Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

PORTUGAL COUNTRY UPDATE

Luís Aires-Barros [1] and José Marques [1]

[1] Instituto Superior Técnico. Laboratório de Mineralogia e Petrologia (LAMPIST).
Av. Rovisco Pais, 1049-001 Lisboa , Portugal. Fax: + 351 21 8400806. E-mail: pcd2045@alfa.ist.utl.pt

Key-words : Portugal, geothermal energy, direct uses, power generation.

ABSTRACT

In the Portuguese mainland Chaves and S. Pedro do Sul springs, in the northern part of the country, contain the hottest waters (76ºC and 69ºC, respectively). Their applications are restricted to space heating, greenhouse heating, bathing and swimming. Near Lisbon, a 1500m deep single well was drilled. Bottom hole temperature is 53ºC and this water has been utilized for heating the Air Force Hospital. In the Azores islands geothermal energy is used for the production of electricity and greenhouse heating. There are three power stations at Pico Vermelho and Ribeira Grande geothermal fields: a 3MWe back-pressure unit in the northern sector of the area, a 5MWe binary plant (2 x 2.5 MWe units) in the central sector, and an 8 MWe binary plant (2 x 4 MWe units) in the northern sector.

1. INTRODUCTION

In Portugal geohydrological studies have increased considerably in the last two decades. Some of the projects have already passed the feasibility phase and currently some spa hotels and swimming pools (for public use) are being heated, in the northern part of the country, with heat extracted from the same hot water that is used for the spas activities.

In the Portuguese mainland, there are about fifty natural low enthalpy geothermal occurrences spread all over the country. Temperatures range from 20°C to 76°C, however, most of these occurrences have temperatures between 20°C and 40°C. Their geographical distribution is not uniform throughout the country. The most important geothermal occurrences are located in the northern part of Portuguese mainland. Most of the thermal waters flow in the Pre-Mesozoic Hesperic Massif (Figs. 1 and 2) associated with granitic and schistose rocks and are related to local and regional fault systems. The thermal occurrences issuing in the Western and Southern Sedimentary Borders (Figs. 1 and 2) display lower temperatures but have higher water flows and total dissolved solids than those from the Hesperic Massif (Carvalho, 1998).

In the Azores islands a large number of active volcanic manifestations are well known, justifying the considerable rise in geothermal investigations. The program on São Miguel Island has resulted in a pilot geothermal generator plant producing 20-25% of the island requirement (Bicudo da Ponte, 1998). Average temperature of the reservoir is 240ºC at 1200 m and the well-head temperature is about 200ºC (Carvalho, 1998).

2. THE GEOLOGY OF PORTUGUESE MAINLAND VS GEOTHERMAL OCCURENCES

On the Portuguese mainland the geology can be divided into three main geological and units (Fig. 1):

i) the Pre-Mesozoic Hesperic Massif, part of the Hercynian basement,
ii) the Western and Southern Meso-Cenozoic borders and
iii) the Tejo and Sado Ceno-Antropozoic basins.

2.1 The Pre-Mesozoic Hesperic Massif

Geothermal occurrences in the Hesperic Massif are confined to low enthalpy fluids and their occurrences are represented mainly by thermal springs. Exploitation of these geothermal reservoirs is mainly related to the spa business. The structural, lithological, geomorphological and climatic characteristics of the northern part of the Hesperic Massif favor the existence of deep fractured reservoirs with localized permeability (Carvalho, 1995). Thermal anomalies follow axis trending NNE, NE and ENE along the main active faults (Cabral and Ribeiro, 1988; Calado, 1991). Portugal Ferreira *et al* (1984) discussed the nature of mineral waters with respect to geochemistry and local and regional tectonics. Most of the Hesperic Massif thermal waters are associated with granitic rocks of Hercynian age. Natural discharge ranges from a few m^3/day to 800 m^3/day. However, in some cases, with new drilled wells, it has been possible to increase the production. Sometimes, cold mineral waters are present a few kilometers away over the same structure. An example is the Verin-Chaves-Penacova fault where cold and hot CO_2-rich mineral waters (15ºC to 76°C) with the same chemical composition (HCO_3 - Na) are located within 10 km distance (Aires-Barros *et al*, 1998). The Chaves thermal waters have been utilized for spa treatments since the Roman settlement and today the geothermal fluid has been used, in a cascade arrangement, for swimming pools, hotels and greenhouse heating. At São Pedro do Sul area a development for direct use of low enthalpy (69°C) sulfurous (H_2S) HCO_3 - Na fluids for space and greenhouse heating is underway.

2.2 The Western and Southern Meso-Cenozoic borders

The geology of the Western and Southern Meso-cenozoic borders (Fig. 1) consists mainly of large sedimentary rocks (mainly limestone and sandstone rocks) with volcanic intrusions, dikes and extensive lava flows and tuffs. Its total thickness reaches 4000 m. The tectonic activity was complex originating with the development of NE graben structures and diapirism responsible for the deformation and structural complexity (Carvalho, 1998). Some of the thermal springs are in use for balneotherapy, but it is important to develop detailed geohydrological studies as in the Hesperic Massif. The average geothermal gradient measured in deep oil and water wells range from 2.2°C/100 m to 3.6°C/100 m over the anomalous areas.

In the Western Sedimentary Basin hot spring waters occur with temperatures ranging between 20°C and 40°C. Here, the highest water temperatures are mainly related to fault circulation or through deep-seated strata associated with the diapiric structures. In the other geological environments, underground flow paths tend to be not so deep, being well controlled by uniform horizontal pathways formed by relatively undisturbed sedimentary rocks. The discharge flows are generally higher than those of the Hesperic Massif. Most of the waters belong mainly to the sodium chloride bicarbonate facies and on a lesser degree to the calcium sulphate facies with a pH close to 7. The salt bodies have an important control on the chemistry of the waters, resulting in an increase in the TDS content that can reach 3400 mg/l, due to the very high content of sodium, chloride and sulphate ions. Near Lisbon, deep oil wells show the existence of a hot aquifer located in Aptian-Albian sandstones, at around 1500 m depth. Recently, a borehole has produced water at 53°C that was utilised for heating the Air Force Hospital.

In the Southern Sedimentary Basin the thermal waters belong mainly to the sodium bicarbonate or to the calcium bicarbonate facies. The Southern Basin is characterised by several flexural fault systems, from the northern border towards the sea. These flexural zones play an active role in the control of hot water occurrences, some of them issuing also in relation with evaporitic structures (Rodrigues da Silva *et al*, 1996).

2.3 The Tagus and Sado Ceno-Antropozoic basins

The Miocene and Pliocene sediments deposited in the basins of the Tagus and Sado Rivers are ,at most, 1400 m deep (Rodrigues da Silva *et al*. 1996). The basins are filled mainly with sandstones and limestones. The Tagus and Sado Ceno-Antropozoic basins are characterised by the existence of aquifers with extraction capacities up to 100 l/s/well (Carvalho, 1998). However, water temperatures do not exceed 32°C restricting their current use to water supply and, in the future, to very low enthalpy geothermal applications.

3. AZORES ISLANDS GEOLOGICAL FRAMEWORK vs GEOTHERMAL SETTING

The Azores archipelago involves nine islands associated with dead and active submarine volcanoes of basaltic origin. The Western islands (Corvo and Flores) are 500 thousand years old and are placed on the American Plate spreading from East (from the Middle Atlantic Ridge) to West. The other seven islands are located on the triple junction of the American, Eurasian and African lithospheric plates. This triple junction is a triangular shaped plateau called the Azores microplate (Forjaz, 1998). This microplate is crossed by West to East convergent oceanic deep faults that are connected (close to the surface) with WNW – ESE and NW – SE graben like structures. All of the Azores islands, with the exception of Santa Maria and Corvo islands, have thermal manifestations that can be considered as evidence of the possible existence of hydrothermal fluids. Thermal manifestations occur within calderas flanks of active volcanoes and associated tectonic structures. Temperatures as high as 200ºC were encountered at depths close of 600 m. The geothermal potential of the Azores was estimated by Forjaz (1997) at 228 MWe gross, distributed through the several islands and reservoirs as shown in Figure 3.

4. BATHING AND SWIMMING

At Chaves (northern Portugal) the Municipal Swimming Pool Geothermal Project has been in normal operation since 1982, including space heating and hot tap water production. Geothermal fluid is pumped from a 150 m deep well (AC2) at a temperature of 76°C. TDS of this fluid is about 2500 mg/l. This well, positioned about 200 m from thermal springs, was located and drilled in Silurian metasediments crossed by hydrothermal quartz veins. At S. Pedro do Sul (northern Portugal) spring water discharges of about 10 l/s at 68°C are also used for bathing and swimming (at the local Spas). The S. Pedro do Sul Spas are the most important in the country with about 20 000 registrations in 1998.

5. SPACE HEATING

The Geothermal Project of the Air Force Hospital in Lisbon has been running since the end of 1992. Pumped geothermal fluid is obtained at 53ºC and is treated to provide potable water. This is distributed all year round as hot tap water and in the heating season is supplied to a small district-heating network. Finally, cooled water from the heating process and/or treated geothermal water goes to a small cooling tower and is distributed as drinkable water (Carvalho, 1998). At Chaves (northern Portugal) geothermal fluids from the well AC2, which is at 60ºC after being used at the municipal swimming pool, is used to heat one of the local hotels (near the Chaves Spas). Heat exchangers are adjusted to meet heating requirements during the heating season (November to April).

6. GREENHOUSES

At São Miguel Island (Azores) six small greenhouses covering an area of about 200 m^2 have been constructed (Rodrigues, 1998). They have different heating schemes and soil types, which make it possible to experiment with several production technologies for windy and humid areas such as those of the Azores archipelago. Several crop varieties are grown in the greenhouse with very attractive results, including cape gooseberry, melon, and pineapple. This greenhouse complex is heated by geothermal fluid after utilization in the Pico Vermelho Geothermal Power Plant. Waste water from the neighboring geothermal power station is used at 90°C with a flow of 8 l/s. At São Pedro do Sul a 2 ha greenhouse, producing tropical fruits (mainly pineapple and banana), is installed. Here, the greenhouses are heated by geothermal water from the well SDV1 at 67ºC, with a flow rate of about 10 l/s. Water runs along the length of each greenhouse through plastic pipes positioned above and below the roof.

7. ELECTRICAL GENERATION

Portugal´s geothermal exploration and exploitation for electric power generation has been limited to Azores Islands. There are three power stations at Pico Vermelho and Ribeira Grande geothermal fields. A 3 MWe back-pressure unit is located in the northern sector of the area, a 5 MWe binary plant (2 x 2.5 MWe units) in the central sector, and an 8 MWe binary plant (2 x 4 MWe units) in the northern sector. In the next few years, these stations (16 MWe in total) will generate almost a quarter of the electricity in São Miguel island. However, since the estimated potential of the Ribeira Grande field is in the order of 80 MWe, other geothermal units (for an additional capacity of 25-30 MWe) are envisaged for construction in the first decade of the next century. The aggregate geothermal electric installed capacity in this field by 2010 (45-50 MWe) is therefore expected to meet 40 - 45% of the electrical demand of the island for that year (Bicudo da Ponte, 1998)

8. DRILLING ACTIVITIES

The Azores Geothermal Project started during 1976 and included geophysical and geochemical exploration, geothermometric drilling and evaluation-production wells up to 1500 m. Five wells were drilled at Ribeira Grande (RG1, RG2, PV1, SB1 and PV2) on the lower flanks of Agua de Pau volcano. They revealed the existence of a 225ºC - 235°C, liquid dominated Na Cl (8g/l) resource. Since 1986, four geothermal wells were drilled to 2000 m at Cachaço-Lombadas (CL1, CL2, CL3 and CL4), a geothermal area adjacent to Ribeira Grande. Average temperature in the reservoir was 240°C at 1200 m, with the well-head temperature being 200°C. Due to low productivity performances, well CL4 was tested for injection purposes (Trota, 1998). At Cachaço-Lombadas area another deep well (CL5) is programmed for production. The Geothermal Project of the Air Force Hospital in Lisbon has been running since the end of 1992. A 1500 m deep single well was drilled in 1987 with wellhead temperature of 53°C. At São Pedro do Sul geothermal field two angle cored wells (SDV1 - 216 m depth and SDV2 - 151 m depth) were drilled in granitic rocks in the Vau area. Well SDV1 has an artesian flow of 1.5 l/s with a temperature of 67°C. Final pumping tests showed that 10 l/s could be pumped. Another angle well (236 m depth) drilled in the Varzea area was unsuccessful. Recently, a geothermal well was drilled to 500 m depth in the Spa area. Artesian flow is about 10 l/s with a temperature of 68ºC. At Chaves geothermal field the Municipal Swimming Pool Geothermal Project has been in normal operation since 1982. The geothermal fluid is pumped from a 150 m deep well at a temperature of 76°C. This well is positioned about 200 m from another drilled well (100 m depth) which supplies the local spas with fluid at a temperature of about 70ºC.

ACKNOWLEDGMENTS

This work has been supported by the PRAXIS /PCNA/C/CTE/7/96 Project. The authors are indebted to Dr. Martins de Carvalho, Dr. Ferreira Gomes, Engº António Trota, Engº Henrique Simões dos Reis, Dr. Adolfo Rodrigues and Drª. Ana Catarina Rodrigues for supplying important data on some topics presented in this manuscript. John Lund critically read an early draft of this manuscript and we gratefully acknowledge his contribution.

REFERENCES

Aires-Barros, L., Marques, J. M., Graça, R. C., Matias, M. J., Weijden, C. H. van der, Kreulen, R. and Eggenkamp, H. G. M. (1998). Hot and cold CO_2-rich mineral waters in Chaves geothermal area (northern Portugal). *Geothermics*, Vol. 27 (1), pp. 89 - 107 .

Bicudo da Ponte, C. (1998). Geothermal electricity production at Azores. *Proceedings of the Seminar – Electricity production from geothermal energy*. International Summer School on Direct Application of Geothermal Energy. Published by Institute for Innovative Technologies of Azores (INOVA), pp. 1 - 5.

Cabral, J. and Ribeiro, A. (1988). Carta Neotectónica de Portugal Continental, escala 1:1.000.000. Serviços Geológicos de Portugal. Departamento de Geologia da Faculdade de Ciências de Lisboa, Gabinete de Protecção e Segurança Nuclear, Lisboa.

Calado, C. (1991). Carta de Nascentes Minerais 1: 1.000.000 Portugal. Atlas do Ambiente. Ministério do Ambiente e Recursos Naturais. Direcção-Geral de Recursos Naturais.

Carvalho, J. M. (1995). Low temperature geothermal reservoirs in the Portuguese Hercynian Massif. *Proceedings of the World Geothermal Congress 95*. Vol. 2, pp. 1343 - 1347.

Carvalho, J. M. (1998). Combination of different heat users: principles and Portuguese case studies. *1998 Course Text-Book on Economy of integrated geothermal Projects*. International Summer School on Direct Application of Geothermal Energy. Published by Institute for Innovative Technologies of Azores (INOVA). pp. 61 - 80.

Forjaz, V. H. (1997). *Alguns vulcões da Ilha de S. Miguel. I Parte.* Observatório Vulcanológico e Geotérmico dos Açores. 3ª Edição. 160 pp.

Forjaz, V. H. (1998). Azores geothermal reservoirs: an overview. *Proceedings of the Seminar – Electricity production from geothermal energy*. International Summer School on Direct Application of Geothermal Energy. Published by Institute for Innovative Technologies of Azores (INOVA). p. 2.2 – 2.8.

I.G.M. [Instituto Geológico e Mineiro] (1998). *Recursos geotérmicos em Portugal Continental. Baixa entalpia*. Direcção de Serviços de Gestão e Recursos Geológicos. Divisão de Recursos Hidrogeológicos e Geotérmicos. 23 pp.

Portugal Ferreira, M., Carvalho, J. M. and Mendonça, J. L. (1984). Águas Minerais na Zona Centro Ibérica-(Sector de Portugal): Metodologia, Tipologias. *I Congreso Español de Geologia.* Ass. Geol. Españoles. Madrid.

Rodrigues, A. C. (1998). Geothermally heated greenhouses at Ribeira Grande (Azores, Portugal). *Proceedings of the Workshop – Heating greenhouses with geothermal energy*. International Summer School on Direct Application of Geothermal Energy. Published by Institute for Innovative Technologies of Azores (INOVA). pp. 433 - 441.

Rodrigues da Silva, A. M., Cruz, J., Lourenço, M. C. and Ramalho, E. C. (1996). Low and very low enthalpy geothermal resources in mainland Portugal. *Geothermal Resources Council Transactions,* Vol. 20, pp. 159 - 164.

Trota, A. N. (1998). Injection tests on Ribeira Grande geothermal field. *Proceedings of the Seminar – Electricity production from geothermal energy*. International Summer School on Direct Application of Geothermal Energy. Published by Institute for Innovative Technologies of Azores (INOVA). pp. 9.2 - 9.13.

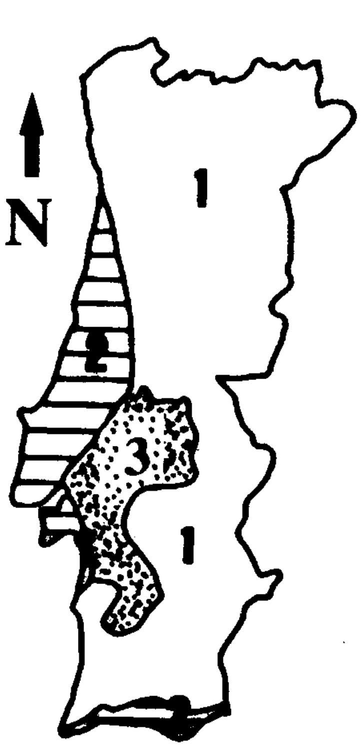

Figure 1. Main geological units of Portuguese Mainland. (1) Pre-Mesozoic Hesperic Massif ; (2) Western and Southern Meso-Cenozoic borders; (3) Tejo and Sado Ceno-Antropozoic basins.

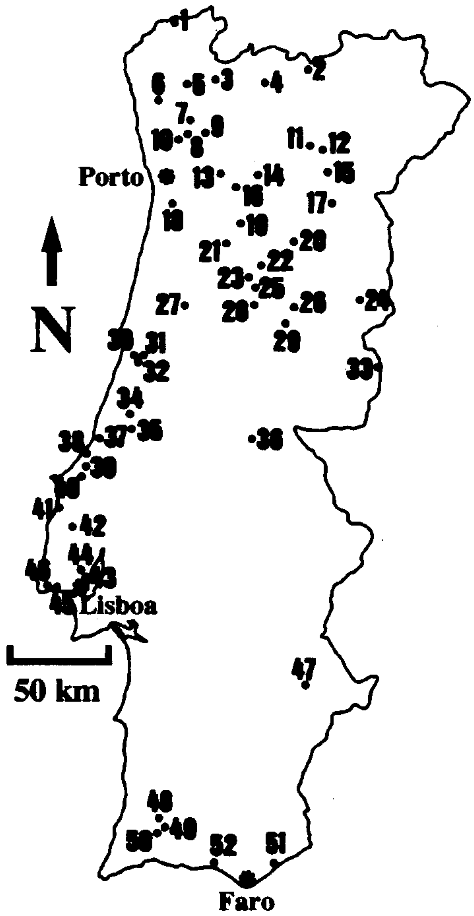

Figure 2. Thermal water sites (T > 20ºC) on Portuguese Mainland (adapted from IGM, 1998).

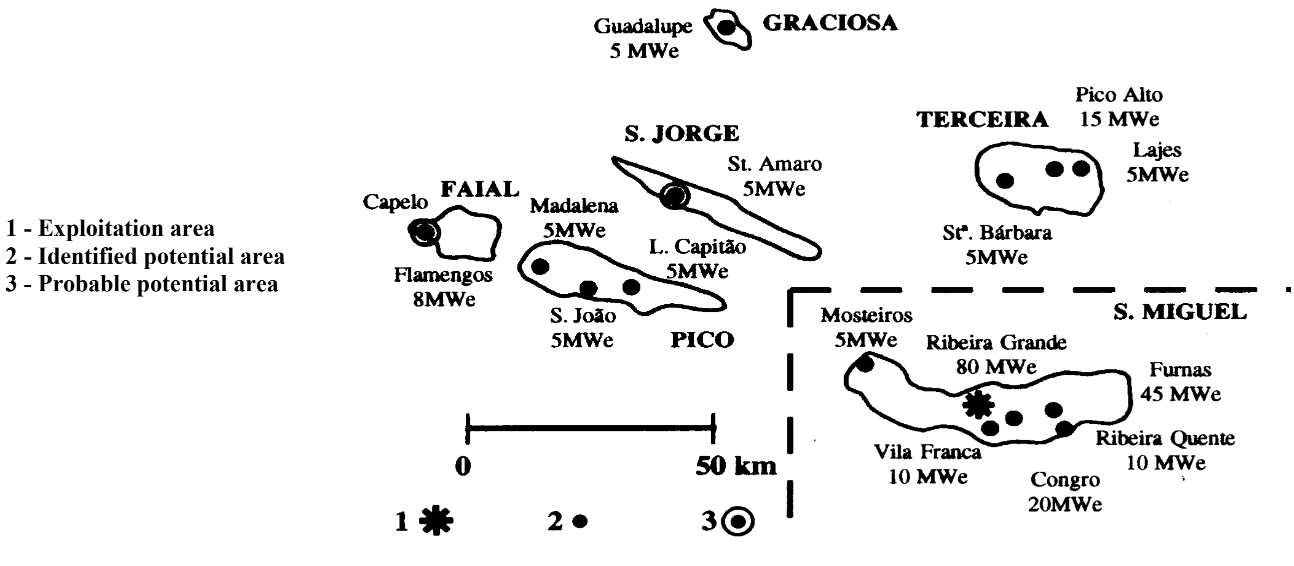

Figure 3. Azores geothermal fields. Estimated reservoir capacity MWe (adapted from Forjaz, 1997).

TABLE 1. LOW-TEMPERATURE GEOTHERMAL WATERS FROM PORTUGUESE MAINLAND (ADAPTED FROM I.G.M, 1998).

No.	Thermal Spring	T (ºC)	Chemical characteristics	No.	Thermal Spring	T (ºC)	Chemical characteristics
1	Monção	50	H_2S,HCO_3,Na,F	27	Luso	27	SiO_2, Cl, Na, K
2	Chaves	76	HCO_3,Na,F,CO_2	28	São Paulo	23	H_2S,HCO_3,Na
3	Gerês	47	HCO_3,Na,F,S_2O_3	29	Unhais da Serra	37	H_2S,HCO_3,Na,F
4	Carvalhelhos	22	HCO_3,Na,F	30	Amieira	27	Cl,Ca,Na
5	Caldelas	33	HCO_3,Ca,F	31	Bicanho	28	Cl,Ca,Mg,Na
6	Eirogo	25	H_2S,Cl,HCO_3,Na,F	32	Azenha	29	Cl,Na
7	Taipas	32	H_2S,HCO_3,Na,F	33	Monfortinho	28	SiO_2, Cl, Na, K
8	S. Miguel das Aves	22	H_2S,HCO_3,Na	34	Fonte Quente	24	Cl,HCO_3,Na
9	Vizela	62	H_2S,HCO_3,F,Na	35	Salgadas	23	Cl,Na
10	Saúde	30	H_2S,Cl,Na,F	36	Envedos	22	SiO_2, Cl, Na, K
11	Carlão	29	H_2S,HCO_3,Na,F	37	Piedade	27	Cl,HCO_3,Na
12	São Lourenço	30	H_2S,HCO_3,Na,K	38	Salir	20	Cl,Na
13	Canavezes	35	H_2S,F,HCO_3,Na	39	Caldas da Rainha	36	H_2S,Cl,SO_4,Na,Ca,Mg
14	Moledo	45	H_2S,HCO_3,Na,F	40	Arrábidos	29	H_2S,Cl,Na
15	Fonte Santa do Seixo	21	H_2S,HCO_3,Na	41	Vimeiro	26	H_2S,Cl,Na,Ca
16	Aregos	62	H_2S,HCO_3,Na,F	42	Cucos	40	Cl,Na,F
17	Longroiva	34	H_2S,HCO_3,Na	43	Alcaçarias	30	Cl,Na
18	São Jorge	23	H_2S,Cl,Na	44	Air Force Hospital	50	HCO_3,Ca,Mg
19	Carvalhal	41	H_2S,HCO_3,Na,F	45	Oeiras-SSFA	30	HCO_3,Na
20	Cavaca	29	H_2S,HCO_3,Na,F	46	Estoril	35	Cl,Na
21	São Pedro do Sul	69	H_2S,HCO_3,Na,F	47	Santa Comba	22	HCO_3,Ca
22	Alcafache	51	H_2S,HCO_3,Na,F	48	Malhada Quente	28	HCO_3,Na,SO_4
23	Sangemil	50	H_2S,HCO_3,Na,F	49	Alterce	27	HCO_3,Na
24	Cró	23	H_2S,HCO_3,Na	50	Monchique	32	HCO_3,Na,F
25	Felgueira	36	H_2S,HCO_3,Na,F	51	Santo António	25	HCO_3,Ca
26	Manteigas	48	H_2S,HCO_3,Na,F	52	F.te S.ta de Quarteira	21	HCO_3,Na,Ca,Mg

Notes: T (ºC) stands for maximum recorded temperature.

TABLE 2. PRESENT AND PLANNED PRODUCTION OF ELECTRICTY

	Geothermal		Fossil Fuels		Hydro		Other Renewables		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
In operation in January 2000	3.0 2 x 2.5 2 x 4.0	160 *	3373	11577	3903	11526	170 (a) 52 (b) 10 (c)	1600 *	7524	24863
Under construction in January 2000										
Funds committed but not yet under construction in January 2000										
Total projected use by 2005	45 -50									

Notes: (a) mini and micro-hydric; (b) wind; (c) biogas and biomass; * total

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 1999.

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
3F = Triple Flash O = Other (please specify)
D = Dry Steam
3) Data for 1999 if available, otherwise for 1998. Please specify which.

Locality	Power Plant Name	Year Commissioned	No. of Units	Status [1)]	Type of Unit [2)]	Unit Rating MWe	Total Installed Capacity MWe	Annual Energy Produced 1999 [3)] GWh/yr
Azores	Pico Vermelho	1980	1		1F	3.0	3.0	4
Azores	Ribeira Grande	1994	2		B	2.5	5.0	52
Azores	Ribeira Grande	1998	2		B	4.0	8.0	104 *
Total			5				16.0	160

Notes: * estimated

TABLE 4. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999.

1) H = Space heating & district heating (other than heat pumps); B = Bathing and swimming (including balneology); G = Greenhouse and soil heating

2) Capacity (MWt) = Max. flow rate (kg/s) [inlet temp. (ºC) – outlet temp. (ºC)] x 0.004184 (MW = 10^6 W)

3) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (ºC) – outlet temp. (ºC)] x 0.1319 (TJ = 10^{12} J)

4) Capacity factor = [Annual energy use (TJ/yr) x 0.03171] / Capacity (MWt)

Locality	Type [1)]	Maximum Utilization			Capacity [2)] (MWt)	Annual Utilization		
		Flow rate (kg/s)	Temperature (ºC)			Ave. Flow (kg/s)	Energy [3)] (TJ/yr)	Capacity Factor [4)]
			Inlet	Outlet				
Chaves	H,B,G	5	76	30	0.96	n.a.		
S. Pedro do Sul	B G	10 10	68 67	28 60	1.67 0.29	n.a. n.a.		
Lisbon (AFH)	H	18	49	35	1.05	0.5	0.92	0.03
Azores (S. Miguel)	G	8	90	25	1.50	1.3	11.15	0.35
Total		48.5			5.47			

Notes: n.a. stands for not available.

TABLE 5. WELLS DRILLED FOR ELECTRICAL AND DIRECT USE OF GEOTHERMAL RESOURCES AS OF 31 DECEMBER 1999.
1) Include thermal gradient wells, but not ones less than 100 m deep.

Purpose	Wellhead Temperature	Number of Wells Drilled		Total Depth (km)
		Electric Power	Direct Use	
Exploration [1)]	(all)	5	2	6.30
Production	> 150ºC	3		4.90
	150 – 100ºC			
	< 100ºC		5	2.50
Injection	(all)	1		1.50
Total		9	7	15.20