONAL GEOTHERMAL STUDIES

The objective here is to provide a brief summary of the progress obtained in recent studies and that have direct bearing on the problem of assessment of geothermal resources. Only those activities carried out since 2005 are considered here. These were conducted by the Geothermal Laboratory of the National Observatory in Rio de Janeiro, as part of academic research projects, and not always related to geothermal energy programs. Nevertheless, the results obtained have been useful in improving the data base for geothermal resource assessments. The earliest of these have been the projects for determination of subsurface thermal field of the Paraná basin in the southern region and São Francisco basin that spreads over the states of Minas Gerais and Bahia. Currently under progress are projects for determining geothermal gradients and heat flow in several of the coastal basins. Given below are brief descriptions of the results obtained in these regional studies.

3.1 Paraná Basin

The main purpose of this project has been to determine the regional variations in geothermal gradient and heat flow in the Parana basin which spans over large parts of the southern states of Rio Grande do Sul, Santa Catarina, Parana, São Paulo, Mato Grosso do Sul and mato Grosso. A summary of recent results has been presented by (Gomes and Hamza, 2009). Experimental data acquired at over 300 localities were used in deriving maps of geothermal gradients and heat flow. The results obtained (see Figure 2a) have allowed identification of regions of higher than normal heat flow on the north-western and south-eastern borders of the basin. Work is currently under progress for assessment of low temperature resources of the Guarani aquifer in this basin.

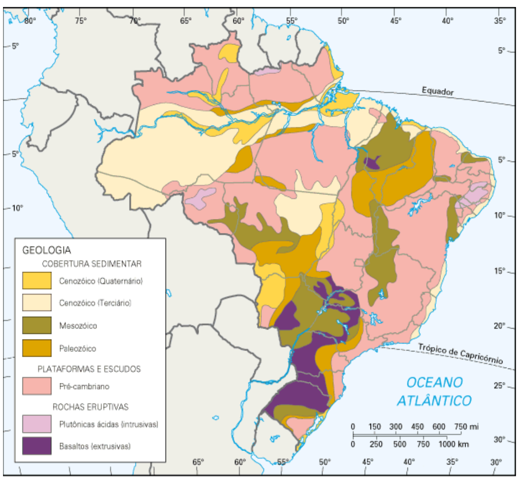

Figure 1. Simplified geologic map of Brazil illustrating spatial coverage of the Precambrian basement, Paleozoic to Mesozoic interior basins and Cenozoic rift basins.

3.2 São Francisco Basin

The main purpose of this project has been to determine the regional variations in geothermal gradient and heat flow in the São Francisco basin and in the surrounding Precambrian fold belts and cratonic areas. Experimental data acquired at over 100 localities were used in deriving maps of the distribution of resources and also in obtaining geothermal parameters (Alexandrino, 2007; Alexandrino and Hamza, 2008). The results obtained have allowed identification of a region of higher than normal heat flow on the eastern border of the basin. The map of excess temperature, presented in Figure (2b) has been useful in identifying the area of occurrence of geothermal resources.

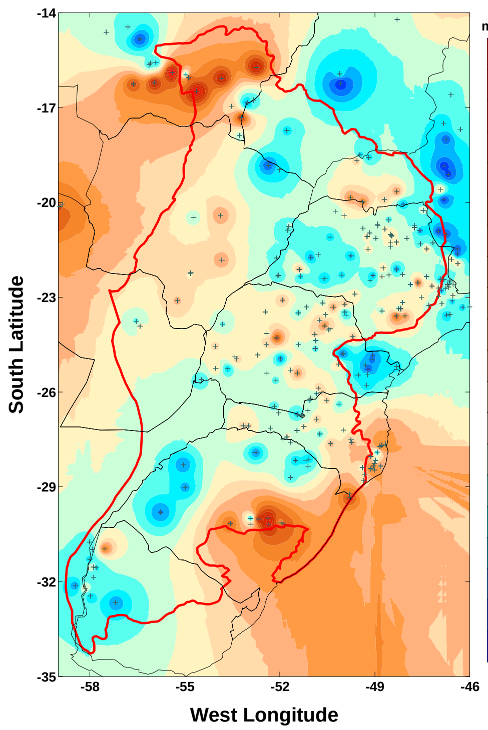

Figure 2a. Heat flow map of the Paraná basin. The symbols indicate localities of geothermal measurements.

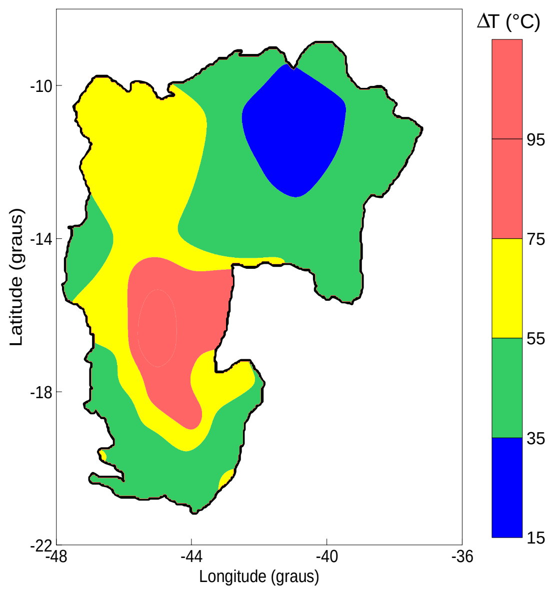

Figure 2b. Map of excess temperatures (relative to the surface temperature) in the area of the São Francisco Province.

3.3 Coastal basins in the state of Bahia

Gutierrez and Hamza (2009) has carried out an analysis of geothermal data for more than 100 wells in the coastal basins of Camamu, Almada, Jequitinhonha and Cumuruxatiba, in the south-eastern parts of the state of Bahia. The focus of this study has been a reinterpretation of the gradient values reported by Silva (2006), after introducing necessary corrections in the original data sets. The results obtained were used in deriving the temperature gradient map of the state of Bahia (see Figure 2c). Note that values of temperature gradients are lower than 20^0C/km in the Precambrian regions in the western parts of Bahia. The basins of Camamu and Almada in the northeast are characterized by gradient values in the range of 20 to 25^0C/km. On the other hand, temperature gradients in excess of 30^0C/km are encountered in the south-eastern parts (basins of Jequitinhonha and Cumuruxatiba). These are much less than the values reported by Silva (2006). According to Gutierrez and Hamza (2009) the reason for the discrepancy lies in the inappropriate correction factors employed in the study by Silva (2006). The results point to the possibility of low temperature resources in the southern coastal parts of the state of Bahia.

3.4 Northern states of Ceará and Rio Grande do Norte

The results of temperature logs in boreholes (Becker and Hamza, 1984) as well as bottom-hole temperatures (BHT) measured in oil wells were used in a recent study by Vieira and Hamza (2009) in analysis of temperature gradients of northeast Brazil and adjacent platform area. According to the results obtained (see Figure 2d) relatively temperature gradients (with values in excess of 40^0C/km) are encountered along a northeast – southwest trending belt in the central parts of the state of Ceará. The quality of data for the continental region is relatively poor as most of the boreholes in which temperature logs were carried out have depths less than 100 meters. Nevertheless it is important to point out that there are indications of volcanic activity during the Oligocene period in areas of high geothermal gradients. Results bottom-hole temperature data from offshore wells indicate that the zone of high gradients extends along the coast, in the direction of the Fernando de Noronha volcanic lineament. The association of high gradients with volcanic lineament and areas of magmatic activity points to the possibility that medium enthalpy geothermal resources may be present at depths less than 3km in the continental area.

3.5 Coastal basins of Sergipe and Alagoas

Andrade Fontes (1980) reported gradient and heat flow values for the basins of Sergipe and Alagoas in the east coast of Brazil. A re-evaluation of these data sets have been concluded recently and the results used in deriving the temperature gradient map of the states of Sergipe and Alagoas (see Figure 2e). Note that temperature gradients in excess of 30^0C/km are encountered in the southern coastal area of the state of Sergipe. This thermal anomaly seems to be bounded in the north by the northwest – southeast trending Ferraz ridge in the adjacent oceanic area. Lack of data in the southern parts of the state of Sergipe has prevented us from determining the westward extension of this anomaly into the continental area. Additional data from deep boreholes in the continental area are necessary before detailed assessment work can be carried out.

3.6 Eastern Coastal basin of Espirito Santo

The results of temperature logs in boreholes as well as bottom-hole temperatures (BHT) measured in oil wells Del Rey and Zembruscki, 1991) were used in deriving the temperature gradient map of this region (see Figure 2f). Note that temperature gradients in excess of 30^0C/km encountered in the offshore area in the northern parts are coincident with the Vitoria – Trindade volcanic lineament. The results point to the possible occurrence of geothermal resources along the westward extension of this volcanic lineament. Additional data from deep boreholes in the continental area are necessary before detailed assessment work can be carried out.

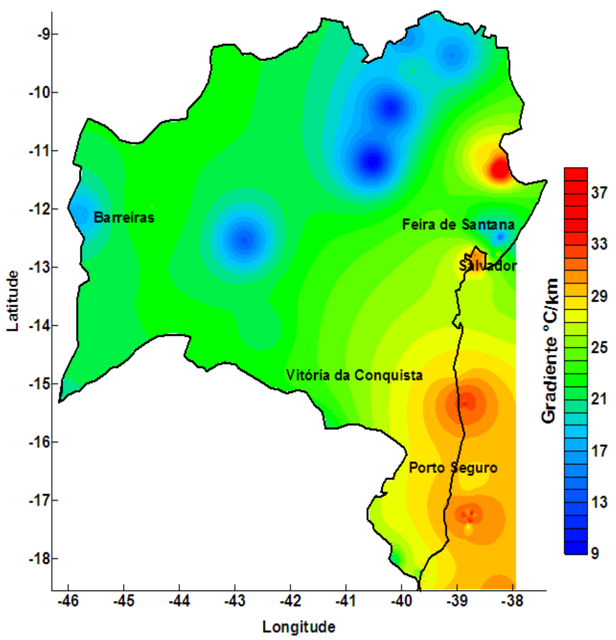

Figure 2c. Geothermal gradient map of the state of Bahia. Note the occurrence of relatively high gradient values in eastern coastal region.

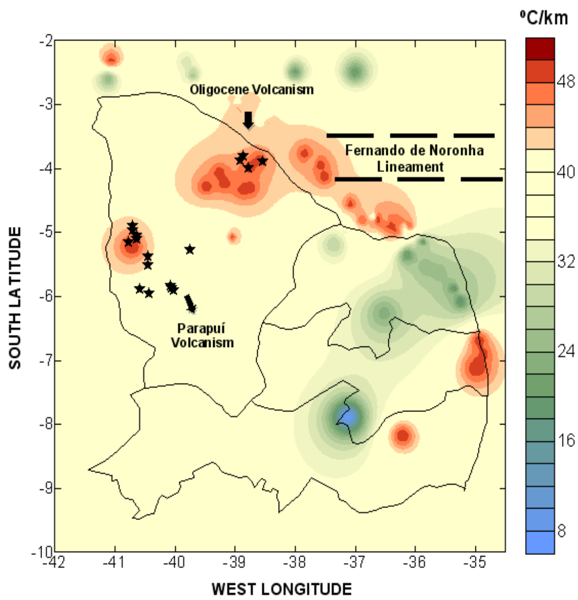

Figure 2d. Map of geothermal gradients of the northeastern states of Ceará and Rio Grande do Norte. The stars indicate locations of Oligocene volcanism.

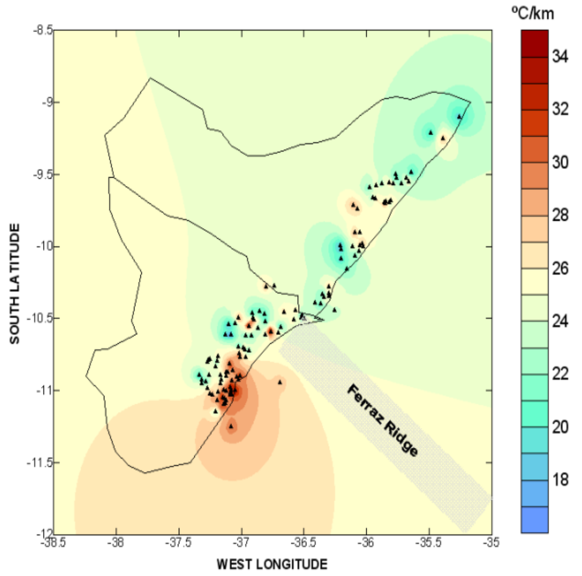

Figure 2e. Map of geothermal gradients in the northeastern coastal states of Sergipe and Alagoas. The dots indicate locations of gradient measurements.

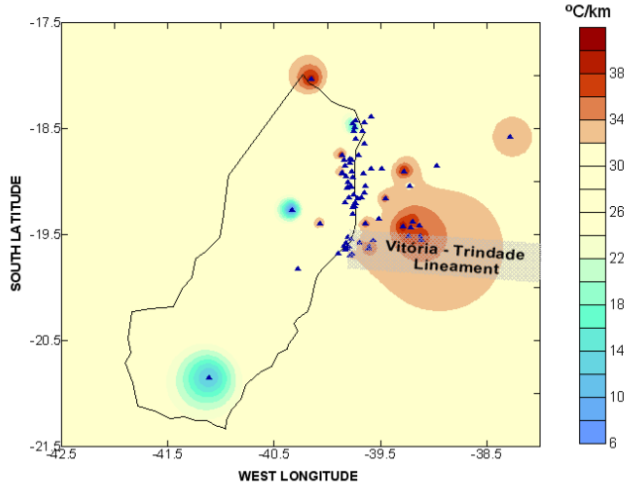

Figure 2f. Map of geothermal gradients in the coastal basin of Espirito Santo. Triangles indicate locations of gradient measurements.

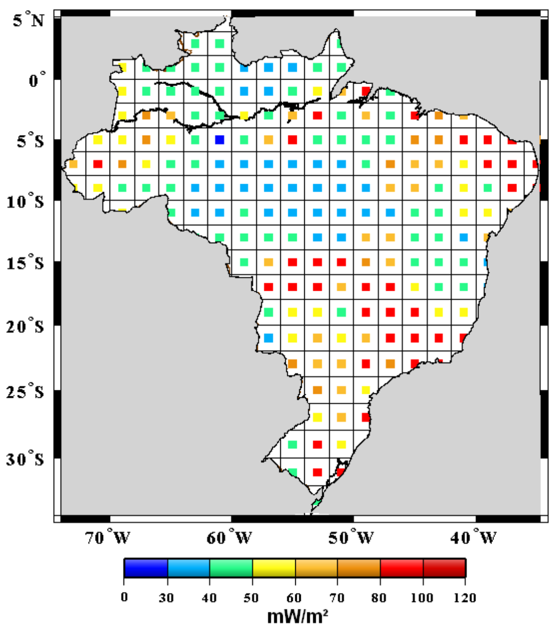

Figure 3: Discretized representation (2ºx2º grids) of geothermal data distribution for Brazil. The colored grids indicate areas with experimental data. Heat flow values for the remaining cells were calculated using spherical harmonic coefficients derived from global heat flow map (Cardoso, 2006; Hamza et al, 2008).

4. GEOTHERMAL RESOURCES AND POTENTIAL

Early works on evaluation of potential for geothermal energy and assessment of resources in Brazil were carried out by Hamza et al (1978) and Hamza and Eston (1983). These early works made extensive use of the results of heat flow measurements. The heat flow data in conjunction with the available information on geological and geochemical characteristics of the upper crust has been useful in obtaining regional estimates of geothermal resources. The spatial distributions of these earlier estimates of resource base have been examined by Hamza and Carneiro (2004).

A major weakness of these earlier studies is that the resource estimates are based mainly on local values of geothermal gradients and heat flow. Very few attempts seem to have been made so far in incorporating information on regional geologic and geophysical characteristics of subsurface strata in geothermal resource assessments. In the present work, a new approach has been adopted that take into consideration not only available data sets on near surface temperatures and heat flow but also supplementary information on regional lithologic and hydrologic characteristics of subsurface strata, that have direct bearings on the occurrence of geothermal resources. Given below brief descriptions of the procedures used in deriving heat flow maps and crustal models employed in resource assessments.

4.1 Sources of Data

The temperature and heat flow data employed in the present work are derived from the geothermal database for South America, which is maintained by the National Observatory, Brazil. Major difficulties in analysis of information contained in this database arise from the large variations in the quality of information and the limited availability of reliable experimental data. Nevertheless, this data base has been useful in determining mean values of temperature gradient and heat flow for 2^0 x 2^0 grid systems covering significant parts of the continental area. Experimental heat flow data are currently available for slightly more than 50% of the grid elements. For purposes of the present work estimated values derived from spherical harmonic expansion of the global heat flow field (Cardoso, 2006; Hamza et al, 2008) were used for those grid elements for which experimental data are not available. The map of Figure (3) illustrates the distribution of experimental and estimated values.

The gridded data has been used in deriving heat flow maps of the South American continent (Hamza and Muñoz, 1996; Hamza et al, 2005). This data base has recently been updated with temperature gradient and heat flow values for several new localities. Most of the new data are from the sedimentary basins in the coastal areas of eastern Brazil (in the states of Ceará, Rio Grande do Norte, Bahia and Espirito Santo) and the São Francisco craton in central Brazil. The new heat flow map derived from the updated data base is presented in Figure (4).

4.2 Crustal model used in Resource Assessment

In addition to the temperature and heat flow data sets use has also been made of complementary information on thickness, density and seismic velocity of the crustal layers. The relevant information available in the global crustal data compilations by Mooney et al, (1998) and by Bassin et al (2000) was considered sufficient for the present purpose. The compilation of Bassin et al (2000) provides mean values for $2^0 \times 2^0$ grid elements. In these data sets the crust is assumed to be composed of five sequential layers, classified as: soft sediments, hard sediments, upper crust, middle crust and lower crust. A schematic representation of the crustal model adopted in geothermal resource estimates is illustrated in Figure (5).

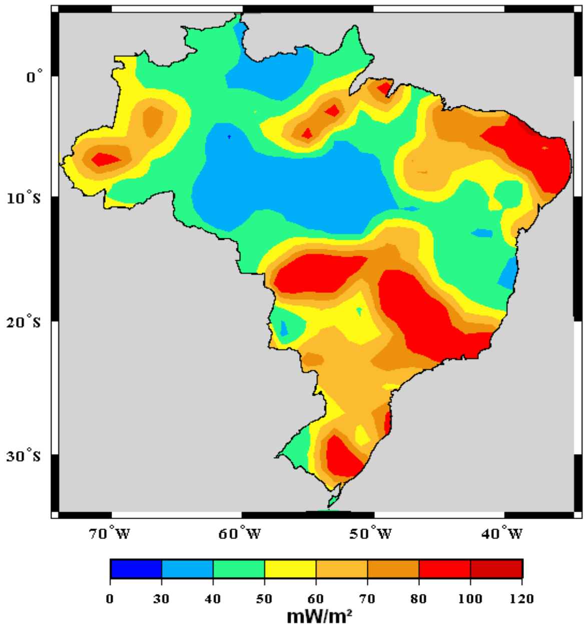

Figure 4: New heat flow map of Brazil based on updated data base and estimated values from spherical harmonic expansion to degree 36 of the global heat flow (Hamza et al, 2008).

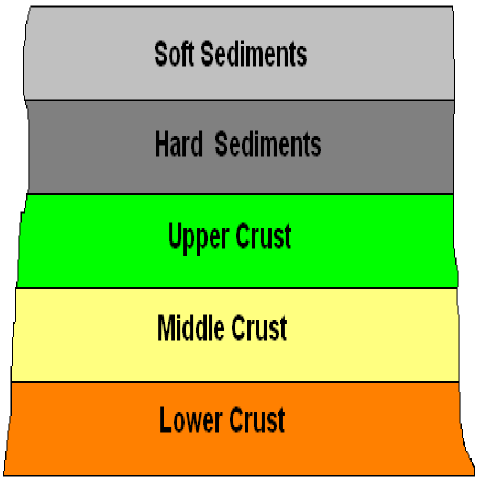

Figure 5: Schematic representation of the crustal model adopted for resource estimates.

It often happens that all three top layers (soft sediments, hard sediments and upper crust) are not present at depths less than 10km in every crustal segment. In fact three possible types of crustal segments can be envisaged:

Type 1- composed of just the sedimentary layers (soft and/or hard), but without the basement rocks of upper crust;

Type 2- devoid of any sedimentary cover, hence only basement rocks of upper crust may be present;

Type 3- where both sediment layers and upper crust are present.

In this last case, three subcategories may exist:

Type 3a: soft sediment and upper crust;

Type 3b: hard sediment and upper crust

Type 3c: soft and hard sediments as well as upper crust.

Following Muffler and Cataldi (1978) we have limited the resource base calculations to the maximum depth limit of 10 km. Since the minimum thickness of the layer classified as upper crust is 10 km it is not necessary to take into consideration resources associated with the middle and lower crustal layers. In some resource assessment studies depth limit for accessible resource base is set as 3 km. In the present work this limit has been adopted in calculating the total resource base.

The maps of Figures (6a), (6b) and (6c) illustrate spatial distributions of the thicknesses of these layers within the Brazilian territory. Note that the thickness of soft sediments (see Figure 6a) is in excess of 1km in most parts of Paleozoic basins (Amazon in the north, Parnaiba in the northeast and Paraná in the south). Soft sediments are practically absent or present as a thin veneer (with thickness less than 500m) in large parts of the Precambrian cratonic areas.

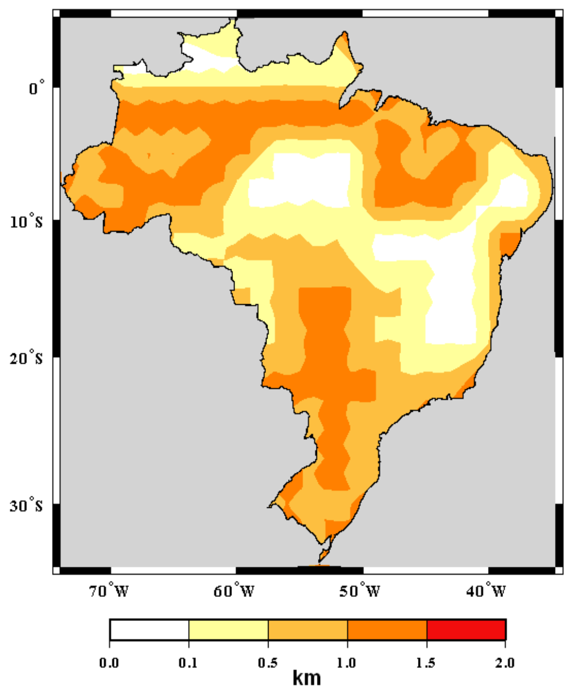

Figure 6a: Map of thickness of soft sedimentary layers, derived from crustal data of Bassin et al (2000).

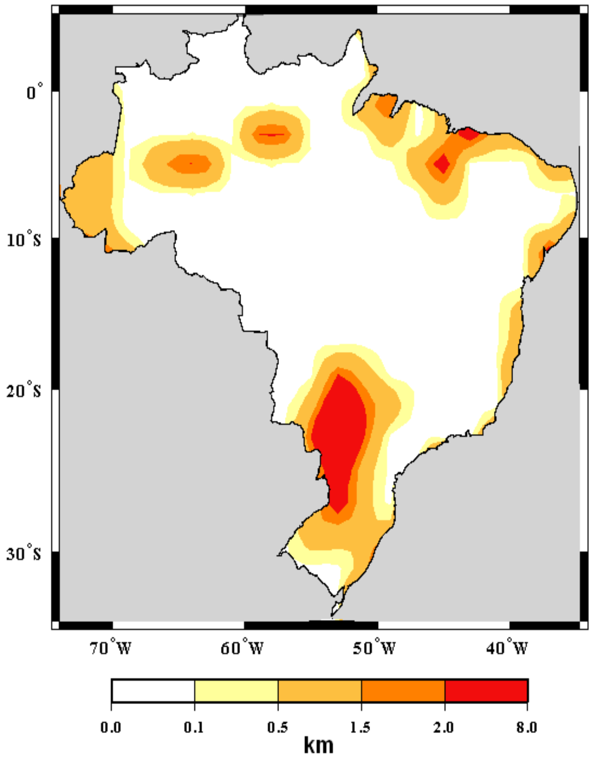

Figure 6b: Map of thickness of hard sedimentary layers, derived from crustal data of Bassin et al (2000).

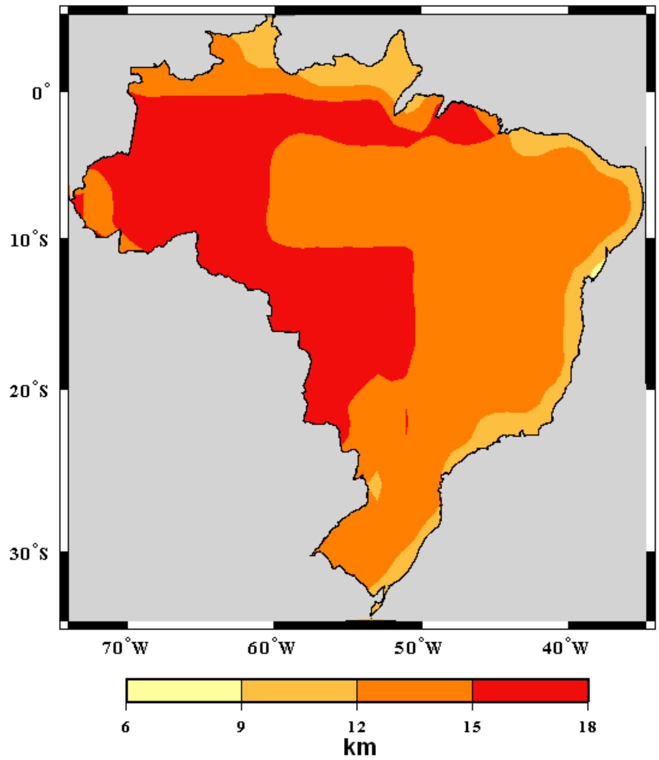

Figure 6c: Thickness of upper crustal layer, derived from crustal data of Bassin et al (2000).

The hard sedimentary layers (see Figure 6b) with thicknesses in excess of 0.5km is present in the basins of Acre (in the west), Upper Amazon basin and Middle Amazon basin (in the north), Parnaiba basin in the northeast and Paraná basin in the south. The thickness of this layer reaches up to 8km in the Paraná basin. The Precambrian areas seem to be practically devoid of hard sediments.

The thickness variations of upper crustal layer are illustrated in Figure (4c). Note that upper crust in the north-western parts of Brazil have thickness values in the range of 15 to 18km. In the eastern parts upper crustal thickness lie in the range of 6 to 12km.

4.2 Crustal Temperatures

Vertical distributions of temperatures in the crustal layers were calculated for each of the 2^0 x 2^0 cells. A simple one dimensional heat conduction model, that incorporates the effects of vertical variations in thermal conductivity and radiogenic heat production, was used for this purpose. The relation for temperature (T_i) as a function of depth (z_i) for the i^{th} grid element is:

$$T(z) = T_{0i} + \frac{q_{0i} - A_{0i}\, D_i}{k_i} z + \frac{A_{0i}\, D_i^{\,2}}{k_i} \left[1 - e^{-Z_i / D_i}\right] \quad (1)$$

where T_{0i} is the surface temperature, q_{0i} the surface heat flux, A_{0i} radiogenic heat productivity and k_i the thermal conductivity of the i^{th} element. The values of A_{0i} is derived from empirical relations (Cermak et al, 1990) relating crustal seismic velocities with radiogenic heat productivity. The thermal conductivity values of the sedimentary layers were derived from the heat flow data base.

The spatial distributions of basal temperatures of the soft sediment layer, hard sediment layer and upper crust, calculated using equation (1), are presented in Figures (7a), (7b) and (7c) respectively. As can be seen from Figure (7a) the basal temperatures of soft sedimentary layer do not exceed 60^0C.

In the case of hard sediments (see Figure 7b) basal temperatures in excess of 80^0C occur only in limited sectors lying in the central parts of the Paleozoic basins (Paraná in the south and Parnaiba in the northeast). Temperatures of less than 40^0C are found in most parts of the Precambrian terrains.

In the case of upper crust (see Figure 7c) basal temperatures in excess of 300^0C are found to occur in specific regions in the southeast, northeast and northwestern parts. In most of the remaining areas it is less than 240^0C.

4.3 Estimates of Resource Base

The resource base calculations were carried out following the methodology proposed in earlier studies (e.g. Muffler and Cataldi, 1978). Volumetric method was considered adequate for the present purpose. In this method the resource base is calculated as the excess thermal energy in the layer, the reference value being the surface temperature. The resource base (Q_{RBi}) for the i^{th} cell, of thickness d_i, associated with the temperature distribution given by equation (1), is calculated using the relation:

$$Q_{RB\,i} = \rho_i\, c_{pi}\, A_i\, d_i\, (T_i - T_{0i}) \quad (2)$$

where ρ_i is the average density, c_{pi} the specific heat, A_i the area of the cell, T_i the bottom temperature and T_{0i} upper surface temperature. The results obtained are presented in Figures (8a), (8b) and (8c) respectively for the soft sediment, hard sediment and upper crustal layers.

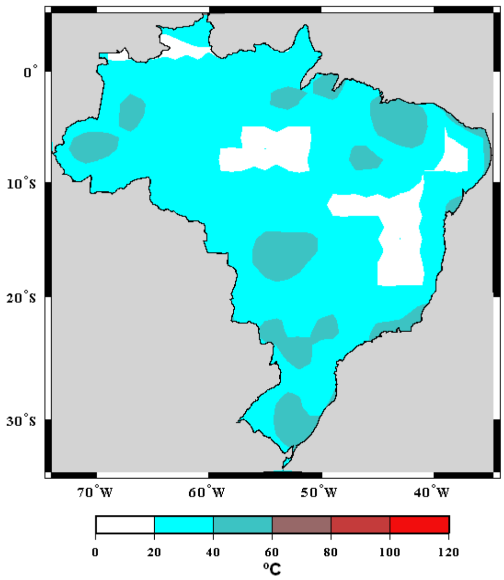

Figure 7a: Temperatures at the base of soft sediments.

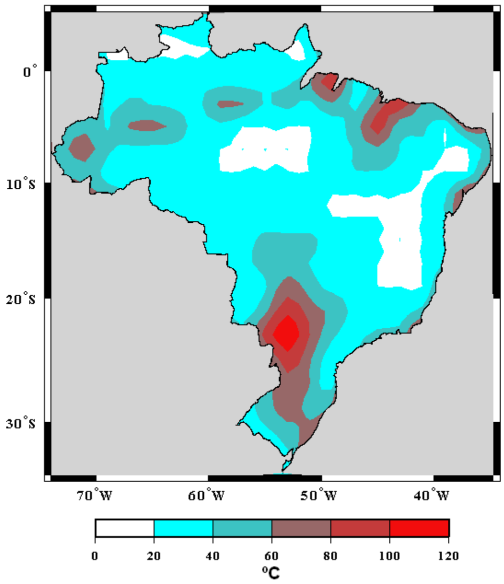

Figure 7b: Temperatures at the base of hard sediments.

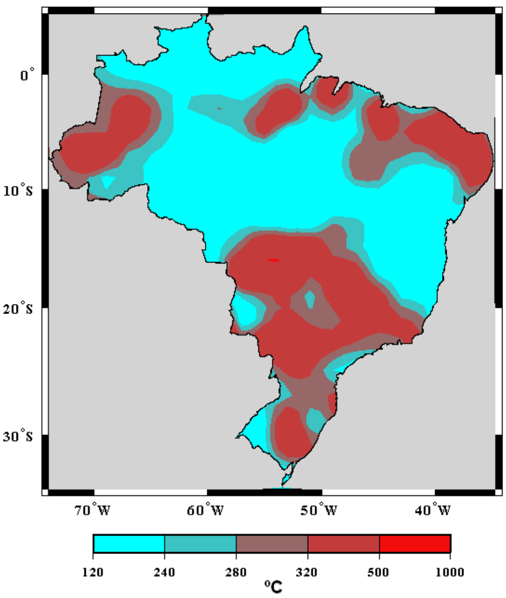

Figure 7c: Temperatures at the base of upper crust.

In the case of the soft sedimentary layer (see Figure 8a) estimates of resource base fall in the range of 10^{12} to 10^{14}J. Values higher than 10^{13}J are found to occur mainly in the southern parts and also along an east west trending belt in the northern parts.

In the case of hard sedimentary layer (see Figure 8b) estimates of resource base fall in the range of 10^{13} to 10^{15}J. Central parts of the Paraná basin in south Brazil have resource base values higher than 10^{14}J. Similar values are also found to occur in a set of discontinuous regions distributed along an east-west trending belt in north Brazil, following roughly the Amazon basins. In the remaining areas the resource base values are less than 10 TJ.

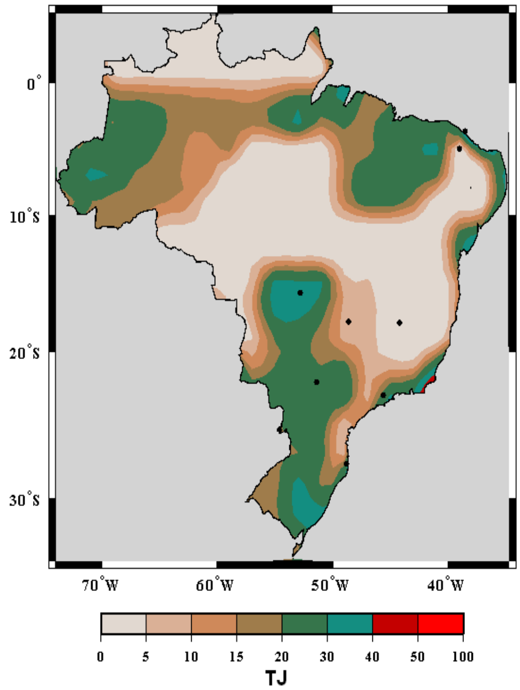

Figure 8a: Resource base for the soft sediment layer. The dots indicate localities of geothermal areas.

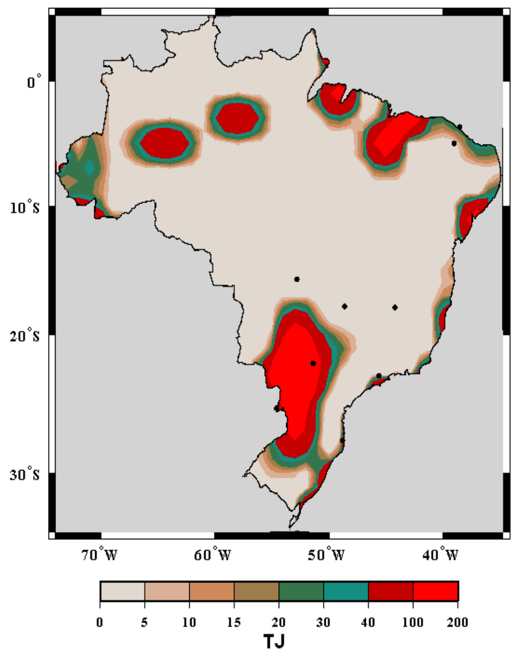

Figure 8b: Resource base for the hard sediment layer. The dots indicate localities of geothermal areas.

In the case of upper crustal layer (see Figure 8c) estimates of resource base fall in the range of 10^{12} to 10^{16}J. Occurrence of values higher than 10^{15}J is restricted to the northwestern border of the Paraná basin and isolated pockets in Acre and lower Amazon basins. In most of the remaining regions the resource base is less than 5000 TJ.

5. DISCUSSION AND CONCLUSIONS

Unlike previous studies the results obtained in the present work have lead to assessments of resources that incorporate not only borehole temperature and heat flow data but also available information on structure and physical properties of the crustal layers. There are indications that this procedure has lead to improvements in our understanding of the spatial distribution of both low and high enthalpy geothermal resources in the South American continent. In particular, it is now possible to understand better the relations between and the crustal layer of origin of surface manifestations of geothermal fluids and the resource base in geothermal areas.

Another important point emerging from the results of the present work is that high enthalpy resources in the western parts of the continent are almost all of deep crustal origin while low enthalpy resources in the eastern parts of the continent are almost all of shallow crustal origin.

We have provided so far separate resource estimates for the main layers in the upper parts of the crust. It is possible to combine these individual contributions to the resource base in obtaining estimates of total resource base. Results of such an attempt are presented in the map of Figure (9). Note that maximum value of the integrated resource base is 100 TJ. This value is significantly different from that obtained in previous studies.

6. ACKNOLEDGEMENTS

The present work was carried out as part of a research project for investigating thermal isostasy in southeast Brazil, with funding from Fundação Amparo á Pesquisa do Estado do Rio de Janeiro – FAPERJ (Grant No. E-26/100.623/2007 – Bolsa), under the program ´Scientist of the state of Rio de Janeiro´.

REFERENCES

Alexandrino, C., H., 2008, Geothermal field of the structural province of São Francisco and adjacent mobile belts (in Portuguese), Unpublished Ph.D. Thesis, Observatório Nacional, Rio de Janeiro, Brazil, pp.1 – 167.

Alexandrino, C., H., Hamza, V., M., 2008, Estimates of heat flow and heat production and a thermal model of the São Francisco Cráton. International Journal of Earth Sciences, Volume 97, Number 2, p. 289-306.

Andrade Fontes, L.C.A, 1980, Determinação do Fluxo Geotérmico na bacia sedimentar Sergipe – Alagoas, M.Sc. Thesis, Univ. Federal de Bahia, Salvador, PP. 78.

Bassin, C., Laske, G. and Masters, G., 2000, The Current Limits of Resolution for Surface Wave Tomography in North America, EOS Trans AGU, 81, F897.

Cardoso, R.R., 2006, Analytic representation of the global thermal Field by the method of spherical harmonics (in Portuguese), Unpublished M.Sc. Thesis, Observatório Nacional – MCT, Rio de Janeiro, Brazil, pp. 1-147.

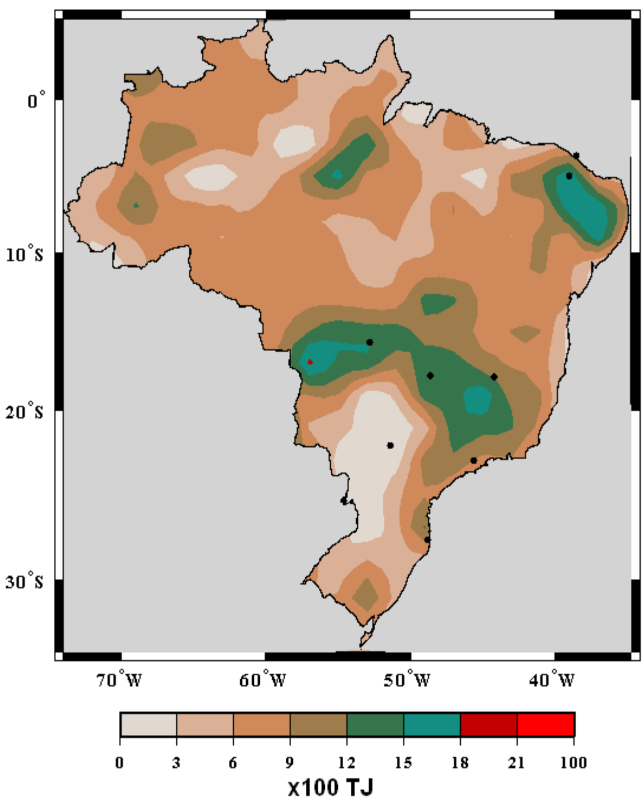

Figure 8c: Resource base for the upper crustal layer. The dots indicate localities of geothermal areas.

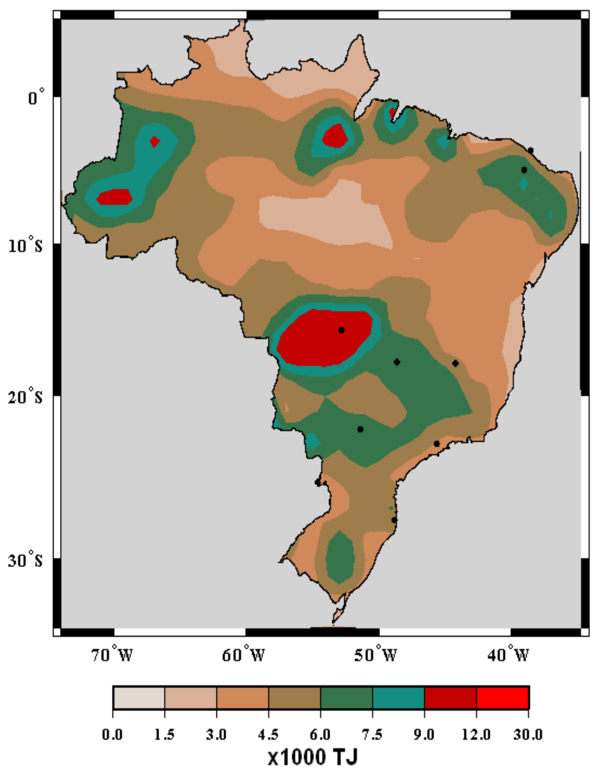

Figure 9: Map of the total resource base for Brazil, referred to the maximum depth limit of 3km. The dots indicate localities of geothermal areas.

Čermak, V., Bodri, L., Rybach, L., Buntebarth, G**.,** 1990, Relationship between seismic velocity and heat production: Comparison of two sets of data and test of validity. *Earth and Planetary Science Letters*, 99, 48–57.

Del Rey, A.C. and Zembruscki, S.G., 1991, Hydrogeothermic study of the Espirito Santo and Mucuri basins., Bol. Geoci. PETROBRÁS, v.5 (1/4), p. 25 – 38, Rio de Janeiro, Brazil.

Eston, S.M. and Hamza, V.M., 1984, Energia Geotérmica no Brasil: Avaliação de Recursos, Avanços Tecnológicos e Perspectivas de Utilização. In: Simpósio Brasileiro Sobre Técnicas Exploratórias Aplicadas á Geologia, Salvador, v.1, p. 109-132.

Gomes, A.J.L. and Hamza, V.M., 2009, Geothermal gradient and heat flow in the Paraná basin (in Portuguese), 11th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, August 24-28.

Gutierrez, M.V. and Hamza, V.M., 2009, Campo Térmico da Crosta na Região Sedimentar Bahia Sul e na Área Precambriana Adjacente: Reavaliação com base em dados corrigidos da Margem Continental, 11th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, August 24-28.

Hamza, V.M., Cardoso, R.R. and Ponte Neto, C.F., 2008, Spherical harmonic representation of Earth´s conductive heat flow. International J. Earth Sciences, 97, 205-226.

Hamza, V.M. and Carneiro, J., 2004, Geothermal Energy: Current use and Future Perspectives (in Portuguese), X Congresso Brasiliero de Energia, v.1, p. 999-1006.

Hamza, V.M. and S.M. Eston, 1983. Assessment of geothermal resources of Brazil – 1981, Zentralblatt fur Geologie und Palaontologie, v.1, p.128–155.

Hamza, V.M., Eston, S.M. and Araújo, R.L.C., 1978, Geothermal energy prospects in Brazil: A preliminary analysis. *Pure Appl. Geophys.* **117**, 180-195.

Hamza, V.M., A. Frangipani, and E.A. Becker, 1990b. Development of Geothermal Projects in Brazil: Current state and Perspectives. Proc. International Seminar on Geothermal Perspectives for Latin America and Caribe (in Spanish), p. 37-52.

Hamza, V.M., Gomes, A.J.L., Ferreira, L.E.T., 2005. Status report on geothermal energy developments in Brazil. In: Proceedings of the World Geothermal Congress, Antalya, Turkey, 24-29 April 2005.

Hamza, V.M. and Muñoz, M., 1996, Hea flow map of South America. Geothermics, 25(6), 599-646.

Hamza, V.M., Soares, F.J.S. and Gomes, A.J.L. and Delgadillo Terceros, Z.G., 2005, Numerical and Functional representations of Regional heat flow in South America, Tectonophysics, v. 152, n. 4, p. 223-256.

Hamza, V.M., Gomes, A.J.L., Ferreira, L.E.T., 2005, Status report on geothermal energy developments in Brazil. In: Proceedings of the World Geothermal Congress, Antalya, Turkey, 24-29 April 2005.

amza, V.M., Cardoso, R.R. and Ponte Neto, C.F., 2008, Spherical harmonic representation of Earth´s conductive heat flow. International J. Earth Sciences, 97, 205-226.

Mooney, W.D., Laske, G. and Masters, G., 1998, Crust 5.1: a global crustal model at 5x5 degrees, Journal of Geophys. Res., 103, 727-747.

Muffler, L.J.P. and R. Cataldi, 1978. “Methods for regional assessment of geothermal resources.” Geothermics, v.7, p.53-89.

MME, 2009, Resenha Energética Brasileira, PP. 1-22, Ministério de Minas e Energia, Brasilia, Brazil.

Silva, G.B.D., 2006, A Superfície Curie na Região Bahia Sul – Análise Espectral sobre Dados Aeromagnéticos de Alta Resolução.,Unpublished M.Sc. Thesis, Observatório Nacional, Rio de Janeiro, Brazil, pp. 1-139.

Vieira, F.P. and Hamza, V.M., 2009, Estrutura Termal da Crosta na Região do Nordeste Setentrional., 11th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, August 24-28.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009			15140	51500	65311	3446000	2007	13800			82458	3511300
Under construction in December 2009												
Funds committed, but not yet under construction in December 2009												
Total projected use by 2010												

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2004

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 2004 if available, otherwise for 2003. Please specify which.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Total Installed Capacity MWe	Annual Energy Produced 2004[3] GWh/yr	Total under Constr. or Planned MWe
Total								

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT

Locality	Type[1]	Maximum Utilization Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Enthalpy[2] (kJ/kg) Inlet	Enthalpy[2] (kJ/kg) Outlet	Capacity[3] (MWt)	Annual Utilization Ave. Flow (kg/s)	Energy[4] (TJ/yr)	Capacity Factor[5]
Águas de Chapecó	B	3	37	30			0.1	2	1.5	0.6
Águas do Veré	B	694	38	30			23.2	405	427.2	0.6
Águas Mornas	B	14	40	30			0.6	8	10.7	0.6
Aguinhas-Chapecó	B	14	37	30			0.4	8	7.5	0.6
Alto Paraiso de Goiás	B	14	38	30			0.5	8	8.5	0.6
Araçatuba	B	417	48	30			31.4	243	577.1	0.6
Araxá	B	14	37	30			0.4	8	7.5	0.6
Bandeirantes	B	14	38	30			0.5	8	8.5	0.6
Cachoeira Dourada	B	139	40	30			5.8	81	106.9	0.6
Caldas	B	6	46	30			0.4	3	6.8	0.6
Caldas Novas	B	333	57	32			34.8	194	640.5	0.6
Cipó	B	31	36	30			0.8	18	14.2	0.6
Concordia	I	28	48	30			2.1	16	38.5	0.6
Cornélio Procópio	I	28	48	30			2.1	16	38.5	0.6
Correia Pinto	B	3	42	30			0.1	2	2.6	0.6
Fernandópolis	B	14	59	30			1.7	8	31.0	0.6
Foz do Iguaçu	B	14	48	30			1.0	8	19.2	0.6
General Carneiro	B	152	46	30			10.2	89	187.1	0.6
Gravatal	B	33	38	30			1.1	19	20.5	0.6
Imaruí	B	3	38	30			0.1	2	1.7	0.6
Itajá	B	4028	38	30			134.8	2350	2479.2	0.6
Itapicuru	B	31	48	30			2.3	18	42.7	0.6
Jaciara	B	6	42	30			0.3	3	5.1	0.6
Jales	B	14	61	30			1.8	8	33.1	0.6
Juscimeira	B	8	44	30			0.5	5	8.4	0.6
Lins	B	6	42	30			0.3	3	5.1	0.6
Londrina	B	6	48	30			0.4	3	7.7	0.6
Mossoró	B	14	54	30			1.4	8	25.6	0.6
Nova Veneza	B	3	38	30			0.1	2	1.7	0.6
Palhoça	B	3	40	30			0.1	2	2.1	0.6
Palmeiras	B	3	40	30			0.1	2	2.1	0.6
Palmitos	B	3	37	30			0.1	2	1.5	0.6
Paraguaçu Paulista	B	28	48	30			2.1	16	38.5	0.6
Pedras Grandes	B	3	37	30			0.1	2	1.5	0.6
Petrolândia	B	3	37	30			0.1	2	1.5	0.6
Piratuba	B	194	39	30			7.3	113	134.6	0.6
Poços de Caldas	B	6	44	30			0.3	3	6.0	0.6
Poxoreu	B	6	40	30			0.2	3	4.3	0.6
Preisdente Prudente	B	56	63	30			7.7	32	141.1	0.6
Presidente Epitácio	B	28	78	30			5.6	16	102.6	0.6
Rio Fortuna	B	3	38	30			0.1	2	1.7	0.6
Rio Pardo de Minas	B	28	40	30			1.2	16	21.4	0.6
Rio Pelotas	B	7	39	30			0.3	4	4.6	0.6
Rio Quente	B, F	1667	42	32			69.7	972	1282.6	0.6
S.A. de Imperatriz	B	3	40	30			0.1	2	2.1	0.6
S.A. do Leverger	B	3	42	30			0.1	2	2.6	0.6
S.J. do Rio Preto	B	28	45	30			1.7	16	32.1	0.6
S.P. de Alcantara	B	3	38	30			0.1	2	1.7	0.6
Salgadinho	B	6	38	30			0.2	3	3.4	0.6
Saltinho	B	3	38	30			0.1	2	1.7	0.6
Santa Rosa de Lima	B	3	38	30			0.1	2	1.7	0.6
São Domingos	B	3	38	30			0.1	2	1.7	0.6
São João do Sul	B	3	41	30			0.1	2	2.4	0.6
Tangará	B	3	38	30			0.1	2	1.7	0.6
Taquaruçu	B	3	38	30			0.1	2	1.7	0.6
Taubaté	B	28	48	30			2.1	16	38.5	0.6
Três Lagoas	B	14	46	30			0.9	8	17.1	0.6
Treze de Maio	B	3	38	30			0.1	2	1.7	0.6
Trombudo Central	B	3	37	30			0.1	2	1.5	0.6
TOTAL							360.1		6622.4	

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2004

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps
Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)
Report the COP = (output thermal energy/input energy of compressor) for your climate
Report the equivalent full load operating hours per year, or = capacity factor x 8760
Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

Locality	Ground or water temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
TOTAL								

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]	4.20	77.0	0.58
Snow Melting			
Bathing and Swimming[7]	355.9	6545.4	0.58
Other Uses (specify)			
Subtotal	360.1	6622.4	0.58
Geothermal Heat Pumps			
TOTAL	360.1	6622.4	0.58

[4] Other than heat pumps
[5] Includes drying or dehydration of grains, fruits and vegetables
[6] Excludes agricultural drying and dehydration
[7] Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)		10			5
Production	>150° C					
	150-100° C <100° C		10			5
Injection	(all)					
Total			20			10

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	2		5			2
2001	2		5			2
2002	2		5			2
2003	2		5			2
2004	2		5			2
Total	10		25			10

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling Million US$	Field Development Including Production Drilling & Surface Equipment Million US$	Utilization		Funding Type	
			Direct Million US$	Electrical Million US$	Private %	Public %
1990-1994	0.3	0.8	0.5		80	20
1995-1999	0.3	0.8	0.5		80	20
2000-2004	0.3	0.5	0.1		80	20
2004-2009	0.3	0.5	0.1		80	20