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Updated Assessment of Geothermal Resources in Brazil

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ABSTRACT

Assessments of geothermal resources of Brazil are presented that include results of recent surveys carried out in the states of Tocantins, Pará and Mato Grosso. Currently, it is based on data acquired at over 1,100 sites as well as information on hydrothermal and energy use on thermal fluid discharge systems at over 110 localities. The total resource base, referred to the accessible depth limit of 3km, is estimated at 1,800 TJ. This is nearly 25% less than previous calculations, as it allows for estimated cooling effects of regional scale groundwater circulation in deep sedimentary strata. A significant low temperature geothermal anomaly has been discovered in the eastern part of the state of Tocantins. Nevertheless, potential for high temperature geothermal systems appears to be restricted to the Atlantic islands of Fernando de Noronha and Trindade. The available parts of resources have been calculated based on regionally averaged values of porosity and permeability. It is estimated to be of the order of 4 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 6,540 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

According to the recent estimates (EPE, 2013) the total energy generation in Brazil is estimated at about $12.717*10^6$ million TOE (tons of oil equivalent). Systems based on the use of hydrocarbon resources, hydroelectric power generation and biomass systems account for nearly 89.1% of this total. Figure 1 provides a summary of the evolution of the energy matrix of Brazil for the last decade. Geothermal energy sources are not directly used for electrical power generation and hence not formally recognized by the National Council of Energy Research (CNPE).

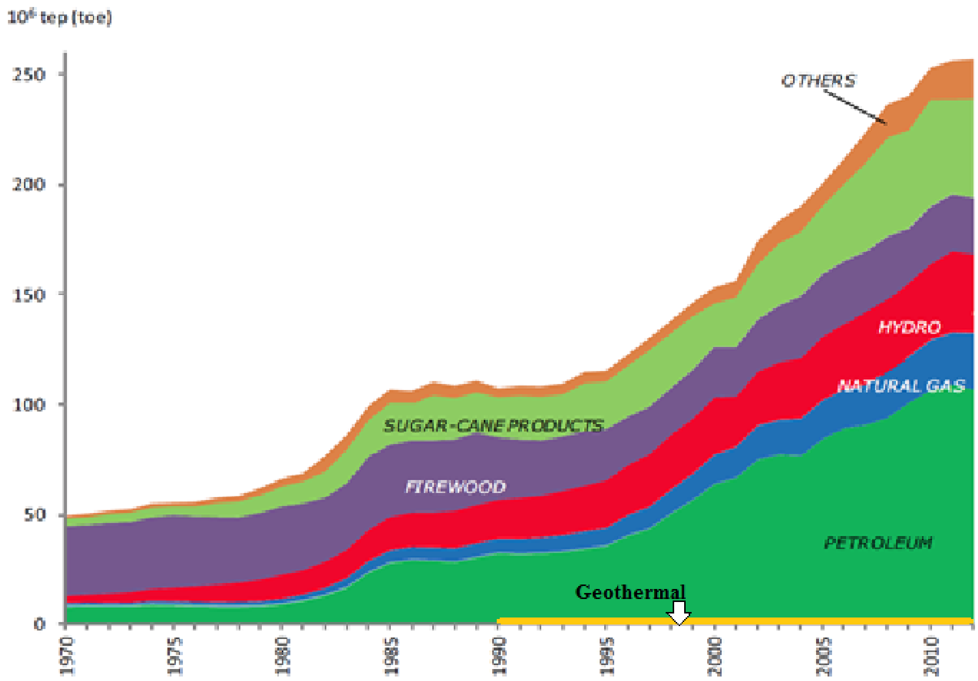

Figure 1: Evolution of Energy matrix of Brazil (Modified after, EPE, 2013).

According to recent compilations of information on energy use geothermal contribution is estimated to be over 360MWt. Geothermal springs are major public attractions in Brazil and have contributed to significant local and regional tourist developments in specific areas. Nevertheless, lack of systematic studies has contributed to poor understanding of the physical and chemical characteristics of geothermal resources and their regional distribution. It is in this context the present study was undertaken.

Early works on the evaluation of the 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. At the beginning of the last decade, attempts were made for assessment of the resources associated with thermal springs in the states of Mato Grosso, Goiás and Tocantins. Hamza et al. (2005) discussed the results of this work, carried out in collaboration with the International Institute of Geothermal Research (IIRG) of Italy. Hamza and Carneiro (2004) have examined the spatial distributions of these earlier estimates of the resource base. Systems with temperatures lower than 90°C constitute the most common type of geothermal reservoirs in Brazil (Hurter et al, 1983).

A major weakness of these earlier studies is that the resource estimates are based mainly on local values of geothermal gradients and heat flow. With the exception of the study by Hamza et al. (2010), few attempts have been made in incorporating information on regional geologic and geophysical characteristics of subsurface strata in resource assessments. In the present work, a new approach has been adopted that takes into consideration not only available data sets on near surface temperatures and heat flow but also supplementary information on regional lithology and hydrologic characteristics of subsurface strata, that have direct bearings on the occurrence of geothermal resources.

2. SOURCES OF DATA

The Geothermal Laboratory of the National Observatory, Brazil, has compiled basic data on physical and chemical characteristics of thermal spring systems. These compilations also include data on thermo-physical properties of the main geologic formations in the upper crust, vertical distributions of temperatures in boreholes and wells as well as estimates of terrestrial heat flow (Vieira and Hamza, 2011). Such data sets have been useful in deriving estimates of geothermal energy resources at several depth levels in the upper crust. The locations of geothermal studies in Brazil are indicated in the map of Figure 2.

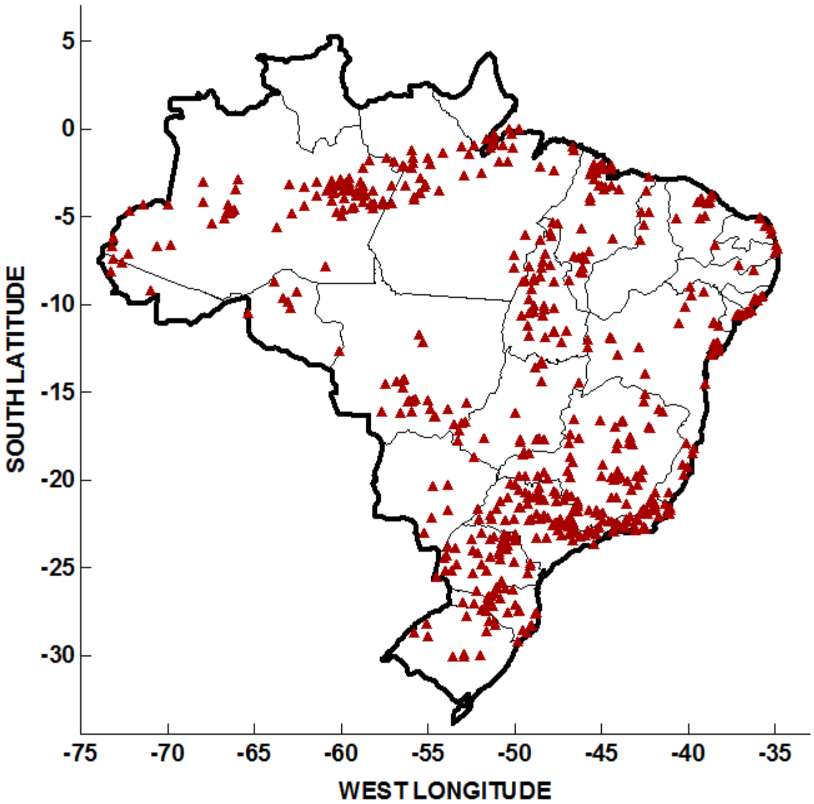

Figure 2: Locations of geothermal studies in Brazil.

3. CRUSTAL TEMPERATURES

The compilations of the geothermal database have been useful in determining vertical distributions of temperatures in the upper crust. 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 "excess temperature" (ΔT) over the mean surface temperature is given by the relation:

$$\Delta T = \frac{q_0}{k} d - \frac{A_{0rad} \, d^2}{2k} \left(1 - e^{-z/D}\right) \qquad (1)$$

where q_0 is the surface heat flux, A_0 is radiogenic heat productivity and k is the thermal conductivity. The values of A_0 is derived from empirical relations (Cermak et al, 1990) relating to crustal seismic velocities with radiogenic heat productivity. The thermal conductivity values of the sedimentary layers were derived from the heat flow database. Regional distribution of excess temperatures, referred to a depth of 3 km, is illustrated in the map of Figure 3.

3. CALCULATIONS 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_{RB}) of thickness d, associated with the temperature distribution given by equation (1), is derived using the relation:

$$Q_{RB\,i} = \rho_i c_{pi} A_i d_i (T_i - T_0) \tag{2}$$

where ρ_i is the average density of the i[th] layer, c_{pi} the specific heat, A_i the area of the cell, T_i the bottom temperature and T_0 upper surface temperature. In the present work, a reference depth of 3 km was chosen in calculations of the resource base. The regional distribution of the resource base, referred to this depth limit is illustrated in the map of Figure 4.

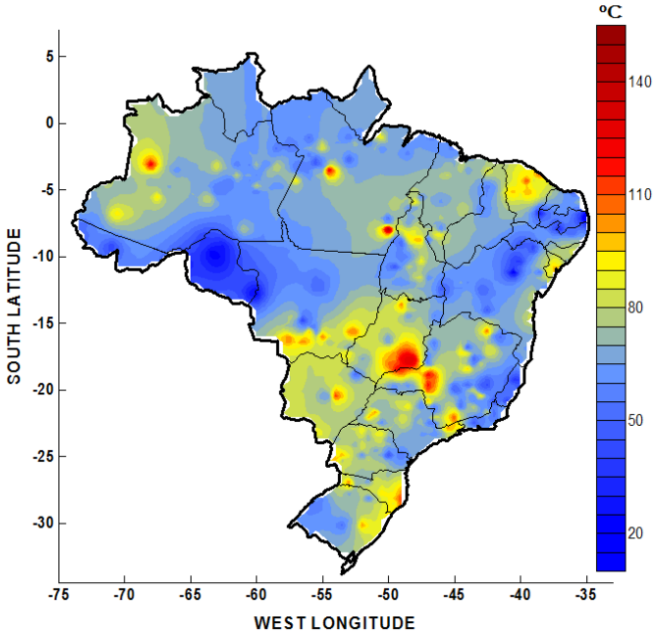

Figure 3: Map of excess temperatures referred to depth of 3 km.

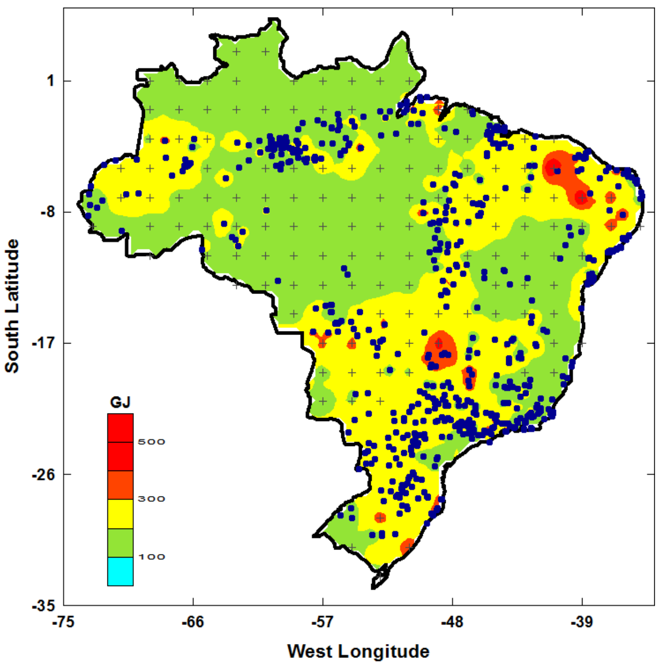

Figure 4: Map of resource base (in GJ) referred to depth of 3 km.

4. ESTIMATES OF RECOVERABLE RESOURCES

The recoverable resource is usually defined as that part of the resource base associated with pore fluids that can be extracted using current technology. In areas of positive geothermal gradients, temperatures of the rock matrix and the pore fluids increase with depth. However, porosity and permeability of most common rocks decrease with depth, which imply corresponding decrease in quantity of circulating fluids in deeper levels. We examine first the nature of opposing roles of temperature and porosity variations with depth.

The relation for the total geothermal resource (Q) of a volume element (of area A and thickness h) with rock temperature T_r and porosity ϕ may be written as:

$$Q = \left[\phi\, C_f + (1-\phi) C_r\right]\left[T_r - T_0\right] A\, h \tag{3}$$

where C_f and C_r are the heat capacities of the fluid and rock matrix respectively. The variation of T_r with depth Z depends on the local value of geothermal gradient (g). The variation of porosity ϕ with depth Z may be represented by a relation of the type:

$$\phi = \phi_0 e^{-Z/D} \tag{4}$$

where D is the logarithmic decrement of porosity with depth. The substitution of (4) in (3) leads to:

$$Q = (Z\, g\, A\, h)\left[\phi_0\, e^{-Z/D}\, C_f\right] + (Z\, g\, A\, h)\left[\left(1-\phi_0\, e^{-Z/D}\right) C_r\right] \tag{5}$$

It is simple to note that the first term in equation (5) represents the recoverable resource while the second term represents the resource associated with the rock matrix. Note also that the vertical variation of the resource is non-linear. Considering the product *gAh* as constant B, the relation is:

$$Q = \left(C_f\, \phi_0\, e^{-Z/D} + C_r - C_r\, \phi_0\, e^{-Z/D}\right) Z\, B \tag{6}$$

The depth at which Q_{RR} is a maximum can be obtained from the derivative of equation (6) and equating it to zero:

$$\phi_0 \frac{e^{-Z/D}}{D} (D - Z)\left(C_f - C_r\right) = C_r \tag{7}$$

It is clear that this condition is satisfied when Z equals D.

Applying the above procedure to the results of the present work revealed that the maximum in recoverable resources occurs in the depth range of 2,500 to 3,500 meters. A summary of the estimates of excess temperatures (T_e), resource base per unit area (RBUA) and recoverable resources per unit area (RRUA) is given in Table 1. As expected, regions with large numbers of thermal springs (such as the States of Santa Catarina, Goiás, Minas Gerais and Mato Grosso) are characterized by relatively high values of recoverable resources. The resource base is high in the state of Ceará because of the relatively high values of excess temperatures. However, the recoverable resource is estimated to be relatively low because of reduced porosity of metamorphic rocks. Recoverable resources are estimated to be less than 10 GJ in ten States.

Table 1. Estimates of excess temperature (Te), resource base per unit area (RBUA) and recoverable resource per unit area (RRUA), in 26 States of Brazil. N_R is number of grid elements used in resource estimates.

State / Region	N_R	Te (^{o}C)	RBUA (10^9 J)	RRUA (10^9J)
Santa Catarina	23	86.2	263.0	20.6
Goiás	14	96.1	286.3	18.9
Minas Gerais	60	71.7	231.6	18.1
Mato Grosso	24	70.3	235.1	17.4
Tocantins	31	70.2	225.9	14.4
Ceará	10	97.9	285.7	14.3
Mato Grosso do Sul	7	75.6	256.1	12.8
Bahia	25	50.9	183.1	12.7
Sergipe	11	86.2	255.0	12.8
Alagoas	9	78.9	233.5	11.7
Paraná	39	76.2	227.3	11.4
São Paulo	69	74.0	217.9	10.9
Rio Grande do Sul	15	75.4	211.4	10.6
Amazonas	72	69.1	205.4	10.6
Maranhão	25	70.1	203.1	10.2
Rio Grande do Norte	14	66.8	202.3	10.1
Pará	40	65.0	192.1	9.6
Rio de Janeiro	27	62.0	179.9	9.0

Piauí	4	56.1	165.2	8.3
Acre	4	49.3	114.8	7.2
Amapá	2	61.3	102.1	5.1
Pernambuco	1	42.5	42.5	2.1
Paraiba	5	25.4	26.7	1.3
Rondônia	7	26.6	26.6	1.3
Roraima	1	26.1	26.1	1.3
Espirito Santo	6	43.3	15.5	0.8
Average			201	11.8

The analysis of the available geothermal data indicates that recoverable resources are significant mainly in areas with sediment cover and in areas of high fracture density. The deeper parts of the upper crust have very little porosity and are incapable of holding significant amount of recoverable resources. In view of these considerations, the resource base calculations have been limited to a maximum depth limit of 3 km. The map of Figure (5) illustrates spatial distribution of the recoverable part of the resource base, referred to the depth limit of 3 km within the continental segment of the Brazilian territory.

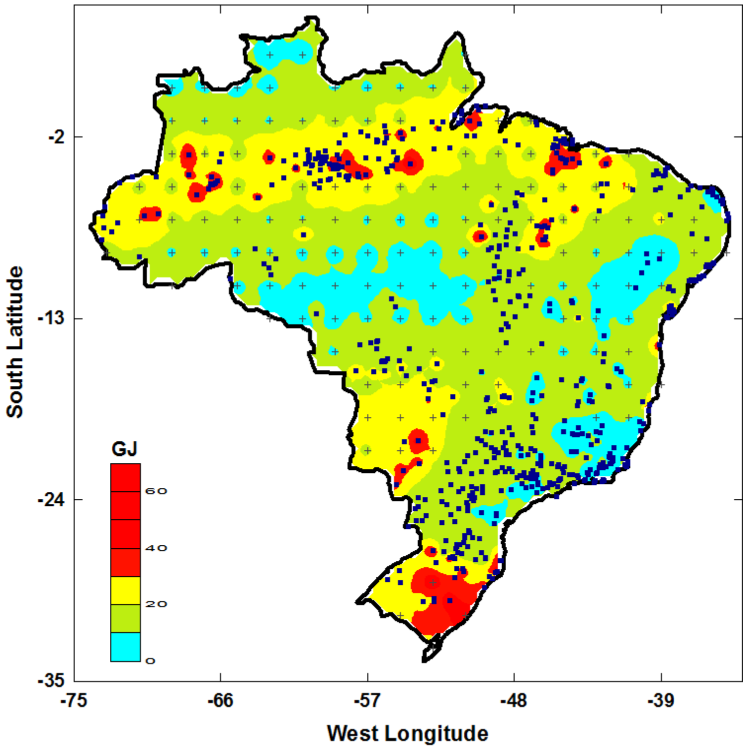

Figure 5: Map of recoverable resource (in GJ) referred to depth of 3 km.

4. USE OF LOW TEMPERATURE GEOTHERMAL RESOURCES

Geothermal Laboratory of the National Observatory has compiled information on the main geothermal systems currently being exploited commercially in Brazil. This compilation includes data on flow rates, range of use of temperatures and chemical characteristics of thermal fluids. Following the practice adopted in earlier works, we found it convenient to classify the information on spring systems into groups, based on such key factors as perspectives for direct use, proximity of large urban centers and local climate characteristics. They are designated as BRT (Bathing, Recreation and Tourism), PIS (Potential for Industrial use and Space heating) and TDB (Therapeutic, Drinking and Bathing) groups. List of thermal springs with capacity greater than 2 MWt (Megawatt Thermal) of these groups are presented respectively in Table 2. Also given in this table are estimates of the thermal capacity of the spring systems in units of MWt (Megawatt Thermal) and of the annual energy use in units of TJ/yr (Tera Joules/Year). The geographic distribution of the main thermal and mineral springs belonging to the three above-mentioned groups is illustrated in Figure (6). As can be seen in this figure, the concentration of thermal springs is relatively high in southern and south-central parts of Brazil, compared with the northern parts. Also indicated in this figure are the sites where industrial use of thermal water has been made.

The spring systems belonging to the BRT group have an estimated total thermal capacity of 16 MWt and an annual energy use of about 189 TJ. The localities of these thermal springs have become popular tourist attractions over the last few decades. Currently such small-scale thermal and mineral spas are visited by an estimated 1.5 million tourists per year. This in turn has spurred considerable local economic activity. The emphasis at these thermal spas and tourist centers is on entertainment and physical conditioning under programs for revitalizing the body in a relaxing environment. Larger spring systems belonging to the PIS group have an estimated total thermal capacity of 343 MWt and an annual energy use of about 6,291 TJ. Currently the thermal resources at these sites are being used almost exclusively for bathing and recreation, in spite of their considerable potential for industrial applications and space heating. Industrial use of thermal water has so far been attempted only in a few localities. In the town of Taubaté, in southeastern São Paulo geothermal water at 48°C was used, during the 1970s and 1980s, for industrial wood processing (pre-heating prior to peeling). In Cornélio Procópio, in the state of Paraná, geothermal water at 50°C pumped from a 950-meter deep well has been used, since 1980, as pre-heated water for boilers, in industrial production of coffee powder. The spring systems belonging to the TDB group have an estimated total thermal capacity of three MWt and an annual energy use of about 56 TJ. Exploration of non-thermal mineral water for therapeutic purposes is quite widespread. According to recent estimates, revenues generated by the mineral water industry make up a significant component of the economy in many municipalities. In this respect, it is convenient to note that the list given in Table 2 and the sites indicated in Figure 6 represent only a tiny fraction of the current total mineral water production.

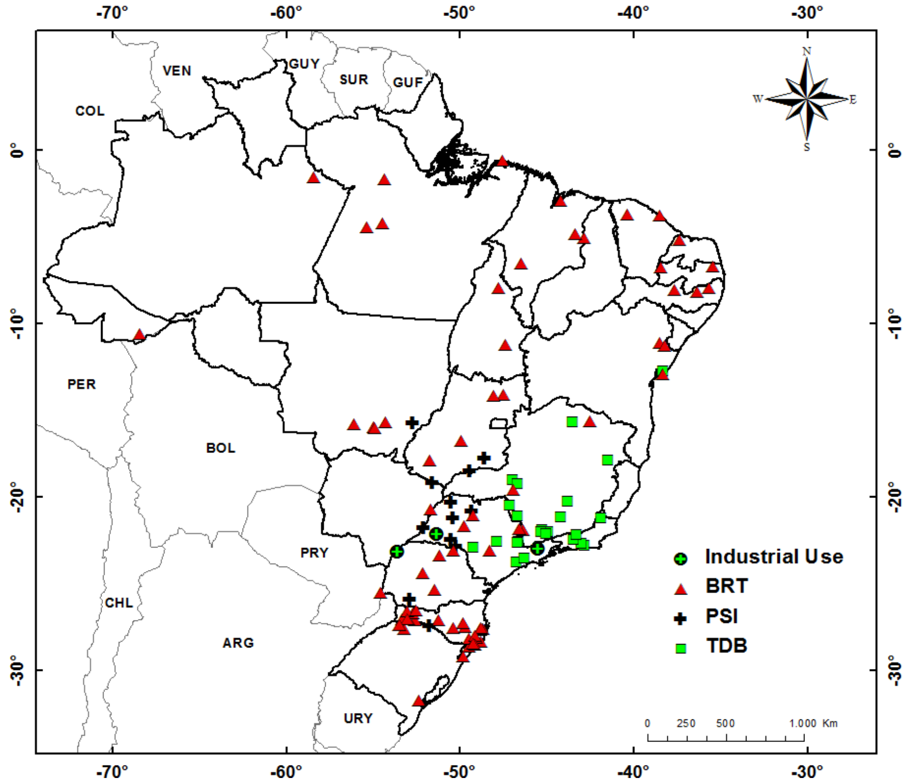

Figure 6: Locations of major thermal spring systems in Brazil. See text for explanations of abbreviations used (BRT, PIS and TDB)

Table (2). Large capacity (>2*MWt*) geothermal systems, classified as belonging to the PIS (Potential for Industrial use and Space heating) group. The flow rate and temperature data are from Hurter et al. (1983) and Furumoto (1990).

Locality	Flow Rate	Temperature (C)		Capacity	Average Flow	Annual Use	Capacity Factor
	(l/s)	Tin	Tout	(MWt)	(l/s)	(TJ/yr)	
Cachoeira Dourada	139	40	30	6	81	107	0.58
Caldas Novas	333	57	32	35	194	641	0.58
Itajá	4,028	38	30	135	2,350	2,480	0.58
Rio Quente	1,667	42	32	70	972	1,283	0.58
General Carneiro	152	46	30	10	89	187	0.58
Águas do Veré	694	38	30	23	405	427	0.58
Piratuba	194	39	30	7	113	135	0.58
Cornélio Procópio	14	48	30	2	16	38	0.58
Araçatuba	417	48	30	31	243	577	0.58
Fernandópolis	14	59	30	2	8	31	0.58
Jales	14	61	30	2	8	33	0.58
Paraguaçu Paulista	14	48	30	2	16	38	0.58
Presidente Epitácio	28	78	30	6	16	103	0.58
Presidente Prudente	56	63	30	8	32	141	0.58
São José do Rio Preto	28	45	30	2	16	32	0.58
Taubaté	28	48	30	2	16	38	0.58
Total				343		6,291	

5. FUTURE PERSPECTIVES

In evaluations of suitable sites for exploitation of resources, use has been made of information on thickness, density and seismic velocity of the crustal layers in addition to the temperature and heat flow data sets. The relevant information available in the global crustal data compilations by Mooney et al., (1998) and by Bassin et al. (2000) are considered sufficient for the present purpose. 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. In the present work, we have introduced a modification that allows for the eventual existence of layers with high fracture density at depths less than 5 km. Such layers are capable of holding significant amount of recoverable resources. Large thicknesses of sedimentary strata are present in the central parts of basins in the Amazon region, Parnaiba and Paraná. Such basins are considered as suitable targets for exploitation of geothermal resources.

Other targets considered suitable for exploitation of resources are some of the Precambrian areas in the states of Goiás and Tocantins where layers of high fracture density exist in the upper crust. In addition, there are indications of medium enthalpy resources in the basal parts of the Parana basin (Gomes, 2017), at depths greater than 5km. Results of aeromagnetic surveys used in mapping depths of Curie isotherms (Guimaraes et al, 2014) have allowed identification of several magma intrusions in deep crustal layers, mainly in the state of Minas Gerais. Recent results of magneto-telluric studies (Santos et al, 2013) have identified the existence of a major anomaly in the central parts of Pernambuco state, in northeast Brazil. There are indications that this anomaly is of geothermal origin. Locations of such suspected medium to high enthalpy resources are indicated in the map of Figure 7.

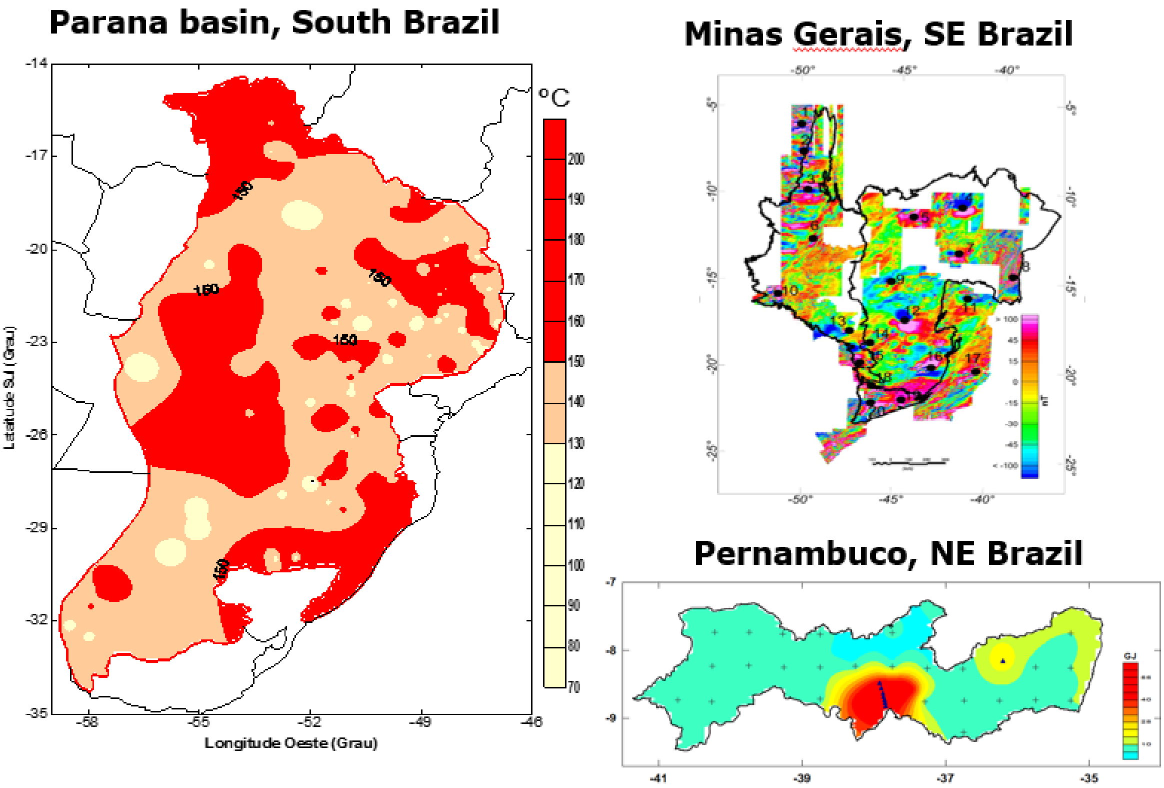

Figure 7: Possible localities of medium to high enthalpy geothermal resources within the Brazilian territory. The upper right panel indicates locations of deep crustal magma intrusions identified in aeromagnetic surveys. The lower panel indicates the anomaly at 5km depth, identified in magneto telluric studies. See text for details.

The map of Figure 8 indicates the thicknesses of reservoirs in locations suitable for exploitation of geothermal resources. It includes hard sediment layers (yellow and red shaded areas) as well as layers of high fracture density (orange shaded areas with blue borders) within the Brazilian territory. Also indicated is the site of the anomaly reported by Santos et al (2013), considered as indicative of a shallow magmatic intrusion. In the case of hard-sediment layers, estimates of the 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. In the case of the soft sedimentary layer, estimates of the resource base are found to 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 upper crustal layer, estimates of the 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 5,000 TJ.

5. DISCUSSION AND CONCLUSIONS

Unlike previous studies, the results obtained in the present work have led 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 led 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.

We have provided 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. Note that the maximum value of the integrated resource base is 100 TJ. This value is significantly different from that obtained in previous studies. Another important point emerging from the results of the present work is that medium to high enthalpy resources may be present at depths greater than 5km in the southern and northwestern parts of Brazil.

In summary the main conclusions are:

1- The resource base of Brazil, referred to the selected depth of 3km, is estimated to be of the order of 10^{24}J.

2- The recoverable part of resource base is estimated to be of the order of 10^{22}J. The deeper parts of the Paleozoic sedimentary basins account for 90% of it.

3- Most of identified resources are of low enthalpy type, with temperatures less than 100°C.

4 – There are, however, indications of medium to high enthalpy resources at depths greater than 5km in southern and northeastern parts of Brazil.

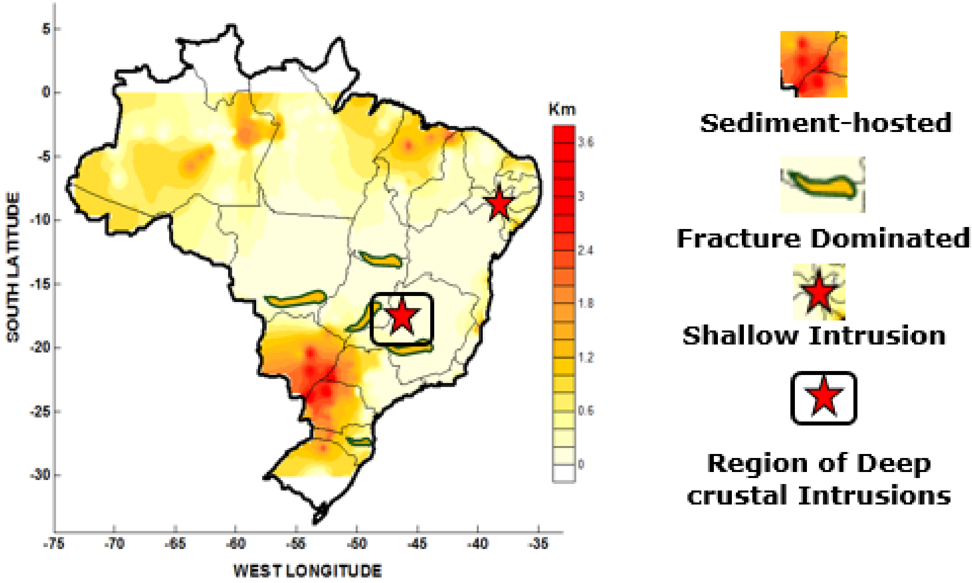

Figure 8: Thicknesses of reservoirs in locations suitable for exploitation of geothermal resources within the Brazilian territory. It includes central parts of Paleozoic sedimentary basins (yellow and red shaded areas) and layers of relatively high fracture density in the upper crust (orange shaded areas with blue borders). Also indicated are locations of shallow and deep crustal magmatic intrusions.

6. ACKNOWLEDGEMENTS

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REFERENCES

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.

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.

EPE, 2013, Brazilian Energy Balance 2012, Empresa de Pesquisa Energética, Ministry of Mines and Energy, 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.

Furumoto S (1990) Geothermal data bank system - SISTERM for IBM microcomputers Pc/Xt/At. Unpublished M.Sc. Thesis, University of São Paulo, pp.161

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.

Guimaraes, S.N.P., Ravat, D. and Hamza, V.M., 2014, Combined use of the centroid and matched filtering spectral magnetic methods in determining thermomagnetic characteristics of the crust in the structural provinces of Central Brazil. Tectonophysics, 624-625, 87-99.

Hamza, V.M., Cardoso, R.R. Gomes, A.J.L. and Alexandrino, C.H., 2010. Geothermal Resources of Brazil. In: Proceedings World Geothermal Congress, Bali, Indonesia, v. 1, p. 1-6.

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., 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, Heat flow map of South America. Geothermics, 25(6), 599-646.
Hurter, S.J., Eston, S.M. and Hamza, V.M., 1983, Brazilian Geothermal Data Collection - Series 2: Thermal Springs. Publication No. 1233, Instituto de Pesquisas Tecnológicas do Estado de São Paulo S/A – IPT, pp. 111.
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.
Santos, A.C.L., Padilha, A.L., Vitorello, I. and Fuck, R.A., 2013, Magnetotelluric imaging of the southeastern Borborema province, NE Brazil, Proceedings 13th International Congress of the Brazilian Geophysical Society, Rio de Janeiro, August 26-29.
Vieira, F.P. and Hamza, V.M., 2011. Global Heat Flow: Comparative analysis based on experimental data and theoretical values. In: Proceedings of the 12th International Congress of the Brazilian Geophysical Society, Rio de Janeiro, v. 1, p. 1-6.

STANDARD TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity). In brackets estimated values.

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Biomass, Wind)		Total	
	Capacity	Gross Prod	Capacity	Gross Prod	Capacity	Gross Prod	Capacity	Gross Prod	Capacity	Gross Prod	Capacity	Gross Prod
	MWe	GWh/yr	MWe	GWh/yr	MWe	GWh/yr	MWe	GWh/yr	MWe	GWh/yr	MWe	GWh/yr
In operation in December 2012			32778	111497	84294	4447599	2007	13800	1894	6443	120973	4579339
Under construction in December 2012			12		18863		(100)		(100)		19075	
Funds committed, but not yet under construction in December 2012												
Total projected use by 2012			32790	111497	103157	4447599	2107	13800	1994	6443	140048	4579339

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity Factor[5)]
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
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 2014									
Locality	Ground or water temperature (°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 2014			
Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Industrial Process Heat[6]	4.20	77.0	0.58
Bathing and Swimming[7]	355.9	6545.4	0.58
Other Uses			
Subtotal	360.1	6622.4	0.58
Geothermal Heat Pumps			
TOTAL	360.1	6622.4	0.58

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2008 TO DECEMBER 31, 2014 (excluding heat pump wells)							
Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth* (km)	
		Electric Power	Direct Use	Combined	Other		
Exploration[1]	(all)		10				(5)
Production	>150° C						
	150-100° C						
	<100° C		10				(5)
Injection	(all)						
Total			20				(10)

* Estimated

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
2002	2		5			2
2004	2		5			2
2006	2		5			2
2008	2		5			2
2010	2		5			2
2012	2		5			2
2014	2		3			2
Total	16		38			16

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2014) US$						
Period	Research & Development Incl. Surface Exploration & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994	0.3	0.8	0.5		80	20
1995-1999	0.3	0.8	0.5		80	20
2000-2004	0.1	0.1	0.1		80	20
2005-2009	0.1	0.1	0.1		80	20
2010-2014	0.1	0.1	0.1		80	20