Revista Brasileira de Geofísica; 1987, Vol. 5, 143-151
doi: 10.22564/brjg.v5i2.2235

A REVIEW OF VENEZUELAN GEOTHERMICS

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About 70% of Venezuela has been covered by a geothermal inventory project which includes detailed geologic and geochemical studies. The geographical, geology and geochemical information is stored in a computerized data bank that now holds data from 361 geothermal localities. The data from the geothermal systems were interpreted using chemical geothermometers and mixing models and in many cases preliminary geothermal models were postulated.

A preliminary assessment of the Venezuelan geothermal potential was done in this way and the most promising known systems is Las Minas-Aguas Calientes at El Pilar, in Sucre state, with a deep reservoir temperature estimate of 280-300°C, here further studies will continue to evaluate its potential for electricity generation. Other areas with high temperature estimates are Las Trincheras-Mariara, Carabobo; Monay, Trujillo; Guanare, Portuguesa and El Cubo-Tarra, Zulia, where the studies are at a lower level needing much more detailed work.

The high heat flow at Las Minas-Aguas Calientes area is believed to be caused by the cooling of a young igneous body associated with subduction at the SE corner of the Caribbean plate.

Aproximadamente 70% do território venezuelano vem sendo coberto por um projeto de levantamento geotérmico que inclui estudos geológicos e geoquímicos detalhados. Informações geográficas, geológicas e geoquímicas são armazenadas em um banco de dados computadorizado que contém atualmente 361 localidades. Os dados sobre os sistemas geotérmicos são interpretados utilizando-se termômetros geoquímicos e modelos de mistura, e em muitos casos, modelos geotérmicos foram postulados.

Uma determinação preliminar do potencial geotérmico venezuelano foi feita desta forma e o sistema promissor conhecido é o de Las Minas-Aguas Calientes em El Pilar, no estado de Sucre, com uma estimativa de temperatura do reservatório profundo de 280 a 300°C. Nessa localidade prosseguirão os estudos para determinar o seu potencial de geração de energia elétrica. Outras áreas com altas estimativas de temperatura são Las Trincheras-Mariara, Carabobo; Monay, Trujillo; Guanare, Portuguesa e El Cubo-Tarra, Zulia. Nessas áreas os estudos são incipientes, necessitando-se de trabalhos muito mais detalhados.

Acredita-se que o alto fluxo térmico na área de Las Minas-Águas Calientes seja causado pelo resfriamento de um corpo magmático jovem associado com a subducção do vértice SE da placa do Caribe.

(Traduzido pela Revista)

INTRODUCTION

Brief Chronology

The german naturalist Alexander von Humboldt was the first to make a scientific description of a Venezuelan hot spring: Las Trincheras, Carabobo with a temperature of 93°C. In the last fourth of the XIX century Vicente Marcano started to make qualitative water analyses of several hot springs. In the first half of this century the main workers that described hot springs were E. Cortese, A. Jahn, G. Febres-Cordero, O.Ostos, G. Delgado-Palacios, V.M. Lopez, A. Otero, L. Prado and T. Bricero-Maas.

At the Department of Geology of the Venezuelan Central University (UCV) in 1969 was started a study of the central region hot springs. In 1975 the work continued in the important El Pilar region, eastern Venezuela, with geological, geochemical and geophysical studies, concluding on the importance of the Las Minas-Aguas Calientes-Mundo Nuevo system and the necessity of exploratory drilling. In 1981 the UCV leeds the new project 'National Geothermal Inventory' and covers the central, eastern and southern regions by means of the thesis of 6 students towards the geologist degree. The andean states are currently beeing worked by the Los Andes University. The western region has not been covered.

Since 1981 most of the results of recent and selected old geothermal works have been published in the periodical *Geotermia* edited by *Centro de Documentación e Información Geotérmica Nacional* (Dept. Geology, UCV). The detailed results of the geothermal inventory can be found in Zannin & Mariño (1983), Rodriguez (1983), Fermin (1983), Hevia & Di Gianni (1984). The Venezuelan geothermal information up to 1984 has been condensed and a general assessment of the geothermal systems was carried out by Urbani (1984) showing that the most promising system for energy applications is Las Minas-Aguas Calientes-Mundo Nuevo near El Pilar in Sucre state, and from the central and western regions also promising but needing much further study are Las Trincheras-Mariara, Carabobo; Monay, Trujillo; Guanare, Portuguesa and El Cubo-Tarra, Zulia.

In the past six years the Ministry of Energy and Mines (MEM) has been working on El Pilar area, Sucre, and two years ago a cooperative study was started with the International Institute of Geothermal Research (IIRG) of Italy, with funds from the International Atomic Energy Comission in order to carry out a detailed geochemical work in water and gases including isotopic analyses. Preliminary results of this project also suggests high reservoir temperatures for Las Minas-Águas Calientes-Mundo Nuevo systems so that further studies will continue.

Geothermal inventory

This unfinished project consists in the study of 'all' Venezuelan geothermal manifestations and possible related features (cold springs with H_2S odor, dry alteration zones, mud volcanoes). On each locality all fluid emissions are located on detailed maps and sketches; description and geological mapping of surroundings is done; samples of water (untreated and acidified), gases, mineral deposits, fresh and altered rocks are taken; the water from nearby drainage or cold water springs were also sampled. Water was analysed by the standard techniques of the APHA (1976) with the exception of Na and K by atomic absorption.

The project data information from previous published and unpublished reports have been stored in a computerized data bank that contains geographical, geological and geochemical information. Up to now the base contains data of the following number of geothermal localities: eastern region (Sucre: 102, Monagas: 45, Anzoátegui: 36, total: 186), central region (D.F.: 10, Aragua: 13, Carabobo: 11, Miranda: 24, Guárico: 6, total: 64), western region (Yaracuy: 2, Falcón: 22, Lara: 10, total: 34), Zulia region: 9, Andes region (Trujillo: 18, Mérida: 20, Táchira: 18, total: 56), western plains (Barinas: 7, Portuguesa: 1, total: 8), southern region (Delta Amacuro: 1, Bolivar: 2, Amazonas: 1, total: 4). This gives a total of 361 geothermal localities but in some of them many springs are located within a few tens of meters which at least in the eastern and central region were all sampled individually.

The water analyses were processed with the GEOTERV computer program (Urbani, 1985c,d) that calculated several chemical geothermometers (SiO_2 and cations) and mixing models as the 'warm spring mixing model' (Truesdell & Fournier, 1977) and the 'boiling spring mixing model' (Truesdell & Fournier, 1976). Results from these models will be referred to as t(wsmm) and t(bsmm), respectivelly. These data together with available geologic and hydrologic information were used to produce preliminary models of many venezuelan geothermal systems, estimating the temperature of geothermal reservoirs that feed the hot springs and possible mixing processes. Further details on the methods used in the national inventory including field, laboratory, data processing and interpretation are found in Urbani (1985a).

GEOTHERMAL SYSTEMS

Tables with all available analytical data of Venezuelan hot springs can be found elsewhere (Urbani, 1984, vol. 2). On Table 1 a summary of the interpretations is presented with the following information:

1. System name or locality, state, geographical coordinates, identification code on the data bank, and number of the figure in which it appears (e.g.: f.1).
2. Maximum field temperature [t(f)].
3. Estimated temperatures of the possible reservoir that feeds the springs, sometimes with two values: $t(r)_i$ a possible intermediate reservoir and $t(r)_d$ a possible deep reservoir. This last data is given only when chemical geothermometers and mixing model suggest that two possible levels of interaction exist, if there is evidence of only one that data appears under t(r)i. The given t(r)d's were always obtained using the 'warm' or 'boiling spring mixing model'.
4. Water type as the major cation and anion.

Western region

In this region (Figs. 1-4) the work has not been carried out with enough detail for a reliable use of chemical geothermometers. Most of the hot springs are in some way related to the main fault zones of the western cordilleras (e.g., Bocono, Valera, Caparo, El Tigre and Las Virtudes faults). Even with this scarse data a few localities show interesting features deserving

Table 1 – Summary of main Venezuelan geothermal systems.

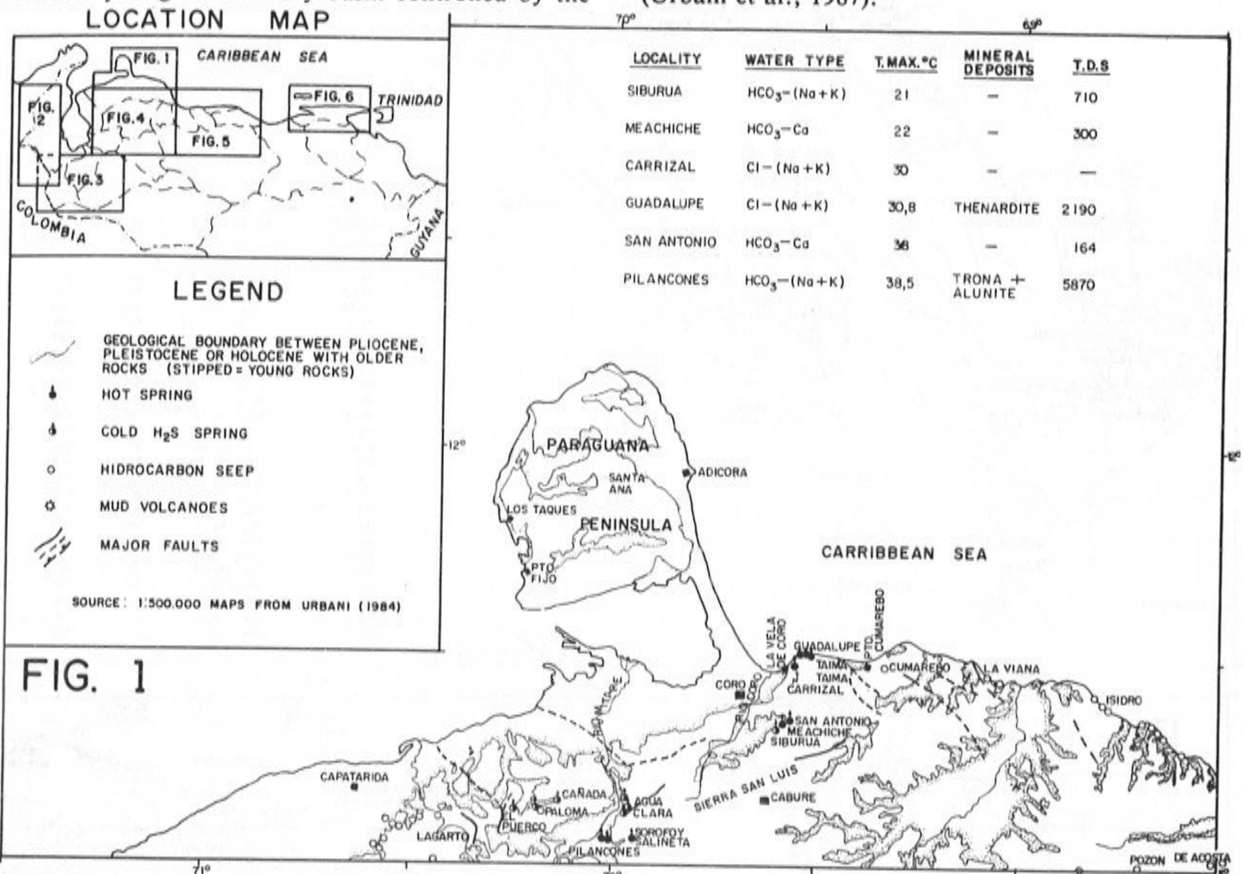
Name-location.	$t(f)$	$t(r)_i$	$t(r)_d$	type
1. Western region (Figs. 1-4)				
El Cubo-Tarra, Zulia 72°30', 8°45' Zu.6, f.2	96 ?	–	–	–
Aguas Calientes, Ureña, Tachira 72°25'50", 7°54'; Ta. 1,f.3	60	78	–	HCO_3–Ca
Santa Ana, Guanare, Portuguesa 69°55'23", 9°6'12", Po.1, f.4	37	190	–	HCO_3–Na
Falla de Valera, Trujillo-Lara 70°38'7", 9°33'45", Tr.2, f.4	85	110	–	HCO_3–Na Cl–Na
Falla de Bocono, Merida, Me.6 eg.: Jaji, 71°18', 8°34', f.3	55	80	–	HCO_3–Ca SO_4–Na
Volcanes Sanare y Cubiro, Lara 66°36'20", 9°45'40", La.1, f.4	115	–	–	–
Pilancones, Falcón 70°0'20", 11°4'40", Fa.1, f.1	39	100	–	Cl–Na
La Vela de Coro, Falcón 69°32', 11°30', Fa.5, f.1	31	100	?	Cl–Na
San Antonio-Meachiche, Falcón 69°33'55", 11°19'30", Fa.9, f.1	38	43	?	HCO_3–Ca HCO_3–Na
2. Central region				
2.1. Coast belt (Morón fault zone)				
Chichiriviche, Distrito Federal 67°14'28", 10°32', DF. 6	73	–	165	Cl–Na
Caruao, Distrito Federal 66°20'16", 10°35'27", DF.1	71	–	155	Cl–Na
2.2. Intermediate valleys				
Trincheras, Carabobo 68°4'56", 10°18'30", Ca.1	97	170	220	HCO_3–Na
Mariara, Carabobo 67°40'54", 10°18'48", Ca.7	75	130	160	HCO_3–Na
El Castaño, Aragua 67°34'2", 10°19'55", Ca.3	42	60	145	HCO_3–Na
Villa de Cura, Belén, Ar. Ca. 67°28'3", 10°1'38", Ar. 9-11	28	40	85	HCO_3–Mg
Tácata, Miranda, Mi.10-20 67°3'3", 10°12'23"	30	80	–	HCO_3–Na
Colonia Mendoza, Miranda 66°50', 10°7'34", Mi.3-4	26	80	–	Cl–Na
Juan Diaz, Miranda, Mi.5-8 66°5'26", 10°10'22"	37	105	–	Cl–Na
2.3. Southern piedmont				
San Juan de Los Morros, Guárico 67°22'17", 9°55'26", Gu.1	34	85	–	HCO_3–Na
San Sebastián-San Casimiro, Ar. 67°7'47", 9°56'39", Ar.5	27	80	?	HCO_3–Na
Name-location	$t(f)$	$t(r)_i$	$t(r)_d$	type
Ortiz, Calabozo, Guárico 67°12'46", 9°36'40", Gu.9	28	80	–	HCO_3–Na

continuação . . .

Guarumen, Guárico, Gu. 13-18 67°4'55", 9°36'53"	47	70	120	HCO_3–Na
Batatal, Miranda, Mi.22-24 65°58'8", 9°58'39"	57	65	170	HCO_3–Na
Clarines, Anzoátegui 65°20'11", 10°1'53", An.32-36	44	70	–	HCO_3–Na
3. Eastern mountains massif region				
3.1. Western part, Anzoátegui				
Pozuelos-Provisor, An. 15, 31 64°35'20", 10°10'27", XIV	34	40	–	HCO_3–Ca
Naricual-Aragüita, An.18, 19, 22 64°36'46", 10°4'47", XVI	45	65	–	HCO_3–Ca Cl–Mg
San Diego-La Toma, An. 23-29 64°31'3", 10°9'40", XV	52	70	–	HCO_3–Na
Bergantin-Querecual, An.9-17 64°21'47", 10°2'7" XVII	24	45	–	HCO_3–Ca
Urica, An.7, XIX 64°3'32", 9°49'4"	36	70	–	HCO_3–Ca
Mundo Nuevo, An.1-6, XVIII 64°3'2", 9°59'25"	26	50	–	HCO_3–Ca
3.2. Southeastern part, Monagas				
Caripito, Mo.1-8 63°5'46", 10°11'3", XXIII	28	50	–	HCO_3–Ca
Quiriquire, Mi.11-19, 25-29 63°15'59", 9°59'37", XXI	36	65	?	HCO_3–Na
San Antonio-San Francisco, XX 63°31'14", 10°0'19", Mo.30-45	28	60	–	HCO_3–Ca
3.3. Cariaco-Paria depressed area, El Pilar fault zone, Sucre				
Los Ipures, Cumaná, Su.92-94 64°8'57", 10°23'25", XI	47	85	?	HCO_3–Na
Golfo Cariaco, Su.73-77, 84-89 63°41'59", 10°28'8", X	60	60	120	HCO_3–Na
Pantoño, Su.41-43, 66-70 63°26'4", 10°28'57", VII	37	100	?	HCO_3–Na
Putucual-Santa Rosa, Su.22-23 63°17'40", 10°24'12", VIII	47	55	?	HCO_3–Na
Rio Casanay, Su.31-38 63°17'45", 10°31'7", VI	37	55	?	HCO_3–Mg HCO_3–Ca
Mundo Nuevo, Su.45-83 63°15'16", 10°30'57", V	95	–	140	SO_4–Ca HCO_3–Ca
Las Minas-Aguas Calientes, IV 63°11'48", 10°31'46", Su.6-18	100	250	320	SO_4–Ca Cl–Ca
Name-location	t (f)	t $(r)_i$	t $(r)_d$l	type
Sur de El Pilar 63°4'30", 10°26'40", III	58	70	70	Cl–Na HCO_3–Ca
Este de El Pilar:				
(1) No Carlos 63°4', 10°35'1", Su.4-5, II	51	–	150	HCO_3–Na
(2) Maraval 62°33'49", 10°38'42", Su.1-2, I	32	60	–	HCO_3–Na

? under the t $(r)_d$ column means that several ion plots suggest mixing, but not enough information is avaible to give a reliable estimate of the possible deep reservoir.

further work. They are: (1) El Cubo-Tarra, Zulia, with a reported 96°C surface temperature; (2) Los Baños de Santa Ana, Guanare, Portuguesa in which the t(Na K Ca Mg) applied to old literature analyses give a result of 190°C; (3) Sabana de Monay, Trujillo, a small intra--mountain young sedimentary basin controlled by the Valera fault zone, around which several hot springs are found with surface temperatures as high as 85°C and t(qz) around 110°C; (4) 'Volcanes de Sanare y San Miguel', Lara, formed by natural underground coal burning with a surface temperature greater than 700°C (Urbani et al., 1987).



LOCALITY	WATER TYPE	T. MAX. °C	MINERAL DEPOSITS	T.D.S
SIBURUA	$HCO_3-(Na+K)$	21	–	710
MEACHICHE	HCO_3-Ca	22	–	300
CARRIZAL	$Cl-(Na+K)$	30	–	–
GUADALUPE	$Cl-(Na+K)$	30,8	THENARDITE	2190
SAN ANTONIO	HCO_3-Ca	38	–	164
PILANCONES	$HCO_3-(Na+K)$	38,5	TRONA + ALUNITE	5870

FIG. 1

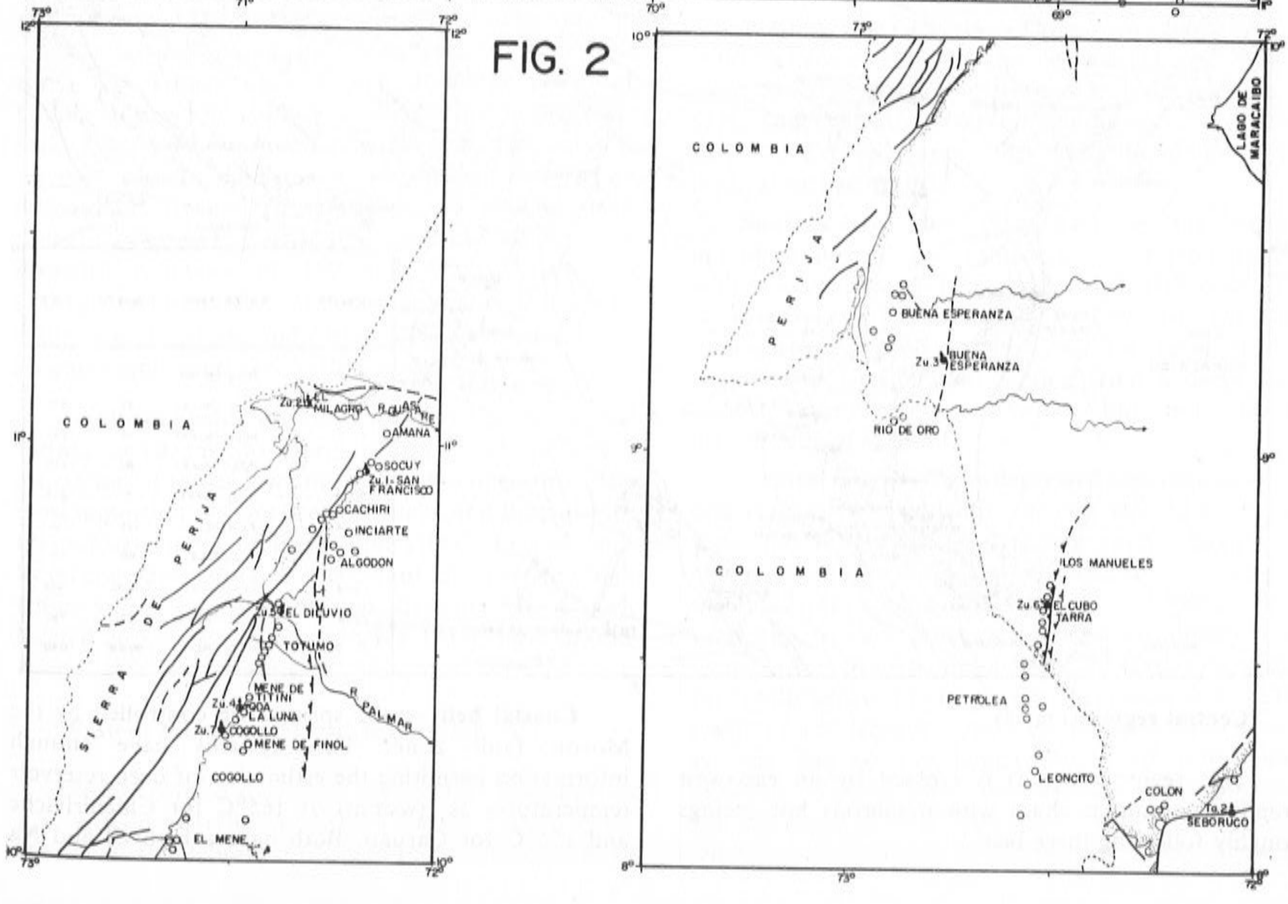
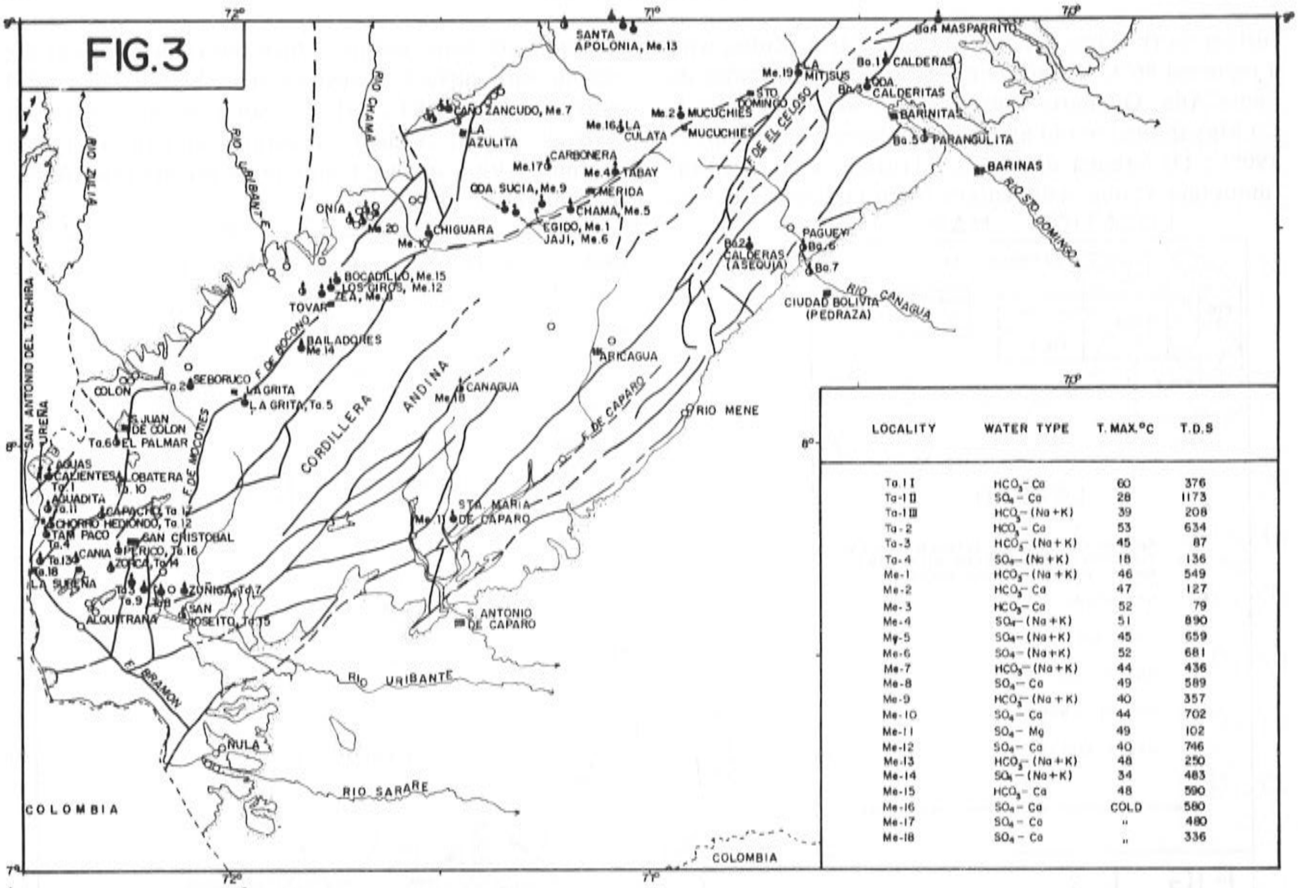


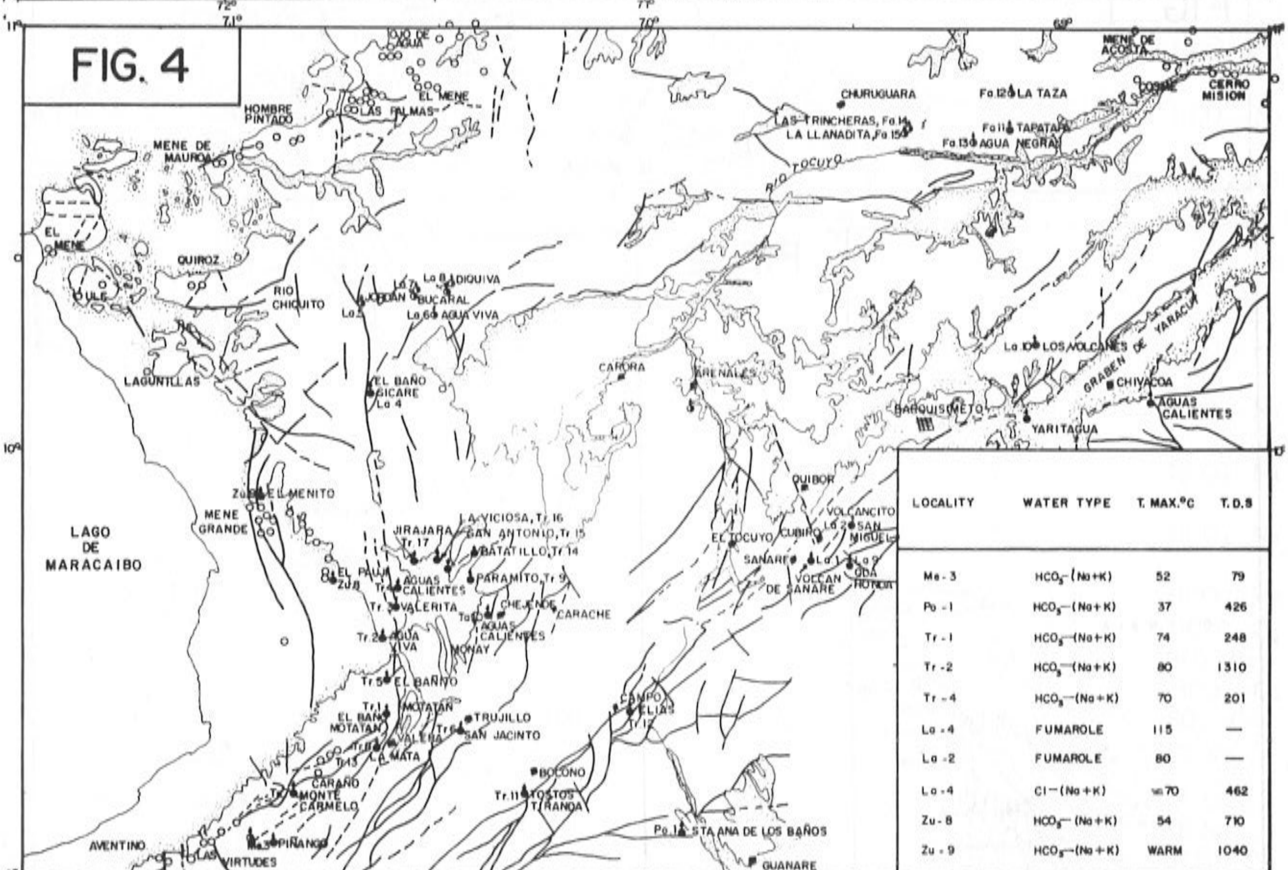
FIG. 2

FIG.3



LOCALITY	WATER TYPE	T. MAX.°C	T.D.S
Ta.1 I	HCO_3 – Ca	60	376
Ta-1 II	SO_4 – Ca	28	1173
Ta-1 III	HCO_3 – (Na + K)	39	208
Ta - 2	HCO_3 – Ca	53	634
Ta - 3	HCO_3 – (Na + K)	45	87
Ta - 4	SO_4 – (Na + K)	18	136
Me - 1	HCO_3 – (Na + K)	46	549
Me - 2	HCO_3 – Ca	47	127
Me - 3	HCO_3 – Ca	52	79
Me - 4	SO_4 – (Na + K)	51	890
Me - 5	SO_4 – (Na + K)	45	659
Me - 6	SO_4 – (Na + K)	52	681
Me - 7	HCO_3 – (Na + K)	44	436
Me - 8	SO_4 – Ca	49	589
Me - 9	HCO_3 – (Na + K)	40	357
Me - 10	SO_4 – Ca	44	702
Me - 11	SO_4 – Mg	49	102
Me - 12	SO_4 – Ca	40	746
Me - 13	HCO_3 – (Na + K)	48	250
Me - 14	SO_4 – (Na + K)	34	483
Me - 15	HCO_3 – Ca	48	590
Me - 16	SO_4 – Ca	COLD	580
Me - 17	SO_4 – Ca	"	480
Me - 18	SO_4 – Ca	"	336

FIG. 4



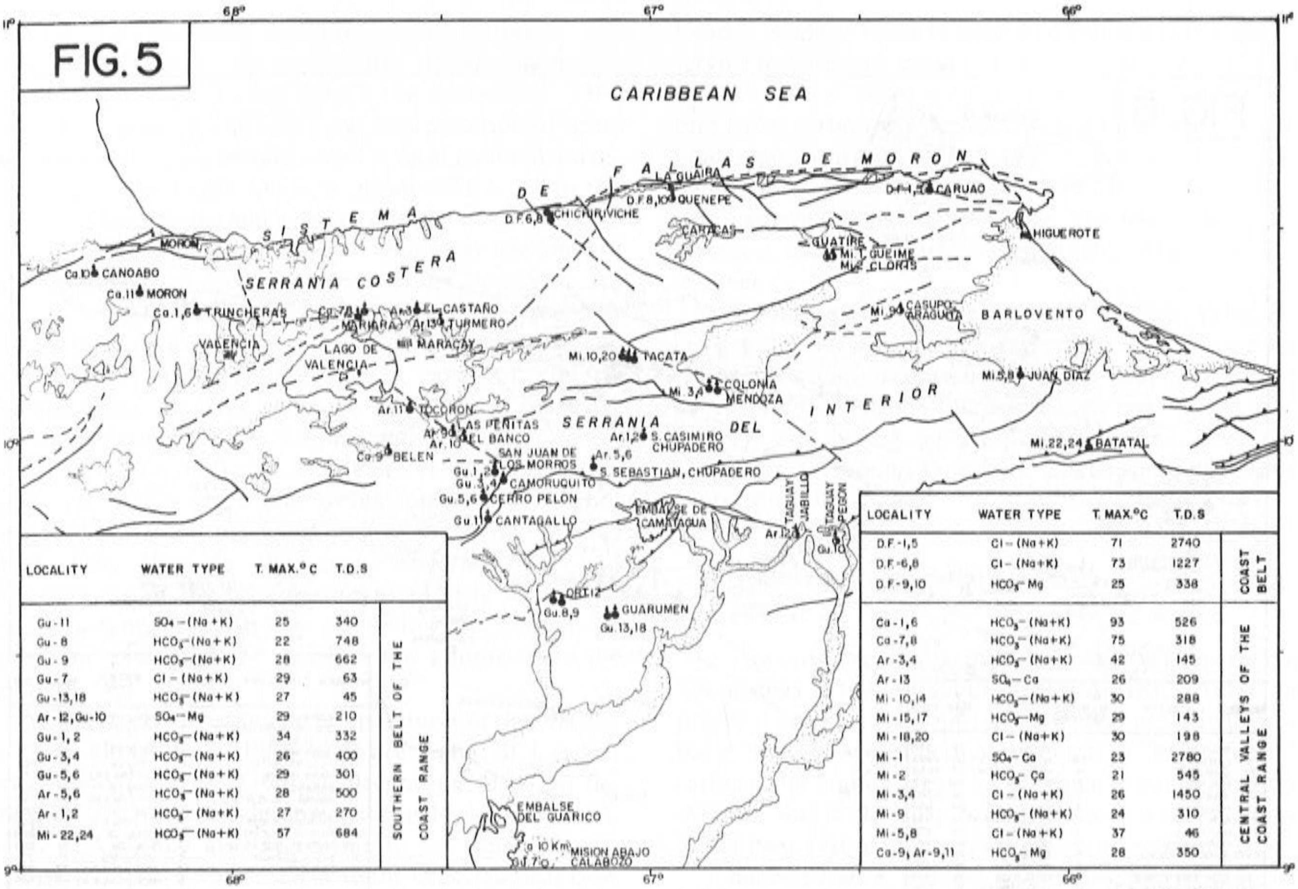
LOCALITY	WATER TYPE	T. MAX.°C	T.D.S
Me - 3	HCO_3 – (Na + K)	52	79
Po - 1	HCO_3 – (Na + K)	37	426
Tr - 1	HCO_3 – (Na + K)	74	248
Tr - 2	HCO_3 – (Na + K)	80	1310
Tr - 4	HCO_3 – (Na + K)	70	201
La - 4	FUMAROLE	115	—
La - 2	FUMAROLE	80	—
La - 4	Cl – (Na + K)	≈ 70	462
Zu - 8	HCO_3 – (Na + K)	54	710
Zu - 9	HCO_3 – (Na + K)	WARM	1040

Central region (Fig. 5)

This region (Fig. 5) is crossed by an east-west trending mountain chain with numerous hot springs roughly following three belts.

Coastal belt — the springs are controlled by the Moron fault zone. Two systems have enough information permiting the estimation of deep reservoir temperatures as t(wsmm) of 165°C for Chichiriviche and 155°C for Caruao. Both have a high Cl and Na

FIG. 5



LOCALITY	WATER TYPE	T. MAX. °C	T.D.S	
Gu-11	SO_4-(Na+K)	25	340	SOUTHERN BELT OF THE COAST RANGE
Gu-8	HCO_3-(Na+K)	22	748	
Gu-9	HCO_3-(Na+K)	28	662	
Gu-7	Cl-(Na+K)	29	63	
Gu-13,18	HCO_3-(Na+K)	27	45	
Ar-12, Gu-10	SO_4-Mg	29	210	
Gu-1,2	HCO_3-(Na+K)	34	332	
Gu-3,4	HCO_3-(Na+K)	26	400	
Gu-5,6	HCO_3-(Na+K)	29	301	
Ar-5,6	HCO_3-(Na+K)	28	500	
Ar-1,2	HCO_3-(Na+K)	27	270	
Mi-22,24	HCO_3-(Na+K)	57	684	

LOCALITY	WATER TYPE	T. MAX. °C	T.D.S	
D.F.-1,5	Cl-(Na+K)	71	2740	COAST BELT
D.F.-6,8	Cl-(Na+K)	73	1227	
D.F.-9,10	HCO_3-Mg	25	338	
Ca-1,6	HCO_3-(Na+K)	93	526	CENTRAL VALLEYS OF THE COAST RANGE
Ca-7,8	HCO_3-(Na+K)	75	318	
Ar-3,4	HCO_3-(Na+K)	42	145	
Ar-13	SO_4-Ca	26	209	
Mi-10,14	HCO_3-(Na+K)	30	288	
Mi-15,17	HCO_3-Mg	29	143	
Mi-18,20	Cl-(Na+K)	30	198	
Mi-1	SO_4-Ca	23	2780	
Mi-2	HCO_3-Ca	21	545	
Mi-3,4	Cl-(Na+K)	26	1450	
Mi-9	HCO_3-(Na+K)	24	310	
Mi-5,8	Cl-(Na+K)	37	46	
Ca-9, Ar-9,11	HCO_3-Mg	28	350	

content, probably produced by deep mixing with sea water.

Intermediate valleys — the central valleys are controlled by several strike-slip faults giving rise to pull-apart basins. The main geothermal systems are in granitic terrains along the Trincheras-Mariara fault zone. Las Trincheras is a high discharge group of boiling and warm springs used as a medical-turistic resort. Boiling is not seen now because the source is enclosed. Using data taken in different season we estimated a t(bsmm) of 220°C which matches with t(Na/Li). The springs of Mariara and El Castaño show t(wsmm) estimates of 160 and 145°C. The high underground estimated temperarture and its nearness to highly populated and industrialized towns makes them an important target for further study.

Southern piedmont — in this region there are several springs used as turistic resorts, but their study allows the estimation of rather low underground temperature. The most important systems are Guarumen and Batatal with t(wsmm) estimates of 120°C and 170°C. Recent work by oil companies discovered a belt of high pressure-high temperaturre hydrocarbon gas deposits. In a well located 20 km east of Guarumen a 193°C bottom hole temperature was measured at 2400 m of depth.

Eastern Mountain Massif region (Fig. 6)

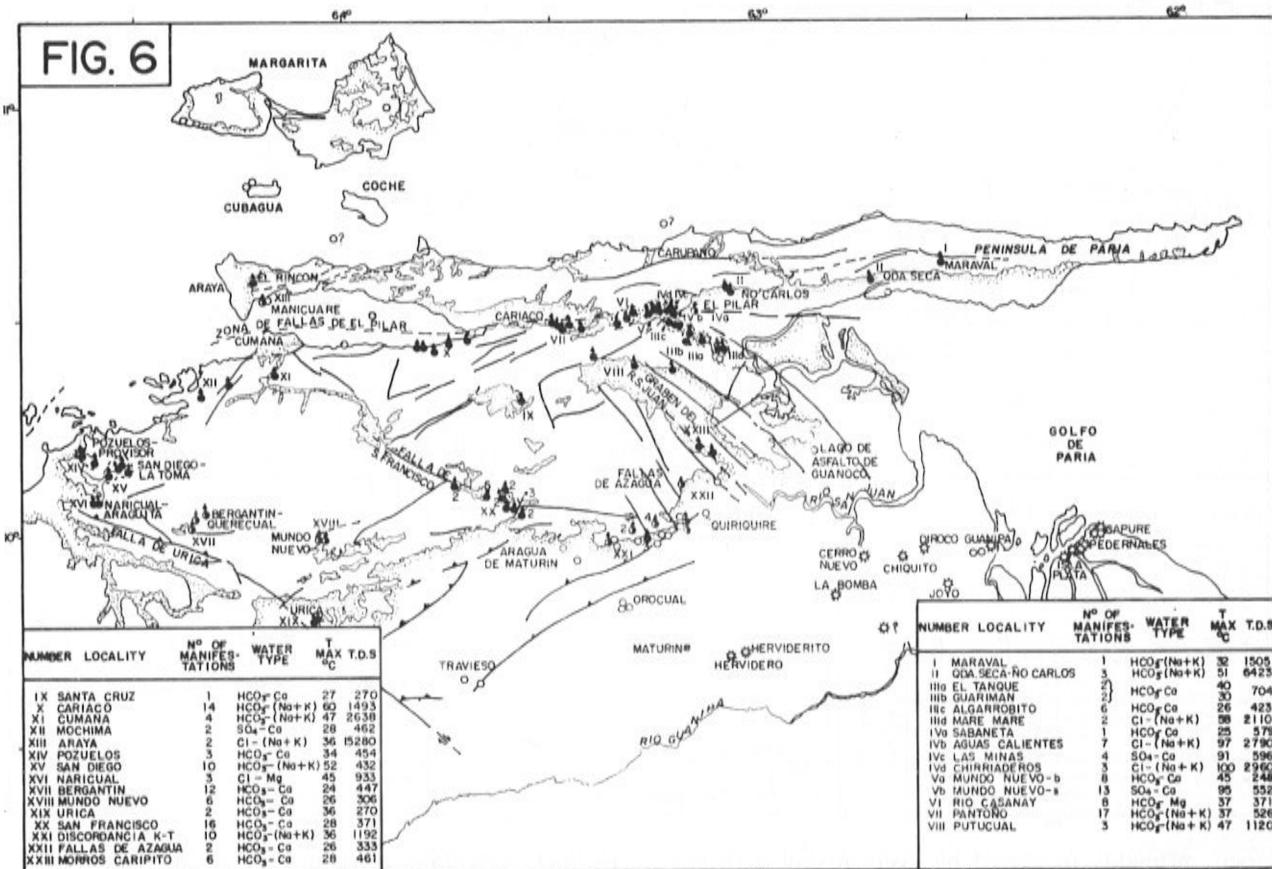
From north to south this region (Fig. 6) comprises the eastwest trending Araya-Paria metamorphic cordillera, the depressed Cariaco-Paria area controlled by the El Pilar fault zone, and a large and high massif of sedimentary rocks. Hot springs are located all around the mountains but most of them along the central depressed area.

Western part (Barcelona-Urica, Anzoategui) — this region is crossed by the major Urica fault zone and has many low temperature hot springs with a maximum of 52°C and estimated reservoir temperatures no higher than 70°C. The area has good possibilities for medical-turistic resorts.

Southeastern part (Monagas) — the surface manifestations of this region are of low temperatures with a maximum of 36°C, with much H_2S odor. The chemical geothermometers allow to estimate temperatures no higher than 65°C, but some ion plots suggest the possibility of mixing from a deeper and higher temperaturer reservoir, but not enough information is available.

Central Cariaco-Paria depressed area (Sucre) — this area is mainly controlled by the east-west El Pilar fault zone and other NW-SE trending faults, having the highest density of surface manifestations in Venezuela, with several boiling springs (up to 100°C), also vegetation free alteration zones with acid-sulphate water springs, fumaroles, sulphur deposits and even a few small hills believed to be phreatic explosion domes. The t(wsmm) and t(bsmm) could be obtained from several systems due to the large amount of information available. Taking into consideration the geothermal systems along El Pilar fault zone, their 'deep reservoir' temperature estimates by the mixing model show an

FIG. 6



NUMBER	LOCALITY	Nº OF MANIFES-TATIONS	WATER TYPE	T MAX °C	T.D.S
IX	SANTA CRUZ	1	HCO_3-Ca	27	270
X	CARIACO	14	HCO_3-(Na+K)	60	1493
XI	CUMANA	4	HCO_3-(Na+K)	47	2638
XII	MOCHIMA	2	SO_4-Ca	28	462
XIII	ARAYA	2	Cl-(Na+K)	36	15280
XIV	POZUELOS	3	HCO_3-Ca	34	454
XV	SAN DIEGO	10	HCO_3-(Na+K)	52	432
XVI	NARICUAL	3	Cl-Mg	45	933
XVII	BERGANTIN	12	HCO_3-Ca	24	447
XVIII	MUNDO NUEVO	6	HCO_3-Ca	26	306
XIX	URICA	2	HCO_3-Ca	36	270
XX	SAN FRANCISCO	16	HCO_3-Ca	28	371
XXI	DISCORDANCIA K-T	10	HCO_3-(Na+K)	36	1192
XXII	FALLAS DE AZAGUA	2	HCO_3-Ca	26	333
XXIII	MORROS CARIPITO	6	HCO_3-Ca	28	461

NUMBER	LOCALITY	Nº OF MANIFES-TATIONS	WATER TYPE	T MAX °C	T.D.S
I	MARAVAL	1	HCO_3-(Na+K)	32	1505
II	QDA. SECA-NO CARLOS	3	HCO_3-(Na+K)	51	6423
IIIa	EL TANQUE	2	HCO_3-Ca	40	704
IIIb	GUARIMAN	2		30	
IIIc	ALGARROBITO	6	HCO_3-Ca	26	423
IIId	MARE MARE	2	Cl-(Na+K)	58	2110
IVa	SABANETA	1	HCO_3-Ca	25	579
IVb	AGUAS CALIENTES	7	Cl-(Na+K)	97	2790
IVc	LAS MINAS	4	SO_4-Ca	91	596
IVd	CHIRRIADEROS	3	Cl-(Na+K)	100	2960
Va	MUNDO NUEVO-b	8	HCO_3-Ca	45	248
Vb	MUNDO NUEVO-s	13	SO_4-Ca	95	552
VI	RIO CASANAY	8	HCO_3-Mg	37	371
VII	PANTOÑO	17	HCO_3-(Na+K)	37	526
VIII	PUTUCUAL	3	HCO_3-(Na+K)	47	1120

interesting east-west trend: Los Ipures (85°C), Cariaco (120°C), Mundo Nuevo (140°C), Las MinasAguas Calientes (280-300°C), No Carlos (150°C). Systems to the south of this zone also decrease in temperature.

The Las Minas-Aguas Calientes-Mundo Nuevo system is the most important and complex with several warm and boiling springs and fumaroles. At higher topographic elevation there are alteration zones with acid-sulphate water and at lower elevation the springs are of HCO_3-Ca and Cl-Na types, this last one is believed to be the closest to the compostion of the deep reservoir water. From the Cl-Na water type the t(NKCM) geothermometer points out to the existense of an intermediate reservoir with temperatures in the order of 250°C. On the other hand the boiling spring mixing model suggests a deeper reservoir with temperature estimates between 280°C and 300°C. Using the fault plane water cooling model given by Hurter (1984) the depth of the deeper reservoir could be estimated in the order of 1 to 2 km (or more properly 1.1 km to 2.2 km) not very deep for economic exploitation.

This system is the most promising for possible electricity generation and a detailed geochemical study is under way by the MEM and IIRG. A preliminary report of such project using cation and gas geothermometers also reached to the conclusion of two possible reservoirs with temperatures in the order of 220°C for an intermediate reservoirs and 300°C in a deeper one (D'Amore & Gianelli, 1986).

CONCLUSIONS

Much has been written on the origin of the surface (or estimated underground) high temperatures of Venezuelan geothermal systems. From the available data we find three main possibilities:

1) **Geotnermal system of Las Minas-Aguas Calientes-Mundo Nuevo, El Pilar, Sucre.** Several factors may explain the high heat flow of this area: (1) this is the area with highest estimated reservoir temperatures of Venezuela (up to 300°C) and has the highest density of hot springs roughly aligned along the seismically active El Pilar fault zone. (2) two very long NE-SW and NW-SE trending lineaments intersect the area as observed on radar imagery, the nature of such lineaments are not well known but seems to be major fault zones. (3) the rocks exposed in the area are Early Cretaceous sandstones (Barranquin Formation) and limestones (El Cantil Formation) all highly fractured, possibly permiting an easy ascend of deep water and also the recharge of aquifers. (4) according to several authors the El Pilar fault zone is the boundary of the Caribbean and South American plates. The tectonic model of the Caribbean-South America plates colission by Speed (1985), is based on an oblique colission which explains the strike-slip movement of El Pilar fault from the Cumana area in the west, up to about the town of El Pilar where the 'point of suturing'

would be located; seismic data supports the interpretation that the present-day active subduction zone of the Antillean arc starts a few kilometers to the NE of the area. (5) the structural interpretation of some workers in the past decade reveal several regional north-dipping thrust faults. (6) at a distance of 6 km to the north of the geothermal area more than 30 small riolite — dacite bodies are exposed, of 5 Ma K-Ar age and are the southern exposed evidence of the Antillean arc volcanism. (7) the gravimetric model of the Carupano — El Pilar region by Vierbuchen (1984) postulates the existence of a large underground body of granitic composition. We have estimated its volume in the order of a few hundreds cubic kilometers.

Using this information Urbani, (1985b) prefers to interpret that a small and young intrusive body (not exposed and not proved yet) may be responsible for the high heat flow in the area. The tectonics and stratigraphy of the area do not necessarily imply that such an igneous body lays just below the anomalous area, but that could be located a few kilometers to the north.

The reservoir estimated temperatures in the systems located along the El Pilar fault are higher at Las Minas-Aguas Calientes (300°C), decreasing faster to the east (150°C) and much slower towards the west (140, 120, 85°C), and also decreasing to the south (70°C). Those results are consistent with the expected heat flow distribution from the interpretation of Speed (1985) about the origin of the El Pilar fault zone with a 'point of suturing' near the town of El Pilar.

2) **Geothermal systems of Guarumen and Batatal, Central Region.** These two isolated systems with high reservoir temperature estimates aparently are related to an E-W trending belt of high pressure-high temperature hydrocarbon gas deposits with a measured bottom hole temperatures as high as 193°C (2400 m). The adiabatic compression of this belt of gas fields could possibly explain the high temperature. The few surface manifestions may be due to the sealing effect of a thick shale cover.

3) **Other geothermal systems.** The other Venezuelan geothermal systems are interpreted as produced by the deep circulation of meteoric water near major fault zones with no volcanic source for their heat. Those systems are usually associated with the main fault zones developed along young mountain chains, many of them neotectonically active.

Geothermal applications

The only use that is given today to the Venezuelan hot springs is that of small medical-turistic resorts. In previous sections we pointed out several areas that probably have good geothermal potential for energy applications, the main system is Las Minas-Aguas Calientes -Mundo Nuevo, El Pilar, Sucre, in which we hope to see in the near future an electricity generation plant.

Barberi *et al.* (1986) gave a conservative estimate of the accesible resource base to 3 km depth of the Venezuelan Coast Range province which is around one million gigawatt-year (thermal) which in general terms is in accordance with the data presented in this paper.

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