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SILICA GEOTEMPERATURE MAPPING AND THERMAL REGIME IN THE MEXICAN VOLCANIC BELT

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RESUMEN

Se utilizaron análisis químicos de 176 manantiales termales para determinar su temperatura con el geotermómetro de sílice. Los principales campos geotérmicos: La Primavera, los Azufres y Los Humeros no se incluyeron en este estudio para evitar que predominaran sobre la tendencia regional, ya que constituyen las anomalías principales. Con base en las temperaturas obtenidas se elaboró un mapa de isotermas, que muestra la existencia de un régimen térmico homogéneo a lo largo del Cinturón Volcánico Mexicano, cuyos límites se definen claramente. Se observó que la zona de altas temperaturas continúa hacia el Oeste, pero en el Este se termina antes de llegar a la costa. Dentro del Cinturón Volcánico las temperaturas son altas, con un promedio de 121°C. Los máximos locales que se observan pueden estar relacionados con sistemas hidrotermales activos.

ABSTRACT

Geochemical analyses for 176 thermal springs were used to determine their silica temperatures. The main geothermal fields, viz., La Primavera, Los Azufres and Los Humeros were not included to avoid distortion of the regional trend by these large anomalies. On the basis of the obtained temperature data an isotherm map was elaborated. This map shows an homogeneous thermal regime along the Transmexican Volcanic Belt. Its limits are well defined and it was found that the high temperature zone continues to the West but it is closed to the East. Within the Belt temperatures are high (average temperature= 121°C) and a few local maxima are observed that may be related to active geothermal systems.

INTRODUCTION

The direct determination of heat flow requires the existence of deep bore-holes drilled for this specific purpose. It is not easy in Mexico to obtain permission for using exploration bore-holes to measure temperature gradients. Therefore, there are only few heat flow measurements in the northwestern part of Mexico (Smith *et al.*, 1979)

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and few unpublished data in the region of the Mexican Volcanic Belt (MVB) (Blackwell *et al.*, 1977). However, this region is very important because of its volcanic activity and economical relevance and it appeared worthwhile to estimate its thermal regime in order to evaluate both geothermal potential and the risk related to volcanic activity. Thermal data have also been used lately in petroleum and mineral prospecting works (Waples, 1980).

The Comisión Federal de Electricidad (CFE) has carried out exploration projects in several areas to assess their geothermal potential. As part of these projects, water samples have been collected and chemical analyses have been carried out for many geothermal springs. Thus, a first approach to determine thermal provinces may be through the calculations of equilibrium temperatures in sampled springs using geochemical data kindly provided to us by CFE.

Most of the springs selected are located within the region of the MVB, and those outside are used to define its limits showing that high temperature springs are related to active areas of volcanism. Silica concentrations were used to calculate equilibrium temperatures assuming the waters were not of a mixed origin, an assumption which is correct in most of the cases.

DATA AND RESULTS

Silica temperatures were calculated for each sample using the equation obtained by Truesdell (1976)

$$T_{SiO_2} = \frac{1315}{5.205 + \log C} - 273.15 \qquad (1)$$

where C is the silica concentration in mg/kg. This equation yields the equilibrium temperature of spring waters assuming no silica precipitation and no mixing of the waters. The results are shown in Fig. 1 and Table 1, where the names and locations of the springs are also given. Most of the chemical analyses were taken from unpublished works. For those already published the reference is included.

The data from the largest geothermal fields (Los Azufres, Los Humeros and La Primavera) were not taken into account in this work, because they would deform the isotherms due to their high values and therefore the regional trend could not be obtained.

A method similar to Brigg's minimum curvature bidimensional interpolation

(Briggs, 1974) was used to configurate the silica temperature map, whereas a regular grid of interpolated values is obtained iteratively. The following is a brief description of the method employed:

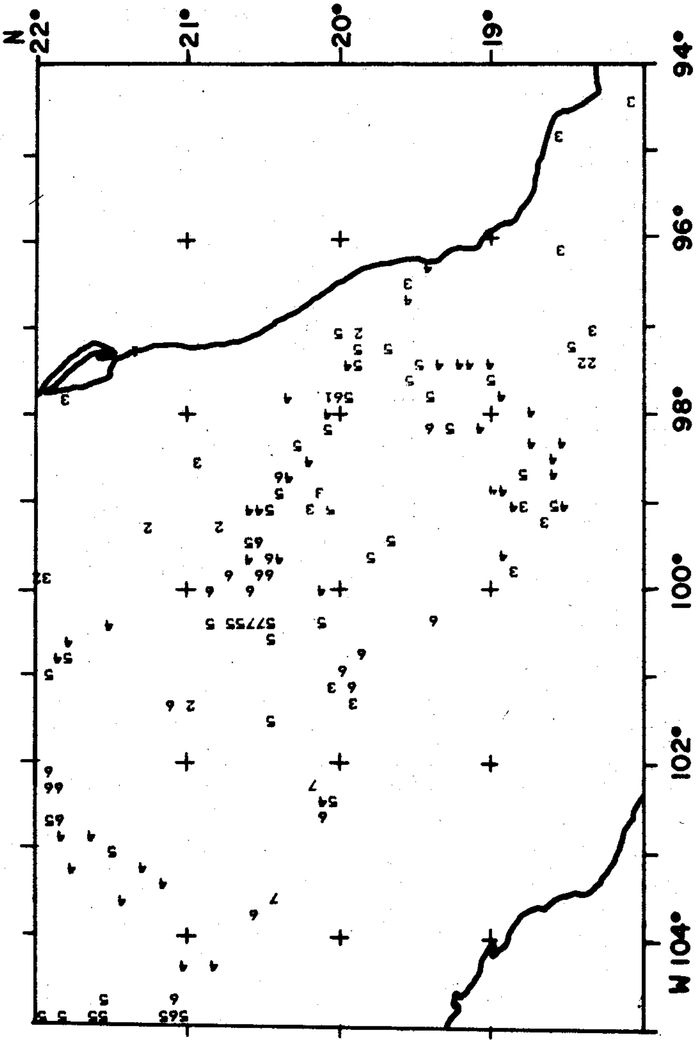

Fig. 1. Location of sampled springs and calculated temperature (in °C) according to the following scale:

9	T > 225	4	100 < T < 125
8	200 < T < 225	3	75 < T < 100
7	175 < T < 200	2	50 < T < 75
6	150 < T < 175	1	25 < T < 50
5	125 < T < 150	0	T < 25

Table 1. Location, silica concentration in p.p.m.(SiO_2) and calculated temperature in °C (T_{SiO_2}). The numbers to the right of the names of some springs indicate the following references: 1- Molina, 1978; 2-Templos, 1980a; 3-Templos, 1980b; 4-Templos, 1982a; 5-Templos, 1982b; 6- Templos, 1980c ; 7- Quijano and Chacón, 1982a; 8- Quijano and Gallardo, 1982a; 9- Quijano and Chacón, 1982b; 10-Quijano and Gallardo, 1982b.

Name of the spring	Lat. N	Long. W	SiO_2	T_{SiO_2}
Chacalapan	18° 2'	94° 40'	29.6	79.1
Agua Xoca	18° 16'	97° 17'	27.2	75.6
Calipan	18° 17'	97° 11'	24.4	71.3
Miahuatlán	18° 17'	97° 17'	34.4	85.3
Acatlán de las Panelas	18° 18'	97° 31'	23.2	69.3
San Sebastián	18° 19'	97° 17'	10.8	42.1
San Martín	18° 20'	97° 31'	16.4	56.4
San Lorenzo Tehuacán	18° 25'	97° 29'	58.4	109.3
San Fco. Tehuacán	18° 26'	97° 24'	83.2	127.2
Lázaro Cárdenas	18° 28'	96° 22'	37.6	89.1
San Tecomapán	18° 30'	95° 0'	37.6	89.1
Colucán	18° 30'	98° 29'	43.2	95.3
Ayustla	18° 30'	98° 30'	68.4	117.1
Las Huertas - 10	18° 30'	99° 10'	56.6	107.8
La Fundición - 10	18° 32'	99° 17'	91.9	132.5
Ixtatlala	18° 34'	98° 43'	60.8	111.2
Tepalcingo - 10	18° 35'	98° 50'	75.3	122.0
San Juan - 10	18° 36'	99° 23'	19.0	61.8
Cuachichiola - 10	18° 38'	99° 20'	35.0	86.1
Ojo del Carbón	18° 41'	98° 31'	74.8	121.6
Huehuetlan	18° 43'	98° 10'	77.6	123.5
Palo Bolero - 10	18° 46'	99° 14'	39.8	91.6
Agua Hedionda - 10	18° 47'	98° 55'	80.8	125.6
San Román - 10	18° 47'	99° 11'	44.1	96.2
Sultepec - 8	18° 50'	100° 2'	38.7	90.4
Temixco - 10	18° 51'	99° 13'	78.3	124.0
Tonatico - 8	18° 53'	99° 42'	44.1	96.2
Tecali	18° 54'	97° 58'	72.4	119.9
Itzamatitlán - 8	18° 54'	99° 0'	78.3	124.0
Oaxtepec - 10	18° 54'	99° 4'	78.2	123.9
Coatepec - 8	18° 54'	99° 42'	52.3	104.0
Ixtapan de la Sal - 8	18° 55'	99° 42'	51.4	103.2
La Esmeralda	18° 56'	97° 54'	69.6	117.9
Actipan	18° 56'	97° 55'	64.4	114.1
Las Palmillas	18° 56'	97° 57'	76.0	122.4
La Candelaria - 6	18° 58'	97° 32'	66.4	115.6
Acozac - 6	18° 58'	97° 50'	96.0	134.9
Tepozotlán - 10	18° 58'	99° 6'	50.2	102.1
Cofradía - 6	18° 59'	97° 44'	99.2	136.7
Agua Azul	19° 1'	98° 15'	67.2	116.2

Table 1 (cont.)

Name of the spring	Lat. N	Long. W	SiO_2	T_{SiO_2}
Rancho Colorado	19° 3'	98° 15'	72.4	119.9
San Juan Atenco - 6	19° 6'	97° 33'	64.2	113.9
Aljojuca - 6	19° 7'	97° 32'	51.4	103.2
Tecuiltlapa - 6	19° 8'	97° 33'	10.0	39.6
Salvador El Seco - 6	19° 10'	97° 40'	75.0	121.8
El Carmen	19° 14'	98° 13'	85.4	128.5
Portes Gil - 6	19° 19'	97° 33'	66.4	115.6
El Carrizal	19° 20'	96° 34'	48.4	100.4
Chignahuapan	19° 20'	98° 2'	48.8	100.8
Sta. Cruz El Porvenir	19° 20'	98° 21'	152.0	161.8
Canada Chica	20° 23'	99° 7'	86.5	129.2
Tagui	20° 23'	99° 48'	56.2	107.4
San Juan del Rio	20° 24'	100° 0'	141.8	157.5
San Marcos - 4	20° 24'	103° 34'	224.0	187.5
Zothe	20° 25'	99° 43'	136.9	155.4
Maguey Blanco	20° 26'	99° 13'	95.2	134.4
Dandho	20° 26'	99° 43'	125.0	149.9
Espejo - 2	20° 26'	100° 33'	97.7	135.9
Apaseo El Alto - 2	20° 27'	100° 38'	115.9	145.5
Abasolo - 3	20° 27'	101° 32'	95.2	134.4
Dios Padre	20° 28'	99° 12'	69.0	117.5
Pathecito	20° 28'	99° 40'	170.0	168.9
San Vicente - 2	20° 28'	100° 32'	93.8	133.6
San Antonio Calichal-2	20° 30'	100° 31'	93.0	133.2
El Llanito - 2	20° 30'	100° 32'	102.5	138.5
San Bartolomé - 2	20° 30	100° 33'	179.0	172.3
Tequisquiapan	20° 31'	99° 54'	152.3	161.9
Marroquin - 2	20° 31'	100° 34'	240.0	192.4
Tecozautla	20° 32'	99° 38'	95.1	134.4
Panhe	20° 32'	99° 42'	77.8	123.7
Pedro Escobedo	20° 32'	100° 10'	146.0	159.3
El Salitre - 2	20° 32'	100° 33'	235.0	190.9
El Pueblito	20° 33'	100° 27'	134.0	154.1
La Norita - 2	20° 33'	100° 31'	99.0	136.6
Ameche - 2	20° 33'	100° 35'	93.0	133.2
Tzindejhe	20° 34'	99° 18'	79.2	124.6
Hervores de la Vega -5	20° 35'	103° 52'	156.6	163.7
Obrajuelos - 2	20° 36'	100° 34'	93.0	133.2
Ezequiel Montes	20° 40'	99° 54'	167.0	167.8
Jurica	20° 41'	100° 29'	99.0	136.6
Zimapán	20° 44'	99° 23'	17.3	58.3
Colón	20° 48'	100° 4'	172.0	169.7
Sta. Rosa Jáuregui	20° 48'	100° 28'	116.0	145.6
Amatlán	20° 48'	104° 24'	74.0	121.1
Atempa	20° 55'	98° 35'	30.6	80.4
Aguas Buenas - 3	20° 57'	101° 22'	17.3	58.3
Terrero del Rio	21° 2'	104° 19'	56.6	107.8
Los Paredones	21° 3'	105° 0'	109.0	142.0
Comanjilla - 3	21° 4'	101° 29'	186.0	174.8
El Conde	21° 5'	104° 57'	136.0	155.0
Tetitlán	21° 7'	104° 41'	158.0	164.3
Mezquitlán del Oro	21° 20'	103° 23'	70.0	118.2

Table 1. (cont.)

Name of the spring	Lat. N	Long. W	SiO_2	T_{SiO_2}
Guasimas	21° 10'	104° 56'	92.0	132.6
Jalpan	21° 13'	99° 27'	17.7	59.2
Tamiagua	21° 16'	97° 27'	9.6	38.3
Moyahua	21° 16'	103° 11'	78.0	123.8
Teul	21° 24'	103° 37'	60.0	110.6
Apozol	21° 30'	103° 4'	80.0	125.1
El Jardin	21° 31'	100° 31'	76.5	122.8
La Fortuna	21° 32'	104° 56'	94.7	134.1
Ixtapan del Oro - 8	19° 20'	100° 28'	134.0	154.1
El Carmen	19° 23'	97° 57'	92.4	132.8
La Unión - 6	19° 27'	97° 33'	86.2	129.1
Los Pocitos	19° 29'	96° 47'	58.6	109.4
Libres - 6	19° 30'	97° 42'	89.8	131.3
Tinajitas	19° 31'	96° 37'	39.6	91.4
Jiquipilco - 8	19° 38'	99° 40'	123.0	149.0
Tepeyahualco	19° 39'	97° 27'	88.8	130.7
Santa Maria - 8	19° 45'	99° 46'	124.0	149.5
Querendaro - 1	19° 48'	100° 53'	135.0	154.5
San Bartolo	19° 49'	97° 13'	19.2	62.2
Ocotlán - 6	19° 49'	97° 32'	83.6	127.4
Acuaco - 6	19° 49'	97° 34'	77.8	123.7
Chignautla - 6	19° 50'	97° 23'	80.6	125.5
La Estancia - 1	19° 50'	100° 51'	28.0	76.8
Tlatlanquitepec - 6	19° 52'	97° 30'	77.6	123.5
Quetzalapa	19° 52'	98° 0'	117.0	146.1
Tolimán	19° 53'	97° 58'	25.2	72.6
Alcaparroza	19° 53'	98° 1'	114.0	144.6
Copándaro - 1	19° 53'	101° 12'	40.0	91.8
Las Arenas - 1	19° 53'	101° 20'	42.0	94.0
San Miguel	19° 54'	97° 58'	46.4	98.5
Tepozan	19° 54'	98° 0'	46.4	98.5
San Agustin del Maiz-1	19° 54'	101° 10'	179.0	172.3
Metlavista	19° 58'	98° 1'	145.0	158.9
San Agustin P. - 1	19° 58'	101° 4'	130.0	152.3
Rio Sordo	19° 59'	97° 13'	113.0	144.1
Zacatlán	20° 0'	98° 7'	73.6	120.8
Vindho	20° 0'	99° 19'	86.5	129.2
Huandacareo - 1	20° 0'	101° 16'	28.0	76.8
Cualtepec	20° 1'	97° 51'	11.6	44.4
Vihto	20° 2'	99° 13'	79.1	124.5
Ventoquilla	20° 3'	98° 22'	86.5	129.2
Platanal - 9	20° 3'	102° 35'	81.1	125.8
Puroagüita - 3	20° 4'	100° 27'	119.4	147.3
Ojo de Agua - 9	20° 4'	102° 34'	72.5	120.0
Los Negritos - 9	20° 4'	102° 37'	167.0	167.8
Temascalsingo	20° 5'	100° 7'	78.0	123.8
La Troje - 9	20° 5'	102° 36'	53.4	105.0
Las Avila - 9	20° 5'	102° 37'	82.6	126.8
Tlaltenango	20° 6'	98° 57'	45.5	97.6
Ajacuba	20° 6'	99° 7'	38.9	90.6
Pozo Municipal - 9	20° 7'	102° 39'	82.8	126.9
Ixtlán - 9	20° 10'	102° 22'	226.0	188.1
Pueblo Nuevo	20° 11'	98° 42'	77.8	123.7

Table 1. (cont.)

Name of the spring	Lat. N	Long. W	SiO_2	T_{SiO_2}
Tezontepec	20° 11'	99° 16'	38.9	90.6
Alchotoya	20° 14'	98° 27'	117.0	146.1
La Blanca	20° 16'	98° 56'	56.2	107.4
El Paraiso	20° 18'	98° 0'	52.0	103.8
Sta. Ma. Amaya	20° 22'	98° 46'	138.0	155.9
Las Lajas	21° 33'	104° 51'	111.0	143.0
Agua Azufrada	21° 33'	104° 52'	91.7	137.0
Bellavista	21° 33'	104° 53'	76.4	122.7
Barranca Blanca	21° 33'	104° 57'	107.0	140.9
F.I. Madero	21° 35'	104° 49'	98.4	136.3
La Cantarilla	21° 35'	104° 50'	72.3	119.9
El Trapiche	21° 35'	104° 59'	91.7	132.4
Benito Juárez	21° 36'	105° 0'	97.5	135.7
Jalpa	21° 39'	102° 54'	52.0	103.8
San Jerónimo	21° 44'	97° 51'	45.6	97.7
Ojo Caliente	21° 45'	100° 46'	72.7	120.2
Villa de Reyes	21° 47'	100° 56'	116.0	145.6
Tlaltenango	21° 47'	103° 19'	74.0	121.1
Gogorrón	21° 49'	100° 54'	70.9	118.9
El Salitre	21° 50'	102° 45'	154.0	162.6
Huamiloyan - 7	21° 50'	104° 50'	110.0	142.5
La Cantera - 7	21° 51'	102° 21'	128.0	151.4
Tabasco	21° 51'	102° 55'	62.0	112.2
Unión Vinícola - 7	21° 52'	102° 20'	142.0	157.6
Ojo Caliente - 7	21° 53'	102° 15'	130.0	152.3
Colonos - 7	21° 53'	102° 39'	60.5	111.0
Jaramito - 7	21° 53'	102° 40'	119.0	147.1
El Carmen	21° 54'	100° 59'	80.9	125.7
La Media Luna	21° 55'	99° 59'	28.5	77.5
Reformita	21° 58'	100° 0'	25.1	72.4
Agua Caliente	21° 59'	105° 0'	103.0	138.8

1. A regular grid of points is placed on the map area (11° x 4°).

2. As observations are randomly distributed on the map, their values are assigned to the nearest grid point.

The dimensions chosen for the grid depend on: a) computer processing time (the finer the grid, the longer the processing time) and b) acceptable location of points (on a coarse grid observations will be significantly removed from their actual locations on the map). Thus, a compromise has to be reached to this respect. In our case, 60 x 60 grid points were the dimensions that provided such a compromise, keeping processing times low and relocation of points small enough to be negligible.

3. The matrix elements which are far from observations are given a value of 100°C regarded as a reference. Matrix elements in the neighborhood of an observation (±3 rows or columns) take the observed value. The radius of this neighborhood is of the same magnitude as the inverse square root of the density of observations per

matrix entry. However, it can not be calculated from this criterion all the times, since this number would be a logical choice for uniformly distributed points but such is not the case with the present data.

4. A new matrix is calculated from the previously determined matrix according to these rules (Fig. 2):

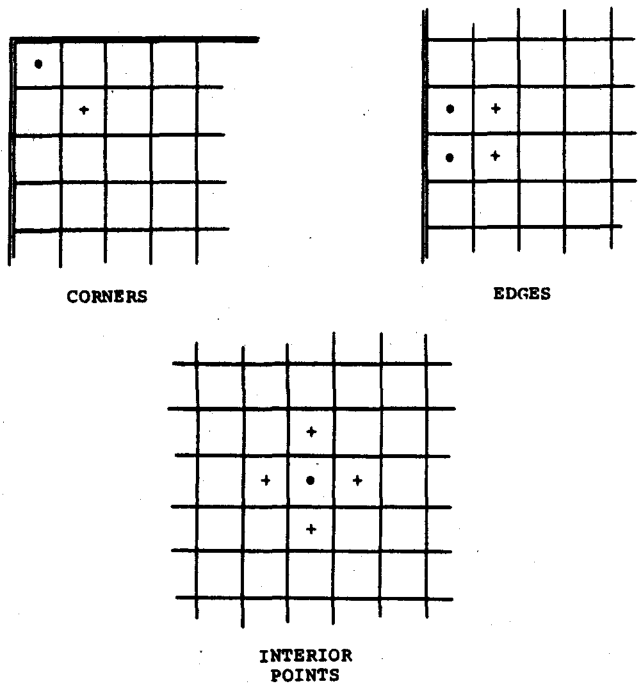

Fig. 2. Smoothing algorithm calculations. For interior points, an average of 4 values (marked +) is assigned to each point (marked .). At corners and edges, neighboring values are copied.

a) Interior points take the average value of the four closest matrix elements.

b) Edge points take the value of adjacent matrix elements.

c) Corners are treated as edge points.

Step 4 is known as a four-point average smoothing, a common method used in the digital processing of images.

5. Observed values are placed again in their initial locations. This time, however,

matrix elements where no observations fall are not affected as in step 3. Instead, they are allowed to "evolve" freely.

Step 5 constitutes one iteration. The map shown in this work is the result of contouring a set of values from a matrix obtained after 10 such iterations.

With this method we have not encountered problems with precision of arithmetic operations and contours can be easily traced. How realistic are the surfaces obtained depends on the number of observations and their distribution. There is a very defined area where control exerted by observations on the surface generated by the interpolating algorithm is evident. Thus, authenticity of the map can be judged from its comparison with the distribution of observed values (Fig. 1).

In the isotherm map (Fig. 3) it is observed that the central part (98° - 102°W) is dominated by very high values, decreasing to the North (20°N, 98°W) and South (19°N, 100°W) limiting the borders of volcanic formations with Jurassic Cretaceous sedimentary rocks to the North and lower Cretaceous limestones to the South (Geological Map of Mexico, 1981).

To the northwest (21°N, 102°W), temperatures decrease more slowly than to the Northeast (21°N, 98 °W), and they remain high within older sedimentary formations near recent volcanics (Geological Map of Mexico, 1981). There is a steep decrease throughout the southern section (19°N, 100°W) where temperature attains its lowest values in the contacts between recent igneous rocks and older sedimentary formations. Lower than average temperatures are also found in the eastern part (21°N, 99°W) which is characterized by older volcanic structures, now inactive.

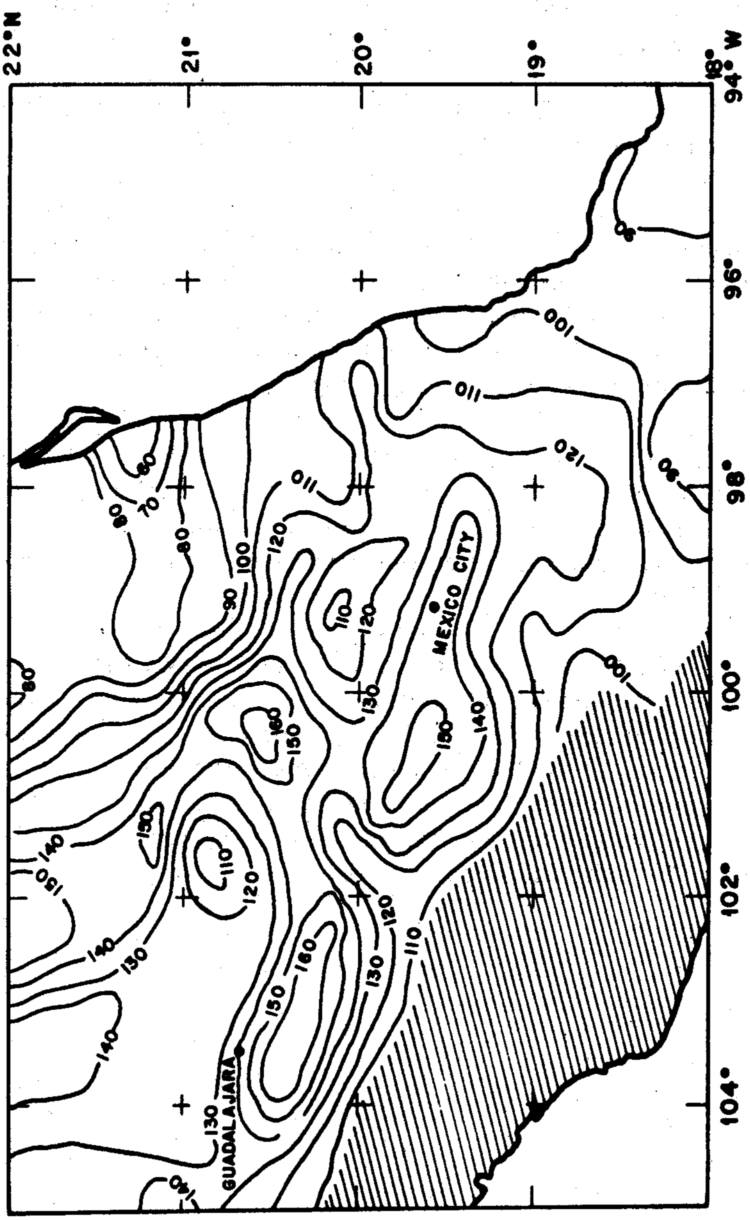

Fig. 3. Isotherm map for the Mexican Volcanic Belt Area. Areas where no information is available are hatched.

DISCUSSION

The most interesting feature in the temperature map is the growing tendency towards the West, where the highest maxima are related to centers of high volcanic risk as, for example, La Primavera (Booth, 1979). This might indicate an activation or reactivation of the volcanic activity in this direction, contrasting with the lower values obtained in the southeastern edge of the MVB, where with the sole exception of Los Humeros Volcanic Center, volcanism might be decaying. Los Humeros is a high temperature hydrothermal system that could distort the temperature map. However, as it is not included in the map, the isotherms show no regional activity in this area, *i.e.* silica temperature decreases with respect to the central and western parts of the MVB.

Several high temperature areas (T $>150^{o}C$) with northwest trend are observed (20^{o} - $22^{o}N$, 100^{o} - $102^{o}W$). They do not seem to be related to recent volcanism but may indicate a hydrothermal activity pattern, because in that zone old sedimentary formations predominate and no recent volcanic structures are exposed (Geological Map of Mexico, 1981). These sedimentary rocks yield favourable conditions for convection and increase the probabilities of finding hydrothermal systems in this zone.

Temperature minima ($T<110^{o}C$) within the Volcanic Belt region belong to samples collected from Cretaceous sedimentary formations. They represent local low temperature regimes associated with outcrops of old geological structures.

A relation between silica temperature and heat flow has been established for the United States (Swanberg and Morgan, 1979). However, when the relationship obtained for various provinces in the United States is applied to Mexican data, the calculated heat flow values are too high (the mean heat flow obtained for the MVB would be 149 mW/m^2), while the conventional heat flow data (Blackwell *et al.*, 1977) suggest an average of approximately 100 mW/m^2. Thus, although a direct relation should exist between these parameters, the use of appropriate corrective factors for each region seems necessary. Furthermore, when relating deep equilibria temperature to heat flow, it would be worthwhile to compare the silica temperatures with temperatures obtained with some alkaline ratio geothermometers as K/Mg. At the present state of knowledge of the heat flow in the MVB, it is not possible to determine the constants for this region. However, a direct relation between silica temperature and heat flow seems quite acceptable and it would mean a shift of thermal activity to the West and into the Pacific Ocean, as oceanic heat flow data indicate (Prol *et al.*, 1985). Average heat flow on the Middle America Trench between 20°25' N and 21°20' N is higher than 200 mW/m^2. This is not a typical value for a subduction zone, therefore it can be assumed that high heat flow values associated with the MVB are not restricted to the continent, but they are still present in the Pacific Ocean interrupting the subduction processes between the Rivera and the North America plates. Several hypotheses may be constructed on the basis of this data about the formation and development of the MVB. However, it seems necessary to wait for more detailed data to make final conclusions.

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BIBLIOGRAPHY

BLACKWELL, D. D., J. ZIAGOS and F. MOOSER, 1977. Heat flow and the thermal effects of subduction in southern Mexico. *EOS Trans. AGU, 58,* 1233.

BOOTH, B., 1979. Assessing volcanic risk. *J. Geol. Soc., 136,* 331-340.

BRIGGS, I. C., 1974. Machine contouring using minimum curvature. *Geophysics, 39,* 39-48.

GEOLOGICAL MAP OF MEXICO, 1981. Secretaría de Programación y Presupuesto, México. Sheets 4 and 5.

MOLINA, R., 1978. Geoquímica de las manifestaciones del Lago de Cuitzeo y su relación con Los Azufres, Michoacán, México. Comisión Federal de Electricidad. Inf. Téc. 35 pp.

PROL, R. M., V. M. SUGROBOV, YA. B. SMIRNOV, L. FLORES, G. JUAREZ, A. P. GORSHKOV, V. G. BONDARENKO, V. A. RASHIDOV, L. N. NEDOPEKIN and V. A. GAVRILOV, 1984. Variaciones en el régimen tectónico a lo largo de la Trinchera Mesoamericana. Reunión de la Unión Geofísica Mexicana. La Paz, B. C.S., México, 12 - 16 noviembre.

QUIJANO, J. L. and M. CHACON, 1982a. Reconocimiento y evaluación geoquímica de zonas termales en el Estado de Aguascalientes, México. Comisión Federal de Electricidad. Inf. Téc. 21 pp.

QUIJANO, J. L. and M. CHACON, 1982b. Evaluación geoquímica de las zonas geotérmicas de Ixtlán de los Hervores y de Los Negritos, Michoacán, México. Comisión Federal de Electricidad. Inf. Téc. 22 pp.

QUIJANO, J. L. and M. GALLARDO, 1982a. Reconocimiento y evaluación geoquímica del Estado de México, México. Comisión Federal de Electricidad. Inf. Téc. 17 pp.

QUIJANO, J. L. and M. GALLARDO, 1982b. Reconocimiento y evaluación geoquímica de zonas termales en el Estado de Morelos, México. Comisión Federal de Electricidad. Inf. Téc. 14 pp.

SMITH, D. L., C. E. NUCKELS III, R. L. JONES and G. A. COOK, 1979. Distribution of heat flow and radioactive heat generation in Northern Mexico. *J. Geophys. Res. 84,* 2371-2379.

SWANBERG, C. A. and P. MORGAN, 1979. The linear relation between temperatures based on the silica content of groundwater and regional heat flow: A new heat flow map of the United States. *Pageoph., 117,* 227-241.

TEMPLOS, L. A., 1980a. Geoquímica preliminar de la zona geotérmica de San Bartolomé de los Baños - El Salitre, Guanajuato, México. Comisión Federal de Electricidad. Inf. Téc. 27 pp.

TEMPLOS, L. A., 1980b. Geoquímica preliminar de las zonas geotérmicas de Comanjilla-Puroagüita y La Caldera, Guanajuato, México. Comisión Federal de Electricidad. Inf. Téc. 15 pp.

TEMPLOS, L. A., 1980c. Informe de la exploración geoquímica en las zonas geotérmicas Humeros-Derrumbadas, Puebla, México. Comisión Federal de Electricidad. Inf. Téc. 21 pp.

TEMPLOS, L. A., 1982a. Estudio geoquímico detallado del campo geotérmico de San Marcos, Jalisco, México. Comisión Federal de Electricidad. Inf. Téc. 19 pp.

TEMPLOS, L. A., 1982b. Geoquímica preliminar de la zona geotérmica de Hervores de la Vega, Jalisco, México. Comisión Federal de Electricidad. Inf. Téc. 11 pp.

TRUESDELL, A. M., 1976. Summary of section III - geochemical techniques in exploration. *In:* Proceedings, Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, Calif., 1975. U. S. Government Printing Office, Washington, D. C., p. iii-xiii.

WAPLES, D. W., 1980. Time and temperature in petroleum exploration. *Am. Assoc. Petrol.Geol., 64,* 916-926.

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