GEOTHERMAL RANKING AND RESOURCE ASSESSMENT OF COSTA RICA

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ABSTRACT

This paper summarizer the results of a study aimed at quantifying the geothermal potential of Costa Rica in terms of *resources* and reserves to a depth of 3 km.

The main conclusions of the study are:

i) the country can be subdivided into 12 *provinces* which include 28 *areas* with different degrees of interest far geothermal exploration:

ii) the extractable energy corresponds to ~ 1.4 x 10^6 OET (oil equivalent tons) in terms of reserves, and to ~ 2.1 x 10^6 OET in terms of resources:

iii) the electric capacity that could be fed at full load for 25 years by the high-temperature (> 150°C) fraction of this energy ranges between almost 1000 MW, (by utilizing the *reserves* only) and 2240 MW, (by utilizing all the *resources*): and

iv) the *areas* of main interest far the production of geothermoelectric energy are Miravalles, Rincón de la Vieja, Irazú-Turrialba, Tenorio, Platanar, Poás, Barva, Fortuna and Orosi-Cacao.

Key words: Casta Rica, geothermal ranking. resource assessment, resources. reserves, geothermoelectric capacity.

1. INTRODUCTION AND GOALS OF THE WORK

The exploitation of geothermal energy to produce electric power is one of the priorities set by the Costa Rican government in the utilization of national energy sources. Thus. in order to define the role that natural heat might play in satisfying the country's energy needs, from 1989 to 1991 ICE (Instituto Costarricense de Electricidad). with the collaboration of UNRFNRE (United Nations Revolving Fund far Natural Resources Exploration), conducted a study called *Evaluación del Potencial Geotérmico de Costa Ricn* (ICE. 1991). Preliminary information on this study has been published by Mainieri *el al.* (1992).

The specific goals assigned to the study were:

- subdivide the country into homogeneous geothermal provinces and areas to enable classification of the various zones according to their temperature conditions. to a depth of 3 km:
- on the basis of a conventionally established scale of technical priority, indicate the degree of interest that each *province* and *area* could have for the exploitation of the natural heat:
- make a quantitative assessment of the resources and *reserves* according to different temperature ranges so as to distinguish the ones that could be used to produce electric power from those usable only for direct applications:
- estimate the electric capacity that the high-temperature *resources* and *reserves* could feed for a period of plant operation of at least 25 years.

2. TERMINOLOGY AND ASSESSMENT METHODOLOGY

To achieve the above goals it was necessary to establish beforehand: *i*) the meaning with which some terms should be used: *ii*) the values of the reference parameters (deplh, temperature ranges. etc.); and *iii*) an assessment methodology applicable to all the zones of the country, in order to get consistent results.

2.1 Principal Terms

The terminology used in this paper is mostly the one proposed by Muffler and Cataldi (1978); it was, however, necessary to adapt it in some cases to take into account the suggestions of other authors (Cataldi and Celati. 1983: Barberi *el al.*, 1986: Cataldi *Pl al.*, 1993) and the conditions of the Costa Rican energy market. In particular. it was necessary to "rethink" (with respect to the one given by Muffler and Cataldi. 1978) the definition of the two terms *resource* and *reserve.*

For the sake of clarity. the meanings with which the principal terms are used in this work are reponed below.

Geothermal potential: collective term used in a broad sense to indicate generically the availability of terrestrial heat in a given zone. Therefore, the term prescinds from any technical and economic considerations related to well depth. temperature, pmduction modes. exploitation period. type nf fluid utilization, costs. etc.

Resource *base*: all of the geuthermal energy in the earth's crust beneath a specified zone, referenced to the mean annual temperature of the zone.

Accessible resource base: that fraction of *resource base* associated with the shallowest part of the earth's crust in a certain zone. down to a specified reference depth.

Resource: that pan of *accessible resource base* that. for a specified reference depth. could be legally extracted and economically utilized according to energy costs assumed to be valid in a future lime staning between 10 and 25 years after the assessment.

Reserve: that pan of *accessible resource* bore that. for a specified reference depth. could he legally extracted and economically utilized according to current and "short term" energy costs. The "short term" was considered to be a period of time staning within 10 years after the assessment.

Dry rock sizeable blocks of lithosphere (> 10 km^3) characterized by very low permeability values. This expression was maintained solely so as not to exclude the possibility that in a long-term future (> 10 years after the assessment) "heat mining" projects could be implemented in some sectors of the country where very low permeability rock formations exist.

Geothermal province. or simply *province:* quite large portion of territory which, due to its geologic and thermal conditions (lithostratigraphy, hydrogeology. volcanology. tectonics. thermal regime. etc.), takes on a **geothermal** character of its own on the regional **scale.** by which it can he distinguished from contiguous portions of territory.

***Geothermal area*, or** simply area: portion of a province characterized by quite **homogeneous** geologic **and** thermal conditions on the local scale. which make it recognizable from other nearby *areas* within the same *province.*

Category: term used to rank the various *provinces* according to a **general** scale of priority **conventionally** characterized with **the** letters A. **B**, **C** and **D**.

Class: term used to rank the *areas* within each province, according to a more detailed **scale** of priority: A_1-A_2, B_1-B_2, C_1-C_2 and D_1-D_2.

2.2. Reference **Depth**

The reference depth considered **for** the calculation of the ***accessible resource*** base is **3 km**. This value was **also** maintained for the calculation of the *resources.*

Conversely. to **calculate** the *reserves* a reference depth of **2.5** km **was taken.** This because in Costa Rica the exploitation of geothermal **energy** in the "short term' (< 10 years) is considered to he economical only for **average** well depths of up to 2.5 km.

2.3. **Temperature** Ranges

The temperature **ranger** shown in Table **I** were established to characterize the *resources* **and** *reserves* on the basis of their energy **content.** and to allow ranking the *provinces* and *areas* according to a **scale of** priority reflecting their greater **or** lesser interest **for** the exploitation of the natural heat. There **temperature** ranges **also make** it possible to recognize the type of utilization that can he implemented in the various *provinces* and *areas* with the **various** components of the **extractable** heat.

In particular. as concerns the lower temperature limit necessary **for** economical production of **geothermoelectric** power, the value of **150°C was** considered.

2.4. Methodology **Used For** The Resource **Assessment**

On account of the considerable **extent** of the study **area** (~ **51,000 km²**) and **the** different geologic conditions of the various **geothermal** *provinces* and *areas* of **Costa** Rica. and in order **also** to get consistent results, the so-called ***volume method*** was chosen **for** the **resource** assessment (Muffler and Cataldi, 1978).

As is known. this method is based on the calculation of the **total** heat stared in the rock **and** fluids of a given **zone** within an established depth, **and** on the subsequent estimation of the **fraction** of **extractable** heat by applying a suitable *recovery factor.* The equation that expresses this concept. in its general form, is the following *one:*

$$\bar{H} = R\,H, \quad \text{where:} \qquad (1)$$

- $\bar{H}$ is the heat extractable in a given zone of **surface area S**;
- R is the *recovery factor* (fraction of total heat that can be extracted and brought to tlic wellhead by means of a carrier fluid):
- $H = K_v \cdot V \cdot (T_m - T_o)$ is the total heat stored in the **subsoil of a** given zone within the established depth (d), with: (2)
  - K_v = volumetric specific heat of rock + water;
  - $V = S \cdot d$ = volume of lithosphere beneath a given **zone** of **surface** area **S**, within **the** reference depth (d):
  - T_m = mean temperature ofthe volume V;
  - T_o = mean **surface** temperature of a given zone.

As stated in section **2.2.** the value of the reference depth (d) was **assumed** to he 3 km for the *resources* and **2.5 km for** the *reserves.*

As for the *recovery factor* (R), bearing in mind the values given in or deducible **from** the literature for some **geothermal** fields under exploitation in various countries around the world. and especially **the Miravalles** field in Costa Rica, it was **deemed** necessary to establish ranges of R for the various types of *resources* and *reserves* capable of reflecting, **for** each *area*, **the different** local geological and thermal conditions (depth of the 150°C isotherm **surface. temperature** variations with depth. degree of fracturing **of the rocks,** etc.). **The ranges** established **for** R are as follows:

Resources
- high temperature (> 150 °C)........0.1 ≤ R ≤ 0.4 %
- moder.-to-low temp. (< 150 °C).....0.1 ≤ R ≤ 1.2 %

Reserves
- high temperature (> 150 °C)........0.09 ≤ R ≤ 0.36 %
- moder.-to-low temp. (< 150 °C)....0.09 ≤ R ≤ 1.08 %

From these **values** it can be **seen** that. to take account of the lesser degree of fracturing of the **rocks** at greater depths. the **ranges** of R for the high-temperature *resources* and *reserves* were kept about **three** times lower than the **ones** corresponding to the moderate-to-law temperature *resources* and *reserves*. In addition, to take into account the expected improvement of natural heat extraction technology in the medium-long **term,** the ranges of the two different types of *resources* (higher and lower than **150°C.** respectively) **were kept a** little higher (~**10%**) than the corresponding ranges ofthe *reserves*.

After estimation for all the *areas* of the **extractable** heat in **terms of** *resources* and *reserves* as indicated above, in order to calculate the electric energy producible by the high-temperature (>150°C) *resources* and *reserves* it was **first assumed** that the geothermal

Table 1. Classification scheme adopted for the resource assessment of Costa Rica

Hydrogeology	Category of *Province*	Class of *Area*	Temperature (at 3 km depth)	Foreseeable type of utilization
Provinces and *areas* with at least one important confined aquifer	A	A_1	T > 200 °C	High-temperature *resources* and *reserves*: suitable for
		A_2	150 °C < T < 200 °C	geothermoelectric production and/or direct applications
	B	B_1	120 °C < T < 150 °C	Moderate-to-low temperature *resources* and *reserves*: suitable
		B_2	90 °C < T < 120 °C	mostly for direct applications
	C	C_1	60 °C < T < 90 °C	Low-temperature *resources* and *reserves*: suitable for direct
		C_2	T < 60 °C	applications only
Provinces and *areas* with no imporrant aquifer	D	D_1	T > 150 °C	HDR possible "heat mining" in the long term (> 10 years)
		D_2	T < 150 °C	*HDR* no foreseeable utilization

reservoirs of Costa Rica are all of the water-dominated type.

A conversion factor, e = f(T), was then used to convert thermal energy to electric energy: this factor is a function of the average temperature of the volume of rock underlying the 150°C isotherm surface. to the considered depth (3 km for *resources* and 2.5 km for *reserves).* This was done for all the category A provinces (separately for the class A_1 and A_2 *areas*), considering two different generating cycles: single flash and dual flash.

Finally, the installable electric capacity in each class A_1 or A_2 *area* was calculated separately far the two different generating cycles mentioned above. assuming that:

- the annual load factor of the plants is 100% (-8730 h/y);
- the plant utilization factor is also 100% (full load);
- the plant production period is 25 years.

These are assumptions that enable simplification of the calculations: however, they have the advantage of allowing comparison between the results of different *areas.* and of leaving a margin of at least 10% for eilher a longer production period or a larger installed capacity.

3. GEOTHERMAL RANKING

Although not distributed uniformly over the whole country, there is a considerable amount of geoscientific data available on Casta Rica that make it possible to subdivide its territory into a series of *provinces* and areas with different geothermal characteristics.

In particular, the information used for the work under review was derived from: *i)* a geothermal reconnaissance Study over the whole national territory: *ii)* prefeasibility Studies carried out on preferential sectors of the Cordillera de Guanacaate: *iii)* feasibility studies conducted for the Miravalles Geothermal Project; *iv)* a few tens of deep wells for oil and geothermal exploration, drilled in various zones of the country: and *v)* surveys, prospectings, analyses and records of various kinds conducted in different regions of the country by government agencies, Universities and other Costa Rican institutions.

The integrated interpretation of all this information on the basis of the analysis of the two main factors that control the formation of a geothermal system (temperature and waler circulation) made it possible to prepare a series of thematic maps. sections, tables. etc., focussed on to the objectives of this study. Simplified versions of just two of these maps are reproduced here (Figures I and 2).

In panicular. the reconstruction of the lemperature map at 3 km depth (Figure 2) was indispensable for the delimitation and the ranking of the different *provinces* and *areas.* as well as for the quantitative assessment of the extractable heat in terms of *resources* and *reserves.*

The results of the geothermal ranking, shown in Figure 3, allow us to say that in Costa Rica there are:

- four category A *provinces* in which nine class A_1 *areas* (with first priority geothermal interest) and seven class A_2 *areas* (with

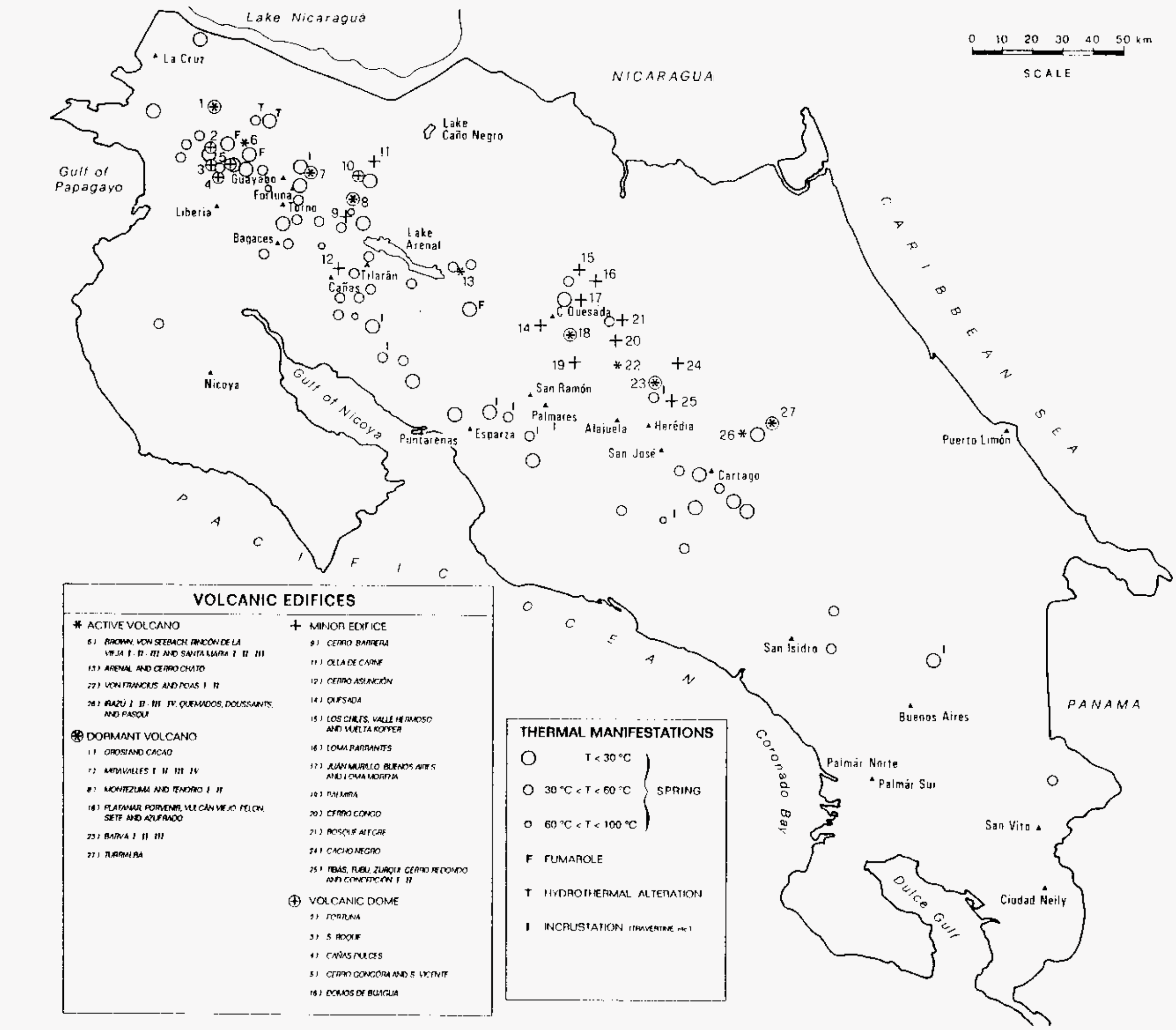

Figure 1: Volcanic edifices and **thermal** manifestations **of** Costa Rira

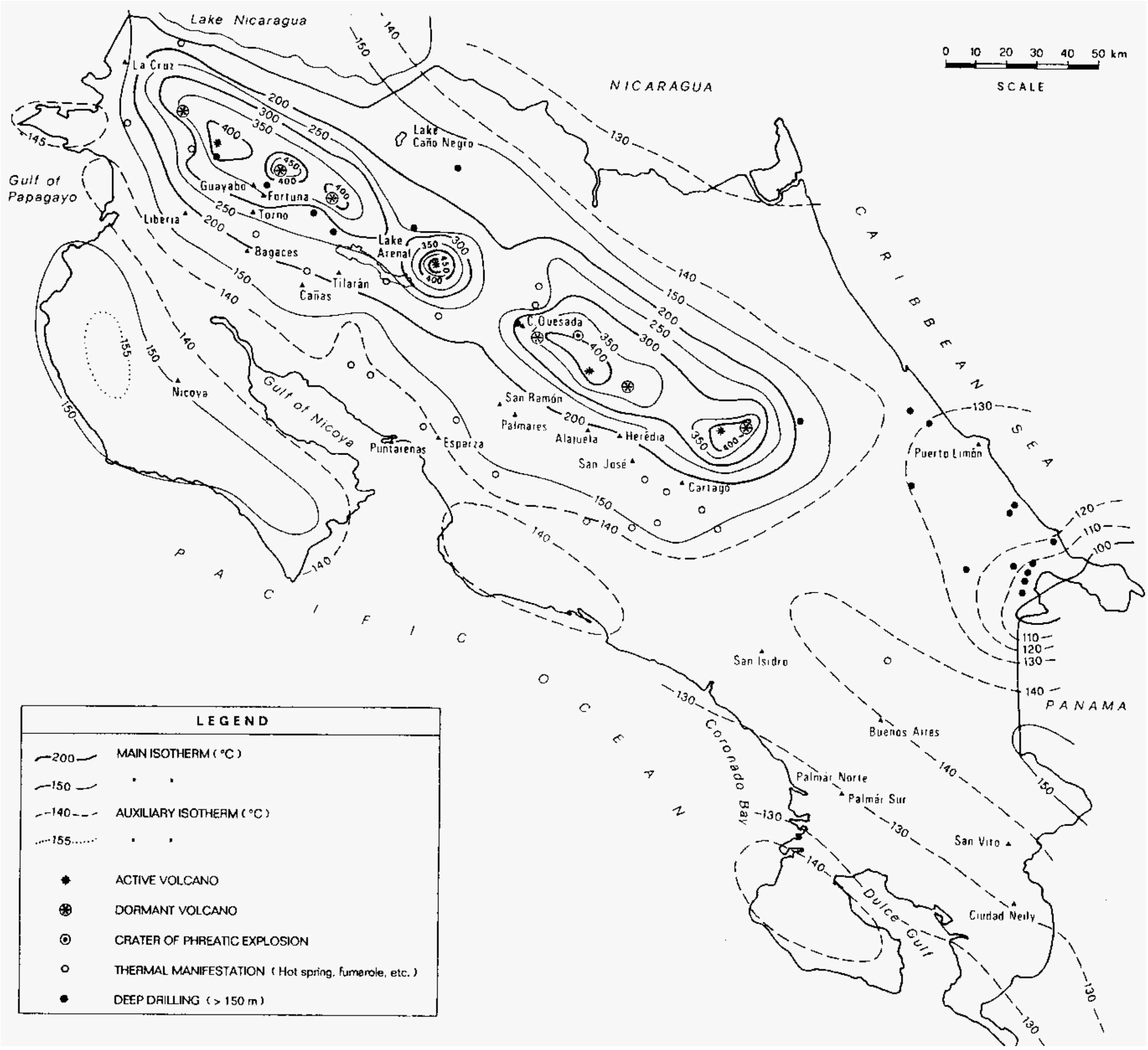

Figure 2: Temperature **map of** Costa **Riea (at 3 km depth)**

subordinate geothermal interest) are recognizable. In all, these *provinces* cover a surface area of nearly 17,000 km^2 ($\approx$ 33% of the entire country):

- five category B *provinces* in which six class B_1 *areas* (of moderate geothermal interest) and one class B_2 *area* (of little geothermal interest) appear. The aggregate surface area of these *provinces* is an the order of 28,000 km^2 ($\approx$ 55% of the national territory):
- no category *C province.* Indeed, although the ranking scheme adopted in setting up the work (Table I) provides for the possibility that zones might exist in Costa Riea with temperatures lower than 90°C within 3 km depth. the data analysis performed later led us to rule out this possibility. at least to the chosen reference depth;
- three category D provinces, formed by one class D_1 *area* (of limited geothermal interest for "heat mining" projects) and four D_2 areas (of no geothermal interest). As a whole. these *provinces* **cover a surface area** of some 6000 km^2 (- 12% of the country).

4. QUANTIFICATION OF *RESOURCES* AND *RESERVES*

The total heat stared underground (i. e. in rock t water) within the maximum reference depth chosen (3 km) was first calculated for each of the *areas* appearing in **Figure** 3. This value **represents** the *accessible* resource *base* of each *area*.

Proceeding separately for each *area,* the average depth of the 150°C isotherm surface was then determined an the basis of the mean geothermal gradient which can be drawn from Figure 2, This was done to calculate, within each *area.* the two components of the "in situ" heat having temperatures above and below *150°C.* These components were respectively termed the "high-temperature" and the "moderate-to-low temperamre" *accessible resource base.*

Afterwards, applying case by case the assessment methodology described in section 2.4. hut keeping in mind the two different reference depths chosen for the *resources* and *reserves* (3 and 2.5 km, respectively). for each *area* the following four components of the extractable heat were calculated:

- *high-temperature* resources (T> 150°C);
- *moderate-to-low temperature* resources (T < 150°C);
- *high-temperature reserves* (T > 150°C);
- *moderate-to-low temperature reserves* (T < 150°C).

The sums of the values obtained in the single *areas* for the different components of the earth energy. and hence the total "in situ"

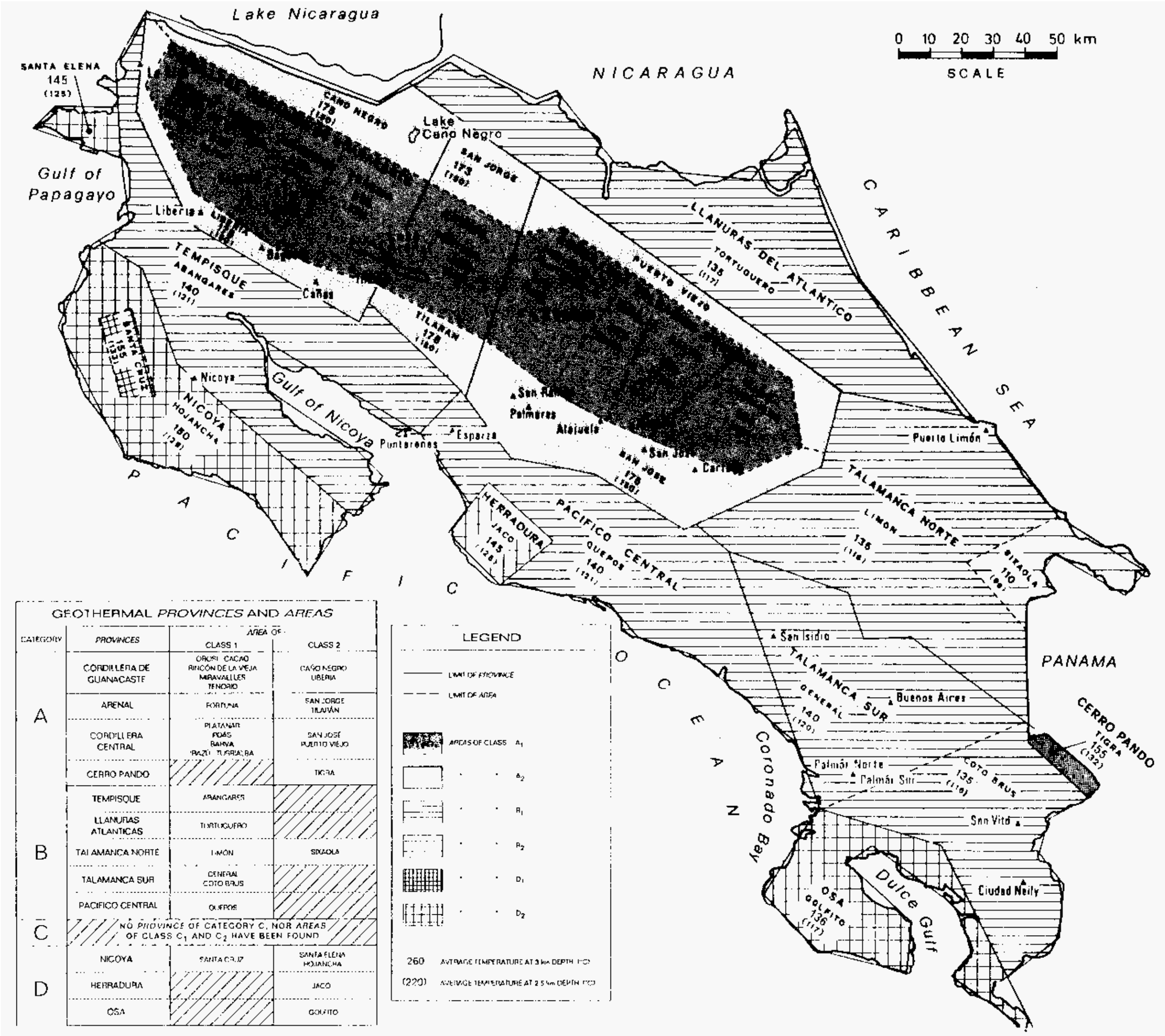

Figure 3: **Geothermal** ranking **of Costa Riea**

and extractable heat in **the** whole **country. are** indicated in Table **2.**
As can be deduced **from this** table, **lhe** total extractable heat corresponds to ~ **0.3%**in terms of ***resources.*** and to ~ 0.2% in terms **of** reserves, wilh respect to the total "in **situ"** heat within **3** km depth.

5. INSTALLABLE GEOTHERMOELECTRIC CAPACITY

As stated in section **2.3. the** lower **temperature** limit considered **useful** for economical production **of** geothermal power in Costa Rica is 150°C. Hence, only the ***high-ranperarurc*** reserves and ***resources* of** the class A_1 and A_2 ***areas*** must be considered **exploitable for this** purpose (Table **I** and Figure **3).**

So, by **starting** aut from the **values** of the ***resources*** and ***reserves*** obtained **for** the various **class** A_1 and A_2 ***areas,*** and applying **case** by **case the** methodology described in section 2.4, **the installable** capacity in **each *area*** was calculated as shown in Table 3.

The **sequence** in which the various ***areas*** **are** listed in this table

Component	High-temperature heat (> 150 °C)			Moderate-to-low temperature heat (< 150 °C)			Total heat
	joule x 10 18	cal x 10 18	OET(c) x 10 6	joule x 10 18	cal x 10 18	OET(c) x 10 6	OET(c) x 10 6
Accessible resource bose (a)	(b)	(b)	(b)	(b)	(b)	(b)	683,000
Resources (a)	**21.8**	5.2	521	65.7	15.7	1514	***2 095***
Reserves (a)	10.9	2.6	**262**	41.1	**11,4**	1 136	1398

corresponds to an order of priority based on installed capacity values ranging from highest to lowest. Therefore, four groups of *areas* can be recognized which are of decreasing interest from the standpoint of geothermal power production.

If reference is made to the average capacity that could be fed by the *resources*, these groups are characterized by the following ranges of values: 330-385 MW, each for the *oreos* of Miravalles and Rincón de la Vieja: 210-260 MW, each for the *areas* of Irazú-Turrialba, Tenorio. Platanar, Poás and Barva; 80-160 MW_e each for the *areas* of Fortuna and Orosi-Cacao; 10-20 MW, each for a group of seven *areas* of minor interest. For this last group. the capacity that can be supplied by the *reserves* is. in fact, null

Table 3. Geothermoelectric capacity installable in Costa Rica (in MWe)

AREA	Capacity that can be fed by the *reserves*			Capacity that can be fed by the *resources*			Priority group
	single flash	dual flash	average	single flash	dual flash	average	
Miravalles	164	213	189	330	437	384	I
Rincón de la Vieja	137	177	157	284	375	330	
Irazú-Turrialba	101	130	115	223	291	257	II
Tenorio	97	123	110	215	278	247	
Platanar	97	122	109	210	272	241	
Poás	90	116	103	189	249	219	
Barva	85	109	97	186	243	214	
Fortuna	61	77	69	139	179	159	III
Orosi-Cacao	33	41	37	71	92	81	
Seven other *areas*(a)	-	-	-	99	118	108	IV
TOTAL	865	1 108	986	1 946	2 534	2 240	

(a) Caño Negro, Liberia. S. Jorge, Tilarán, Puerto Viejo, San José and Tigra

6. CONCLUSIONS

Almost 90% of Costa Rica's territory is characterized by favorable geologic conditions for the exploitation of geothermal energy.

The extractable heat in the whole country is ~ 2.1×10^6 OET in terms of *resources*, and ~ 1.4×10^6 OET in terms of *reserves*. Of these values. some 25 and 19%, respectively, is made up by high-temperahlre heat (> 150°C) that can be used for economical generation of electric power: the rest (i.e., ~ 75% of the *resources* and ~ 81% of the *reserves)* is available only for possible applications of the direct type.

However, geothermoelectric production appears to be economically advantageous only in the category A provinces (class A_1 and A_2 *areas),* which together cover about one-third of the country. On them. the capacity that could be fed at full load for a period of 25 years ranges between almost 1000 MW_e (by utilizing the *reserves* only) and ~ 2240 MW_e (by utilizing all of the *resources).*

Although they cannot be considered either definitive or certain until feasibility studies are carried out in the various *areas*, these values of installable capacity are very significant if compared to the total capacity of the existing and planned power plants in the country. At any rate, they are sufficient to delineate the rule that the utilization of natural heat could play in Costa Rica in the medium and long term as an autochthonous energy source. Indeed, the capacity that could be fed by the *reserves* only would suffice to meet at least 15 % of the country's foreseeable electric power demand for the next 25-30 years.

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