Assumptions and Applications

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The Silica Heat Flow Interpretation Technique: Assumptions and Applications

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We have previously established a linear relation between temperatures based on the silica content of groundwater and regional heat flow and used the relation to prepare a new heat flow map of the continental United States. We now examine the assumptions upon which the relation is based, the accuracy to which groundwater silica data can be used to estimate regional heat flow, and the limitation of the technique. By averaging silica geotemperatures and traditional heat flow values over 1° × 1° blocks, the linear regression is $TSiO_2 = mq + b$, where m and b are constants determined to be $680 \pm 67°C\ m^2\ W^{-1}$ and $12.4 \pm 5.1°C$. The physical significance of b is mean annual surface temperature, and the product of m times thermal conductivity reflects the minimum mean depth to which groundwaters may circulate. These values are not sufficiently different from our earlier values ($m = 670$, $b = 13.2$) to justify using the newer values. To illustrate the application of the linear regression in predicting regional heat flow, data sets are presented from upstate New York, south central New Mexico, and Egypt. In each case, the predicted heat flow is tectonically reasonable and consistent with whatever traditional data are available.

INTRODUCTION

The silica geothermometer is based on the temperature dependence of quartz solubility in water [*Fournier and Rowe*, 1966] and is usually applied to thermal waters to estimate reservoir base temperatures of geothermal systems. This geothermometer can be quantitatively expressed according to the conductive cooling equation of *Truesdell* [1976]:

$$TSiO_2 = \frac{1315}{5.205 - \log_{10} SiO_2} - 273.15 \qquad (1)$$

where $TSiO_2$ is the silica geotemperature in degrees Celsius and dissolved silica SiO_2 is expressed in milligrams per liter. The quantitative use of this geothermometer requires that water-rock equilibrium exists within the geothermal system and that there is neither silica precipitation, continued water-rock reactions, nor mixing with nonthermal groundwaters as the water migrates from the geothermal reservoir to the sampling point.

In our earlier publication [*Swanberg and Morgan*, 1979] we applied equation (1) to approximately 100,000 groundwater silica analyses from the United States and developed the following linear regression by averaging silica geotemperatures and heat flow values over the five major heat flow provinces for which both parameters were sufficiently abundant to permit calculation of reliable mean values:

$$TSiO_2 = mq + b \qquad (2)$$

A contour map (of $TSiO_2$) was then prepared to show regions of low, normal, moderate, and high heat flow. The present manuscript redevelops (2) by averaging heat flow and silica geotemperatures over 1° × 1° blocks, thus making it possible to assign heat flow estimates to these relatively small areas with the ultimate goal of preparing a quantitative heat flow map of the United States.

In the present study, groundwater silica data have been taken primarily from the U.S. Geological Survey Water Quality File Watstore, a computerized data bank containing roughly 100,000 silica analyses for groundwaters of the United States. In areas where the Watstore data are sparce we have utilized state water quality files (~100,000 silica analyses) and data from the published literature. The heat flow data have been supplied by J. Sass (personal communication, 1979) and basically represent an update of his 1976 heat flow compilation of the United States [*Sass et al.*, 1976].

JUSTIFICATIONS AND ASSUMPTIONS

Since (2) is empirical in nature, its main justifications are the quality of the fit, the reasonable values obtained for the constants, and the fact that it can be successfully used to predict regional heat flow [*Swanberg and Morgan*, 1979]. Thus the only assumption necessary to predict heat flow from groundwater silica data is that the groundwaters in the area under investigation have behaved in a similar manner to those waters used in constructing (2). Still, the technique is theoretically plausible, and in the following paragraphs we present a physical model which may help to explain why groundwater silica data can be used to predict regional heat flow. While the proposed model may not be theoretically rigorous, it does explain the observational data without violating any basic geological concepts. The essence of the model is that a circulating groundwater will become saturated with quartz at some point in its circulation path. The temperature of this point can be calculated from (1) and the depth of the point can be obtained from a modification of (2), as described below. The temperature-depth data can be combined with an assumed mean air temperature and an estimated thermal conductivity to yield heat flow. The requisite assumptions are summarized below.

Assumption 1. The first assumption is that (1) can be used to predict subsurface temperatures. This means that water-rock equilibrium exists at depth and that there is neither silica precipitation, continued water-rock reactions, nor mixing with waters of different silica concentrations as the water migrates from depth to the surface sampling point. These conditions are fairly realistic for a geothermal water which may migrate rather quickly to a surface hot spring but are less certain for a nonthermal groundwater which may have resided within a sedimentary section for a substantial period of time. Still, these conditions are supported by the general reluctance of quartz to precipitate from supersaturated solutions [*Truesdell*,

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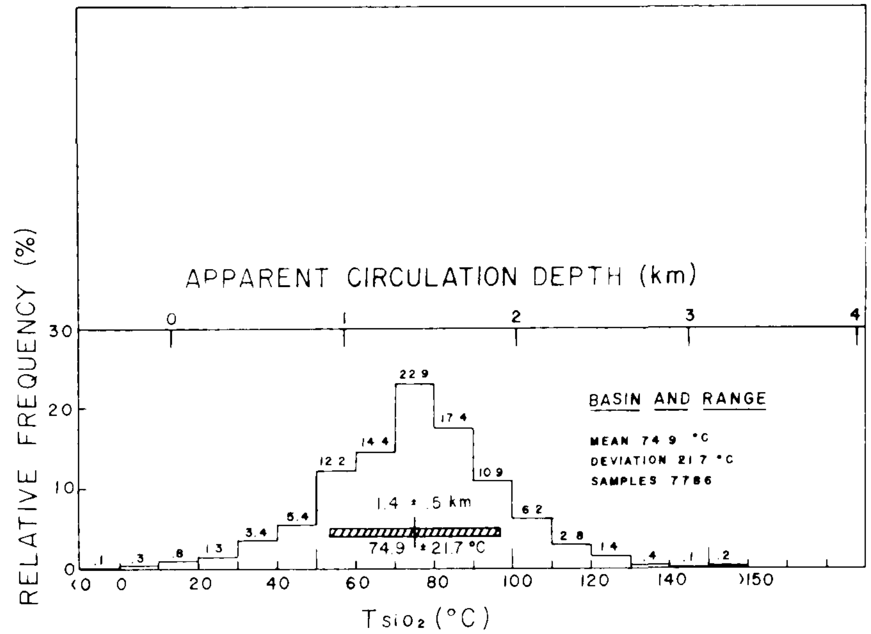

Fig. 1. Histogram showing relative abundances of silica geotemperatures within the Basin and Range Province, along with their apparent minimum circulation depths.

1976] and the very slow water-rock reaction rates at low temperatures [*Rimstidt*, 1977].

Assumption 2. The defining equation for terrestrial heat flow q can be written

$$q = K\, dT/dz \qquad (3)$$

where K is thermal conductivity, and dT/dz is the geothermal gradient. Substituting (3) into (2) and solving the resulting differential equation, we obtain

$$(\mathrm{TSiO_2} - b)z = mK(T_z - T_0) \qquad (4)$$

where T_0 and T_z are the temperatures at the surface and depth z, respectively, and the constant of integration is $-mKT_0$. However, $T_0 = b$, since the physical significance of b is mean annual surface temperature [*Swanberg and Morgan*, 1979] and $T_z = \mathrm{TSiO_2}$ under assumption 1 above so that (4) reduces to

$$mK = z \qquad (5)$$

The second assumption is that this depth is the depth of the last water-rock equilibrium or, for geothermal systems, the depth of the geothermal reservoir. Since the constant m has been determined and thermal conductivity can be estimated, it becomes possible to estimate the mean circulation depth of groundwaters. Since nearly all of our silica data represent groundwaters in sedimentary aquifers, we have used a mean conductivity of sediments (2.1 W m^{-1} $°C^{-1}$) so that the mean

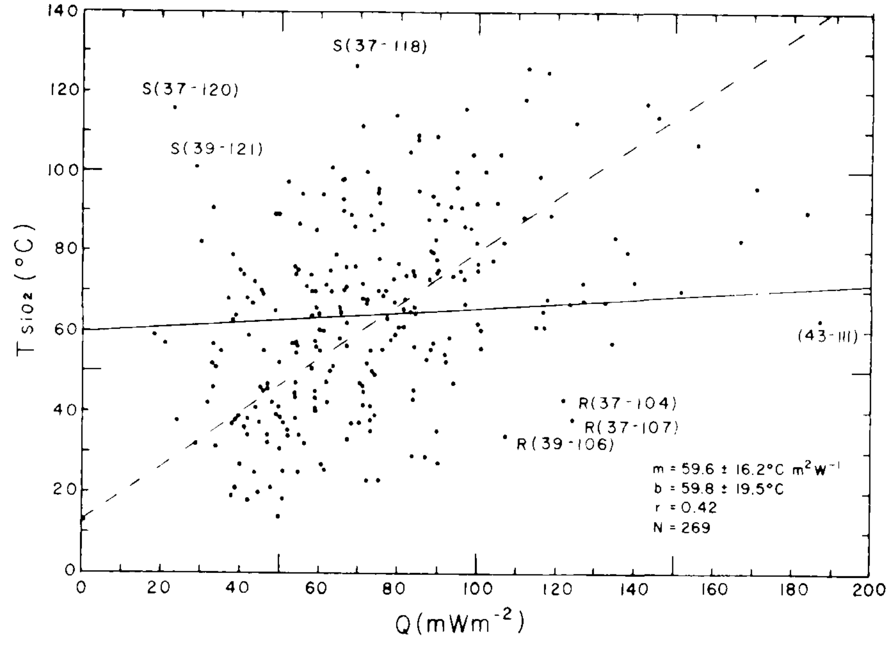

Fig. 2. Plot of silica geotemperature against heat flow for 1° × 1° blocks in the United States. The r is the correlation coefficient for N number of $\mathrm{TSiO_2} - q$ pairs. The dashed line is the regression of *Swanberg and Morgan* [1979] (m = 670° m^2 W^{-1}, b = 13.2°C). Individual blocks are designated by the southeast coordinate and are discussed in the text.

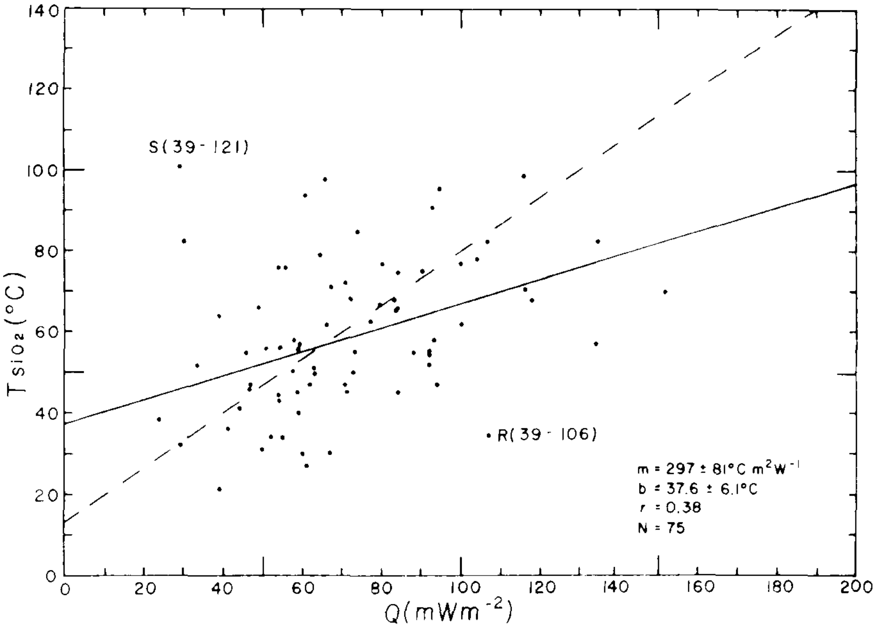

Fig. 3. Plot of silica geotemperatures against heat flow for 1° × 1° blocks meeting our requirements for reliable silica data (see text). Other notations are the same as for Figure 2.

circulation depth becomes 1.4 km. This is a minimum depth if circulating groundwaters contribute a convective component to the total heat flow [*Lachenbruch and Sass*, 1977] or if silica precipitation has occurred, so it is more appropriate to call it an apparent minimum mean circulation depth.

Figure 1 shows the silica geotemperatures for 7786 groundwaters in the Basin and Range Province of western United States and the corresponding apparent circulation depths. The mean and standard deviation of the silica geotemperatures are 74.9 ± 21.7°C, which correspond to a circulation depth of 1.4 ± .5 km, and although this value cannot be confirmed or rejected, it is not unrealistic. The waters giving negative apparent circulation depths represent meteoric waters (particularly snow melt) which have circulated in shallow aquifers and never reached equilibrium with their host rock due to the extremely slow water-rock reaction rates at low temperatures [*Rimstidt*, 1977]. Waters having circulation depths above 4 km (equivalent to 190°C, Figure 1) are not common, and the lithostatic pressures may severely restrict circulation to these depths. A review of the geothermal literature [*Muffler*, 1979] shows that most geothermal areas having temperatures greater than 200°C are associated with suspected magmatic heating (i.e., Yellowstone, Valles, Newberry, Mono Calderas) and not due strictly to deeply circulating groundwater.

Assumptions 3 and 4. The final assumptions are that the main factor governing effective permeability is lithostatic pressure and that nearly all rocks contain sufficient silicate

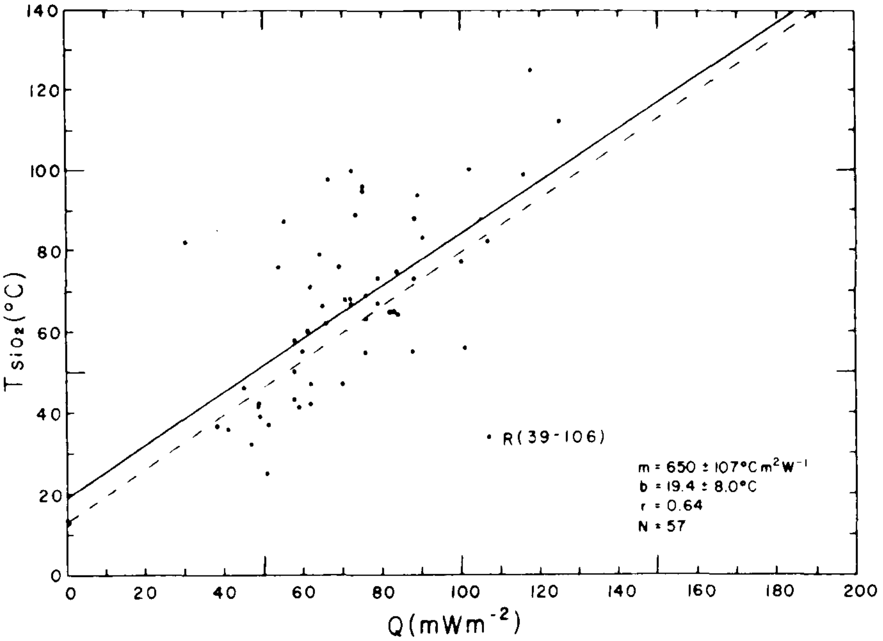

Fig. 4. Plot of silica geotemperature against heat flow for 1° × 1° blocks meeting our requirements for reliable heat flow data (see text). Other notations are the same as for Figure 2.

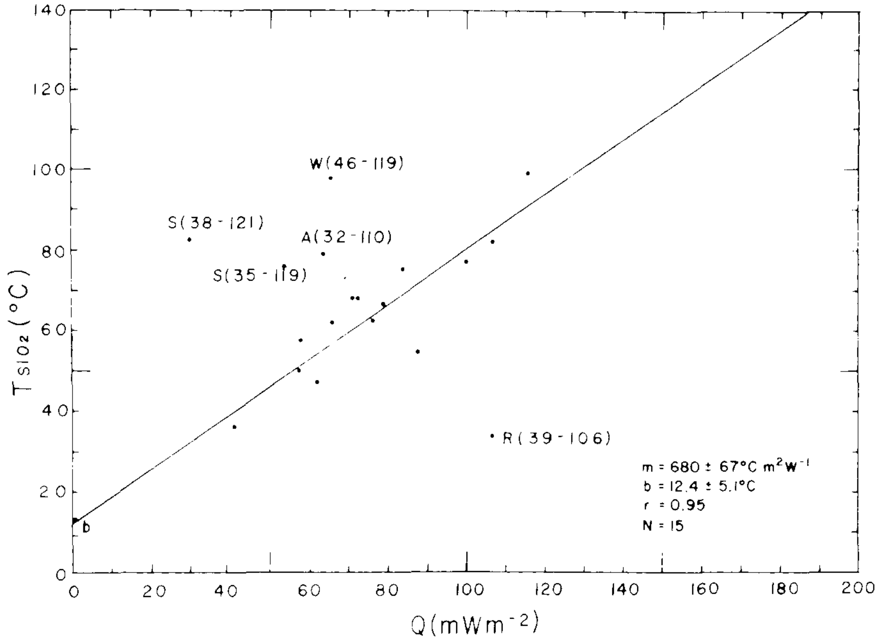

Fig. 5. Plot of silica geotemperature against heat flow for 1° × 1° blocks meeting our requirements for both reliable silica and heat flow data sets. Other notations are the same as for Figure 2.

minerals to saturate the groundwater with quartz. These assumptions make it possible to utilize waters from differing tectonic, geographic, and geologic environments.

Summary of assumptions. Under assumptions 1 and 2 the silica geothermometer (equation (1)) gives a temperature at a depth which can be calculated from (5) by assuming a regional mean value for thermal conductivity. We have used a conductivity of 2.1 W m^{-1} °C^{-1} to represent the sedimentary rocks most typical of our data set so that the depth becomes 1.4 ± .5 km. The temperature depth data can be combined with an assumed mean surface air temperature to give geothermal gradients. Finally, under assumption 3, silica geotemperatures can be used directly to calculate regional heat flow by using (2) in any regional geologic environment.

ACCURACY OF THE TECHNIQUE

Figure 2 shows silica geotemperatures plotted against heat flow for each 1° × 1° grid block in the United States for which data exist. Also shown is the regression line from *Swanberg and Morgan* [1979]. It is clear from the low correlation coefficient ($r = 0.42$), the large standard deviations, and the discrepancy between the two regressions that the technique has failed for some reason. A closer look at the points which fall farthest from the regression line shows that part of the

TABLE 1. Heat Flow and Silica Geotemperatures for 1° × 1° Blocks for Which Both Heat Flow and Silica Geotemperatures are Well Defined (See Text)

Latitude-Longitude of SE Corner of 1° × 1° Block	Heat Flow Number	Heat Flow Average, mW m^{-2}	Heat Flow SD, mW m^{-2}	Comments	$TSiO_2$ Number	$TSiO_2$ Average, °C	$TSiO_2$ SD, °C	Silica Heat Flow, mW m^{-2}
32°-110°	4	64.4	11.3	omit*	181	79	15	98.2
33°-116°	3	71.1	8.8		532	68	23	81.9
34°-117°	13	66.5	7.9		782	62	21	72.7
34°-118°	10	71.9	12.5		485	68	16	81.9
35°-119°	10	54.3	10.4	omit*	447	76	16	93.6
37°-121°	8	78.6	10.9		375	67	17	80.3
38°-121°	3	29.7	3.8	omit*	212	82	24	102.8
38°-105°	6	76.5	15.0		224	63	21	74.4
38°-108°	3	58.1	2.5		107	50	24	54.8
39°-105°	7	87.8	15.9		611	55	18	62.3
39°-106°	3	107.0	11.7	omit*	217	34	16	30.9
39°-108°	3	57.7	5.4		571	58	14	66.9
41°-91°	3	61.9	0.4		789	47	19	50.6
40°-116°	5	116.2	22.6		300	99	21	127.9
40°-118°	6	107.0	15.9		260	82	23	102.8
32°-106°	8	100.3	18.8		456	77	19	95.3
40°-112°	3	83.6	10.9		333	75	23	92.4
46°-119°	6	65.6	5.0	omit*	248	98	19	126.6
Lake Superior†	166	41.0	7.9		122	36	10	34.3

*Omitted from data set because heat flow and silica data come from separate heat flow regimes within the 1° × 1° block (see text).

†Heat flow data from Lake Superior—silica data form 1° × 1° blocks adjacent to Lake Superior.

TABLE 2. Summary of Silica-Heat Flow Data

Area	Number of Samples	Silica Geotemperature, °C	Mean Surface Temperature, T_0	Equivalent Heat Flow (Equation (7)), mW m^{-2}	Traditional Heat Flow: Number Points	Traditional Heat Flow: Milliwatts per Square Meter
New York						
All data	45	41.7 ± 10.8	9	48.8 ± 10.8[a]	13	48.1 ± 11.3[b]
Anomalies only	15	50.9 ± 8.5	9	62.5 ± 11.7		
Anomalies excluded	29	37.2 ± 8.8	9	42.1 ± 10.3		
Rio Grande Rift of Southern New Mexico						
All data	300	84.1 ± 18.4	16	101.6 ± 14.3	11[g]	102.9 ± 24.1
Perferred sampling technique	71	90.2 ± 27.0[c]	16	110.7		
Egypt						
Eastern Desert	28	76.6 ± 16.1	26	75.5 ± 12.6	8	77.6 ± 42.4[d]
Western Desert	43	53.0 ± 4.9	26	40.3 ± 10.2		40–45[d]
Cairo Area	4[c]	89.1 ± 13.5	26	94.2		
Gulf of Suez Area	3[c]	83.0 ± 24.6	26	85.1		80–100[e] 116[f]

[a] The errors are calculated from equation (6).

[b] All New York State (J. Sass, personal communication, 1979).

[c] This value fails to meet our requirement for a reliable data set.

[d] Estimate by *Morgan and Swanberg* [1979].

[e] *Morgan et al.* [1976].

[f] Value for the Red Sea [*Haenel*, 1972].

[g] Geothermal areas omitted from the average.

problem results from 1° × 1° blocks which overlap province boundaries in such a way that the silica and heat flow data represent different thermal regimes within the block. Such points obviously should be removed from the data set. For example, the three points labeled 'S' all involve heat flow measured in the low heat flow, Sierra Nevada province, whereas the silica data come from the higher heat flow adjacent provinces such as the Basin and Range or the San Joaquin-Sacramento valleys. Likewise, the three points labeled 'R' involve heat flow values representing the high heat flow Rio Grande Rift of Colorado and New Mexico, whereas the silica data come from the adjacent normal heat flow areas such as the Colorado Plateau or the High Plains.

There are several other 1° × 1° blocks in the United States which overlap province boundaries, but the problem may also result from inadequate heat flow and/or silica data. To check these possibilities, we consider only the most reliable data. The silica data are considered reliable only if more than 100 points are available and the standard deviation is less than 25°C. For heat flow we require at least three individual values whose standard deviation is less than 20% of the mean value. These requirements should also reduce the problem of 1° × 1° blocks overlapping province boundaries, since those blocks are generally characterized by large standard errors (or even bimodal distribution) in both heat flow and silica geotemperatures.

Figure 3 shows a plot of silica geotemperatures against heat flow for only those 1° × 1° blocks meeting our requirements for adequate silica data. This regression appears to be an improvement over that shown in Figure 2, since it approximates more closely our original regression [*Swanberg and Morgan*, 1979]. However, the correlation coefficient ($r = 0.38$) remains basically unchanged, and we interpret this to mean that the poor fit shown in Figure 2 does not result entirely from the quality of the silica data.

Figure 4 is similar to Figure 3 except that it represents only 1° × 1° blocks which meet our criteria for adequate heat flow. In this case we reproduce quite well our original regression line, and the correlation coefficient has been increased to $r = 0.64$. We interpret these data to indicate that the poor fit shown in Figure 2 does not result from the technique itself (equation (2)) or from the lack of adequate silica data but rather from the lack of traditional heat flow data with which to calibrate. Correlaries to this conclusion are that a single heat flow determination may or may not be a good estimate of regional heat flow, that significant misinterpretation may result from characterizing large areas on the basis of a single determination, and that much of the United States (particularly the east) is seriously understudied with respect to regional heat flow.

Figure 5 shows silica geotemperatures and heat flow for only those 1° × 1° blocks which meet our criteria for both adequate silica and heat flow data. In this case we reproduce quite well our original regression, and the correlation coefficient has jumped to $r = 0.95$. The linear regression to the best 15 points (Table 1) yields values of 680 ± 67°C m^2 W^{-1} and 12.4 ± 5.1°C for m and b, respectively, and these values are not sufficiently different from our earlier values ($m = 670$°C m^2 W^{-1}; $b = 13.2$°C) to justify using the newer values.

Five points have been omitted from the linear regression shown in Figure 5. The points labeled 'S,' 'R,' and 'A' can be rejected because they overlap province boundaries in such a way that the silica and heat flow data represent different thermal regimes within the 1° × 1° block as discussed earlier. The point labeled 'W' is located on the Columbia Plateau near the Oregon boundary and is truly anomalous. It is possible that the silica data are too high because of leaching of amorphous silica from the Columbia basalts. It is also possible that the heat flow is too low because of regional hydrologic disturbances, and *Blackwell* [1978] has noted such disturbances in the eastern Snake River Plain. *Blackwell* [1978] also notes a close correlation between areas of Cenozoic volcanism and

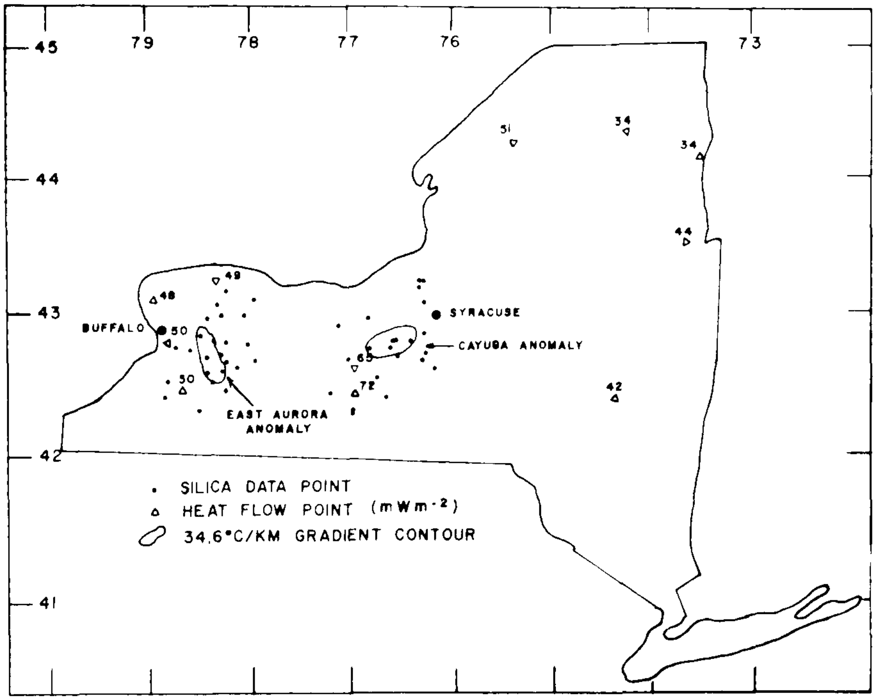

Fig. 6. Locations of silica data points and traditional heat flow values for New York. The 34.6°C/km gradient contour is from *American Association of Petroleum Geologists* [1976]. The heat flow values in milliwatts per square meter are from the compilation of J. Sass (personal communication, 1979).

areas of high heat flow with the notable exception of the Columbia Plateau basalts in the area of point 'W' in Figure 5.

Summary. Figure 5 shows the accuracy of the silica geotemperature/heat flow regression. Heat flow can thus be determined to an accuracy of

$$7.5 \pm 0.067q \text{ mW m}^{-2} \qquad (6)$$

This variation is about the same as typically observed among traditional heat flow values covering a comparable area, so it appears that the silica heat flow method is working as well as the traditional approach. Over the range of typical heat flow values (40–120 mW m^{-2}) the above errors correspond to between ±11.5 mW m^{-2} (0.28 HFU) and ±19.5 mW m^{-2} (0.47 HFU). These values are only valid under the constraint that 100 silica geotemperatures are available, and their standard deviation about the mean is less than 25°C. The resulting heat flow represents a regional mean and is the same value that would be obtained if three traditional determinations had been obtained and if their standard deviation about the mean is less than 20% of the mean. It should also be noted that the silica method yields a meaningful standard deviation of regional heat flow, since all groundwaters including geothermal and meteoric waters are included in the data sets. This is not true in traditional heat flow studies, since thermal areas may be deliberately avoided and boreholes exhibiting disturbed gradients (i.e., isothermal) are often deleted from the data set.

Significance of 'b.' In our earlier study [*Swanberg and Morgan*, 1979] we used a mean surface temperature of 13.2°C (b of equation (2)). This approach worked quite well since most or our data came from geographic terrains where 13.2°C was a reasonable estimate of surface temperature. However, more accurate results can be obtained using a mean air temperature determined locally so that (2) becomes

$$TSiO_2 = mq + T_0 \qquad (7)$$

where T_0 may be obtained by surface extrapolation of temperature-depth data, by averaging the mean air temperatures of nearby weather stations (provided the low end of the temperature sinusoid is not truncated by snow cover), or by some other suitable method. By substituting (7) for (2) and repeating the regression shown in Figure 5 we improve slightly the correlation coefficient (r = 0.942 to 0.956) and more individual points are actually drawn toward rather than away from the traditional heat flow value. For the data in Figure 5 the average difference between heat flow calculated from (2) and (7) is 5.9 mW m^{-2}, a value which is well within the suggested accuracy of the technique (equation (6)). However, for an area such as Egypt where the mean surface temperature is 26°C (following section), (7) represents a significant improvement over (2). For the case histories presented in the following section we have used (7) to convert silica data to heat flow.

CASE HISTORIES

In applying the silica method in estimating regional heat flow the first question one must address is how many groundwaters must be analyzed and from how large an area. The best answer is to use the same criteria as that used in constructing Figure 5. That is, 100 samples covering an area of 1° × 1°. However, this may involve considerable time and expense, and in many cases a much smaller data set will suffice. A reasonable and pragmatic approach is as follows. Sample several groundwaters which may be expected to give the extremes of silica geotemperatures (i.e., the hottest and coldest springs and/or the deepest and shallowest wells). Then collect as many additional samples as is necessary to bring the standard deviation below 25°C, from whatever area is necessary to collect physically an areally unbiased data set. For the example from upstate New York (following section), only 10 samples were necessary. However, for the southern Rio

Grande Rift of southern New Mexico, 210 samples were necessary.

In the following sections we present three case histories where we have used the silica method to estimate regional heat flow. The areas were chosen because of their tectonic diversity and because we sampled each area with the objective of obtaining the most representative suite of groundwaters possible with the ultimate goal of testing the silica–heat flow technique.

Upstate New York. This area is located generally between Buffalo and Syracuse, New York, in a relatively stable portion of the eastern United States. The geology is primarily Silurian and Devonian shales. During the summer and fall of 1978, 45 groundwaters (Table 2; Figure 6) were collected and subjected to a routine chemical analysis. Considering all the samples, the average silica geotemperature is 41.7 ± 10.8°C, implying a regional heat flow in the area of 48.8 ± 10.8 mW m^{-2} (errors calculated from (6)). Thirteen traditional heat flow value from New York (J. H. Sass, personal communication, 1979) average 48.1 ± 11 mW m^{-2} in good agreement with the value obtained from the silica data.

Actually, the data were collected to evaluate the potential of two prospective low temperature geothermal resource areas named the East Aurora and Cayuga anomalies. These prospects have been delineated on the basis of bottom hole temperature data obtained from oil tests, and the contours shown in Figure 6 represent the 36.4°C/km maximum contours shown in the geothermal gradient map of North America [*American Association of Petroleum Geologists,* 1976). These gradient anomalies are also associated with Bouguer gravity anomalies, and it is possible that these anomalies result from the presence of highly radioactive plutons in the Precambrian basement complex [*Hodge et al.,* 1979]. A similar situation has been described by *Costain et al.* [1977] in the Atlantic Coast province. Considering only the groundwaters within the prospective anomalies, the average silica geotemperature is 50.9 ± 8.5°C, implying a heat flow of 62.5 ± 11.7 mW m^{-2}. The two highest traditional heat flow values in New York are 64.8 and 71.9 mW m^{-2} (J. H. Sass, personal communication, 1979) located just southwest of the Cayuga Anomaly (Figure 6). Eliminating the above samples from the overall data set, the average silica geotemperature is 37.2 ± 8.8°C, implying a regional heat flow of 42.1 ± 10.3 mW m^{-2} for the nongeothermal portions of upstate New York.

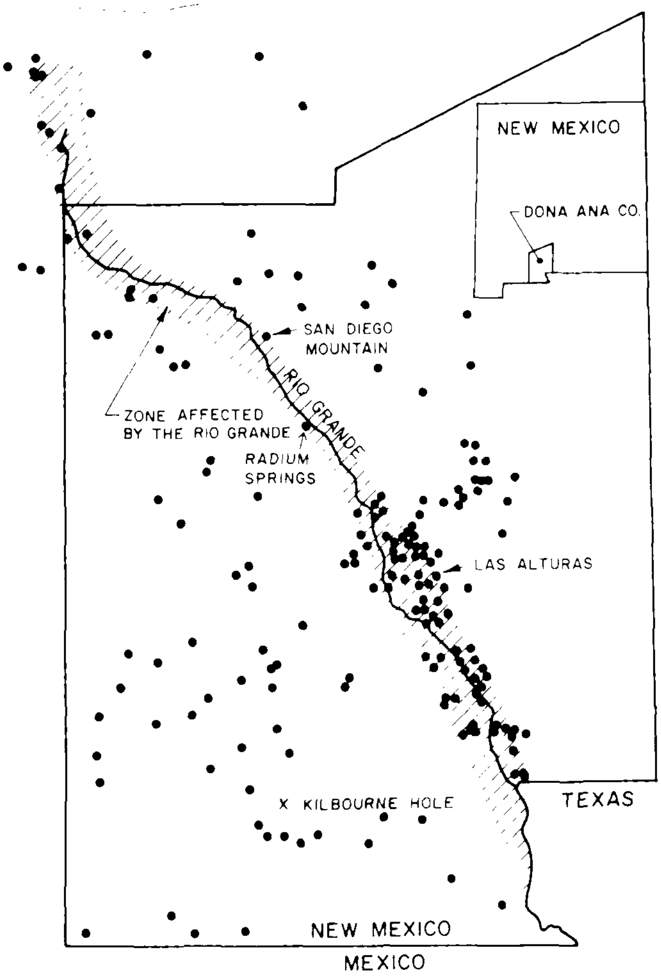

Fig. 7. Silica geotemperatures for groundwaters from the southern Rio Grande Rift, Doña Ana County, New Mexico.

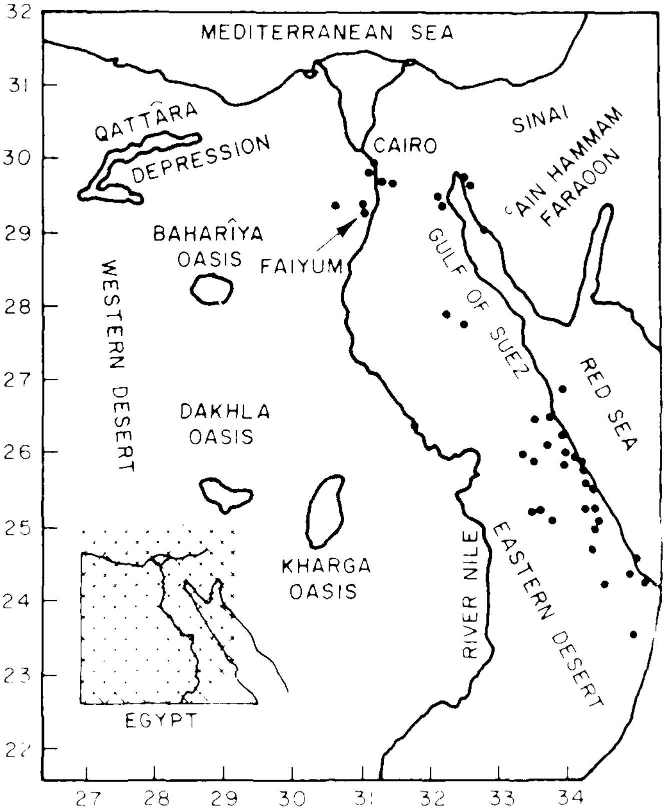

Fig. 8. Locations of silica data points for Egypt [after *Swanberg et al.,* 1976].

Southern Rio Grande Rift. The Rio Grande Rift extends from west Texas and northeast Chihuahua to central Colorado, essentially following the trend of the Rio Grande River. The rift is characterized by high heat flow and crustal thinning, extensional tectonics, fault block mountains and deep sedimentary basins, Quaternary volcanics (as young as several thousand years), and numerous Quaternary faults [*Seager,* 1975]. The area under investigation is in southern New Mexico, as is shown in Figure 7. Estimating regional heat flow in this area is a difficult task by either the traditional heat flow method or by the silica technique. The area contains two known geothermal resource areas (Radium Springs and Kilbourne Hole), two additional geothermal prospects (San Diego Mountain with a measured temperature of 51.8°C at 150 m; Las Alturas with a measured temperature of 64°C at

300 m), and several additional promising areas. The area is further complicated by the fact that many of the groundwaters available for study are located in the floodplain of the Rio Grande River and may represent meteoric waters that have circulated in shallow aquifers and not reached equilibrium with the host rock as required by assumption 1 above. Also, the traditional heat flow values in the area vary from lows near 70 mW m^{-2} (1.7 HFU) to over 670 mW m^{-2} (16 HFU) at San Diego Mountain [*Reiter et al.*, 1978].

Using our preferred sampling technique, three thermal waters (Las Alturas, Radium Springs, San Diego Mountains) and four shallow (<30 m) wells from the Rio Grande floodplain were sampled in addition to 64 random groundwaters (Figure 7, Table 2). The mean silica geotemperature was 90.2 ± 27.0°C, implying a heat flow of 110.7 mW m^{-2}, but the standard deviation did not meet our criterion for a reliable data set (Table 2). Further, it was apparent that a reliable data set could not be obtained without utilizing the abundance of groundwaters near the Rio Grande River. The U.S. Geological Survey (C. Wilson, personal communication, 1979) provided us with 229 additional chemical analyses representing mostly waters near the Rio Grande, and the final average silica geotemperature was found to be 84.1 ± 18.4°C, implying a regional heat flow at 101.6 ± 14.3 mW m^{-2} (Table 2). This value is in good agreement with the average of 11 traditional values (102.9 ± 24.1 mW m^{-2}; Table 2), but both are likely to be underestimates: the silica data because of the disproportionately large number of groundwaters from the Rio Grande flood plain and the heat flow because the geothermal areas were intentionally omitted from the average. In reality, much of the area may have heat flow in excess of 125 mW m^{-2}, and the area has been so contoured by *Seager and Morgan* [1979] and *Swanberg* [1979].

Egypt. The Arab Republic of Egypt lies in the northeast corner of Africa. Tectonically, the area is a Precambrian platform province which should reflect low-to-normal heat flow values. To the north of Egypt is the eastern Mediterranean, an area of low heat flow [*Erickson et al.*, 1977], and to the east of Egypt is the Red Sea spreading center, an area of high-to-very-high heat flow [*Girdler and Evans*, 1977]. The primary question regarding Egyptian heat flow is whether or not the high values associated with the Red Sea spreading center are also to be found in the adjacent Precambrian basement complex of eastern Egypt, and if so, how far west do they extend.

During the summers of 1976–1978, groundwaters were samples from available wells and springs in the Eastern Desert and from the artesian wells of the major accessible oases of the Western Desert. The sampling locations are shown in Figure 8, and the silica data are summarized in Table 2. The silica data from the Eastern Desert are high and imply a regional heat flow of 75.5 ± 12.6 mW m^{-2}, thus indicating a major heat flow anomaly in the Precambrian of eastern Egypt. This anomaly has been confirmed by traditional heat flow determinations [*Morgan and Swanberg,* 1979]. Unfortunately, the western boundary of the high heat flow zone cannot be determined by the silica method because there are no suitable groundwaters available west of those shown in Figure 8. However, the zone does not extend as far west as the Western Desert oases where the silica geotemperatures reflect normal heat flow (Table 2). On the basis of a very scanty data set it would appear that typically high Eastern Desert heat flows extend west from the Gulf of Suez as far as the Cairo area and the Faiyum Oasis. Geothermal studies are continuing in Egypt, using both traditional and silica geothermometry heat flow methods.

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