Portugal Geothermal Country Update 2005

José Martins Carvalho[1], José Manuel Monteiro da Silva [2] Carlos Alberto Bicudo da Ponte[2] and Rui Martins Cabeças[2]

[1]Dep. Eng. Geotécnica, Instituto Superior de Engenharia do Porto, R. Dr. Bernardino de Almeida, nº 431, 4200-072 Porto.

[2]SOGEO, Sociedade Geotérmica dos Açores S.A. – Rua Eng.º José Cordeiro, n.º6, 9504-535 Ponta Delgada

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ABSTRACT

The geology of Portugal determines different conditions for geothermal energy occurrences. In the mainland, where crystalline rocks outcrop over 60% of the area, thermal waters are related with active faulting. Twenty-seven springs have discharge temperatures between 25ºC and 75ºC and are used in balneotherapy. Three small, low enthalpy operations for direct use at existing hotels are operating normally. A dozen of feasibility studies already carried out demonstrate adequate conditions for further operations.

In the sedimentary basins, particularly in the Lisbon area where important heat consumers are located, Lower Cretaceous reservoirs with temperatures up to 50ºC are adequate for small multipurpose geothermal operations, but technical difficulties resulted in the stoppage of the only two existing operations.

The already studied potential for developing geothermal heat pumps over proven aquifers is high all over the country. However, no reports are available on the application of any kind of geothermal heat pumps.

In the volcanic Azores Archipelago, high enthalpy geothermal resources are exploited for power generation since 1980, in São Miguel Island. Pico Vermelho and Ribeira Grande geothermal power plants, with a total installed capacity of 3+13 MWe, supply over 25% of the electrical consumption of the island. A new geothermal power plant (10 MWe) is previewed to start production by the beginning of 2006, replacing the existing Pico Vermelho generation unit. A total of 5 to 6 production/injection wells are to be drilled in the scope of this project and as make-up wells to supply additional geothermal fluid to Ribeira Grande power plant.

In Terceira island, a new high temperature geothermal field was identified in the central region of the island, as a result of the exploratory drilling of geothermal gradient holes that revealed a maximum temperature of 234ºC. A confirmation-drilling program is being planned with the objective to install a 12 MWe geothermal power plant to supply approximately 50% of the consumption needs of Terceira Island by the year 2008.

1. INTRODUCTION

According to the Portuguese Decree-Law n.º90/90, of 16th March, geothermal resources are “the fluids and underground geological formations, of high temperature, whose heat can be susceptible of utilization”. This definition is sufficient wide to cover all the modern utilizations of this energy.

Furthermore, Decree-Law n.º87/90 and n.º90/90, of 16th March, determine that geothermal resources belong to the public domain, but private companies and municipalities can apply for the right of exploration and exploitation, on the basis of a concession granted by the Ministry of Economy, or in the Autonomous Region of Azores by the Regional Secretariat of Economy. As for the mining industry, the exploration and exploitation of geothermal resources have to be carried out under the supervision of a “Technical Director”, generally a geologist or mining engineer, employed by the concessionaire and accepted by the Direcção Geral de Geologia e Energia (DGGE), the governmental agency in charge of all mining and oil development as well energy subjects in Portugal, or in The Azores by the regional authorities.

Main governmental agencies involved in geothermal are: (i) DGGE, as regulator of overall activity, as well mineral water and bottled water industry, (ii) INETI, the National Institute for Technology and Innovation, very active in the field of renewable energy, (iii) AGENE, Agency for Energy and, (iv) CEDINTEC, a public institute active in the promotion of new technologies.

Some national and EU financial tools allow founding of public and private geothermal operations. In some cases and locations the financing measures can cover up to 75% of the investment. However there are not instruments to cover the mining risk.

Research on geothermal and thermo-mineral resources is carried out by several Universities as: i) University of Azores, Ponta Delgada, Azores, ii) Instituto Superior Técnico, Lisbon, (iii) Évora University, Évora, (iv) UTAD, Vila Real, (v) Coimbra University, Coimbra, (vi) Universidade do Minho, Braga, and (vii) Oporto University.

A few small Portuguese private companies are involved in the geothermal market with ability for carrying out: (i) feasibility studies, (ii) geothermal resources prospecting and evaluation including drilling up two 1500 m, and, (iii) consultancy.

In the Azores, exploitation of geothermal resources for electric power generation has been developed successfully on the largest and most populous island, São Miguel, since 1980, by SOGEO - Sociedade Geotérmica dos Açores, S.A., an affiliated company of the regional electric utility EDA – Electricidade dos Açores, S.A. Expansion of the generation capacity in the 1990’s to 16 MWe has led to the present situation, in which geothermal supplies about 25% of São Miguel’s electrical energy needs. The generation results during over two decades classify geothermal as secure and reliable energy source that typically satisfies the base-load demand. Compared with other renewable energy sources, geothermal production holds a leading position and provides an important contribution to the energy autonomy of the Azores region. With the objective of installation of a geothermal power station of about 12 MWe capacity in Terceira island, a new company was established, GeoTerceira – Sociedade Geoeléctrica da Terceira, S.A., inside EDA group.

The governmental policy for power generation in the Azorean archipelago is focused in the development of new geothermal projects to support the strong growth of the demand rate (over 8%) and therefore is expected that by 2008 the present geothermal generation capacity will be duplicated, representing an investment of approximately 60 million Euros.

As it can be seen in Table 1, the electrical production from geothermal energy in Portugal is modest considering: (i) the overall consumption on the entire country; and (ii) the fact that high enthalpy geothermal resources are restricted to the Azores Archipelago.

2. GEOLOGY AND HYDROGEOLOGY BACKGROUND

As represented in fig 1 the Portuguese mainland is composed by the following geological units: (i) Pre Mesozoic Variscan basement, (ii) Western and Southern Meso-Cenozoic borders, and (iii)Ceno Antropozoic basins of Tejo and Sado rivers.

The following geotectonic zones are generally considered part of the Variscan Massif: (i) Central Iberian zone including the Middle Galicia-Trás os Montes domain, (ii) Ossa-Morena zone and (iii) South-Portuguese zone.

From the lithological point of view, main rocks are granites of the Variscan orogeny and metasediments pre and post orogenic. Weathering is quite irregular depending on tectonics and present and past climates. Average reported depths to sound rock ranges from 0 to 60 m but in the vicinity of main tectonic axis it is not infrequent to drill up to 300 m of weathered rock.

Most Portuguese thermo-mineral water of hard rock origin comes from the Central Iberian zone. As pointed out by Ribeiro and Almeida (1981) this could not be a simple inheritance of the historical geology. Another factor plays an important role in the productivity and distribution of springs: the recharge conditions which are largely higher in the northwestern area of Portugal.

The average annual rainfall (P) reaches 1811 mm in this area, but these figures decrease to less than 600 mm in some eastern and southern regions, the average annual rainfall for the entire country being 917 mm. About 55% of precipitation is lost by evapotranspiration. Average air temperature is about 15ºC, but the winter season is severe in the northern areas.

The infiltration (I) has values ranging from 20 to 135 mm. Carvalho et al. (2000) studied the recharge over the Central Iberian Zone and found an average Rate of Infiltration (I/P) of about 17%.

As expected, tectonics (and particularly active structures, for thermal waters, in a geological sense) is closely related to the occurrence of thermal springs. The distribution of mainland users of geothermal energy is superimposed at fig 1 with tectonic data from Cabral (1995). It is clear that thermal anomalies follow axis trending NNE, NW and ENE along the main active faults.

Naturally available discharging flows from former exploitation systems range from a few m3/d to 10 l/s. In general, with new-drilled wells, it has been possible to increase former production. However, for the running exploitation, and considering real needs and/or environmental constraints, exploited yield is normally under the maximum permitted by hydrodynamics of the aquifer and tube wells.

Temperature of occurrences goes up to 76ºC. Among Portuguese mineral waters twenty-eight discharge with temperatures higher than 25ºC and are used for balneological purposes. Ten of those springs reach over 50ºC.

Other thermal springs occur al over the Northern area of Portugal and at the Sedimentary Basins. Anon (1998) identifies 52 springs with temperatures higher than 20 ºC. They are not considered in this synthesis by two reasons: (i) modest productions and temperature and (ii) no recognized official utilization in balneology or other uses.

Typical cold mineral waters, in a geological sense, could be present a few kilometres away over the same structure. This is the case of the so-called Verin-Régua-Penacova fault where cold and hot mineral waters (15 to 76ºC) of the same chemical composition are so close at surface, as 10 km, Carvalho (1995 and 1996a).

Regarding chemistry, the following groups could be considered at the Variscan Massif: (i) hypo-saline waters with Total Dissolved Solids (TDS) less than 150 ppm, frequently, under 50 ppm. This group corresponds mainly to water circulating in depth in quartzite reservoirs, (ii) sulphurous waters with up to 1000 ppm and temperatures up to 62ºC, and (iii) carbonated waters with TDS up to 2500 ppm and temperatures up to 76ºC.

The sedimentary borders composed of sequences of post Palaeozoic sediments with thickness up to 4000 m also present several thermal waters related to deep faulting and diapiric tectonics. These waters are generally of the sodium chloride type and temperature from 20 to 40 ºC.

Synthesis of the Portuguese geological conditions related to geothermal conditions is available in Aires-Barros and Marques (2000), Costa and Cruz (2000), Carvalho (1995, 1996b; 1998), and Carvalho et al. (2004).

The Azores archipelago, Fig 2, consisting of 9 inhabited islands of volcanic origin, is located in a complex geotectonic setting associated with the triple junction point of the North American, Euro-Asian and African plates. Since the 15th century, over 30 volcanic eruptions were registered inland and close to the shore, the last occurring a few miles west of Terceira island in 1998 – 2000. Present volcanic activity is restricted to thermal springs and fumarolic fields in the islands of São Miguel, Terceira, Graciosa, Faial and Pico.

At Madeira Islands, mid-way to Canary Islands, recent work carried out by Fonseca et al (2000) and Forjaz (2001) identified a small low temperature geothermal occurrence inside a tunnel at Vale de S. Vicente. Some recent strombolian cones suggest the possibility for geothermal anomalies.

3. GEOTHERMAL RESOURCES AND POTENTIAL

As previously stated, geothermal resources are closely related with volcanic activity in Azores Islands and active faulting and diapirism in mainland Portugal, as represented in Figures 1 and 2.

Currently in the Azores, is under exploitation the Ribeira Grande Geothermal Field which conceptual model has been described by GeothermEx (1996), Cabeças et al. (2001) and recently updated by GeothermEx (2002). Geothermal fluids in excess of 250ºC originate at depth near the summit area of the Fogo volcano and, above an elevation of -1,000 m, the fluid moves laterally to northwest in an extensive zone at least several hundred meters thick, in which temperatures exceed 220ºC. The boundaries of the system are likely related to a NW-trending pattern of faulting created by the regional tectonic stress regime. The reservoir fluid is a fairly typical geothermal water of sodium - chloride type, with high alkalinity and low Ca with TDS of about 6-7 g/l. Isotopic analysis indicate that liquid in the reservoir lies close to the expected composition of meteoric water, with only a small positive shift of 18O caused by water-rock isotope exchange, which is usually interpreted to signify that the geothermal system has a relatively high water-rock ratio, with little to no magmatic water component. Although the reservoir fluid is predominantly liquid water, boiling occurs and forms a steam or two-phase zone at the top of the reservoir in some sectors of the field.

The recoverable energy reserves of Ribeira Grande Geothermal Field were estimated by GeothermEx, Inc. (1996) using the volumetric reserve estimation introduced by the United States Geological Survey, combined with a probabilistic approach (Monte Carlo simulation), that indicated that the most likely capacity is about 90 MWe.

In Terceira island, after a series of previous exploration studies held from the 1970’s to the early 1990’s, an exploration program has been developed recently by GeoTerceira that included a detailed geoelectrical survey with a total of 624 AMT stations and 9 MT stations and the drilling of 4 intermediate-depth temperature observation wells, to observe directly the temperature gradient produced by the geothermal system. The AMT survey executed in 2000 revealed a large conductive zone trending NW-SE that has been interpreted as the result of hydrothermal alteration of original rocks to hydrated clay minerals near the top and lateral margins of the geothermal reservoir. The temperature gradient drilling program, developed between July 2003 and April 2004, allowed estimating confidently that deep temperatures exceeding 200ºC should be present over a substantial area. In one of the temperature observation wells a convective profile in the bottom interval and a maximum measured temperature of 234ºC demonstrate the presence of a high-temperature geothermal reservoir.

As a result of these investigations a new high-temperature geothermal field was identified, the Pico Alto geothermal field (Henneberger et all 2004), and have provided the information needed to proceed with confirmation drilling, having reduced exploration risk to an acceptable level. The presence of high temperatures over a substantial area and the direct evidence of convective fluid movement provide strong encouragement that commercial development of a geothermal project at Pico Alto of the size considered by GeoTerceira may be feasible.

Considering the abundant surface manifestations of hydrothermal activity, it is reasonable to consider that the geothermal potential of the Azores is significant and, on at least several of the islands, there is potentially exploitable geothermal energy for power generation. However, extensive exploration studies for evaluation of geothermal resources potential are limited to the islands of São Miguel and Terceira, where technical-economical feasibility of geothermal power projects is easily demonstrated (Ponte 2002a, 2202b; Ponte & Cabeças 2003). Further investigations in other areas, including a variety of surface studies and drilling activities, are required for a complete and accurate assessment of the capacity for power generation of the islands of the Azores.

A few thermal springs with temperature up to 92 ºC occur in almost all the Islands (cf Fig 2) but the existing spas are restricted to the Islands of S. Miguel, Graciosa and Faial (Table 3). A Governmental project for the evaluation of these resources and other hot spots revealed by ground water prospecting wells is in due course, under the control of INOVA, the local agency for innovation.

In Mainland Portugal, classical geothermal resources are generally associated to the following origins: i) thermo-mineral waters related to active faulting and diapirism, and

ii) Deep circulation in some peculiar structures in the basement (quartzite strata) and particularly in the sedimentary borders trough permeable formations. The existing temperatures restrain the utilization to direct uses.

Main geothermal resources - thermo-mineral springs - related to faulting in the Variscan basement and diapirism in the sedimentary borders are indicated in Table 3.

From these origins the total available capacity is of the order of 24 MW(t), about 20,4 MW(t) if considering only the Variscan Massif. These capacities refer to an outlet temperature of 20 ºC.

In the sedimentary borders deep aquifers are known as in the Lisbon area where a 1500 m deep well taped Cretaceous sandstones with 53-ºC-bottom hole temperature (BHT) This well supplied the Air Force Hospital geothermal project in operation since 1992 till 2002 with drinkable water with 500 mg/l TDS and temperature of 49ºC.

Oil wells in the Tejo and Sado basins (Carvalho et all 1990) suggest temperatures of 75 ºC at 2500 m in Jurassic limestone with 5 000 ppm TDS water.

The higher geothermal gradient is about 3,5 ºC/100 m (Anon, 1998a). Normal gradients are in the range of 2,1 ºC/100m (Ribeiro and Almeida 1981). That means average BHT of ca 50 ºC at 1500 m depth.

Regarding the utilization of shallow aquifers with Geothermal Heat Pumps a study was undertaken in 1997 by a EU Dissemination Project aiming “to promote the use of geothermal energy from proven aquifers and match this energy to existing or potential heat users”, Anon (1998b).

In Portugal 63 wells with capacities in excess of 20 l/s were chosen. For these wells the calculated energy at the local conditions is about 5TWh(t). The study within this Dissemination Project of several thousand of wells up to 700 m deep in the sedimentary basins delivered the following equation for the estimation of the temperature in a given depth in the Portuguese Sedimentary Borders:

$$T(ºC) = 0{,}021 \times \text{Depth (m)} + 17{,}66$$

This linear regression model confirms an average geothermal gradient of 2,1 ºC/100 m with an average shallow groundwater temperature of 17,7 ºC.

According to Correia et al (2002) the regional heat flow density (HFD) is about 60-90 mW/m2 in the Variscan Massif and 40-90 mW/m2 in the sedimentary basins.

4. GEOTHERMAL UTILIZATION

Current utilisation of geothermal energy for electric power generation, direct use and geothermal heat pumps is presented in Tables 2, 3, 4 and 5.

4.1 Electrical Power generation

In the Azores islands, where high enthalpy geothermal resources are present, the contribution of geothermal energy for power generation possesses an important strategic and economic role in the increase of the power self-sufficiency of this remote archipelago. SOGEO - Sociedade Geotérmica dos Açores S.A. owns a concession for exploitation of high enthalpy geothermal resources in the northern flank of the Fogo volcano, in São Miguel island, and operates two geothermal power plants – Ribeira Grande and Pico Vermelho - with a combined capacity of 16 MWe, that produce approximately 90 GWh.

The geothermal plant located at Pico Vermelho was installed in 1980. It uses a Mitsubishi back-pressure steam turbine integrated in a single-flash system, with a rated capacity of 3 MW. This plant never produced more than 0,8 MW, because of insufficient supply of steam from the slim-diameter well PV1, which was drilled as an evaluation well. In the Pico Vermelho sector of the geothermal field there are two other wells: PV2, drilled in 1980 with technical characteristics similar to PV1, and well PV3, drilled in 2000 with a large-diameter production interval. Presently, SOGEO is preparing to replace the existing generation equipment with new units with a maximum overall capacity of 10 MW, and to drill a fourth production well and two reinjection wells to receive the liquid effluent of the power plant.

The Ribeira Grande Geothermal Power Plant consists of four Ormat dual turbo-generators developed in two phases: Phase A (2 x 2,5 MW) installed in March 1994, and Phase B (2 x 4 MW) completed in November 1998; and related auxiliary equipment, namely transformers, switching gear, an emergency diesel generator, a fire-fighting system and a connection line to the transmission grid. There are four geothermal wells producing fluid to the plant and one injection well to receive the liquid effluent.

The maximum contribution of geothermal source of over 35% was achieved in 2001, but the strong growth of the demand rate and the natural decline of geothermal wells reduced its contribution to about 25% of the electrical consumption of the island.

4.2 Direct heat uses

Direct use application in Mainland and Azores is restricted to small district heating operations, green house heating and mainly balneological applications

4.3 District heating

Main operations:

Chaves, Northern Portugal: a dedicated well, 150 m deep, 76 ºC, TDS of 2500 mg/l, 5 l/s capacity, drilled in metamorphic slates with quartz veins, is used in a small district heating network (swimming-pool, hotel and a green house). The greenhouse operation is practically abandoned. An independent well (100 m deep, 73 ºC, TDS of 2500 mg/l, 10 l/s capacity, also drilled in metamorphic slates with quartz veins, feeds the thermal bath. A cooling tower is needed to cool part of the water to be used in the spa.

The geothermal field is the heart of the town. A project aiming to create a geothermal district-heating network comprising the main local users is in the stage of feasibility study.

S. Pedro do Sul, central Portugal, the main Portuguese Spa: one inclined well, 500 m deep, 350 mg/l TDS, 10 l/s artesian flow, 69 ºC drilled in fractured granite, supply the Bath and is in use in a small heating operation in two hotels, further extension being under study.

Lisbon Air Force Hospital: An well 1500 m deep in Cretaceous sandstone, 49 ºC, 5 l/s, 500 mg/l TDS, supplied from 1992 till 2002 the entire hot tap water production and the heating of part of the hospital. Drinkable water was also produced, the favourable pay back period resulting from al savings. The operation is not running since 2002 due to the well collapse apparently connected with an important increment on the water salinity.

4.4 Greenhouse heating

The most successful are:

S. Pedro do Sul (Vau): two km south of São Pedro do Sul Spa two angle wells up to 216 m were drilled in granitic rocks after an extensive program of geothermal exploration including geological mapping, geophysics and radon measurements. 10 l/s of 68 ºC, 350 mg/l TDS is used in a 2ha greenhouse producing tropical fruits (mainly pineapple).

São Miguel, Azores: 6 x 200 m2 demonstration greenhouses from INOVA are heated with the geothermal effluent of Pico Vermelho Geothermal power plant. 5 l/s at 90 ºC is used in a scheme using an heat exchanger to avoid incrustation problems.

4.5 Bathing and Swimming

Balneological activities using termo-mineral waters are quite popular in Portugal for cure and tourist purposes. Main spas, operating within a legal framework, are indicated in Table 3. Most are open only in summer, but some of them are operating normally all over the year. All the balneological activity inside the spas is carried out under strict medical control.

Recently the Azores Government decided to undertake the study on the possible utilization of the geothermal effluents of São Miguel Island for direct use including touristic activities and balneology.

4.6 Geothermal heat pumps

One single operation of geothermal heat pump is known in Portugal (nº 31 SSFA of Table 3). It is not operating because the well is out of service with water salinity problems and reduced specific capacity.

5. DISCUSSION

Geothermal energy is in the Azores an abundant, secure, reliable energy source that is considered the first option within renewable energies to increase the power self-sufficiency. Since 1994 that geothermal power production has been developed successfully, achieving its maximum production in 2001 (Figure 3). The new projects under preparation by SOGEO and GeoTerceira are expected to triplicate the power production from geothermal resources by 2008, to approximately 275 GWh/year. Investments in these projects are estimated on 60 million euros.

In Mainland geothermal activity is practically restricted to balneological uses. A few direct-use projects are representative of further operations but replicability potential is limited by tradition, mild climate and possibly low energy costs.

The level of allocation of personnel and Investment is quite modest as reported in Table 7 and Table 8.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

The geothermal projects planned for the coming years include the installation of a 12 MW power plant on Terceira Island and the expansion of the Pico Vermelho Geothermal Power Plant to 10 MW on São Miguel island. The electricity demand of the other islands of the archipelago is insufficient to support geothermal power plants of large enough capacity to justify their development.

The replacement of the Pico Vermelho Pilote Power Plant (3 MWe) by new generation units with a total capacity of 10 MWe will boost the geothermal production in São Miguel by the year 2006, together with the drilling of make-up wells to supply additional fluid to Ribeira Grande Power Plant.

In the island of Terceira, the final stage of exploration comprising the drilling of evaluation wells is carried on during 2005, after the promising results of the exploratory drilling of geothermal gradient holes that shown a maximum temperature of 234ºC. The project, owned by GeoTerceira – Sociedade Geoeléctrica da Terceira, S.A., consists in a 12 MWe geothermal power plant to supply approximately 50% of the consumption needs of Terceira Island by the year 2008.

The new projects estimated in approximately 60 million euros are expected to triplicate the present geothermal power output to 275 GWh by 2008, representing over 30% of the electrical energy needs of the Azores islands.

In Mainland there are no governmental projects for developing geothermal. However, some improvements, financed by EU founds, are expected in a few spas concerning drilling at greater depths and the execution of small direct use projects. These attempts are limited by mining risk, not covered by the local funding measure for renewable energy (MAPE).

A dozen of geothermal feasibility studies carried out for several promising sites (including spas) demonstrate that the development of projects with pay-back period up to 10 years is normally possible, the local consumers being not enough to exhaust the resource or endanger the existing bathing industry (Carvalho et al., 2002).

There is no local tradition on the utilization of reversible Geothermal Heat Pumps (GHP) for heating and cooling which is quite disappointing considering the favourable local conditions. Carvalho et al (2002) suggested several measures to disseminate these applications at an appropriate level; however no attempts are known to pursue this policy.

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TABLE 1. Present and planned production of electricity (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (wind+biomass+photovoltaic)		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 2004	16	90	n.a	29000	4880	15230	0	0	450	1254	n.a	45574
Under construction in December 2004	10											
Funds committed, but not yet under construction in December 2004												
Total projected use by 2010	35	275	n.a	n.a	n.a	n.a	0	0	3674	10109	n.a	n.a

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

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Annual Energy Produced 2003 GWh/yr	Total under Constr. or Planned MWe
Azores	Pico Vermelho	1980	1		1F	3	7	
Azores	Ribeira Grande (Phase A)	1994	2		B	5		
Azores	Ribeira Grande (Phase B)	1998	2		B	8	83	
Azores	New Pico Vermelho	2006	?		?			10
Total			5			16	90	10

TABLE 3. Utilization of geothermal energy for direct heat as of 31 December 2004 (other than heat pumps)

I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

Locality	Type	Maximum Utilization					Capacity	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy (kJ/kg)			Ave. Flow	Energy	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor
1 Monção	B	10,0	50	20			1,26	4,0	15,8	0,40
2 Chaves	B+D+G	15,0	76	20			3,52	11,0	81,3	0,73
3 Caldelas	B	9,3	33	20			0,51	4,5	7,7	0,48
4 Gerês	B	0,9	47	20			0,10	0,8	2,8	0,89
5 Taipas	B	7,3	32	20			0,37	2,0	3,2	0,27
6 Caldas da Saúde	B	4	30	20			0,17	3,0	4,0	0,75
7 Vizela	B+D	3,8	62	20			0,67	2,5	13,8	0,66
8 Carlão	B+G	0,5	29	20			0,02	0,5	0,6	0,99
9 S Lourenço	B	2,0	30	20			0,08	1,0	1,3	0,50
10 Canaveses	B	0,7	35	20			0,04	0,4	0,8	0,58
11 Moledo	B	19,1	45	20			2,00	4,0	13,2	0,21
12 Aregos	B	7,5	62	20			1,32	4,0	22,2	0,53
13 Carvalhal	B	6,0	58	20			0,95	0,3	1,5	0,05
14 Cavaca	B	1,3	29	20			0,05	0,0	0,0	0,00
15 São Pedro do Sul	B+D+G	19,4	69	20			3,97	9,0	58,2	0,46
16 Alcafache	B	5,9	51	20			0,77	4,0	16,4	0,68
17 Sangemil	B	6,5	50	20			0,82	4,0	15,8	0,61
18 Felgueira	B	5,7	36	20			0,38	4,0	8,4	0,71
19 Luso	B	5,4	27	20			0,16	2,0	1,8	0,37
20 Manteigas	B	5,5	48	20			0,65	3,0	11,1	0,54
21 Unhais da Serra	B	10,2	37	20			0,72	5,0	11,2	0,49
23 Monfortinho	B	36,0	31	20			1,66	4,0	5,8	0,11
25 Piedade	B	6,0	27	20			0,18	2,0	1,8	0,33
26 Caldas da Rainha	B	15,0	34	20			0,88	13,0	24,0	0,87
27 Vimeiro	B	15,0	26	20			0,38	2,0	1,6	0,13
28 Cucos	B	10,4	40	20			0,87	5,0	13,2	0,48
30 Air Force Hospital	D	5,0	49	20			0,61	0,0	0,0	0,00
31 SSFA Oeiras		5,9	30	20			0,25	0,0	0,0	0,00
33 Monchique	B	7,0	31	20			0,32	3,0	4,4	0,43
34 Longroiva	B	8,3	44	20			0,83	2,5	7,9	0,30
Azores Islands										
INOVA (S. Miguel)	G	5,0	90	20			1,46	4,2	11,15	0,24
Furnas (S. Miguel)	B	5,0	92	20			1,51	2,5	23,8	0,50
Ferraria (S. Miguel)	B	20,0	55	20			2,93	0,0	0,0	0,00
Carapacho (Graciosa)	B	0,5	42	20			0,05	0,2	0,6	0,40
Varadouro (Faial)	B	2,0	40	20			0,17	0	0,0	0,00
TOTAL							30,6		385,33	0,40

TABLE 4. Geothermal (ground-source) heat pumps as of 31 December 2004

Locality	Ground or water temp. (°C)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type	COP	Heating Equivalent Full Load Hr/Year	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
29-SSFA-Oeiras	30		1	W			0	
	Obs: Out of service							
TOTAL							0	

TABLE 5. Summary table of geothermal direct heat uses as of 31 December 2004

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr = 10^{12} J/yr)	Capacity Factor
Individual Space Heating			
District Heating	1,47	12,93	0,28
Air Conditioning (Cooling)			
Greenhouse Heating	1,79	13,84	0,25
Fish Farming			
Animal Farming			
Agricultural Drying			
Industrial Process Heat			
Snow Melting			
Bathing and Swimming	27,09	358,56	0,42
Other Uses (specify)			
Subtotal	30,35	385,33	0,40
Geothermal Heat Pumps	0,25	0	0,00
TOTAL	30,6	385,33	0,40

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)	4				2,200
Production	>150° C	2				2,270
	150-100° C					
	<100° C			2		1,000
Injection	(all)					
Total		6		2		5,470

TABLE 7. Allocation of professional personnel to geothermal activities (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	1	3	9			1
2001	1	4	9			1
2002	2	4	9			1
2003	2	5	9			1
2004	2	6	9			1
Total	8	22	45			1

(1) – Government (2) – Public Utilities (3) –Universities

(4) – Paid Foreign Conmetants (5) – Foreign Aid Programs (6) – Private Industry

TABLE 8. Total investments in geothermal in 2004 (US$)

Period	Research & Development Incl. Surface Explor. & 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						
1995-1999						
2000-2004	2,5	6,4	0,25	8,5	50	50

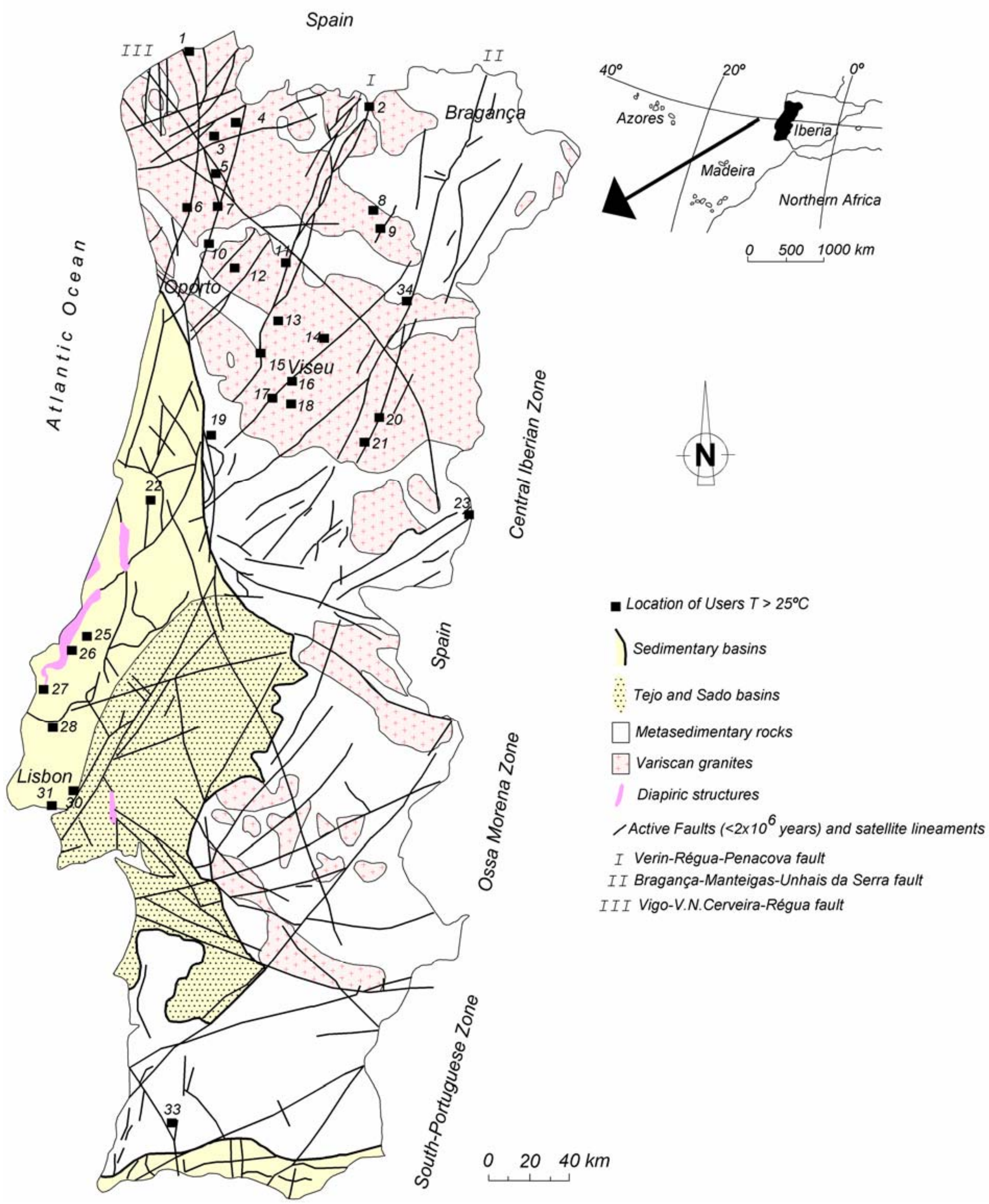

Figure 1 –Users of geothermal energy for direct heat in Portuguese Mainland

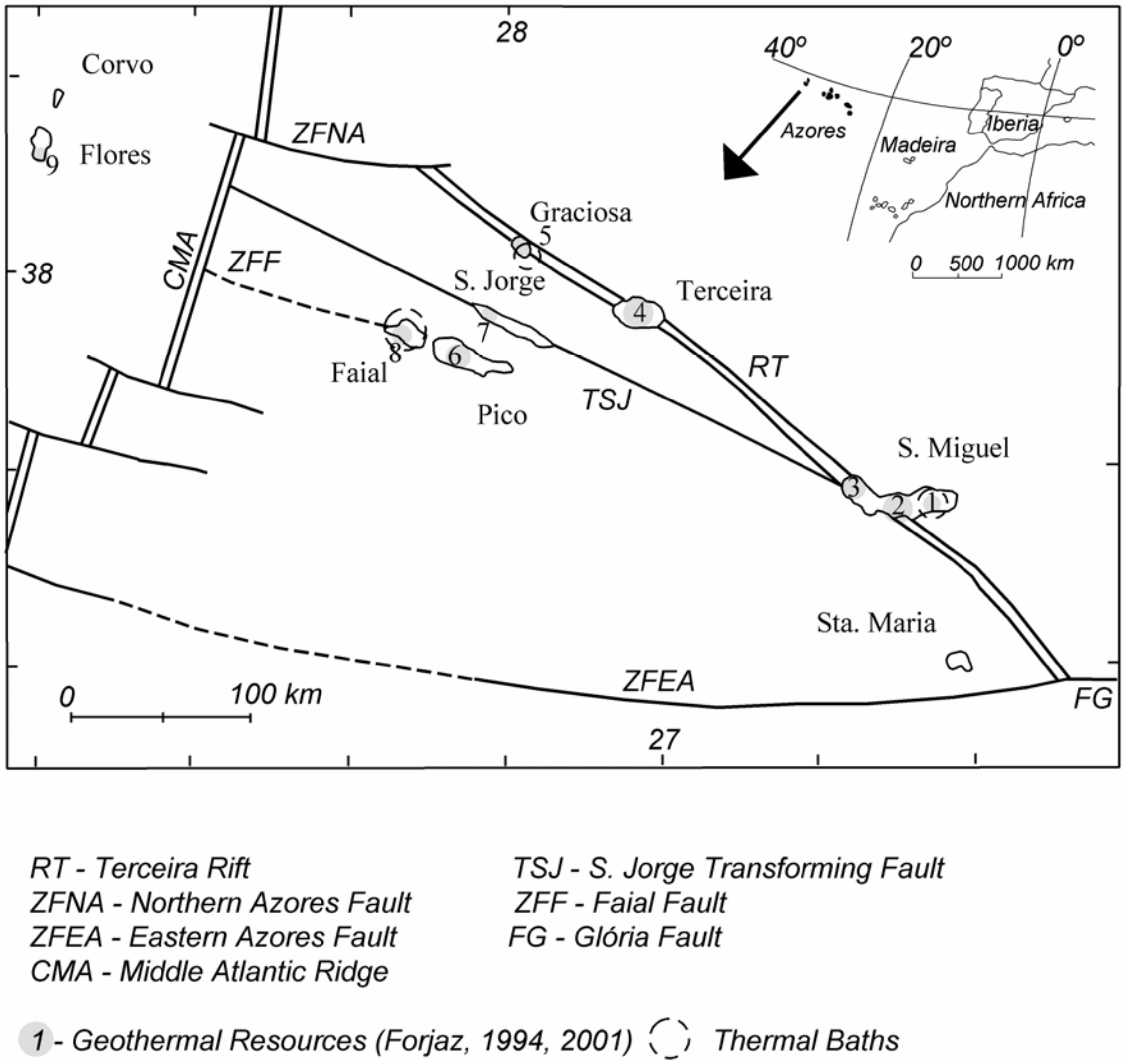

Figure 2 – Location of geothermal manifestations at Azores (adapted from Nunes 1991)

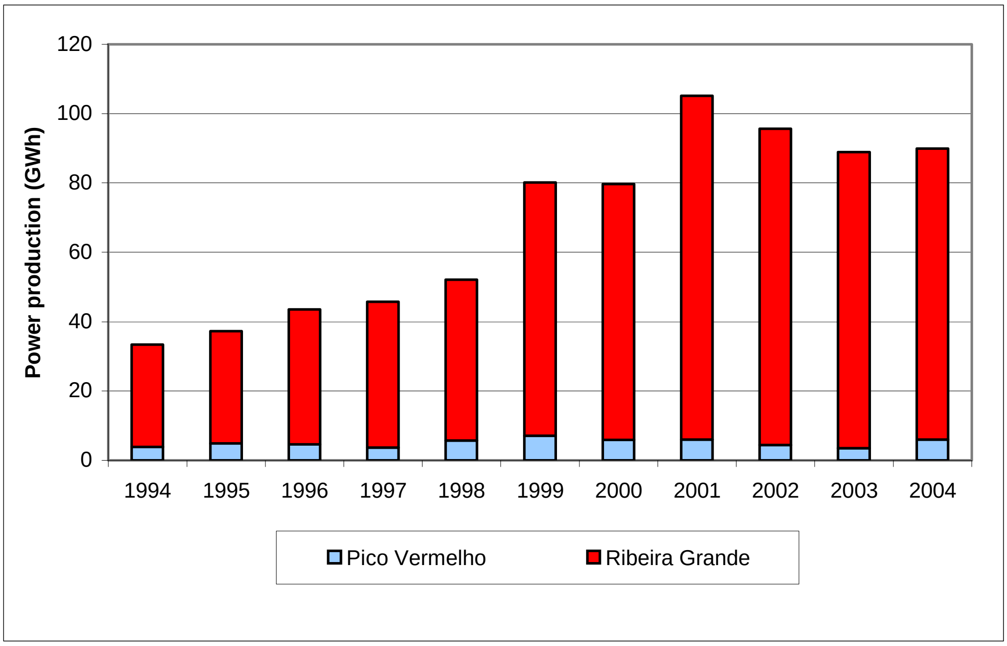

Figure 3– Electric power generation from geothermal resources in the Azores (1994 – 2004)