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Geothermal Country Update for Ecuador, 2000-2005

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ABSTRACT

Due mainly to its favorable geodynamic setting along the active convergent plate margin of Southamerica, characterized by a broad continental volcanic arc with numerous active volcanoes and intense seismicity, and to the elevated oil prices of the time, Ecuador started the exploration of its geothermal resources about 30 years ago, aiming on high enthalpy prospects, suitable for electricity production.

Exploration for geothermal resources was carried out from the mid 1970´s through the early 1990´s by ecuadorean government institutions (former INECEL and INE) with the aid of foreign technical assistance programs (mainly OLADE, IAEA, UNDP).

Reconnaissance studies focused on areas with recent volcanic and tectonic activity in the Plio-Quaternary volcanic arc, which covers most of the northern andean highlands of Ecuador. Results from geo-scientific surveys revealed the presence of several active hydrothermal systems. Tufiño-Chiles, Chachimbiro and Chalupas appeared as the most promising prospects, with deep temperatures in excess of 200 °C and a combined potential of about 500 Mwe. This potential was inferred from surface data only, since no geothermal exploratory wells have been drilled yet in Ecuador.

A dozen other geothermal prospects, related to silicic calderas and /or evolved stratovolcanoes can substantially increase the inferred potential, but quantitative data are scarce or even nonexistent. Other areas of interest, including the Galapagos hot spot islands, still remain unexplored.

Low to medium temperature resources are abundant along the volcanic arc and are mainly related to recent NNE strike slip faulting and local pull appart structures; these geothermal resources are not confined to the volcanic highlands, but are also present in the fore-arc plains as well as in back-arc areas, mostly related to deep cutting basement faults.

As for now, geothermal utilization in Ecuador is currently restricted to direct use in swimming pools, only. Basic research, applicable to geothermal is done, scarcely, at few universities.

Geothermal is considered a renewable non-conventional type of energy, together with solar, wind, biomass and others. CONELEC and MEM (Ministry of Energy and Mines) are the leading national agencies for energy issues and promote the use of renewable resoures by assigning them a especial status regarding priority for development and connection to the national grid, as well as a favorable price for selling electricity.

The energy market is dominated by Hydro (50.6 %) and Fossil Fuel (49.4 %) generation, with a total installed capacity of 3451 Mwe, yielding a gross electricity production of 12357 GWh/yr (as of Dec 2002).

Production from renewable energy sources in Ecuador, including geothermal, solar and wind, is still neglegible, but is planned to increase in the future. The Tufiño-Chiles geothermal prospect owns the especial status of Bi-National Project, due to its location on the Ecuador-Colombia border. This and several other high and low-medium temperature geothermal prospects in Ecuador await state and private investment to be developed in order to lessen the dependence on fossil fuel use. Finally, in Ecuador, geothermal energy is challenged to be cost-efficient in front of an abundant hydro resource, as well as to be environmentally safe.

1. INTRODUCTION

Ecuador needs energy resources to keep pace with the fast track of globalization, therefore it is the government´s priority to explore and develop indigenous energy resources, both conventional and renewable, which includes geothermal energy. Ecuador is a democratic republic, located on the western edge of equatorial Southamerica; it has 12 156 608 inhabitants living in a territory of 256 370 km2 (INEC 2001); the official language is Spanish and the GNP was 17 302 986 000.- USD for the year 2002.

Lead government agencies involved in geothermal energy are the MEM (Ministerio de Energía y Minas - Ministry of Energy and Mines), CONELEC (Consejo Nacional de Electricidad – National Council for Electricity) and the CNRH (Consejo Nacional de Recursos Hídricos – National Council for Water Resources).

Geothermal Energy is considered a renewable type of energy and has a special status to encourage its development involving private investment. This policy is part of the modernization trend of the ecuadorean state.

In the following pages we present an overview of Ecuador´s geological setting, a description of the geothermal resources and potential, together with the history of exploration, the state of geothermal utilization and a discussion of the actual and future development.

2. OVERVIEW OF ECUADOR´S GEOLOGICAL SETTING

Geographically and geomorphologically, mainland Ecuador consists of three regions: the coastal plains or *COSTA*, the Andes mountain chain or *SIERRA* and the Amazon basin or *ORIENTE*. A fourth region comprises the Galapagos Islands, located about 1000 km W in the Pacific Ocean (see fig.1)

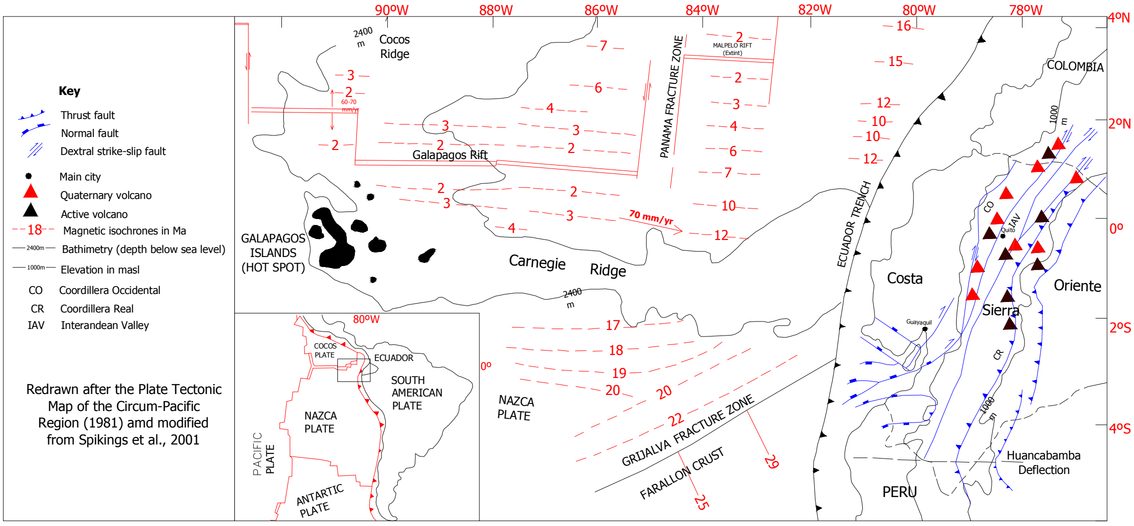

Fig. 1 Geodynamic Setting of Ecuador, showing mainland Ecuador on South American plate and the Galapagos Islands on Nazca plate

The Andes are the backbone of the country. They were formed by multiple accretion since Jurassic times (Aspden &Litherland, 1992; Eguez and Aspden, 1993), and consists of two paralell NNE striking mountain chains: a) the Cordillera Real (CR or Eastern Cordillera), made up of sublinear belts of metamorphic rocks intruded by both, S and I – type granitoids of early Mesozoic age. b) the Cordillera Occidental (CO or Western Cordillera) consists of late Mesozoic to Early-Cenozoic basalts and volcaniclastics, which represent accreted oceanic terrains (Hughes and Pilatasig, 2002); these rocks are intruded by Tertiary granitoids. Both cordilleras have been uplifted and are capped by late Tertiary volcanics. Between the two Cordilleras is the Interandean Valley (IAV), which is laterally bonded by active faults, mostly thrust faults, and comprises thick Late-Tertiary to Recent volcaniclastic and epiclastic sedimentary sequences. Covering both Cordilleras in its northern half, a well developed, broad, calk-alkaline volcanic arc extends northwards into Colombia (Barberi et al., 1988; Hall & Beate, 1991). The arc is of Quaternary age and consists of more than 50 volcanoes, of which at least 30 are active. The southern part of the Andes shows only extinct volcanic activity due to the flattening of the slab since late Miocene (Gutscher et al., 2000).

The *Oriente* is an extensive sedimentary basin, which overlies cratonic basement (Baldock, 1982) Older rocks include Jurassic batholiths and a Cretaceous carbonate platform, covered by Tertiary epiclastic sediments. Large thrust folds cut the sequence with a NS strike.

Quaternary alcaline volcanoes are present along the central W margin of the basin in a back-arc setting.

The *Costa* is the flat region W of the Andes; it comprises a late-Cretaceous to Cenozoic fore-arc basin underlain by early Mesozoic oceanic crust. No active volcanism is present in this region. The Galápagos Islands represent, together with the submarine Carnegie Ridge, the Galapagos hot spot trace above the Nazca Plate. The islands consist of about fifteen basaltic shield volcanoes, increasing in age towards the East.

Geodynamic processes are controlled since Late Oligocene by the nearly orthogonal convergence between the Nazca and Southamerican plates, which has generated regional uplift and crustal faulting and deformation as well as extensive volcanism (Lonsdale, 1978). The northern half of the country is part of the North Andean Block, which moves at 6-10 mm/yr in a NE direction along strike-slip faults entering the gulf of Guayaquil (Ego et al.,1993). This compressive regime formed several intramontane basins of pull-appart nature between the two cordilleras since the Miocene. The IAV has been formed as a spindle shaped basin by displacement along a restraining bend in a transpressive regime since about 6 My due to an increase in the coupling of Carnegie ridge in the subduction zone (Spinkings, 2001; Winkler, 2002; Villagomez, 2002). This setting, as well as the extensive Quaternary volcanism, favours the presence of high heat-flow anomalies along the ecuadorean Andes, hence, the availability of heat sources for geothermal systems to exit is plentyful.

3. GEOTHERMAL RESOURCES AND POTENTIAL

The Reconnaisance Study of the Geothermal Resources of Ecuador, carried out from 1979 to 1980, started geothermal exploration in Ecuador. It was aimed to find high-temperature hydrothermal systems along the Andes in the areas of recent volcanism, following the methodology recommended by OLADE (1978). The report (INECEL/OLADE 1980) produced by INECEL (Instituto Ecuatoriano de Electrificación, now defunct) and OLADE (Organización Latinoamericana de Energía), together with AQUATER (Italy) and BRGM (France), summarized the areas of interest in two main groups: Group A (high-temperature; Tufiño, Chachimbiro and Chalupas) and Group B (low-temperature; Ilaló, Chimborazo and Cuenca). INECEL, through its Geothermal Project, carried out follow-up prefeasibility studies between1981 and 1992, first at Tufiño with OLADE and ICEL (Instituto Colombiano de Electrificación), since the project has the status of Bi-National (Ecuador – Colombia), and later on Chachimbiro and Chalupas. In 1985, INE (Instituto Ecuatoriano de Energía, now defunct), carried out prefeasibility studies for low-mid temperature resources at the Ilaló and Cuenca prospects, but funding for drilling failed because potential industrial and direct uses showed up to be non economic at the time. The Tufiño prospect gained the first priority for exploration and the results of advanced geological, geochemical and geophysical surveys indicated a high-temperature resource underneath volcan Chiles (INECEL-OLADE-AQUATER, 1987). Results of scientific surface studies at Chachimbiro and Chalupas indicated the existence at depth of high-temperature resources. Results were summarized by Beate (1991) and by Almeida (1990, 1992), who also gives an assessment of the potential for these three prospects, based on surface data. INECEL´S Geothermal Project was shut down in 1993 and since then, no further government-run geothermal exploration has been done in Ecuador. A private funded MT (Magneto-Telluric) survey in Tufiño (Tecniseguros, 1994) confirmed the presence of a deep, high-temperature resource, but the number of soundings was not enough to fully constrain the size of the reservoir. Further desk-top studies were written with the aim to promote development of the Tufiño prospect as a Bi-National project (Coviello, 2000; Aguilera, 2001), without success.

3.1 Description and Assessment of Geothermal Prospects

This assessment takes into account the earlier studies mentioned above, as well as new data generated in the last decade, especially on the regional geology of the two main cordilleras (Litherland & Eguez, 1993; CODIGEM-BGS, 1987 - 2000), the tectonic evolution of the intramontane sedimentary basins (Hungerbuehler et al. 2002) and on the recent volcanoes of the continental volcanic arc and their geodynamic implications (Bourdon, 2002).

Below is a description of “what”, “where”(see Fig.2) and the characteristics of the geothermal prospects regarding their resource and potential; and which eventually may be taken into account by interested investors. It follows an order of priority from greater to less atractive regarding electrical uses, but are for overall interest regarding direct uses.

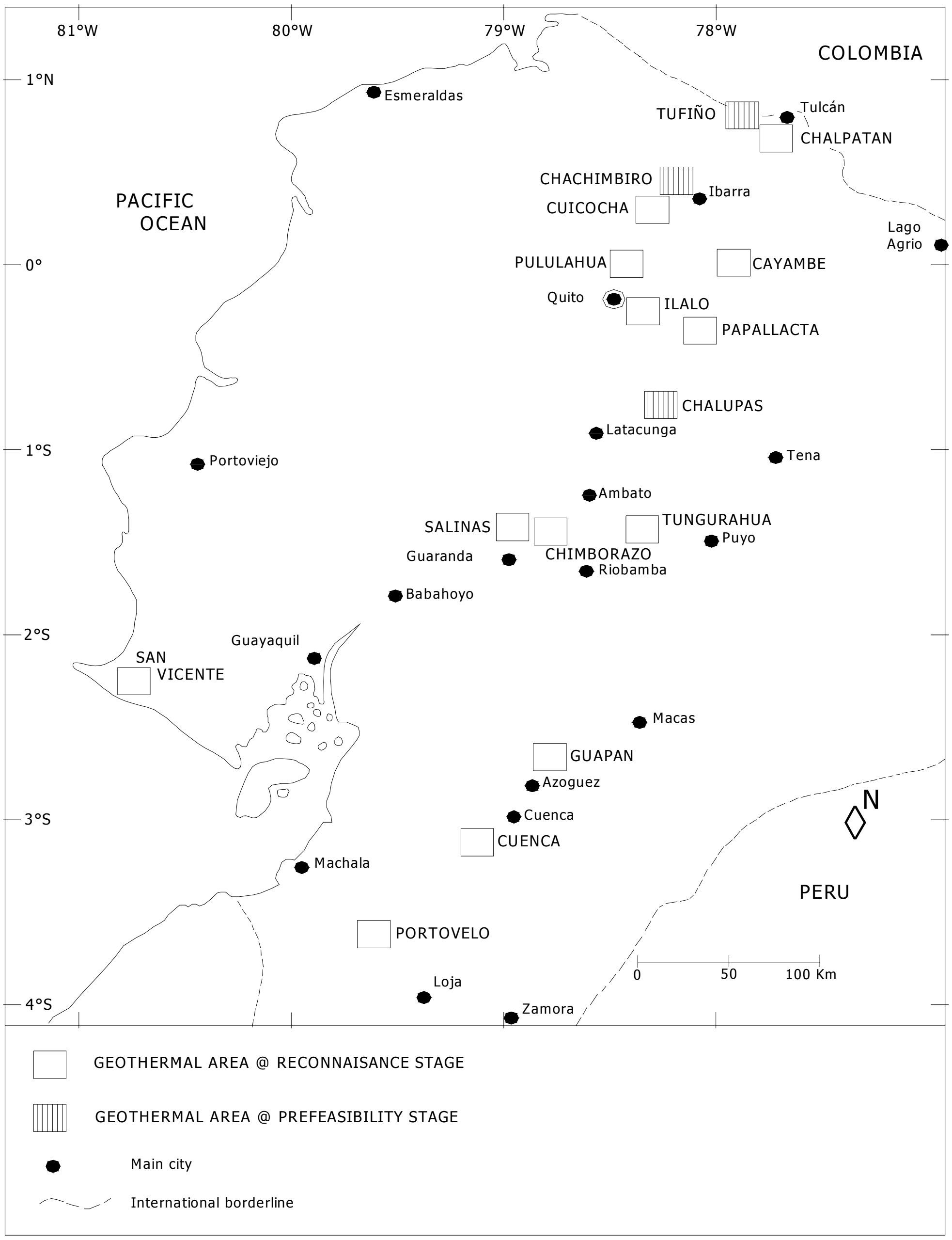

Fig. 2 Location map for geothermal areas in mainland Ecuador. Modified from Almeida, E./INECEL, 1990

Table 1 Chemical Composition of hot spring waters from several geothermal areas of mainland Ecuador (all values in ppm).

Hot Spring	T°C	pH	Na	K	Ca	Mg	HCO3	Cl	SO4	SiO2	B	altitude (masl)
Tufiño 1 (Aguas Hediondas)	41	3.1	78	18	328	64	-----	320	1300	226	-----	3850
Tufiño 2	53	5.9	149	34	100	70.6	350	110	550	159	-----	3530
Tufiño 3	40	6.2	134	3.1	104	70.7	670	74	2100	157	-----	3260
Chachimbiro 1	58	6.3	1250	155	77	47	661	2040	30	200	-----	2618
Chachimbiro 2 (Pitzantzi)	41	6.7	665	63	248	145	1276	879	10	168	-----	2740
Chachimbiro 3	45	7.5	1230	135	85	44	606	1860	32	204	44	2590
Papallacta 1	66	6.8	1350	80	337	54	1425	619	440	80	-----	3510
Papallacta 2	48	6.8	332	6	215	3	941	514	369	-----	45	3260
Papallacta 3	41	7.0	1270	54	277	8	409	1980	282	9.3	93	2750
El Tingo*	41	7.2	441	33	34	155	1824	275	17	74	9	2460
Cachiyacu*	50	6.7	1150	78	313	57	1780	508	1480	93	28	3420
La Merced*	34	6.8	134	9	43	54	616	71	14	131	-----	2610
Chalupas 1	35	6.8	312	38	9.6	16	858	39	5	153	1.5	3740
Chalupas 2	25	6.1	245	14	29	74	937	87	0.4	-----	2	3520
Tungurahua 1	52	7.0	525	74	212	450	1445	450	450	190	-----	1910
Tungurahua 2	36	6.8	217	28	171	240	1525	49	328	154	-----	2840
Chimborazo	47	7.5	682	7.5	320	0.5	37.9	1340	252	48	-----	3660
Guapán**	45	6.7	5600	160	363	65	3090	5160	35	42	105	2660
Baños Cuenca 1	73	7.4	750	59	184	23	782	874	233	66	14.2	2715
Baños Cuenca 2	56	6.6	743	59	152	24	890	861	227	59	13	2720
Portovelo**	57	7.1	84	22	145	0.2	19	200	288	27	7.8	630

Sources:
INECEL 1992
* INE 1986
** De Grys et al., 1970
----- not determined

3.1.1 Tufiño – Chiles Geothermal Prospect

This prospect is located in the CO (Cordillera Occidental or Western Cordillera), 35 km W of the city of Tulcán and 7 km W of the villages of Tufiño and Chiles, in the province of Carchi (Ecuador) and Nariño department (Colombia). The development area lies across the Ecuador - Colombia border and comprises about 4900 ha; likely drilling sites on the SE slopes of Chiles volcano are between 3800 and 4200 masl, where climate is wet and cold most of the year and vegetation is grassy. Gravel roads give access to the area, where the principal activities are agriculture and cattle farming. The cities of Tulcán and Ipiales are the main load centres.

Volcan Chiles, a moderate size, andesitic to dacitic, stratocone active in late Pleistocene, constitutes the main heat source, this is reinforced by Cerro Negro de Mayasquer, an active dacitic volcano adjacent to the W of volcan Chiles. These two volcanoes are built upon a thick pile of late Tertiary volcanics (Pisayambo Fm.) overlying accreted oceanic crust of Cretaceous age (Pallatanga Terrain). Reservoir rocks could be fractured Tertiary volcanics, affected by the intersection of active NNE -trending regional strike slip faults with local E-W faults, which are likely to produce reasonable permeability. Acid hot springs, up to 55°C (see table 1), occur 2 – 3 km to the East of Volcan Chiles, along zones of E-W faulting, and have a strong H_2S smell. Bicarbonate springs are common several km to the East, close to the villages of Tufiño and Chiles. Fossil silica sinter terraces, about 1 km East of the acid springs, show that neutral chloride waters, indicative of a high temperature hydrothermal system, discharged at this site sometime in the past. Extensive areas of hydrothermally altered rocks are found 2.5 km N and 1.5 km S of volcán Chiles. These are at ambient temperature, but show local emission of H_2S, and have been active in the Holocene; it is likely that the shallow part of the system has sealed up. Gas geothermometers indicate reservoir temperatures as high as 230 °C. Location of acid springs and altered ground suggest considerable size of reservoir, mostly overlain by rugged terrain. Resistivity data (Schlumberger and MT soundings) confirm the existence of a conceptual model of geothermal reservoir under volcan Chiles massif, with a fault-controlled E-wards lateral outflow on the East flank (INECEL-OLADE-AQUATER, 1987). Elevation of top of reservoir is below 3100 masl with 100 °C waters, but exploitable temperatures are 200 – 300 m deeper, indicating drilling targets for production at 1000 to 1500 m depth; this is indicated by the presence of a thick conductive layer, which is shallow (about 100 m) below the acid springs, but deepens 400 to 500 m towards E (outflow).

The altered ground towards the S indicates a low temperature conductive layer associated with steam-heated rocks consisting of clays. Best sites for exploration-production drilling appear to be to the W of the acid springs, at about 3800 – 4000 masl, which would need the building of 1 – 3 km long access roads from the existing gravel roads. Water for drilling might be scarce in the dry season. Inmediate future work should involve the drilling of three exploration wells to at least 2000 m depth, following a complementary MT survey to fully constrain the reservoir size. This should lessen the risk in choosing drilling targets, since production zones are probably fault-controlled. Almeida (1990) gives an estimate of 138 MWe for the Tufiño prospect, based on surface data.

3.1.2 Chachimbiro geothermal prospect

This prospect is located on the E slopes of the CO, at about 20 km W of the city of Ibarra in the province of Imbabura. It is accessed by gravel and dirt roads. Climate is temperate and vegetation changes from forested to grassy on a rather rugged topography. Possible drilling site location are at elevations of 3500 masl. A 4900 ha development area has been proposed, with elevations varying from 2800 to 4000 masl. The area is partly inside the Cotacachi – Cayapas Ecological Reserve and land is used for agriculture.

The heat source is the Quaternary Chachimbiro volcanic complex, which includes the collapsed mid Pleistocene andesitic volcano Huanguillaro, the caldera filling rhyodacitic Hugá dome and the Late Pleistocene Chachimbiro – Pucará NNE line of dacitic domes, the youngest of which (Pitzantzi dome) is only 5000 years old (Beate 2001); older Yanaurcu volcano (andesitic to rhyodacitic) as well as andesitic Pilavo volcano (andesitic, late Pleistocene in age), are located to the W of Huanguillaro. The whole complex is underlain by mid-Terciary vulcaniclastic sediments (Silante Fm.) and by intenselly tectonized Cretaceous oceanic basalts and asociated sediments (Pallatanga Terrain). Active NNE trending faults cut the volcanic complex, assuring reasonable permeability.

Reservoir rocks could be fractured volcanics related to dome activity and concealed proximal lava flow facies related to early volcanic activity covering the basement rocks.

Near – neutral chloride – bicarbonate hot springs are present to the East of the system, with temperatures ranging from 40 to 55 °C (see table 1) . Possible deep-temperatures are in excess of 200 °C. Fault controlled areas of hydrothermally altered rocks with no anomalous temperature, crop out in the central part of the area, giving a slight H2S smell, indicating selfsealing of the upper part of the system. Resistivity soundings on the E part of the area, reveal a lateral outflow to the E. There are no deep-reaching resistivity surveys in the centre of the system.

Recommendations for future works include a) sample, analyze and interpret all gas emissions in the area to better understand the geothermal system and to obtain more accurate deep system temperatures; b) carry out a MT survey to get a comprehensive picture of the resistivity structure of the system and thus site the exploration wells; and, c) drill three wells to a depth of about 2000 m, spaced 1000m appart, in relative flat area between the dacitic domes, depending on the results of MT survey. This will require upgrading 5 km of existing dirt road, plus some site access.

The nearest major load centre is Ibarra. A high voltage transmission line, 20 km from the area, connects Colombia to the ecuadorean grid. A potential of 113 Mwe has been estimated by Almeida (1990) from interpretation of surface data.

3.1.3 Chalupas Geothermal Prospect.

This prospect is located 70 km SSE of Quito, at the crest of the CR (Eastern Cordillera), in the province of Napo. It can be accessed from Latacunga along gravel and dirt roads. Average elevation of prospect is 3600 masl, climate is cold and wet for most of the year and vegetation is grassy. Topography is mostly flat. The area of interest, the Chalupas caldera floor, is greater than 200 km2. Latacunga is the nearest load centre at a distance of 30 km.

The Chalupas caldera is 12 km in diametre and formed after the explosive eruption of about 100 km3 of rhyolitic pumitic ash (INECEL, 1983; Beate, 1985;). Hammersley (2004) obtained an age of 200 000 years for the ash. Volcanic activity resumed after caldera collapse, building Quilindaña volcano inside it, which is andesitic to dacitic in composition; youngest intracaldera lava flows have a basaltic andesite composition and are not affected by glacial erosion. The huge volume of erupted silicic magma as well as the persisting volcanic activity through time, guarantees the presence of a heat source in the areaas pointed out by Bloomquist, 1995. Due to the formation of the caldera by collapse, high permeability is expected at depth; regional NNE trending faults cross the caldera structure. The caldera collapse affected a thick pile of late Terciary intermediate volcanics (Pisayambo Fm.), which overlie the Triassic-Jurassic metamorphic basement (blue qtz gneises of Tres Lagunas Granite).

The caldera has been eroded by glaciers and partly filled by cold water-saturated morraines; hence, only a few low temperature springs, between 30 to 40 °C, are found at the edges of the caldera structure, and are too diluted to give an estimate of the deep temperature. This may be also indicative of the abscence of a shallow high-temperature system. Fault controlled hydrothermally altered rocks appear in the N and S caldera rims; crystobalite is found at the W rim affecting pre-caldera lavas. Other alteration zones may be concealed underneath the morraine cover. A gravity survey shows the caldera structure, the geometry of the basement as well as the regionally N-trending Peltetec fault (Beate, 2001).

Future work should carry out a Schlumberger resistivity survey with traversing (mapping) measurements at 500 m spacing, and a number of deep vertical electrical soundings (VES), so to define the upper surface of any geothermal system, since the topography is mostly flat and reasonably accessible. Depending on the results of the Schlumberger survey, a deeper-penetrating MT survey may be recommended. If the system is shallow, this prospect may be suitable for the drilling of shallow temperature-gradient wells (400 to 500 m deep) to confirm high temperatures and sample deep fluids. If results are encouraging, an exploration drilling program is recommended at a spacing conmensurate with the size of the system as defined. Almeida (1990) estimates a potential of 283 Mwe for the Chalupas prospect, from interpretation of surface data.

3.1.4 Papallacta Geothermal Prospect

This prospect is located 60 km E of Quito on the CR (Eastern Cordillera), in the province of Napo. Elevations range between 3200 and 4000 masl on rugged topography covered with grassland and few a forest patches. Climate is wet and cold for most of the year.

The main load centre is Quito and a high voltage transmission line already runs through the area, as well as do adequate paved and gravel roads. A developement area has not been defined yet due to lack of data. The prospect is mostly located in environmentlly sensitive territory, namely the Antisana and Cayambe-Coca ecological reserves.

The heat source are the younger volcanics of the Chacana caldera complex, which has been persistently active through all the Quaternary (the last 2 million years). Important rhyolitic eruptions occurred 240, 180 and 160 ky ago producing extensive ignimbrites, thick plinian pumice falls and a large obsidian flow; voluminous andesitic and dacitic lava flows were erupted 40, 20, 10 and 2 ky ago, outside and inside the 35 km N-S diameter silicic Chacana caldera, which is open to the E, and is deeply eroded in that direction (Hall & Beate, 1991; Hall & Mothes, 2001).

An almost 2 km thick pile of volcanic rock from the Chacana complex and the underlying late Tertiary Pisayambo Fm., constitute the cover to the early Mesozoic metamorphic basement. The collapse structures of the coalesced caldera complex , as well as major active NNE – trending faults cut the entire sequence, assuring reasonable permeability.

Hot springs, mainly located inside the caldera in the Papallacta area, show temperatures between 40 and 67 °C (see table 1). The springs are near- neutral alkaline chloride waters with anomalous high concentrations of boron and arsenic, typical of a high temperature water-dominated geothermal system. Travertine is deposited in aprons on river banks and terraces; more distal waters tend to be of bicarbonate type. Deep temperatures are estimated to be in eccess of 160 °C. Fossil hydrothermal alteration zones are abundant along the N, S and central parts of the caldera structure, as well as along main NNE – trending faults. No active ground alteration is visible nowadays, sugesting a sealing up of the shallow parts of the system. No geophysical surveys have been done in the area to date.

Future work should include: a) a thorough regional geovulcanological survey at the volcanic massif (Chacana Complex) and surrounding area, to define the volcanic centers, the extent, composition and age of its products as well as to better define the old and the active structures of the area and the patterns of the hydrothermal alteration. b) re-sample, analize and interpret the thermal waters and gases in the prospect area (Chacana Caldera) to better understand the geothermal system and to obtain better estimates of deep temperatures. c) consider a resistivity survey in the more promising area(s).

3.1.5 Chimborazo Geothermal Prospect

This prospect is located 35 km NW of Riobamba, at the crest of CO (Western Cordillera), in the province of Chimborazo. Elevations are in the range of 3500 to 4500 masl, vegetation is scarce and grassy at best, topography is hummocky and climate is cold throughout the year. Access is good along paved and gravel/dirt roads. The load centres are the cities of Ambato, Guaranda and Riobamba, situated within a radius of 40 km.

The development area is of 4200 ha, situated on the NNW slope of Chimborazo volcano.

Chimborazo is a big composite stratovolcano, reaching 6310 masl on its summit and starting at 4000 m at its base. Composition of its products vary from basaltic andesites and andesites through dacites and rhyolites, beeing the later between 1 and 2 My old and the former between 1 and 10 ky old. The whole edifice rests on Tertiary vulcaniclastic sediments (Saquisilí Fm.) which overlay accreted Early Cretaceous ocean crust (Pallatanga Fm.). Reservoir host rocks are likely to be composed of fractured volcanic rocks. Active faults cut the prospect area, but are concealed due to thick tephra cover.

Only one hot spring exists in the area at the NNW foot of the volcano, with a temperature of 47°C and a dilute neutral chloride chemistry (see table 1). The fluids show water – rock equilibrium and indicate deep reservoir temperatures between 100 and 200°C.

No geophysical survey has been done yet. A Schlumberger resistivity survey is recommended to determine the location of the outflow structure.

3.1.6 Cuenca Geothermal Prospect

The hottest springs of this prospect are located 7 km SW of the city of Cuenca (2700 masl) in the province of Azuay. The geothermal system lies some 20 km further SW at an elevation of about 4000 masl, at the crest of the CO (Western Cordillera), where the climate is cold and wet.Topography varies from flat on top, to gentle dipping slopes to locally rugged. Vegetation is grassy at high elevations to patchy forested at lower altitudes. Land is used mainly for agriculture and cattle raising. Access to upper parts is scarce along few dirt roads, but gravel roads are more common in lower elevations. Cuenca is the main load centre.

The area of interest lies partly inside an environmentally protected area and covers the mid-upper part of the Quimsacocha outflow.

The heat source is the Late Miocene-Pliocene Quimsacocha volcanic complex, located about 25 km SW of Cuenca. It produced a cal-alcaline andesitic shield with lava flows and breccia, an extensive high sulfidation epithermal Au-Ag deposit, a caldera forming rhyolitic ignimbrite (Tarqui Fm.) at about 5 My and late intrusive and extrusive caldera - filling domes of dacite and rhyolite porphyries of adakitic signature at about 3.6 My (Beate, 2002); volcanic activity did not resume after extrusion of the domes.

The Quimsacocha volcanic complex overlies a thick pile of volcaniclastic sediments of late Miocene age (Turi Fm.), which in turn cover Mesozoic basement rocks. Major NE-trending faults cut the whole sequence and serve as primary channelways for the deep fluids, indicating reasonable permeability. Likely reservoir host rocks are the Late Miocene volcanics as well as previously silicified volcaniclastics of Turi Fm.

With a temperature of 75°C, the Baños hot springs are the hottest in mainland Ecuador (see table 1). The waters are of the alcali chloride – bicarbonate type and deposit travertine along 8 m high and 200 m long ridges. Deep temperatures of at least 200°C are indicated. These springs represent the likely lateral outflow of the Quimsacocha geothermal system, at about 20 km to the SW of Cuenca. Extensive high grade fossil hydrothermal alteration has been mapped along SW – NE strike and include silicification and clay alteration, which indicate probable former deep boiling zones. Today, the system is self-sealed.

Future work includes: a) sample, analyze and interpret thermal waters and gases as well as hydrothermally altered rocks to characterise the geothermal system and define deep conditions. b) carry out a Schlumberger resistivity survey, consisting of traversing (mapping) measurements at 500 m spacing, and a number of VES to define the top of the outflow. c) a deeper reaching MT survey may be recommended , especially in the upper part of the area, to locate the drilling targets in order to reach the deep hot fluids.

3.1.7 Other Geothermal Areas

CHALPATÁN is a Late Pliocene – Early Pleistocene andesitic to silicic collapse caldera, 5 km in diameter, located in the IAV about 20 km SW of Tulcán. Few warm springs crop out along NNE trending faults, which cut the main structure. Spring waters are likely to be related to a deeper reservoir of moderate temperature (INECEL-OLADE-AQUATER, 1987).

CUICOCHA is a 3 ky old explosion caldera, 3 km in diametre, asociated with dacitic domes. It is located 45 km SW of Ibarra on the crest of the CO, on the S flank of andesitic Cotacachi volcano. The caldera hosts a cold water crater lake with few subaqeous gas outcrop. Distal bicarbonate spring water show a positive 18Oxygen shift (Almeida, 1992) and may be related to a hydrotermal sistem below the caldera.

CAYAMBE is a big composite central stratocone, located on top of the CR, about 60 km NE of Quito. Its composition varies from andesitic to dacitic in a time range of 100 ky and its last eruption is historic (around year1770, dacitic tephra), which indicates a long lasting heat source. Hot springs are known to exist but at remote sites of difficult access.

PULULAHUA is a young dacitic dome complex, consisting of a 3 km diametre explosion caldera, which formed 2400 years ago. It is located 20 km N of Quito, on the Cordillera Occidental. Low-temperature bicarbonate springs and the young age of the complex, may indicate a deeper , hotter system with reasonably good permeability, due to the caldera structure as well as to the fact that important faults cut the rim on its W side. Quito is the nearest load center.

GUAGUA PICHINCHA is situated 10 km W of Quito on the Cretaceous oceanic basement rocks of the CO. This volcano has been active for the last 50 ky. Several events of debris avalanche and later dacitic dome growth, did affect the earlier basal andesitic edifice. The actual caldera is 3 km in diametre and 600 m deep, and open to W. The flat caldera floor hosts on its W ramp a dacitic dome, extruded 330 years ago and a collapsed dome complex extruded 4 years ago (Monzier at al., 2002). Active faults cross the structure and hydrothermal alteration is widespread. The pre-eruption situation showed a vigorous high temperature hydrothermal system underneath Pichincha caldera as indicated by geothermal fumaroles, steaming ground, hydrothermal explosion craters and neutral chloride outflow. A dacitic feeder-dike intrusion,which occured in 1999, disrupted the western part of the geothermal system, causing phreato-magmatic explosions, where ashes and aerosols eventually reached Quito. Studies are needed to assess the actual recovery of the system.

TUNGURAHUA, located 30 km SE of Ambato, is a young andesitic stratovolcano constructed above an older avalanched volcanic edifice of Late Pleistocene age, which in turn rests above the metamorphic basement of the CR (Hall et al., 1999). NS-trending regional faults cut the area. Several hot springs, between 40 and 55°C (see table 1), are situated on the N slope and on the foothills of the volcano, but it is not clear if they derive from a high temperature geothermal system or from heating of deep circulating groundwaters by hot magmatic fluids; hence, no reliable deep temperature can be obtained. At present, the volcano is on its fifth year of moderate to intense strombolian eruptive activity associated with the ascent of discrete slugs of basaltic andesite magma. Nevertheles, despite the continous volcanic activity, the nature of the hot springs hasn´t changed yet.

SALINAS is located 15 km NNE of Guaranda, on Late Tertiary volcanics (Zumbahua Fm.), which overlay the Cretaceous basement of the CO. Highly saline warm springs, asociated with recent faults, indicate the presence of a heat source at depth, which could consist of shallow stocks, likely related to the formation of a local high sulfidation epithermal Ag-Au system. Hydrothermal alteration is widespread, but not active. It is likely that the system has sealed up. Local agribusiness is very active in the area, which is located at an elevation of 2700 to 3200 masl. Production of geothermal heat for direct uses may have high demand.

GUAPÁN is located 20 km NNE of Cuenca, very close to Azogues. Several springs, with temperatures in the range of 20 to 45°C and high solute concentrations (TDS = 10000 to 13000, De Grys, 1970), occur in Late Cretaceous and Miocene sediments on the E margin of the Cuenca Basin. No active or recent volcanism has been reported in the area. Extensive travertine deposits are asociated with the springs. The springs are fault controlled and have been lately lowering their discharge due to carbonate self- sealing.

SAN VICENTE is located in the Santa Elena peninsula, about 100 km W of Guayaquil. The springs are saline waters with temperatures between 30 to 43 °C. They are related to recent faults, which cut the Mid -Late Terciary marine sedimentary sequence of the Progreso basin as well as the Cretaceous basement, made of ocean floor basalts. No recent volcanism is reported in the area and the water is likely to be heated up by normal geothermal gradient due to deep circulation. The waters are contaminated by sea water and by petroleum brines from nearby oilfields, and are used for spas and mud baths. There are not enough data to assess the resource, but demand for direct use may be high due to fast development of the area.

PORTOVELO is located about 150 km S of Guayaquil at the Portovelo-Zaruma gold mine district on the western foothills of the CO. Country rocks are Mid-Tertiary volcanics which were intruded by dioritic plutons about 15 my ago. The area is cut by active faults. Hot springs show temperatures between 30 and 57 °C (see Table 1) and seem to pick up remnant heat through deep circulation. Waters are used for bathing purposes and this use may be increased with the help of drilling.

ALCEDO is located on Isabela Island, in the Galápagos Archipelago. It shows extensive hydrothermal alteration, numerous explosion craters, strong superheated fumaroles discharging vapor 127 °C and a heat source related to a primary basaltic origin but also to explosive silicic volcanism of recent age, like obsidian flows and rhyolitic plinean tephra. The area is situated on the SSW caldera structure, which might indicate good permeability at depth, where a shallow high-temperature geothermal resource may be present. This prospect is on Galápagos National Park land, and any innitative to explore and exploit it must obey strict environmental regulations, if a geothermal permit is granted at all.

4. GEOTHERMAL UTILIZATION

Today, utilization of geothermal resources in Ecuador is restricted to direct uses only, that is for bathing resorts, balneology, mud baths and swimming pools. A summary of many, but not all, hot and warm springs used for swimming pools is shown in table 3, giving a total installed capacity of 5.157 MWt and an annual energy output of 102.401 TJ/yr.

5. DISCUSSION

Tables 2 to 5 show clearly that conventional energy generation by fossil fuels (51%) and hydro (49%), dominates by far the Ecuadorean energy market, with a total installed capacity of 3521 Mwe and a gross production of 11546 GWh/yr (CONELEC, 2003). At present, other forms of energy production, i.e. nuclear, geothermal and other renewables, are non-existent or neglegible. In the future, the general trend seems to favor hydro, with an increase in renewables and a decrease in fossil fuel, which in turn favors geothermal energy development.

Table 3 shows the utilization of geothermal energy for direct use. This information has to be taken as a minimum estimate for hot spring waters used for swimming pools. Inlet-temperature is a safe parameter, but outlet-temperature has been arbitrarily assumed to be 35°C if temperature is above 40°C, 20°C if it is between 30 and 40°C and 15°C if it less than 20°C. The average flow rate has been assumed to be 63% of the maximum flow rate, which is also arbitrary. The max. flow rate has been measured at the spring in most cases, but in others it has been estimated. This activity has been increasing successfully in last years, but is difficult to assess due to lack of data.

In Ecuador, there is no electricity production from geothermal, there are no heat pumps installed and there are no wells drilled for geothermal purposes. This last statement is questionable, since some wells have been drilled to obtain water for swimming pools, but data are not available now; most wells have been drilled to obtain water only for agricultural or industrial uses, without using any heat. Allocated professional personell to geothermal is non-existent in the industry; few professionals do some random desk-top activities on renewable energy issues as consultants, as official staff for government agencies (MEM and CONELEC) or international agencies (OLADE), or as university staff (EPN, ESPE, ESPOL are main universities in Quito and Guayaquil). There is no actual sustained geothermal activity in Ecuador.

Table 5 shows that no investment has been allocated to geothermal activities in this last decade (1995 to 2004). The last funding for geothermal purposes (about 0.61 million USD) ocurred in 1990 to 1994, when the Geothermal Project of INECEL was active until 1993, and where the only, and last, private investment funded the complementary MT survey (Tecniseguros, 1994) on the Tufiño prospect.

General policies regarding energy are issued by the government through the Ministry of Energy and Mines (MEM), which involve both oil and gas, and electricity, including renewable energies. The MEM coordinates the electric energy issues with CONELEC, which in turn depends directly on the central government. CONELEC is in charge of regulating and supervising the companies which generate, transport and distribute electricity. It also gives concessions for electricity generation, fixes the price of electricity and is in charge of the planning of the sector. One of the problems in the electricity market is the availability of energy, rather than the installed capacity, since the reservoirs for hydro generation are in some cases small and fossil fuels are expensive and not always at hand. This situation favours the demand of geothermal power as base load.

Any project to generate electricity, including geothermal, needs a concession permit issued by CONELEC, which in turn demands a water-use permit from CNRH and an environmental permit from the Ministry of the Environment. Regarding geothermal electricity generation, CONELEC favours the producers of electricity, which use renewable resources, with a special treatment reflected in the payment of higher-than-average prices. The price for geothermal power is 8.12 USDcents per kWh, for installed capacities of 15 MW or less, which suits a modular development of a geothermal resource.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

No geothermal developments or instalations are planned for the near future, apart from small investments in swimming pools or bathing resorts as direct uses.

Nevertheless, due to higher oil prices and due to locally and regionally increasing energy demand, geothermal energy uses can become cost-efficient in relation to conventional hydro, oil and gas, and to other renewable energy forms. Private investment plays a key role in funding future geothermal enterprises for both, electric and direct uses.

Several regions in the country remain un-explored for geothermal resources, namely the sedimentary basins in the Costa, the back-arc volcanic chain with recently active alkalic volcanoes and the sedimentary basins in the Oriente, as well as the Galapagos Archipelago. This increases the exploration potential for geothermal resources in the country, in addition to the follow up exploration of the prospects cited above. Application of actual and future technology will allow the discovery of hidden resources, those where geothermal evidence at surface is nil (Duffield and Sass, 2003). A good start will be to re-assess and update geothermal data nationwide and to produce a heat flow map and the geothermal map of Ecuador, as well as to get private funding to finally drill the most promissing prospects and tap geothermal power in Ecuador.

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TABLE 2 **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 2004	------	------	1775.05	4366	1746.34	7180	------	------	------	------	3521.39	11546
Under construction in December 2004	------	------	------	------	250.7	1486	------	------	------	------	250.7	1486
Funds committed, but not yet under construction in December 2004	------	------	------	------	263.6	1098	------	------	------	------	263.6	1098
Total projected use by 2010	------	------	2277	7959	2195	9755	------	------	81.7	287.5	4553.7	18001.5

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2004 (other than heat pumps)

[1] 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)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity Factor[5]
			Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
Baños Cuenca	B	8.000	73.000	35.000	-----	-----	1.272	5.040	25.261	0.629
Baños Tungurahua- Virgen	B	5.120	53.000	35.000	-----	-----	0.386	3.226	7.659	0.629
El Salado	B	5.000	44.300	35.000	-----	-----	0.195	3.150	3.864	0.628
Palictahua	B	2.800	40.700	35.000	-----	-----	0.067	1.764	1.326	0.627
Chachimbiro- Toma	B	1.500	58.000	35.000	-----	-----	0.144	0.945	2.867	0.631
Pitzantzi	B	0.950	40.800	35.000	-----	-----	0.023	0.599	0.458	0.631
Naugulví	B	2.000	52.000	35.000	-----	-----	0.142	1.260	2.825	0.631
Cununyacu- Chimborazo	B	1.400	47.500	35.000	-----	-----	0.073	0.882	1.454	0.632
Guayllabamba- Chimborazo	B	5.000	40.000	35.000	-----	-----	0.105	3.150	2.077	0.627
Ilaló- Cununyacu	B	8.000	27.000	15.000	-----	-----	0.402	5.040	7.977	0.629
Tingo	B	1.200	32.000	20.000	-----	-----	0.060	0.756	1.197	0.633
San Antonio	B	12.000	35.500	20.000	-----	-----	0.778	7.560	15.456	0.630
Ushimana	B	1.000	19.000	15.000	-----	-----	0.017	0.630	0.332	0.619
Chunchi	B	2.000	29.500	15.000	-----	-----	0.121	1.260	2.410	0.632
Ilaló	B	5.000	35.000	20.000	-----	-----	0.314	3.150	6.232	0.629
Papallacta- Termas	B	1.100	53.000	35.000	-----	-----	0.083	0.693	1.645	0.628
El Tambo	B	1.000	50.000	35.000	-----	-----	0.063	0.630	1.246	0.627
Jamanco	B	2.000	66.000	35.000	-----	-----	0.259	1.260	5.152	0.631
Cachiyacu	B	1.200	68.000	35.000	-----	-----	0.166	2.756	3.291	0.629
Portovelo Río Amarillo	B	1.200	57.000	35.000	-----	-----	0.110	0.756	2.194	0.632
Tufiño Aguas Hed.	B	3.000	53.000	35.000	-----	-----	0.226	1.890	4.487	0.630
San Vicente	B	2.000	38.000	20.000	-----	-----	0.151	1.260	2.991	0.628
TOTAL		72.470					5.157	47.657	102.401	

TABLE 4. . SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

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]	--------	--------	--------
Snow Melting	--------	--------	--------
Bathing and Swimming[7]	5.157	102.401	0.629
Other Uses (specify)	--------	--------	--------
Subtotal	5.157	102.401	0.629
Geothermal Heat Pumps	--------	--------	--------
TOTAL	5.157	102.401	0.629

[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 5. **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	0.61	-------	-------	-------	41	59
1995-1999	-------	-------	-------	-------	-------	-------
2000-2004	-------	-------	-------	-------	-------	-------