Presented at "Short Course on Surface Exploration for Geothermal Resources",
organized by UNU-GTP and LaGeo, in Ahuachapan and Santa Tecla, El Salvador, 17-30 October, 2009.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

GEOTHERMAL DEVELOPMENT IN CENTRAL AMERICA: OPPORTUNITIES AND DIFFICULTIES

Carlos Pullinger
LaGeo S.A. de C.V.
15 Av. Sur, Col. Utila, Santa Tecla,
EL SALVADOR
cpullinger@lageo.com.sv

ABSTRACT

Geothermal exploration in Central America began in the 1960's and electricity generation from this resource, a decade later. Despite a potential capacity of 8 GW available with the present technology and 13 GW using enhanced technology, only a fraction has been developed. Three and a half decades after the initial production began in Ahuachapán, El Salvador; the total installed capacity from geothermal resources in Central America adds up to 530 MW, only about 5% of the total geothermal potential of the region.

Clearly, several factors have contributed to the delay in the development of the geothermal resources in the region. Amongst these are political instability, regulatory, institutional, political, economic and financial barriers, which are common problems in the whole region.

In order to revert this trend and accelerate the geothermal development in the future, the National Energy Authorities have to take clear actions to promote the development of known high enthalpy resources and invest in basic exploration of low-medium enthalpy resources, in order to fully take advantage of this indigenous source of energy that has several economic, social and environmental advantages over other renewable and non-renewable sources of energy.

1. INTRODUCTION

Central America's location along the tectonically active margin between the Cocos and Caribbean tectonic plates is the main reason for the existence of many high temperature geothermal areas. The Central American volcanic arc supplies most of the high enthalpy resources found in the region, which are associated to active and dormant volcanoes, caldera structures, and other volcano tectonic structures. Geothermal resources of medium enthalpy are either associated to tectonic structures that allow deep circulation of fluids, or to older volcanoes that contain remnant heat which contributes to the production of geothermal resources. Approximately 50 known geothermal areas are found in Central America (Bundschuh 2002; Chandrasekharam, 2008); however this does not include all of the medium enthalpy and possible resources associated to active volcanoes.

The interest in commercially exploiting geothermal resources in the region began in the middle of the 20th century with the initial academic investigations on fumarolic and hot spring areas. Some countries like El Salvador, Nicaragua and Costa Rica started nationwide reconnaissance studies in the mid 1960's in order to assess each country's geothermal potential.

By the 1970's, the entire region had advanced in carrying out assessment of its potential, and El Salvador was the first to implement geothermal production with the installation of a 35 MWe unit. The 1980's brought a growth in geothermal exploration activities and knowledge of individual resources, but production was only increased by 135 MWe (65MWe in El Salvador and 70 MWe in Nicaragua). The 1990's witnessed production being implemented in Costa Rica where a 115 MWe power plant was commissioned at the Miravalles geothermal field, and Guatemala with 28 MWe at Zunil and 5 MWe at Amatitlán. El Salvador increased its capacity by 64 MWe installed at the Berlín geothermal field. The last decade of the 20th century brought a total increase of 212 MWe in the region. In the 21st century, an additional 145 MWe was installed in the region bringing the total to 530 MWe, out of a potential of approximately 13 GW using enhanced extraction technologies (Gawell et al., 1999).

This paper describes the main resources of each country where geothermal exploration, development and production have taken place. A brief history of the development in each country is also presented in order to help understand the evolution of policy, institutions and politics that had influence in the development of geothermal resources. An attempt has been made to identify the difficulties of each country to explain why only an average of 132 MWe per decade has been installed in the whole region. Finally, opportunities for development are described so that the rate of growth can be increased in the following decades.

2. GUATEMALA

Geothermal resources in Guatemala, as in most of Central America, are located along an active volcanic arc (Figure 1). A total geothermal resource potential of 3,320-4,000 MWe has been estimated for the country (Battocletti, 1999) from which approximately 1,000 MWe could be accessible with the present technology.

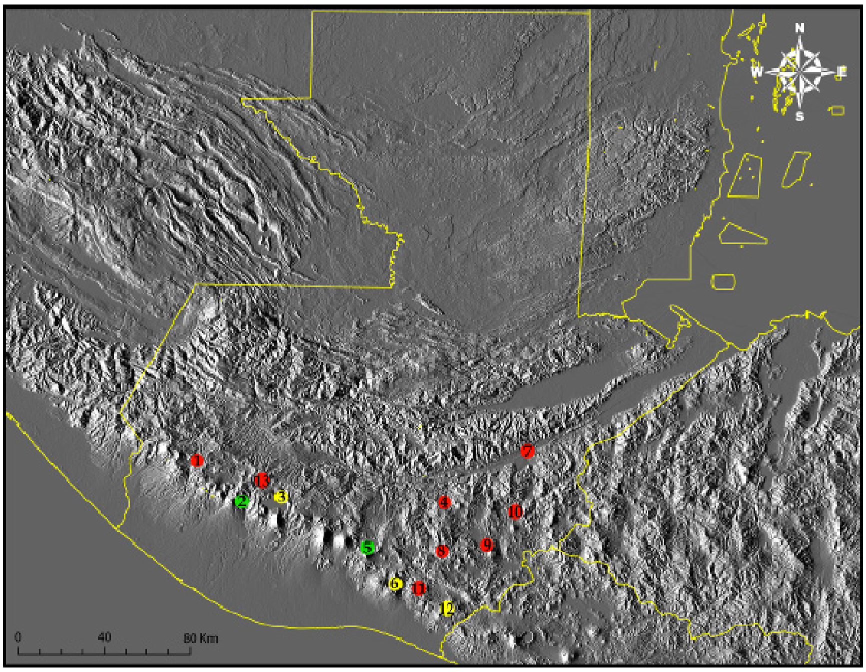

FIGURE 1: Geothermal areas in Guatemala (modified from Chandrasekharam (2008)). 1) San Marcos; 2) Zunil; 3) Atitlán; 4) Palencia; 5) Amatitlán; 6) Tecuamburro; 7) Motagua; 8) Ayarza; 9) Retana; 10) Ixtepeque-Ipala; 11) Los Achiotes; 12) Moyuta and 13) Totonicapán. Green circles denote areas where production is in place, yellow circles where both surface exploration and drilling have been done and red circles where only surface exploration has been carried out

In the early 1970's, the Guatemalan government took interest in the country's geothermal resources and carried out reconnaissance studies in order to identify and prioritize all of the resources in Guatemala. This study included seven high enthalpy geothermal areas (Amatitlán, Tecuamburro, Zunil I, Zunil II, San Marcos, Moyuta, and Totonicapán) and seven mid-low enthalpy resources (Los Achiotes, Palencia, Retana, Ayarza, Atitlán, Motagua, and Ipala) (Roldan, 2005).

Further studies and development have only been done in Moyuta, Tecuamburro, Zunil I, and Amatitlán. More recently, a geothermal resource was identified during the drilling of a water well at a mine concession in Agua Blanca near Asunción Mita. Additional drilling of four small diameter exploratory wells indicated a 200°C geothermal resource at the site.

2.1 Moyuta

In the mid1970's, surface exploration was carried out in Moyuta in an area of approximately 330 km^2 (Asturias, 2008). The results of these studies indicated a 180°C geothermal resource at a shallow depth; however, two exploratory wells drilled up to 1,000 m did not find the resource. Later geochemical studies indicated that a deep geothermal resource of 210°C did not exist and that other sites for drilling should be considered (Goff et al., 1991). Currently, ENEL Guatemala S.A. is doing an additional surface exploration for new sites of drilling.

2.2 Tecuamburro

After the initial reconnaissance studies done by the Guatemalan government in the early 1970's, exploration activities at the Tecuamburro geothermal were not undertaken until the 1980's and early 1990's. These included geological, and geochemical field studies, and drilling of a small diameter shallow continuous core well to a depth of 800 m (Asturias, 2008) with bottom hole temperatures in the order of 235°C.

More recently in 2005, West Japan Engineering Consultants (WJEC) re-analyzed the existing data and carried out an MT survey that was used to estimate a potential resource of 50 MWe. Presently, ENEL Guatemala, S.A. is implementing other surface exploration techniques to further delimit the resource and propose sites for drilling.

2.3 Zunil

After efforts at Moyuta failed to prove a viable geothermal resource, the Guatemalan government focused the exploration at the Zunil geothermal area, which was eventually divided into Zunil I and Zunil II geothermal areas. Drilling at Zunil I began in 1981 which confirmed a shallow two-phase 280°C reservoir; additional drilling in 1991 into a deeper reservoir identified a single-phase 300°C resource.

In 1999, Ormat Inc. through Orzunil installed a 28 MWe power plant which only generated 16 MWe, due to the low permeability of the shallow reservoir and a poor connection between the reinjection and production areas (Asturias, 2003). Drilling of makeup wells in 2005 did not provide a solution for the lack of production since they had low permeability. Currently, a plan to install a 5 MWe backpressure unit used in Amatitlán is in place as well as negotiations with the communities in the Zunil II geothermal area to start the development of this area.

2.4 Amatitlán

Between 1972 and 1989, exploration in Amatitlán was initially carried out by the government of Guatemala and later by the private consultancy firm, Electroconsult. In 1993, exploratory drilling confirmed the existence of a 285°C geothermal system. After further successful drilling, a total capacity of 50 MWe was estimated.

A backpressure unit owned by the government of Guatemala generated 5 MWe from 1998 to 2007. In 2001, the concession of the Amatitlán geothermal field was awarded to Ormat Inc. which later installed a 24 MWe binary power plant. Future development of the field promises to increase the capacity to 50 MWe.

2.5 Other geothermal areas

Additional surface exploration and/or drilling activities, other than those undertaken by the government in the early 1970's were only done in the San Marcos geothermal area in the western part of Guatemala. During 1993 to 1995, field geology, geophysics and geochemical studies were carried out, concluding the development of a 30 MWe resource. However, this could not be proven since there has not been any drilling yet.

Even though Guatemala has a geothermal resource potential of 1,000 MWe, it has only managed to develop 46 MWe in the last 40 years. Additionally, it can develop 20-30 MWe in the next 2-5 years, which will only constitute a 7% use of its geothermal resources.

The lack of advancement in the development of Guatemala's geothermal resources can be attributed to several factors including financial, economic, political and technical limitations. During the first three decades (1970-2000), the central government, Instituto Nacional de Electrificación (INDE), undertook the responsibility of surface exploration and drilling in the geothermal areas it has identified with potential for electricity generation. Political instability limited the possibilities for major development of the geothermal fields and in addition to this, the high initial costs and long period of time to develop geothermal resources urged the government to prioritize the development of hydroelectric projects.

Towards the end of the 1990's, the government decided to motivate the development of indigenous renewable energy resources with the participation of the private sectors by awarding concessions of the different geothermal areas to interested private firms. This has resulted in an increase in electricity generation from 5 MWe to 46 MWe in the last 10 years. However, even with the observed increase in electricity generation and the potential to develop an additional 105 MWe in the geothermal areas under study in the next decade, there is still a need to accelerate the development in those resources that have not yet been studied in detail or have not been proven by drilling.

3. EL SALVADOR

Exploration of geothermal resources in El Salvador began in the mid 1960's. During this period, a general reconnaissance of geothermal areas was carried out by the government of El Salvador assisted by several international institutions and private consultancy firms, which identified 18 potential areas of low and high-enthalpy resources (Figure 2). After the initial studies, priority was given to the Ahuachapán, Berlín, San Vicente and Chinameca high enthalpy geothermal areas as well as the low-enthalpy geothermal area of Santa Rosa de Lima. Drilling was undertaken in all of these sites in the late 1960's and throughout the 1970's and confirmed a resource of 230°C in Ahuachapán and 300°C in Berlín, while in the other fields, further studies and drilling need to be done.

3.1 Ahuachapán

Production in the Ahuachapán geothermal field began in 1975 when the operation of the first 30 MWe plant was commissioned. Continued surface exploration and development of the field in the 1970's and early 1980's brought an increase in Ahuachapán's installed capacity to 95 MWe.

Due to the intense drought during 1986-87 and limited source of electricity, El Salvador's government decided to push the Ahuachapán geothermal plant to its maximum capacity from 1987 to 1991. The overexploitation of the geothermal resource during these years brought a decrease in the electricity generation to 45 MWe. Subsequently, drilling of make-up wells and replacement of power plant components were undertaken in the 1990's in order to stabilize the resource and recover the power generation.

At present, Ahuachapán produces 85 MWe, with a total of 46 wells (19 production wells) drilled in the field and an additional 10 wells in the Chipilapa field, an extended area east of the Ahuachapán field that is used for cold reinjection of 100% of the residual waters (Burgos et al., 2006). Future plans include the replacement and/or modification of major components of one of the producing units, drilling of make-up wells, repair of existing wells and drilling in an area previously undeveloped, hoping to reach its original capacity and maintain the production for at least 10 years.

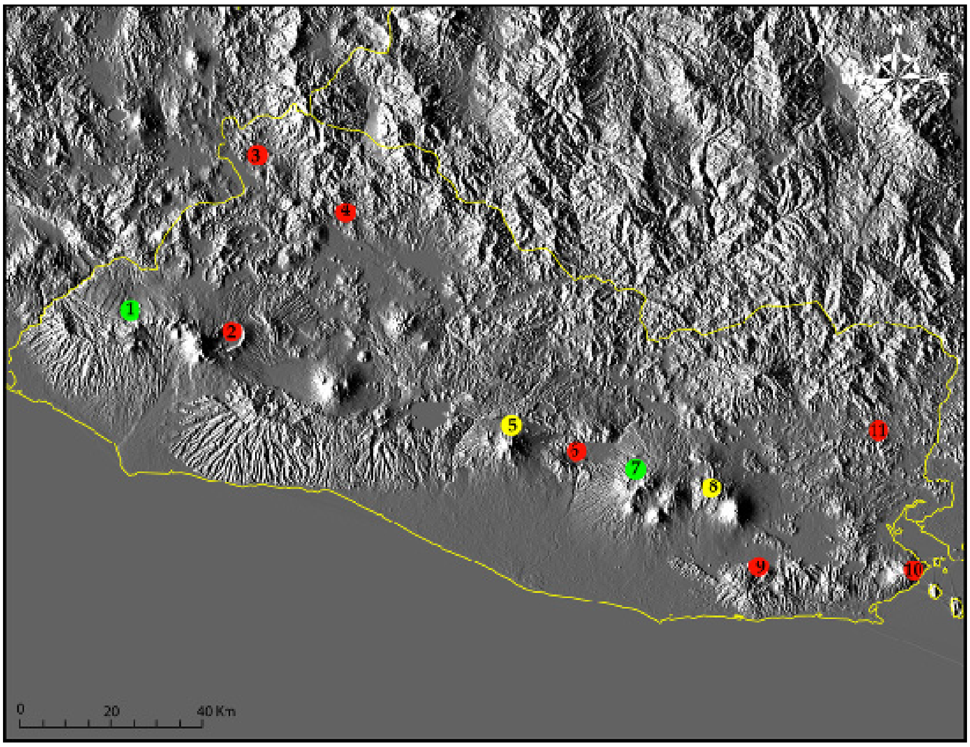

FIGURE 2: Geothermal areas in El Salvador. 1) Ahuachapán; 2) Coatepeque; 3) Metapán; 4) Chalatenango; 5) San Vicente; 6) Obrajuelo; 7) Berlín; 8) Chinameca; 9) Chilanguera; 10) Conchagua; 11) Santa Rosa de Lima. Green circles denote areas where production is in place, yellow circles where both surface exploration and drilling have been done and red circles where only surface exploration has been carried out

3.2 Berlín

The second geothermal field in El Salvador where production is underway is Berlín, which started production in 1992 with two back-pressure units of 5 MW each. Like Ahuachapán, initial exploration studies and drilling were carried out in the 1960's and mid 1970's. A second period of drilling in the early 1980's resulted in the installation of the back pressure units mentioned earlier. Political instability and civil war during the 1980's prevented further development and studies in the geothermal fields in central and eastern El Salvador, thereby limiting more geothermal activities in Berlín. As soon as the political stability and cessation of armed conflict took place in the early 1990's, the installation of two condensing units was carried out, giving a total installed capacity of 54 MWe in 1999.

At present, the total installed capacity in Berlín is 109 MW, generated by three single flash units (100 MWe) and a binary cycle power plant (9 MWe). An increase approximately of 25 MWe is planned for the following 5 years, which will be achieved by additional drilling, repair of existing wells and installation of a fifth single flash unit.

3.3 San Vicente

Initial drilling in the San Vicente geothermal area in central El Salvador was carried out in the late 1970's when a deep geothermal well (SV-1) and two small diameter shallow wells (500-600 m depth) were drilled. Primary results indicated the existence of a 240°C resource, but due to the civil war at that time and priority of development in Ahuachapán and Berlín, no further work was carried out in San Vicente until the 1990's. During this time, the national energy institution (CEL) carried out additional surface exploration studies, which included field geology, geochemistry and geophysical surveys of the area.

After the privatization of the electricity sector in El Salvador in the late 1990's, the national entity, in charge of geothermal development in the previous decades, had to compete with other private firms in order to acquire concessions. As a result of this process, the San Vicente and Chinameca geothermal concessions was granted to Ormat Inc. No considerable works were undertaken in any of the two fields, thereby; in 2004, both concessions were sold to LaGeo S.A. de C.V (LaGeo), a joint venture between ENEL of Italy and the government of El Salvador. Additional surface exploration was carried out in 2005, resulting in the proposal of four sites for drilling. Of these, only three wells were drilled. The first well identified a maximum temperature of 250°C but with very low permeability, and the other two wells did not intersect a high temperature resource.

Recent evaluation of the exploration and drilling results indicated that the initial estimate of the potential of the field of 50 MWe is higher than what the field can handle, hence additional drilling is necessary to confirm that there is enough permeability to support a much smaller resource, somewhere between 10-20 MWe.

3.4 Chinameca

Geothermal development in Chinameca, at the eastern part of El Salvador, is almost similar to that of the San Vicente geothermal area. Initial studies were done in the mid 1960's, while drilling in the late 1970's identified a 200°C resource. Due to the low temperature resource and the civil war that affected the area, no additional work was carried out until the late 1990's when the electricity sector was privatized.

LaGeo acquired the concession from Ormat Inc. in 2004 and began the surface exploration in 2005. As a result, an area of interest was identified to the south of the existing wells indicating a geothermal reservoir with temperatures ranging from 240 to 260°C. Sites for drilling four wells were proposed while plans and logistics to start drilling were carried out in 2007-2008. Two of the four planned wells have been drilled, both with reservoir temperatures of at least 220°C, although the mineralogy indicates temperatures in the order of 240-260°C.

Due to the positive results in Chinameca, the drilling of two additional wells is planned for the first half of 2010. If results continue to be favourable, further development of the field will be carried out in order to install a 25-50 MWe power plant.

3.5 Other geothermal areas

Other areas with possible high-enthalpy resources in El Salvador than those described above are limited to the Coatepeque geothermal field where initial pre-feasibility studies were done in the mid 1990's, identifying a possible resource with temperatures of around 220°C. Environmental concerns from the communities surrounding the lake in the field impeded drilling that could have confirmed the existence of a resource.

Surface exploration has been carried out by LaGeo at several medium enthalpy resources, including Conchagua, Chilanguera and Obrajuelo, where geological, geochemical and geophysical field studies have identified resources in the order of 180-220°C. Plans for drilling small diameter exploratory wells and MT surveys are in place in order to verify the existence of these resources. A country wide reconnaissance is also being carried out by LaGeo to identify all low-temperature resources that might prove a potential for electricity generation with enhanced technologies.

El Salvador's estimated total potential for power generation from known high and low enthalpy geothermal resources is approximately 700 MWe. Of these, 200 MWe are being generated from Ahuachapán and Berlín and an additional 85 MWe could potentially be produced from Chinameca, Ahuachapán and Berlín in the next decade (Rodriguez et al., 2005). This would constitute close to 40% of the total potential, considered to be a high value compared to neighbouring countries.

It is clear that the civil war in El Salvador had a severe impact on the geothermal development as it was limited to only one geothermal area in the decade it lasted. Other factors that have affected further development were the environmental impact study procedures, concerns and opposition from communities, and economic, technical and political limitations.

If El Salvador chooses to move ahead with development of its geothermal resources, numerous studies are necessary for medium-low enthalpy geothermal areas as well as investigation of the potential of active volcanoes and their surroundings. Consequently, there should be incentives from the government in order to facilitate the concession and environmental permits and to promote a national energy policy that gives priority to renewable resources.

4. HONDURAS

Honduras is one of the two countries in Central America (aside from Panama) that does not have an active volcanic chain. This fact severely limits the geothermal potential of the country as there are few sources of heat that can develop high-enthalpy resources, and therefore, is one of the main reasons why Honduras has not yet developed a single geothermal resource for electricity generation. Areas of potential geothermal resources are confined to spreading ridges where an anomalous high heat flow is found due to the extrusion of small volumes of mafic magmas and the volcanic islands in the Gulf of Fonseca, which are part of the Central American volcanic arc.

Surface exploration in Honduras was carried out in the 1970's. The main geothermal areas identified during the surface exploration are Platanares, San Ignacio, Azacualpa, Sambo Creek, Pavana, El Olivar and El Tigre Island (Figure 3). Only Platanares has temperatures that could indicate a high enthalpy resource, the other areas have estimated temperatures in the range of 130-180°C. Drilling of three shallow coreholes in Platanares during the mid 1980's identified temperatures of 165°C at 250 m depth and suggested a deeper reservoir (1,200-1,500 m depth) with temperatures in the order of 220°C (Laughlin, et al., 1988).

Due to the low temperature resource found in most of the identified geothermal areas and the low potential for electricity generation, the government of Honduras decided not to pursue the geothermal development and focus instead on other sources of energy. However, once the reform of the electric sector was established, private firms were allowed to invest in geothermal resources. In 2005, Geotérmica Platanares S.A. de C.V. (Geoplatanares) acquired the concession of the Platanares geothermal area. Additional surface exploration activities were immediately carried out, which resulted in a proposal of three sites for drilling three deep exploratory wells that would contribute to the development of a potential resource estimated at 35-50 MWe.

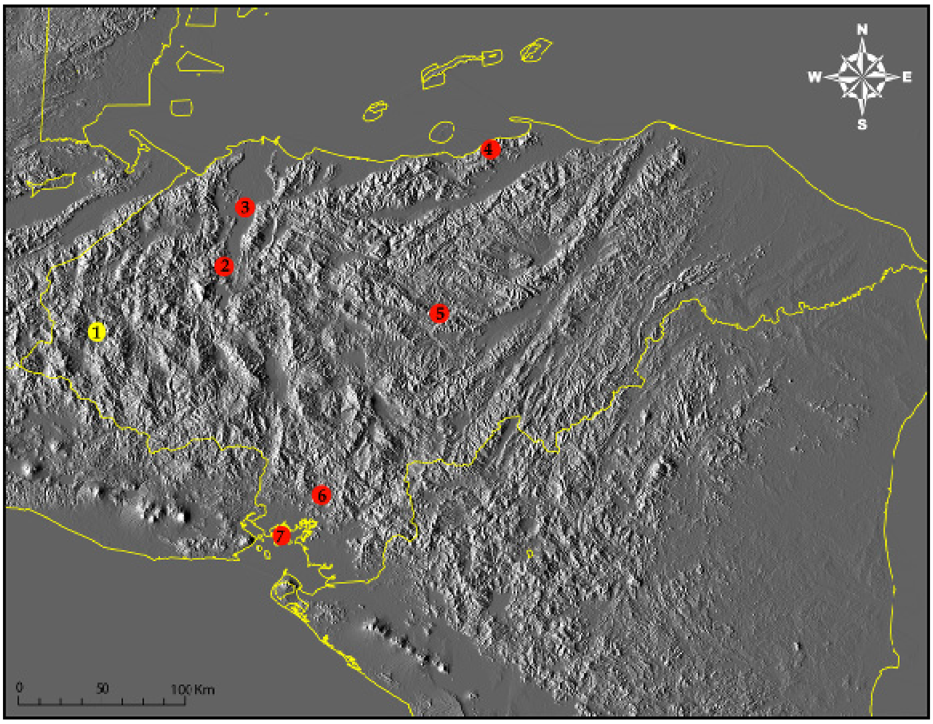

FIGURE 3: Geothermal areas in Honduras as modified from Chandrasekharam (2008). 1) Platanares; 2) Azacualpa; 3) El Olivar; 4) Sambo creek; 5) San Ignacio; 6) Pavana; 7) Isla El Tigre. Yellow circles denote geothermal areas where both surface exploration and drilling have been done and red circles where only surface exploration has been carried out

Even though the total geothermal potential in Honduras is considered low at 100 MWe compared to other Central American countries, it can still be considered an important contribution to the country's overall energy demand. However, in order to conduct further development of the few resources available, not only the known sites have to be reanalyzed in view of enhanced technologies but a new country-wide reconnaissance survey needs to be implemented to identify other sites previously overlooked. Moreover, the government of Honduras has to promote the development of renewable energies and facilitate the permitting procedures.

5. NICARAGUA

Nicaragua has the largest geothermal potential in Central America estimated to be 1,100 MWe (Zuñiga, 2005). Geothermal surface exploration began in the 1960's, when regional reconnaissance studies were carried out in order to identify available resources. In the mid 1970's, as a result of the global oil crisis, more emphasis was given to exploration of geothermal resources. Priority was given to the following geothermal resources: San Jacinto-Tizate, Momotombo, El Hoyo-Monte Galán, Managua-Chiltepe, Volcán Cosigüina, Volcán Casita- San Cristobal, Volcán Télica-El Ñajo, Tipitapa, Masaya- Granada-Nandaime and Isla de Ometepe (Figure 4).

In 2001, a nationwide reassessment of the geothermal resource potential of the identified fields and prospects in the country was completed. The purpose of this study was to provide a document with a unified base of current information of all the known geothermal resources in order to promote them to the private sectors interested in obtaining exploration and development concessions of one or more geothermal areas.

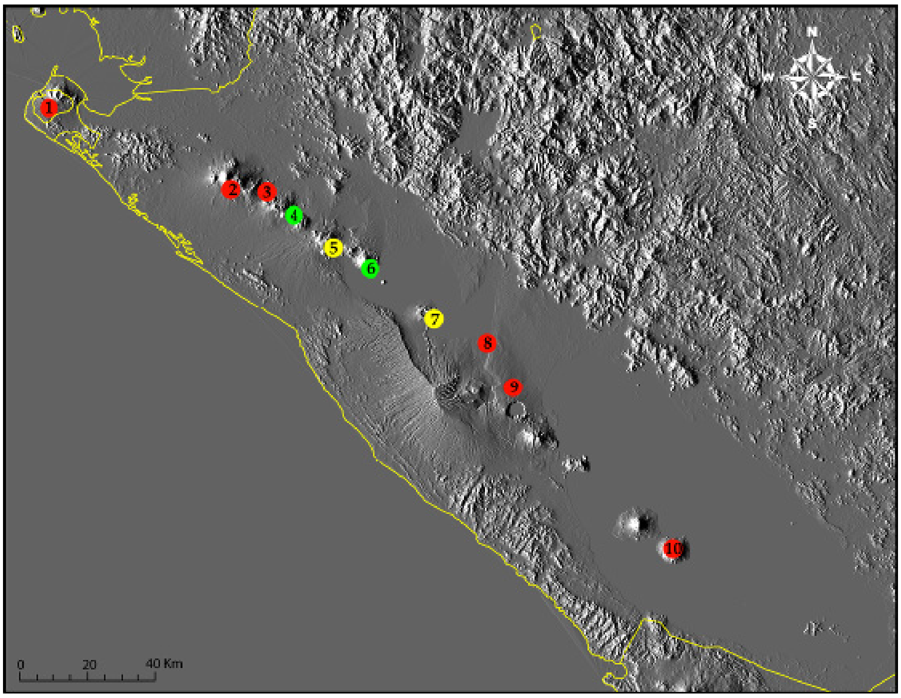

FIGURE 4: Geothermal areas in Nicaragua as modified from Chandrasekharam (2008). 1) Cosigüina; 2) Casitas-San Cristobal; 3) Ñajo-Santa Isabel; 4) San Jacinto Tizate; 5) El Hoyo-Monte Galán; 6) Momotomo; 7) Managua-Chiltepe; 8) Tipitapa; 9) Masaya-Granada; 10) Ometepe Island. Green circles denote areas where production is in place, yellow circles where both surface exploration and drilling has been done and red circles where only surface exploration has been carried out

5.1 Momotombo

Immediately after the nationwide geothermal exploration, detailed surface investigations were focused on the Momotombo geothermal area and during the period 1974-1978 exploration and development drilling began, resulting in the installation of the first 35 MWe condensing unit in 1983. Power output started decreasing from the end of 1986, which led to additional drilling of shallow production wells in order to support a second 35 MWe condensing unit, which was installed and commissioned in March 1989. An over-exploitation of the reservoir and lack of a proper field development strategy resulted in a fast decline of the power output from 69 MWe in 1990 down to 8 MWe in 1999 (Porras, 2008).

In order to cope with the decline in the power generation, drilling of makeup wells, repair of damaged wells and evaluation of the field were carried out. As a result of these actions, the recovery of steam production was achieved but the decline of production remained. It was observed that scaling and cooling were the two principal causes for the overall decline.

In 1997, Ormat Inc. took over the management of the geothermal resource from the government as part of a 15-year concession. It has since invested in surface exploration to determine new production targets, workover of existing wells, installation of scaling inhibitors, acid stimulation, drilling in the new target areas, installation of a 7 MWe power plant and reinjection of 100% of residual waters. As a result, production has stabilized at 35 MWe out of a total 77 MWe total installed capacity.

Future plans in Momotombo depend on the extension of the concession period as Ormat believes that drilling outside of the boundaries of the present concession area can produce enough steam for the second 35 MWe condensing unit, currently not being operated.

5.2 San Jacinto-Tizate

During the mid 1990's, several wells were drilled in the San Jacinto-Tizate geothermal area with depths up to 2,200 m. These wells verified the existence of a high temperature (260-290°C) geothermal resource and an estimated potential of 25 MW. Initial production at San Jacinto-Tizate by Polaris Geothermal started in 2005 with the installation of two 5 MWe back pressure units. In 2008, four additional wells were drilled for the expansion of generating capacity of 24 MWe.

5.3 El Hoyo-Monte Galán

Initial reconnaissance studies done in the 1970's and the reassessment carried out in 2001 estimate that the El Hoyo-Monte Galán geothermal area has a total potential capacity of approximately 150 MWe. Surface exploration undertaken as part of the reassessment of the field included geology, geophysics and geochemistry as well as the drilling of several shallow gradient wells, which identified temperatures in the order of 120°C at depths of no more than 150 m.

The El Hoyo-Monte Galán concession was awarded to Geotérmica Nicaragüense S.A. (Geonica) a joint venture between ENEL (Italy) and LaGeo (El Salvador) in 2006. Geonica carried out surface exploration including several geophysical surveys, geochemical sampling and analysis of fluids and gases as well as field geology in order to propose sites for drilling of four exploratory wells that would confirm the existence of a geothermal resource. The first well was drilled in April 2009, which identified temperatures in the range of 220°C at 2,000 m depths and plans for a second well are underway.

5.4 Managua-Chiltepe

Initial surface exploration at the Managua-Chiltepe geothermal area consisted of geological investigations, geophysical surveys and geochemical analysis of fluids. Additional work done in 2000-2001 identified a potential resource of approximately 110 MWe.

Geonica also obtained the concession of Managua-Chiltepe in 2006 and carried additional surface exploration, including a magnetotelluric, gravity and aeromagnetic geophysical surveys, geochemistry and field geology. A small diameter corehole was recently drilled to a depth of approximately 1200 m and results are currently being evaluated.

5.5 Other geothermal areas

In addition to the above mentioned geothermal areas, the government of Nicaragua has also granted an exploration concession of the Volcán Casita-San Cristobal geothermal area to Cerro Colorado Power, which has proposed two sites for future drilling. Negotiations with landowners and obtaining environmental permits are presently being undertaken in order to start drilling. The government of Nicaragua is also currently receiving bids for the concessions of Caldera de Apoyo (40 MWe), the Mombacho volcano (40 MWe) and the Concepción volcano in the Ometepe Island (30 MWe).

Political instability, civil war and financial limitations have prevented Nicaragua from developing more geothermal resources. The national energy policy of Nicaragua wants to develop rapidly its indigenous sources of energy and it has made great efforts to promote them with the private sector in order to accelerate electricity generation. The oil crisis of the 1970's and the more recent crisis in 2008 strongly affected the country's economy as it is strongly dependent on fossil fuels for power generation.

Nicaragua has only managed to produce 45 MWe, a mere 4% of the total potential of 1,100 MWe. However, with the current state of surface exploration and drilling, a possibility of an additional 100 MWe capacity to go online in the next 5-10 years is foreseen.

6. COSTA RICA

Geothermal surface exploration in Costa Rica began in the mid 1960's with the study of the Las Pailas and Las Hornillas geothermal areas. In the mid 1970's, a general study was carried out at the Guanacaste province and an overall resource assessment was done in the later part of that decade. By the early 1990's, it had completed a nationwide reconnaissance assessment of geothermal resources and had classified them into different categories depending on the expected temperatures and existence of potential geothermal reservoirs. This study also concluded that the possible total geothermal potential of Costa Rica was about 900 MWe (Yock Fung, 2008).

Amongst the geothermal areas identified are Miravalles, Las Pailas, Borinquen, Mundo Nuevo, Tenorio, Rincón de la Vieja, Poco Sol and potential areas around the volcanoes Platanar, Poás, Barva, Irazú and Turrialba. Of these, production has only been focused at Miravalles, while production is expected to start in 2011 at Las Pailas (Figure 5).

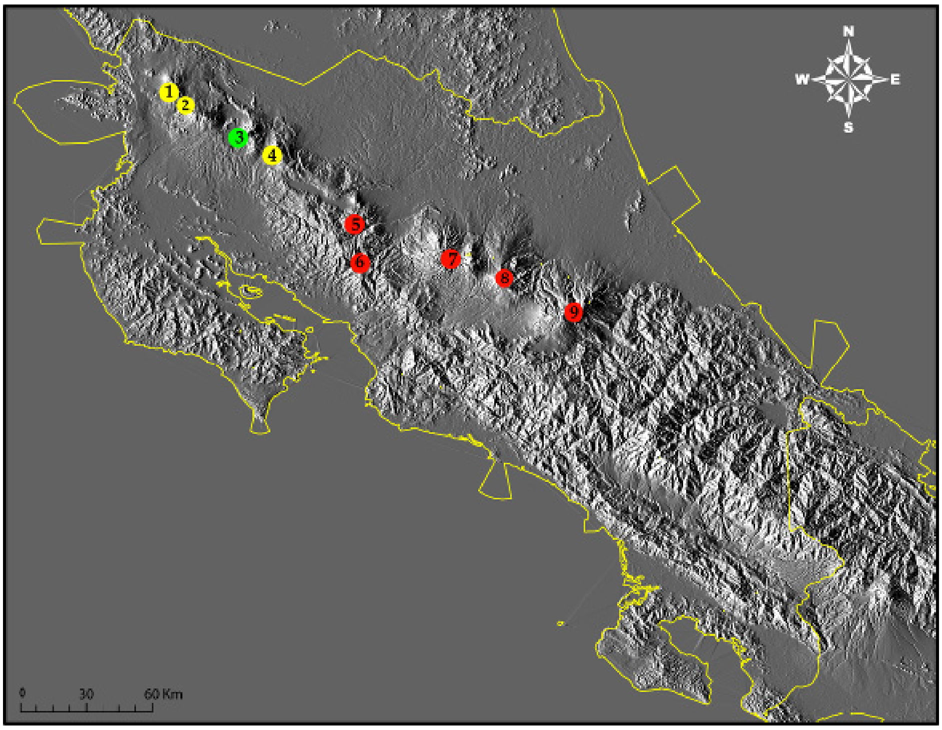

FIGURE 5: Geothermal areas in Costa Rica (modified from Chandrasekharam (2008)). 1) Borinquen; 2) Las Pailas; 3) Miravalles; 4) Tenorio; 5) Pocosol; 6) Cerro Pelado; 7) Platanar-Poás; 8) Barva; 9) Iraza-Turrialba. Green circles denote areas where production is in place, yellow circles where both surface exploration and drilling have been done and red circles where only surface exploration has been carried out.

6.1 Miravalles

Feasibility studies at the Miravalles geothermal area were carried out in the mid 1980's followed by the development of the field that led to the installation of a first 55 MWe condensing unit in 1994. Development continued until 2004 when the total installed capacity reached 163 MWe. A total of 53 wells have been drilled (29 production and 16 reinjection wells) into a reservoir with a temperature of 220-240°C (Moya, et al 2007). Prior to reinjection, the residual water is sent to a binary power plant that generates approximately 15 MWe.

Since the beginning of operation, the Miravalles wells have been affected by scaling and corrosion, which has been controlled by the installation of inhibitor systems and acid stimulation to remove formation scaling. Zones where reinjection does not reach the reservoir have shown a decrease in the overall production.

6.2 Las Pailas

Detailed surface exploration was done at Las Pailas in 1999-2001, and more studies and drilling took place between 2003 and 2005. Results from these investigations concluded that there was evidence of a 240°C reservoir with enough potential to support the installation of a 35 MWe power plant. Because of its location on the southern slope of the Rincón de la Vieja volcano, a large part of the geothermal resource is within the Rincón de la Vieja National Park boundaries and the Guanacaste Dry Forest property, which has prevented further studies within the park boundaries.

At present, development wells are being drilled in order to supply the necessary steam and reinjection capacity to install a 35 MWe power plant. Civil works are also being undertaken for the installation of the power house, separator station and other facilities, hoping to start production in 2011 (Yock Fung, 2008).

6.3 Borinquen

At the Borinquen geothermal area, detailed field geology, geochemistry and geophysical surveys have been carried out as part of the feasibility study that has also included drilling of several gradient wells and geothermal exploration wells with temperatures of up to 275°C and good permeability. Future plans include more drilling in order to delimit the resource and estimate the potential for power generation.

6.4 Other geothermal areas

Additional detailed surface exploration (geology, geochemistry, geophysics) and drilling (gradient and deep geothermal exploration wells) have been carried out at Tenorio, Mundo Nuevo, Poco Sol and the northern flank of the Rincón de la Vieja volcano.

At the Tenorio geothermal area, two exploratory wells were drilled at depths of almost 2,500 m in 1999-2000 with unfavourable results as only temperatures less than 160 ºC were encountered. Because part of the geothermal area is within the Tenorio national park, more investigations that would help determine the exact location of higher temperature resources cannot be carried out.

At the Mundo Nuevo, Poco Sol and the northern flank of Rincón de la Vieja geothermal areas, surface exploration and in some cases, drilling of gradient wells have been carried out, but the potential of the geothermal resources has not yet been determined. Exploration has been limited due to its proximity to the national parks and reserves, thereby preventing any geothermal activities within the park boundaries.

In spite of having developed only 22% of the total geothermal potential, Costa Rica has gone ahead in the geothermal exploration of most of its resources. Unfortunately, further geothermal and hydroelectric development is limited as a substantial geothermal potential is found inside protected areas in Costa Rica. Development can only be achieved unless the government modifies its environmental and national park laws. If this does not happen, the increase in electricity generation will have to be supplied by other sources of energy.

7. PANAMA

In Panama, a nationwide geothermal exploration program was carried out in the 1970's in order to identify all of the potential geothermal areas in the country. Of all the fumarole and hot spring areas visited, the Barú-Colorado, Valle de Antón, Tonosí, Coiba Island and Chitre de Calobre areas were identified as a priority for electricity generation. However, future work was only focused on the Barú-Colorado, Valle de Antón and Chitre de Calobre areas, both the Tonosí and Coiba Islands areas were considered to have only marginal temperatures and therefore of no immediate interest (Reyes, 2005) (Figure 6).

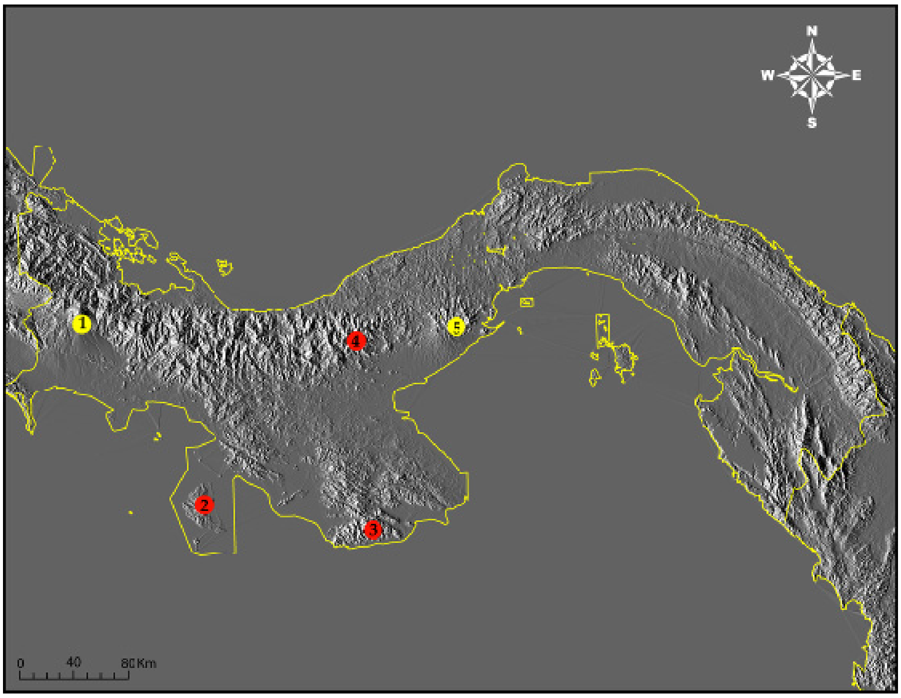

FIGURE 6: Geothermal areas in Panama as modified from Chandrasekharam, (2008). 1) Barú-Colorado; 2) Coiba Island; 3) Tonosí; 4) Chitre de Calobre; 5) Valle de Antón. Yellow circles denote geothermal areas where both surface exploration and drilling have been done and red circles where only surface exploration has been carried out

Further investigations were done in Barú-Colorado in 1976-1977 when six wells were drilled to an approximate depth of 1,000 m. Results from these wells were unfavorable as maximum temperatures at those depths were in the order of 100°C. Based on the results, the government of Panama decided not to continue studies and development of this area and focus instead on other areas.

Surface exploration of the Chitre de Calobre and Valle de Antón geothermal areas began in the 1980's where field geology, geochemistry and geophysics surveys were carried out. Government policy at that time and environmental concerns resulted in the suspension of further activities in the area. A second attempt to study Barú-Colorado, Valle de Antón and Chitre de Calobre continued in 2000-2003, but because of insignificant results, the government cancelled again all geothermal exploration, leaving the total potential energy of Panama unresolved (Chandrasekharam, et al., 2008).

Considering that most of the exploration in Panama was done during the 1970's to 1990's and that the techniques used were not as powerful as those available today, a reassessment of the main geothermal areas and others previously not considered important should be carried out in view of the enhanced technologies in drilling and extraction of heat. The resources that were not previously considered of importance might now be available for exploitation as a thermal or electric source of energy.

8. CONCLUSIONS

Several stages of geothermal development such as initial geothermal exploration and nationwide assessments of geothermal potential have been carried out in Central America, all of which are common to most of the countries in the region.

In the period from 1960 to the1990's, every country in Central America relied on government institutions with the aid of international consultants and institutions like the United Nations to undertake geothermal exploration and development. However, this limited the capability of each country as this brought insufficient technical and economic abilities to develop geothermal resources. As time passed, some countries were able to make progress on both aspects and managed to develop one or two geothermal fields.

The end of the 20th century brought a change in policy in most governments of the region as the electric sector encouraged private investment for the development of indigenous renewable sources of energy. Only Costa Rica and Panama maintained government control of the electric sector. Even though private investors in countries like Guatemala and Costa Rica have managed to increase the development of geothermal resources, this has not taken place in the rest of the region and has not been as fast as it was expected.

It is clear from the lack of major development of geothermal resources that there existed and still are important barriers that limit the potential growth in the region. Political stability, civil war, technical limitations, financial (high initial cost of developing resources) and economic (competition with cheaper sources of energy) problems were faced by all or most countries in the first four decades (1960-1990's).

The 21st century opened up the market to private investors but problems remain causing an impact on the rate of development of geothermal resources, which included regulatory barriers (forest laws, environmental impact procedures, procedures to obtain concessions, etc.), institutional ambiguity of functions, economic and financial limitations seem to be common factors. Technical factors should be considered as the risk of initially finding a resource is very high (approximately 75%), hence, immediate results are necessary so private companies can keep their losses at a minimum.

In spite of all the difficulties faced by geothermal development in the region, there exist several opportunities that might help improve the growth rate of development of new fields. The government in most countries is starting to realize that in order to facilitate the development of resources, the institutional and regulatory frameworks have to be improved to reduce bureaucracy and ambiguity of functions as well as increase the incentives for the development of renewable resources through a clear energy policy that emphasizes renewables.

The Clean Development Mechanism (CDM) of the Kyoto Protocol has helped some countries overcome economic barriers by obtaining other sources of income that eases the financial constraints of geothermal development. The high price of oil in the past couple of years gave opportunities to the geothermal sector because even with the initial high cost of development, a geothermal resource is very competitive once it is developed. Technical advancement in modeling geothermal resources as well as improved drilling and extraction technologies can reduce the high risk and improve financial conditions for new fields

Even though the Central American countries had slow progress in developing their own geothermal resources, the amount of resources available and the opportunities for the future foresees an accelerated progress in the upcoming decades, however, in order for this to be possible the government has to guarantee stability and invest in incentives (economic or in kind) in order to make the geothermal resources attractive for investment.

REFERENCES

Asturias, F., 2003: Reservoir assessment of the Zunil I and II geothermal fields, Guatemala. Report 3 in: *Geothermal Training in Iceland.* UNU-GTP, Iceland, 1-32.

Asturias, F., 2008: Geothermal resources and development in Guatemala. In: Georgsson, L.S., Holm, D.H., and Fridleifsson, I.B. (eds.), *Papers presented at the 30th Anniversary Workshop of the United Nations University Geothermal Training Programme*, UNU-GTP, Reykjavík, CD, 8 pp.

Battocletti, L., 1999: *Geothermal resources in Latin America and the Carribbean.* Sandia Nacional Laboratories and US Department of Energy, report.

Bundschuh, J., Alvarado, G., Reyes, E., A.R.R. Rodriguez, Palma, M.J., Zuñíga, A., Castillo, G., 2002: Geothermal energy in the Central-American region. In: Chandrasekharam, D. & Bundschuh, J. (eds.), *Geothermal energy for developing countries*. Balkema Publisher, The Netherlands, 313-364.

Burgos, J.A., and Guidos, J.A., 2006: Lessons learned from geothermal development. *Proceedings of the Workshop for Decision Makers on Geothermal Projects in Central America, San Salvador, El Salvador,* UNU-GTP and LaGeo, CD SC-02, 8 pp.

Chandrasekharam, D. and Bundschuh, J., 2008: Low-enthalpy geothermal resources for power generation. CRC Press, 149 pp.

Gawell, K., Reed, M., and Wright, P.M. 1999: *Preliminary report: Geothermal energy, the potential for clean power from the earth.* Geothermal Energy Association, Washington, D.C. 14 pp.

Goff, F., Janik, C., Fahlquist, L., Adams, A., Roldan M., A.R., Revolorio, M., Trujillo, P.E., and Counce, D., 1991: A re-evaluation of the Moyuta geothermal system, Southern Guatemala. *Geothermal Resources Council, Transactions, 15,* 3-10.

Laughlin, W., 1988: *Recommendations report for the Platanares geothermal site*. Department of Copán, Honduras; Central American Energy and Resources Project, Los Alamos National Laboratories and United States Geological Survey, Los Alamos, New Mexico.

Moya, P., and Yock F., A., 2007: Assessment and development of the geothermal energy resources of Costa Rica. *Papers presented at the Short Course on Geothermal Development in Central America Resource Assessment and Environmental Management, San Salvador, El Salvador,UNU-GTP and La Geo,* CD SC-04, 18 pp.

Porras, 2008: Twenty five years of production history at the Momotombo geothermal field, Nicaragua In: Georgsson, L.S., Holm, D.H., and Fridleifsson, I.B. (eds.), *Papers presented at the 30th Anniversary Workshop of the United Nations University Geothermal Training Programme*, UNU-GTP, Reykjavík, CD, 7 pp.

Reyes, E., 2005: Estado actual de la geotermia en Panamá. *Presentation at the VI Foro Regional: Impacto Estratégico de la Energía Geotérmica y Otros Renovables en Centroamérica*, Managua, Nicaragua.

Rodriguez, J.A., and Herrera, A., 2005: El Salvador country update. *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey,* CD, 4 pp.

Roldan M., A.R., 2005: Geothermal power development in Guatemala, 2000-2005. *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey,* CD, 8 pp.

Yock Fung, A. 2008: Geothermal resources development in Costa Rica. In: Georgsson, L.S., Holm, D.H., and Fridleifsson, I.B. (eds.), *Papers presented at the 30th Anniversary Workshop of the United Nations University Geothermal Training Programme*, UNU-GTP, Reykjavík, CD, 8 pp.

Zúñiga, A., 2005: Nicaragua country update. *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey*, 5 pp.