3. ZUNIL I (Morrison Knudsen, MK-Ferguson, Cordón y Mérida)

3.1 General Comments (R. Dipippo)

The Panel bases its remarks on the following reports by MK-F an C y M

- Geoscientific studies, Report No. 1, August 1989
- Well Testing, Production-Interference, and Chemical Tests, August/89
- ZD Production wells, August 1989, and on the oral presentations made during the meeting.

As far as geological studies are concerned, the main question remains -- about the location and nature of the principal and minor faults. Since these are assumed to be the conduits for the geothermal fluid their --- identification and characterization is crucial. It is clear that potential landslide areas must be avoided in sitting wells and other plant facilities.

In the area of geochemistry, it is not certain yet whether or not the mercury studies will prove useful in locating good well targets. The - fluid inclusion studies are quite comprehensive and should prove quite useful. The main point seems to be that the open fractures in the granodiorite appear to be manifestations of the present geothermal system, and not ancient relies.

The hydrogeological study is good, but much remains to be done. The Panel was disappointed in that the data of the fluid sampling that was done during the flow tests was not presented in an acceptable and useful - manner.

With respect to the geophysics, the Panel offers suggestions as to how to interpret the results of the gravity survey using a 4-layer model with a variable density, but with layer thickness determined from lithology - according to drill logs.

The well test results were misleading in that much more data interpretation is needed before clear conclusions can be drawn about the production characteristics of the wells. The long-term behavior of the Zunil I field cannot be predicted at this time. It is clear that all wells are flashing in the formation, a situation that may have detrimental long-term effects on production. Much work must be done in the interpretation of the interference tests.

The reservoir model should be calibrated using all reliable test data - from the very first well tests. Any discrepancies among test results - must be explained, a recommendation that the Panel has made in each of - its reports.

The hydrology study is very simplistic and does not resolve the question of the recharge to the field.

The power potential of the wells has been recalculated in light of the - new tests, but caution is advised in using this value because the wells were not flowing simultaneously and the effect of interference has not been factored in because the numerical reservoir model is not available.

The Panel accepts most of the drilling targets proposed by the consul - tants but recommends that the decision tree be deferred until the results of the drilling of the first well is available. We endorse the idea of directional drilling but suggest that fewer well pads be used to drill - the targets, in accordance with accepted methods.

3.2 Geología (G. Marinelli)

3.2.1 Neotectónica

Cuando el objetivo de una exploración en el subsuelo se encuentra a importante profundidad (por ejemplo, mayor de 100 m), el costo de la perforación es tan elevado que se justifica el empleo de varios métodos de exploración, para disminuir el riesgo de fracaso.

Esta consideración tiene validez, a pesar del valor comercial de la sustancia buscada; es decir, petróleo, gas, fluidos geotérmicos. El valor comercial del producto afecta solamente la utilización de metodologías de costo elevado. Por ejemplo, la sísmica de reflexión, que es empleada en forma generalizada en la exploración petrolífera, es utilizada poco y solamente en casos particulares en la exploración geotérmica. Las metodologías fotogeológicas y geológicas de campo son, por otra parte, de uso generalizado, en consideración a su costo tan bajo. Por estas razones, en el caso particular de Zunil I, la identificación esmerada de los sistemas de fallas y fracturas en el área geotérmica había sido recomendada por el Panel. Esta investigación puede indicar el más probable sistema de fracturas que alimenta el supuesto reservorio profundo, disminuyendo así el riesgo de fracaso en la localización de las perforaciones profundas inclinadas.

Los estudios del Consultor han llevado a la conclusión que son productoras tanto las fallas o fracturas de rumbo NE-SO (Falla de Zunil) como aquellas de rumbo ortogonal. El Panel no sabe cómo se haya alcanzado este resultado y lo considera poco probable, porque, en general, en un área de tamaño tan reducido (unos km^2), el sistema activo de fallas o fracturas de carácter tensional es uno solamente. De todas formas se re comienda que el objetivo de los pozos inclinados no debe ser el punto de intersección de los dos sistemas de fallas. La experiencia minera muestra, en efecto, que en estos puntos donde la circulación inicial de los fluidos es mayor ocurre una mayor deposición de minerales debido a la disminución de la velocidad de los fluidos. Estas zonas, las cuales son favorables en el campo minero porque son lugares de concentración de los minerales útiles, pueden perder rapidamente su permeabilidad por "self - sealing" de incrustación.

El Panel recomienda, por lo tanto, que los pozos no sean localizados según la figura 1, sino conforme a la figura 2 :

Fig. 1

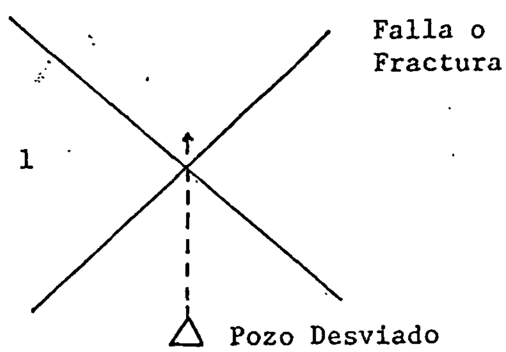
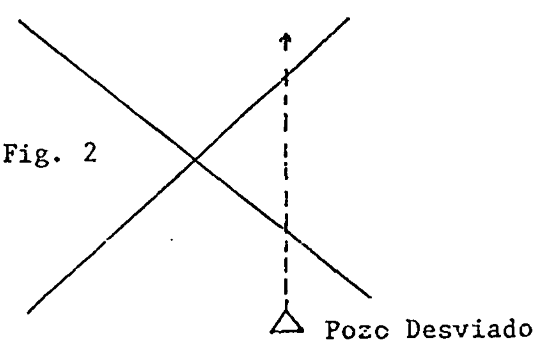


Fig. 2



3.2.2 Mineralogía de alteración

En lo que se refiere a la mayor o menor permeabilidad de los reservorios por fracturación, ésta es, si es igual al modelo tectónico, proporcional a la rigidez (y por ende, a la fragilidad) de las rocas encajantes.

Las cuarzitas, las calizas dolomíticas y las calizas son, por lo tanto, rocas ideales, así como las rocas magmáticas intrusivas ricas en cuarzo (granitos, granodioritas) siempre y cuando estas rocas no sean alteradas. La alteración hidrotermal, produce en estas rocas un cierto grado de plasticidad, particularmente en profundidad. En efectos los feldespatos, la hornblenda y las biotitas se transforman en filosilicatos muy hidratados (caolín, ilitas, smectitas) o poco hidratados (sericitas, clori -

tas): los planos de "Cleavage" muy fáciles de estos minerales hidrotermales, facilitan la modificación de forma bajo el efecto de la presión - litostática. Pero estas rocas se vuelven nuevamente rígidas y frágiles cuando la alteración hidrotermal ocurre a temperaturas elevadas. En efecto, a 300°C y a temperaturas mayores, los minerales de alteración hidrotermal estables : cuarzo, epidota, albita, adularia, anhidrita, vuelven las características mecánicas de estas rocas similares y quizas aún mejores de las de las rocas no alteradas.

Los estudios petrográficos de la granodiorita procedente de los pozos de Zunil I muestran una alteración hidrotermal típica de la zona a filosilicatos; sin embargo, ya se observan vetas de cuarzo y epidota que anuncian equilibrios de temperaturas más elevadas. Por lo tanto, el Panel sugiere que la búsqueda del reservorio en la granodiorita sea efectuada a profundidades lo más elevadas posible de manera que aumente la probabilidad de encontrar un sistema de fracturas altamente productivo.

3.2.3 Deslizamientos

Para la elección de los sitios de ubicación de los pozos profundos de Zunil I hay que tomar en cuenta la presencia en la zona de derrumbes y de deslizamientos.

3.3 Geochemistry (Fraser Goff)

3.3.1 Mercury Anomalies

In the past, I have never been very impressed by mercury (or radon) anomaly maps because I have always felt that good geologic mapping and surface alteration studies in combination with the distribution of thermal features would yield nearly the same information. we --

already know, for example, that there is cinnibar in the altered rocks near ZCQ-4 and that the cinnibar is deposited as a result of volatilization at depth. None the less, MKF performed a Hg-survey of approximately 40 soil samples laid out in a grid and by contouring the data, have found a "best target area" for drilling on the basis of correlations of anomalies with mapped fault and fault intersections. I give MKF credit for initiating the study on their own and acknowledge that they may have identified a productive target zone. Only drilling will prove it.

I'd also like to mention that soil mercury is not in the form of cinnibar but rather as elemental mercury or complex organic compounds. This requires that the anomalies be very young and must, therefore be manifestations of open fractures.

3.3.2 Fluid Inclusions

Although fluid inclusion measurements were first used to study deposition temperatures and fluid compositions of ore deposits, the science of fluid inclusions has advanced rapidly in recent years because of its application to active geothermal systems. This application is particularly enhanced where reservoir chemistry, hydrothermal alterations, and measured temperatures in wells are available.

The fluid inclusion investigation performed by MKF is a very nice integration and is typical of similare studies now widely carried out in Japanese, New Zealand, and US geothermal systems. The major results are these :

1. The alteration and vein minerals observed in the cuttings and cores from Zunil I were formed from hydrothermal solutions very similar to those now circulating at Zunil I today.

2. The types of fluid inclusions, their salinities, and their distribution with depth are similar to the configuration of vapor, Na-HCO_3 - and Na-Cl fluids observed at the surface and in the existing wells at Zunil I.

3. The homogenization temperatures closely approximate the measured well temperatures. Where they do not, the T_h is only a few degrees lower than T_m suggesting that, locally, the system may be heating up (in geologic time).

4. Most important, the fluid inclusions in vein minerals from granodiorite cores and cuttings are no different in salinity or T_h than similar inclusions in overlying rocks. Clearly, the open fractures in the granodiorite are a manifestation of the present geothermal system. They are not a relict of an ancient hydrothermal went.

3.3.3 Hidrogeochemistry

I was less impressed by the interpretations made with the new MKF hydrogeochemical data. Also, some data was still incomplete (stable isotopes) or poorly analyzed (tritium data). The basic water types and their general configuration in the system was already known. Of major interest was to aquire a set of internally consistent analyses (same laboratory) from all features (surface and wells) in order to interpret the wide array of mixing, boiling, and cooling processes occuring in the reservoir. Also of major interest was to obtain a comprehensive set of stable isotope data on cold waters around the area (10 km radius) to find the recharge -- areas. Neither problem was adequetty answered. In particular :

1. I firmly believe that all hydrogeochemical interpretations start with simple plots and tables to charactarize water types, identify mixing processes and tabulate the standard sweater of chemical geothermometers (specially those with a proven track record like Na/k and Na-K-Ca). Instead, chloride enthalphy diagrams were analyzed with little back - ground interpretation.

2. The chloride-enthalphy diagram that was stressed used enthalphy based on a somewhat obscure geothermometer, k-Mg. The accuracy of this geo thermometer is still not widely proven but, in any event, the plot - compared data from two different types of springs, Na-HCO_3 and Na-Cl. The latter is the one of greatest interest (or mixtures of Na-Cl with other types). Also, all data were thrown on the plot (who knows how reliable they all are), making a confusing array of data clusters and trends. The new set of internally consistent data should have been used first and then older data compared. The point of all this is - that there may be no strong evidence for temperatures of 325°C exis- ting in the reservoir.

3. Another way to assess the reservoir temperature of the "mother fluid" is to compare geothermometers from the least boiled and least mixed - fluid. Don't stop with the chemical ones; use $S^{18}O$-SO_4 and the gas geothermometer of D'Amori and Panichi as independent checks. If they all agree reasonably well (remember, these geothermometers have errors as high as ± 30°C), then you may not get a lot more out of your chlo ride enthalphy diagrams. The temperatures that I calculated on data from ZCQ-6 were fairly consistent at 270 to 300°C very similar to the measured temperature of 280°C.

4. Since MKF now has quality samples taken from miniseperators during - the latest flow tests the quartz geothermometer should be useful when applied to the flash corrected analysis.

5. Also, an MKF subcontractor made the horrible statement that since Zunil I reservoir fluids are dilute, they can't cause scaling or sealing problems if the fluids flash in the formation. Since silica concentration is wholly dependent on temperature in neutral-chloride reservoir fluids (like Zunil I), a 280°C fluid with 500 mg/kg TDS will have - the same silica concentration as a 280°C fluid with 50,000 TDS. And if the fluid boils, it will precipitate silica.

6. With no new isotope data to present, the location of recharge areas - is still one of speculation.

7. There are more up to date ways of interpreting tritium data based on a short paper by Pearson and Truesdell (1928). An application of this method was developed for Central American geothermal waters by Goff- et al (1987) in a Los Alamos report on Honduras. It should be viewed qualitatively. Write me for a reprint. Also, doesn't it strike MKF as unusual that the Zunil I reservoir fluids (mother fluid) would have more tritium than overlying Na-HCO_3 waters?. The data must originate from different labs, or some data must come from a lab with poor precision, or the wells contain some young water from injection or - other operations.

3.3.4 Fluid Sampling During Flow tests

It was unfortunate that the reconstituted analyses of the well samples including their isotopic results were not available for scrutiny. These - analyses and similar ones that will follow as the field is developed and produced will become one of the very best tools to monitor the "health" of individual wells and of the entire field at relatively low cost.

3.4 Hydrology (Fraser Goff)

The simple hydrologic models that were presented were interesting but were very simplistic. In addition, without the results of the stable isotope survey of cold waters, it is still not clear if the region north west of Zunil I is the recharge area. Once the latter issue is resolved, the models can be constained with realistic boundaries, structures, permeabilities, etc.

If the Quetzaltenango Caldera indeed exists, the depression that it created would serve as a gigantic recharge area for the Zunil reservoir, -- which occurs at a lower elevation than the postulated caldera floor. There would be some merit in establishing whether or not this caldera indeed exists, in defining its subsurface structure, and in particular, defining its southeastern boundary zone (beneath the underlying young volcanic rocks) and understanding the structural and hidrologic significance of the Q.Cal to the Zunil fault zone and the geothermal system. Similar features have a profound influence on the hydrologic control of the geothermal system at Valles Caldera, New Mexico, as stated in your new report. At the present time, the Panel is not recommending a reprograming of funds to unravel this problem but, if the Zunil I field is developed, the problem should be addressed. By the way, the style and presentation of the new report were much better than the Mision de Enfoque report of a year ago.

3.5 Geofísica (A. Duprat)

3.5.1 Gravimetría

En el año 1989 MKF efectuó un estudio gravimétrico de detalle en el campo de Zunil I. Los resultados de este estudio han sido presentados: Anomalía de Bouguer con más densidades, residuales (anomalía regional escogida = plano inclinado) que permitieron trazar las discontinuidades gravimétricas principales para cada una de las densidades. El perfil de Nettleton muestra que la densidad de corrección más conveniente está comprendida entre 1.9 y 2.2.

Un mapa con d = 2.3 ha sido escogido para la interpretación, MKF modeló solamente un perfil con parámetros demasiados sencillos (2 capas con densidad del basamento de 2.6).

3.5.2 Eléctrica

Para lo que concierne el estudio eléctrico, solo se efectuó una diferenciación cualitativa entre sondeos eléctricos: los que han alcanzado un substrato resistivo y los que han alncanzado un substrato conductor.

Se puede sugerir a MKF :

- De establecer cortes eléctricos cuantitativos en los datos de inversión de los sondeos eléctricos. Para cada sondeo que ha alcanzado el substrato resistivo efectuar una prueba de equivalencia para la capa conductora que sobre yace el substrato.
- Utilizando estos datos eléctricos completados, con las informaciones litológicas y cuantitativas de los pozos profundos, de realizar una

serie de perfiles (con una sola densidad, 2.2 por ejemplo) sobre el campo de Zunil I.

Se podría empezar con un modelo de 4 capas :

1. Capa superficial (volcanitas)
2. Capa representativa de las formaciones alteradas (capa conductora de los sondeos eléctricos)
3. Capa andesitica que representa el reservorio
4. Basamento

Siendo la geometría del campo bastante bien conocida se podría intentar (fijando los datos cuantitativos) estudiar las posibilidades de variaciones de las densidades en el interior de cada capa y en modo particular en el basamento.

Este conjunto de perfiles tendría que permitir localizar con más precisión las principales discontinuidades (zonas de mayor fracturación probable) y contribuir a un mejor conocimiento de la estructura de el campo de Zunil I.

3.6 Pruebas de Pozo (P.E. Liguori)

3.6.1 Pruebas de corta duración

Estas pruebas consistieron en poner en producción uno a la vez, durante una semana más o menos, los tres pozos ZCQ-3, 5 y 6 dejándoles descargar libremente el silenciador con posición de válvula fija. Durante la producción se midieron caudales de agua y vapor, se sacaron unos perfiles de presión, temperatura y "spinner" y se tomaron muestras químicas. Antes de terminar la producción se bajó en el pozo un elemento de presión y, al cerrar el pozo, se llevó a cabo la prueba de "build-up", limitadamente a los pozos ZCQ-3 y 5. Los datos se han presentado bien organizados y están claros lo suficiente como para apreciar los resultados de las pruebas aún cuando estos no estén ampliamente descritos.

La interpretación de las pruebas de corta duración ha sido dirigida a dos fines :

- Establecer la potencia eléctrica disponible y;
- Determinar las características hidráulicas de cada pozo probado.

Sobre la potencia disponible se comenta en otra parte de este informe, sin embargo, se recuerda aquí que la potencia disponible a la fecha de pozos descargando uno a la vez y sin soporte de estudios de reservorios es únicamente un ejercicio peligroso, que puede llevar a injustificados optimismos, por no contener el abatimiento de la producción que necesariamente ocurrirá con el tiempo. Sobre las características hidráulicas de los pozos, ellos han sido calculados según los métodos clásicos de la ingeniería de transientes de presión.

Los valores obtenidos para la transmisivilidad de la formación y el factor de daño de los pozos se enmarcan en un cuadro normal para campos geotérmicos en ambiente volcánico, inclusive el hecho de que el factor de daño es negativo.

Cabe hacer notar que los tres pozos tienen columna totalmente bifásica, significando que el punto de "flash" se encuentra en la formación; aún si esto puede aparecer como una ventaja, en cuanto se tiene menos agua líquida que desechar, en efecto no es muy buen indicio con respecto a la capacidad del pozo de mantener su caudal de vapor a largo plazo.

3.6.2 Pruebas de larga duración

Estas pruebas consistieron en descargar el pozo ZCQ-3 durante casi cuatro meses, con posición de válvula fija, midiendo al mismo tiempo la presión de fondo en los cuatro pozos de observación ZCQ-1, 4, 5 y 6. Después de dos meses de producción se empezó a reinyectar el agua separada en el pozo ZCQ-2 lo que se hizo durante un mes y medio. Durante este plazo se midieron los caudales en producción y en reinyección, se sacaron unos perfiles de presión y temperatura y se tomaron muestras químicas. Se está midiendo todavía la presión en los pozos de observación para tener registros del período de recuperación.

Tal como para las pruebas de corto plazo la interpretación ha sido dirigida a dos fines : establecer la potencia eléctrica disponible (de solo el pozo ZCQ-3 en este caso) y determinar las características hidráulicas del reservorio. Sobre la potencia se comenta en otra parte del presente informe.

Es sorprendente observar que la interpretación de las pruebas de interferencia a fines de reservorio no se hizo, cuando al contrario justamente esta interpretación constituye la razón para hacer estas pruebas. Bajo la definición "interpretación a fines de reservorio" se entiende la búsqueda, a través de la respuesta de los pozos de observación, de características fundamentales del reservorio como son al menos la existencia de barreras y de alimentaciones profundas, valorización de las eventuales recargas, ubicación de fallas de alimentación (para dirigir los pozos desviados)

La interpretación presentada se ha limitado a reinterpretar las características hidráulicas y a comentarios generales sobre la comunicación o me -

nos de los pozos entre ellos. Los valores presentados por las caracte - rísticas hidráulicas vienen acompañados de comentarios genéricos del tipo "normal para campos geotérmicos" o "congruentes entre ellos", cuando al contrario habría mucho que hablar.

La impresión general es que la interpretación de estas pruebas practicamente no se hizo, limitándose a presentar los datos e interpretaciones - standard, (como se encuentran en los textos básicos), sin ninguna tentativa de comprender lo que efectivamente ocurre en el reservorio superficial.

Cabe notar que la interpretación estandard de la respuesta del pozo ZCQ-4 no ha individualizado rasgos muy importantes y valiosos en ellos contenidos y que en general muchas interpretaciones son superficiales y discutibles. Considerando que todavía se está monitoreando la recuperación en los pozos y hay que probar en producción corta el pozo ZCQ-4, la sugerencia que se puede dar es la siguiente :

- Continuar la observación en los pozos ZCQ-1 y ZCQ-5 también durante - la prueba de producción del pozo ZCQ-4.
- Pedir a MKF que haga una interpretación cuidadosa y completa de las pruebas de interferencia.
- Con base en la interpretación completa, revisar los comentarios genéricos como "producción estable" y hacer una evaluación sería de la declinación de producción que ocurriría en el reservorio somero bajo explotación.

3.6.3 Modelo del Campo

La respuesta de MK-F (Dr. Subir Sanyal) a las observaciones sobre la falta de una interpretación adecuada de las pruebas de larga duración se ha desarrollado en dos líneas :

- Que las pruebas todavía están en curso
- Que la ocurrencia de la fase vapor hace necesario el uso de un modelo que no estaba previsto a la fecha.

Puesto que hay tiempo hasta el inicio de las perforaciones derivadas para tener los resultados de una interpretación adecuada y la actividad de modelado se pone en paralelo con otros, el Dr. S. Sanyal se ha comprometido hacer el modelo y entregar los resultados hasta Diciembre de 1,989.

Es oportuno entonces, establecer los fines y los límites del modelo, quienes son los siguientes :

- Que esté estructurado conteniendo los rasgos del modelo conceptual del sistema geotérmico (geometría, litología, tectónica, hidrología, termalismo)
- Que maneje fluidos mono y bi-fásicos con inclusión de gases (por lo menos CO_2).
- Que consiga reproducir de manera satisfactoria las pruebas de interferencia con producción-reinyección.
- Que consiga reproducir las declinaciones de caudal que se observaron en los años de 1,981 a 1,985.

Una vez que se tenga este modelo funcionando, será muy fácil incorporar en él los resultados de perforaciones y pruebas que se lleven a cabo en un futuro hasta que el modelo se vuelva en la mejor herramienta para -

evaluar el potencial del campo y luego para manejarlo durante la explotación.

3.6.4 Conclusiones

Las pruebas de producción/reinyección en los pozos ZCQ se han llevado a cabo siguiendo en principio las recomendaciones del Grupo Consultivo (segunda Reunión), con cambios menores que no han modificado la validez de los resultados.

Los datos han sido tomados con buena técnica y buen equipo y también han sido bien presentados.

Atrás de esta muy buena presentación se manifiestan todavía fallas importantes, unas de ellas ya subrayadas por el Grupo Consultivo anteriormente, como son :

- Se insiste en despreciar la importancia de la valoración de las pruebas de producción anteriores, que indicaron una declinación preocupante en la producción de los pozos.

- Puesto que, en base a las pruebas de corta duración, se encontró que el método del vertedero resulta mejor que él del orificio en la determinación del caudal, se sostiene ahora que las mediciones anteriores son malas (durante la Segunda Reunión MK-F había sostenido que el orificio era mejor que el vertedero), borrando de una vez una declinación de caudal cuya importancia no puede ser olvidada.

- La interpretación de las pruebas de interferencia ha sido conducida según métodos correctos pero muy elementales y no aceptables en el marco de un proyecto de envergadura.

- Números importantes, como son caudales de vapor, índices de productividad/inyectividad, se siguen cambiando de un informe a otro con mucha facilidad y sin dar explicaciones.

La impresión general sobre las pruebas es entonces que hace falta la necesaria dedicación en la elaboración e interpretación de los datos.

Respondiendo a las críticas, el Dr. S. Sanyal dijo que el campo es difícil por tener presencia de la fase vapor y que entonces se necesita de un modelo para interpretar correctamente las pruebas.

Es cierto que un modelo es importante y ayuda en la interpretación, sin embargo se subraya que hasta ahora se ha seguido presentado en forma contradictoría y con cambios repentinos injustificados una parte de los resultados; se recomienda por lo tanto que el modelo sea utilizado en forma clara y que sus voluminosos datos de salida sean bien presentados e interpretados.

3.7 Power Potential of Existing Wells (R. Dipippo)

In this section we will update our estimate of the electric power potential of the existing wells. The basis for the calculation is the set of data taken during the well tests conducted from February until July 1989.

3.7.1 Revised Estimate of Power Potential

On page 39 of the Report of the Second Meeting of the Advisory Panel,we presented an estimate of the potential power output of the existing ZCQ-wells.

In table 3.7.1 we present revised values using the test data for the -

short-term tests on wells ZCQ-5 and ZCQ-6 and the end-point of the long-term test on well ZCQ-3. Earlier data was used for well ZCQ-4 and may not be reliable, as was discussed in the Panel's previous report. Including the possibly questionable data on well ZCQ-4, the total estimated power comes to about 13.6 MW, or 3.4 MW/well.

However, great caution must be used in interpreting this total. Wells ZCQ-3, ZCQ-5 and ZCQ-6 were each tested separately, and thus any effects of interference are neglected. The consultants have reported that all the wells are in communication with each other, except for well ZCQ-6. When all the wells are opened simultaneously as they must to feed the power plant, the power potential will decrease. This problem will be discussed in the next section.

3.7.2 Effect of Production Decline in Well ZCQ-3 on Its Estimated Power Potential

The Panel was told by Dr. S. Sanyal that there was no decline in power during the long-term flow test on well ZCQ-3. It was reported that the following changes took place during the test :

- Total flow rate : 120 to 80 t/h (33.3 to 22.2 kg/s)
- Steam mass fraction : 30 to 40% (approx)
- Enthalpy : 310 to 360 cal/g (1297.0 to 1506.2 kj/kg)
- Wellhead pressure : 9.5 to 6.8 kg/cm^2, abs (9.3 to 6.7 bar, abs)

Dr. Sanyal assumed a constant specific steam consumption of 7.7 (t/h)/MW or 2.14 (kg/s)/ MW arriving at his conclusion that the power potential would remain constant at 4 MW.

TABLE 3.7.1

REVISED ESTIMATE OF POWER POTENTIAL OF ZCQ-WELLS

WELL No.	Steam Quality At Separ.	Turbine Inlet Pressure bar, abs	Total Mass Flow kg/s	Estimate Electric Power MW
ZCQ-1	(Not productive	at presente)		
ZCQ-2	(Proposed injection well; best power est. = 5.7MW)			
ZCQ-3	0.396	6.0	22.2	4.37
ZCQ-4	0.199	6.0	27.8	2.75
ZCQ-5	0.829	6.0	9.17	3.78
ZCQ-6	0.396	6.0	13.89	2.73
			TOTAL :	13.63 MW

NOTES :

1. All wells have separators operating at 6.5 bar, abs.
2. ZCQ-4 data is from earlier testing and may not be reliable.
3. ZCQ-5 is an average of reported data
4. Condenser operates at 41°C, 0.078 bar.
5. Turbine insetropic efficiency = 77%.
6. ZCQ-2 not included in total.
7. ZCQ-3, ZCQ-5, ZCQ-6 tested separately with other wells closed.

A more detailed thermodynamic analysis of this data reveals that the power potential in fact declined by 10.5% during the period of the long-term test. Furthermore, if one takes into account the power potential calculated during the earlier short-term test, the decline in power from that time to the end of the long-term test is actually about 19%.

These results follow from the analysis of the turbine which receives - steam separated at 6.5 bar, abs and delivered as a satured vapor at 6.0 bar, abs. A turbine isentropic efficiency of 77% is assumed and a condenser pressure of 0.078 bar is assumed. The specific output of the turbine is 496.9 kj/kg of steam. The power is found by multiplying this by the steam mass flow rate which is the product of the quality and the total mass flow rate. At the start of the long-term test, these values are 0.295 and 33.3 kg/s, respectively; at the end, they are 0.396 and 22.2 kg/s, respectively. Thus, the initial power is 4.88 MW and the final - value is 4.37 MW. This is a loss of 10.5%. The stabilized conditions during the short-term test were 0.356, 30.56 kg/s, and 5.41 MW.

Thus, the power potential of well ZCQ-3 fell from 5.41 MW to 4.37 MW during the 5 month test period from 6 February 1989 to 13 July 1989. This is a drop of 19% which may be partly attributed to the effect on well ZCQ-3 of the flow tests on well ZCQ-5 and, perhaps, on well ZCQ-6.

3.7.3 Conclusion

Although the revised power potential of wells ZCQ-3 through ZCQ-6 is - 13.6 MW compared with 8.6-11.2 MW reported in the Panel's previous report it must be undestood that this total will decline when all four wells - are flowing simultaneously.

The data shown in table 3.7.1 for well ZCQ-4 are based on a test conducted during 1983-84 when four wells were tested simultaneously. Finally, it is unknow how much of a decline will occur with time, but the results obtained during the 5 months of testing on well ZCQ-3 may give some idea of the size of this effect.

3.8 Drilling Program

In this section we will discuss several aspects of the drilling program proposed by MK-F and CyM as well as certain matters relating to the bidding document for a drilling contractor.

3.8.1 Deviated Wells

The Panel agrees with the plan to drill future wells at Zunil -I as deviated wells. This scheme is logical given the steeply dipping faults in the area which are assumed to be carrying geothermal fluid.

3.8.2 Targets

The Panel concurs that the drilling targets should be in the granodiorite in the neighborhood of intersections of major open faults and fractures. MKF and CYM have identified seven targets.

We agree that the targets (except for the deepening of wells ZCQ-5 and ZCQ-6) acceptable, based on the state of knowledge of the field. Considering the anticipated capacity of the drilling rig, it seems that targets should be held to depths of about 1700-2000m. The Panel, however, feels that a rig with a greater capacity (2500-3000 m) would allow for more flexibility in this phase of drilling. Since the purpose of these wells is to find permeability in a formation where essentially no permeability has been found before, it may be necessary to drill below 2000 m to find good production.

3.8.3 Drill Pads

One of the advantages of directional drilling is that several wells can be located on a single pad. This has not be utilized in the MK-F and CyM plan. They propose to drill up to five wells, each from a separate pad. The Panel believes this is not necessary and that one pad at the proposed site 2A can be used to drill three targets : The ones from pads 1, 2A, and MC. These targets can be reached from pad 2A without exceeding a desviation angle of 10° with a kick-off point at 700 m, as proposed by MK-F and CyM. Pad 2A is the one proposed by the consultants. It is relatively close to the proposed plant site and could be equipped with a large capacity separator to handle the total flow from the three wells if they are all good producers.

This new plan would also result in a savings in the length of pipe that would be needed to transmit the steam and hot water to the plant and injection well (s), respectively.

In a similar manner, proposed pad 2B can be eliminated. The same target can be drilled using a new well sited on the same pad as well ZCQ-5.

The whole matter of where are the faults and what are their orientations and strikes is still controversial. The targets may have to be revised in light of the drilling results.

In this regard it is worth noting that the Panel recommended in its First Report (April 1986) that a microseismic survey of the Zunil I area would be very useful in defining the fault system and fluid novement within -

The fault system. The Panel understood that such a series of mea - surements might not be easy to carry out, but we now feel the lack of such information that would aid in siting the ZD wells.

The whole matter of where are the faults and what are their orientations and strikes is still controversial. The targets may have to be revised in light of drilling results.

3.8.4 Selection and testing of Production Zones

The productive wells in the area of wells ZCQ-3 through ZCQ-6 have encountered hot fluids at or near the top of the granodiorite basement. Presumably, the new ZD wells will also find this production horizon at a true depth of between 1000-1100 m. Since these wells are programmed for 1700-2000 m, the question arises as to what to do about this "shallow" production horizon. If the wells are cased to 700 m, the kick-off started at 700 m, and a build of 10° requires 150 m, then the shallow zone will be found while drilling the deviated straight section.

In the event that unsatisfactory production is found at depth, the shallow zone must be available for production.

In the event that satisfactory production is found at depth, it may be - necessary to seal off the shallow zone. Howcver, the Panel believes that production from both the shallow and the deep zones may be acceptable.

3.8.5 Decision Tree for ZD Wells

MK-F and CyM presented a decision tree for ZD well development. The primary well ZD-1 is directed at target T1. If well ZD-1 is "poor" or "good" then well ZD-2 will be aimed at target t2; if it is "moderate", then ZD-2 will be aimed at target T3. Their decision tree went to the next level, but the Panel believes it is not necessary to decide this level at this time.

Although no rationale was given in their report to support the decision tree, in their oral presentation they defined a "poor" well as one with less than 2 MW power potential and a "good" well as one with more than 4 MW potential.

Since the ZD wells are aimed at a new region of the "reservoir", they - must be viewed, at least partly, as exploration wells. As such, the de finition of a "good" well will involve more than simply its power produc tion. It is also important to learn which of the faults are open and - acting as conduits for the parent reservoir fluid.

The Panel does not believe that deepening and diverting wells ZCQ-5 and ZCQ-6 is worth the risk of losing the wells.

The Panel recommends that the decision tree be developed bases on the - findings of the well ZD-1.

3.8.6 Drilling Bidding Document

The Panel urges INDE and its consultants to add an addendum to the bidding document stating clearly that the wells will be directionally drilled. The Panel suggests that, if possible, the document call for a rig with at least 2500 m capability as well and that it allow sufficient flexibility to drill below 2000 m.

PETROLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF THE ZUNIL GEOTHERMAL SYSTEM

By

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Michael C. Adams
Michele M. Lemieux
Susan J. Lutz

III. FLUID INCLUSION SYSTEMATICS

June 1989

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ABSTRACT

Microthermometric measurements on 525 fluid inclusions from the Zunil I geothermal system have been used to characterize the chemistry of the reservoir as well as the processes occurring within it. Three distinct fluid types have been identified in the reservoir. These are: high-temperature, low salinity fluids with low gas contents; low salinity steam-heated waters with variable gas contents; and near surface, low-temperature, steam-heated water with low gas contents. The high-temperature fluids are most similar to the deep reservoir fluids.

The steam-heated waters form a CO_2-enriched cap over the geothermal system that thickens from the west to east. The geometry of this cap suggests that the deep upwelling center of the system originates near the western side of Zunil I. As the high-temperature fluids migrate from west to east, they are progressively diluted by downward incursions of CO_2-enriched steam-heated waters.

INTRODUCTION

Fluid inclusions can be used to characterize the chemistry of a geothermal reservoir and the processes occurring within it, particularly in regions that are not directly sampled by the production or gradient wells (Hedenquist and Henley, 1985; Moore and others, 1989). Fluid inclusions are micron-sized cavities filled with the fluid trapped during mineral precipitation or during subsequent fracturing. Information on the temperature of trapping and on the composition of the inclusion fluids they contain are derived from phase changes occurring in the inclusions during heating and freezing. At room temperature, fluid inclusions from geothermal systems typically contain a single liquid and vapor phase. If the inclusion trapped a single phase, either liquid or vapor (steam), then the trapping temperature can be determined from the temperature at which the liquid and vapor phases homogenize (homogenization temperature). Comparison between the measured and homogenization temperatures for a particular well indicates whether temperatures have increased, decreased or remained constant since formation of the inclusions.

Freezing measurements provide information on the salinities and gas contents of the inclusions, since there is a direct relationship between the freezing point depression and the total dissolved solids content of a fluid. Variations in the freezing point depressions can be used to map horizontal and vertical changes in the reservoir chemistry. These variations can be combined with the homogenization temperatures of the inclusions to determine the composition of the thermal fluids and extent of boiling, dilution, and conductive cooling within the reservoir.

In this paper we present the results of microthermometric measurements made on fluid inclusions from 9 wells. The data are used to develop a hydrogeochemical model of the geothermal system at Zunil I.

DISTRIBUTION AND DESCRIPTION OF FLUID INCLUSIONS

Microthermometric measurements were made on 525 fluid inclusions from the production wells ZCQ-1 through 6, and thermal gradient wells Z-11, -2 and -7. Emphasis was placed on inclusions from the production wells (see Figure 1 for locations).

Fluid inclusions were studied in vein calcite, quartz and epidote. Both primary inclusions occurring in three dimensional arrays that define crystal growth zones and secondary inclusions occurring along short healed fractures within the crystals were analyzed. No correlation between

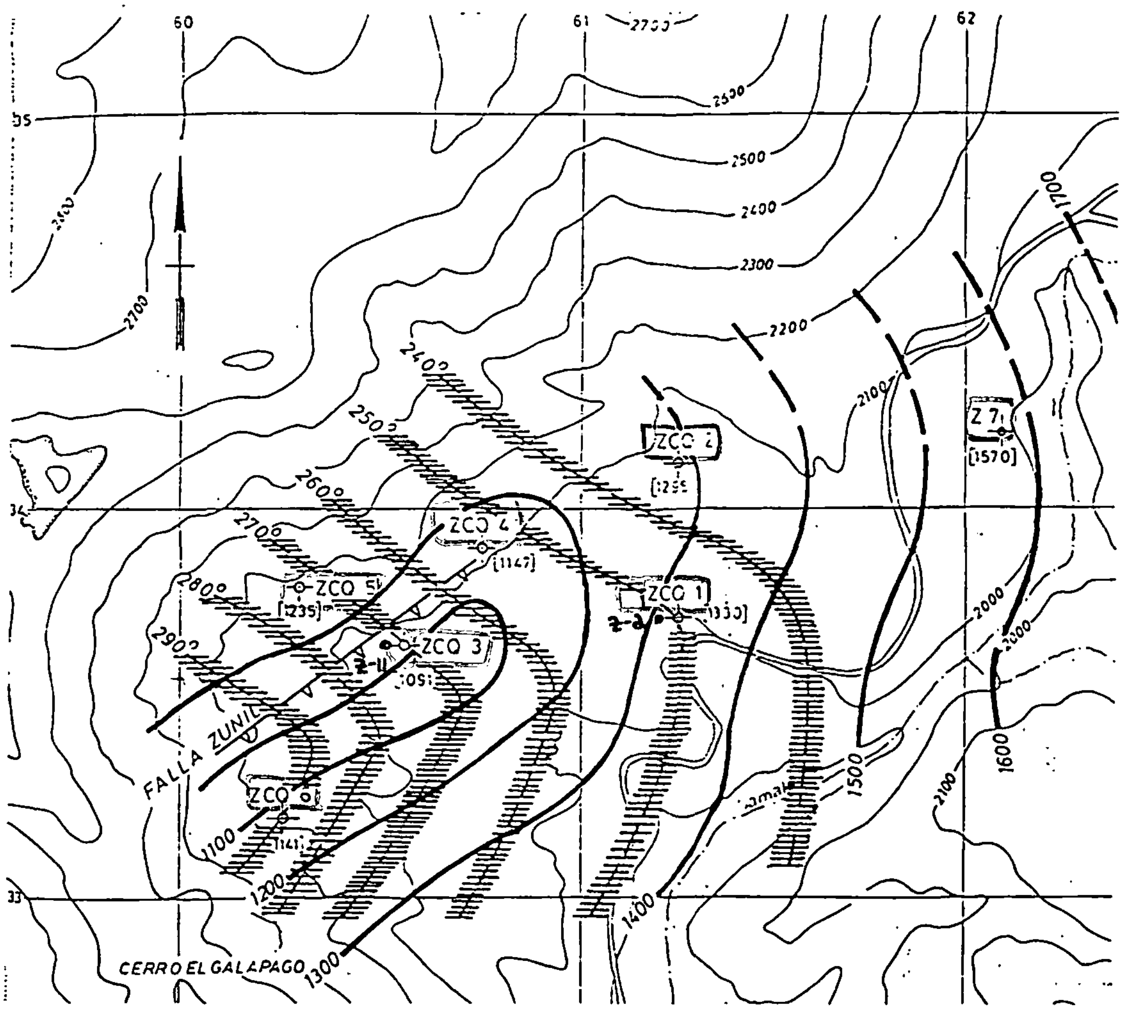


Figure 1. Location of wells studied

SIMBOLOGIA

COTAS DE TEMPERATURA

INFORMACION BASE: INFORME FINAL, ELECTRO-CONSULT, 1982.

INSTITUTO NACIONAL DE ELECTRIFICACION
INDE GUATEMALA C.A.

PROYECTO GEOTERMICO ZUNIL I

COTAS Y TEMPERATURAS AL TECHO DEL SUBESTRATO

CyM/MKF.

FIGURA: 3.3-16

the origin of the inclusions (secondary or primary) and the microthermometric measurements was found.

All of the inclusions observed consisted of two phases at room temperature. Three types of two-phase inclusions were recognized. Type I and II inclusions are liquid-rich. In Type I inclusions, the final phase to melt was ice whereas in Type II inclusions the final phase to melt was CO_2 clathrate at temperatures above 0.0°C. Type III inclusions are vapor-rich. Figure 2 shows examples of two-phase inclusions.

Types I and II differ only in the amount of CO_2 present in the inclusion fluids. Concentrations of CO_2 greater than approximately 3.8 weight percent (Type II) will produce CO_2 clathrate upon freezing that melts at temperatures greater than 0.0°C. If the CO_2 content is less than 3.8 weight percent (Type I), the last solid phase to melt will be ice, which will melt at temperatures less than or equal to 0.0°C.

The presence of planes of vapor-rich inclusions (Type III) in the vein minerals studied is significant because these inclusions provide evidence of boiling within the reservoir. Unfortunately, it was not possible to make reliable microthermometric measurements on the vapor-rich inclusions because of their small size (less than 10 μ). Vapor-rich inclusions were found at depths of 200 - 300 m in ZCQ-5 and ZCQ-6, and at a depth of 1015 m in ZCQ-4.

All of the inclusions measured in this study were liquid-rich and contained a small vapor bubble that occupied about 15% of the inclusion volume at room temperature. The majority of the inclusions studied had maximum dimensions of 2 to 15 μ. Fluid inclusion heating and freezing measurements were made using a Fluid Inc. heating/freezing system. All measurements were made in duplicate. Replicate measurements were within ± 0.2°C. We estimate a temperature uncertainty of ± 0.1°C for freezing measurements and ± 2.0°C for heating measurements. The results of the fluid inclusion measurements are listed in Appendix I, and illustrated in Figures 3 through 20.

FLUID INCLUSION DATA

ZCQ-6

Vein minerals containing fluid inclusions are common in the upper 800 m of ZCQ-6. At greater depths, the small size of the drill cuttings limited the amount of vein material suitable for study. The maximum homogenization temperature recorded in this well was 263°C.

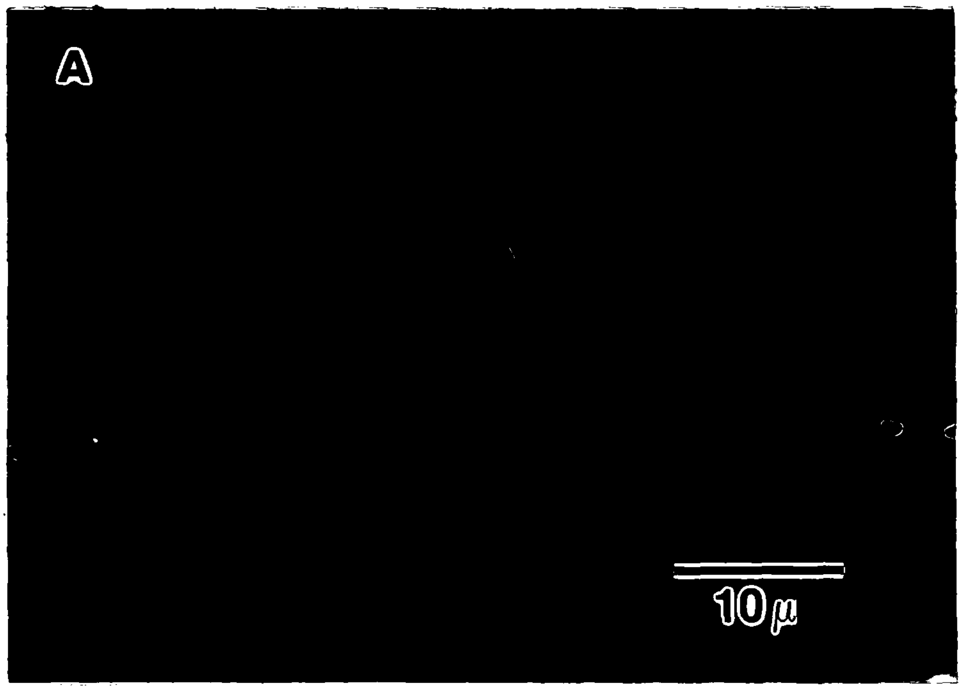


Figure 2a. Two-phase liquid-rich inclusions in Quartz from 1015 m in ZCQ-4.

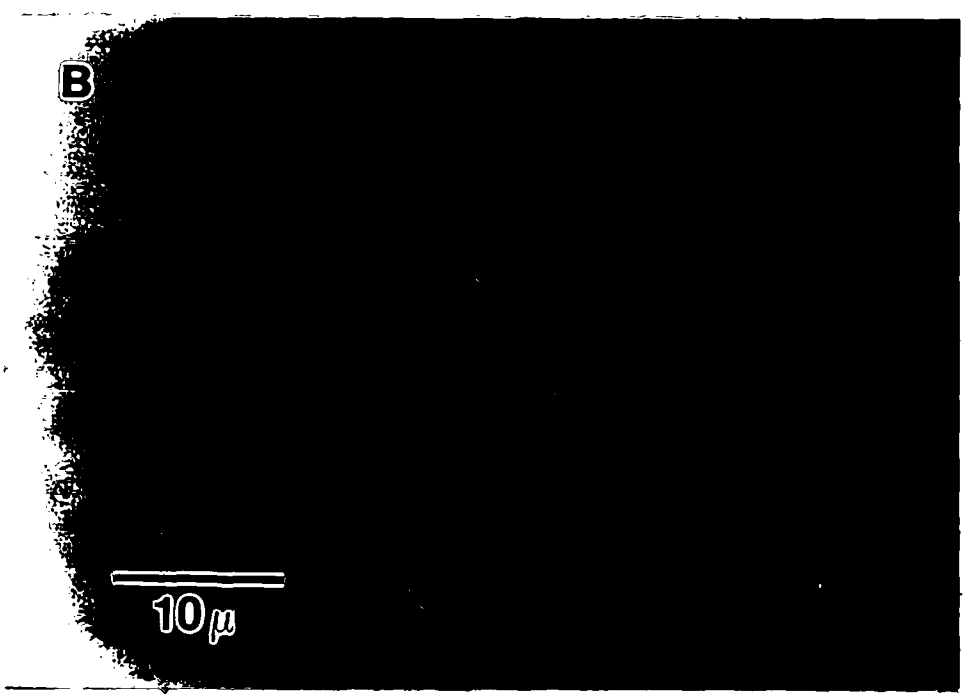


Figure 2b. Two-phase vapor-rich inclusions in Quartz from 1015 m in ZCQ-4.

Figure 3 compares the measured homogenization temperatures to the downhole temperature log. Most depth intervals display a relatively narrow range of homogenization temperatures. In several samples, the homogenization temperature varied by approximately 40°C. However, within an individual primary growth zone or secondary plane the temperatures were consistent; the variation was between different areas of the same crystals. At depths shallower than 400 m, the homogenization temperatures are higher than the downhole measured temperatures. In contrast, homogenization temperatures from depths greater than 400 m plot below the present day temperatures. Figure 3 also compares the inclusion temperatures to the boiling point curve for a fluid with a chlorinity of 1800 ppm, which is estimated to be the reservoir fluid composition. Since the exact elevation of the piezometric surface at the time of inclusion formation is unknown, we have assumed that the boiling point curve intersected the surface at the time of trapping. This assumption is consistent with evidence of boiling found in primary inclusions from a depth of 200 m.

Figure 4 shows the variations with depth in the ice-melting temperatures of Type I inclusions. The ice-melting temperatures of Type I inclusions in the upper 200 m defined a narrow range; 0.0° to -0.2°C. Type II inclusions with clathrate-melting temperatures that ranged from +0.4° to +0.6°C were found at 200 m. From approximately 300 to 700 m, individual samples showed a broad range of ice-melting temperatures. For example, several crystals recorded ice-melting temperatures that ranged from 0.0° to -0.7°C. In contrast, the deepest sample measured in ZCQ-6 (790 m) had ice-melting temperatures that were consistently -0.2°C.

ZCQ-5

Figure 5 shows homogenization temperatures samples from ZCQ-5, which ranged from 152° to 282°C. In contrast to ZCQ-6, the present day temperatures are most similar to the lower homogenization temperatures. However, the upper limits of the data plot close to the boiling point to depth curve for a fluid with a chlorinity of 1800 ppm. Extensive evidence of boiling was also found in inclusions from 200 to 300 m in ZCQ-5 .

Variations in ice-melting temperatures of Type I inclusions with respect to depth are illustrated in Figure 6. Ice-melting temperatures ranged from 0.0° to -0.7°C between depths of 400 and 900 m. In contrast the inclusions at 940 m had ice-melting temperatures ranging form 0.0° to -0.2°C. Type II inclusions were found in the shallow portions of the well, between depths of 200 and 400 m. The CO_2 clathrate-melting temperatures of the Type II inclusions ranged from

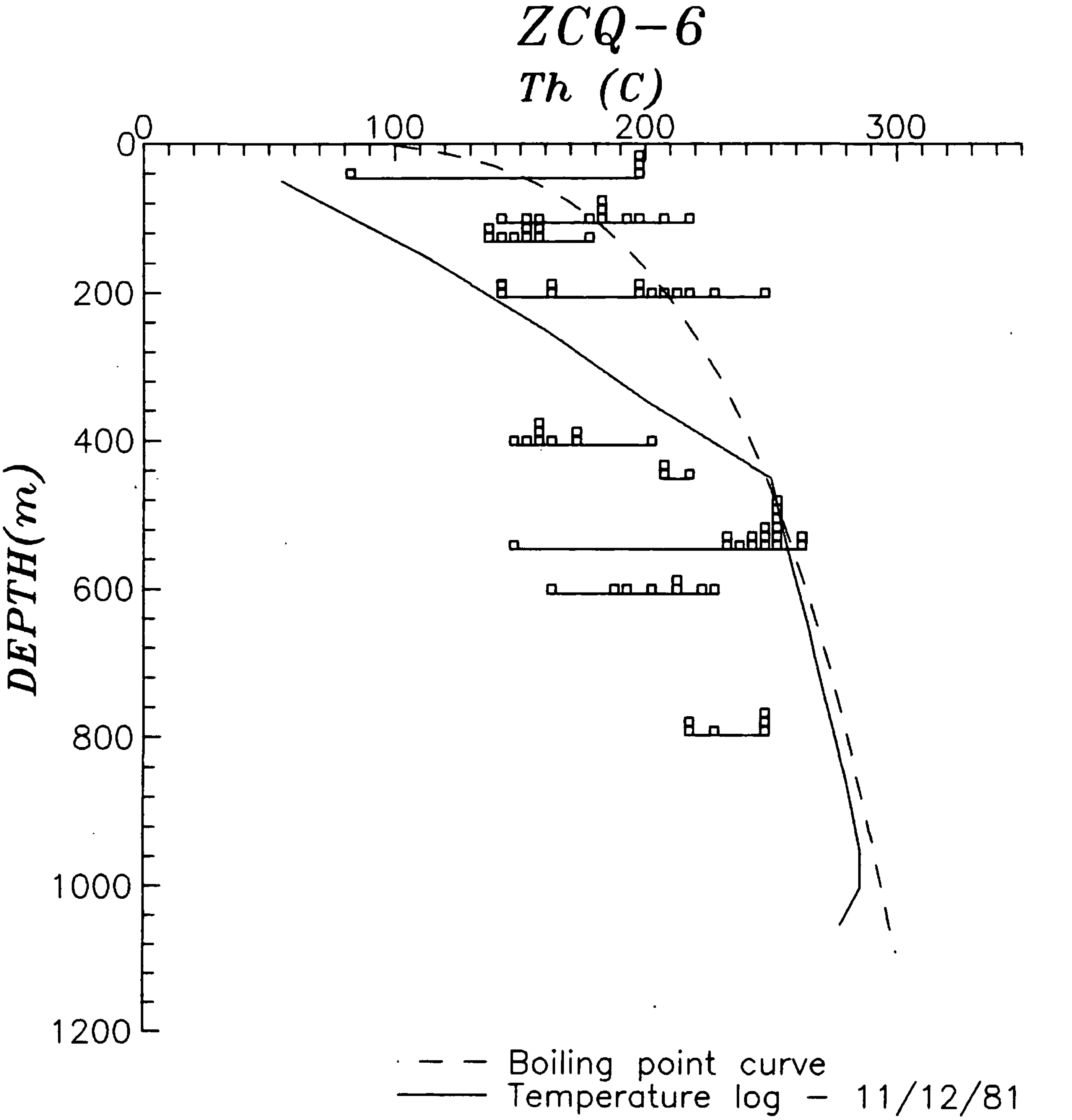


Fig. 3. Temperatures of homogenization (Th) versus depth for ZCQ-6.

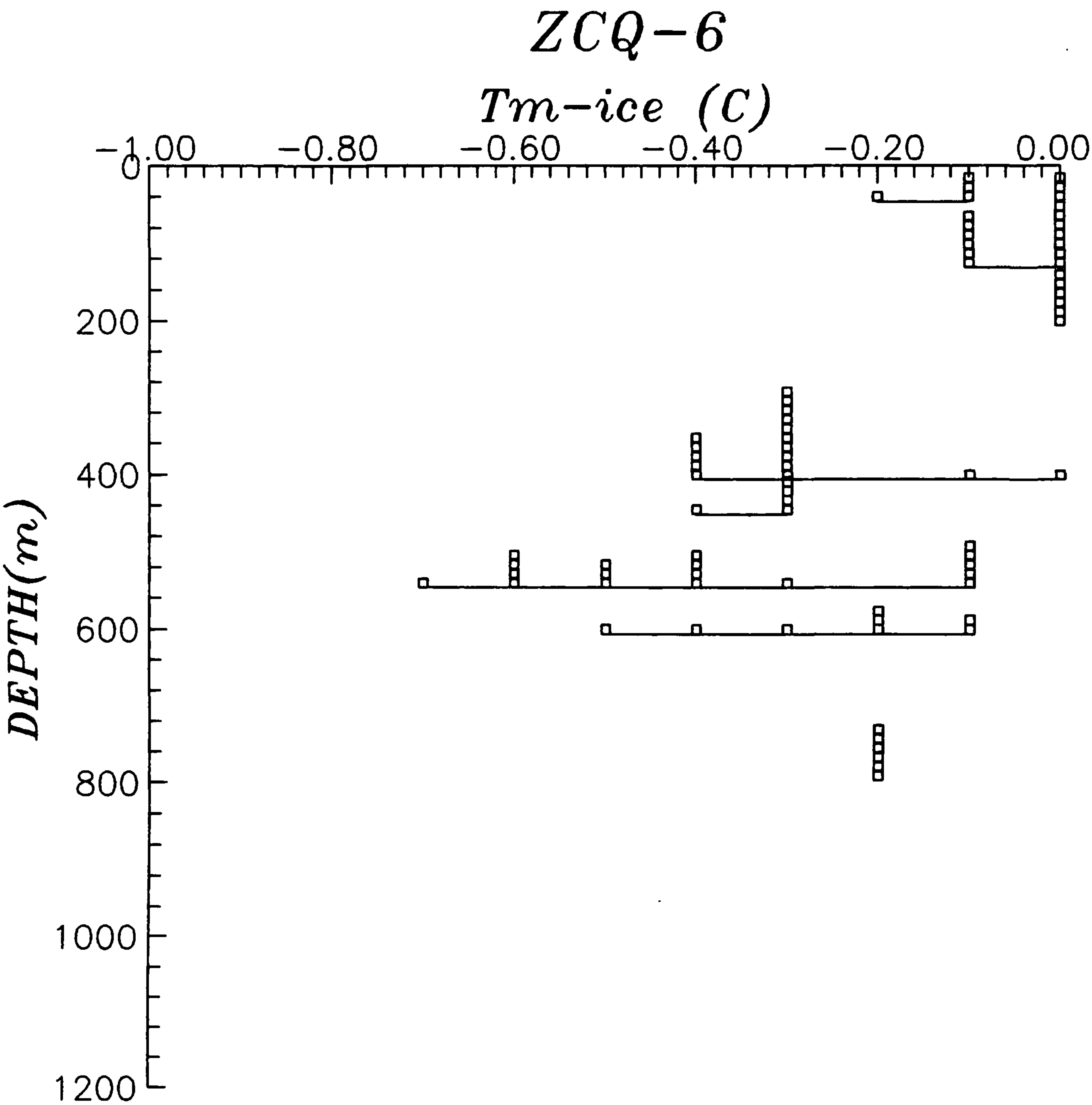


Fig. 4. Temperatures of ice-melting (Tm-ice) versus depth for ZCQ-6.

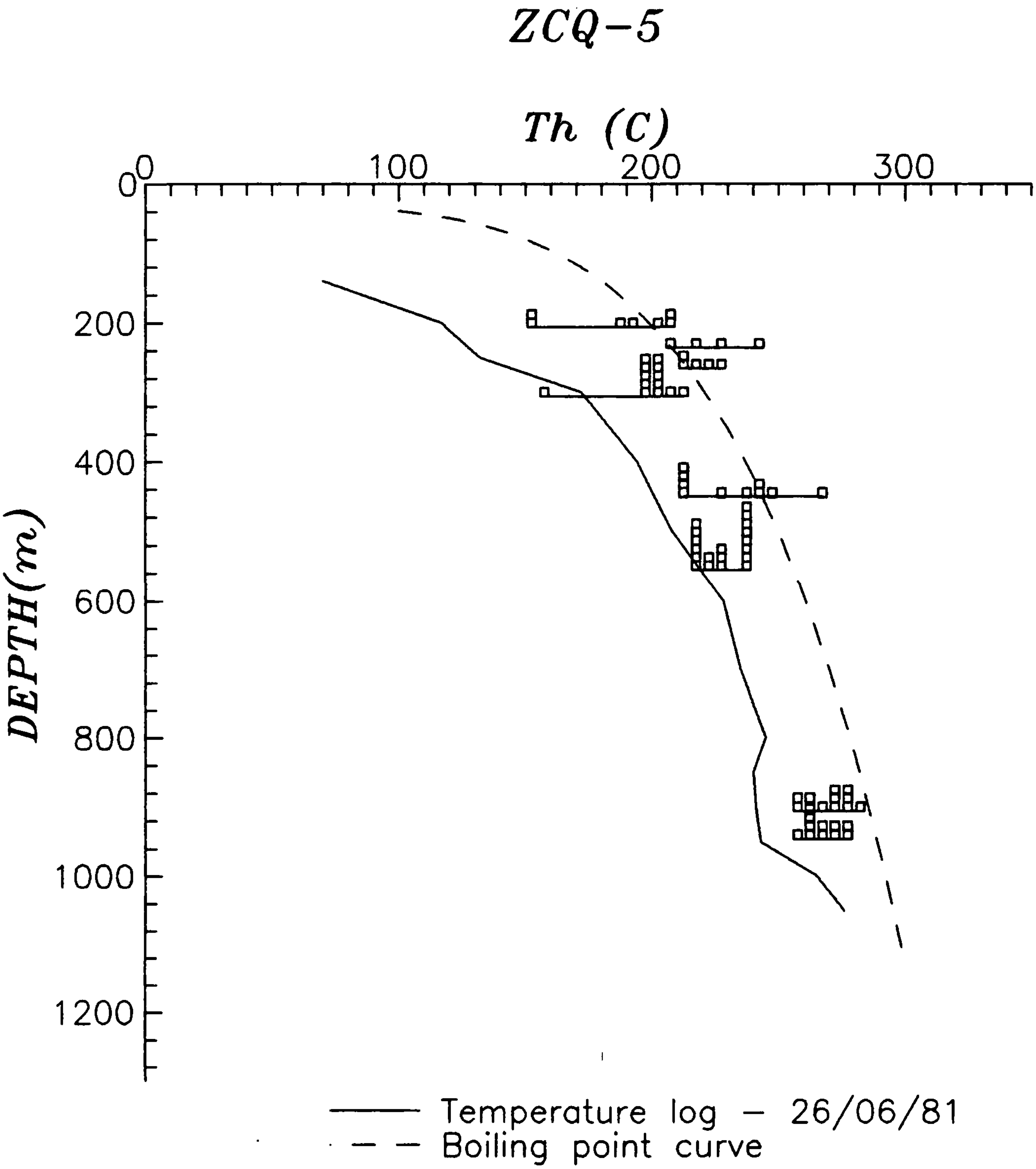


Fig. 5. Temperatures of homogenization (Th) versus depth for ZCQ-5.

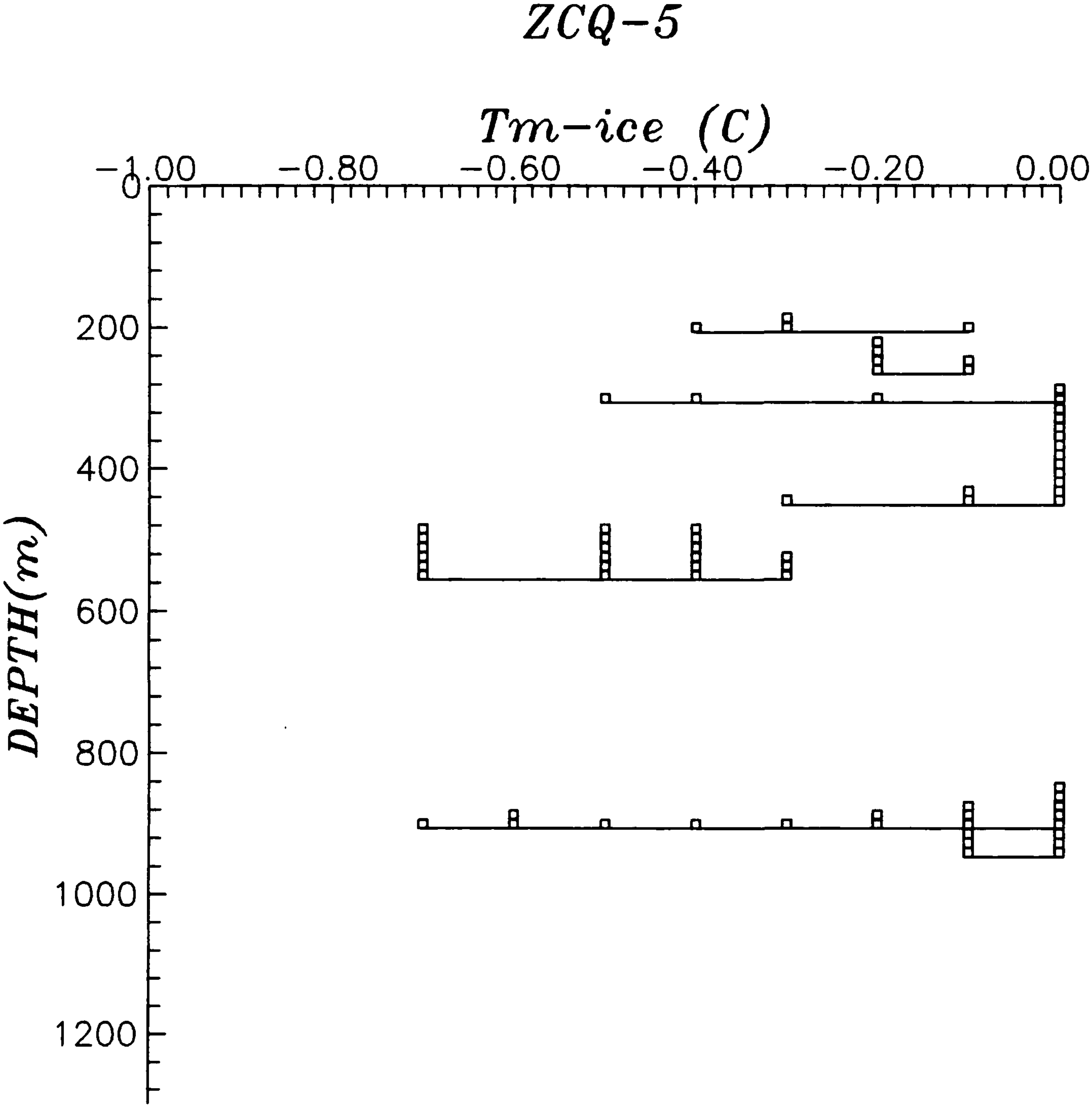


Fig. 6. Temperatures of ice-melting (Tm-ice) versus depth for ZCQ-5.

+0.1° to +0.3°C. The vertical extent of Type II inclusions appears to be greater in ZCQ-5 than in ZCQ-6.

ZCQ-3

Figure 7 depicts the homogenization temperatures for ZCQ-3. Inclusion temperatures in this well ranged from 152° to 300°C. There are some subtle differences between this data set and the data from ZCQ-5 and ZCQ-6. The homogenization temperatures from ZCQ-3 follow the present day temperature profile closely, while the downhole measured temperatures from ZCQ-5 and ZCQ-6 plot on upper and lower limits of the inclusion data, respectively. In addition, homogenization temperatures from ZCQ-3 plot below the boiling point curve to a depth of approximately 600 m. At greater depths the inclusion temperatures follow the boiling point curve closely. In ZCQ-5 and ZCQ-6, the homogenization temperatures plot close to the boiling point curve even at shallow depths.

Figure 8 illustrates the ice-melting temperatures of Type I inclusions in ZCQ-3. The general trends displayed by inclusions in ZCQ-5 and 6 are also observed in ZCQ-3. Ice-melting temperatures close to 0.0°C were found near the surface. Below 400 m there is an increase in the range of ice-melting temperatures with depth (0.0° to -1.1°C). However, the low apparent salinity fluids that were found at the bottom of ZCQ-5 and ZCQ-6 were not observed in ZCQ-3. Type II inclusions were found between depths of 200 and 400 m. CO_2 clathrate-melting temperatures of these inclusions ranged from +0.1° to +0.3°C.

Z-11

Although considerably less data was available for Z-11, the fluid inclusion measurements were similar to those found in ZCQ-3. This was expected since the two wells are located adjacent to each other. As in ZCQ-3, homogenization temperatures plot below the boiling point curve to a depth of 600 m. Below this depth, the data plot close to the boiling point curve (Fig. 9). Figure 10 shows that the same trends in freezing data found in ZCQ-3, -5 and -6 were also found in Z-11. Ice-melting temperatures of Type I inclusions ranged from 0.0 to -0.4°C below a depth of 200 m. Type II inclusions occurred at a depth of 200 m and have CO_2 clathrate-melting temperatures that ranged from +0.3° to +0.6°C.

ZCQ-4

Fluid inclusion measurements were conducted on core samples taken at depths of 776 m and 1015 m. The upper core consists of andesite containing veins of calcite. The deeper core

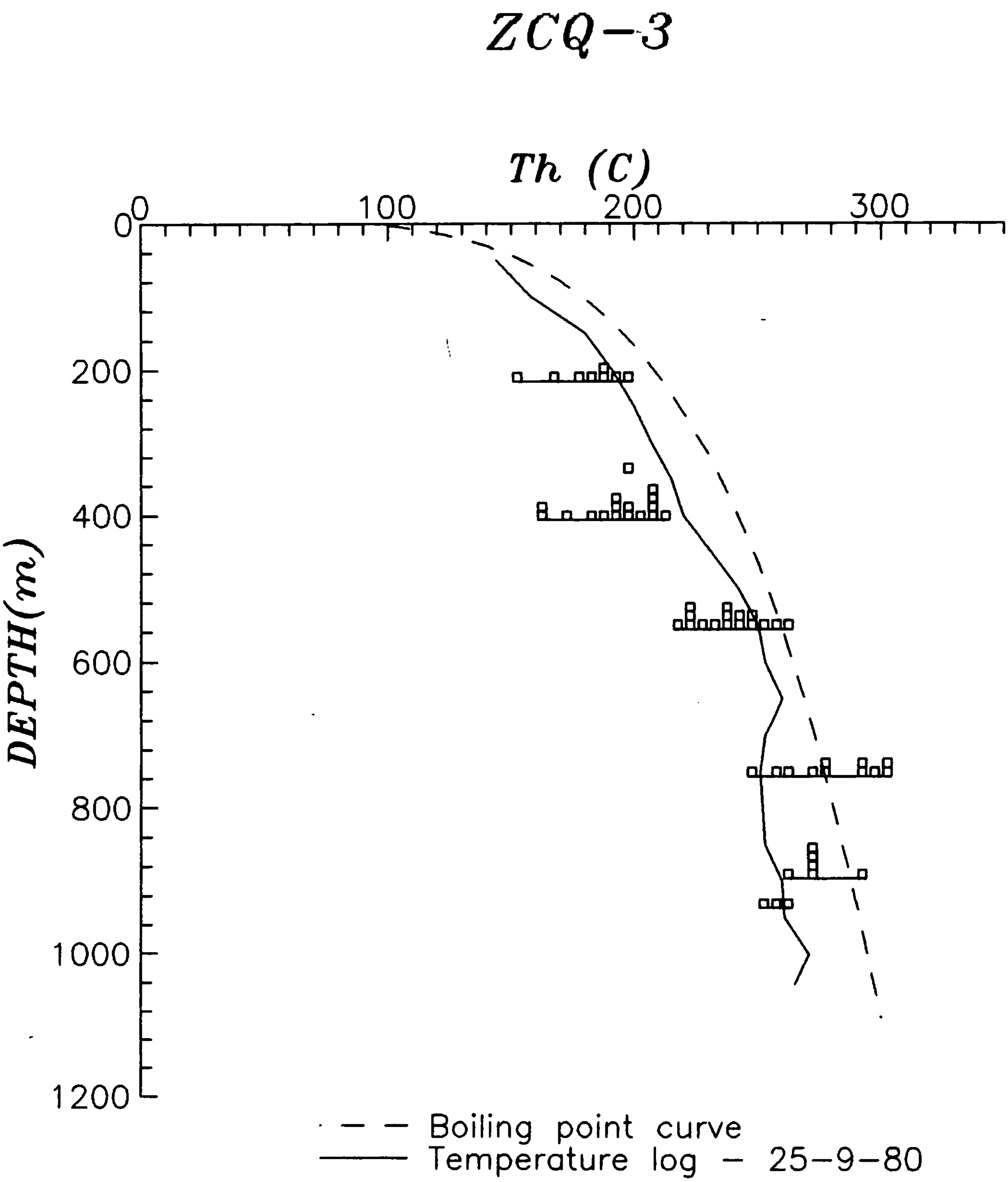


Fig. 7. Temperatures of homogenization (Th) versus depth for ZCQ-3.

ZCQ-3

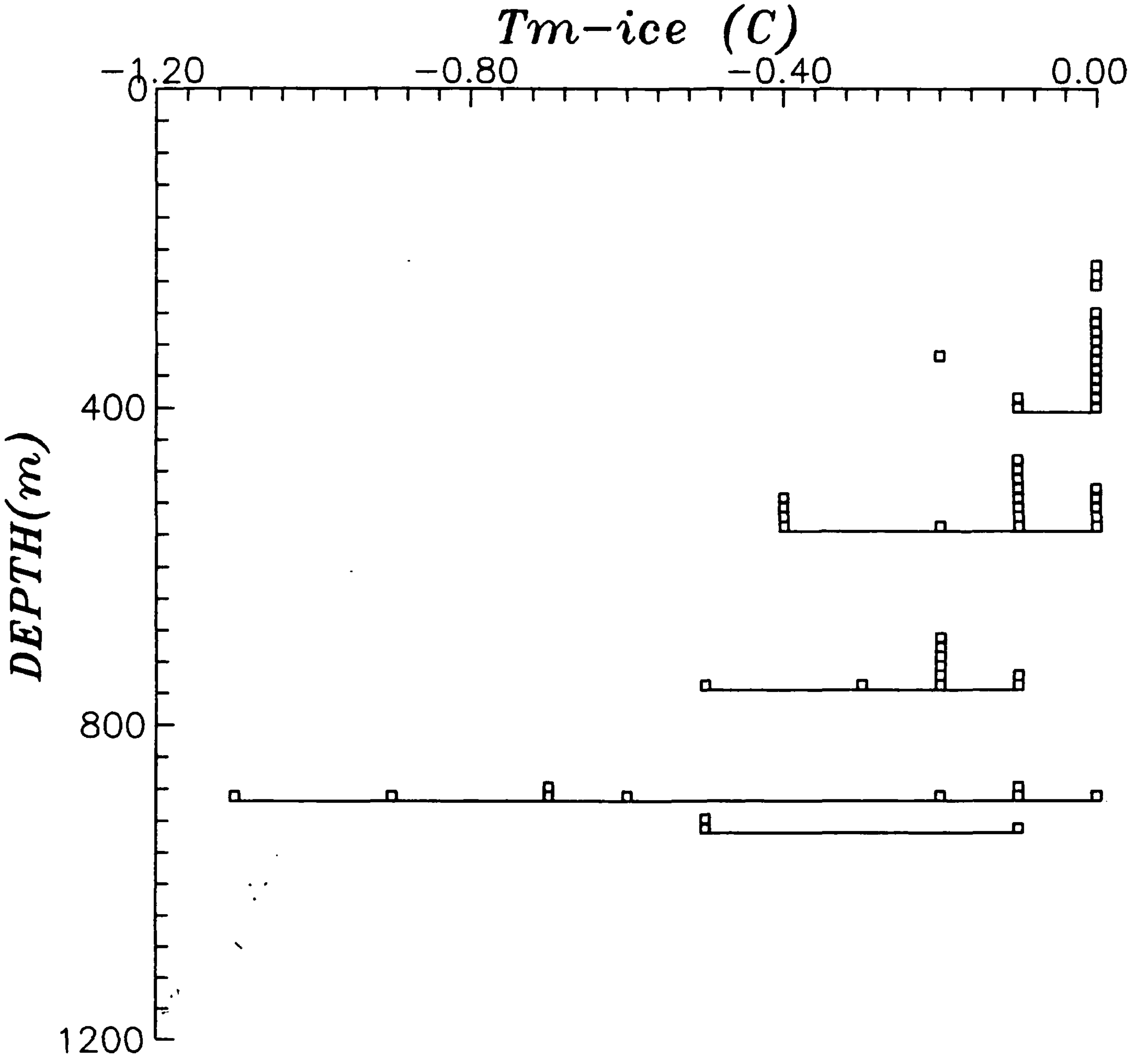


Fig. 8. Temperatures of ice-melting (Tm-ice) versus depth for ZCQ-3.

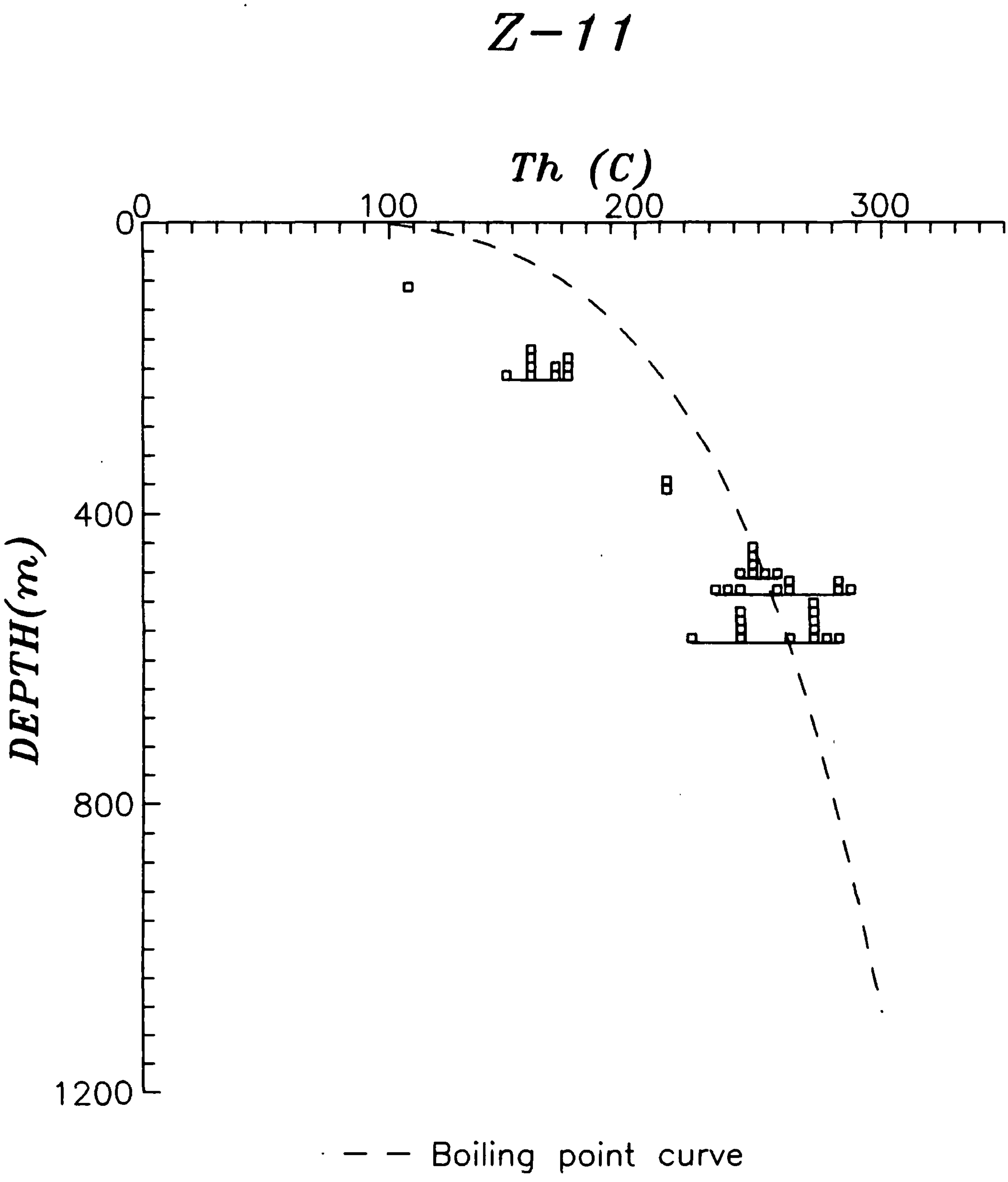


Fig. 9. Temperatures of homogenization (Th) versus depth for Z-11.

Z-11

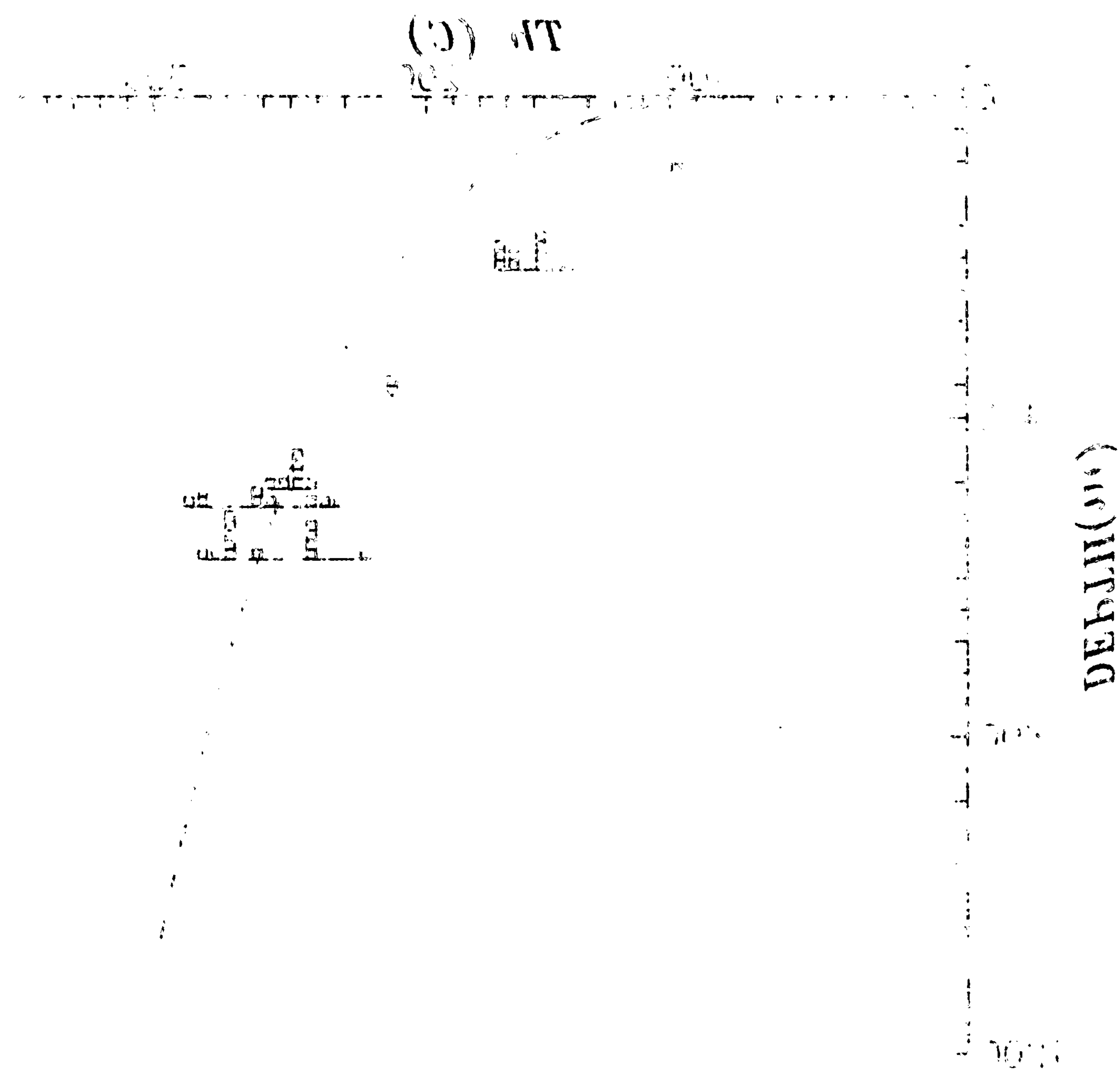


Fig. 9. Temperatures of homogenization (Th) versus depth for Z-11.

Z-11

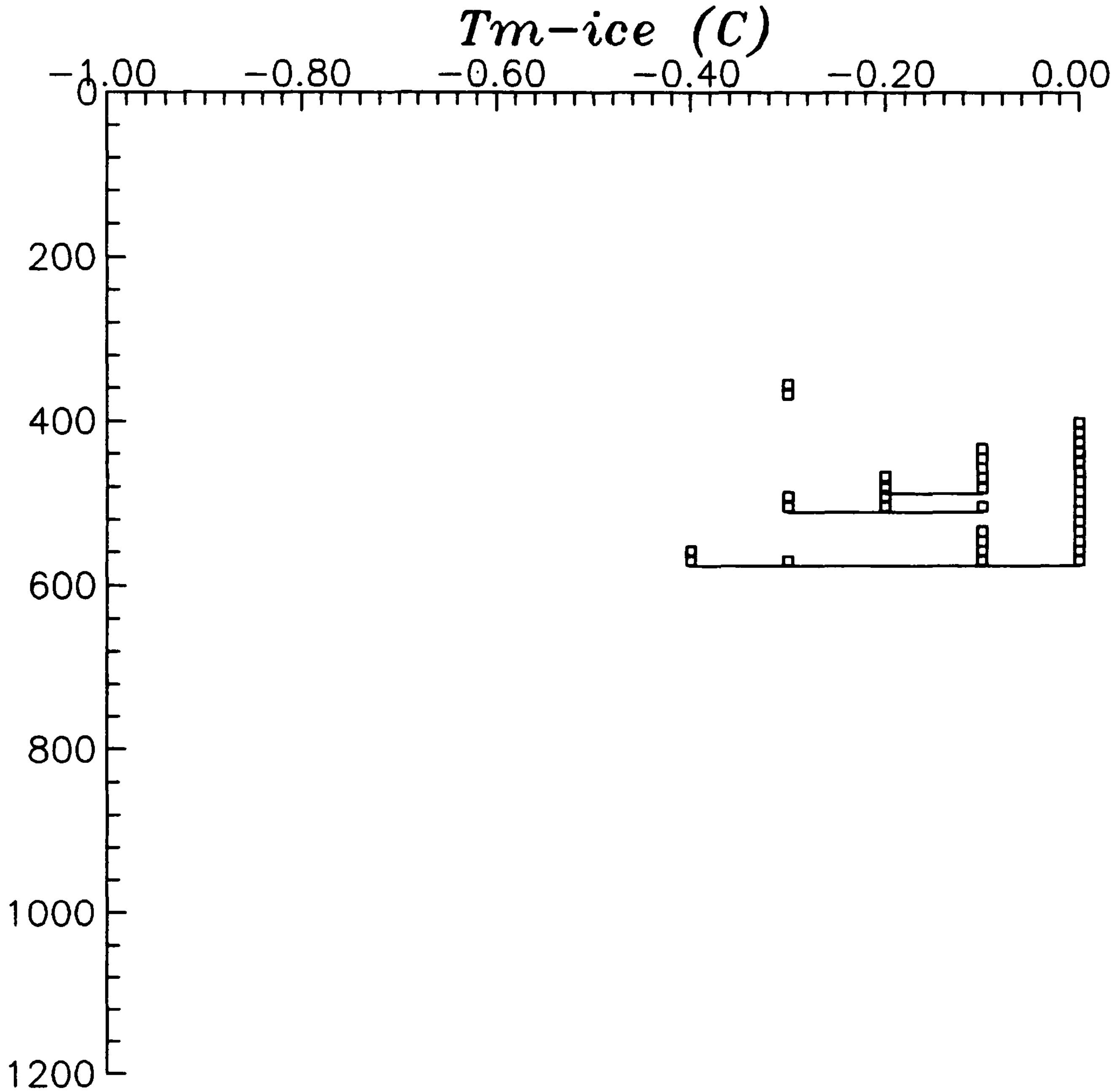


Fig. 10. Temperatures of ice-melting (Tm-ice) versus depth for Z-11.

sample was taken in granodiorite that is cut by veins of quartz-chlorite-epidote-pyrite. The veins in these samples contained inclusions that recorded some of the highest homogenization temperatures found in any of the wells at Zunil I (252° to 342°C). Figure 11 shows that the homogenization temperatures plot close to the boiling point curve, which is consistent with the presence of vapor-rich inclusions found in samples from 1015 m (refer to Figure 2c). The measured downhole temperatures plot significantly below these homogenization measurements. Figure 12 illustrates the ice-melting temperatures of inclusions in the two samples. Only Type I inclusions were found.

ZCQ-1

Figure 13 shows the homogenization temperatures for inclusions from ZCQ-1. These temperatures ranged from 145° to 248°C. The homogenization temperatures displayed little variation with depth and within each individual sample the range of homogenization temperatures was approximately the same as the overall range. With the exception of inclusions from a depth of 200 m, where both the homogenization and measured temperatures are similar, the present day temperatures fall closest to the maximum homogenization temperatures of the inclusions. The sample from 200 m is also the only sample which plots on the boiling point curve.

Figure 14 shows that the ice-melting temperatures of Type I inclusions from ZCQ-1 are similar to those of the other wells. From 800 m to 1100 m, the range in ice-melting temperatures increases (-0.2° to -1.6°C). Similar large variations were found in sections of ZCQ-6, -5, -4, -3. At the base of ZCQ-1, the range of ice-melting temperatures narrows to 0.0° to -0.2°C. The same range of freezing point depressions were also found at the base of ZCQ-5, -6, and -2.

Type II inclusions, however, are found over a much greater vertical extent in ZCQ-1 than they are in the other wells studied. In ZCQ-1 Type II inclusions occur between depths of approximately 200 to 800 m. In contrast, Type II inclusions are restricted to a zone that is 100 m thick in ZCQ-6, 200 m thick in ZCQ-5, and 300 m thick in ZCQ-3. The CO_2 clathrate-melting temperatures range from 0.0° to +0.6°C.

Z-2

Homogenization and ice-melting temperatures of fluid inclusions from depths of 500 to 600 m in Z-2 are illustrated in figures 15 and 16 respectively. The homogenization temperatures fall below both the present day temperature profile and the boiling point curve. Ice-melting temperatures (Type I inclusions) ranged from 0.0° to -0.4°C.

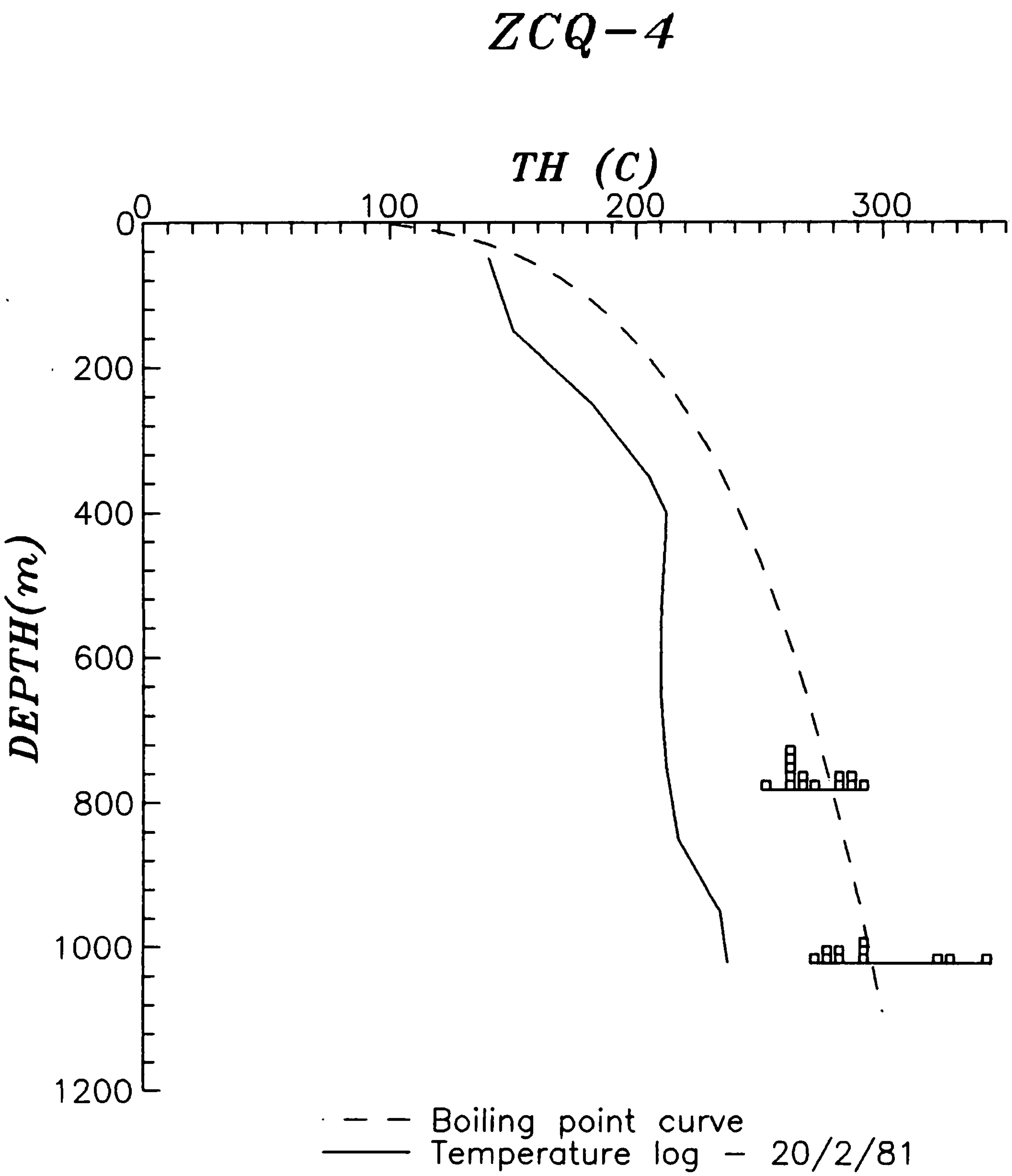
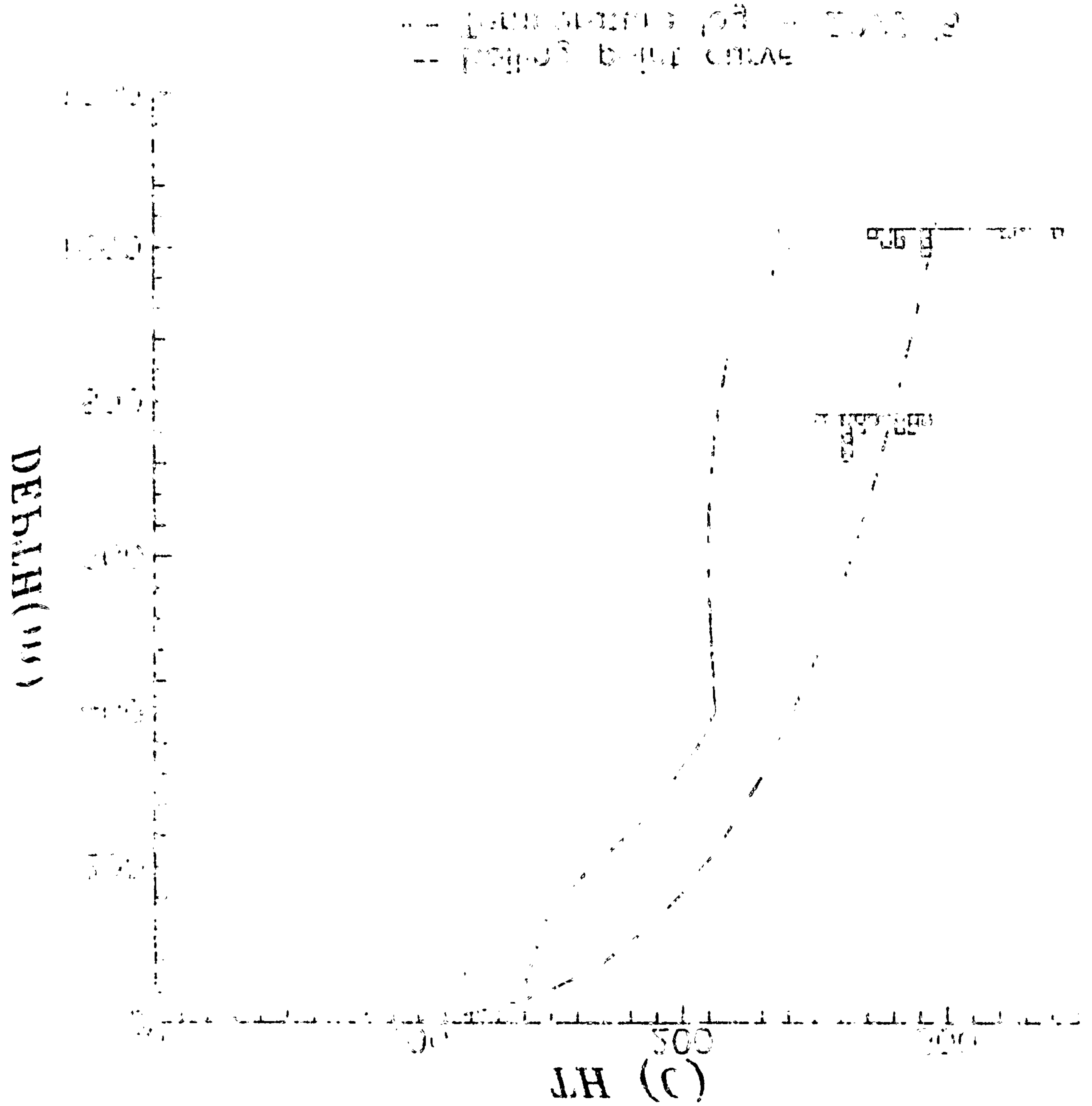


Fig. 11 Temperatures of homogenization (Th) versus depth for ZCQ-4.

Fig 11 Temperatures of homogenization (Th) versus depth for ZO-4



ZO-4

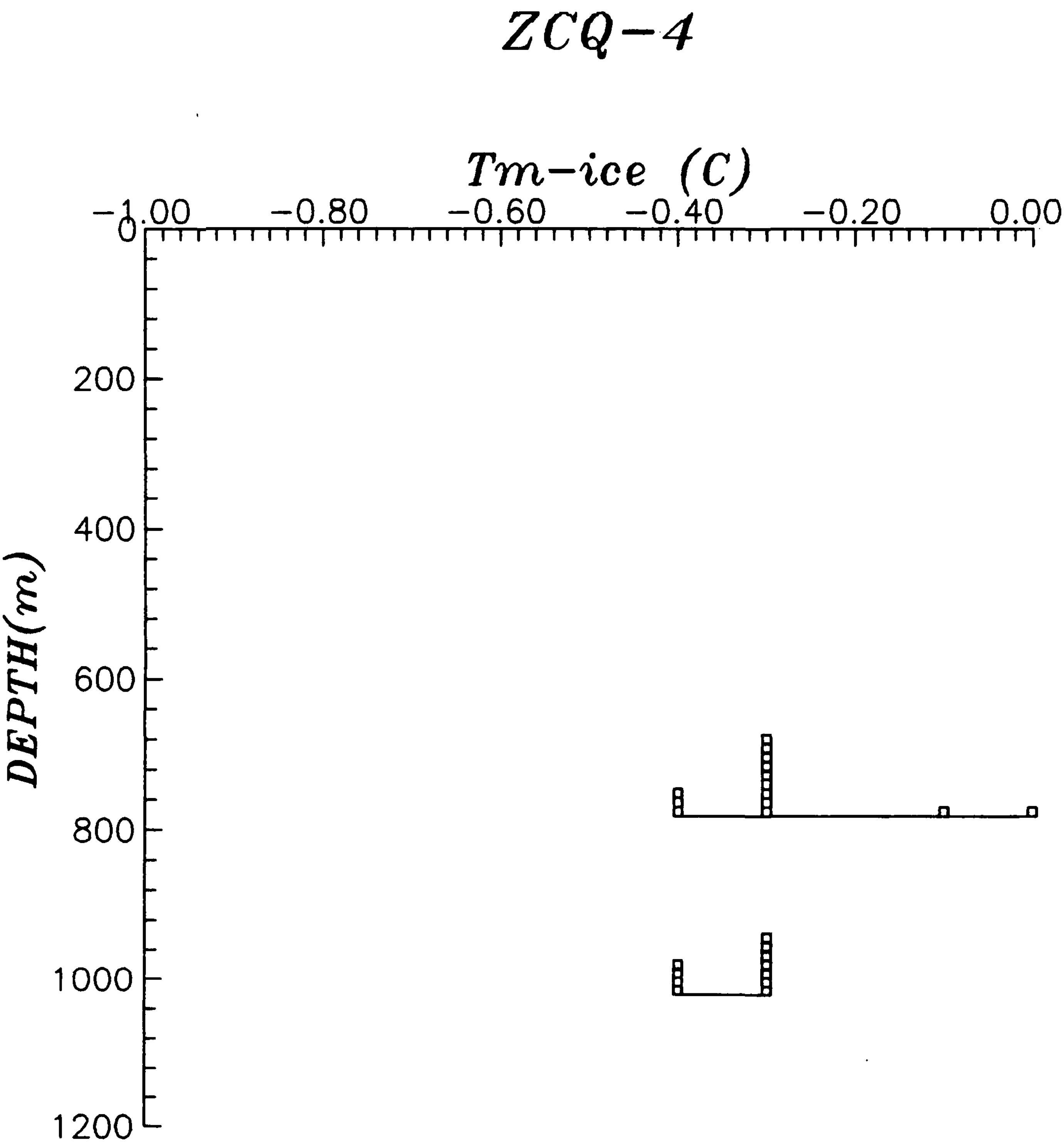
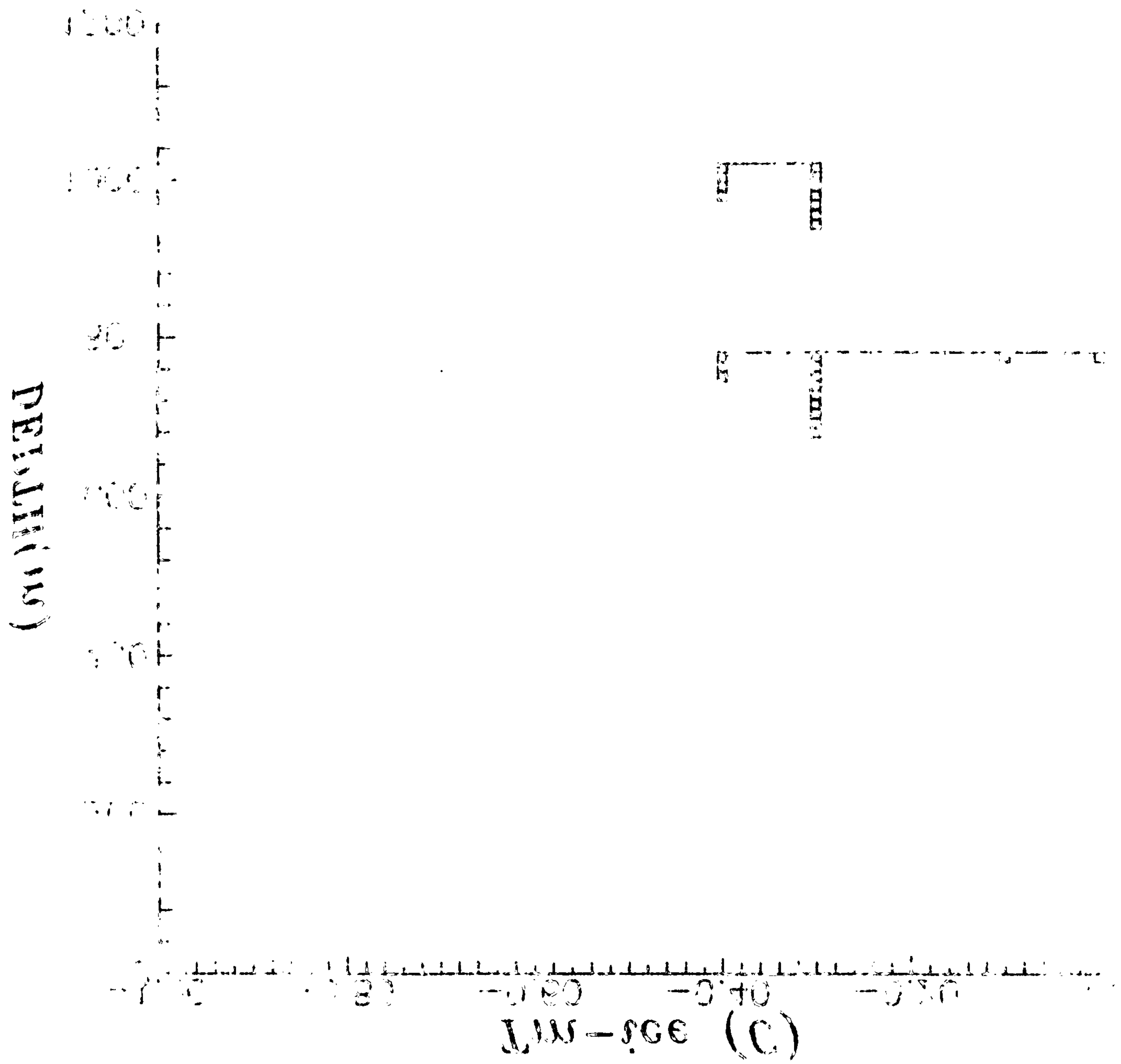


Fig. 12. Temperatures of ice-melting (Tm-ice) versus depth for ZCQ-4.

Fig. 12. Temperatures of ice-melting (Tm-ice) versus depth for ZCG-4.



ZCG-4

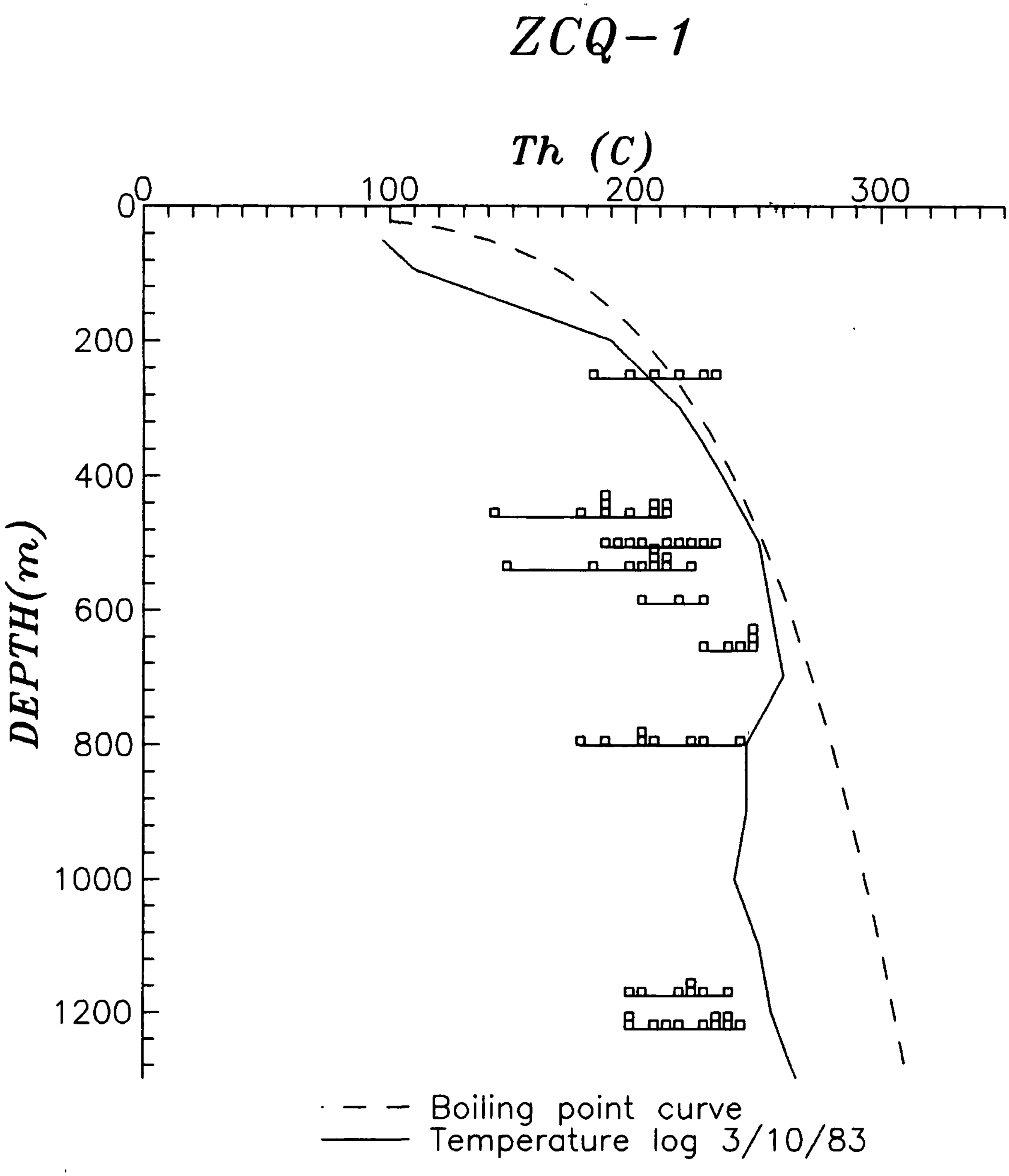


Fig. 13. Temperatures of homogenization (Th) versus depth for ZCQ-1.

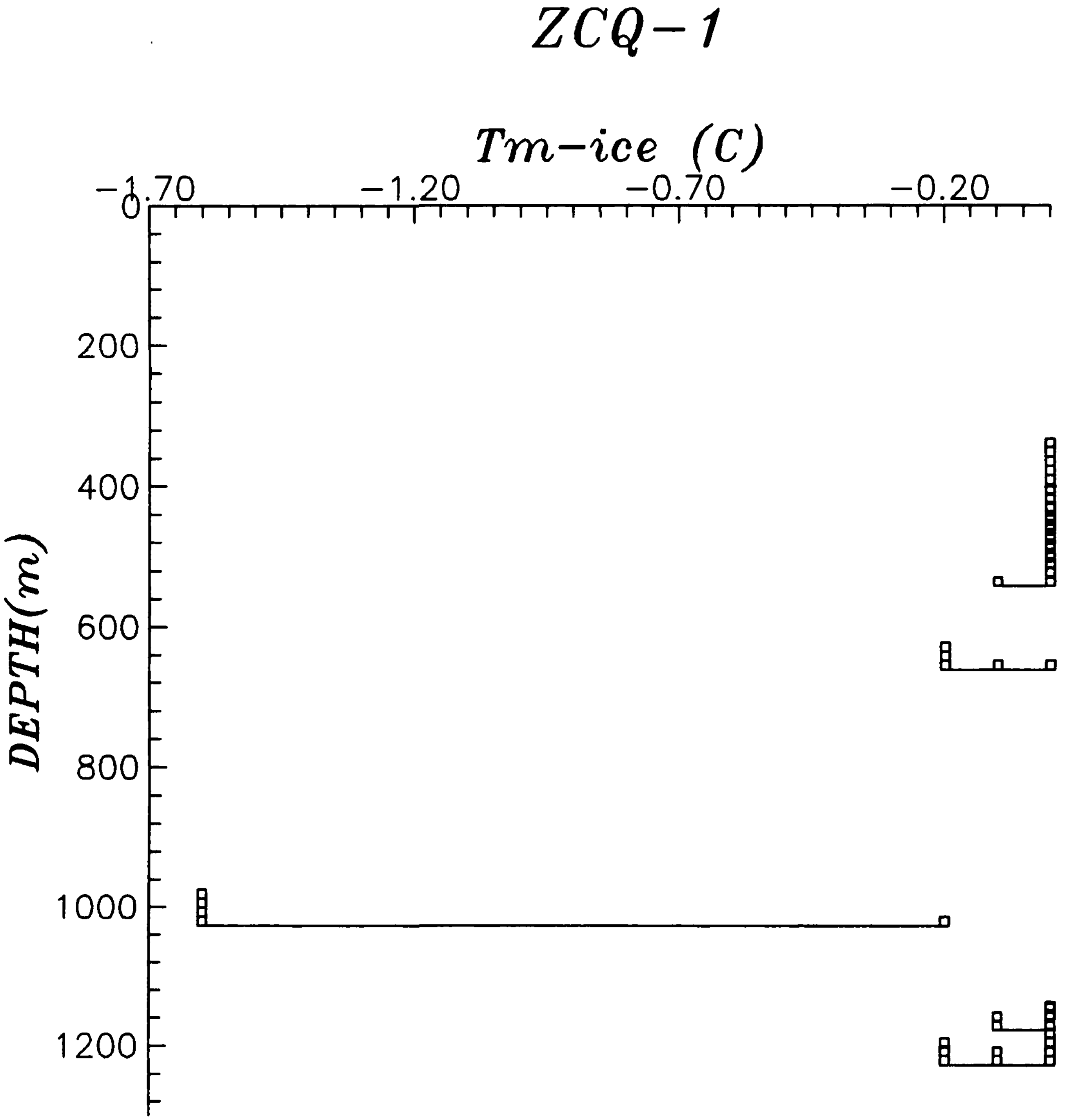


Fig. 14. Temperatures of ice−melting (Tm−ice) versus depth for ZCQ−1.

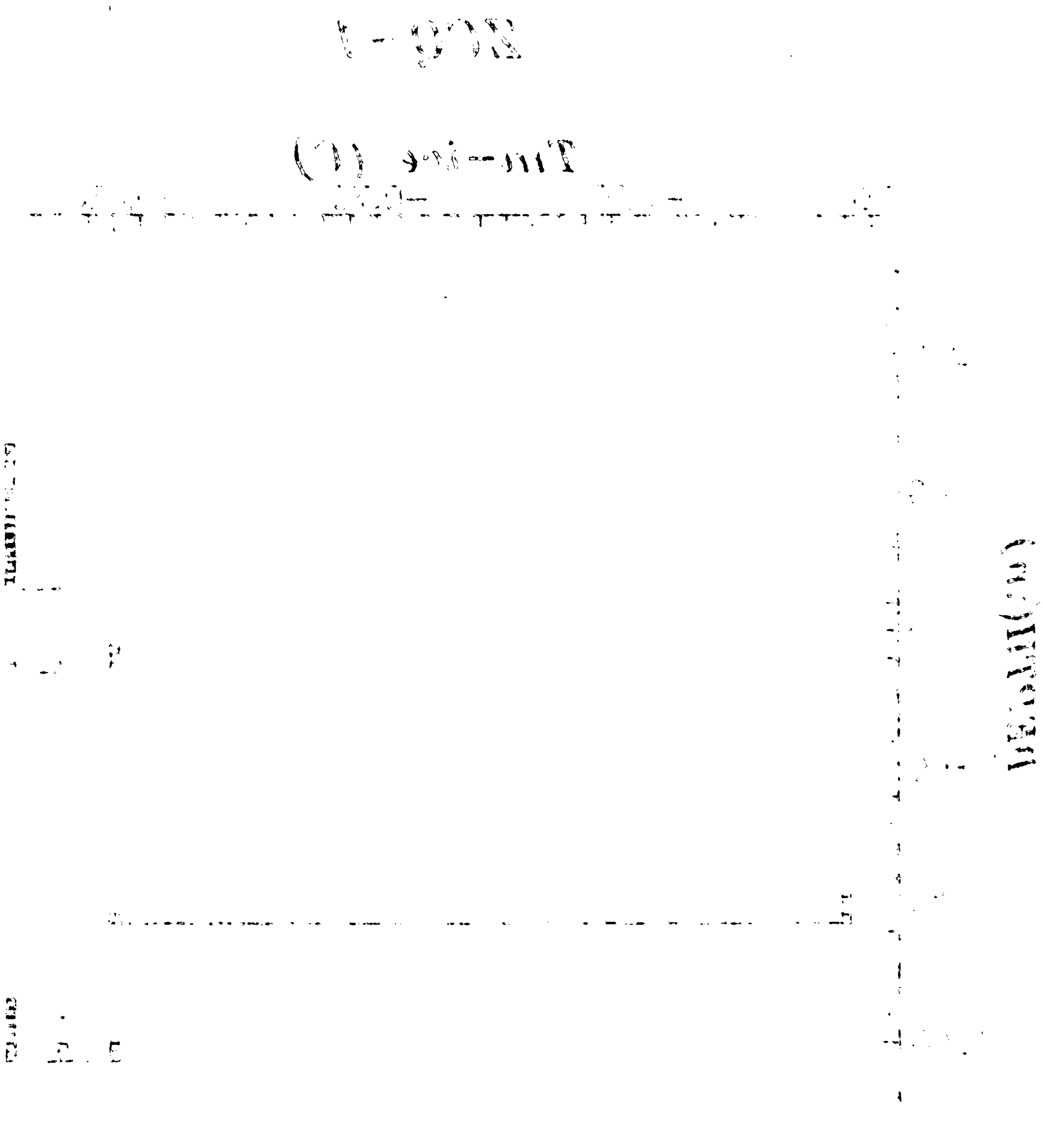


Fig. 14. Temperature of ice-melting (Tm-ice) versus depth for ZK-1.

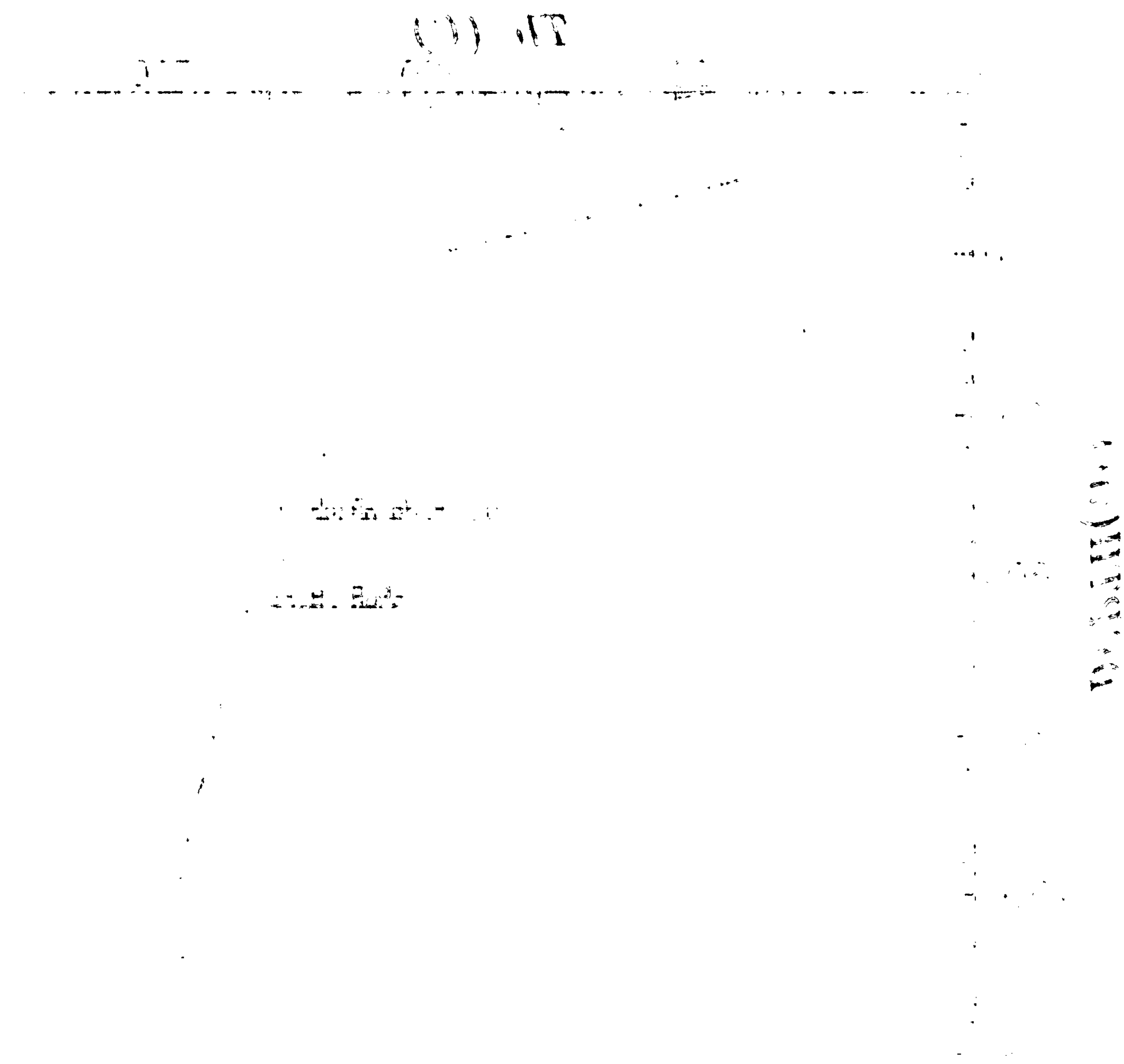


Fig. 15 Temperatures of homogenization (Th) versus depth for Z-11.

Z−2

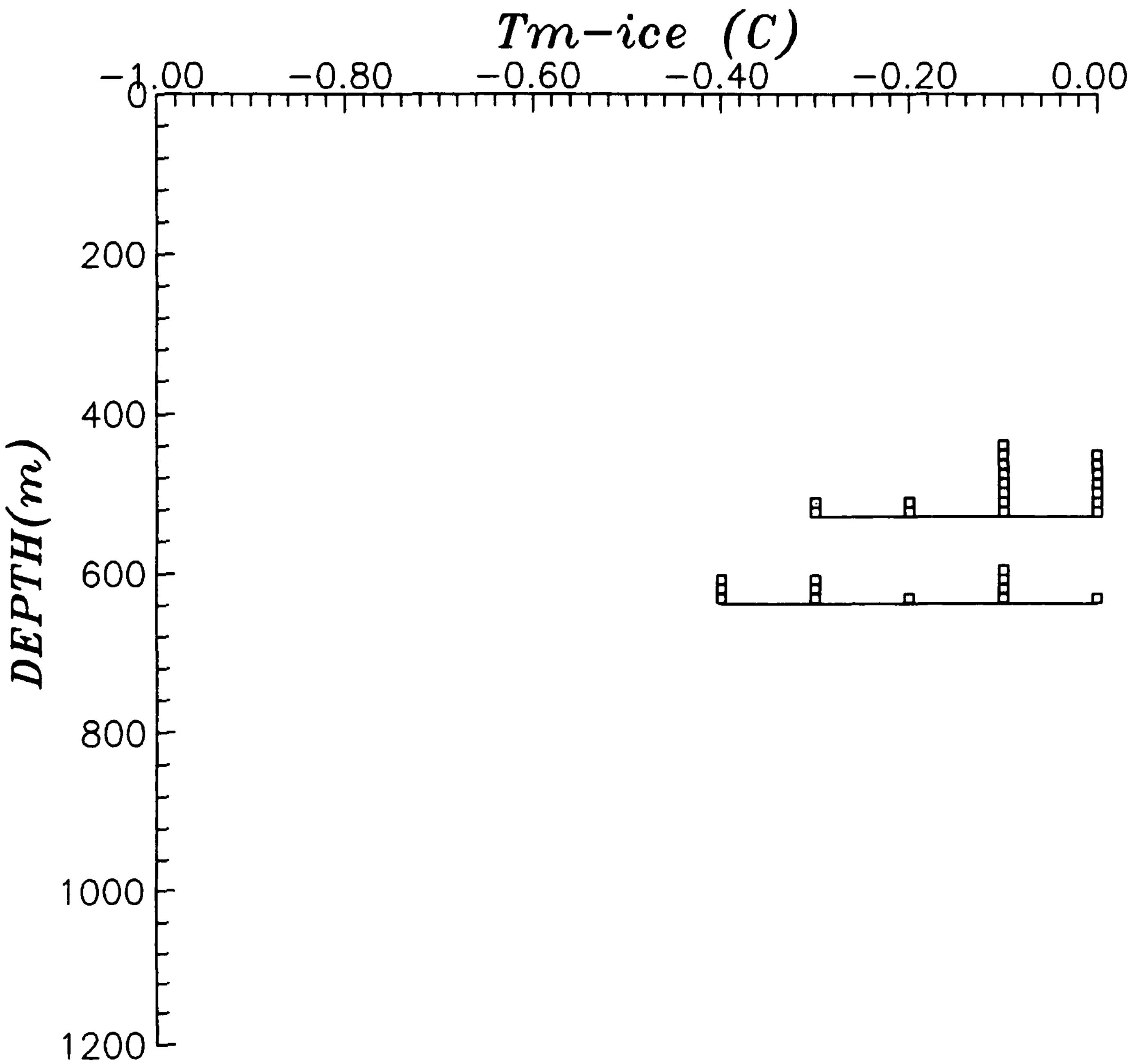


Fig. 16. Temperatures of ice−melting (Tm−ice) versus depth for Z−2.

ZCQ-2 and Z-7

Only one sample was obtained from each well. These data are presented in figures 17 to 20. In both cases the samples were from shallow intervals above a depth of 200 m. Homogenization temperatures ranged from 132° to 209°C. The ice-melting temperatures of these inclusions are consistent with values found at similar depths in ZCQ-5 and -6, and ranged from 0.0° to -0.2°C.

DISCUSSION

Thermal history of Zunil I

The temperatures of homogenization indicate that both minor heating and cooling are occurring in Zunil I. The overall homogenization temperatures vary slightly from the downhole measured temperatures in most cases. Temperature variations are also indicated within a single individual crystal. The homogenization temperatures are consistent within each secondary plane or growth zone. However, other secondary planes in the same crystal will differ in temperature. Thus, the crystal must have been exposed to fluids with different temperatures. However, the salinties are approximately the same, which implies that the fluids have not changed composition. These variations in temperature appear to be caused by two factors as discussed below: self sealing of fractures resulting in a permeability decrease; and local downward incursions of cool steam-heated waters.

In ZCQ-6, present-day measured temperatures display a conductive gradient down to 480 m, followed by a convective gradient. In contrast, the fluid inclusion data (Fig. 3) indicate that temperatures in well ZCQ-6 followed the boiling point curve to depths of approximately 520 m. These data demonstrate the development of a shallow low-permeability zone, possibly due to mineral precipitation. The present day temperature profile below 520 m is higher than the homogenization temperatures indicating heating has occurred since inclusion formation. This heating could be due to the shallow low-permeability zone having cut off the downward percolation of low-temperature fluid, preventing mixing between the high- and low-temperature fluids.

A comparison of homogenization temperatures with downhole measured temperatures indicates that ZCQ-5 is cooling down. The downhole logs record temperatures that follow the lower measured homogenization temperatures. In addition, primary growth zones and secondary planes in the same crystals also record temperature decreases. The cooling in ZCQ-5 could have

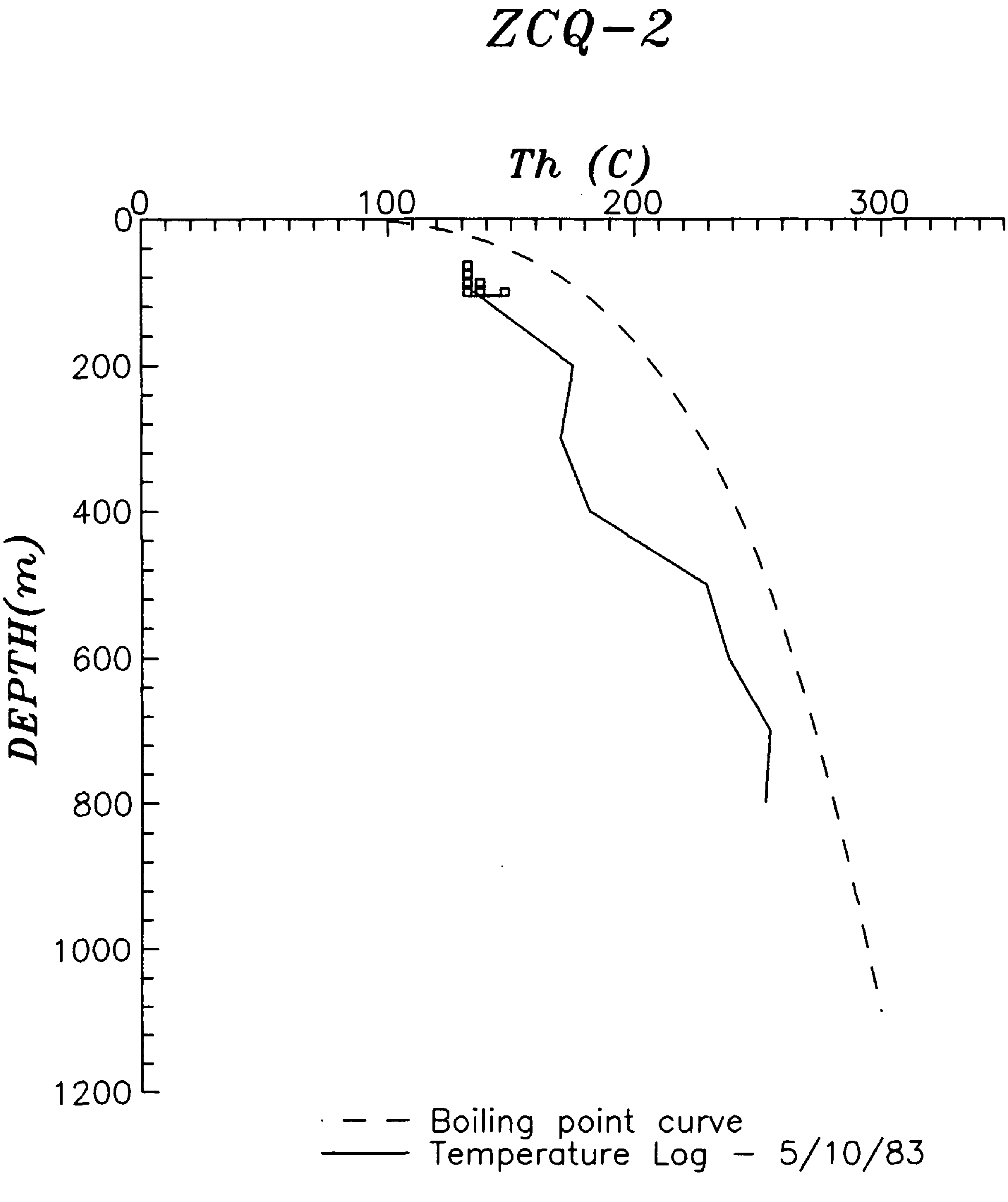


Fig. 17. Temperatures of homogenization (Th) versus depth for ZCQ-2.

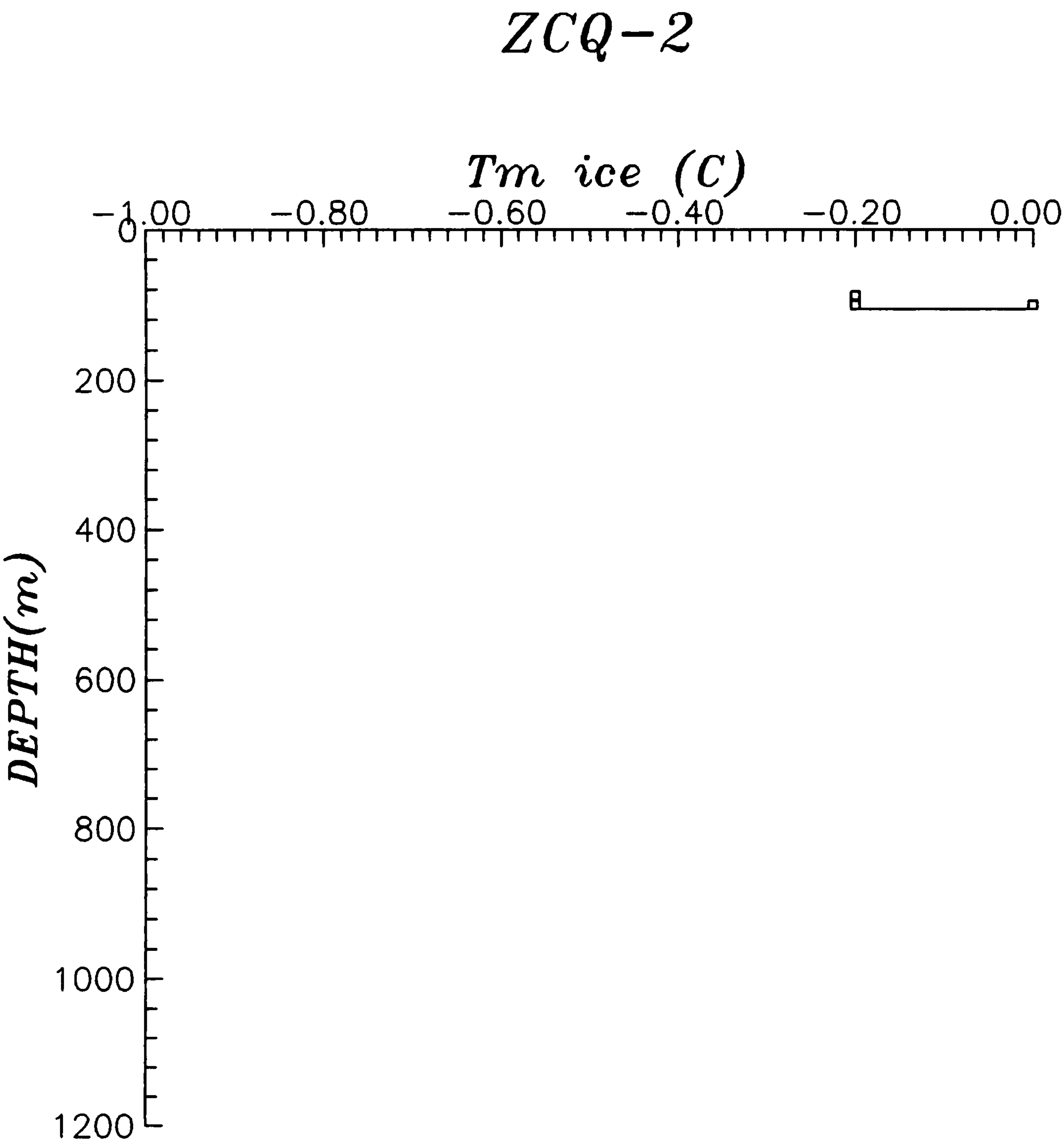


Fig. 18. Temperatures of ice-melting (Tm-ice) versus depth for ZCQ-2.

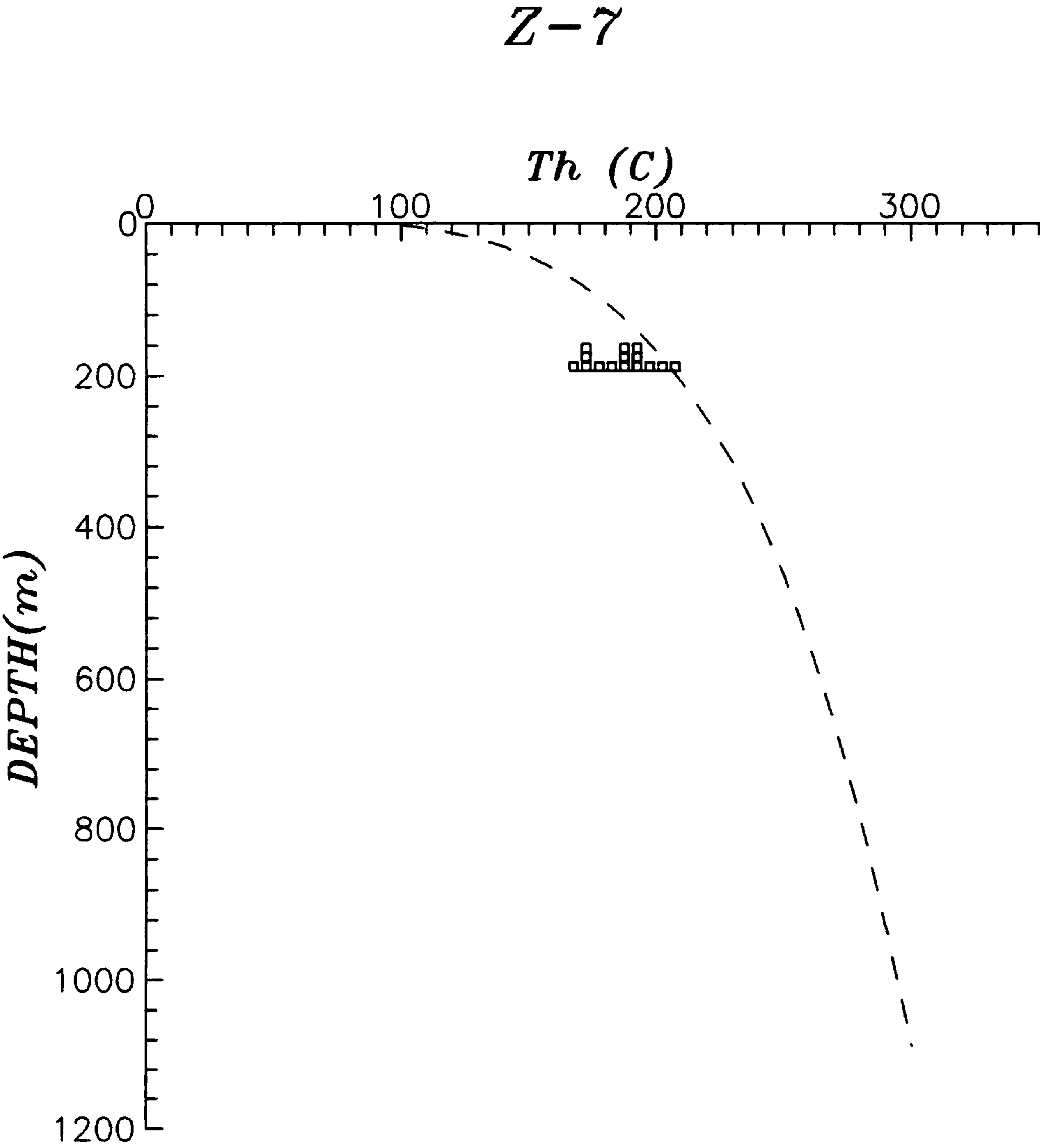


Fig. 19. Temperatures of homogenization (Th) versus depth for Z-7.

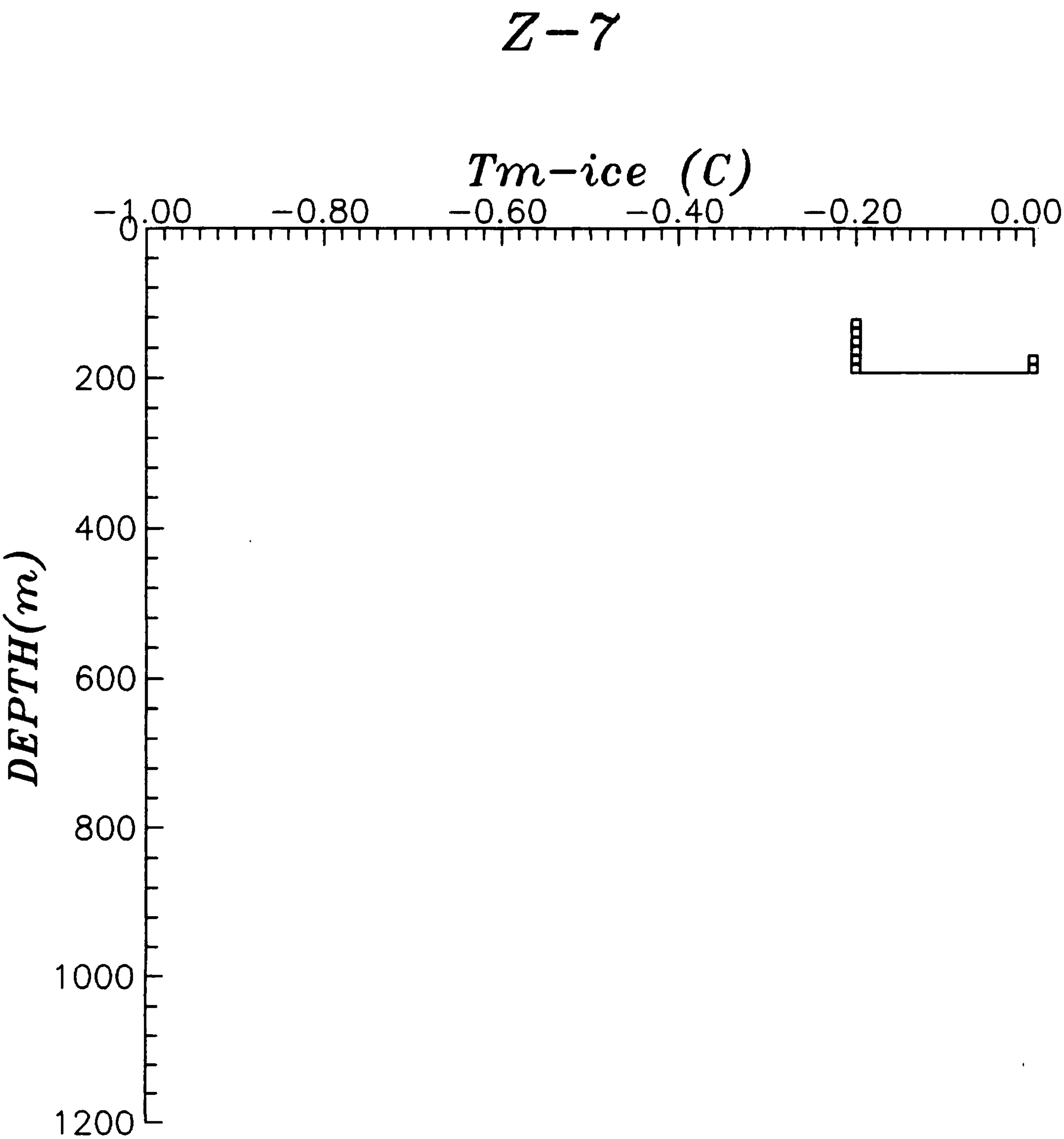


Fig. 20. Temperatures of ice-melting (Tm-ice) versus depth for Z-7.

been caused by a combination of local self-sealing and downward incursions of steam-heated waters.

The fluid inclusion and measured temperature curves are nearly identical in well ZCQ-3 (Fig. 7). The slight downward shift of fluid inclusion temperatures with respect to the boiling point curve in the upper 500 m suggests that the permeability in the shallow 500 m of ZCQ-3 may be low, or that fluid in the upper portions of the well boiled at lower temperatures due to high gas contents. There appears to be a temperature reversal at the base of ZCQ-3 that is apparent in both the fluid inclusion data and in the measured temperatures. This reversal is likely due to a downward incursion of cooler steam-heated waters.

The fluid inclusion temperatures and downhole measured temperatures in well ZCQ-1 increase with depth until approximately 700 m (Fig. 13). Then both the homogenization temperatures and measured temperatures decrease slightly and stay relatively constant to depths of approximately 1100 to 1200 m. At the bottom of the hole, both data sets indicate that the well heats up again. This observation implies that there is a downward incursion of cooler waters that is intersecting ZCQ-1 at depths of approximately 700 to 1100 m.

Estimation of Salinities and Gas Contents

Consistent variations in the apparent salinities were found in all of the wells studied. Samples from the upper 200 m recorded ice-melting temperatures that ranged from 0.0° to -0.2°C. Underlying this zone is a 200 to 500 m thick interval where most of the samples contained Type II inclusions with clathrate-melting temperatures that ranged from 0.0° to +0.6°C. Beneath this interval inclusions typically displayed large ranges of ice-melting temperatures (0.0° to -1.6°C). Finally, in the deepest portions of the wells, the inclusions recorded ice-melting temperatures that ranged from 0.0° to -0.2°C. A few crystals from the intermediate interval with the large range of ice-melting temperatures in ZCQ-6 and -3 had relatively small ice-melting temperatures ranging from 0.0° to -0.4°C. As discussed below, these are more similar to the inclusions from the deeper portions of the wells. A summary of the distribution of temperatures of ice-melting and CO_2 clathrate-melting in Zunil I is shown in Figures 21 a and b.

The systematic differences in the ranges of ice-melting temperatures and the presence of Type II inclusions implies that there has been extensive gas flux through the reservoir. Inclusions can become gas-enriched by trapping gas that is released during boiling within the reservoir (Moore et al., 1989). Since CO_2 is typically the dominant non-condensable gas in geothermal reservoir fluids, it is likely that most of the gas flux was CO_2. At least 3.8 weight percent CO_2

Figure 21. Variations in ice-melting and CO_2 clathrate_melting temperatures from wells in Zunil I. a) Cross-section orientated approximately west to east; wells ZCQ-5, -3, -1. b) Cross-section orientated approximately southwest to northeast; wells ZCQ-6, -3, -4, -2. Abbreviations: Tm-ice = ice melting temperatures (Type I inclusions); Tm-clath = CO_2 clathrate melting temperatures (Type II inclusions); Th = Temperatures of homogenization.

–Tm-ice = 0.0° to $^{-}0.2^{\circ}$ C; Th < 200°C

–Tm-clath = $+0.1^{\circ}$ to $+0.6^{\circ}$ C

–Tm-ice = 0.0° to $^{-}1.6^{\circ}$ C

–Tm-ice = 0.0° to $^{-}0.4^{\circ}$ C; Th > 200°C

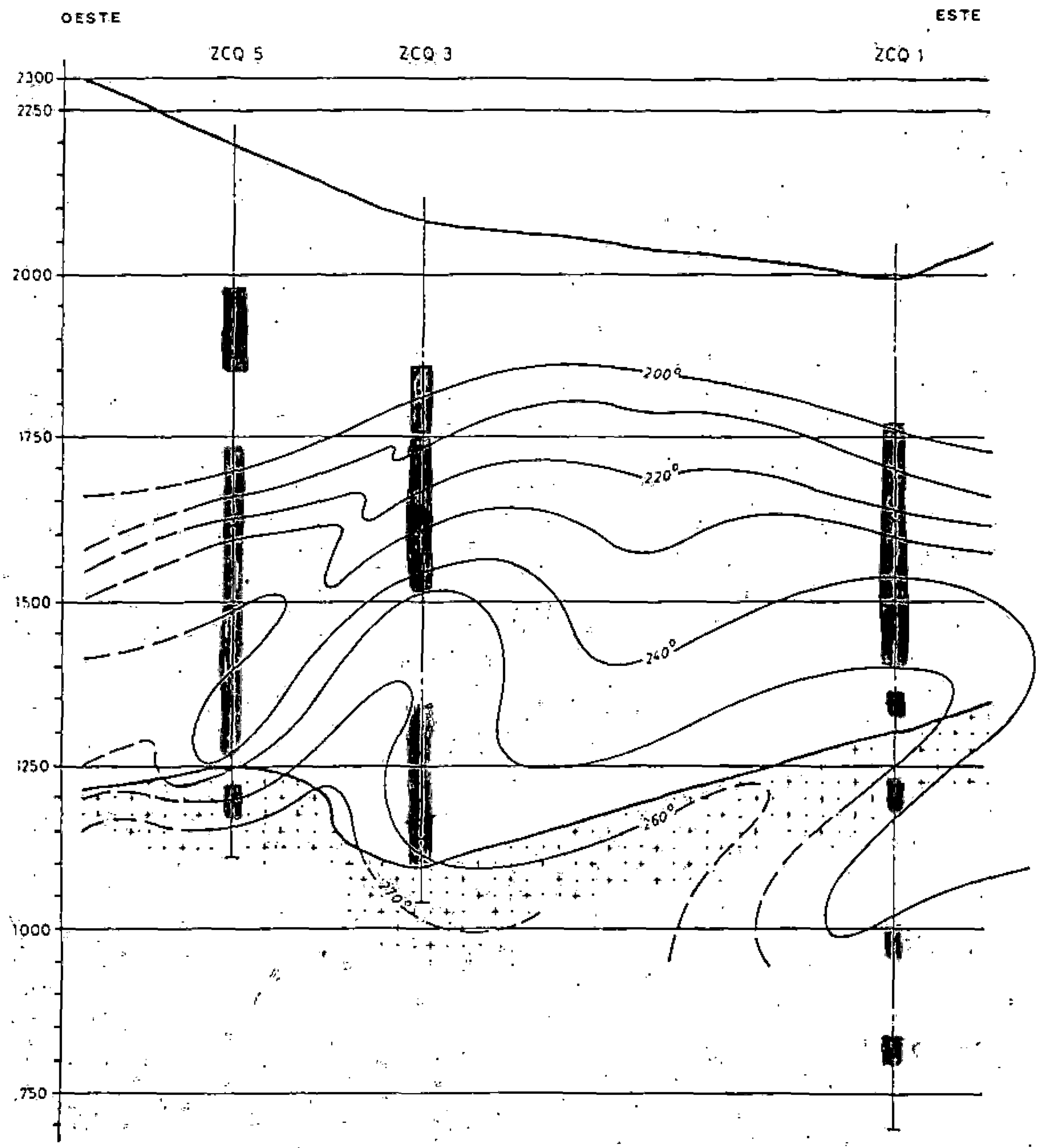


Figure 21 a.

SIMBOLOGIA

ISOTERMA

INFORMACION BASE: INFORME FINAL ELECTRO-CONSULT, 1982.

INSTITUTO NACIONAL DE ELECTRIFICACION INDE GUATEMALA C.A.	
PROYECTO GEOTERMICO ZUNIL 1	
ISOTERMAS EN LOS POZOS SECCION B-B	
CyM/MKF.	FIGURA: 3.3-18

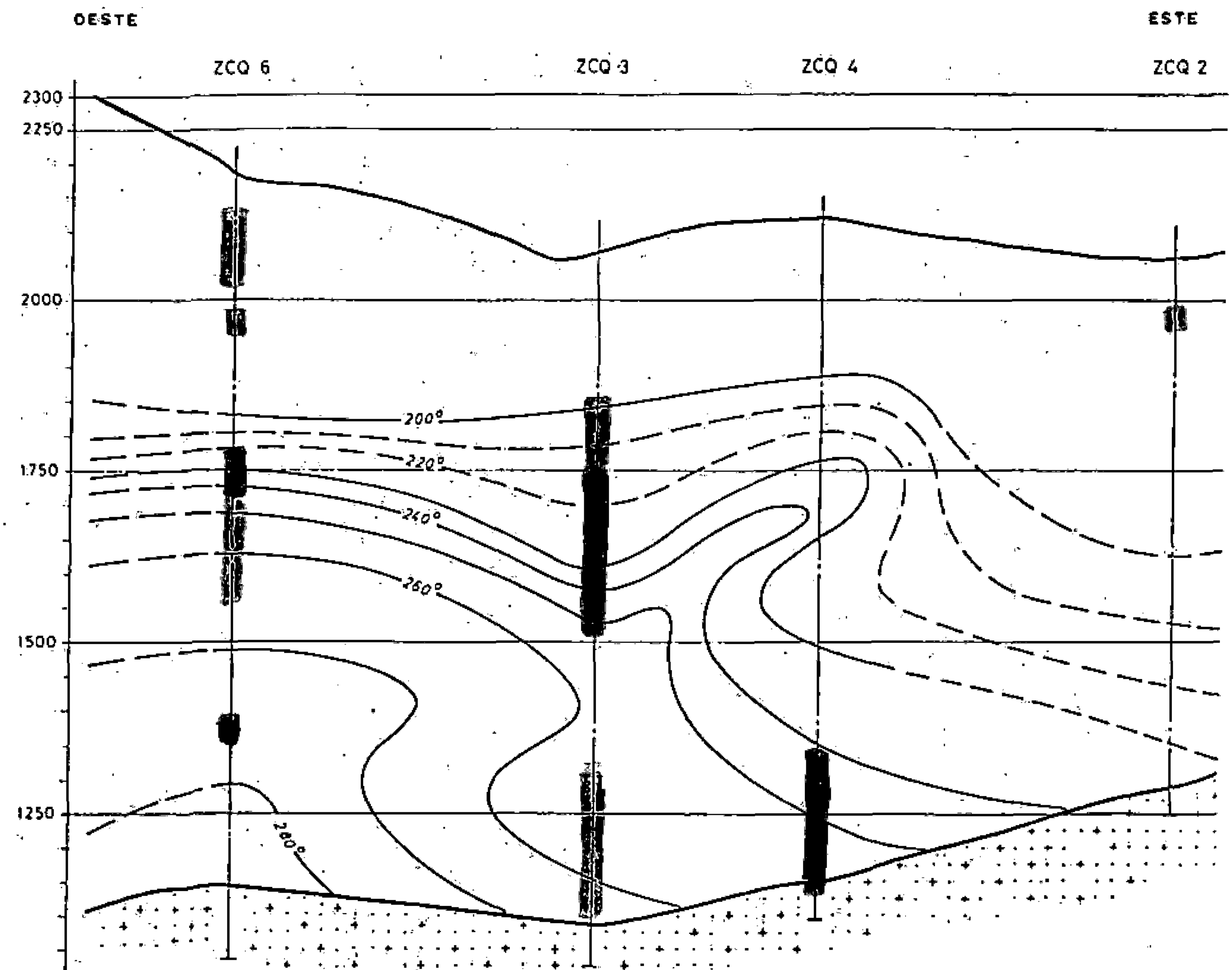


Figure 21 6

SIMBOLOGIA

ISOTERMA

INFORMACION BASE: INFORME FINAL, ELECTRO-CONSULT, 1982.

INSTITUTO NACIONAL DE ELECTRIFICACION
INDE GUATEMALA C.A.

PROYECTO GEOTERMICO ZUNIL I.

ISOTERMAS EN LOS POZOS

CyM-MKF.

FIGURA: 2.13

must have been present in the fluids in order for Type II inclusions to form. The large differences in ice-melting temperatures of the Type I inclusions that are found at intermediate depths in the reservoir also suggest large variations in their CO_2 contents. For example, an inclusion containing fluid with a salinity of 3500 ppm NaCl would have an ice-melting temperature of -0.2°C (Potter et al., 1978). The freezing point depression would be due entirely to the salts in the fluid. However, if the same inclusion contained one weight percent CO_2, the ice-melting temperature would be -0.6°C. In this case the freezing point depression would be caused by the combination of salts and CO_2. Thus, calculations based on the ice-melting temperatures of the fluid inclusions can yield information not only on the salinities of the fluids, but on their CO_2 contents as well.

The narrow range of ice-melting temperatures of inclusions from the upper 150 m indicates they have low salinities and low gas contents, as evidenced by the narrow range in ice-melting temperature and the lack of Type II inclusions. These inclusions can be differentiated from deeper fluids by their lower temperatures.

The Type II inclusions from depths of 200 to 500 m contain considerable CO_2 and have low salinities. Although the both the CO_2 contents and the salinity of the fluid determines the melting temperatures of the CO_2 clathrate, the contribution made by salinity cannot be determined in Type II inclusions unless the CO_2 occurs in both a liquid and vapor phase. None of the CO_2-enriched inclusions in Zunil I contained sufficient CO_2 to produce a liquid phase. However, crystals which contained the Type II inclusions typically contained a few low salinity Type I inclusions as well. The presence of these low salinity inclusions indicates that the salt content in the Type II inclusions is also low. Because of the low salinity, the CO_2 contents of the Type II inclusions can be calculated by combining the decomposition curve of CO_2 clathrate in pure water (Bozzo, et al., 1975), with Henry's law relationships and the homogenization temperatures of the inclusions (Moore et al., 1989). Using this approach, the calculated CO_2 contents of the Type II inclusions in Zunil I range from 3.8 to 4.3 weight percent.

The salinity and CO_2 contents of inclusions that displayed large variations in ice-melting temperatures can be calculated from the minimum and maximum ice-melting temperatures and the average homogenization temperatures of an individual crystal. For example, the inclusions from 890 m in ZCQ-3 have ice-melting temperatures that range from 0.0° to -1.1°C, and homogenization temperatures that average 270°C. Assuming that the variation in the ice-melting temperatures is due to gas, the maximum CO_2 content of these inclusions is calculated to be 2.79 weight percent, or 27,900 ppm. The salinity of these fluids can be calculated by using the average minimum freezing point depression of samples in this zone, which is -0.1°C. This corresponds to a salinity of 0.2 equivalent weight percent NaCl or 2000 ppm.

Fluid inclusions from the deepest samples in ZCQ-6, -5 and -1 are characterized by high homogenization temperatures and low freezing point depressions (0.0° to -0.2°C). This indicates that these fluids have a low salinity and also contain a low CO_2 content. These fluids appear to represent the production fluid which is found at similar depths. The production fluid is estimated to have a salinity of 3500 ppm, which corresponds to a freezing point depression of -0.2°C. This value is similar to the ice-melting temperatures that we measured in the deep samples from ZCQ-6, -5, and 1. A few similar inclusions that also appear to be related to the production fluid were found shallower depths in ZCQ-6 and -3. These inclusions have a slightly greater range of ice-melting temperatures (0.0° to -0.4°C). The greater range is likely due to a slightly higher CO_2 content.

Well ZCQ-4 is of particular interest since it is the only well where a core sample of the granodiorite could be obtained. There appears to be no variation between the salinities of inclusions in quartz veins from the granodiorite at 1015 m and inclusions in calcite veins from the shallower volcanics. This suggests that the geothermal system is not limited to the volcanic rocks, but exists in the granodiorite basement as well.

Conceptual model of the Reservoir

A conceptual model of the Zunil I geothermal system is shown in Figure 22 a and b. The main feature of this model is the compositional zonation of the reservoir. The reservoir can be divided into three distinct regions: a deep high temperature reservoir fluid; a region of steam-heated, CO_2-enriched waters that forms a cap over the geothermal system; and shallow, gas poor, steam-heated groundwaters.

The gas poor steam-heated groundwaters are characterized by moderate temperatures and low salinities. These shallow waters extend to a depth of approximately 150 m and typically have temperatures less than 200°C.

The region of CO_2-enriched steam-heated waters can be divided into two zones based on the amount of CO_2 present. In the upper portion, the fluids contain at least 3.8 weight percent CO_2 as indicated by the presence of Type II inclusions. The lower portion has insufficient CO_2 to form Type II inclusions. However, there is still significant CO_2 present in the fluids.

Figure 22. Conceptual model of the Zunil I geothermal field. a) Cross-section orientated approximately west to east; wells ZCQ-5, -3, -1. b) Cross-section orientated approximately southwest to northeast; wells ZCQ-6, -3, -4, -2. Arrows indicate upwelling and downwelling fluids.

The high CO_2 contents of inclusions could only have formed at pressures above hydrostatic since all of the inclusions were trapped as a single liquid phase. Thus, the fluids must have been trapped in zones of low permeability where gas pressures could have exceeded hydrostatic. Low permeabilities could have been developed locally by boiling and self-sealing of fractures.

The deep reservoir fluid is characterized by high temperatures, low salinities and low gas contents. Where the reservoir fluid has reached shallow depths, as in ZCQ-6 and 3, the fluids appear to be slightly gas-enriched relative to the deeper fluids. The reservoir fluids are located in both the granodiorite and the volcanics.

The CO_2-enriched fluids extend to greater depths in the eastern portion of Zunil I, and appear to form a "cap" over the system. The geometry of the CO_2-rich cap suggests that both upwelling of the deep reservoir fluid and downwelling of the cooler CO_2-enriched fluids is occurring. The upflow zones are represented by high temperature inclusions with a narrow range of freezing point depressions. These zones occur principally in ZCQ-6 and 3. However, fluid inclusion data shows that well ZCQ-4 was a major upwelling zone in the past. The main downwelling zones occur in the eastern portion of the field. The upwelling and downwelling suggested by the fluid inclusion data is also similar to flow patterns indicated by present day isotherms (Figure 22 a and b).

CONCLUSIONS

Fluid inclusions from nine wells in Zunil I have been studied to better characterize the reservoir and develop a fluid flow model. Microthermometric measurements indicate that the fluids have low salinities and contain variable but significant CO_2 contents. Fluids from the upper 150 m of the reservoir have homogenization temperatures less than 200°C and low gas contents. These low-temperature fluids overlie a region of the reservoir that is enriched in CO_2. The upper part of this region is characterized by CO_2 contents in excess of 3.8 weight percent. The low salinities and low to moderate temperatures of both the CO_2-enriched fluids and the overlying gas poor fluids indicate that they represent steam-heated groundwaters. These steam-heated waters overlie a deep high temperature gas poor fluid.

Zones of upwelling of the deeper fluids are represented by inclusions with low gas contents, low salinities and temperatures above 200°C. The distribution of these inclusions correspond closely with location of upwelling zones defined by downhole measured temperatures.

The steam-heated waters form a cap over the geothermal system that becomes progressively thicker to the east. The geometry of the cap suggests that the thermal fluids originate near the western edge of Zunil I. The thermal fluids are progressively diluted by downward incursions of CO_2-enriched steam-heated waters as they move laterally away from the upwelling center.

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APPENDIX

Key Abbreviations:

Th = temperatures of homogenization
Tm = temperatures of melting
    Tm < or = 0.0°C ice-melting temperature
    Tm > 0.0°C CO_2 clathrate-melting temperature
NaCl wt % = Equivalent weight percent sodium chloride
p = primary inclusions
s = secondary inclusions
? = origin of inclusion unknown
Cc = Calcite
Qtz = Quartz
Ep = Epidote

ZCQ-6

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
40	196	-0.1	0.2	0.87	s	Qtz
40	197	-0.1	0.2	0.87	s	Qtz
40	84				p	Qtz
40	196	-0.1	0.2	0.87	s	Qtz
40					?p	Qtz
40	197	-0.2	0.4	0.87	s	Qtz
100	206	0.0	0.0	0.86	s	Cc
100	141				?	Qtz
100	193	0.0	0.0	0.88	s	Cc
100	216				s	Cc
100	215	0.0	0.0	0.85	s	Cc
100	198	0.0	0.0	0.87	s	Cc
100	184				s	Cc
100	175	0.0	0.0	0.90	s	Cc
100	183				s	Cc
100	182	0.0	0.0	0.89	s	Cc
100	190	0.0	0.0	0.88	s	Cc
100	152	0.0	0.0	0.92	?	Qtz
125	139	-0.1	0.2	0.93	s	Cc
125	135	-0.1	0.2	0.94	s	Cc
125	150				s	Cc
125	151	0.0	0.0	0.92	s	Cc
125	141	-0.1	0.2	0.93	s	Cc
125	156	0.0	0.0	0.92	s	Cc
125	156	-0.1	0.2	0.92	s	Cc
125	147				s	Cc
125	179	-0.1	0.2	0.89	s	Cc
125		-0.1	0.2		s	Cc
125	157				s	Cc
190	140				?	Cc
200	219	+0.1			s?	Qtz
200	227	0.0	0.0	0.83	p	Qtz
200	143				p	Qtz
200	208	0.0	0.0	0.86	p	Qtz
200		+0.4			p	Qtz
200	144	+0.6			p	Qtz
200		+0.4			p	Qtz
200	160	0.0	0.0	0.91	p	Qtz
200		+0.4			p	Qtz
200	198				p	Qtz
200	198				p	Qtz
200	195	0.0	0.0	0.87	p	Qtz
200	203				p	Qtz
200	212	0.0	0.0	0.85	p	Qtz
200		+0.1			s?	Qtz
200	217				p	Qtz
200	197	+0.3			s	Qtz
200		+0.4			p	Qtz
200	215				p	Qtz

ZCQ-6

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
200	160	0.0	0.0	0.91	p	Qtz
200	246	+0.6			p	Qtz
400		-0.4	0.7		s	Cc
400		0.0	0.0		s	Cc
400	147				s	Cc
400		-0.3	0.5		s	Cc
400	157	-0.3	0.5	0.92	s	Cc
400	156	-0.3	0.5	0.92	s	Cc
400	200	-0.3	0.5	0.87	s	Cc
400	164	-0.3	0.5	0.91	s	Cc
400		-0.3	0.5		s	Cc
400	156	-0.3	0.5	0.92	s	Cc
400		-0.1	0.2		s	Cc
400		-0.4	0.7		s	Cc
400		-0.4	0.7		s	Cc
400	152	-0.3	0.5	0.92	s	Cc
400	150	-0.4	0.7	0.93	s	Cc
400	174	-0.4	0.7	0.90	s	Cc
400	171	-0.3	0.5	0.90	s	Cc
400	155	-0.3	0.5	0.92	s	Cc
445	209	-0.3	0.5	0.86	p	Cc
445	218	-0.4	0.7	0.85	p	Cc
445	216	-0.3	0.5	0.85	p	Cc
445	215	-0.3	0.5	0.85	p	Cc
445	209	-0.3	0.5	0.86	p	Cc
540	242	-0.6	1.0	0.82	p	Cc
540	252	-0.4	0.7	0.80	s	Cc
540	254	-0.1	0.2	0.79	?p	Cc
540	146	-0.5	0.9	0.93	p	Cc
540	252	-0.5	0.9	0.80	p	Cc
540		-0.7	1.2		p	Cc
540	232	-0.3	0.5	0.83	p	Cc
540	248	-0.6	1.0	0.81	p	Cc
540	249				p	Cc
540	251	-0.6	1.0	0.80	?p	Cc
540	240	-0.4	0.7	0.82	s	Cc
540	239	-0.4	0.7	0.82	?p	Cc
540	231	-0.1	0.2	0.82	s	Cc
540	263	-0.1	0.2	0.77	?p	Cc
540	252				p	Cc
540	263	-0.5	0.9	0.78	p	Cc
540	247	-0.1	0.2	0.80	p	Cc
540	246	-0.6	1.0	0.81	p	Cc
540	252	-0.4	0.7	0.80	p	Cc
540	246	-0.1	0.2	0.80	p	Cc
600	163	-0.2	0.4	0.91	s	Cc
600		-0.2	0.4		?	Cc
600	189	-0.1	0.2	0.88	?	Cc
600	222	-0.3	0.5	0.84	p	Cc

ZCQ-6

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
600	202				?	Cc
600		-0.4	0.7		?	Cc
600	213	-0.2	0.4	0.85	s	Cc
600	228				?	Cc
600	212	-0.5	0.9	0.86	s	Cc
600	193	-0.1	0.2	0.88	?	Cc
790	245	-0.2	0.4	0.80	s	Cc
790	227	-0.2	0.4	0.83	s	Cc
790	245	-0.2	0.4	0.80	s	Cc
790	219	-0.2	0.4	0.84	s	Cc
790	245	-0.2	0.4	0.80	?	Cc
790	219	-0.2	0.4	0.84	s	Cc

ZCQ-5

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
200	204	-0.1	0.2	0.86	s	Cc
200	206	-0.4	0.7	0.86	s	Cc
200	152	-0.3	0.5	0.92	s	Cc
200	190				s	Cc
200	188				s	Cc
200	206	-0.3	0.5	0.86	s	Cc
200	151				s	Cc
230	228	+0.3			s	Qtz
230	209	+0.3			p	Qtz
230	216	+0.2			?	Qtz
230	225	+0.1			s	Qtz
230	241	+0.2			?	Qtz
260	217	-0.1	0.2	0.85	p	Cc with Ep
260	215	-0.2	0.4	0.85	p	Cc with Ep
260	213	-0.2	0.4	0.85	p	Cc with Ep
260	216				p	Cc with Ep
260	213	-0.2	0.4	0.85	p	Cc with Ep
260	227	-0.1	0.2	0.83	p	Cc with Ep
260	226	-0.2	0.4	0.83	p	Cc with Ep
260	221				p	Cc with Ep
300	204	0.0	0.0	0.86	s	Qtz
300	204	+0.3			s	Qtz
300	204	0.0	0.0	0.86	s	Qtz
300	206				?	Qtz
300	196	-0.4	0.7	0.88	?	Qtz
300	198	-0.5	0.9	0.88	?	Qtz
300		-0.2	0.4		p	Qtz
300	198				?	Qtz
300	204	+0.3			s	Qtz
300	204	+0.3			s	Qtz
300	157				?	Qtz
300	195				?	Qtz
300	211	+0.3			s	Qtz
300	196				p	Qtz
300	204	+0.3			s	Qtz
445	213	0.0	0.0	0.85	s	Qtz
445	211	0.0	0.0	0.85	s	Qtz
445	210	0.0	0.0	0.85	s	Qtz
445	211	0.0	0.0	0.85	s	Qtz
445	211	0.0	0.0	0.85	s	Qtz
445	242	-0.1	0.2	0.81	s	Qtz
445	210	0.0	0.0	0.85	s	Qtz
445	229	-0.3	0.5	0.83	?	Qtz
445		0.0	0.0		s	Qtz
445	240	0.0	0.0	0.81	?	Qtz
445	249	0.0	0.0	0.79	s	Qtz
445	236	-0.1	0.2	0.82	s	Qtz
445	211	0.0	0.0	0.85	s	Qtz
445	265	0.0	0.0	0.77	?	Qtz

ZCQ-5

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
445	243	0.0	0.0	0.80	s	Qtz
550	217	-0.4	0.7	0.85	s	Cc
550	223	-0.3	0.5	0.84	s	Cc
550		-0.5	0.9		s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550	237	-0.5	0.9	0.82	s	Cc
550	216	-0.5	0.9	0.85	s	Cc
550	226	-0.4	0.7	0.84	s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550	226				s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550	216	-0.4	0.7	0.85	s	Cc
550	224	-0.3	0.5	0.84	s	Cc
550	237	-0.5	0.9	0.82	s	Cc
550	217	-0.4	0.7	0.85	s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550	217	-0.3	0.5	0.85	s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550	226				s	Cc
550	236	-0.7	1.2	0.83	s	Cc
550		-0.5	0.9		s	Cc
550	216	-0.5	0.9	0.85	s	Cc
550	229				s	Cc
550	216	-0.4	0.7	0.85	s	Cc
550	225	-0.4	0.7	0.84	s	Cc
900	282	-0.2	0.4	0.74	?	Cc
900	274	-0.2	0.4	0.76	?	Cc
900	258	0.0	0.0	0.78	s	Cc
900	267	-0.6	1.0	0.77	s	Cc
900	260	0.0	0.0	0.78	s	Cc
900	276	-0.1	0.2	0.75	s	Cc
900	273	-0.1	0.2	0.75	s	Cc
900	277	-0.3	0.5	0.75	s	Cc
900	274	-0.4	0.7	0.76	s	Cc
900	258	0.0	0.0	0.78	s	Cc
900	279	-0.5	0.9	0.75	s	Cc
900	268	-0.6	1.0	0.77	?	Cc
900		-0.7	1.2		s	Cc
900	258	0.0	0.0	0.78	s	Cc
900	260	0.0	0.0	0.78	s	Cc
900	278				s	Cc
940	276				p	Cc
940	275				p	Cc
940	272				p	Cc
940	262	0.0	0.0	0.77	p	Cc
940	262	-0.1	0.2	0.78	p	Cc
940		-0.1	0.2		p	Cc
940	264	0.0	0.0	0.77	p	Cc
940	268	-0.1	0.2	0.76	?	Cc

ZCQ-5

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
940	267	0.0	0.0	0.76	?	Cc
940	258	-0.1	0.2	0.78	p	Cc
940	265	-0.1	0.2	0.77	p	Cc
940	273	0.0	0.0	0.75	?p	Cc
940	276				?	Cc
940	266	0.0	0.0	0.77	?	Cc
940	268	-0.1	0.2	0.76	p	Cc
940	263	0.0	0.0	0.77	p	Cc

ZCQ-3

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
210	190	+0.3			p	Cc
210	183	+0.3			p	Cc
210	188	+0.3			p	Cc
210	152	+0.3			p	Cc
210	181	+0.3			p	Cc
210	199				p	Cc
210	188				p	Cc
210	169	+0.3			p	Cc
210	177				p	Cc
245		0.0	0.0		s	Cc
245		0.0	0.0		s	Cc
245		0.0	0.0		s	Cc
310		+0.3			p?	Cc
335	198	-0.2	0.4	0.87	p?	Cc
400	195	0.0	0.0	0.87	p	Cc
400	172	0.0	0.0	0.90	p	Cc
400	195	0.0	0.0	0.87	p	Cc
400	205				p	Cc
400	205				p	Cc
400	192				p	Cc
400	181	0.0	0.0	0.89	p	Cc
400	201	0.0	0.0	0.87	p?	Cc
400	164	0.0	0.0	0.91	p	Cc
400	194	0.0	0.0	0.87	p	Cc
400	185	0.0	0.0	0.89	p	Cc
400	160	0.0	0.0	0.91	s	Cc
400	214	+0.1			p	Cc
400	192	+0.1			p	Cc
400	199	-0.1	0.2	0.87	s	Cc
400	206	-0.1	0.2	0.86	p	Cc
400	199	0.0	0.0	0.87	p	Cc
400	209	0.0	0.0	0.85	p	Cc
550	253	-0.1	0.2	0.79	s	Cc
550	260	0.0	0.0	0.78	?	Cc
550	233	-0.2	0.4	0.82	s	Qtz
550	240	-0.1	0.2	0.81	s	Qtz
550	222				?	Cc
550	216	0.0	0.0	0.84	?	Cc
550	220				?	Cc
550	249	-0.1	0.2	0.80	s	Qtz
550	259	-0.1	0.2	0.78	p	Cc
550	264	0.0	0.0	0.77	p	Cc
550	244	-0.1	0.2	0.80	s	Qtz
550	236	-0.1	0.2	0.82	s	Qtz
550		0.0	0.0		s	Cc
550	227	-0.4	0.7	0.84	s	Qtz
550	237	-0.4	0.7	0.82	s	Qtz
550	246	-0.1	0.2	0.80	s	Qtz
550	249	-0.4	0.7	0.80	s	Qtz

ZCQ-3

DEPTH(m)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
550	254	-0.1	0.2	0.79	p	Cc
550	223	0.0	0.0	0.84	s	Qtz
550	237	-0.4	0.7	0.82	s	Qtz
750	278	-0.2	0.4	0.75	s	Cc
750	291	-0.1	0.2	0.72	s	Cc
750	256				?	Cc
750	277	-0.2	0.4	0.75	s	Cc
750	263	-0.1	0.2	0.77	s	Cc
750	299	-0.2	0.4	0.71	s	Cc
750	300	-0.3	0.5	0.71	s	Cc
750	300	-0.5	0.9	0.71	s	Cc
750	270	-0.2	0.4	0.76	s	Cc
750	291	-0.2	0.4	0.72	s	Cc
750	274	-0.2	0.4	0.76	s	Cc
750	248				s	Cc
890		-0.7	1.2		s	Cc
890	271	-0.7	1.2	0.77	s	Cc
890	273	-0.1	0.2	0.75	s	Cc
890	290				s	Cc
890	271	0.0	0.0	0.76	s	Cc
890		-0.6	1.0		s	Cc
890	260	-0.2	0.4	0.78	s	Cc
890	263	-0.1	0.2	0.77	s	Cc
890		-0.9	1.6		s	Cc
890	272	-1.1	1.9	0.78	s	Cc
930	256	-0.5	0.9	0.79	p?	Cc
930	254	-0.1	0.2	0.79	p?	Cc
930	262	-0.5	0.9	0.78	p?	Cc

ZUNIL Z-11

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
89	109				s	Cc
210	145	+0.3			s	Cc
210	174	+0.6			?	Cc
210	168				?	Cc
210	174	+0.3			s	Cc
210	158	+0.4			s	Cc
210	158				s	Cc
210	157	+0.4			s	Cc
210	158				s	Cc
210	169				?	Cc
210	174	+0.6			?	Cc
368	211	-0.3	0.5	0.86	p?	Cc
368	210	-0.3	0.5	0.86	p?	Cc
483	245	-0.1	0.2	0.80	s	Cc
483	242	-0.1	0.2	0.81	s	Cc
483	245				s	Cc
483	254	-0.1	0.2	0.79	s	Cc
483	242	-0.1	0.2	0.81	s	Cc
483	259	-0.1	0.2	0.78	s	Cc
483	245	-0.2	0.4	0.80	s	Cc
483	249				s	Cc
505	244	-0.2	0.4	0.81	s	Cc
505	283				s	Cc
505	235	-0.1	0.2	0.82	s	Cc
505	262	-0.3	0.5	0.78	s	Cc
505	283	-0.2	0.4	0.74	s	Cc
505	287	-0.3	0.5	0.73	s	Cc
505	259	-0.2	0.4	0.78	s	Cc
505	262	-0.2	0.4	0.78	s	Cc
505	231				s	Cc
571	242	-0.1	0.2	0.81	s	Cc
571	272	0.0	0.0	0.75	s	Cc
571	282	0.0	0.0	0.74	s	Cc
571	272	0.0	0.0	0.75	s	Cc
571	241	-0.1	0.2	0.81	s	Cc
571	275	-0.4	0.7	0.76	s	Cc
571	241	-0.1	0.2	0.81	s	Cc
571	263	0.0	0.0	0.77	s	Cc
571	242	0.0	0.0	0.81	s	Cc
571		0.0	0.0		s	Cc
571	241	0.0	0.0	0.81	s	Cc
571		-0.1	0.2		s	Cc
571	242	0.0	0.0	0.81	s	Cc
571	270	-0.4	0.7	0.77	s	Cc
571	241	0.0	0.0	0.81	s	Cc
571	242	0.0	0.0	0.81	s	Cc
571	244	0.0	0.0	0.80	s	Cc
571	284	0.0	0.0	0.73	s	Cc
571		-0.3	0.5		s	Cc

ZUNIL Z-11

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
571	220	0.0	0.0	0.84	s	Cc
571	270	0.0	0.0	0.76	s	Cc
571	270	0.0	0.0	0.76	s	Cc

ZCQ-4

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
775	269	-0.1	0.2	0.76	p?	Cc
775	288	-0.3	0.5	0.73	s	Cc w/ epid.
775	291	-0.3	0.5	0.73	s	Cc w/ epid.
775	261	-0.3	0.5	0.78	s	Cc w/ epid.
775	283	-0.3	0.5	0.74	s	Cc w/ epid.
775	252	-0.4	0.7	0.80	s	Cc w/ epid.
775	288	-0.3	0.5	0.73	s	Cc w/ epid.
775	260	-0.4	0.7	0.78	s	Cc w/ epid.
775	284	-0.3	0.5	0.74	s	Cc w/ epid.
775	264	0.0	0.0	0.77	p?	Cc
775	268	-0.3	0.5	0.77	p?	Cc
775	260	-0.4	0.7	0.78	s	Cc w/ epid.
775	293				s	Cc w/ epid.
775	273	-0.3	0.5	0.76	s	Cc w/ epid.
775	264	-0.3	0.5	0.77	p?	Cc
1015	274	-0.4	0.7	0.76	p	Qtz
1015	282	-0.3	0.5	0.74	p	Qtz
1015	277	-0.4	0.7	0.75	p	Qtz
1015	292	-0.3	0.5	0.72	p	Qtz
1015	342				p	Qtz
1015	292	-0.3	0.5	0.72	p	Qtz
1015	293	-0.3	0.5	0.72	p	Qtz
1015	292	-0.3	0.5	0.72	p	Qtz
1015	326				p	Qtz
1015	282	-0.3	0.5	0.74	p	Qtz
1015	321	-0.4	0.7	0.67	p	Qtz
1015	293	-0.3	0.5	0.72	p	Qtz
1015	279	-0.4	0.7	0.75	p	Qtz

ZCQ-1

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
250	184				p	Cc
250	205	+0.6			p	Cc
250	195				s	Cc
250	233				s	Cc
250	227				?	Cc
250	215				p	Cc
250	198	+0.2			p	Cc
455	188	0.0	0.0	0.88	s	Cc
455	177				s	Cc
455	186	0.0	0.0	0.88	s	Cc
455	196	0.0	0.0	0.87	s	Cc
455	198	0.0	0.0	0.87	s	Cc
455	209	0.0	0.0	0.86	s	Cc
455	213	0.0	0.0	0.85	s	Cc
455	209	0.0	0.0	0.86	s	Cc
455	210	0.0	0.0	0.85	s	Cc
455	186	0.0	0.0	0.88	s	Cc
455	140				s	Cc
455	210	0.0	0.0	0.85	s	Cc
500	191	0.0	0.0	0.88	s	Cc
500	216	0.0	0.0	0.85	s	Cc
500	221	+0.3			s	Cc
500	204	+0.3			s	Cc
500	195				s	Cc
500	224	0.0	0.0	0.83	s	Cc
500	226	0.0	0.0	0.83	s	Cc
500	185	+0.3			s	Cc
500	231	+0.3			s	Cc
500	211	0.0	0.0	0.85	s	Cc
535	196	0.0	0.0	0.87	s	Cc
535	205	0.0	0.0	0.86	s	Cc
535	224	0.0	0.0	0.83	s	Cc
535	212	0.0	0.0	0.85	s	Cc
535	207	0.0	0.0	0.86	s	Cc
535	221				s	Cc
535	203	0.0	0.0	0.86	s	Cc
535	182	0.0	0.0	0.89	s	Cc
535	208	0.0	0.0	0.86	s	Cc
535	206	0.0	0.0	0.86	s	Cc
535	209				s	Cc
535	145	-0.1	0.2	0.93	s	Cc
535	212	0.0	0.0	0.85	s	Cc
585	218	+0.3			s	Cc
585	229	+0.3			s	Cc
585	204	+0.3			s	Cc
655	244	0.0	0.0	0.80	s	Cc
655	229				s	Cc
655	235	-0.2	0.4	0.82	s	Cc
655	248	-0.2	0.4	0.80	s	Cc

ZCQ-1

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
655	246	-0.1	0.2	0.80	s	Cc
655	248	-0.2	0.4	0.80	s	Cc
795	178	+0.5			s	Cc
795	200				s	Cc
795	200	+0.5			s	Cc
795	223	+0.5			s	Cc
795	243	+0.1			s	Cc
795	185	+0.5			s	Cc
795		+0.1			s	Cc
795	205	+0.1			s	Cc
795		+0.5			s	Cc
795	244	+0.5			s	Cc
795	225	+0.4			s	Cc
795		+0.3			s	Cc
795		+0.1			s	Cc
1020		-1.6	2.7		s	Cc
1020		-1.6	2.7		s	Cc
1020		-1.6	2.7		s	Cc
1020		-1.6	2.7		s	Cc
1020		-0.2	0.4		s	Cc
1170	221	0.0	0.0	0.84	p	Cc
1170	221				p	Cc
1170	195				p	Cc
1170	227	-0.1	0.2	0.83	p	Cc
1170	218	0.0	0.0	0.84	p	Cc
1170	235	-0.1	0.2	0.82	p	Cc
1170	200	0.0	0.0	0.87	p	Cc
1220	227	-0.2	0.4	0.83	s	Cc
1220	230				s	Cc
1220	237	0.0	0.0	0.81	s	Cc
1220	215				s	Cc
1220	233	-0.2	0.4	0.82	s	Cc
1220	235	-0.1	0.2	0.82	s	Cc
1220	196	0.0	0.0	0.87	s	Cc
1220	213	-0.1	0.2	0.85	s	Cc
1220	237	0.0	0.0	0.81	s	Cc
1220	208	0.0	0.0	0.86	s	Cc
1220	235	0.0	0.0	0.82	s	Cc
1220	196	0.0	0.0	0.87	s	Cc
1220	241	-0.2	0.4	0.81	s	Cc
1220	234	0.0	0.0	0.82	s	Cc

ZUNIL Z-2

DEPTH(M)	(Th)	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
524	234	0.0	0.0	0.82	?	Cc
524	203	-0.1	0.2	0.86	s	Cc
524	205	-0.3	0.5	0.86	?	Cc
524	223	-0.1	0.2	0.84	s	Cc
524	208	0.0	0.0	0.86	s	Cc
524	228	-0.2	0.4	0.83	s	Cc
524	207	-0.1	0.2	0.86	s	Cc
524	242	-0.1	0.2	0.81	s	Cc
524	204	-0.2	0.4	0.86	s	Cc
524	225	-0.1	0.2	0.83	s	Cc
524	197	0.0	0.0	0.87	s	Cc
524	225	0.0	0.0	0.83	?	Cc
524	228	-0.1	0.2	0.83	s	Cc
524	231	-0.1	0.2	0.82	s	Cc
524	182	0.0	0.0	0.89	s	Cc
524	214	-0.3	0.5	0.85	s	Cc
524	198				s	Cc
524	200	0.0	0.0	0.87	s	Cc
524	239				s	Cc
524	241	0.0	0.0	0.81	s	Cc
524	177	-0.1	0.2	0.90	s	Cc
633	216	-0.4	0.7	0.85	s	Cc
633	256	-0.1	0.2	0.79	?	Cc
633	225	-0.2	0.4	0.84	s	Cc
633	252				?	Cc
633	243	-0.3	0.5	0.81	s	Cc
633	222	-0.1	0.2	0.84	s	Cc
633	244	0.0	0.0	0.80	?	Cc
633	227	-0.1	0.2	0.83	s	Cc
633	218	-0.3	0.5	0.85	s	Cc
633	216	-0.4	0.7	0.85	s	Cc
633	211	-0.3	0.5	0.86	?	Cc
633	233	-0.4	0.7	0.83	s	Cc
633	226	-0.1	0.2	0.83	s	Cc

ZCQ-2

WELL/DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
100	138				s	Qtz
100	132	-0.2	0.4	0.94	s	Qtz
100	147	-0.2	0.4	0.93	s	Qtz
100	134				s	Qtz
100	134				s	Qtz
100	138				s	Qtz
100	132	0.0	0.0	0.94	s	Qtz

ZUNIL Z-7

DEPTH(M)	Th	Tm	NaCl wt%	Density (g/cc)	prim.(p) or sec.(s)	mineral
188	165				s	Cc
188	185	-0.2	0.4	0.89	s	Cc
188	201	-0.2	0.4	0.87	s	Cc
188	182				s	Cc
188	173				s	Cc
188	171				s	Cc
188	199				s	Cc
188	192	-0.2	0.4	0.88	s	Cc
188	194	0.0	0.0	0.87	s	Cc
188	171	0.0	0.0	0.90	s	Cc
188	177	-0.2	0.4	0.90	s	Cc
188	209				s	Cc
188	190				s	Cc
188	188	-0.2	0.4	0.88	s	Cc
188	189	-0.2	0.4	0.88	s	Cc

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PETROLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF THE ZUNIL GEOTHERMAL SYSTEM

By

Joseph N. Moore
Michael C. Adams
Michele M. Lemieux
Susan J. Lutz

II. STRATIGRAPHY AND HYDROTHERMAL ALTERATION

June 1989

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ABSTRACT

The secondary minerals occurring in rock samples from the production and thermal gradient wells at Zunil I are typical of many high-temperature geothermal resources. Hydrothermal alteration and veining increases in intensity with depth. Alteration in the upper parts of the wells is characterized by assemblages containing smectite. At intermediate depths, the characteristic clay is interlayered illite-smectite. With the exception of ZCQ-6, illite is the dominant sheet silicate in the lower portions of the production wells. The persistence of interlayered illite-smectite to the base of ZCQ-6 where temperatures exceed 260°C, suggests that the reservoir rocks in the vicinity of this well are undergoing heating.

Permeabilities within the reservoir are fracture controlled. Veins of epidote and quartz formed by upwelling fluids are most abundant in the lower portions of ZCQ-3, 5, and 6. The permeabilities in these wells appear to be associated with steeply dipping fault zones.

Boiling has occurred throughout the reservoir. CO_2 released by the boiling fluids has dissolved into the overlying groundwaters, producing a steam-heated cap over the thermal system. The increases in thickness of this cap from west to east, the recent heating in the vicinity of ZCQ-6, and the abundance of high-temperature veins in ZCQ-3, 5, and 6 implies that the main upwelling center is located near the northwestern corner of Zunil I.

INTRODUCTION

Detailed geologic models of geothermal systems are needed to site exploration and development wells. Such models must provide information on the size, geometry and temperature of the resource, the location of permeable zones and the geologic factors controlling their distribution, and the composition of the thermal fluids. The secondary minerals occurring in drill chips and core are an important source of information since their distributions are strongly dependant on the physical and chemical conditions within the reservoir. Consequently, petrologic studies have proven to be an essential part of most exploration and development programs.

In this paper we document the results of petrographic and mineralogic studies of core and cuttings samples from production wells ZCQ-1, 3, 4, 5, and 6, and thermal gradient wells Z-2 and 11 (Figure 1). The data are used to better characterize the size and shape of the geothermal reservoir and the geologic controls on reservoir permeability at Zunil I.

Analytical Methods and Procedures

Mineral assemblages in approximately 100 samples were studied using petrographic and X-ray diffraction techniques. Thin sections were prepared of each of the major lithologies encountered in the wells. Because of the importance of fracture permeability at Zunil, particular emphasis was placed on samples containing veins. Mineral identifications and abundances in 25 samples were confirmed by X-ray diffraction analysis. Bulk rock samples were prepared for analysis by grinding in acetone to <325 mesh. The clay minerals (less than 5 μ fraction) were separated from the bulk samples by sonic disaggregation in deionized water, Stokes's law settling and centrifugation. The resulting slurries were smeared on glass slides and irradiated at after each of the following processes: air drying, vapor glycolation at 60°C for 24 hours, heating to 250°C for 1 hour, and heating to 550°C for one hour. Approximate weight percentages were determined by referring to appropriate calibration curves prepared using standard phases mixed in different proportions.

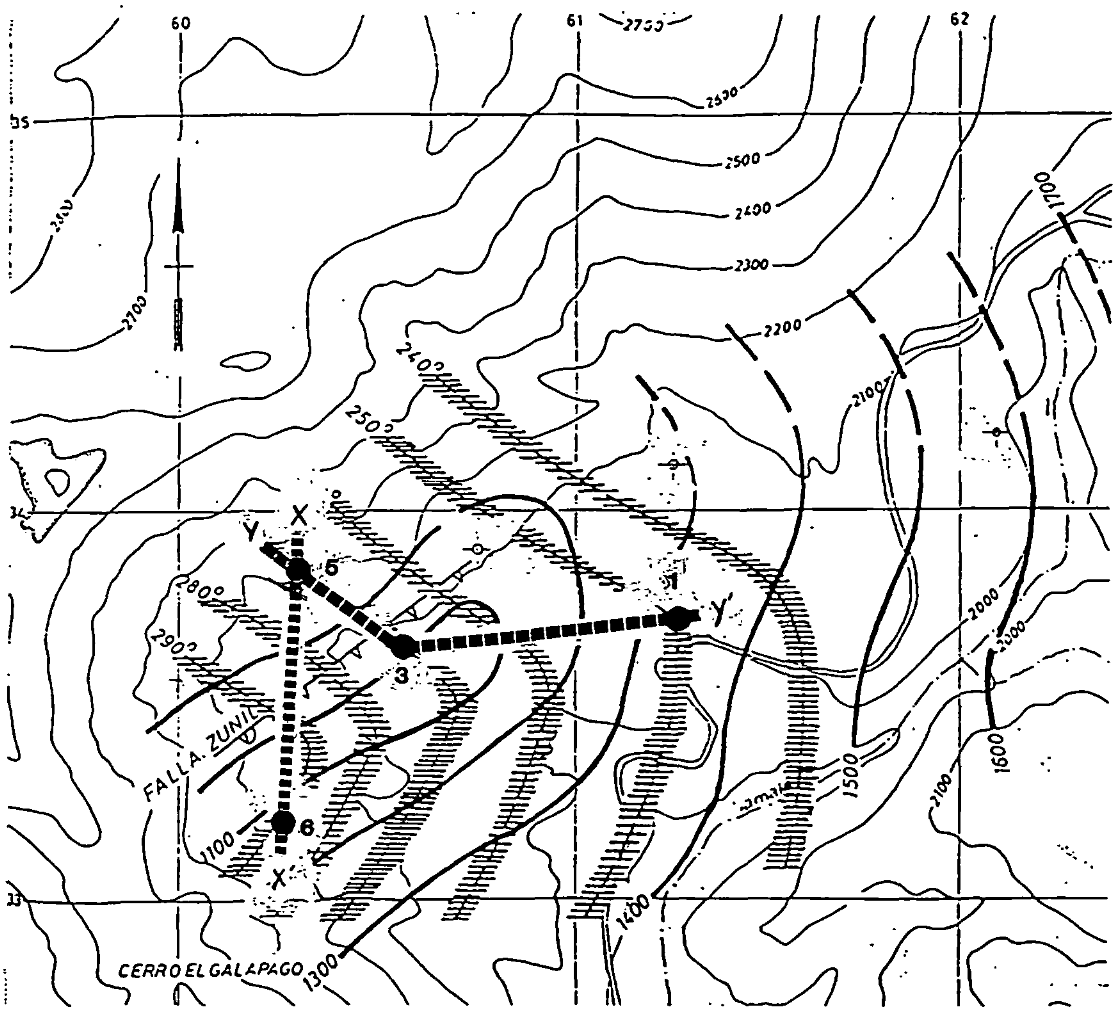


Figure 1. Well and cross-section locations, Zunil geothermal field, Guatemala.

STRATIGRAPHIC RELATIONSHIPS

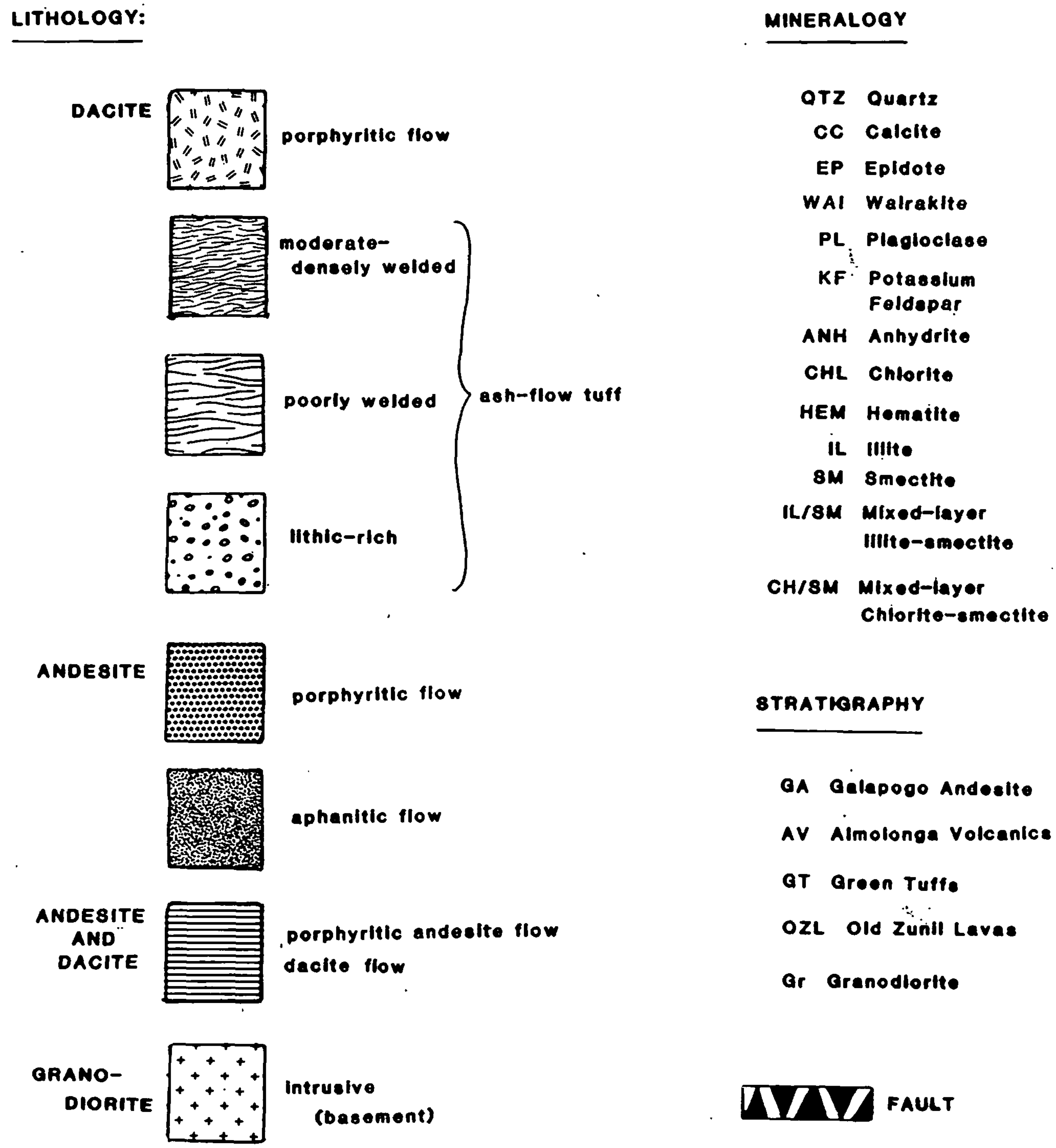
The lithologies encountered in the thermal gradient and production wells at Zunil I consist of a thick sequence of lava flows and ash-flow tuffs that unconformably overlie a basement of granodiorite (ELC-Electroconsult, 1980; Tobias, 1978, unpub. lithologic logs). Throughout most of the area, the volcanic rocks are covered by a thin veneer of alluvium, pumiceous deposits, and recent landslide debris.

The volcanic rocks range in composition from basaltic andesite to rhyodacite. Hydrothermal alteration related to geothermal activity has converted the glassy matrix and primary mineral assemblages of these rocks to mixtures of clays, calcite, iron oxides, quartz and epidote. However, even in the intensely altered rocks the primary textures and proportions of ferromagnesian minerals and plagioclase can frequently be determined.

Stratigraphic relationships of the deep production wells are illustrated in Figure 2A and 2B. According to Tobias (1978), the volcanic rocks can be assigned to four volcanic sequences that range in age from Pleistocene to Tertiary. These include the Galapago Andesite (Pleistocene), Almolonga Volcanics (Pleistocene), Green Tuff (Pliocene), and the Old Zunil Lavas (Pliocene). However, the absolute ages of the rocks have not yet been well established.

The Galapago Andesite consists of a sequence of lava flows that reach a maximum thickness of 200 m in ZCQ-5 and 6. The flows thin to the east, suggesting that they were erupted from a vent located to the west of Zunil I. In thin section, the andesite flows were found to contain phenocrysts of plagioclase and rare clinopyroxene in a matrix of variably altered glass, plagioclase microlites, and disseminated magnetite. The microlites commonly exhibit well developed flow-banded textures.

The andesite flows are underlain by a thick succession of dacite lava flows, minor ash-flow tuffs and andesite flows of the Almolonga Volcanics. The Almolonga Volcanics have a maximum thickness of 800 m in well ZCQ-3. The dacite lava flows are porphyritic and mostly crystal-poor, containing only 10-20% percent phenocrysts of plagioclase, and rare hornblende and biotite in a matrix of altered and devitrified glass. Granophyric and spherulitic devitrification textures are common. Hydrothermal alteration has replaced the devitrified matrix with fine-grained quartz that is accompanied in places by sericite. The plagioclase phenocrysts have been replaced by calcite, illite-smectite and rare epidote. The ferromagnesian minerals have been altered to chlorite-smectite.



Legend for figures.

Some ash-flow tuffs are interbedded with the dacite lava flows in the upper half of the flow sequence, especially in ZCQ-3. The ash-flow tuffs contain a few percent broken plagioclase phenocrysts in a matrix of ash and rare shards. Lithic fragments of andesite are also present.

In wells ZCQ-6, ZCQ-5, Z-11 and ZCQ-1, thin (25-50 m thick) and discontinuous andesite lava flows are present which separate the Almolonga Volcanics into major upper and lower dacite flow sequences. The andesite flows vary in texture and mineralogy. Most of the flows in the production wells are porphyritic and contain phenocrysts of clino- and orthopyroxene, plagioclase, and magnetite. Aphyric andesite flows occur in well Z-11 and are distinguished from the porphyritic varieties by a lack of pyroxene phenocrysts, abundant, fine-grained matrix magnetite, and elongated amygdules. The amygdules are filled with quartz, chlorite-smectite, and calcite.

The lower flow sequence may be partially tuffaceous, but silicification has obscured any relict shard texture in the possibly densely welded ash-flow tuffs. Spherulitic and granophyric textures are common in the upper part of the lower flow sequence beneath the andesite flows. These textures probably represent the rapidly cooled upper portion of a thick dacite flow.

The contact between the Almolonga Volcanics and the underlying Green Tuff is marked by a lithic-rich ash-flow tuff in wells ZCQ-6, ZCQ-5 and ZCQ-1. The Green Tuff is composed of two major units, the upper lithic-rich tuff and a lower welded dacite ash-flow tuff. Both units are highly variable in thickness. In well ZCQ-6 to the west, only the lithic-rich unit is present where it is about 100 m thick. In well ZCQ-5, the Green Tuff is predominantly poorly to moderately welded tuff and is nearly 200 m thick. Farther to the east in wells ZCQ-3 and ZCQ-1, the Green Tuff is thin to absent.

The Green Tuff can be distinguished from all the other volcanic units by the presence of phenocrysts of quartz (which commonly appear resorbed). The ash-flow tuffs are also characterized by a few percent phenocrysts of plagioclase and rare biotite in a devitrified and altered matrix of ash and shards with a variable amount of welding. Lithic fragments of andesite are common and constitute up to 30% of some samples. The Green Tuff is silicified in the production wells and veins of hematite are especially common in the more poorly welded tuffs.

The lithic-rich unit at the top of the Green Tuff has previously been interpreted as an intraformational conglomerate (Conglomerate A; CyM/MKE, 1988). However, the presence of poorly welded shards, pumice fragments and quartz phenocrysts suggest that the rock represents an ash-flow tuff unit.

The oldest volcanic unit encountered in the wells consists of up to 200 m of thinly interbedded andesite lava flows and dacite flows. The sequence has been variously assigned to the Old Zunil Lavas by Tobias (1978) and to the undifferentiated Tertiary Volcanics of CyM/MKE (1988). The andesite lava flows are porphyritic, and contain phenocrysts of clinopyroxene, plagioclase, and magnetite. The dacite flows are also porphyritic with granophyric textures well-developed around plagioclase phenocrysts. Hydrothermal alteration varies from moderate to strong.

The contact between the volcanic rocks and the underlying granodiorite is marked by a paleosol up to about 10 m thick in exposures south and east of Zunil I. There is no evidence for the development of a thick paleosol in the production wells at Zunil I. However, some of the cuttings from the granodiorite contact in ZCQ-3 and ZCQ-1 may represent altered soil material. Petrographically, these cuttings consist of hematite-stained clay containing angular quartz, plagioclase, and biotite grains. The grain size and mineralogy of these crystals are similar to that of the underlying granodiorite. The lack of a thick paleosol in ZCQ-3 and ZCQ-1, in contrast to areas outside of Zunil I suggests that these wells may have been drilled on basement highs.

The base of the volcanic section in ZCQ-3 and 6 is associated with intense veining and lost circulation. In ZCQ-5, the granodiorite displays evidence of brecciation. These relationships indicate that the permeable zones located near the base of these wells are associated with major faults.

The granodiorite encountered in the wells is equigranular and coarse-grained. The essential minerals are quartz, plagioclase, biotite, minor potassium feldspar, and apatite. The age of the granodiorite has not been established. However, it appears to be significantly older than the overlying volcanics and deeply eroded prior to their deposition.

ALTERATION

The hydrothermal alteration in Zunil I can be broadly characterized as argillic, phyllic, or propylitic. The secondary minerals in these zones are found as both pervasive alteration that has affected the groundmass and phenocrysts of the volcanic rocks, and as veins. Detailed distributions of the alteration minerals are shown in Figures 3 through 7. A generalized cross-section of the alteration zones showing all of these boreholes is illustrated in Figure 8.

Argillic Alteration

Argillic alteration is restricted to the upper 100-150 m of the wells. This zone is characterized by the assemblage smectite, kaolin, quartz, chalcedony, calcite, interlayered chlorite-smectite, zeolites, and minor hematite. The clay minerals occur principally as an alteration product of the groundmass of the volcanic rocks. Quartz, zeolites, and smectite infill amygdules. Calcite is found primarily as a replacement of plagioclase and clinopyroxene phenocrysts.

Veins within the argillic zone are most common in wells ZCQ-3 and Z-11. These veins consist of calcite $\pm$ barite, quartz + calcite, and calcite + hematite.

Phyllic Alteration

Phyllic alteration is at least weakly established in all the wells below 200 m and is the dominant alteration type to a depths of 600 m. Rocks within the phyllic zone are pervasively but weakly altered to mixtures of interlayered illite-smectite, illite and quartz. With the exception of veins related to a shallow hydrothermal breccia, little veining has been recognized with this zone. Phyllic alteration is best developed in the upper dacite lava flows of the Almolonga Volcanics.

The top of the phyllic zone consists of a hydrothermal breccia that is developed in lava flows of the Galapago Andesite in wells ZCQ-5 and 6 and in dacite flows occurring at the top of the Almolonga Volcanics in wells ZCQ-1 and 3. In thin section, the breccia consists of rounded clasts in a matrix of quartz and finely comminuted country rock. Veins of intergrown calcite and quartz are common in the lower portion of the breccia.

The breccia occurs at depths of 175-250 m and increases in thickness from east to west. In well ZCQ-6, the breccia is about 100 meters thick whereas in well ZCQ-1, the breccia is only about 25 meters thick and occurs as isolated veins of brecciated dacite flow rock.

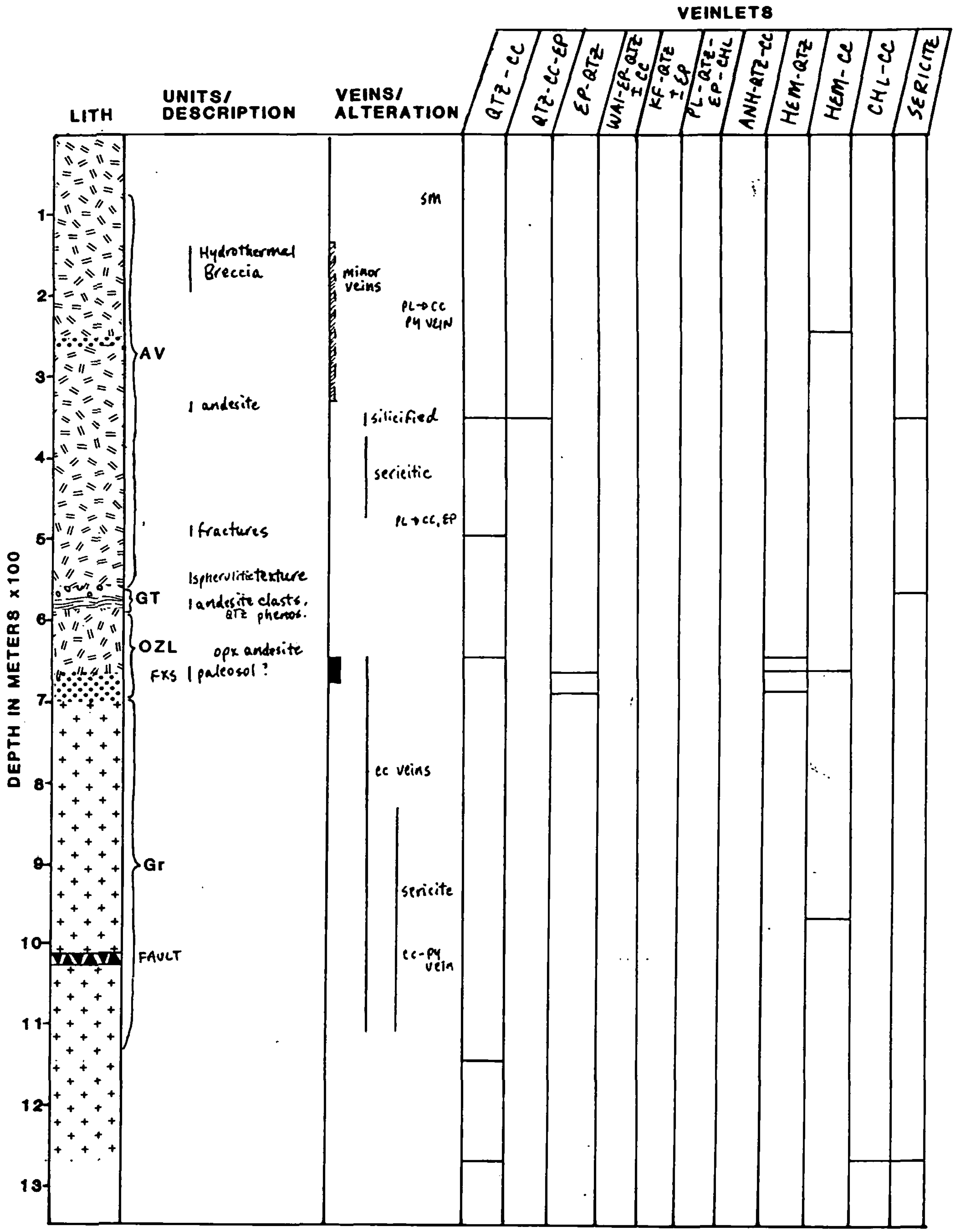


Figure 3. Summary of volcanic stratigraphy and hydrothermal alteration mineralogy in well ZCQ-1. Refer to legend for abbreviations.

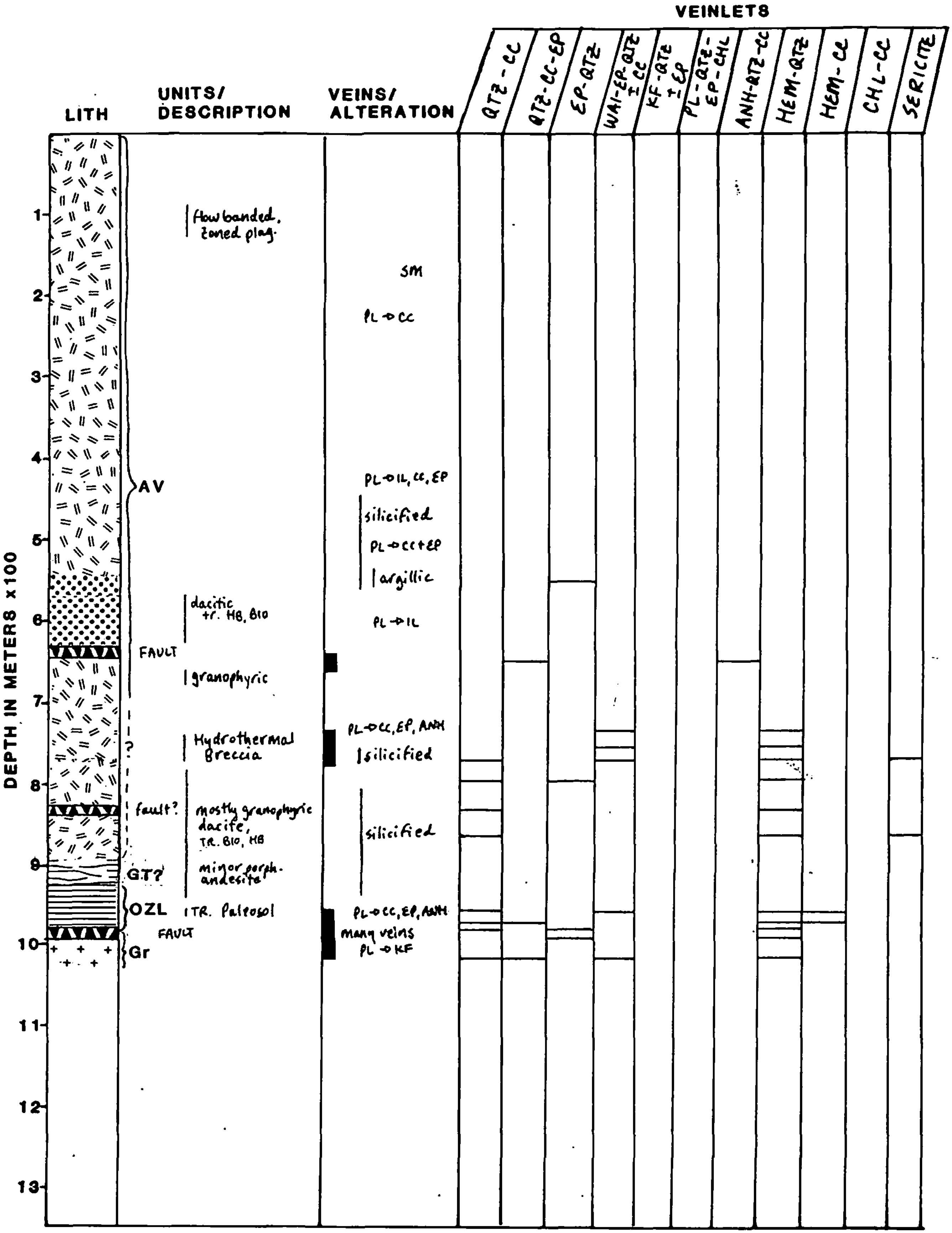


Figure 4. Summary of volcanic stratigraphy and hydrothermal alteration mineralogy in well ZCQ-3. Refer to legend for abbreviations.

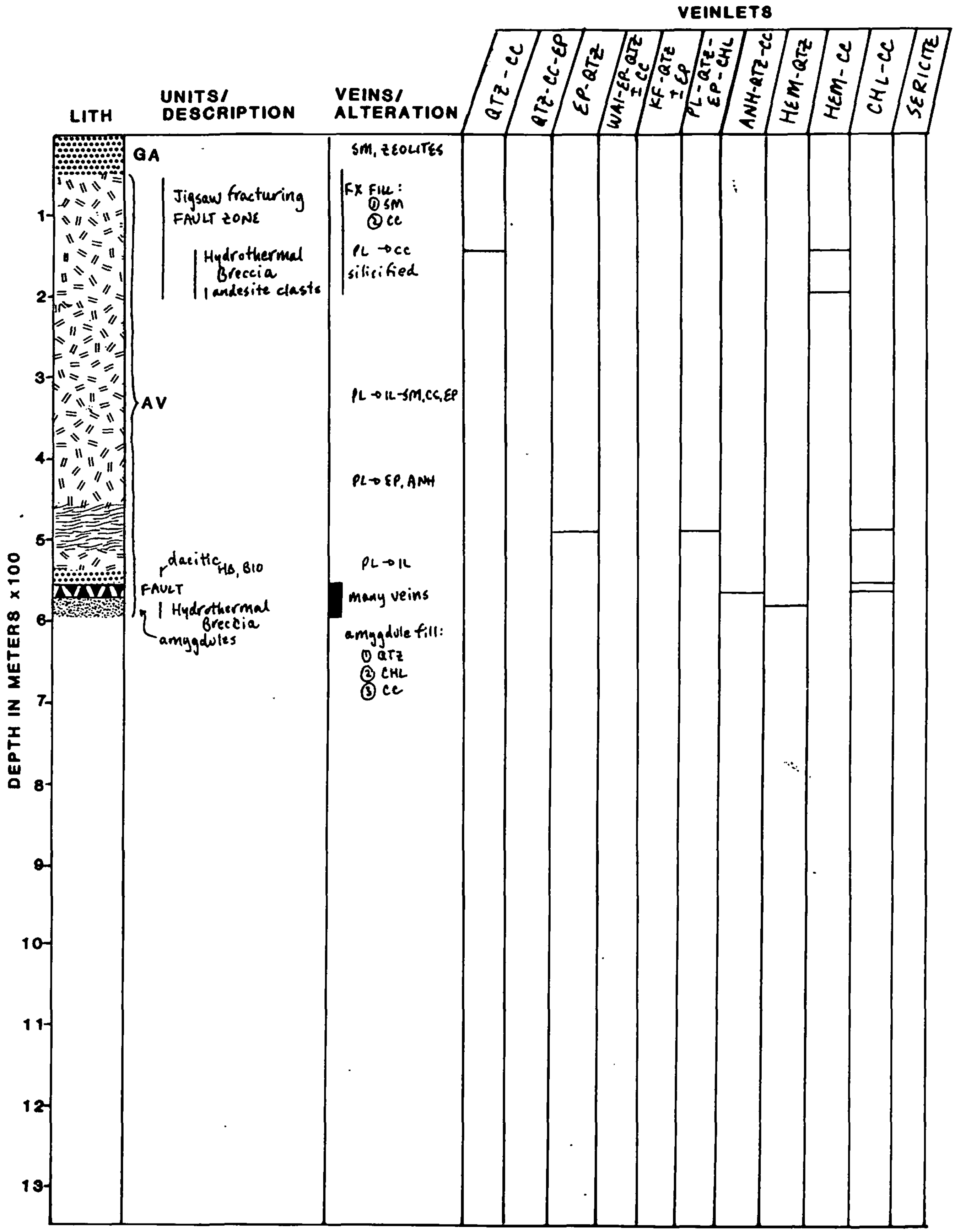


Figure 5. Summary of volcanic stratigraphy and hydrothermal alteration mineralogy in well Z-11. Refer to legend for abbreviations.

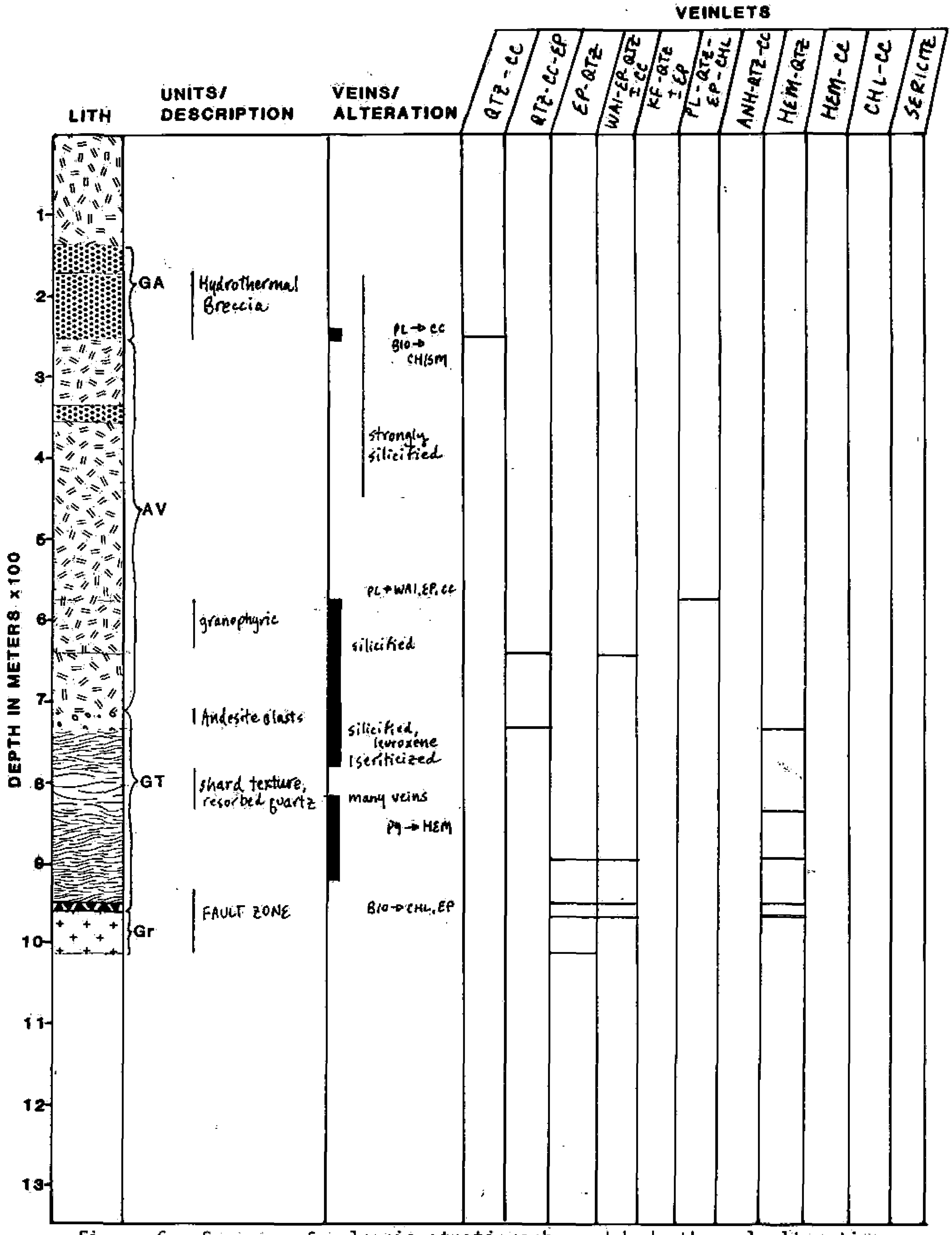


Figure 6. Summary of volcanic stratigraphy and hydrothermal alteration mineralogy in well ZCQ-5. Refer to legend for abbreviations.

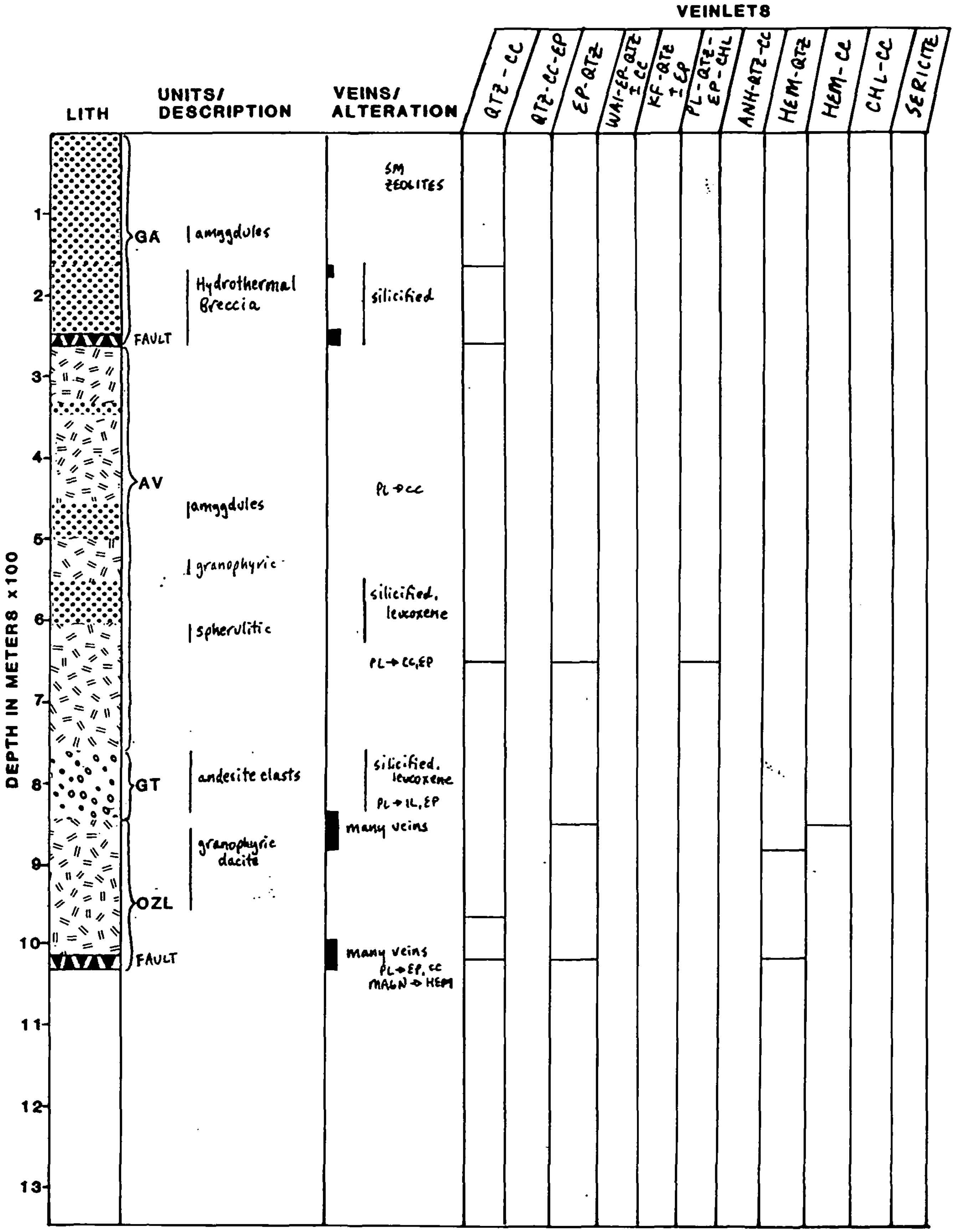


Figure 7. Summary of volcanic stratigraphy and hydrothermal alteration mineralogy in well ZCQ-6. Refer to legend for abbreviations.

The hydrothermal breccias in well ZCQ-6 and Z-11 are closely associated with fault zones. These zones occur at the base of the breccias. Chip and core samples from the fault zones are characterized by jigsaw fracturing, abundant veining, and gouge material.

The illite-smectite minerals display systematic changes in composition and structure with respect to depth. The results of X-ray diffraction analyses of the clay minerals in ZCQ-5 and 6 are illustrated in Figures 9 and 10 respectively. The phyllic zone in ZCQ-5 extends from 250 to 585 m (Figure 9) and from 250 to 640 m in ZCQ-6 (Figure 10). Illite and illite-smectite, comprise up to 15 to 20% of the bulk samples and about 85% of the clay fraction of the rocks. The X-ray data indicate that the illite content of the interlayered illite-smectite is about 90% in ZCQ-5 and ranges from 70 to 90% in ZCQ-6. Reconnaissance X-ray studies of the clay minerals at the base of the phyllic zone in ZCQ-1 and 3 indicate that the illite lacks expandable (smectite) interlayers.

Minor amounts of chlorite or chlorite-smectite are present in the phyllic zone. These minerals compose up to 20% of the clay fraction. Some of the chlorite in the dacite flow rocks may represent alteration of biotite phenocrysts; chlorite or chlorite-smectite is also common as a replacement of the matrix of the andesitic rocks.

Epidote occurs as a trace constituent in the phyllic zone below the hydrothermal breccia in wells ZCQ-1, and 3 and Z-11. In this zone, it is associated with calcite as a replacement of plagioclase phenocrysts. In contrast, epidote is also found as a vein mineral in the underlying propylitic zone.

Propylitic Alteration

Propylitically altered rocks are characterized by veins containing plagioclase, chlorite, wairakite, epidote, calcite, and quartz. Illite, pyrite, magnetite, and hematite are also present. In general, the intensity of the propylitic alteration and veining increases with depth.

The top of the propylitic zone is marked by veins consisting of plagioclase + epidote + chlorite. These veins occur at depths of 500 to 600 m in wells ZCQ-5 and 6, and Z-11. At greater depths, the most common hydrothermal vein assemblage is quartz + epidote ± calcite. These veins are most abundant near the granodiorite contact, in both the overlying volcanics and within the granodiorite.

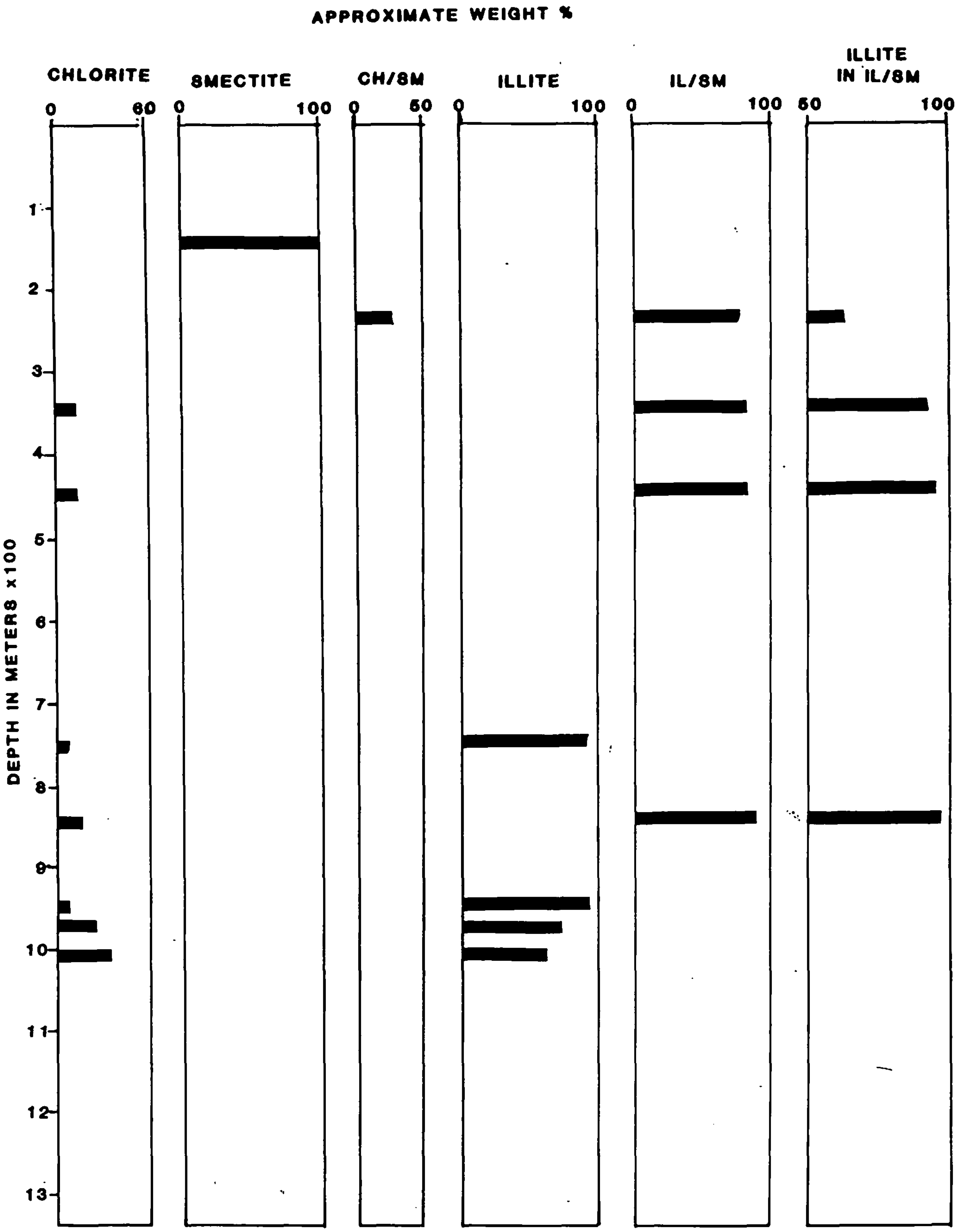


Figure 9. Distributions of hydrothermal layer silicates in clay (< 5 μm) fractions of cuttings samples from well ZCQ-5. Column at right shows increasing amount of illite in mixed-layer illite-smectite with a complete loss of expandible layers at the bottom of the well.

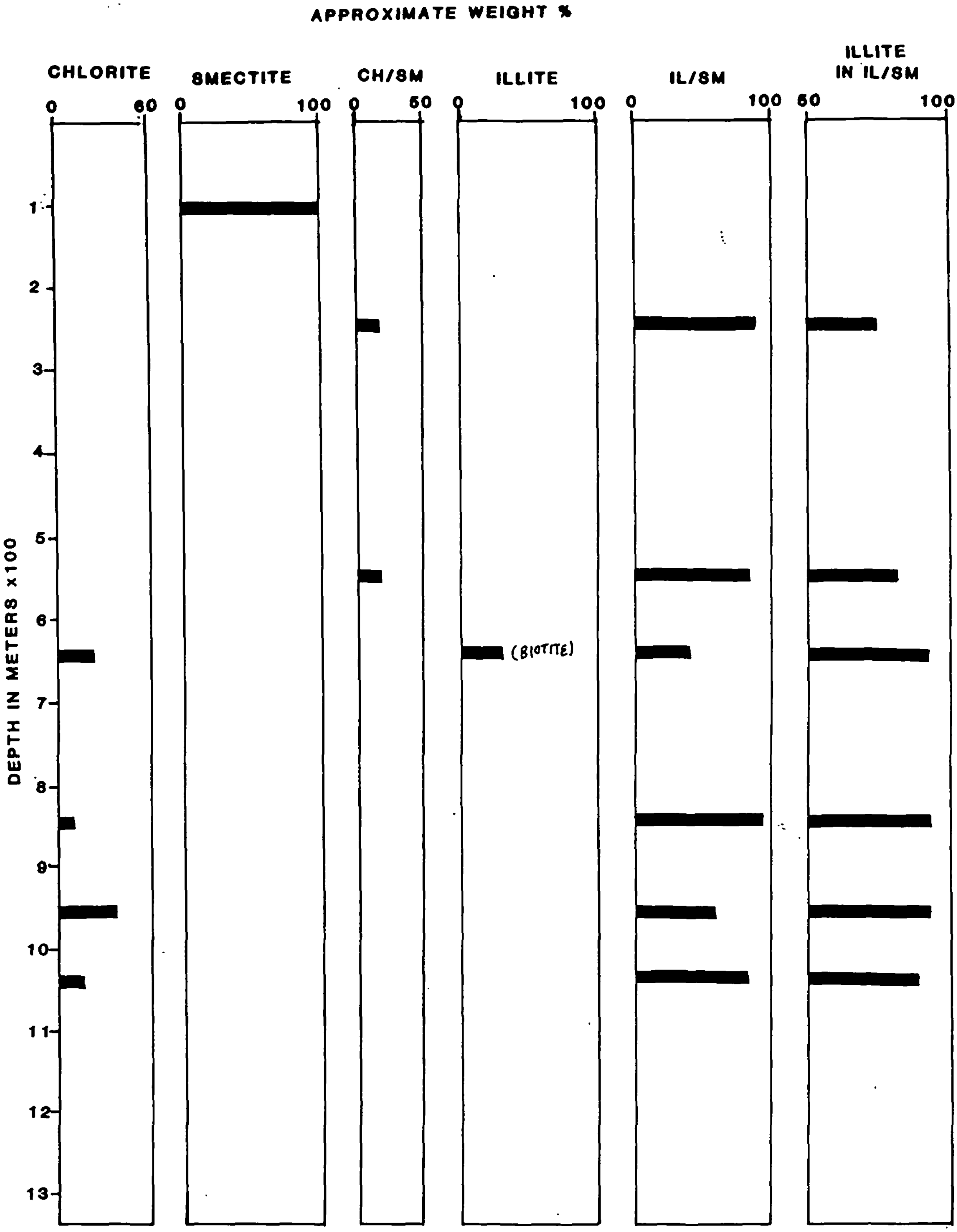


Figure 10. Distributions of hydrothermal layer silicates in clay (< 5 μm) fractions of cuttings samples from well ZCQ-6. Column on right shows downward increasing amount of illite in mixed-layer illite-smectite, without complete loss of expandible layers at the bottom of the well.

Veins containing wairakite occur in the upper part of the propylitic zone and near the granodiorite contact in wells ZCQ-3 and 5. Wairakite in these veins is associated with calcite, epidote, and quartz.

Hydrothermal rutile and leucoxene become gradually more common with depth within the propylitic zone of wells ZCQ-6 and ZCQ-5. These minerals occur in veins with quartz, and as disseminated granular aggregates intergrown with illite or interlayered illite-smectite where they represent an alteration product of magnetite and ilmenite within andesite.

Quartz veins containing abundant hematite and traces of pyrite and magnetite are commonly found in the poorly welded dacite ash-flow tuff adjacent to the granodiorite contact in all of the wells but are best developed in ZCQ-5 where these ash-flow tuffs are thickest. In places the hematite clearly replaces preexisting pyrite or magnetite. However, the hematite may also be a primary phase in some of the veins. Quartz + pyrite veins are also present in the granodiorite samples from 1015 m in ZCQ-4 and at 755 m in ZCQ-1.

Veins of calcite and illite, are found sporadically in the volcanic rocks and in the granodiorite in ZCQ-1.

Illite, interlayered illite-smectite, chlorite, minor calcite, and epidote also occur as alteration products of the volcanic rocks and granodiorite. Thin zones of intensely sericitized dacite lava flows are found in the upper part of the propylitic zone. Fragments of dacite altered to illite were ejected from wells ZCQ-5 and 1 during the flow tests conducted in 1989. X-ray diffraction and petrographic analyses of the sample from well ZCQ-5 indicate that it consists dominantly of illite with minor pyrite (4 wt.%) and wairakite (2 wt.%). This assemblage closely matches the mineralogy from a depth of about 770 m. The sample from well ZCQ-1, is mostly illite with some plagioclase and epidote, which matches the mineralogy at about 625 meters depth.

Interlayered illite-smectite occurs within the propylitic zone in well ZCQ-6. X-ray diffraction analysis indicates that the mixed-layer clay in the volcanic rocks is more than 90% illite whereas the illite content of illite-smectite in the granodiorite ranges from about 85 to 90%. In contrast, illite from the propylitic zone of the other deep production wells is devoid of expandable interlayers.

Chlorite is found as a replacement of the groundmass in the andesite lava flows and as an alteration product of biotite and hornblende in the granodiorite. Calcite and epidote occur mainly as a replacement product of plagioclase.

DISCUSSION

The distribution of secondary mineral assemblages observed in samples from Zunil I provides a unique record of the physical and chemical conditions within the reservoir. Browne (1978) has shown that six factors are of particular importance in controlling the distributions of alteration minerals in geothermal systems. These factors are temperature, fluid chemistry, permeability, rock type, and time. Although it is difficult to separate the importance of each factor, the results of the present petrologic studies suggest that secondary mineralogy at Zunil I has been controlled primarily by permeability, temperature, and fluid chemistry.

Variations in the permeabilities of the reservoir rocks are reflected in the abundance of the secondary minerals occurring within the drill holes. Petrographic studies suggest that the intensity of pervasive alteration in the reservoir rocks is closely related to the distribution of veins and that in general, there is an increase in both the abundance of alteration minerals and veining with depth.

Several major zones of veining and alteration were encountered in the wells. The highly altered volcanic rocks in the lower portions of ZCQ-3, 5, and 6 are located above zones of lost circulation (ZCQ-3, 6) or microbreccia (ZCQ-5). These relationships suggest that the deep alteration is developed in the more highly fractured hanging walls of the fault zones. Zones of strong alteration at shallower depths in these wells further suggest that the faults are steeply dipping. Figure 8 shows the locations of the fault zones inferred from the distribution of veins and pervasive alteration.

Variations in temperature with depth are reflected in systematic changes in the alteration minerals. The clay mineralogy and the extent of interlayering are especially useful indicators of the past and present temperature regime. A comparison of many geothermal systems indicates that Ca-smectite is stable to temperatures of 140°C, interlayered illite-smectite to 220°C, and illite above 220°C (Moore and Adams, 1989). With the exception of ZCQ-6, temperatures defined by the clay mineralogy are consistent with present downhole measured temperatures.

X-ray diffraction analysis of the clays from ZCQ-6 indicates that the rocks in the northwest portion of Zunil I are being heated. This well is characterized by interlayered illite-smectite at the bottom of the well where present well temperatures are 280°C. Such temperatures are significantly higher than the commonly observed upper stability limit of this mineral. In contrast, illite at the bottom of well ZCQ-5 (where present temperatures are slightly lower than those of ZCQ-6) lacks smectite interlayers.

With few exceptions, epidote and wairakite occur in the reservoir rocks at Zunil I where measured temperatures exceed 200°C. This relationship is consistent with the lower stability of epidote in other high-temperature systems (Henley and Ellis, 1983). Traces of epidote in rocks with slightly lower temperatures occur in the upper portions of ZCQ-3. Here, traces of epidote in plagioclase occur at depths of 355 m where measured temperatures are 190°C. The matrix of these rocks is altered to interlayered illite-smectite, indicating that peak temperatures are not likely to have exceeded 220°C at these depths. Thus, temperatures at this depth may have been several tens of degrees hotter in the past. This local cooling may be due to sealing of the shallow fracture zones in this well.

Veins of epidote (or wairakite) + quartz are abundant in the lower portions of the production wells ZCQ-3, 5, and 6. These veins are indicative of high-temperature, near-neutral reservoir fluids. Their common occurrence in the wells in the northwest portion of Zunil I depth suggests that this area represent a major zone of shallow upwelling.

Boiling is a common and important process in many high-temperature geothermal systems. Textures and mineral assemblages indicative of boiling are found in all the wells. Hydrothermal breccias that formed as a result of violent boiling occur in the upper portions of all the wells at a depth of about 200 m and at a depth of 600 m in ZCQ-4 and Z-11. Core from Z-11 shows that the breccias in this well form steeply dipping veins that crosscut the host rocks.

Hydrothermal brecciation in the upper part of ZCQ-5 and 6 is associated with the base of the andesite lava flows. The zone of brecciation is about 100 m thick in both wells. The association of this zone with the basal portion of the andesite suggests that boiling may have occurred where the upwelling hydrothermal fluids encountered highly permeable flow breccias.

Because of the differences in the solubilities with respect to temperature of quartz and calcite, veins containing intergrowths of these minerals also imply boiling. Veins containing quartz + calcite veins are found in all of the wells, implying that boiling has been widespread.

Vein relationships near the granodiorite-volcanic contacts in ZCQ-3, 5, and 6 suggest that both boiling and cooling have been important in controlling mineral deposition. In these wells, veins of quartz + calcite + epidote and epidote + calcite + wairakite occur in the volcanic rocks. The presence of calcite suggests that these veins were deposited as a result of boiling. In contrast, the veins within the granodiorite consist mainly of quartz + epidote. This assemblage suggests that mineral deposition occurred as a result of cooling rather than boiling. Boiling may have been promoted by increased fracture permeability in the hanging walls of the faults encountered near the base of these wells.

The presence of veins containing plagioclase or illite suggests that boiling of the reservoir fluids has led to the development of a steam-heated cap over the thermal system. The presence of these minerals in veins is indicative of thermal fluids with pH values lower than fluids in equilibrium with illite-potassium feldspar and potassium feldspar-plagioclase (Browne and Ellis, 1970). The latter mineral pairs are present in the rocks at Zunil I and thus, it can be expected that the reservoir fluids should be in equilibrium with all three phases. Fluids with a reduced pH, allowing equilibrium with illite and plagioclase, will form over zones of boiling were CO_2 released from the boiling fluid dissolves into the overlying waters.

Veins containing plagioclase + epidote + chlorite are present at intermediate depths (500-600 m) in wells ZCQ-3, 5 and 6. Illite-bearing veins crosscut the silicified matrix of the hydrothermal breccia in Z-11 and occur in the upper and lower portions of ZCQ-1. In Z-11 the vein paragenesis is illite followed by calcite + epidote + anhydrite. This paragenesis suggests that the illite was deposited by early steam-heated waters while the later minerals were deposited from neutral pH fluids. The widespread occurrence of illite-bearing veins in ZCQ-1 suggest that the steam-heated waters form a cap that thickens from west to east. Such steam-heated caps appear to be an important feature of the marginal parts of high-temperature geothermal systems (Henley and Ellis, 1983; Lemieux et al., 1988)

The reverse solubility of calcite with respect to temperature suggests that veins consisting only of calcite may have been deposited from fluids undergoing heating. These veins are common below 700 m in the granodiorite in ZCQ-1. This observation implies that ZCQ-1 is located on the margin of the thermal system. The location of this well on the margin of the system is further indicated by the presence of hematite in calcite veins in ZCQ-1, indicating the influx of oxidized waters (Aumento et al., 1982).

Fracture zones associated with present fluid entries in ZCQ-1, 3, and 6 are characterized by veins containing quartz + hematite ± pyrite ± magnetite. Petrographic observations indicate that the hematite postdates the pyrite and magnetite. These relationships suggest that the present fluids may be more oxidizing than the fluids that precipitated the quartz veins and that these entries represent reactivation of older structures.

In contrast, production intervals in ZCQ-5 and Z-11 appear to be associated with highly illitized rock. The low permeabilities of ZCQ-5 may be due to the deposition of illite by steam-heated waters in the producing fractures.

CONCLUSIONS

The mineralogic and petrographic data suggest that the Zunil I is located within a high-temperature, fracture-controlled geothermal reservoir. Hydrothermal alteration is widespread within the reservoir rocks and generally increases in intensity with depth. Temperatures inferred from mineral relationships are consistent with measured downhole temperatures, and suggest that no significant cooling has occurred within the explored portions of the reservoir. Veins of quartz + epidote (or wairakite) are more abundant in the lower portions of ZCQ-3, 5, and 6 than they are in ZCQ-1. The veins in ZCQ-3, 5, and 6 are associated with fault zones that offset the volcanic rocks and underlying granodiorite.

Boiling occurred as the fluids moved upwards into the volcanic rocks. Veins of quartz + calcite and hydrothermal breccias indicate that boiling occurred throughout the volcanic section. Dissolution of CO_2 derived from the boiling fluids into shallow groundwaters has produced a steam-heated cap over the thermal system. This cap is thickest in ZCQ-1, indicating the ZCQ-1 is located closer to the margin of the system than wells ZCQ-3, 5, and 6.

Recent heating of the rocks in the vicinity of ZCQ-6 is indicated by the presence of interlayered illite-smectite at the bottom of well where downhole measured temperatures exceed 260°C. The recent heating in ZCQ-6, the distribution of steam-heated waters, and the abundance of high-temperature veins suggests that the upwelling center of the reservoir is located near the northwest portion of Zunil I.

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PETROLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF THE ZUNIL GEOTHERMAL SYSTEM

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IV. FLUID GEOCHEMISTRY AND ISOTOPE SYSTEMATICS

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ABSTRACT

The chemical and isotopic relationships of fluids from wells and springs in the Zunil I geothermal field follow a clear and consistent pattern with respect to their location. The source of the geothermal fluid lies near ZCQ-3, -5, and -6. This high-temperature fluid travels south and east throughout the Zunil I area, boiling and mixing with shallow waters. Boiling of the geothermal fluid produces steam which interacts with groundwater to produce sulfate-rich thermal springs. Some of the high-temperature fluid does not mix significantly with groundwater, but instead forms a pristine outflow plume southeast of wells ZCQ-6.

INTRODUCTION

Chemical analyses of spring and well fluids have been collected from the Zunil I geothermal area during the past ten years. Our interpretation of the Zunil fluid geochemistry is based on chemical data from the production and thermal gradient wells obtained from INDE (Michels, 1988), the springs from JICA (1977), and the isotopic and chemical data of springs and production wells from CyM/MKF (Michels, in prep), Fournier and Handshaw (1981), and Giggenbach (1986). These data consist of over 700 analyses from cold springs, hot springs, thermal gradient wells, and production wells, and are listed in Tables 1 to 3.

GEOTHERMOMETRY

Equilibria based on fluid-rock interactions can be used as geothermometry to predict the subsurface temperature of a geothermal fluid. Giggenbach (1988) has shown that the ratio of K to Mg in a geothermal fluid equilibrates rapidly and can be used to calculate the most recent temperature of a fluid, while the slowly-equilibrating ratio of K to Na predicts temperatures close to that of the reservoir. Furthermore, the K/Mg geothermometer can be used with fluids that have been produced by the interaction of steam and groundwater. Steam-heated waters are generally not in equilibrium with Na-bearing minerals, rendering any Na/K geothermometer unreliable.

Enthalpies derived from geothermometer temperatures can also be used in conjunction with the fluid concentrations of Cl. Enthalpy and Cl are both conserved when a fluid undergoes mixing and boiling, providing a linear relationship on a plot of enthalpy vs. Cl.

Enthalpy-Cl plots have been prepared for the Zunil fluids using both the K/Mg and the K/Na geothermometers (Fig. 1 and 2). The trends expected for boiling, mixing, and conductive cooling are also shown in these figures. It is apparent from these figures that the fluids from different wells in the Zunil geothermal system are all related to a parent fluid by boiling and mixing processes. Fluids from ZCQ-3 and -6 are nearly identical, and related to fluid from ZCQ-2, Z-4, and the local hot springs by mixing. The mixing proportion appears to be about 50%. The composition of ZCQ-4 lies along a boiling trend, and is related to the compositions of ZCQ-3 and -6 by boiling of a parent fluid. Furthermore, ZCQ-3 and -6 can be related to fluid from the thermal gradient wells Z-2 and -6 by conductive cooling,

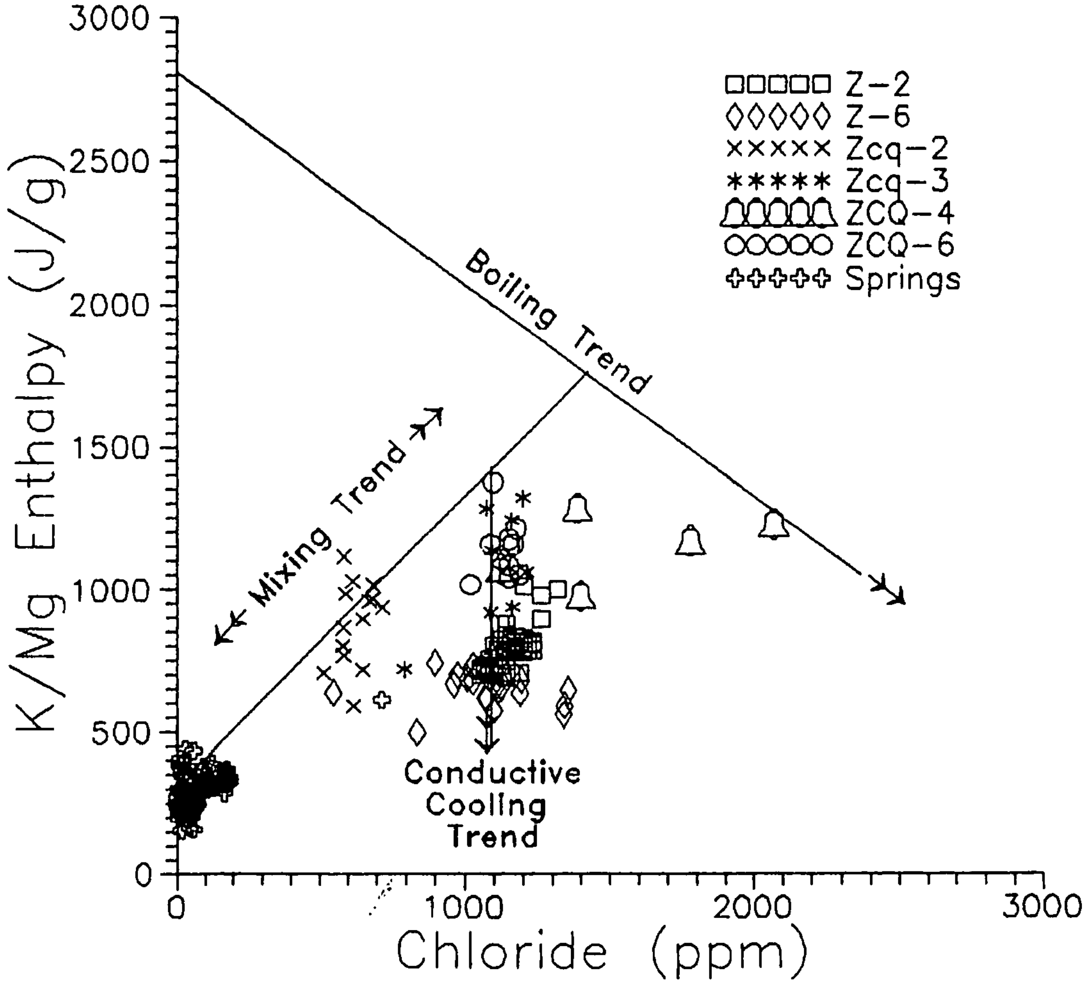

Figure 1. K/Mg enthalpy-chloride relationships of thermal fluids from Zunil I.

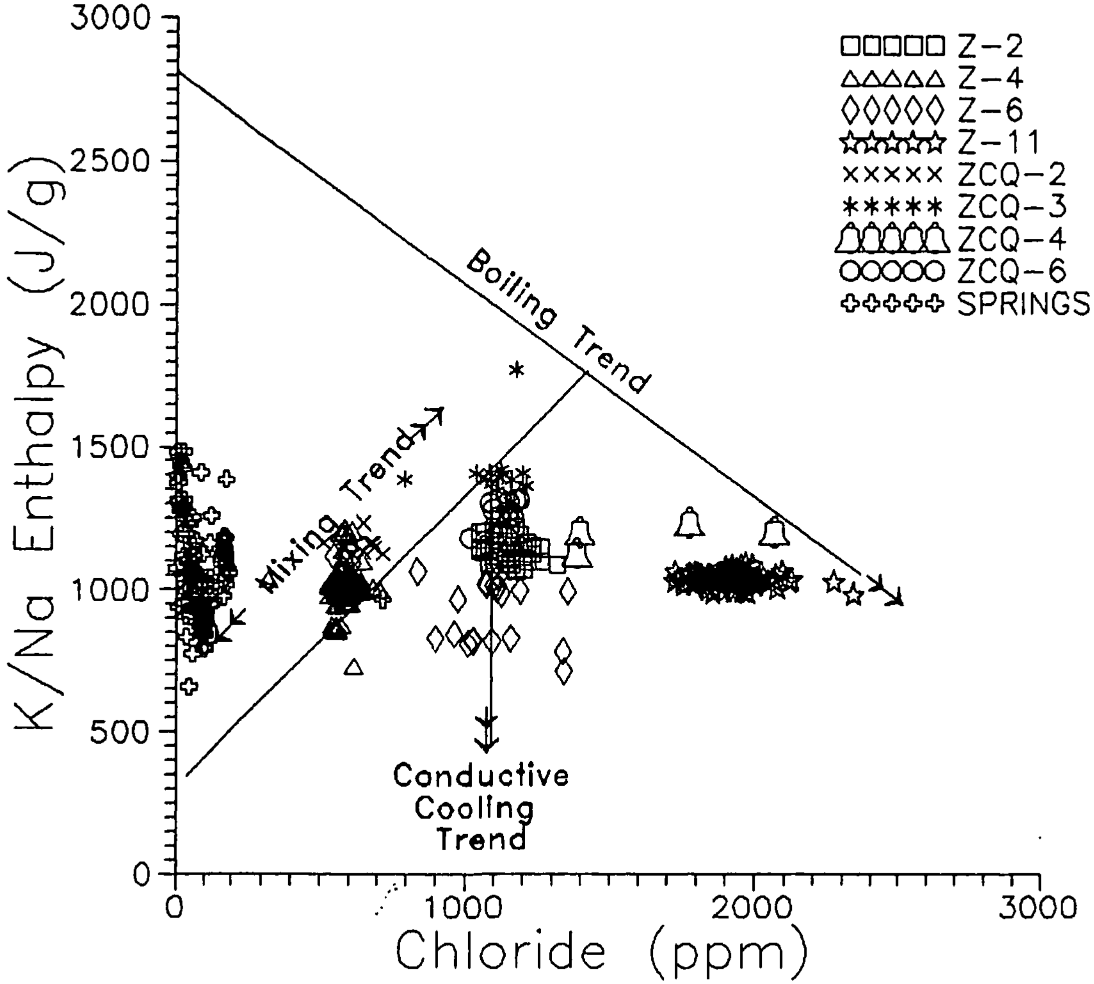

Figure 2. K/Na enthalpy-chloride relationships of thermal fluids from Zunil I.

i.e., they have simply undergone cooling but have not mixed with cooler fluid or boiled. Alternatively, fluid from Z-2 and -6 can be related to ZCQ-4 by mixing.

The intersection of the boiling and mixing lines can be used to predict the composition and temperature of the undiluted, unboiled geothermal parent fluid. As shown in Figures 1 and 2, the parent fluid is predicted to have a temperature of approximately 340°C and a chlorinity of 1300 ppm.

It should be noted that these conclusions are best illustrated on the K/Mg plot in Figure 1. K/Na geothermometer temperatures (Fig. 2) do not change rapidly, and tend to remain high after mixing or boiling. Thus the points in Figure 2 do not plot as well along the linear mixing and boiling trends as those in Figure 1.

Several points of interest can be drawn from the discussion above. The fluids that are most closely related to the parent fluid are found in wells ZCQ-3 and -6. Fluids that have conductively cooled and represent outflow have been sampled from well Z-6, Z-2, and spring z-15. These wells are found south and southeast of wells ZCQ-3 and -6. Diluted fluids flow from wells ZCQ-2, Z-4, and spring z-20, northeast of wells ZCQ-3 and -6. ZCQ-4 produces fluid that can be related to the parent fluid by boiling. This well is located northeast of wells ZCQ-3 and -6. The direction of greater boiling is also demonstrated by higher sulfate concentrations in fluids from wells and springs found northeast of wells QCQ-3 and -6. Enrichment of sulfate in these fluids is produced by oxidation of H_2S derived from the contact of steam with oxygenated groundwater. Clarify

FLUID MATURITY INDICES

A mature fluid has been defined by Giggenbach (1988) as one that is in full equilibrium with Na-, K-, and Mg-bearing minerals. The implication is that a mature fluid will have identical temperatures predicted by the K/Mg and K/Na geothermometers. When these predicted temperatures differ widely, the fluid is defined as immature. The most immature fluid will be one produced by the acidification and heating of a groundwater by steam. Acid fluids will quantitatively dissolve rock, transferring the elemental ratios of the rock to the fluid and producing spurious geothermometer temperatures.

The maturity relationships for the Zunil fluids are summarized in a ternary plot of Na, K, and Mg, shown in Figure 3. Points that plot below the lowermost curved line are immature fluids. Most of the springs from the Zunil area plot in this region. The indicated immaturity of these fluids is in agreement with the high acidity and sulfate contents found in many of these fluids. Fluids that plot above the lower curved line are more mature, and those that plot on the upper curved line are fully mature, with concordant K/Na and K/Mg geothermometer temperatures. The predicted temperatures are marked on the upper curve.

Fluids from many of the wells display a range of maturities Some of these ranges intersect both immature and fully mature boundaries (Fig. 3). This range may be due to poor Mg precision due to the low Mg contents of the production fluids, or may reflect mixing of the high-temperature fluids with steam-heated groundwaters. Mg contents in fluids from the thermal gradient wells were relatively high, so conclusions with respect to the maturity of these fluids are sound. Figure 3 shows that the

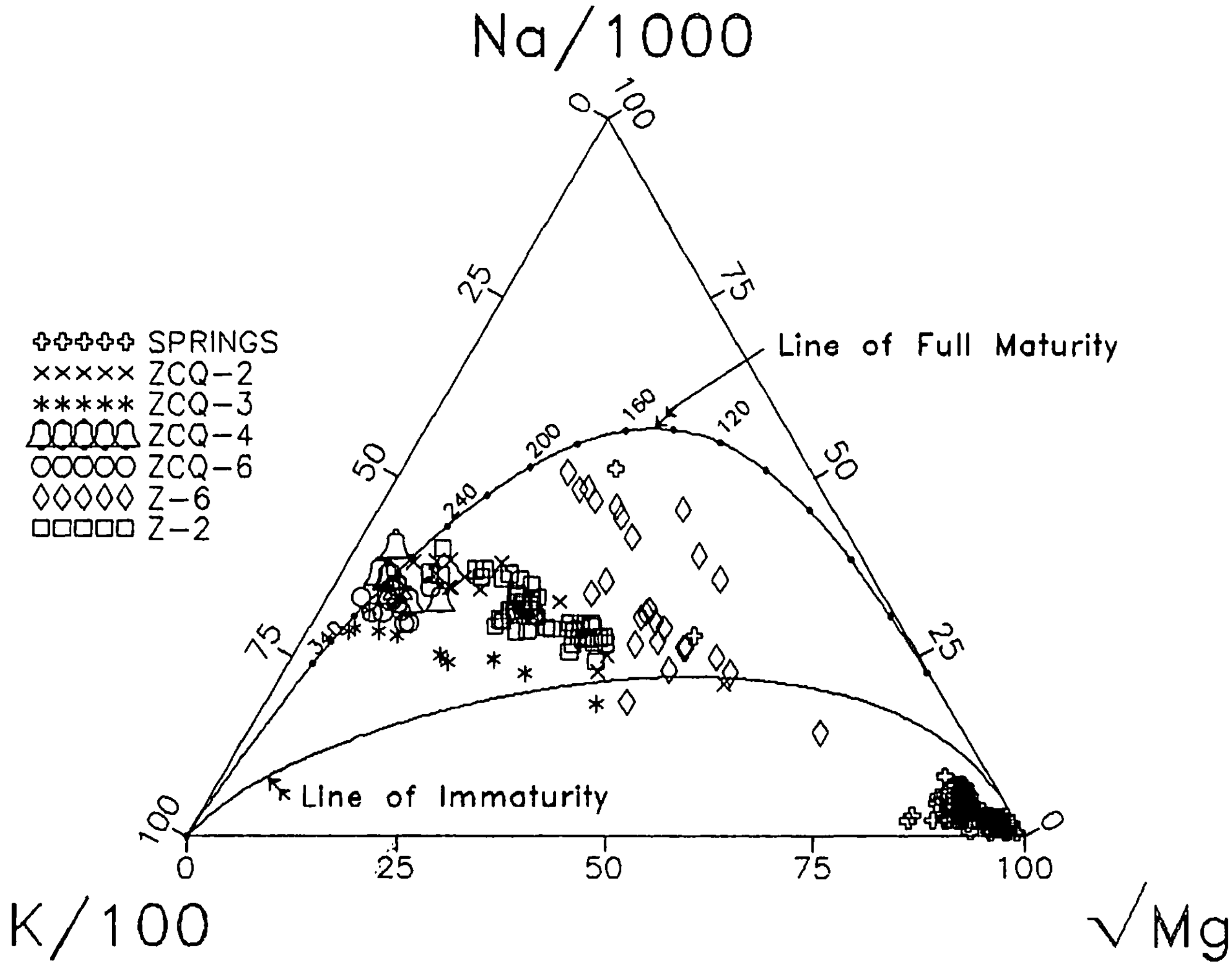

Figure 3. Maturity indices of thermal fluids from Zunil I.

predicted reservoir temperatures of the mature production fluids range from 280° to 320°C.

Fluid from the thermal gradient well Z-2 predicts a maximum temperature 10° to 20°C cooler than fluid from wells ZCQ-3 and -6, and ranges from immature to fully mature. The prediction of cooler temperatures for a fully mature fluid suggests that fluid from Z-2 is a conductively cooled version of the production fluid from wells ZCQ-3 and -6 mixed with steam-heated groundwater. The chemistry of fluid from the thermal gradient well Z-6 also indicates a range from partial to full equilibrium, but both the K/Na and K/Mg geothermometers predict a temperature of 200°C. The close approach to equilibrium and the low temperature of this fluid demonstrate conductive cooling, and indicate an outflow plume moving southeast from the high-temperature wells ZCQ-3 and -6. Some mixing of primary geothermal fluid and steam-heated groundwater is also indicated for fluid from well Z-6. This is demonstrated by the range of maturities of this fluid (Fig 3).

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STABLE ISOTOPES

Fluids from wells ZCQ-3 and -6 and several hot springs were analyzed for their concentrations of oxygen and hydrogen isotopes. The results of these analyses are plotted on Figures 4a. Also plotted on this figure is the Western Guatemala local (Fournier and Hanshaw, 1981) and global (Craig, 1961) meteoric water line. Rain- and groundwater from any given region will usually plot near the global meteoric water line. Small deviations from the global meteoric water line result from local variations in storm paths and elevations above sea level, producing a local water line.

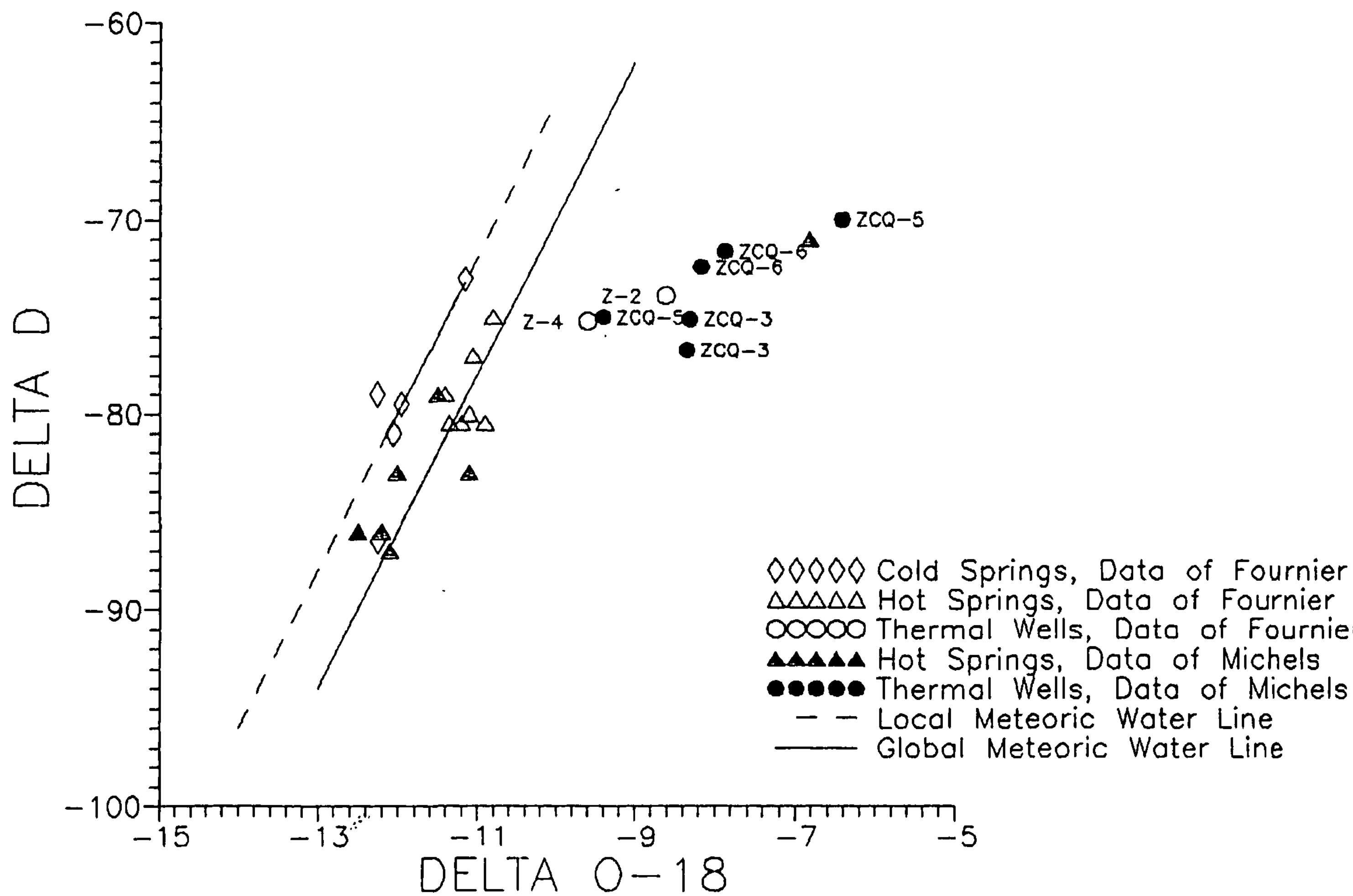

Figure 4a. Isotopic data of fluids from Zunil I.

It has been shown that geothermal water is derived from meteoric water, and subsequent reactions with rock alter the oxygen isotopic composition but do not generally alter the hydrogen composition of the fluid (Craig, 1963). This relationship is called the geothermal oxygen shift. Thus, geothermal fluids will generally plot to the right of meteoric fluids on a graph of oxygen-18 vs. deuterium fluid concentrations.

The isotopic compositions of the geothermal fluids show a 5 part per mil oxygen shift. This is comparable to productive geothermal systems throughout the world. The hot spring compositions trend subparellel to the meteoric water line but span a greater range of deuterium than the cold springs. This range can be explained by mixing of steam from the geothermal fluid with groundwater (Fig. 4c). The compositions of steam separated at various temperatures from ZCQ-6 are shown in figure 4b. These compositions were calculated for equilibrium compositions of reservoir liquid and steam at temperatures ranging from 275° to 140°C.

The isotopic difference between fluid from wells ZCQ-3 and -6 is greater than analytic error, and is consistent with analyses of fluid from the same wells sampled in 1985 (Giggenbach, 1986). The only way to explain the compositional difference between the wells is by mixing of a single parent geothermal fluid with two different groundwaters. Well ZCQ-6 appears to have mixed with groundwater containing an identical hydrogen isotopic ratio (Fig 4c). In contrast, fluid from well ZCQ-3 has mixed with isotopically-light steam-heated groundwater. This is consistent with the close proximity of ZCQ-3 to the steam well ZCQ-5, and to ZCQ-4, which produces fluid that has been previously boiled.

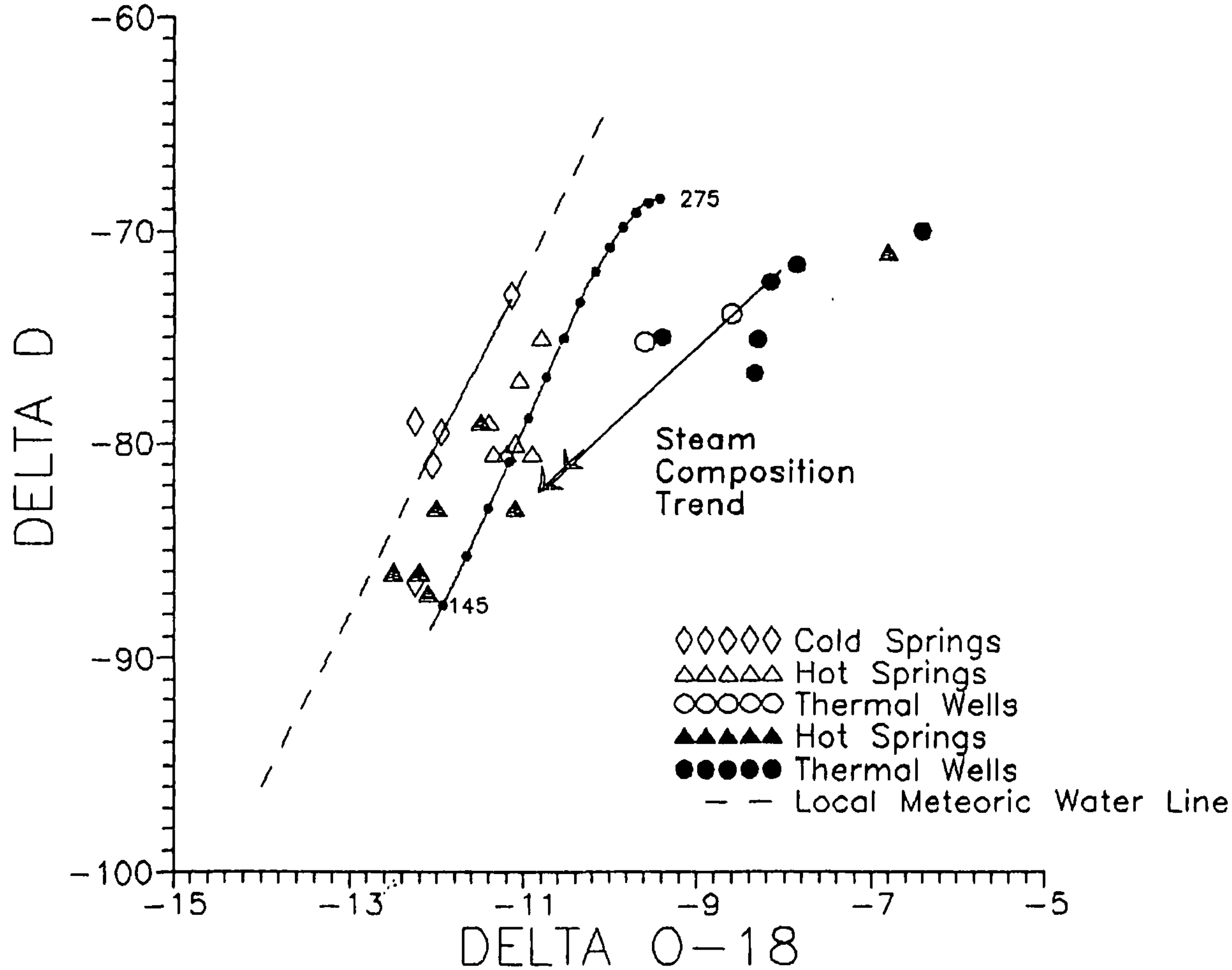

Figure 4b. Isotopic composition of steam in equilibrium with production fluid.

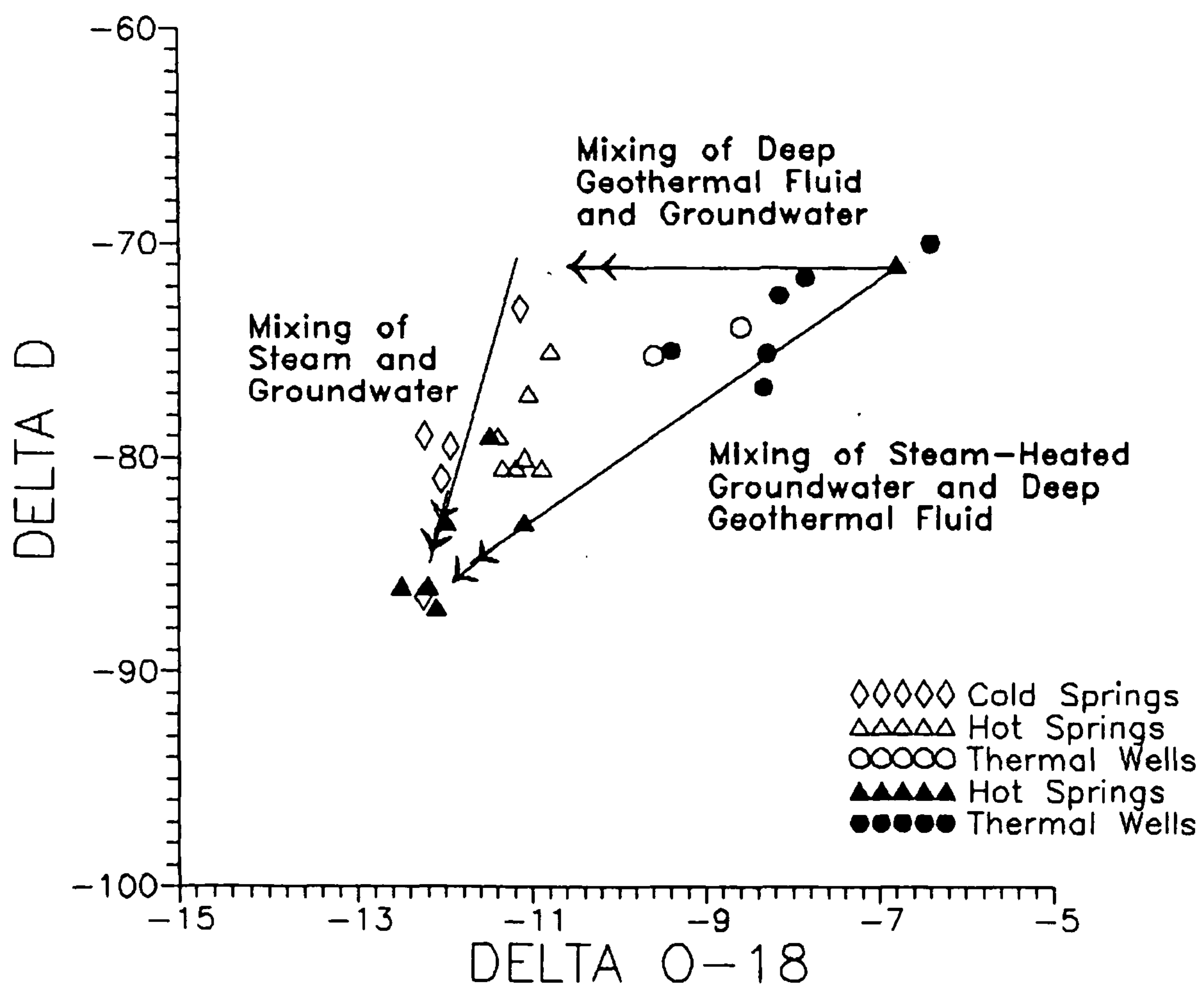

Figure 4c. Isotopic end-members and mixing trends of the Zunil I fluids.

The isotopic composition of steam from well ZCQ-5 lies between that of the production wells and their predicted steam compositions. The slope of the line that connects the compositions of the liquid and steam sampled from ZCQ-5 indicates that separation occurred at temperatures near 200°C. The isotopic composition of the hypothetical parent fluid also lies on the line that connects the steam and liquid compositions of the fluid from well ZCQ-5. If it is assumed that the hypothetical fluid is similar to the unboiled fluid from ZCQ-5, then the compositions of the steam and liquid from well ZCQ-5 can be matched by continuously boiling the fluid from 275°C down to 200°C. The calculated temperatures agree with those measured in well ZCQ-5, where the bottom-hole temperature was approximately 275°C, and rapidly declined to aproximately 200°C. These relationships imply that the alternating liquid and steam from well ZCQ-5 are the result of an incomplete boiling of a fluid that closely resembles the hypothetical parent fluid.

TRITIUM

Tritium has been analyzed in samples from the Rio Samala, hot and cold springs, and thermal wells. Concentrations of tritium in the thermal well waters are greater than or equal to those in the hot springs (Fig.5). Tritium in the cold springs and the Rio Samala are 5 to 25 times greater. The concentrations in the thermal waters are sufficiently low that precision is +/- 10 to 50%.

Natural tritium is produced by the impact of cosmic neutrons on nitrogen nuclei in the upper atmosphere, resulting in steady-state concentration of approximately 5 tritium units in groundwater. However, this natural background has been swamped since 1952 by enormous amounts of man-made tritium from open air

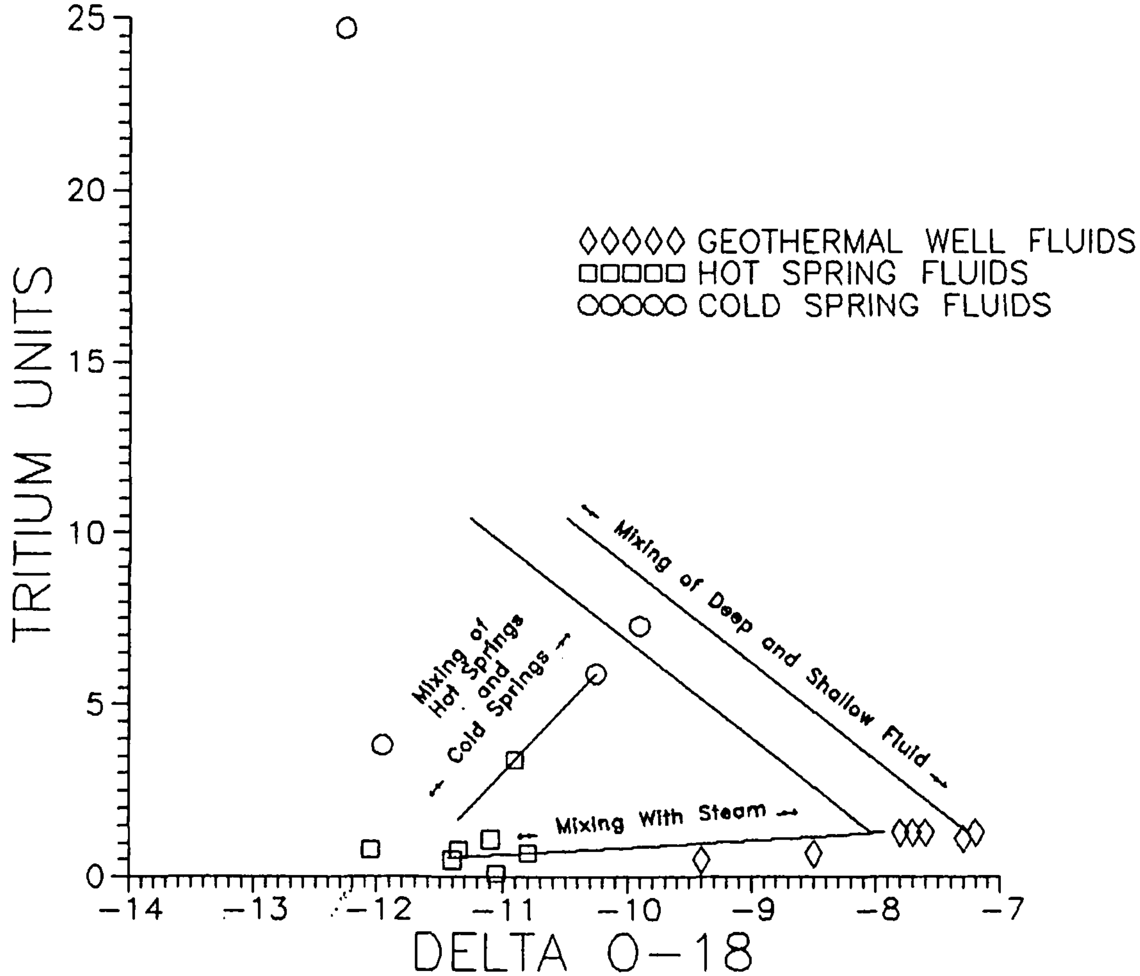

Figure 5. Tritium−oxygen isotopic relationships for fluids from Zuni I.

thermonuclear tests. At its maximum level of 1963, the contribution of artificial tritium to precipitation reached 2 to 3 orders of magnitude above that of natural tritium. Levels of artificial tritium also vary from year to year due to atmospheric destorage and radioactive decay, so that there is no longer a steady-state concentration in groundwater. Thus, only waters older than approximately 30 years can be dated reliably without careful documentation of tritium variations in the area since 1952.

Tritium concentrations in the thermal well waters are approximately 1.3 tritium units. If these concentrations are the result of decay from pre-bomb concentrations, the waters would have descended from the surface 28 years ago. However, the thermal well waters could have mixed with a small amount of water containing more recent levels of tritium. Mixing with a small amount of post-bomb water containing large quantities of artificial tritium could have easily produced a concentration of 1.3 tritium units. This explanation is suggested by the fact that tritium concentrations in the thermal well waters did not change from 1980 to 1985. If the thermal waters from the deep wells had no influx of tritium from mixing, the concentrations should have changed from 1.3 to 0.92.

The tritium concentrations in the hot springs are generally consistent with steam-enriched groundwaters, as shown in Figure 5. Tritium and oxygen-18 concentrations in the hot springs are less than or equal to those in the well waters. Isotopic depletion of heavy isotopes in steam applies to tritium as well as oxygen and deuterium. Thus, steam-enriched hot springs should show less tritium and oxygen-18 than either groundwaters or deep thermal waters. The amount of depletion in the hot springs indicates a large component of steam in these waters, which is also shown by the stable isotopes (Fig. 4a-c).

SUMMARY

The chemical and isotopic relationships of fluids from wells and springs in the Zunil 1 geothermal field follow a consistent pattern with respect to their location. Fluids most closely related to the hot (>300°C) parent fluid flow from wells ZCQ-3, -5, and -6. These wells are clustered in the northwest corner of Zunil 1. Well Z-6 and spring z-15 represent an outflow zone from the hot wells in the northeast corner. These fluids are conductively cooled and only slightly diluted with respect to the parent fluid. They occur along a northwest trending structure which also transects the location of the hot wells.

Fluids from wells ZCQ-4 and -3 both display a relationship to boiling. Well ZCQ-4 fluid has been previously boiled, and well ZCQ-3 fluid has mixed with steam-heated groundwater produced by boiling. Although well ZCQ-5 is a steam well, its boiling appears to related only to low permeability and no evidence has been found to connect its composition to a vapor-phase reservoir.

Boiling is common in the geothermal system at Zunil. With two exceptions, hot springs at Zunil are mixtures of steam and groundwater. These hot springs frequently have high acidities and sulfate contents from absorption of steam.

Mixing in fluids from both wells and springs increases to the northeast. Wells ZCQ-2, Z-4, and spring z-15 represent a 50% mixture of parent geothermal fluid and steam-heated groundwater.

Tritium concentrations in the thermal waters are inconclusive. The most likely explanation for the measurable concentrations of tritium is mixing with post-bomb (< 30 years

old) groundwater. However, the data can also be interpreted as indicating a residence time of approximately 30 years.

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TABLE 1. CHEMICAL COMPOSITIONS OF ZUNIL HOT SPRINGS

NAME	SOURCE	DATE	NA	K	CA	MG	LI	B	SIO2	CL	SO4	HCO3	PH
4	DM	19-Jan-87	165	11.0	22.8	5.7	0.19	2.6	336	96	91	268	7.4
4	DM	05-Feb-87	165	12.3	19.6	5.5	0.25	2.4	352	101	99	220	7.2
4	DM	17-Mar-87	165	12.5	16.3	5.0	1.33	2.0	334	98	100	256	7.5
4	DM	08-May-87	162	10.0	17.0	5.3	0.25	3.2	353	89	97	230	7.3
4	DM	01-Jun-87	164	11.5	25.9	5.6	0.28	2.8	363	92	101	244	7.7
4	DM	09-Jul-87	175	9.6	15.0	5.3	N.D.	2.6	282	99	101	268	7.8
4	DM	13-Aug-87	180	11.2	16.9	4.8	0.40	3.7	310	98	113	253	7.6
4	DM	29-Sep-87	180	12.8	16.8	5.0	0.13	3.7	245	106	98	253	6.4
41	J	01-Jan-77	10	1.2	2.4	0.2	N.D.	N.D.	N.D.	3	0	17	6.5
41	DM	19-Jan-87	148	20.0	15.5	5.4	0.19	3.0	296	92	89	183	7.2
41	DM	05-Feb-87	140	12.3	15.3	6.5	0.23	2.6	332	88	89	161	7.2
41	DM	17-Mar-87	145	11.3	13.5	5.3	0.23	3.0	314	93	92	150	7.9
41	DM	08-May-87	146	10.0	15.9	5.6	0.20	4.1	242	85	86	207	7.3
41	DM	01-Jun-87	141	11.5	15.7	5.3	0.23	3.2	291	85	85	244	7.9
41	DM	09-Jul-87	135	11.6	12.1	6.5	N.D.	2.4	344	85	88	195	7.8
41	DM	13-Aug-87	149	9.2	16.5	4.8	0.11	1.7	286	89	86	100	7.8
41	DM	29-Sep-87	142	10.8	16.3	4.7	0.35	2.3	323	98	83	222	7.7
6	J	01-Jan-77	186	14.2	16.0	7.2	N.D.	N.D.	N.D.	94	86	386	7.4
6	DM	19-Jan-87	168	12.0	18.8	5.9	0.19	2.8	334	96	91	254	7.5
6	DM	05-Feb-87	150	12.3	19.1	5.9	0.25	2.6	339	92	100	200	7.3
6	DM	17-Mar-87	161	11.8	16.3	5.0	0.25	2.4	320	93	106	226	7.4
6	DM	08-May-87	159	10.0	8.0	2.7	0.16	3.5	355	92	99	163	7.7
6	DM	01-Jun-87	159	11.5	19.9	5.2	0.25	3.0	313	89	105	268	7.5
6	DM	09-Jul-87	179	19.7	16.0	7.1	N.D.	2.2	315	95	104	268	7.7
6	DM	13-Aug-87	175	9.2	16.5	4.8	0.05	3.6	329	98	113	256	7.6
6	DM	29-Sep-87	161	12.8	17.3	5.1	0.13	3.2	260	98	97	232	7.8
9	DM	19-Jan-87	198	22.0	25.9	15.6	0.29	3.0	362	120	102	373	7.2
9	DM	05-Feb-87	190	19.6	23.1	16.0	0.33	3.0	394	122	124	256	7.3
9	DM	17-Mar-87	197	18.8	23.8	15.0	0.30	2.8	364	117	114	325	7.6
9	DM	08-May-87	199	17.1	26.0	15.6	0.30	3.0	396	116	118	329	7.4
9	DM	01-Jun-87	200	18.5	27.9	15.2	0.33	4.1	370	116	122	345	7.6
9	DM	09-Jul-87	214	31.7	23.0	15.1	N.D.	3.5	302	119	127	415	7.6
9	DM	13-Aug-87	195	35.2	27.0	14.2	0.57	2.5	341	124	187	305	7.7
9	DM	29-Sep-87	195	16.8	24.3	14.9	0.20	3.0	400	124	92	361	7.5
ZMF12	DM	17-Mar-87	15	7.0	12.5	10.9	0.05	0.7	338	5	133	N.D.	3.6
ZMF12	DM	08-May-87	31	2.6	5.9	3.8	0.10	1.1	426	7	71	24	5.0
ZMF12	DM	29-Sep-87	18	2.8	17.8	12.4	N.D.	0.2	249	18	133	N.D.	3.4
ZR16	DM	19-Jan-87	42	11.0	19.5	8.2	0.02	1.3	173	27	32	98	6.6
ZR16	DM	05-Feb-87	22	7.8	20.2	8.0	0.06	0.6	162	27	35	90	6.7
ZR16	DM	17-Mar-87	44	7.8	14.5	7.1	0.05	1.1	254	29	36	95	7.2
ZR16	DM	08-May-87	43	5.8	17.9	7.8	N.D.	0.9	149	27	28	110	6.9
ZR16	DM	01-Jun-87	37	7.5	15.7	12.3	0.03	0.9	219	27	35	110	7.0
ZR16	DM	13-Aug-87	28	5.2	10.0	4.1	N.D.	N.D.	154	27	30	49	7.8
ZR16	DM	29-Sep-87	28	6.8	10.2	3.8	N.D.	N.D.	213	18	18	71	6.4

N.D. = No Data, DM = D. Michels report to CyM/MKE, CyM/MKE = COLLECTION BY CyM/MKE, J = JICA

TABLE 1. CHEMICAL COMPOSITIONS OF ZUNIL HOT SPRINGS

NAME	SOURCE	DATE	NA	K	CA	MG	LI	B	SIO2	CL	SO4	HCO3	PH
10	DM	19-Jan-87	269	40.0	41.7	29.1	0.44	3.7	458	171	177	506	6.5
10	DM	05-Feb-87	265	37.5	41.1	30.5	0.50	2.4	412	173	203	506	7.3
10	DM	17-Mar-87	266	37.1	26.6	40.0	0.48	2.8	411	171	163	537	7.6
10	DM	08-May-87	260	32.3	40.0	40.7	0.48	5.0	437	162	171	540	7.4
10	DM	01-Jun-87	274	39.2	45.8	39.8	0.50	4.9	417	167	188	659	7.3
10	DM	09-Jul-87	293	45.7	40.1	38.6	0.25	3.9	432	170	189	659	7.3
10	DM	13-Aug-87	294	45.3	38.0	34.8	0.93	7.0	426	177	186	601	7.6
10	DM	29-Sep-87	274	32.8	38.0	44.5	0.40	5.3	391	177	185	573	6.0
13	DM	19-Jan-87	262	40.0	47.7	46.9	0.46	5.2	463	168	183	451	6.9
13	DM	05-Feb-87	250	23.3	40.2	44.7	0.53	3.2	444	168	191	451	7.5
13	DM	17-Mar-87	261	37.1	43.6	45.4	0.50	2.8	421	171	180	590	7.0
13	DM	08-May-87	253	33.0	46.0	45.8	0.50	5.2	373	160	185	566	6.9
13	DM	01-Jun-87	266	36.5	51.8	44.7	0.53	2.8	421	164	184	634	7.1
13	DM	09-Jul-87	275	35.6	38.1	43.0	0.23	4.1	456	164	180	610	7.7
13	DM	13-Aug-87	283	35.3	40.0	41.0	0.39	4.7	453	177	171	600	7.2
13	DM	29-Sep-87	264	34.8	47.0	46.3	0.40	5.2	351	177	169	603	7.6
15	DM	19-Jan-87	160	24.0	98.2	30.0	0.79	2.4	336	69	228	504	6.6
15	DM	05-Feb-87	167	19.3	49.2	29.7	0.83	1.7	358	69	224	428	7.8
15	DM	17-Mar-87	155	18.0	48.7	27.6	1.40	3.0	345	69	215	356	7.1
15	DM	08-May-87	154	15.9	46.1	28.5	0.80	2.6	380	65	191	342	6.8
15	DM	01-Jun-87	156	17.5	43.9	28.4	0.83	3.7	302	61	196	381	7.2
15	DM	09-Jul-87	151	11.6	40.0	28.0	0.45	0.2	355	51	166	374	7.2
15	DM	13-Aug-87	159	15.2	41.0	25.9	0.62	0.9	301	62	170	350	6.7
15	DM	29-Sep-87	150	12.8	41.0	30.4	0.65	2.3	258	71	161	350	7.6
16	J	01-Jan-77	273	37.2	44.5	60.3	N.D.	N.D.	N.D.	162	169	668	7.5
17	DM	19-Jan-87	288	35.0	51.7	37.7	0.55	5.2	447	181	207	575	6.9
17	DM	05-Feb-87	157	35.5	51.2	36.8	0.50	5.0	464	178	188	302	7.0
17	DM	17-Mar-87	268	36.1	38.6	37.4	0.48	4.3	404	176	201	500	8.1
17	DM	08-May-87	290	32.1	34.0	37.3	0.48	7.1	443	174	158	561	7.7
17	DM	01-Jun-87	292	37.0	37.7	36.2	0.53	4.8	421	174	203	544	7.5
17	DM	09-Jul-87	305	31.7	34.0	37.2	0.23	4.3	410	177	205	517	7.3
17	DM	13-Aug-87	291	33.3	42.0	30.4	0.42	4.9	423	186	200	525	7.4
17	DM	29-Sep-87	282	32.8	42.0	39.0	0.43	5.1	387	166	173	598	7.0
17	CyM/MKE	11-May-89	305	35.1	42.9	39.6	0.55	5.3	205	183	213	653	6.8
19	J	01-Jan-77	93	30.4	34.1	16.9	N.D.	N.D.	N.D.	30	1180	0	2.3
19	DM	19-Jan-87	90	40.0	25.5	13.1	N.D.	2.8	485	14	1298	N.D.	2.3
19	DM	05-Feb-87	94	32.8	21.1	13.6	0.06	1.5	484	14	1145	N.D.	2.3
19	DM	17-Mar-87	88	32.8	40.6	12.4	0.05	1.7	437	10	1143	N.D.	2.1
19	DM	08-May-87	88	27.9	42.0	13.0	N.D.	1.7	500	17	1186	N.D.	1.9
19	DM	01-Jun-87	87	30.8	47.8	12.3	0.03	3.0	448	38	1248	N.D.	2.3
19	DM	09-Jul-87	93	55.7	40.0	13.9	N.D.	1.7	469	27	1341	N.D.	2.1
19	DM	13-Aug-87	97	31.3	41.5	11.6	N.D.	1.5	436	18	1397	N.D.	2.2
20	J	01-Jan-77	585	53.0	3.2	1.0	N.D.	N.D.	N.D.	718	183	136	8.0
20	CyM/MKE	05-May-89	545	45.8	14.8	0.5	2.75	21.7	358	663	183	88	9.1

N.D. = No Data, DM = D. Michels report to CyM/MKE, CyM/MKE = COLLECTION BY CyM/MKE, J = JICA

TABLE 1. CHEMICAL COMPOSITIONS OF ZUNIL HOT SPRINGS

NAME	SOURCE	DATE	NA	K	CA	MG	LI	B	SIO2	CL	SO4	HCO3	PH
20Adn	CyM/MKE	05-May-89	133	24.0	55.2	21.8	0.21	1.8	184	46	471	19	5.4
20Aup	CyM/MKE	05-May-89	110	24.7	43.7	17.7	0.08	0.6	195	10	523	N.D.	3.3
21	J	01-Jan-77	95	8.0	14.0	10.6	N.D.	N.D.	N.D.	56	76	7	7.4
23	J	01-Jan-77	81	10.4	6.0	24.9	N.D.	N.D.	N.D.	43	32	16	7.0
23	DM	19-Jan-87	92	8.0	23.1	10.7	0.09	1.3	390	34	60	241	6.1
23	DM	05-Feb-87	87	10.1	25.2	11.3	0.13	1.3	403	37	65	246	6.2
23	DM	17-Mar-87	79	8.3	22.6	10.6	0.10	1.5	375	34	56	200	7.4
23	DM	08-May-87	82	6.3	23.9	11.2	0.08	1.3	301	34	61	195	6.1
23	DM	01-Jun-87	77	7.5	25.7	9.9	0.10	0.9	373	31	59	256	6.2
23	DM	09-Jul-87	77	7.6	20.0	11.1	N.D.	1.1	388	37	59	220	6.0
23	DM	13-Aug-87	85	5.2	22.0	9.1	N.D.	N.D.	422	36	70	207	6.3
23	DM	29-Sep-87	87	2.8	22.3	9.7	N.D.	1.3	316	44	56	210	6.6
24	J	01-Jan-77	116	15.4	12.8	10.6	N.D.	N.D.	N.D.	62	54	207	7.3
26	J	01-Jan-77	89	14.0	13.6	15.4	N.D.	N.D.	N.D.	36	41	224	7.2
27	J	01-Jan-77	136	14.0	14.4	8.0	N.D.	N.D.	N.D.	102	72	214	7.3
29	J	01-Jan-77	71	12.0	10.0	7.0	N.D.	N.D.	N.D.	47	16	165	7.1
30	J	01-Jan-77	34	4.0	11.2	8.0	N.D.	N.D.	N.D.	50	4	126	6.9
31	J	01-Jan-77	104	37.0	46.1	33.6	N.D.	N.D.	N.D.	20	969	0	1.5
32	J	01-Jan-77	23	5.0	10.4	7.5	N.D.	N.D.	N.D.	9	5	122	6.9
33	J	01-Jan-77	80	32.8	9.6	5.5	N.D.	N.D.	N.D.	56	20	157	7.3
34	J	01-Jan-77	151	36.4	66.1	31.4	N.D.	N.D.	N.D.	24	1534	0	2.5
35	J	01-Jan-77	26	9.8	22.0	10.6	N.D.	N.D.	N.D.	4	140	27	5.5
36	J	01-Jan-77	34	31.6	32.1	22.9	N.D.	N.D.	N.D.	20	266	0	3.5
36	DM	19-Jan-87	26	12.0	15.4	8.6	N.D.	0.6	197	7	134	N.D.	4.4
36	DM	05-Feb-87	30	7.8	18.1	10.2	N.D.	0.4	305	7	168	N.D.	4.8
36	DM	17-Mar-87	35	8.8	32.6	14.8	0.05	0.2	431	10	256	N.D.	3.4
36	DM	08-May-87	35	7.0	36.0	15.5	N.D.	0.9	514	7	261	N.D.	4.1
36	DM	01-Jun-87	38	8.8	49.8	18.2	N.D.	0.7	408	7	262	12	4.3
36	DM	09-Jul-87	43	9.6	54.0	23.8	N.D.	N.D.	309	10	380	N.D.	3.5
36	DM	13-Aug-87	59	11.2	54.5	19.8	N.D.	N.D.	513	18	492	N.D.	4.1
37	J	01-Jan-77	105	24.6	36.1	53.3	N.D.	N.D.	N.D.	87	96	619	6.7
37	DM	19-Jan-87	112	20.0	33.1	45.7	0.19	1.9	273	55	75	470	6.4
37	DM	05-Feb-87	113	15.6	24.1	45.2	0.23	1.3	290	58	84	380	6.4
37	DM	17-Mar-87	108	15.6	32.6	43.6	0.20	2.6	288	59	64	390	7.0
37	DM	08-May-87	108	12.9	36.0	44.8	0.20	4.5	292	55	72	390	6.6
37	DM	01-Jun-87	105	14.2	39.7	43.4	0.20	2.8	288	58	79	400	6.6
37	DM	09-Jul-87	113	5.6	34.0	44.4	N.D.	0.7	302	57	76	412	6.3
37	DM	13-Aug-87	117	13.2	38.0	40.7	0.08	0.5	265	62	90	380	7.5
37	DM	29-Sep-87	112	14.8	43.0	43.6	0.33	1.7	208	62	72	473	7.0
38	J	01-Jan-77	34	25.8	5.6	42.2	N.D.	N.D.	N.D.	17	311	28	4.6
38	DM	19-Jan-87	72	18.0	53.8	49.8	0.19	1.9	579	17	1773	N.D.	2.7
38	DM	05-Feb-87	56	11.1	49.2	29.6	0.15	0.9	723	13	1168	N.D.	2.6
38	DM	09-Jul-87	33	9.6	90.0	31.4	N.D.	0.4	416	17	1491	N.D.	2.4
4	J	01-Jan-77	146	13.8	15.2	7.5	N.D.	N.D.	N.D.	84	69	243	7.3

N.D. = No Data, *DM = D. Michels report to CyM/MKE,* CyM/MKE = COLLECTION BY CyM/MKE, *J = JICA*

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_11	15-Feb-80	694	67	19.5	N.D.	4.36	N.D.	41.0	356	1149	116
z_11	16-Feb-80	714	78	15.0	N.D.	4.94	N.D.	47.2	383	1156	126
z_11	17-Feb-80	1066	110	23.5	N.D.	6.69	N.D.	52.7	557	1680	191
z_11	19-Feb-80	1117	113	24.5	N.D.	N.D.	N.D.	40.6	742	1737	N.D.
z_11	29-Apr-80	1451	161	25.9	N.D.	8.55	N.D.	95.3	220	2326	202
z_11	02-May-80	1333	147	25.9	N.D.	7.76	N.D.	85.1	243	2162	200
z_11	03-May-80	543	63	10.0	N.D.	3.63	N.D.	38.0	236	925	69
z_11	05-May-80	1362	161	33.9	N.D.	7.86	N.D.	92.1	272	2219	213
z_11	08-May-80	1557	157	15.5	N.D.	8.51	N.D.	62.2	236	2446	220
z_11	09-May-80	1038	98	6.0	N.D.	5.58	N.D.	49.9	349	1563	140
z_11	11-May-80	1208	114	8.5	N.D.	6.72	N.D.	55.0	360	1932	153
z_11	14-May-80	1008	90	6.5	N.D.	5.48	N.D.	49.9	467	1606	126
z_11	15-May-80	938	96	17.0	N.D.	4.88	N.D.	N.D.	466	1482	148
z_11	17-May-80	1015	113	15.7	N.D.	5.76	N.D.	65.3	N.D.	1641	132
z_11	02-May-80	1005	107	17.1	N.D.	5.36	N.D.	12.5	N.D.	1507	139
z_11	21-May-80	64	10	2.1	N.D.	0.35	N.D.	9.9	N.D.	106	N.D.
z_11	23-May-80	1352	162	21.6	N.D.	7.82	N.D.	80.7	254	2265	180
z_11	26-May-80	1372	164	21.4	N.D.	7.82	N.D.	81.2	226	2287	187
z_11	27-May-80	1392	172	21.6	N.D.	8.06	N.D.	83.4	210	2304	179
z_11	29-May-80	1352	164	21.2	N.D.	7.82	N.D.	76.0	235	2287	183
z_11	01-Jun-80	1352	158	21.2	N.D.	7.70	N.D.	78.3	237	2244	178
z_11	02-Jun-80	1372	162	38.4	N.D.	7.70	N.D.	74.1	228	2276	177
z_11	05-Jun-80	1386	159	26.9	N.D.	7.99	N.D.	88.4	223	2443	186
z_11	08-Jun-80	1306	151	17.7	N.D.	7.62	N.D.	87.3	203	2333	177
z_11	09-Jun-80	1366	157	22.6	N.D.	8.11	N.D.	84.5	213	2333	186
z_11	11-Jun-80	1225	149	25.8	N.D.	7.62	N.D.	83.9	239	2240	180
z_11	14-Jun-80	1386	153	20.4	N.D.	7.75	N.D.	82.6	256	2272	210
z_11	15-Jun-80	1386	151	20.2	N.D.	7.62	N.D.	83.2	258	2187	216
z_11	17-Jun-80	1346	151	21.0	N.D.	7.87	N.D.	83.9	263	2297	220
z_11	19-Jun-80	1265	145	20.7	N.D.	7.50	N.D.	89.2	261	2216	187
z_11	21-Jun-80	1502	164	22.2	N.D.	8.21	N.D.	91.3	279	2368	245
z_11	03-Jun-80	1463	153	30.1	N.D.	7.85	N.D.	92.7	287	2354	185
z_11	05-Jul-80	1364	149	24.5	N.D.	7.61	N.D.	82.5	212	2287	156
z_11	07-Jul-80	1502	162	24.1	N.D.	8.21	N.D.	89.4	256	2489	189
z_11	09-Jul-80	1384	155	37.3	N.D.	7.61	N.D.	81.5	261	2269	183
z_11	11-Jul-80	1384	151	22.5	N.D.	7.73	N.D.	80.9	261	2304	157
z_11	13-Jul-80	1423	159	22.7	N.D.	7.85	N.D.	91.6	226	2393	187
z_11	15-Jul-80	1631	158	29.9	N.D.	7.54	N.D.	85.9	168	2326	162
z_11	17-Jul-80	1380	154	24.2	N.D.	7.54	N.D.	80.6	209	2361	141
z_11	19-Jul-80	1302	154	19.1	N.D.	7.05	N.D.	77.1	209	2262	131
z_11	21-Jul-80	1302	154	119.3	N.D.	7.30	N.D.	80.6	212	2312	146
z_11	23-Jul-80	1321	150	25.2	N.D.	7.17	N.D.	78.5	242	2276	158
z_11	25-Jul-80	1282	152	24.2	N.D.	7.30	N.D.	83.0	236	2255	131
z_11	27-Jul-80	1341	150	25.5	N.D.	7.30	N.D.	83.0	247	2276	136

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_11	06-Aug-80	1248	143	13.1	N.D.	7.37	N.D.	80.9	221	2131	146
z_11	07-Aug-80	1209	137	20.6	N.D.	7.12	N.D.	85.4	220	2081	137
z_11	09-Aug-80	1248	141	13.0	N.D.	7.37	N.D.	78.8	204	2138	126
z_11	11-Aug-80	1248	147	12.7	N.D.	7.24	N.D.	84.0	194	2120	125
z_11	13-Aug-80	1248	N.D.	12.7	N.D.	7.12	N.D.	82.8	204	2106	125
z_11	15-Aug-80	1170	134	12.4	N.D.	6.99	N.D.	85.9	237	2123	121
z_11	17-Aug-80	1189	136	12.4	N.D.	7.12	N.D.	85.2	213	2120	127
z_11	19-Aug-80	1170	134	12.4	N.D.	6.99	N.D.	85.9	228	2088	121
z_11	21-Aug-80	1455	151	31.6	N.D.	7.56	N.D.	85.7	197	2361	142
z_11	23-Aug-80	1349	145	26.0	N.D.	7.32	N.D.	85.9	165	2233	138
z_11	03-Sep-80	1348	139	30.4	N.D.	7.32	N.D.	79.1	220	2219	135
z_11	01-Sep-80	1261	131	33.5	N.D.	6.83	N.D.	76.3	208	2109	127
z_11	12-Sep-80	1251	135	24.6	N.D.	6.83	N.D.	74.5	191	2109	137
z_11	14-Sep-80	1222	127	28.9	N.D.	6.59	N.D.	74.5	231	2067	125
z_11	17-Sep-80	1232	131	24.2	N.D.	6.71	N.D.	74.1	243	2063	125
z_11	22-Sep-80	1397	157	24.3	N.D.	7.92	N.D.	81.7	243	2127	135
z_11	24-Sep-80	1337	134	22.4	N.D.	6.93	N.D.	86.3	290	2170	127
z_11	26-Sep-80	1356	130	22.9	N.D.	7.05	N.D.	83.0	247	2187	125
z_11	28-Sep-80	1376	134	36.0	N.D.	7.05	N.D.	83.5	230	2233	125
z_11	03-Sep-80	1433	140	35.5	N.D.	7.54	N.D.	85.8	281	2304	131
z_11	21-Nov-80	1496	162	40.0	N.D.	7.50	N.D.	49.0	237	2180	172
z_11	23-Nov-80	1446	160	29.7	N.D.	7.74	N.D.	37.4	194	2177	131
z_11	27-Nov-80	1427	160	26.9	N.D.	7.50	N.D.	41.4	209	2177	150
z_11	29-Nov-80	1387	158	41.2	N.D.	7.38	N.D.	45.4	209	2174	161
z_11	01-Dec-80	1427	158	26.2	N.D.	7.62	N.D.	45.6	180	2179	166
z_11	03-Dec-80	1456	160	30.2	N.D.	7.62	N.D.	54.9	209	2184	135
z_11	05-Jul-83	1039	114	11.3	N.D.	7.07	N.D.	50.2	394	1631	30
z_11	07-Jul-83	1069	115	11.2	N.D.	7.46	N.D.	49.4	390	1648	40
z_11	11-Jul-83	1068	117	11.3	N.D.	7.61	N.D.	53.4	342	1646	41
z_11	13-Jul-83	1029	116	11.1	N.D.	7.56	N.D.	49.8	414	1631	34
z_11	15-Jul-83	1020	115	11.0	N.D.	7.37	N.D.	48.9	411	1613	35
z_11	19-Jul-83	1029	116	11.1	N.D.	7.37	N.D.	48.9	479	1631	40
z_11	21-Jul-83	1029	113	11.2	N.D.	7.41	N.D.	49.8	522	1613	33
z_11	22-Jul-87	1096	98	19.2	N.D.	5.85	N.D.	48.7	1426	1619	106
z_11	29-Jul-87	1123	118	20.4	N.D.	6.08	N.D.	48.9	1501	1659	101
z_11	07-Aug-87	1026	101	27.5	N.D.	5.88	N.D.	57.6	1134	1764	124
z_11	26-Aug-87	1060	88	24.8	N.D.	4.88	N.D.	41.8	698	1640	97
z_11	26-Aug-87	1110	98	22.8	N.D.	4.88	N.D.	36.1	752	1622	96
z_11	09-Aug-87	1192	98	22.8	N.D.	5.90	N.D.	65.6	791	1773	129
z_11	06-Aug-87	1146	98	22.8	N.D.	5.90	N.D.	50.4	1422	1708	105
z_11	23-Jul-87	1067	90	24.4	N.D.	5.69	N.D.	72.0	1686	1626	110
z_11	02-Jul-87	580	113	1.3	N.D.	3.47	N.D.	57.3	469	985	76
z_11	02-Jul-83	1029	115	10.9	N.D.	7.37	N.D.	49.4	497	1613	130
z_11	18-Jul-83	1049	116	11.1	N.D.	7.41	N.D.	49.4	486	1613	35

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_11	14-Jul-83	1039	119	21.1	N.D.	7.41	N.D.	52.6	398	1613	37
z_11	12-Jul-83	1029	115	11.1	N.D.	7.61	N.D.	50.2	373	1613	38
z_11	08-Jul-83	1029	116	11.3	N.D.	6.83	N.D.	48.3	398	1613	29
z_11	06-Jul-83	1049	114	11.0	N.D.	7.46	N.D.	48.9	390	1613	30
z_11	04-Jul-83	1039	115	11.2	N.D.	7.61	N.D.	48.3	326	1613	33
z_11	02-Dec-80	1397	160	25.9	N.D.	7.50	N.D.	57.7	238	2182	168
z_11	03-Nov-80	1427	158	45.0	N.D.	7.50	N.D.	53.7	225	2174	149
z_11	28-Nov-80	1437	162	25.4	N.D.	7.50	N.D.	40.6	224	2179	162
z_11	25-Nov-80	1476	160	34.2	N.D.	7.50	N.D.	32.2	228	2177	144
z_11	22-Nov-80	1466	166	25.7	N.D.	7.74	N.D.	42.2	230	2179	156
z_11	19-Nov-80	1427	162	25.9	N.D.	7.74	N.D.	45.1	209	2179	166
z_11	29-Sep-80	1425	140	33.9	N.D.	7.42	N.D.	86.0	281	2318	132
z_11	27-Sep-80	1376	134	22.8	N.D.	7.42	N.D.	83.3	252	2269	132
z_11	25-Sep-80	1346	134	22.7	N.D.	7.05	N.D.	85.8	262	2191	136
z_11	23-Sep-80	1368	157	23.8	N.D.	7.68	N.D.	81.0	237	2145	136
z_11	21-Sep-80	1378	159	24.2	N.D.	7.68	N.D.	76.8	229	2097	136
z_11	15-Sep-80	1242	133	28.9	N.D.	6.83	N.D.	74.3	243	2092	127
z_11	13-Sep-80	1222	135	24.1	N.D.	6.71	N.D.	72.1	193	2045	126
z_11	11-Sep-80	1251	131	24.6	N.D.	6.95	N.D.	74.3	199	2116	126
z_11	09-Sep-80	1290	133	26.1	N.D.	6.95	N.D.	76.6	210	2162	138
z_11	31-Aug-80	1339	143	30.2	N.D.	7.07	N.D.	85.5	169	2209	131
z_11	22-Aug-80	1397	145	26.8	N.D.	7.44	N.D.	88.1	184	2297	143
z_11	02-Aug-80	1261	135	30.6	N.D.	6.83	N.D.	83.7	180	2031	133
z_11	18-Aug-80	1209	136	12.4	N.D.	6.99	N.D.	85.7	232	2145	121
z_11	16-Aug-80	1170	134	12.4	N.D.	6.99	N.D.	84.9	221	2120	121
z_11	14-Aug-80	1228	136	12.8	N.D.	7.12	N.D.	83.7	213	2120	121
z_11	12-Aug-80	1248	140	12.7	N.D.	7.49	N.D.	81.3	221	2184	127
z_11	01-Aug-80	1248	141	13.1	N.D.	7.49	N.D.	83.2	203	2170	141
z_11	08-Aug-80	1189	139	12.5	N.D.	6.87	N.D.	78.5	218	2035	127
z_11	29-Jul-80	1302	150	24.5	N.D.	7.30	N.D.	84.2	245	2297	125
z_11	28-Jul-80	1321	148	102.6	N.D.	6.93	N.D.	78.3	226	2262	126
z_11	26-Jul-80	1302	150	25.2	N.D.	7.42	N.D.	77.3	243	2297	131
z_11	24-Jul-80	1302	150	24.4	N.D.	7.42	N.D.	79.2	243	2226	125
z_11	22-Jul-80	1302	150	26.4	N.D.	7.17	N.D.	78.0	217	2262	152
z_11	02-Jul-80	1302	148	107.9	N.D.	7.05	N.D.	80.6	207	2255	132
z_11	18-Jul-80	1321	156	22.7	N.D.	7.05	N.D.	78.3	181	2262	149
z_11	16-Jul-80	1341	158	100.0	N.D.	7.66	N.D.	84.9	186	2283	157
z_11	14-Jul-80	1384	143	22.0	N.D.	7.61	N.D.	89.1	264	2269	172
z_11	12-Jul-80	1423	153	22.1	N.D.	7.73	N.D.	89.4	261	2357	172
z_11	01-Jul-80	1384	153	22.7	N.D.	7.73	N.D.	89.1	231	2375	166
z_11	08-Jul-80	1482	160	26.4	N.D.	8.33	N.D.	94.4	232	2428	193
z_11	06-Jul-80	1384	153	24.1	N.D.	7.61	N.D.	86.2	227	2244	155
z_11	04-Jul-80	1443	157	26.7	N.D.	7.73	N.D.	91.6	239	2269	160
z_11	22-Jun-80	1423	155	22.0	N.D.	7.73	N.D.	88.1	287	2301	163

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_11	02-Jun-80	1660	178	24.3	N.D.	9.42	N.D.	87.8	234	2673	313
z_11	18-Jun-80	1446	169	21.5	N.D.	8.59	N.D.	89.7	260	2467	244
z_11	16-Jun-80	1326	149	20.8	N.D.	7.62	N.D.	83.9	256	2248	199
z_11	13-Jun-80	1326	153	21.4	N.D.	7.87	N.D.	85.0	254	2322	198
z_11	12-Jun-80	1306	153	19.0	N.D.	7.75	N.D.	83.9	235	2272	182
z_11	01-Jun-80	1265	147	20.2	N.D.	7.62	N.D.	83.7	208	2209	176
z_11	07-Jun-80	1607	153	24.7	N.D.	8.59	N.D.	88.7	198	2754	952
z_11	06-Jun-80	1406	151	20.9	N.D.	7.87	N.D.	86.5	200	2411	177
z_11	03-Jun-80	1392	164	21.9	N.D.	7.82	N.D.	79.5	237	2308	192
z_11	31-May-80	1352	158	30.0	N.D.	7.94	N.D.	83.2	210	2276	183
z_11	03-May-80	1392	162	31.0	N.D.	7.94	N.D.	78.1	223	2301	183
z_11	28-May-80	1311	166	21.5	N.D.	7.94	N.D.	85.4	228	2322	189
z_11	25-May-80	1372	170	21.5	N.D.	8.19	N.D.	80.7	244	2347	190
z_11	24-May-80	1352	168	21.4	N.D.	7.82	N.D.	78.1	210	2269	188
z_11	22-May-80	749	82	11.8	N.D.	4.27	N.D.	40.3	N.D.	1237	91
z_11	19-May-80	163	18	6.0	N.D.	0.99	N.D.	15.8	N.D.	312	29
z_11	18-May-80	1214	153	17.2	N.D.	6.65	N.D.	87.0	N.D.	1932	164
z_11	16-May-80	76	8	3.8	N.D.	0.45	N.D.	13.0	N.D.	156	2
z_11	13-May-80	1278	118	11.0	N.D.	6.82	N.D.	57.6	385	1975	158
z_11	12-May-80	958	84	6.5	N.D.	5.23	N.D.	72.1	423	1556	120
z_11	01-May-80	918	75	6.0	N.D.	4.78	N.D.	67.7	403	1489	117
z_11	07-May-80	889	86	13.0	N.D.	4.57	N.D.	51.7	250	1287	113
z_11	06-May-80	928	104	15.5	N.D.	5.50	N.D.	64.8	245	1510	136
z_11	04-May-80	1175	127	18.5	N.D.	6.83	N.D.	72.0	302	1879	176
z_11	01-May-80	1412	155	22.4	N.D.	8.01	N.D.	84.6	253	2209	195
z_11	03-Apr-80	1392	151	24.4	N.D.	7.96	N.D.	90.9	250	2209	194
z_11	24-Apr-80	1579	172	52.7	N.D.	N.D.	N.D.	N.D.	N.D.	2503	N.D.
z_11	17-Feb-80	976	103	21.1	N.D.	6.20	N.D.	49.5	577	1531	163
z_11	16-Feb-80	795	83	22.5	N.D.	5.14	N.D.	45.7	409	1263	157
z_11	15-Feb-80	976	106	28.0	N.D.	6.49	N.D.	52.5	495	1595	160
z_2	20-Jul-78	763	99	34.5	0.13	6.76	0.13	36.6	473	1383	41
z_2	20-Jul-78	793	98	21.9	0.19	6.92	0.19	40.3	N.D.	1383	39
z_2	01-Aug-78	800	127	35.6	0.37	6.76	0.37	39.6	293	1365	44
z_2	31-Jul-78	748	99	43.4	0.60	6.88	0.60	39.6	N.D.	1355	47
z_2	31-Jul-78	793	98	33.7	0.13	6.76	0.13	39.4	464	1355	40
z_2	05-Aug-78	763	100	33.3	0.34	6.84	0.34	40.1	441	1400	43
z_2	04-Aug-78	N.D.	N.D.	N.D.	N.D.	6.88	N.D.	38.9	N.D.	1436	40
z_2	04-Aug-78	795	125	36.2	0.34	6.84	0.34	36.9	447	1436	46
z_2	02-Aug-78	N.D.	N.D.	N.D.	N.D.	6.88	N.D.	39.4	N.D.	1418	29
z_2	02-Aug-78	795	132	36.4	0.36	5.76	0.36	40.1	293	1418	30
z_2	01-Aug-78	781	N.D.	34.4	N.D.	6.88	N.D.	39.9	N.D.	1365	46
z_2	05-Aug-78	795	99	41.4	0.36	6.88	0.36	37.4	N.D.	1400	39
z_2	09-Aug-78	778	106	37.4	0.33	6.75	0.33	33.9	N.D.	1418	27
z_2	13-Aug-78	838	111	35.9	0.37	6.95	0.37	36.1	N.D.	1453	20

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_2	13-Aug-78	953	113	34.9	0.28	6.90	0.28	35.7	466	1453	17
z_2	12-Aug-78	785	114	34.9	0.32	6.95	0.32	36.3	N.D.	1436	17
z_2	12-Aug-78	780	110	48.3	1.04	7.00	1.04	34.6	443	1436	17
z_2	11-Aug-78	763	108	35.1	0.36	6.60	0.36	33.5	437	1418	25
z_2	01-Aug-78	835	109	37.2	0.32	6.75	0.32	33.5	N.D.	1400	32
z_2	01-Aug-78	833	107	35.7	0.30	6.45	0.30	33.5	417	1400	31
z_2	09-Aug-78	890	105	36.5	0.36	6.65	0.36	32.4	335	1418	28
z_2	08-Aug-78	790	105	37.8	0.38	6.96	0.38	40.3	N.D.	1418	29
z_2	08-Aug-78	910	108	37.2	0.31	6.96	0.31	40.6	434	1418	62
z_2	07-Aug-78	755	103	39.2	1.06	6.72	1.06	39.9	N.D.	1383	49
z_2	07-Aug-78	760	103	36.5	0.32	6.84	0.32	39.9	386	1383	50
z_2	06-Aug-78	753	103	36.1	0.35	6.76	0.35	40.3	N.D.	1400	32
z_2	06-Aug-78	780	106	47.9	0.95	6.92	0.95	40.3	445	1400	27
z_2	14-Aug-78	818	111	34.3	0.41	7.05	0.41	36.3	462	1453	18
z_2	16-Aug-78	825	119	36.1	0.38	7.15	0.38	37.4	456	1489	16
z_2	18-Aug-78	823	119	35.1	0.39	6.70	0.39	37.2	442	1489	24
z_2	03-Sep-78	821	131	93.5	1.52	6.40	1.52	34.4	540	1276	30
z_2	05-Sep-78	850	118	84.1	0.90	6.75	0.90	36.7	552	1294	42
z_2	07-Sep-78	922	121	92.5	1.42	6.85	1.42	38.5	N.D.	1383	36
z_2	09-Sep-78	892	111	95.5	1.00	6.65	1.00	36.4	N.D.	1312	36
z_2	11-Sep-78	824	117	89.6	0.96	6.35	0.96	35.4	N.D.	1276	49
z_2	15-Sep-78	919	129	91.0	0.64	7.05	0.64	39.5	526	1383	42
z_2	16-Sep-78	853	123	86.1	0.06	7.40	0.06	41.0	534	1453	34
z_2	14-Sep-78	961	136	95.0	0.10	7.65	0.10	43.3	531	1524	40
z_2	13-Sep-78	1142	142	108.0	0.09	8.45	0.09	46.3	N.D.	1595	40
z_2	13-Sep-78	998	126	97.5	0.18	7.75	0.18	43.8	526	1524	36
z_2	11-Sep-78	806	115	95.5	0.97	6.45	0.97	36.7	484	1276	42
z_2	01-Sep-78	809	113	93.5	0.98	6.65	0.98	36.4	N.D.	1312	39
z_2	01-Sep-78	880	122	95.5	0.89	6.65	0.89	36.4	484	1329	43
z_2	09-Sep-78	880	113	95.5	0.91	6.85	0.91	37.4	481	1329	37
z_2	08-Sep-78	907	125	88.1	1.02	6.85	1.02	36.9	N.D.	1329	36
z_2	08-Sep-78	912	115	102.5	1.10	6.85	1.10	38.0	477	1383	35
z_2	07-Sep-78	863	125	88.6	0.76	6.75	0.76	38.5	533	1312	39
z_2	06-Sep-78	863	115	94.0	0.93	6.80	0.93	38.5	N.D.	1329	34
z_2	06-Sep-78	738	99	75.1	0.90	5.75	0.90	33.1	542	1329	45
z_2	04-Sep-78	752	122	86.1	0.92	6.55	0.92	35.9	N.D.	1294	41
z_2	04-Sep-78	792	121	87.1	0.94	6.60	0.94	37.7	557	1294	33
z_2	03-Sep-78	841	118	89.1	1.09	6.70	1.09	36.9	N.D.	1276	34
z_2	02-Sep-78	951	139	83.6	0.86	6.85	0.86	40.5	N.D.	1347	29
z_2	02-Sep-78	868	136	84.6	0.64	6.75	0.64	36.9	537	1347	31
z_2	01-Sep-78	748	122	80.6	0.43	6.45	0.43	35.9	463	1329	39
z_2	17-Aug-78	813	116	35.1	0.46	6.95	0.46	36.3	N.D.	1489	32
z_2	17-Aug-78	858	117	35.1	0.36	6.95	0.36	38.7	510	1489	29
z_2	16-Aug-78	823	119	36.3	0.36	7.15	0.36	36.1	N.D.	1489	16

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_2	15-Aug-78	810	121	35.9	0.37	7.05	0.37	37.0	N.D.	1471	17
z_2	15-Aug-78	905	116	35.7	0.46	7.05	0.46	36.1	503	1471	19
z_2	14-Aug-78	818	115	34.7	0.48	7.05	0.48	35.2	N.D.	1453	18
z_4	21-Dec-79	519	54	12.2	N.D.	2.80	N.D.	14.2	175	744	177
z_4	22-Dec-79	524	54	12.7	N.D.	2.76	N.D.	14.5	166	737	189
z_4	23-Dec-79	524	54	6.9	N.D.	2.86	N.D.	9.0	159	752	199
z_4	31-Dec-79	529	54	7.0	N.D.	2.78	N.D.	19.6	N.D.	802	184
z_4	03-Dec-79	534	56	10.2	N.D.	2.78	N.D.	19.0	N.D.	730	196
z_4	01-Jan-80	539	54	9.5	N.D.	2.80	N.D.	20.6	N.D.	645	185
z_4	29-Dec-79	534	54	6.9	N.D.	2.80	N.D.	19.3	N.D.	744	182
z_4	15-Feb-80	511	53	6.9	N.D.	2.86	N.D.	21.2	328	737	170
z_4	14-Feb-80	506	53	6.8	N.D.	2.84	N.D.	21.0	341	716	190
z_4	13-Feb-80	511	52	13.1	N.D.	2.84	N.D.	22.0	335	727	175
z_4	12-Feb-80	511	52	12.4	N.D.	2.84	N.D.	23.6	330	734	191
z_4	11-Feb-80	511	52	6.8	N.D.	2.88	N.D.	25.1	318	737	180
z_4	28-Dec-79	529	54	7.2	N.D.	2.78	N.D.	15.9	N.D.	751	186
z_4	27-Dec-79	524	54	11.4	N.D.	2.85	N.D.	11.8	N.D.	755	205
z_4	26-Dec-79	529	53	9.5	N.D.	2.79	N.D.	16.4	N.D.	730	181
z_4	25-Dec-79	524	54	7.2	N.D.	2.78	N.D.	11.6	N.D.	737	188
z_4	24-Dec-79	534	54	6.8	N.D.	2.76	N.D.	16.1	159	723	199
z_4	02-Jan-80	529	54	8.0	N.D.	2.78	N.D.	20.6	N.D.	755	184
z_4	21-Feb-80	520	50	7.6	N.D.	2.92	N.D.	24.4	344	720	187
z_4	02-Feb-80	506	51	7.8	N.D.	2.62	N.D.	25.2	189	755	184
z_4	19-Feb-80	506	50	7.3	N.D.	2.96	N.D.	24.6	242	741	186
z_4	18-Feb-80	520	53	12.2	N.D.	2.92	N.D.	25.1	249	716	189
z_4	17-Feb-80	501	52	6.7	N.D.	2.84	N.D.	22.7	306	723	180
z_4	16-Feb-80	516	52	6.6	N.D.	2.84	N.D.	21.7	305	727	185
z_4	06-Jan-80	534	55	7.1	N.D.	2.81	N.D.	21.3	241	744	190
z_4	01-Jan-80	524	53	7.2	N.D.	2.79	N.D.	21.7	231	N.D.	204
z_4	14-Jan-80	509	54	7.3	N.D.	2.82	N.D.	22.6	315	752	183
z_4	18-Jan-80	530	52	13.6	N.D.	2.79	N.D.	21.3	223	752	201
z_4	22-Jan-80	540	53	7.2	N.D.	2.79	N.D.	20.1	249	709	188
z_4	31-Mar-80	564	60	6.6	N.D.	2.56	N.D.	20.2	354	691	153
z_4	03-Mar-80	529	60	6.6	N.D.	2.51	N.D.	19.8	357	691	152
z_4	29-Mar-80	484	51	6.8	N.D.	2.64	N.D.	19.5	364	684	174
z_4	28-Mar-80	484	50	6.4	N.D.	2.59	N.D.	18.1	386	649	169
z_4	27-Mar-80	489	50	10.2	N.D.	2.73	N.D.	20.4	364	689	174
z_4	26-Feb-80	520	52	7.3	N.D.	2.82	N.D.	23.9	341	720	182
z_4	25-Feb-80	491	52	7.3	N.D.	2.92	N.D.	24.4	341	720	183
z_4	24-Feb-80	511	53	7.3	N.D.	3.01	N.D.	24.4	305	744	187
z_4	23-Feb-80	501	52	7.9	N.D.	2.92	N.D.	25.1	273	723	183
z_4	22-Feb-80	511	51	7.4	N.D.	2.87	N.D.	24.4	274	723	196
z_4	28-Jan-80	525	52	7.1	N.D.	2.79	N.D.	19.8	334	723	178
z_4	15-Apr-80	481	49	6.4	N.D.	2.58	N.D.	20.7	369	677	173

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_4	14-Apr-80	481	53	6.4	N.D.	2.53	N.D.	20.7	365	674	170
z_4	13-Apr-80	456	49	6.2	N.D.	2.44	N.D.	21.4	314	652	166
z_4	12-Apr-80	452	49	6.2	N.D.	2.49	N.D.	20.7	311	645	157
z_4	11-Apr-80	454	53	6.5	N.D.	2.47	N.D.	19.6	366	670	155
z_4	01-Apr-80	464	50	12.8	N.D.	2.56	N.D.	19.5	296	663	148
z_4	09-Apr-80	574	48	13.2	N.D.	2.47	N.D.	19.0	304	663	145
z_4	08-Apr-80	524	45	6.2	N.D.	2.32	N.D.	18.9	272	652	146
z_4	07-Apr-80	529	51	6.2	N.D.	2.42	N.D.	18.9	332	656	148
z_4	02-Apr-80	574	53	6.4	N.D.	2.61	N.D.	19.8	340	674	160
z_4	01-Apr-80	554	56	6.6	N.D.	2.47	N.D.	19.9	334	674	148
z_4	24-Apr-80	474	47	6.2	N.D.	2.55	N.D.	19.5	394	663	161
z_4	23-Apr-80	518	47	6.4	N.D.	2.55	N.D.	19.8	365	674	159
z_4	22-Apr-80	479	46	6.5	N.D.	2.60	N.D.	19.2	381	674	161
z_4	21-Apr-80	484	47	6.5	N.D.	2.60	N.D.	19.3	376	656	156
z_4	02-Apr-80	456	48	6.3	N.D.	2.58	N.D.	21.2	356	666	166
z_4	19-Apr-80	471	49	6.3	N.D.	2.58	N.D.	21.7	370	681	169
z_4	18-Apr-80	471	49	6.4	N.D.	2.63	N.D.	20.2	360	688	172
z_4	17-Apr-80	471	49	6.5	N.D.	2.58	N.D.	20.2	377	670	166
z_4	16-Apr-80	476	56	6.4	N.D.	2.63	N.D.	22.0	373	677	172
z_4	01-Feb-80	516	53	10.9	N.D.	2.81	N.D.	22.7	258	727	180
z_4	05-Feb-80	506	52	6.7	N.D.	2.79	N.D.	23.6	302	727	191
z_4	06-May-80	469	49	6.6	N.D.	2.60	N.D.	20.1	410	677	166
z_4	05-May-80	479	49	12.5	N.D.	2.70	N.D.	20.5	413	688	161
z_4	04-May-80	489	48	9.0	N.D.	2.60	N.D.	20.2	400	691	165
z_4	03-May-80	489	50	6.5	N.D.	2.75	N.D.	20.1	408	709	162
z_4	02-May-80	469	48	6.5	N.D.	2.60	N.D.	20.2	382	705	156
z_4	01-May-80	469	49	6.4	N.D.	2.65	N.D.	20.3	405	684	163
z_4	03-Apr-80	474	48	6.5	N.D.	2.65	N.D.	20.2	404	695	159
z_4	29-Apr-80	479	49	6.4	N.D.	2.65	N.D.	19.2	387	713	166
z_4	28-Apr-80	474	49	9.9	N.D.	2.55	N.D.	20.2	391	713	161
z_4	27-Apr-80	489	49	11.0	N.D.	2.75	N.D.	20.2	403	688	163
z_4	26-Apr-80	464	47	6.5	N.D.	2.55	N.D.	19.7	358	645	152
z_4	16-May-80	518	51	6.1	N.D.	2.78	N.D.	21.1	370	695	182
z_4	15-May-80	494	55	6.6	N.D.	2.64	N.D.	19.5	382	709	183
z_4	14-May-80	499	56	6.5	N.D.	2.69	N.D.	20.0	383	705	181
z_4	13-May-80	499	54	6.6	N.D.	2.69	N.D.	19.5	413	702	181
z_4	12-May-80	489	58	7.6	N.D.	2.69	N.D.	19.8	427	684	191
z_4	11-May-80	599	59	6.6	N.D.	2.69	N.D.	19.8	367	734	191
z_4	01-May-80	504	59	13.3	N.D.	2.69	N.D.	19.4	373	713	183
z_4	09-May-80	504	59	8.9	N.D.	2.64	N.D.	20.8	367	705	185
z_4	08-May-80	509	53	6.7	N.D.	2.69	N.D.	19.7	351	713	190
z_4	07-May-80	524	66	14.7	N.D.	2.79	N.D.	21.2	345	762	194
z_4	25-Apr-80	469	47	6.3	N.D.	2.55	N.D.	20.0	403	691	160
z_4	29-May-80	489	51	11.5	N.D.	2.74	N.D.	19.7	360	705	182

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_4	28-May-80	489	51	6.9	N.D.	2.74	N.D.	20.8	407	730	174
z_4	27-May-80	494	51	6.9	N.D.	2.69	N.D.	20.2	370	709	170
z_4	26-May-80	489	50	8.7	N.D.	2.69	N.D.	17.5	374	723	175
z_4	25-May-80	594	51	6.9	N.D.	2.69	N.D.	16.6	354	698	175
z_4	24-May-80	514	50	7.5	N.D.	2.74	N.D.	20.2	376	741	174
z_4	22-May-80	493	51	8.3	N.D.	2.73	N.D.	20.8	381	695	177
z_4	21-May-80	487	51	6.0	N.D.	2.58	N.D.	22.3	385	709	173
z_4	02-May-80	483	51	6.0	N.D.	2.73	N.D.	22.1	381	702	171
z_4	19-May-80	483	21	6.1	N.D.	2.68	N.D.	21.9	384	727	172
z_4	18-May-80	483	50	6.0	N.D.	2.58	N.D.	20.7	369	702	177
z_4	01-Jun-80	477	48	9.8	N.D.	2.76	N.D.	21.6	375	684	185
z_4	09-Jun-80	457	48	6.6	N.D.	2.71	N.D.	20.8	363	684	178
z_4	08-Jun-80	477	48	6.6	N.D.	2.71	N.D.	21.4	331	698	188
z_4	07-Jun-80	477	48	6.5	N.D.	2.71	N.D.	20.2	363	695	182
z_4	06-Jun-80	477	48	6.5	N.D.	2.11	N.D.	19.7	382	688	178
z_4	05-Jun-80	467	50	11.7	N.D.	2.76	N.D.	20.7	373	709	182
z_4	03-Jun-80	489	51	10.8	N.D.	2.69	N.D.	18.3	414	716	183
z_4	02-Jun-80	489	50	7.0	N.D.	2.69	N.D.	20.5	412	698	172
z_4	01-Jun-80	484	51	6.9	N.D.	2.69	N.D.	18.7	389	720	184
z_4	31-May-80	489	50	12.6	N.D.	2.78	N.D.	20.9	375	705	180
z_4	03-May-80	489	50	11.9	N.D.	2.98	N.D.	19.2	351	705	167
z_4	18-Jun-80	467	48	6.3	N.D.	2.71	N.D.	20.2	391	748	173
z_4	17-Jun-80	457	47	6.5	N.D.	2.61	N.D.	20.8	397	702	174
z_4	16-Jun-80	467	48	6.5	N.D.	2.66	N.D.	20.7	381	709	177
z_4	15-Jun-80	472	48	6.5	N.D.	2.66	N.D.	21.9	381	705	177
z_4	14-Jun-80	462	48	6.5	N.D.	2.66	N.D.	21.5	364	720	175
z_4	13-Jun-80	467	47	6.3	N.D.	2.47	N.D.	20.7	373	744	183
z_4	12-Jun-80	467	47	6.6	N.D.	2.61	N.D.	20.1	384	688	177
z_4	11-Jun-80	462	48	6.5	N.D.	2.71	N.D.	21.1	395	688	177
z_4	17-May-80	483	51	6.0	N.D.	2.73	N.D.	20.9	352	713	183
z_4	09-Feb-80	516	53	6.8	N.D.	2.81	N.D.	23.7	328	695	190
z_4	08-Feb-80	505	54	6.7	N.D.	2.81	N.D.	22.5	311	752	175
z_4	01-Jul-80	474	49	13.4	N.D.	2.61	N.D.	20.6	365	670	165
z_4	09-Jul-80	499	48	14.1	N.D.	2.66	N.D.	22.0	359	695	180
z_4	08-Jul-80	479	47	6.6	N.D.	2.56	N.D.	21.5	351	670	170
z_4	07-Jul-80	455	47	12.9	N.D.	2.61	N.D.	20.7	345	666	170
z_4	06-Jul-80	465	47	7.0	N.D.	2.61	N.D.	21.8	372	666	172
z_4	05-Jul-80	465	46	13.3	N.D.	2.66	N.D.	22.0	368	695	172
z_4	04-Jul-80	474	48	13.2	N.D.	2.66	N.D.	22.6	351	663	163
z_4	25-Jun-80	479	48	12.9	N.D.	2.66	N.D.	23.5	333	681	178
z_4	22-Jun-80	479	48	6.8	N.D.	2.66	N.D.	21.4	320	684	182
z_4	21-Jun-80	504	48	7.2	N.D.	2.70	N.D.	22.4	293	698	180
z_4	02-Jun-80	499	48	6.8	N.D.	2.46	N.D.	22.8	320	741	187
z_4	23-Jul-80	463	51	6.7	N.D.	2.77	N.D.	19.7	307	381	169

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_4	22-Jul-80	454	50	6.7	N.D.	2.63	N.D.	20.2	283	659	174
z_4	21-Jul-80	463	50	6.8	N.D.	2.68	N.D.	20.8	304	670	171
z_4	02-Jul-80	463	49	6.4	N.D.	2.63	N.D.	20.2	301	695	176
z_4	19-Jul-80	468	49	6.6	N.D.	2.63	N.D.	20.6	300	677	171
z_4	18-Jul-80	468	50	6.8	N.D.	2.63	N.D.	20.8	299	688	176
z_4	17-Jul-80	463	49	6.6	N.D.	2.68	N.D.	20.8	306	674	176
z_4	16-Jul-80	468	50	13.7	N.D.	2.63	N.D.	19.7	287	677	171
z_4	15-Jul-80	478	50	6.6	N.D.	2.68	N.D.	19.6	297	705	170
z_4	14-Jul-80	470	47	12.9	N.D.	2.61	N.D.	22.6	375	670	171
z_4	13-Jul-80	460	47	6.6	N.D.	2.61	N.D.	22.7	348	695	170
z_4	09-Aug-80	473	76	13.4	N.D.	2.80	N.D.	19.8	325	677	174
z_4	08-Aug-80	478	75	6.4	N.D.	2.75	N.D.	18.6	313	684	177
z_4	07-Aug-80	458	64	6.4	N.D.	2.70	N.D.	21.0	314	684	168
z_4	06-Aug-80	473	77	13.9	N.D.	2.80	N.D.	20.8	330	720	174
z_4	29-Jul-80	463	50	7.0	N.D.	2.77	N.D.	20.2	303	681	167
z_4	28-Jul-80	454	50	6.6	N.D.	2.68	N.D.	19.6	302	666	176
z_4	27-Jul-80	463	50	6.9	N.D.	2.63	N.D.	20.7	311	666	175
z_4	26-Jul-80	459	50	12.7	N.D.	2.63	N.D.	19.4	311	677	171
z_4	25-Jul-80	463	52	6.7	N.D.	2.68	N.D.	20.9	386	691	176
z_4	24-Jul-80	459	50	6.6	N.D.	2.68	N.D.	20.8	300	670	179
z_4	12-Jul-80	474	46	6.5	N.D.	2.61	N.D.	22.6	345	663	173
z_4	02-Aug-80	485	49	6.5	N.D.	2.68	N.D.	19.1	260	666	173
z_4	19-Aug-80	458	74	6.6	N.D.	2.65	N.D.	19.7	338	677	169
z_4	18-Aug-80	453	57	6.5	N.D.	2.75	N.D.	20.2	339	681	176
z_4	17-Aug-80	458	76	6.4	N.D.	2.70	N.D.	20.8	335	691	172
z_4	16-Aug-80	463	77	6.3	N.D.	2.70	N.D.	20.9	314	688	170
z_4	15-Aug-80	453	56	6.4	N.D.	2.60	N.D.	19.7	327	688	177
z_4	14-Aug-80	468	75	7.0	N.D.	2.85	N.D.	20.2	339	688	173
z_4	13-Aug-80	453	60	7.2	N.D.	2.75	N.D.	20.8	327	691	172
z_4	12-Aug-80	453	72	14.1	N.D.	2.75	N.D.	20.3	339	702	177
z_4	11-Aug-80	458	68	8.9	N.D.	2.65	N.D.	20.2	316	702	168
z_4	01-Aug-80	463	77	13.3	N.D.	2.70	N.D.	19.7	316	688	177
z_4	16-Sep-80	446	47	13.8	N.D.	2.63	N.D.	19.9	340	666	168
z_4	14-Sep-80	446	46	6.3	N.D.	2.63	N.D.	20.1	334	681	171
z_4	13-Sep-80	461	48	6.2	N.D.	2.68	N.D.	20.6	335	674	168
z_4	12-Sep-80	461	47	9.8	N.D.	2.68	N.D.	30.0	345	691	174
z_4	11-Aug-80	466	48	13.7	N.D.	2.78	N.D.	20.2	324	688	173
z_4	01-Sep-80	475	49	6.7	N.D.	2.73	N.D.	20.4	332	674	177
z_4	09-Sep-80	470	48	11.6	N.D.	2.68	N.D.	20.3	299	688	172
z_4	04-Sep-80	470	49	6.9	N.D.	2.73	N.D.	20.9	318	684	177
z_4	03-Sep-80	470	47	6.5	N.D.	2.68	N.D.	20.2	310	720	174
z_4	23-Aug-80	475	49	6.5	N.D.	2.68	N.D.	20.7	280	681	180
z_4	22-Aug-80	485	51	6.4	N.D.	2.68	N.D.	20.3	275	709	175
z_4	24-Sep-80	457	44	6.8	N.D.	2.48	N.D.	19.7	385	684	165

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_4	23-Sep-80	451	46	3.8	N.D.	2.63	N.D.	19.8	334	670	170
z_4	22-Sep-80	446	45	6.4	N.D.	2.63	N.D.	19.6	323	674	170
z_4	21-Sep-80	446	46	6.6	N.D.	2.68	N.D.	20.0	339	709	177
z_4	02-Sep-80	456	46	6.2	N.D.	2.63	N.D.	20.0	345	681	173
z_4	21-Aug-80	475	50	6.6	N.D.	2.73	N.D.	20.3	283	684	178
z_4	11-Jul-80	479	46	6.5	N.D.	2.66	N.D.	21.0	374	663	176
z_4	19-Jun-80	467	48	6.9	N.D.	2.61	N.D.	21.0	386	734	174
z_4	07-Feb-80	511	53	6.7	N.D.	2.84	N.D.	24.3	313	734	183
z_4	06-Feb-80	511	52	8.7	N.D.	2.81	N.D.	24.4	304	734	184
z_4	04-Feb-80	506	53	6.6	N.D.	2.81	N.D.	23.7	296	720	181
z_4	27-Nov-80	433	46	6.4	N.D.	2.38	N.D.	14.3	332	631	145
z_4	25-Nov-80	438	46	9.3	N.D.	2.43	N.D.	12.9	317	629	175
z_4	23-Nov-80	428	46	6.3	N.D.	2.38	N.D.	15.8	331	633	187
z_4	22-Nov-80	438	46	6.9	N.D.	2.43	N.D.	14.7	338	636	146
z_4	21-Nov-80	438	46	7.0	N.D.	2.38	N.D.	15.5	327	634	163
z_4	19-Nov-80	443	46	7.0	N.D.	2.43	N.D.	13.8	316	630	164
z_4	31-Oct-80	438	47	6.0	N.D.	2.48	N.D.	20.0	315	656	136
z_4	29-Oct-80	443	49	6.0	N.D.	2.43	N.D.	19.6	301	674	129
z_4	28-Oct-80	438	47	6.1	N.D.	2.43	N.D.	19.2	340	656	151
z_4	27-Oct-80	443	48	6.2	N.D.	2.43	N.D.	19.2	311	638	135
z_4	26-Oct-80	443	47	6.1	N.D.	2.43	N.D.	19.0	321	674	130
z_4	03-Nov-80	487	51	7.2	N.D.	2.76	N.D.	15.2	343	633	155
z_4	29-Nov-80	487	46	16.8	N.D.	2.43	N.D.	14.5	339	630	141
z_4	28-Nov-80	433	46	6.3	N.D.	2.38	N.D.	15.1	315	630	143
z_4	25-Oct-80	443	47	6.2	N.D.	2.43	N.D.	19.4	329	638	142
z_4	21-Oct-80	443	47	6.1	N.D.	2.43	N.D.	19.7	331	674	143
z_4	02-Oct-80	443	48	6.0	N.D.	2.43	N.D.	19.2	293	674	130
z_4	19-Oct-80	438	46	6.0	N.D.	2.43	N.D.	19.7	300	656	135
z_4	18-Oct-80	443	46	6.1	N.D.	2.43	N.D.	18.6	289	638	146
z_4	17-Oct-80	448	45	6.2	N.D.	2.43	N.D.	20.0	246	656	149
z_4	16-Oct-80	458	47	12.3	N.D.	2.43	N.D.	19.2	329	691	127
z_4	15-Oct-80	449	31	5.9	N.D.	2.36	N.D.	18.9	351	638	162
z_4	02-Dec-80	492	51	7.5	N.D.	2.71	N.D.	12.6	348	640	173
z_4	01-Dec-80	487	51	6.9	N.D.	2.71	N.D.	11.5	318	638	169
z_4	14-Oct-80	449	31	6.2	N.D.	2.36	N.D.	19.5	386	656	169
z_4	13-Oct-80	459	31	6.1	N.D.	2.41	N.D.	20.1	368	656	165
z_4	12-Oct-80	459	30	8.2	N.D.	2.46	N.D.	19.2	356	656	169
z_4	11-Oct-80	459	31	6.1	N.D.	2.36	N.D.	19.3	374	656	168
z_4	01-Oct-80	449	31	6.3	N.D.	2.36	N.D.	19.4	362	656	164
z_4	09-Oct-80	454	31	6.3	N.D.	2.46	N.D.	19.4	363	656	161
z_4	08-Oct-80	454	31	8.1	N.D.	2.50	N.D.	20.0	374	656	170
z_4	07-Oct-80	454	30	6.2	N.D.	2.55	N.D.	18.9	381	656	165
z_4	06-Oct-80	454	31	8.8	N.D.	2.50	N.D.	19.1	362	656	162
z_4	03-Dec-80	492	51	14.5	N.D.	2.71	N.D.	12.9	359	638	149

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_4	05-Oct-80	469	31	5.9	N.D.	2.55	N.D.	20.6	383	638	165
z_4	04-Oct-80	474	33	6.1	N.D.	2.55	N.D.	20.0	374	674	169
z_4	03-Oct-80	479	33	6.1	N.D.	2.55	N.D.	20.0	392	656	166
z_4	02-Oct-80	452	43	6.7	N.D.	2.48	N.D.	21.0	362	709	161
z_4	01-Oct-80	452	40	11.9	N.D.	2.48	N.D.	21.4	N.D.	684	162
z_4	03-Sep-80	452	40	6.5	N.D.	2.48	N.D.	20.0	368	698	164
z_4	29-Sep-80	461	40	6.6	N.D.	2.48	N.D.	20.8	374	691	162
z_4	28-Sep-80	457	42	6.7	N.D.	2.48	N.D.	20.4	358	674	160
z_4	27-Sep-80	457	40	12.2	N.D.	2.53	N.D.	19.8	362	709	162
z_4	26-Sep-80	452	39	13.4	N.D.	2.48	N.D.	20.0	338	688	170
z_4	25-Sep-80	457	43	6.8	N.D.	2.53	N.D.	20.9	364	698	162
z_4	03-Feb-80	511	53	6.7	N.D.	2.81	N.D.	24.5	241	752	190
z_4	02-Feb-80	501	53	6.8	N.D.	2.84	N.D.	24.3	280	741	175
z_4	31-Jan-80	511	55	6.6	N.D.	2.79	N.D.	22.9	226	720	173
z_4	03-Jan-80	521	56	8.0	N.D.	2.84	N.D.	23.6	243	755	186
z_4	01-Feb-80	511	53	15.1	N.D.	2.84	N.D.	24.5	329	727	190
z_4	29-Jan-80	525	52	7.1	N.D.	2.79	N.D.	19.4	346	730	197
z_4	26-Jan-80	520	53	7.2	N.D.	2.79	N.D.	20.7	328	752	188
z_4	24-Jan-80	525	52	7.2	N.D.	2.79	N.D.	20.0	299	727	186
z_4	23-Jan-80	525	51	7.1	N.D.	2.79	N.D.	20.5	289	713	187
z_4	21-Jan-80	540	52	7.1	N.D.	2.79	N.D.	21.0	238	752	188
z_4	02-Jan-80	530	52	7.3	N.D.	2.79	N.D.	21.2	235	734	191
z_4	19-Jan-80	535	54	13.3	N.D.	2.92	N.D.	21.6	202	762	193
z_4	17-Jan-80	530	52	7.2	N.D.	2.86	N.D.	21.0	226	833	191
z_4	16-Jan-80	530	53	7.8	N.D.	2.92	N.D.	21.0	220	748	192
z_4	15-Jan-80	530	53	7.5	N.D.	2.92	N.D.	20.6	219	752	191
z_4	13-Jan-80	529	53	6.9	N.D.	2.78	N.D.	21.7	288	716	186
z_4	12-Jan-80	519	53	7.3	N.D.	2.78	N.D.	22.0	261	748	189
z_4	11-Jan-80	519	53	6.8	N.D.	2.78	N.D.	21.9	272	716	188
z_4	09-Jan-80	519	53	7.3	N.D.	2.79	N.D.	22.5	232	N.D.	194
z_4	08-Jan-80	529	53	7.2	N.D.	2.81	N.D.	22.0	244	737	199
z_4	07-Jan-80	524	54	7.4	N.D.	2.78	N.D.	21.9	193	716	180
z_4	05-Jan-80	554	56	7.2	N.D.	2.81	N.D.	23.3	232	737	195
z_4	04-Jan-80	514	53	12.6	N.D.	2.75	N.D.	20.4	198	702	196
z_4	03-Jan-80	524	54	12.2	N.D.	2.81	N.D.	20.8	N.D.	713	183
z_6	18-Apr-78	716	89	64.1	1.16	5.69	1.16	28.9	295	1213	92
z_6	18-Apr-78	711	69	74.8	2.13	5.68	2.13	28.6	N.D.	N.D.	77
z_6	18-Apr-78	730	67	69.7	0.83	5.69	0.83	28.6	298	N.D.	81
z_6	04-May-78	697	42	N.D.	N.D.	N.D.	N.D.	35.8	N.D.	N.D.	N.D.
z_6	03-May-78	818	42	80.0	1.10	6.91	1.10	34.7	311	1478	34
z_6	03-May-78	833	33	80.6	0.45	7.04	0.45	35.1	298	1482	80
z_6	18-Apr-78	706	35	68.1	0.57	5.66	0.57	N.D.	N.D.	N.D.	78
z_6	16-Jun-78	366	33	47.1	0.11	5.17	0.11	32.8	281	1078	94
z_6	08-Jul-78	415	43	36.5	0.95	6.09	0.95	34.3	339	1212	138

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
z_6	07-Jul-78	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	35.8	347	1280	149
z_6	07-Jul-78	394	41	35.8	0.49	6.03	0.49	33.8	347	1188	139
z_6	06-Jul-78	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	35.8	367	1198	132
z_6	06-Jul-78	440	42	67.5	0.31	5.99	0.31	33.5	348	1241	133
z_6	15-Jun-78	435	88	72.8	1.00	6.33	1.00	38.4	358	1315	145
z_6	14-Jun-78	489	48	90.0	0.45	7.31	0.45	43.2	373	1496	136
z_6	13-Jun-78	181	24	83.2	0.13	2.80	0.13	19.0	123	606	37
z_6	19-May-78	303	35	78.0	2.04	3.41	2.04	21.6	263	925	N.D.
z_6	10-Jul-78	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	36.1	369	1308	145
z_6	12-Jul-78	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	35.3	329	1188	131
z_6	06-Oct-78	701	41	31.2	0.22	5.60	0.22	31.0	N.D.	1134	107
z_6	17-Oct-78	805	48	22.6	0.19	5.90	0.19	40.0	N.D.	1276	137
z_6	16-Oct-78	668	42	21.5	0.27	5.10	0.27	35.1	N.D.	1064	111
z_6	15-Oct-78	756	44	20.7	0.09	5.86	0.09	35.6	N.D.	1205	125
z_6	14-Oct-78	639	38	23.2	0.09	4.84	0.09	33.4	N.D.	993	105
z_6	05-Oct-78	705	40	25.3	0.19	5.63	0.19	32.3	N.D.	1117	113
z_6	04-Oct-78	679	39	17.9	0.11	5.33	0.11	31.8	N.D.	1134	107
z_6	13-Jul-78	389	41	35.4	0.47	6.08	0.47	35.3	336	1180	133
z_6	12-Jul-78	375	42	40.0	0.35	5.93	0.35	34.3	339	1229	133
z_6	11-Jul-78	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	33.3	331	1227	131
z_6	11-Jul-78	478	47	35.5	0.49	6.77	0.49	37.4	372	1312	148
z_6	10-Jul-78	430	43	30.4	0.30	6.18	0.30	34.3	367	1223	143
z_6	09-Jul-78	417	43	28.9	0.15	6.23	0.15	35.6	352	1227	139
zcq_2	23-Oct-80	501	74	4.6	0.04	3.07	0.00	24.6	354	686	191
zcq_2	13-Nov-80	503	72	4.0	0.02	2.94	3.76	19.7	358	687	161
zcq_2	26-Nov-80	463	64	5.8	0.06	2.95	2.44	20.1	555	651	117
zcq_2	03-Dec-80	467	69	4.4	0.48	2.48	6.70	19.9	N.D.	514	172
zcq_2	23-Jan-81	454	52	6.3	0.05	2.69	2.60	17.3	447	585	109
zcq_2	05-Feb-81	495	64	5.5	0.02	2.86	4.18	18.1	N.D.	593	139
zcq_2	24-Mar-81	438	62	3.9	0.01	2.72	3.56	N.D.	156	586	125
zcq_2	26-Mar-81	482	57	4.5	1.47	2.65	N.D.	N.D.	125	620	130
zcq_2	19-Feb-81	467	63	4.6	0.02	2.78	4.01	20.2	N.D.	616	144
zcq_2	28-Jan-81	448	54	4.7	0.15	2.61	4.00	18.1	460	585	94
zcq_2	07-Jan-81	503	71	4.4	0.18	2.37	3.78	17.6	510	583	168
zcq_2	11-Dec-80	505	87	4.8	0.68	2.37	4.71	20.1	207	651	214
zcq_2	19-Nov-80	485	66	5.5	0.04	3.01	3.78	19.9	118	718	82
zcq_2	03-Oct-80	486	72	4.4	0.04	3.11	2.87	20.2	317	674	145
zcq_3	19-Nov-80	485	110	5.1	1.08	4.67	4.00	20.6	65	795	48
zcq_3	02-Mar-80	718	156	7.1	0.08	6.26	7.35	28.0	100	1211	11
zcq_3	31-Mar-81	675	244	6.9	0.00	6.16	7.93	28.0	144	1176	6
zcq_3	09-Apr-81	611	144	6.4	0.00	5.50	5.01	25.4	150	1041	15
zcq_3	01-Jun-81	671	155	6.8	0.00	5.22	5.67	27.3	175	1127	13
zcq_3	18-Jun-81	625	149	6.6	0.00	5.37	7.50	29.5	51	1125	6
zcq_3	07-Jul-81	646	147	6.6	0.00	5.33	5.70	26.0	227	1117	N.D.

N.D. = No Data

TABLE 2. ZUNIL GEOCHEMICAL DATA FOR WELLS. DATA FROM D. MICHELS REPORT TO CyM/MKE

WELL	DATE	NA	K	CA	MG	LI	ARS	B	SIO2	CL	SO4
zcq_3	16-Oct-81	645	151	11.0	0.25	5.92	0.00	24.4	311	1088	7
zcq_3	16-Jul-81	707	165	7.5	0.02	6.40	6.84	26.8	287	1199	2
zcq_3	02-May-81	629	143	6.7	0.01	5.66	5.48	28.6	174	1075	11
zcq_3	19-Feb-80	621	137	6.8	0.03	5.81	5.89	33.9	N.D.	1093	9
zcq_3	12-Dec-80	671	133	7.3	0.02	6.88	0.00	22.2	130	1160	13
zcq_3	29-Jan-80	630	134	14.9	0.65	6.26	5.55	29.1	557	1109	7
zcq_3	09-Dec-80	663	138	15.1	0.43	6.84	0.00	16.6	118	1158	21
zcq_3	03-Nov-80	669	152	7.1	0.22	6.36	6.35	28.3	135	1163	11
zcq_4	29-Jul-83	664	115	17.7	0.04	7.55	N.D.	29.1	228	1124	34
zcq_4	27-Sep-83	1187	190	33.3	0.04	12.32	N.D.	46.0	135	2071	65
zcq_4	06-Oct-83	2916	463	26.4	0.23	29.46	N.D.	148.0	79	5075	343
zcq_4	25-Oct-83	1899	313	57.0	0.17	20.08	N.D.	75.0	169	3326	95
zcq_4	13-Dec-83	1948	311	45.2	0.06	20.99	N.D.	134.8	123	3326	73
zcq_4	06-Sep-83	778	125	23.0	0.10	8.44	N.D.	37.8	182	1400	47
zcq_4	14-Sep-83	989	169	29.3	0.04	10.88	N.D.	41.1	204	1779	54
zcq_4	23-Aug-83	716	92	20.1	0.00	7.27	13.22	32.0	231	1200	33
zcq_4	19-Aug-83	732	99	19.8	0.01	7.43	N.D.	30.7	171	1389	29
zcq_6	29-Jul-83	682	128	3.9	0.01	5.85	8.23	26.2	147	1098	31
zcq_6	06-Oct-83	698	123	7.1	0.02	6.08	6.49	27.5	251	1151	38
zcq_6	25-Oct-83	724	129	7.1	0.00	6.05	5.94	25.9	167	1151	47
zcq_6	09-Nov-83	713	133	8.0	0.05	6.09	6.49	27.1	280	1151	34
zcq_6	23-Nov-83	747	149	7.0	0.08	6.29	6.84	29.5	157	1189	31
zcq_6	08-Dec-83	698	140	7.1	0.02	6.05	N.D.	26.8	76	1176	42
zcq_6	13-Dec-83	678	112	7.1	0.02	7.77	N.D.	24.9	134	1151	42
zcq_6	17-Nov-83	747	147	8.2	0.08	6.26	6.70	29.8	198	1151	42
zcq_6	06-Sep-83	667	131	3.8	0.03	5.86	5.93	25.5	160	1087	42
zcq_6	14-Sep-83	690	125	6.7	0.03	6.15	5.99	25.5	102	1124	39
zcq_6	27-Sep-83	743	134	6.8	0.03	6.17	5.45	25.9	118	1167	28
zcq_6	23-Aug-83	628	97	4.3	0.04	5.30	7.31	24.7	207	1020	30
zcq_6	19-Aug-83	691	99	4.7	0.00	5.77	8.16	27.5	150	1158	36

N.D. = No Data

TABLE 3. ISOTOPIC COMPOSITIONS OF ZUNIL FLUIDS

NAME	TYPE	DELTA D	DELTA 0-18	TRITIUM (TU)	SOURCE
13	hot spring	-83	-11.1	<2.0	DM
37	hot spring	-87	-12.1	N.D.	DM
58	hot spring	-86	-12.5	N.D.	DM
none	hot spring	-86	-12.2	N.D.	DM
46	hot spring	-83	-12.0	N.D.	DM
zcq-3	well, liquid	-74	-7.7	N.D.	DM
zcq-3	well steam	-79	-10.6	N.D.	DM
zcq-3	well, liquid	-76	-7.8	<2.0	DM
zcq-3	well steam	-79	-10.2	N.D.	DM
zcq-5	well, liquid	-70	-6.4	N.D.	DM
zcq-5	well steam	-75	-9.4	N.D.	DM
zcq-6	well, liquid	-70	-7.2	N.D.	DM
zcq-6	well steam	-77	-10.1	<2.0	DM
15	hot spring	-71	-6.8	N.D.	DM
zcq-6	well, liquid	-72	-7.6	N.D.	DM
zcq-6	well, steam	-74	-10.0	N.D.	DM
47	hot spring	-79	-11.5	<2.0	DM
20	hot spring		-8.2	1.1	F
59	hot spring	-81	-12.05	0.8	F
none	cold spring	-73	-11.15	N.D.	F
none	cold spring	-79.5	-11.95	3.8	F
none	cold spring	-86.5	-12.25	N.D.	F
none	cold spring	-79	-12.25	24.7	F
15	hot spring	-80.5	-10.9	3.4	F
13	hot spring	-80.5	-11.35	0.8	F
10	hot spring	-80.5	-11.2	N.D.	F
17	hot spring	-77	-11.05	0.1	F
41	hot spring	-80	-11.1	1.1	F
23	hot spring	-79	-11.4	0.5	F
29	hot spring	-75	-10.8	0.7	F
z-2	well, liquid	-68	-7.3	1.1	F
z-2	well, steam	-86.5	-11.45	N.D.	F
z-4	well, liquid	-70	-8.5	0.7	F
z-4	well, steam	-94	-12.95	N.D.	F
Rio Samala		-71.5	-10.25	5.9	F
Rio Samala		-68	-9.9	7.3	F
zcq-3	well, total	-79.3	-8.74	1.3	G
zcq-6	well, total	-75.9	-8.36	1.3	G
zcq-5	well, steam	-75	-8.66	0.5	G

DM=D. Michels report to CyM/MKE, F=Fournier (1981), G=Giggenbach (1985)

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THE IDB

NOVEMBER 1987

MONTHLY NEWS FROM THE INTER-AMERICAN DEVELOPMENT BANK

Preventive medicine. How to ensure that development projects do not jeopardize human health was the focus of a meeting at the IDB in Washington, D.C. Page 2.

Spotlight on AIDS: A hemispheric dialogue on a dread disease—by satellite. Page 2.

The Bank in action. Turning pollutants into products in Colombia... Costa Rica's president starts up new hydroelectric plant... More silver, zinc and lead production in Peru... Unsnarling traffic in Chile's third largest city... and more. Page 4.

New projects. The IDB is arranging meetings to explore the possibilities of ventures between private companies in Germany and four Latin American countries. Page 10.

Environmental sanitation. New handbooks—with computer software—are available for professionals involved in water and sewage system projects. Page 11.

Power from the earth. Central America's unstable geology, with its earthquakes and volcanos, has long caused destruction and loss of life. Now the earth's energy will also be a source of electric power. Page 6.

What could have been a pollutant is bagged for sale.

COLOMBIA

Pollutants turned into products

A chemical company in Colombia has built a new plant which will take what were formerly industrial wastes and turn them into a chemical compound which is used in making a wide range of consumer goods.

The plant, owned by the company Anhidridos y Derivados de Colombia S.A., in Antioquia, will enable the country to substitute imports of fumaric acid valued at some $250 million annually. At the same time, the plant is purifying wastes that otherwise would be discharged into the Medellín River.

The $107 million plant was built with support from an IDB-funded scientific research and technological development program.

The plant combines the pollutants with water, forming malic acid, which is then converted into fumaric acid. This compound, being insoluble in water, separates out.

After purification, the fumaric acid is used in the production of a great variety of consumer goods, such as paints, fabrics, plastics, shoes, toys, and electric cables.

The chief engineer fine tunes operations at the Bridgetown sewage treatment plant.

BARBADOS

Call to stem contamination

The prime minister of Barbados has called on residents of the capital of Bridgetown who have not already done so to link up to the city's new sewage system, which was completed in 1982 with the help of IDB financing.

Prime Minister Erskine Sandiford made his statement at a national meeting on the environment in which he also warned about the serious impact that inadequate sewage disposal has on the marine and coastal environments. He expressed hope that construction of a south coast sewage system, to be financed by the IDB, will begin next year.

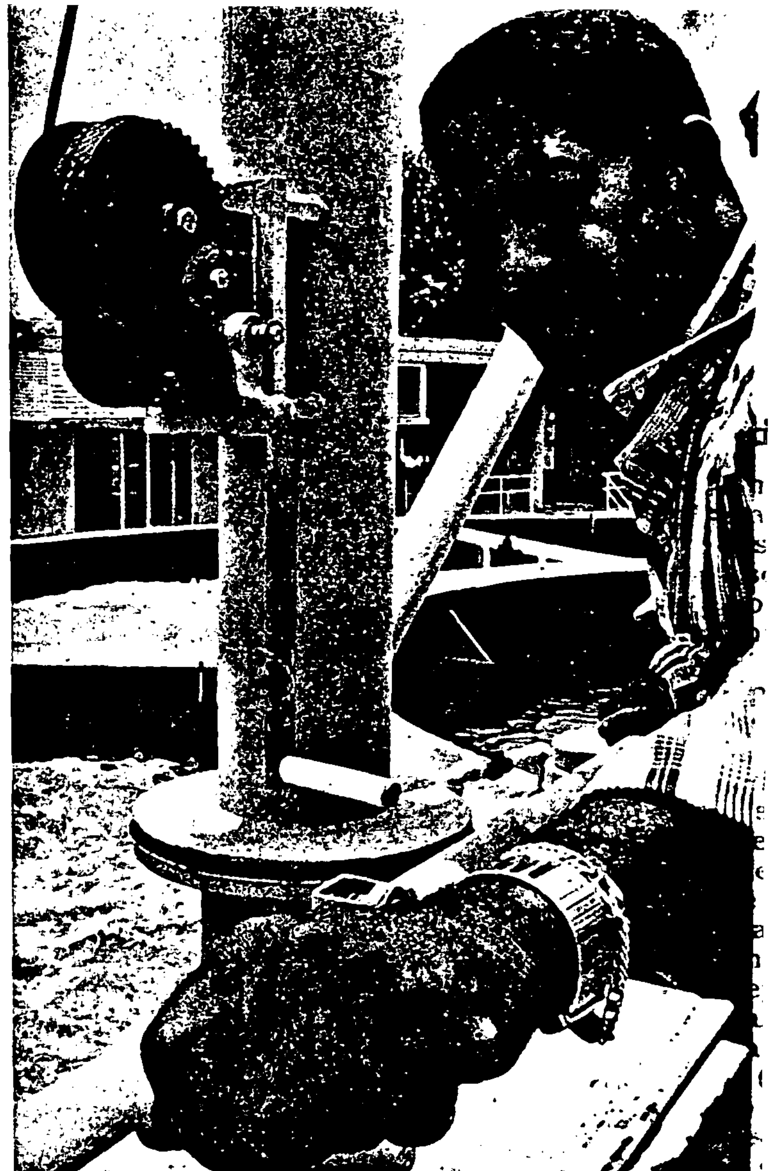
In Barbados, the high water table restricts the effectiveness of the traditional soil absorption methods of sewage disposal.

GUATEMALA

Firms picked for geothermal study

Guatemala's National Institute of Electrification has signed a contract with a Guatemalan-United States consortium to make the studies, final designs and bidding documents for the country's first geothermal plant.

The firms, Cordón y Mérida, of Guatemala, and Morrison Knudsen, of Idaho, in the U.S., will also supervise the plant's operations. The 15,000-kilowatt IDB-financed plant, in Zunil, in the Department of Quetzaltenango, will begin operations in 1991.



PERU

Mine to increase output

A newly expanded mine 4,500 meters high in the Peruvian Andes will be producing an additional 1.5 million ounces of silver, 31 million pounds of zinc and 5 million pounds of lead annually.

The IDB-financed improvements in the Andaychagua mine included works to gain access to veins of ore 200 meters below the present level, a new concentrate plant, and equipment to provide electricity, water and drainage. A school, health facilities and other services were constructed for the workers.

The mine complex now has the capacity to produce 350,000 tons annually of the three metals. It will employ about 300 miners and 50 engineers and technicians.

Presiding over the inauguration ceremonies in August was the country's Minister of Energy and Mines, Abel Salinas Izaguirre.

Peru depends on mining for the largest share of its foreign exchange. The mining sector also provides raw materials for domestic use and for the production of export goods.

Reporting on **The Bank in Action** this month are Mary Greaves-Venner/Barbados, Gabriel Gutiérrez/Chile, Dalia Losada/Colombia, Fabio Muñoz Campos/Costa Rica, Julio César Anzueto/Guatemala, and Rosario de Gastañaga/Perú.

Steam from a geothermal well mingles with clouds sweeping up Guatemala's Cerro Quemado Volcano. This 1,043-meter-deep well is producing water heated to temperatures of 274 degrees centigrade. The bottled water samples will be analyzed for gas and mineral content.

ENERGY

Harnessing the earth's heat

Major new power source for Central America

This is a restless earth. Its crust buckles, shifts, grinds, most of the time imperceptibly, but every so often with the explosive fury of an earthquake or a volcano.

Central America is one of the earth's most geologically active areas. Its people have long suffered more than their share from the twin scourge of earthquake and volcano. But now, Central Americans are starting to benefit from these geological forces by bringing the heat they produce to the surface in controlled amounts. The heat is used to drive turbines and produce electricity.

"Central Americans believe in geothermal energy. They are enthusiastic about it."

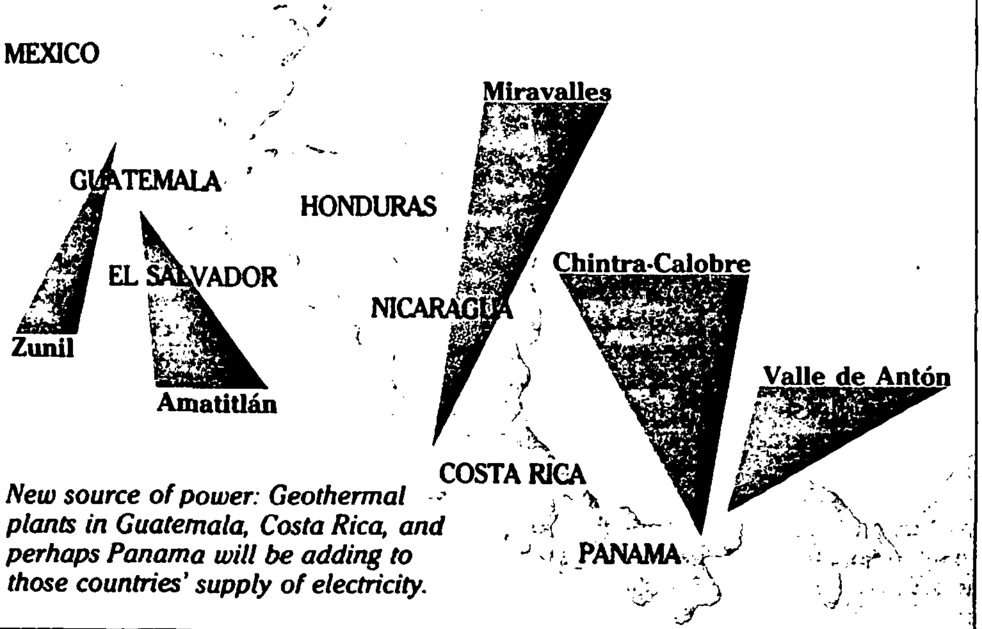
So says Gustavo Calderón, who as chief of the IDB's Nonconventional Energy Section anticipates the time when geothermal power will not be unconventional anymore. In just a couple of decades, he believes, geothermal power plants will rank in importance with hydropower and fossil fuels as a source of electricity for the countries of the isthmus. According to a recent study prepared at Los Alamos National Laboratory in the United States, at least 10 per cent of Central America's electric generating capacity is expected to be geothermal by the year 2000.

Easy on the environment. In addition to being plentiful, Central Americans will find that geothermal power offers some important advantages, according to Mr. Calderón. For example, geothermal projects do not occupy great land areas, displacing people and causing environmental problems. The geothermal reservoir already exists, far underground.

The IDB is financing major geothermal projects—not pilot projects, but full-scale generating units—in Guatemala and Costa Rica. In both cases, the construction is following exhaustive tests made over a period of years. The new projects include further testing and probing to determine how extensive the geothermal resources are and the possibilities for future new plants.

In a third country, Panama, an IDB-financed study is producing the data that will quite likely encourage that country to join the geothermal club. The bank also financed preliminary studies in the Dominican Republic.

While geothermal plants have operated in Mexico, El Salvador and Nicaragua for some years, the Guatemalan and Costa Rican projects will be the first IDB-funded efforts in the isthmus to exploit this power source. These new plants will produce a small but significant percentage of each country's additional capacity, and Mr. Calderón sees clear potential for greater contributions in the years to come.



New source of power: Geothermal plants in Guatemala, Costa Rica, and perhaps Panama will be adding to those countries' supply of electricity.

Rugged setting. The Cerro Quemado Volcano is located near the town of Zunil, in Guatemala's lush but rugged Quetzaltenango Department. The area is so steep that the problem has been to find areas flat enough to locate the geothermal wells and site a generating plant.

It appears that the site chosen for the country's first geothermal plant, Zunil I, sits on the edge of a much larger field.

Each geothermal field is different, explained Mr. Calderón. For one thing, some fields produce hot water, and others produce steam. As shown in the earlier IDB-financed studies, wells in the Zunil field produce both steam and hot water.

Not all volcanic areas have exploitable geothermal fields. Several conditions must be present. First is a heat source, the molten rock called magma. Above this must be a layer of highly porous rocks into which rainwater can enter. The heat from the magma radiates up, heating the water. Capping the permeable, water-laden stratum is a layer of impermeable rock.

The objective of the well is to penetrate through the upper impermeable layer of rock and into the rock saturated with hot water. This geothermal fluid, being under pressure, flows to the surface. At the Zunil I plant, the steam will be separated from the water, which is then reinjected back into the rock formation to replenish the field. The steam powers the generator.

The Zunil plant, due for completion in 1991, will have the capacity to produce 15,000 kilowatts of power. This

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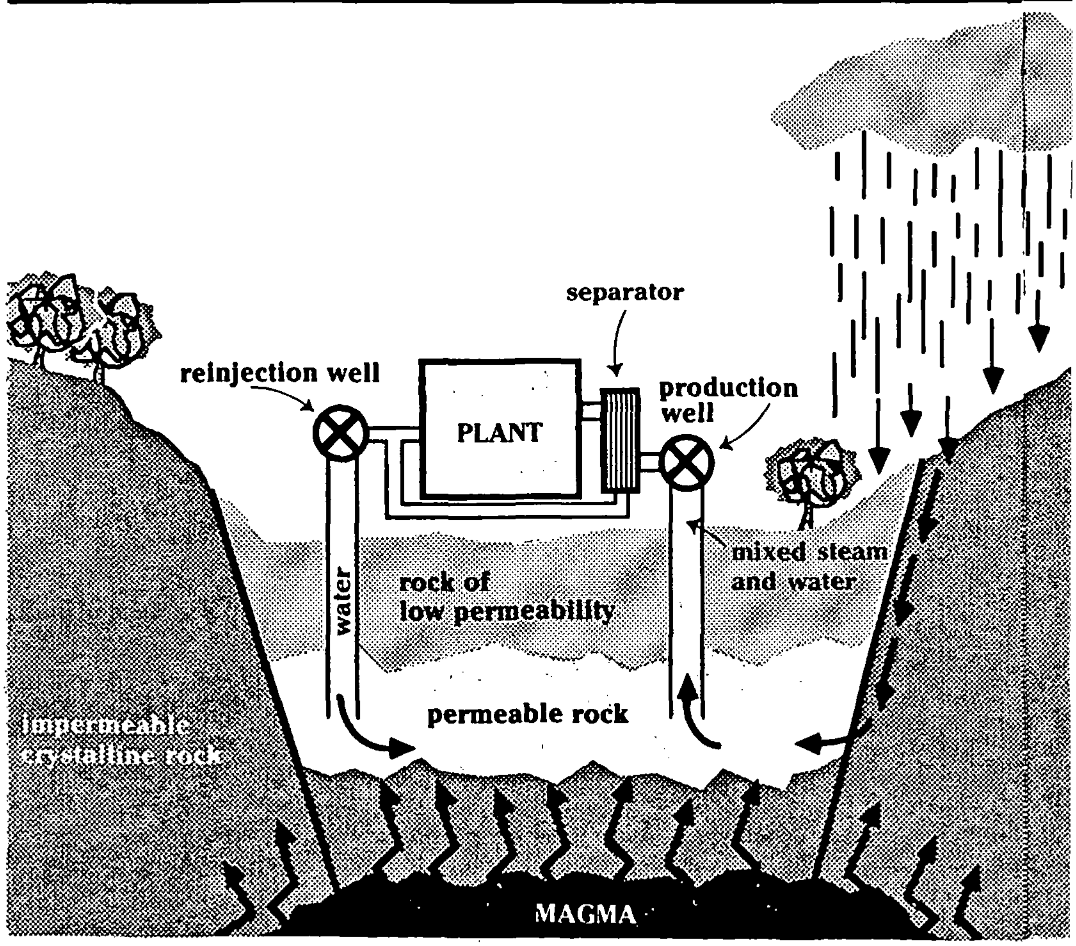

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is not a large amount, although it will have a considerable impact on the immediate region. For the country and for Central America as a whole, the new plant will demonstrate that geothermal power is a practical energy alternative.

While Zunil I is under construction, a series of studies—including the drilling of small diameter wells—will be carried out both in the Zunil geothermal field and in another promising field close to Guatemala City, Amatitlán. Within a year, these studies will indicate where Guatemala should concentrate its future efforts in geothermal power. Three or four deep commercial-diameter wells will then be drilled in the area chosen, and eventually, a second plant—much larger than the Zunil I plant—will be constructed.

'Tremendous field.' This is how Mr. Calderón characterized the site for the IDB's other ongoing geothermal project, this one at the foot of the Miravalles Volcano in Costa Rica's northern Guanacaste Province.

Preliminary estimates put the area of the Costa Rican field at 11 square miles, with a generating potential of 200,000 kilowatts. "We still have not come to the edge of the field," said Mr. Calderón. "The wells keep getting better and better."

Like Zunil, the Costa Rican field has been the subject of extensive studies, including IDB-financed geoscientific research and test wells.

The 55,000-kilowatt Miravalles plant will begin production in 1992. Studies show that the same field can support another 55,000-kilowatt plant. The next step is to drill three exploratory wells to confirm the feasibility of a third and fourth unit.

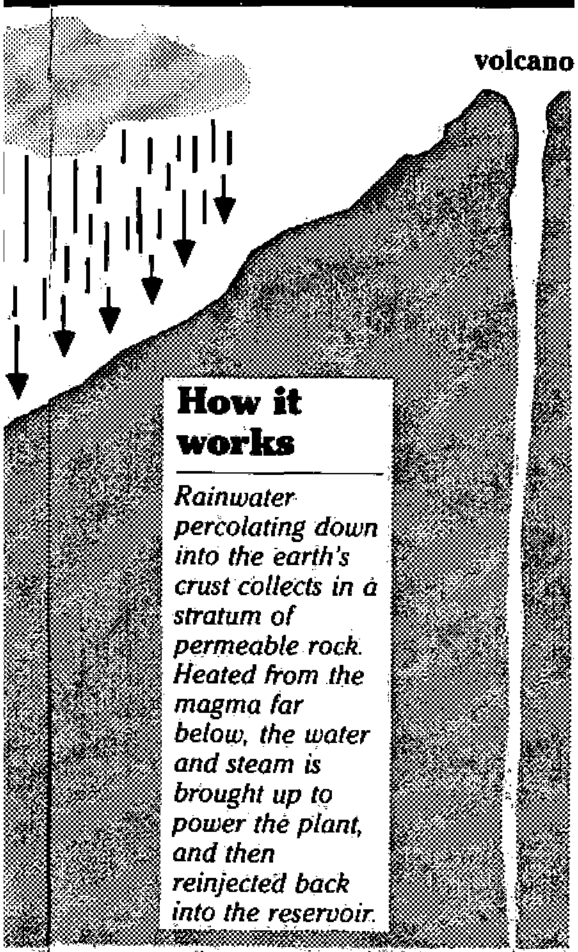
Future plants in both countries will be cheaper to construct because the infrastructure established for the first plant already exists. Technical improvements should also reduce costs. Meanwhile, in both Costa Rica and Guatemala, technicians employed by the national utility agencies will receive training in the theoretical and practical aspects of plant operation.

Further down the isthmus. Panama may well be the next country in the isthmus to exploit its geothermal resources. Studies indicate that Panama cannot maintain its rate of economic growth if it is to continue to rely on conventional energy sources, particularly petroleum-based fuels.

The IDB is financing reconnaissance studies to evaluate Panama's geothermal potential and advance prefeasibility studies in two promising fields in the Valle de Antón/ Chintra-Calobre area in the central part of the country. Their location augers well for future energy utilization, as they are close to the major consumption center of Panama City, and would boost the amount of power coming from the new IDB-financed La Fortuna hydroelectric plant further west.

With the drilling of two deep wells early next year, Panama will have the information it needs to decide if it should enter into the second, far more costly, stage of drilling production capacity wells for the plant's feasibility studies. With this second phase completed, the decision can be made on building the geothermal plant itself.

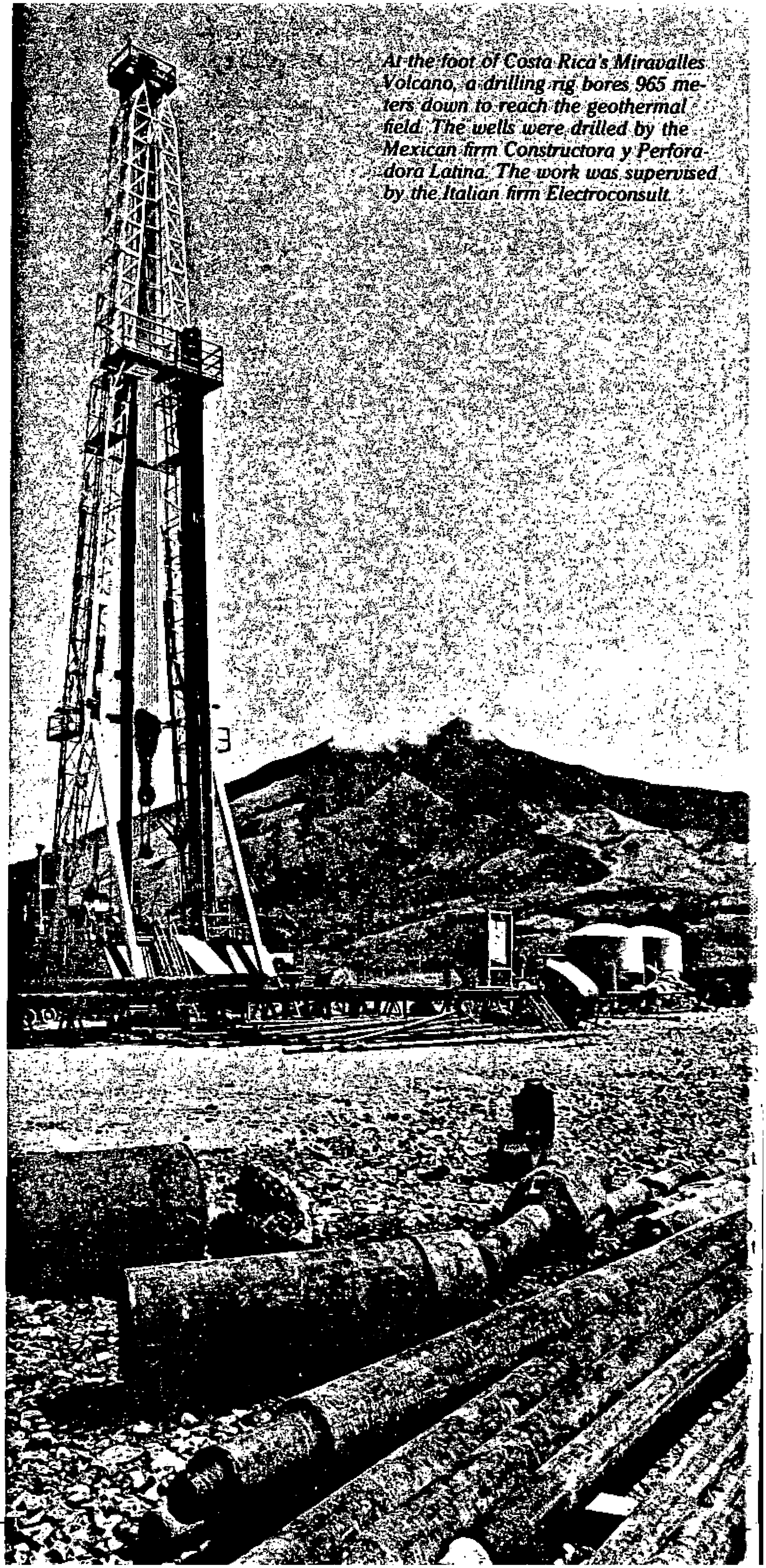
Meanwhile, geothermal studies underway in Honduras, El Salvador and Nicaragua are pointing to a significant potential for further projects, all of which will require international financing. The energy future for this land of volcanos appears bright indeed.
by Roger Hamilton



How it works

Rainwater percolating down into the earth's crust collects in a stratum of permeable rock. Heated from the magma far below, the water and steam is brought up to power the plant, and then reinjected back into the reservoir.

Multinational conference: Engineers from Mexico, Italy and Costa Rica discuss the results of a test to clear a well of water to bring up steam.



At the foot of Costa Rica's Miravalles Volcano, a drilling rig bores 965 meters down to reach the geothermal field. The wells were drilled by the Mexican firm Constructora y Perforadora Latina. The work was supervised by the Italian firm Electroconsult.

EMPRESA GUATEMALTECA DE TELECOMUNICACIONES

" G U A T E L "

CONFERENCIA SOBRE:

ESTACIONES REPETIDORAS DE TELECOMUNICACIONES

Y SISTEMAS FOTOVOLTAICOS

(APLICACION PARA ABONADOS REMOTOS EN SISTEMAS MULTIACCESO

POR:

JOSE MANUEL ARAGON H

DIVISION DE PLANEAMIE

MIAMI, 31 DE M

ECRE Conference presentation

OBJETIVOS

- Presentar los alcances obtenidos por GUATEL en el uso de sistemas de energía renovable (no convencionales), así como las espectativas para su aprovechamiento en proyectos por realizarse a corto y mediano plazo.

- Describir la forma en que GUATEL aprovecha la energía solar para la alimentación de equipos de telecomunicaciones en estaciones de baja capacidad y consumo de potencia, utilizando para ello sistemas fotovoltaicos.

- Dar a conocer la configuración de los sistemas fotovoltaicos utilizados para la alimentación de equipos de radiocomunicación por microondas para los abonados remotos en sistemas de multiacceso.

INTRODUCCION

En estos últimos años la Empresa Guatemalteca de Telecomunicaciones "GUATEL", entidad estatal encargada del desarrollo y administración del servicio de telecomunicaciones en Guatemala, da una importancia cada vez mayor a la implementación de proyectos tendientes a llevar servicio telefónico especialmente a poblaciones del area rural que aún no lo poseen así como mejorar el de aquellas que actualmente cuentan con él, de tal manera que cuenten con medios confiables para satisfacer sus necesidades de comunicación vital, comercial, social, etc.

Por su misma condición topográfica, geográfica y de acceso, muchas de las poblaciones involucradas en dichos proyectos no cuentan con un servicio confiable de energía eléctrica, o si lo poseen es muy deficiente. Es así como ha surgido la necesidad de utilizar otras fuentes de energía distintas a las convencionales, como la energía solar, por ejemplo, haciendo uso de sistemas fotovoltaicos de pequeña potencia para solventar las necesidades de alimentación a los equipos de telecomunicaciones requeridos.

SITUACION ENERGETICA ACTUAL

En Guatemala actualmente se cuenta con energía eléctrica producida principalmente a base de generadores térmicos, geotérmicos e hidráulicos, siendo estos últimos los que contribuyen en mayor porcentaje al total de energía producida.

La estructura de la red de distribución de dicha energía en todo el país ha permitido con relativa facilidad, llevar energía eléctrica hasta los puntos donde GUATEL ha construído centrales telefónicas o estaciones repetidoras, siendo muy pocos los lugares en los cuales debido a la ausencia de tal red se ha optado por alimentación a base de sistemas motorgeneradores de uso contínuo, tomando en cuenta la magnitud de la potencia demandada así como la importancia y confiabilidad que deben poseer dichas estaciones, siendo interesante notar que en muchos casos la mayor parte de la potencia requerida es para alimentar equipos de aire acondicionado o iluminación.

A medida que se amplía la cobertura de los sistemas de telecomunicaciones se atiende a poblaciones cada vez más pequeñas, alejadas y algunas sin servicio de energía eléctrica comercial, hasta llegar al grado de resultar necesario y más conveniente (económica, técnica y funcionalmente) su alimentación a través de sistemas fotovoltaicos cuando su potencia requerida sea modesta.

Tomando en consideración la situación geográfica y climática del país se estableció la energía solar como un recurso potencial explotable, iniciandose por lo tanto la implementación de la primer estación repetidora llamada "El Hallazgo" energizada por un sistema fotovoltaico y cuya configuración inicial fue la mostrada en la Figura 1, posteriormente fue ampliada a la forma como se encuentra actualmente, ver Figura 2.

PROYECTO TELEFONIA RURAL 3a. FASE

En el mes de septiembre de 1983 se publicaron las bases técnicas del Proyecto de Telefonía Rural III Fase, cuyo objetivo fue el de adquirir, entre otros, sistemas de radio y energía para dar servicio telefónico al area rural (pequeñas poblaciones, cabeceras municipales, caseríos, fincas, etc.), para integrarlos al Sistema Nacional de Telecomunicaciones. La adjudicación se realizó en el mes de marzo de 1986, adquiriéndose, entre otros, los siguientes equipos:

- PUNTO A PUNTO: 3 sistemas de 120 ch, 5 sistemas de 60 ch, 41 sistemas de 24 ch, 31 sistemas de 6 ch, 28 sistemas monocanales y equipo multiplex totalmente equipado. Este equipo será utilizado para realizar los enlaces troncales del Sistema Rural y para los enlaces con estaciones terminales.
- MULTIACCESO: Con un total de 460 abonados remotos servidos a través de 10 estaciones base. Estos sistemas comprenden las centrales electrónicas tipo concentrador de línea, los transmisores-receptores para las estaciones base y los transmisores-receptores terminales de abonado.
- SISTEMAS DE ENERGIA SOLAR: Comprende la adquisición de los equipos enumerados en el Cuadro No. 1, los cuales servirán para proveer la energía necesaria en algunos enlaces punto-punto de baja capacidad y el resto para alimentar los transmisores-receptores terminales de abonado servidos por las estaciones base y en cuyo sitio de instalación no se cuenta con servicio de energía comercial, tal como se

muestra en la figura No. 3.

Los diferentes tipos de sistemas fotovoltaicos fueron el resultado de las consideraciones tomadas para el dimensionamiento, las cuales incluyeron estimaciones de radiación solar, características eléctricas de los equipos a ser alimentados, condiciones de funcionamiento y factores climáticos.

CUADRO No. 1

Cant. de Sistemas	Tipo de Sistema	Cant. de Modulos	Cant. de Reguladores	Cant. de Baterias
1	C	16	1	24
7	B3	6	1	7
7	B2	4	1	7
13	B1	3	1	7
13	A	4	1	7

Nota:

- Todos los módulos utilizados son marca PHOTOWATT, modelo BPX 47-402.
- Todos los reguladores son marca PHOTOWATT, modelo PWR 10C12,

exceptuando el del sistema tipo C, modelo PWR 20C24.

- Las baterías para los sistemas tipos A y C son modelo TUS 4, las restantes son modelo TUS 3.

FOCUS ON

DRAFT

GUATEMALA

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARMTENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
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PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

The series is available for the following countries:
Argentina, Azores (Portugal), China, Costa Rica, Ecuador, El Salvador, Ethiopia, Guatemala, Honduras, Indonesia, Jordan, Mexico, St. Lucia, Thailand.

Additional countries might be available in the future.

The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

- The *"Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities."* Final Report, August 1987. Prepared for Los Alamos National Laboratory.

- The *"Summary Report"* of the above publication.

- *"Equipment and Services for Worldwide Applications,"* U.S. Department of Energy.

- The *"Listing of U.S. Companies that Supply Goods and Services for Geothermal Explorers, Developers and Producers Internationally,"* August 1987, prepared by GRC.

Copies of these publications can be obtained from the Geothermal Technology Division of the U.S. Department of Energy. Correspondence should be addressed to:

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NOTE

Data presented in this document are based on several U.S. government official publications as well as international organizations, namely:

- Background Notes (U.S. Department of State)
- Foreign Economic Trends (U.S. Department of Commerce)
- World Development Report 1987 (World Bank)
- International Data Base for the U.S. Renewable Energy Industry, May 1986 (U.S. Department of Energy)

The country's geothermal resources write-up is a revision and update of the Appendix in the "Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities." LANL, August 1987.

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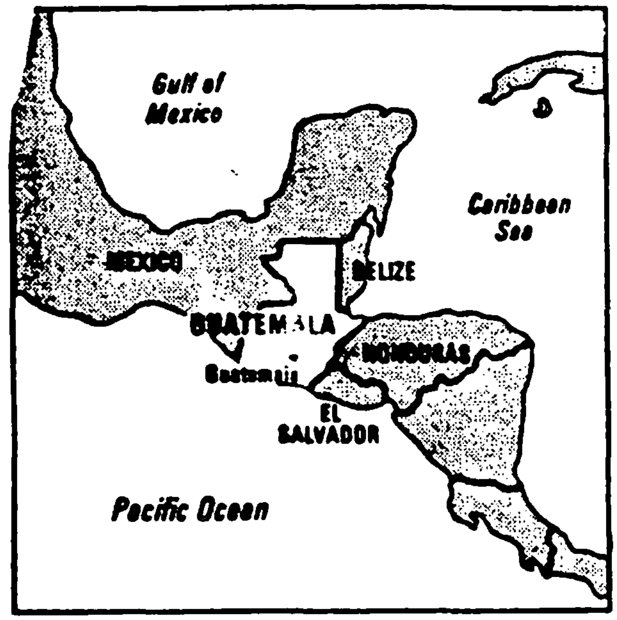
FOCUS ON GUATEMALA



Official Name: Republic of Guatemala

Area: 108,780 sq. km. (42,000 sq. mi.)

Capital: Guatemala

Population (1985): 8.0 million

Population Growth Rate: 3.1%

Languages: Spanish, 23 Indian languages

Economic Indicators:

Real GDP (1985): $8.9 billion
Real Annual Growth Rate (1985): -1.1%
Per Capita Income (1985): $1,000
Avg. Inflation Rate (1986): 18.7% change from 1980 base year

Trade and Balance of Payments:

(1985) Exports: $1.0 billion; Major Markets: U.S., Central America Common Market (CACM), FRG, Japan
(1985) Imports: $1.1 billion; Major Suppliers: U.S., Japan, CACM, FRG, Venezuela
Official Exchange Rate: 1 quetzal = US $1
2.5 quetzales = US $1 (controlled export/import rate)
2.62 quetzales = US $1 (parallel interbank rate)

Energy Profile: (Based on 1982 data)

- Commercial Fuel Energy Consumption:

  Total: 1.237 million ton of oil equivalent (mtoe)
  1-Yr. Growth: -2.9%

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: 95%
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: 5%
  Commercial Fuel Consumption Growth Rate (1970-1980): 5.9%

* Negligible

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: 606 MW
  Hydro: 23%
  Hydro Potential: 5,426 MW
  Steam: 39%
  Gas Turbine: 30%
  Diesel: 8%
  Other: *

- Electricity Sales:

  Total: 1236 GWh
  Residential: 25%
  Commercial: 19%
  Industrial: 42%
  Government: 14%
  Other: *
  Average Electric Price: 13.40 US cents/kWh

- Geothermal Power Generation:

  Reservoir Potential (MW): No figures available
  Temperature Range: Low-medium enthalpy in general, 287°C at Zunil

- Geographic Locations: Southern region

- Development Status: Prefeasibility studies and preliminary resource assessment, no on-line power generation.

- Countries Actively Involved: U.S., Japan

- General Need for Assistance: Feasibility studies, further deep exploratory drilling, well testing, reservoir modelling

- International Funding: $58 million (IDB)

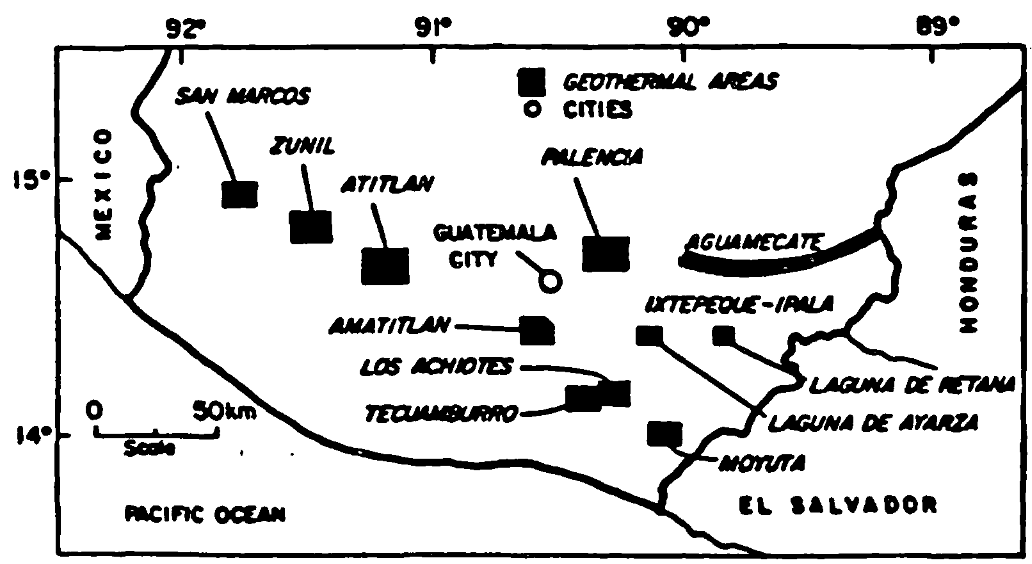
* Negligible

GEOTHERMAL RESOURCES

The southern part of Guatemala lies along the Middle Trench in a volcanically active area. Numerous hot springs area also present within the high-temperature geothermal prospects of Guatemala.

Geothermal exploration began in Guatemala during 1972. Initial studies were performed at the Moyuta and Zunil geothermal fields. The volcanic belt that hosts the geothermal areas lies in a convex strip nearly 40 km wide and containing 35 volcanoes (three of which are active). Volcanic activity has continued from the Tertiary to the present, as early fissure eruptions and lateral flows were later covered by composite volcanoes.

The Zunil geothermal field is located 120 miles northwest of Guatemala City in western Guatemala's volcanic province, near the Cerro Quemado and Volcan Santa Maria volcanoes. Preliminary exploration at Zunil began in 1973 and continued through 1977. Technical assistance was provided by the government of Japan through geophysical studies. Deep drilling began in 1977 by the National Electrification Institute (INDE) as a prelude to a power plant feasibility study. The drilling program was successful in discovering a high-temperature (287°C) reservoir encountered at 1,130 m. A total of six exploratory wells were drilled, with five eventually producing steam in commercial quantities. IDB is funding a $58 million project for the development of the Zunil geothermal site, which includes the installation of a



Geothermal areas in Guatemala

Source: R. DiPippo, 1986, "Geothermal Energy Development in Central America."

15-MW power plant. Estimates of 50 MW or more of geothermal electricity potential at Zunil are still uncertain. Meanwhile, a 15 MW demonstration plant is planned for construction. In a joint effort, Los Alamos National Laboratory (LANL), the Guatemalan Ministry of Energy and Mines (MEM), and INDE, are investigating the use of low- and medium-enthalpy geothermal heat for industrial and agricultural processes. An agricultural processing center that will use geothermal energy is under construction near Zunil. It is hoped that this demonstration plant will prove successful and would lead to the building of a commercial plant.

The geothermal reservoir is contained within a conglomeratic unit overlying a Cretaceous granodiorite basement, which in turn is overlain by Tertiary volcanic rocks. Fluids are thought to migrate "up-dip" (eastward) within the conglomerate unit and into the thermal area. Fractures within the basement granodiorite may also contribute to fluid movement. Production testing has shown that a rapid phase change from liquid to vapor (steam) occurs in the wellbores upon drawdown of formation fluids.

The Moyuta geothermal field was the first geothermal area to be explored in Guatemala. Geological, geochemical, and geophysical prospecting were performed in 1972. After surface studies were completed, two exploratory wells were drilled to a depth of 1000 m each. Maximum temperature reversals were observed below that point. Exploration at Moyuta was terminated after completion of exploratory drilling.

The Amatitlan geothermal field is located within the volcanic belt of south-central Guatemala. Preliminary surface geoscience investigations have shown that high-temperature resources may be present at depth. Geothermometers applied to fluid chemistry data have indicated a possible reservoir temperature of 280^{o}C. Shallow thermal gradient drilling has revealed a temperature of 140^{o}C at a depth of 80 m within the field. Further deep exploratory drilling by INDE was to have been performed at Amatitlan upon release of drilling equipment from the Zunil field. Preliminary estimates of geothermal electric generation is around 100 MW.

The Las Majades-Cerro Quemado area, adjacent to Zunil I, has been selected for exploratory drilling, but further prefeasibility work is necessary before a precise drilling location can be chosen.

Other geothermal areas in Guatemala have been assessed in a preliminary manner. Surface geologic mapping and geochemistry has been performed by INDE in the areas of Atitlan, Palencia, Tecuamburro, Los Achiotes, Laguna de Ayarza, and Laguna de Retana.

<u>Bibliography</u>:

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Donovan P.R., 1985, "The Status of High Enthalpy Geothermal Exploration in the Developing Countries," <u>Geothermics</u>. Vol. 14, No. 2/3, pp. 487-494.

LANL, 1987, <u>The Energy Situation in Five Central American Countries</u>, Central American Energy and Resource Project. (LA-10988-MS) June 1987, pp. 200-203.

REFERENCES

AND

KEY CONTACTS

A. Business Climate Sources of Information

The following references are suggested for timely information on the business climate in Guatemala.

U.S. GOVERNMENT PUBLICATIONS

U.S. Department of Commerce

- Foreign Economic Trends (FET) and their Implications for the U.S.
- Overseas Business Reports (OBR)

U.S. Department of State

- Background Notes

NON-GOVERNMENT PUBLICATIONS

- International Series, published by Ernst and Whinney
- Businessman's Guide to......., published by Price Waterhouse and Co.
- Information Guide: Doing Business in ......, published by Price Waterhouse and Co.
- Task and Trade Guide, published by Arthur Andersen
- Task and Investment Profile, published by Touche Ross and Co.

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory:

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
- International Data Base for the U.S. Renewable Energy Industry
- Committee on Renewable Energy Commerce and Trade: CORECT's Second Year - October 1985-November 1986

California Energy Commission (CEC)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

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UNIVERSITY OF UTAH RESEARCH INSTITUTE

UURI

EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108–1295
TELEPHONE 801-524-3422

MEMO TO: ASSOCIATED PRESS

FROM: PHILLIP MICHAEL WRIGHT PMW

SUBJECT: EXPLOSION IN GUATEMALA

January 8, 1991

Newspaper articles with the AP byline have been published in the Salt Lake Tribune on each of the last two days about an "explosion" at a geothermal power plant in Guatemala, near Quetzaltenango, about 70 miles west of Guatemala City. Some of your information is entirely incorrect and the whole text is grossly misleading. The potential for damage to the reputation of the geothermal industry is considerable from such bad reporting. In fact, geothermal energy is a safe, environmentally advantageous way to generate electricity. We believe that AP has responsibility to help clear up the misconceptions it has generated on this story. I am offering what I know about what really happened there and some people to contact in Guatemala City who can be interviewed to help you get the story straight.

First, there is no geothermal power plant at the Zunil site, near Quetzaltenango, even an unfinished one. In fact, there is no power plant of any type at this site. Therefore, your reference to "the Saturday night blast at the Zunil plant ... (being) the most deadly accident at any electrical generating plant since the April 1986 explosion at the Soviet Union's Chernobyl nuclear plant" is entirely inappropriate, apparently aimed at sensationalism rather than responsible journalism. The area is simply being explored through drilling to determine whether or not enough geothermal water and steam can be produced from wells to justify building a power plant. There is one small vegetable-drying plant at the site, built as a demonstration project, that has not run much since its completion. It uses hot water from one of the wells directly, and does not operate on or generate electricity.

Our reports are that the accident is the result of a natural disaster -- a landslide. A massive landslide moved through the center of the Zunil geothermal field after originating on the steep slopes immediately behind well ZCQ-4. The deaths, injuries and destruction were due to the landslide, which destroyed a number of small homes inhabited by local farmers. The amount of earth coming down in the slide was reported to be substantial. The landslide extended to the main highway and further down slope an unknown distance, making the road impassible. Geothermal well ZCQ-4, drilled in early 1981, was damaged by the landslide, and now steam is issuing from the area around the well site, which is covered by debris. The nature of the damage to the well is unknown -- either the wellhead was stripped off or the casing in the hole was sheared off some distance down. It must be understood that the well has been sitting for 10 years with no problem. The steaming well probably poses no danger at present, but there is certainly danger of further landslide activity. The head of the slide is still reported to be unstable and sloughing rock which rolls down hill.

Geothermal exploration at Zunil has been going on for more than a decade with help from geothermal experts from Italy, Japan and the United States. Geothermal fluids discovered so far are insufficient for development of a 15 megawatt power plant, the target size set by the Guatemalan Instituto Nacional de Electrificacion (INDE). Thus, new drilling is now in progress at the site of old well ZCQ-5, a few hundred meters from ZCQ-4. The project is under the direction of INDE. The drilling operation at ZCQ-5 was undamaged by the slide, but has been suspended because the road to the area was covered by slide debris, and it is now impossible to bring fuel and other supplies to the drilling rig.

Geothermal reservoirs occur in areas that are active geologically worldwide, and landslide and other natural geologic occurrences such as the present one can be expected with or without geothermal exploration. The Zunil area is located on the flanks of two active volcanos, Cerro Quemado and Santa Maria. Volcanic rocks often weather to clay minerals after they are deposited. When the clay layers are covered by more volcanic rocks, they can form planes of slippage for landslides. The area is steep and rainy, further leading to an extreme landslide hazard. Water tends to lubricate slippage planes. Geologic mapping in the area reveals the presence of many landslides of various geologic ages up to the present time. The danger of new slides in the area has been recognized by all geologists who have worked there, including geologists associated with the present geothermal exploration project. Recent new cracking and other signs of movement on the particular slide that gave way were seen and reported last week. Earthquakes, too, are a common occurrence in the Zunil area, and often trigger landslides.

Another natural disaster occurred at the Ahuachapan geothermal field in El Salvador a few months ago, also incorrectly reported by the press (AP, I believe). At Ahuachapan, it was reported that a geothermal well blew out, causing a great deal of destruction and a large crater. In fact, there was no geothermal well at the site of the explosion. The explosion was a natural event, termed a "phreatic explosion" by geologists and hydrologists. Phreatic explosions result from natural buildup of pressure in geothermal areas worldwide, and occur whether or not there is geothermal development in the area. Very large phreatic explosion craters are known from Yellowstone National Park, and they apparently were formed after the last glacial age when unloading of the hydrostatic pressure due to melting of the ice caused the fluid pressure to build to explosive levels. Historic phreatic explosions are known from the Clear Lake area in northern California, from New Zealand and many other places. Phreatic explosions are a natural hazard at any site of high-temperature hydrothermal occurrence.

All of the above means that people living in these geologic environments, which spawn geothermal energy resources, are subject to a number of natural disasters -- volcanic eruptions, earthquakes, land slides and phreatic explosions -- that have nothing to do with geothermal use in the area. To imply that the geothermal exploration work is responsible for such events is not generally true.

I would invite you to call one or both of the following people in Guatemala for further information:

1. Luis Felipe Merida
   Cordon y Merida
   6a Avenida 6-94
   Zona 9
   502-2-318631.

   Luis is associated with the geothermal exploration project at the Zunil site, and is a contractor to INDE. Cordon y Merida are engineering contractors of very good reputation in Guatemala.

2. Ing. Andres Caicedo
Coordinador Ejecutivo
Unidad de Desarrollo Geothermico.
INDE
Torre Profesional I
Centro Comercial Zona 4
2-345711

For your further information on geothermal energy and its contribution worldwide, I have attached several pages. I would be happy to provide further details at your request.

GEOTHERMAL ENERGY

Geothermal energy is the heat of the earth. Since the depths of the earth are very hot, heat flows outward toward the surface, and the temperature increases with depth below the surface. The several thermal regimes in the earth give rise to a classification of geothermal resource types, illustrated in Figure 1.

Hydrothermal energy, geopressured energy, and magma energy, all result from the *concentration of earth's heat* in discrete regions of the subsurface by one or more of several geologic processes. *Earth energy* is thermal energy at the normal temperature of the shallow ground, *without anomalous enhancement* due to geologic processes. It is energy that is found everywhere across the United States and the world and can be used with geothermal heat pumps to heat and cool homes and buildings, supply domestic hot water and provide industrial heat needs. *Hot dry rock energy* occurs at depths of 5 to 10 miles beneath the surface everywhere, although it also occurs in areas of thermal enhancement due to geologic processes.

Naturally occurring hot water and steam form the *hydrothermal energy* resource. Hydrothermal development is economic today at a few high-grade sites. A relatively small industry generates electrical power and supplies heat for direct uses from hydrothermal resources. Many more hydrothermal resources could be used if better technology were available and if their development were actively promoted by the government. Geopressured, hot dry rock and magma energy all require further R&D to enable them to be economically developed.

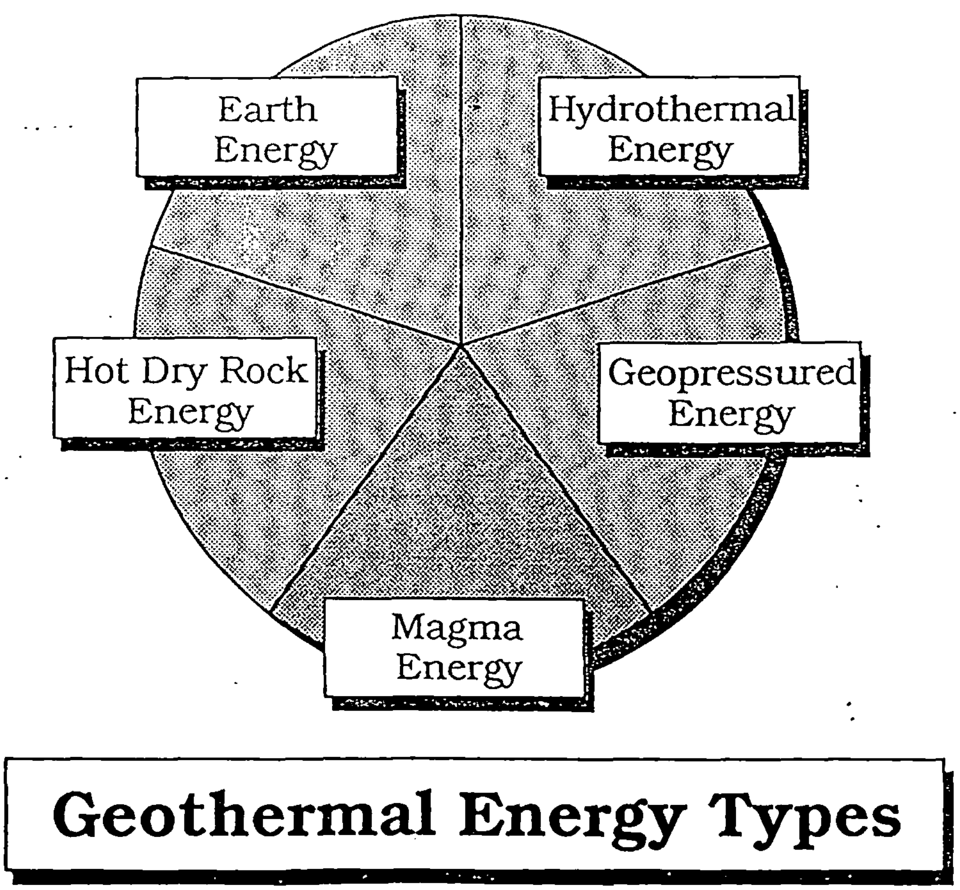


Figure 1.

CURRENT AND POTENTIAL CONTRIBUTION OF GEOTHERMAL ENERGY

Geothermal energy is here today -- it is not merely a hope for the future. *The production of geothermal energy in the U.S. currently ranks third in renewable energy sources,* following hydroelectric power and biomass energy. As a result of geothermal production today, consumption of exhaustible fossil fuels is offset along with the release of the greenhouse and acid-rain gases that are caused by fossil-fuel use. Geothermal energy use in the United States is equivalent to the burning of about 60 million barrels (bbl) of petroleum each year, while worldwide geothermal energy use is equivalent to the burning of about 150 million barrels of oil per year. The U.S. Strategic Petroleum Reserve contains less than 600 million barrels of oil, an amount that could be replaced every four years with the savings from worldwide geothermal use.

There is a very large geothermal resource base in the U.S., much of which can not yet be economically developed. In fact, *the total resource base for the renewable/sustainable energies -- geothermal, solar, biomass and wind -- is much larger than the total resource base in coal, oil, gas, uranium (nuclear power) and hydropower combined.*

It is difficult to estimate the ultimate potential contribution of geothermal energy to mankind's needs for four reasons:

1. Future energy costs are uncertain, and many lower-grade hydrothermal resources would become economic at higher energy prices;

2. Technology is not yet available for economic use of many hydrothermal resources, nor for use of any of the geopressured, hot dry rock, or magma resources;

3. Only preliminary estimates of the U. S. and worldwide resource base have been made; and,

4. Figures for demand reduction through widespread use of geothermal heat pumps are not available.

Geothermal resources can contribute greatly to the energy needs in the U.S., both on the *supply side* (generation of geothermal electricity and production of geothermal heat for direct use) and on the *demand side* (reduction in the need for new electrical generating capacity and savings in natural gas consumption through the use of geothermal heat pumps). Although most geothermal electrical power generation will be restricted to the western U.S. until deep hot dry rock resources can be tapped, geothermal heat pumps can be installed virtually anywhere, bringing the benefits of geothermal energy to all parts of our Nation.

Geothermal Heat Increases our Energy Supplies

At our current stage of technology and with current energy costs, economic development of geothermal energy can be accomplished in *some* areas where the heat is concentrated by geological processes. Hot water and steam exist at many subsurface locations in the western U.S. in the form of hydrothermal systems. These hydrothermal systems can be tapped by existing well-drilling and energy-conversion technology to generate electricity or to produce hot water for direct use. For generation of electricity, hot water is brought to the surface through production wells and is flashed to steam in special vessels by release of pressure. The steam is separated and fed to a turbine engine, which turns a generator. Spent geothermal fluid is injected back into cooler parts of the reservoir to obviate environmental problems and to help maintain reservoir pressure (Figure 2). Some high-temperature (+450 °F) resources yield steam from the reservoir rather than water, and this steam is fed straight to the turbines. If the reservoir is to be used for direct-heat application, the geothermal fluid is usually fed to a heat exchanger before being reinjected into the earth. Hot water from the output side of the heat exchanger is then used for home heating, greenhouse heating, vegetable drying and a wide variety of other uses.

Geothermal Resource

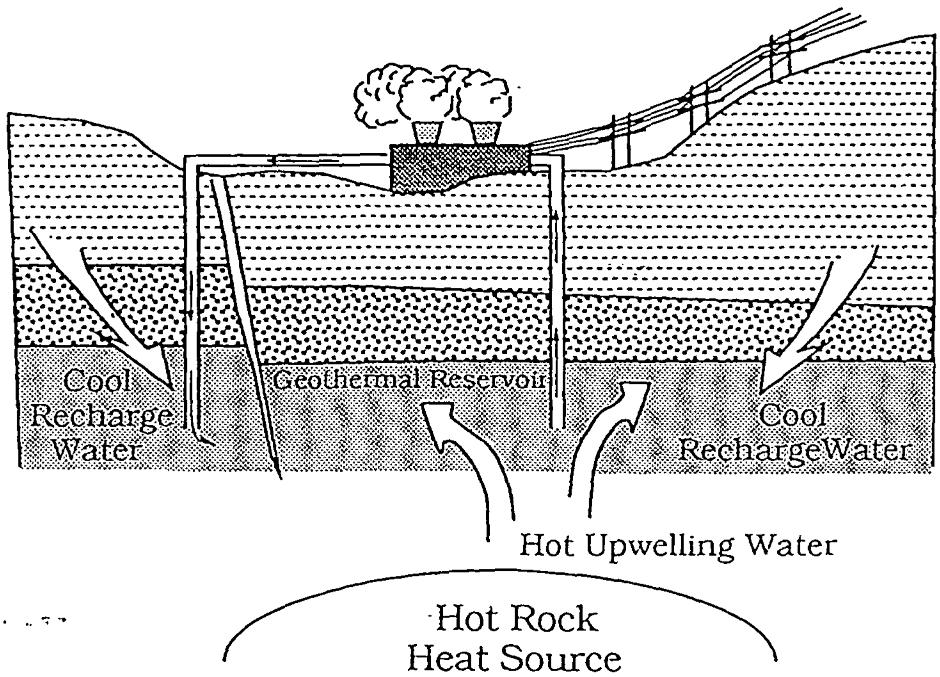


Figure 2

The U.S. geothermal industry currently has an *installed capacity of 2,800 megawatts of electrical power* (MWe) from hydrothermal resources (1), while direct applications of hydrothermal energy in the U. S. have a total installed capacity in excess of 2,100 thermal megawatts (MWt), including geothermal heat pumps (2,3).

Geothermal energy is found in many places on the earth in addition to the U. S., and its utilization is growing rapidly worldwide. *Approximately 5,700 megawatts of electricity are currently being generated in some 20 countries from geothermal energy (1), and there are 11,300 thermal megawatts of installed capacity worldwide for direct-heat applications* at inlet temperatures above 95° F (35° C) (4). If we include the use of geothermal water at lower temperatures and geothermal heat pumps operating at normal groundwater temperature, the energy production throughout the world from geothermal resources is very much greater, but unquantified at this time.

Reserves of hydrothermal energy in the U. S. are difficult to quantify. However, the United States Geological Survey has estimated that geothermal energy from identified high-temperature U.S. hydrothermal systems could supply 23,000 megawatts of electrical energy for 30 years (5). In addition, they believe that about 5 times this amount may be available from undiscovered hydrothermal resources in the U. S.

Low- to moderate-temperature geothermal resources, suitable for direct-heat application, are widely distributed throughout the western and mid-western United States (6). Discrete resources exist throughout the western third of the country in subsurface reservoirs of a few acres to a few square miles in extent, while in the northern Great Plains, major stratabound geothermal aquifers may extend in a continuous manner for thousands of square miles (7). It is estimated that more than 7,800 MWt could be installed in district heating systems in the U. S. using *identified* resources, and that the ultimate potential is much larger.

Systems for use of hydrothermal energy have proven to be extremely reliable and flexible. During 1987, hydrothermal electric power plants were on line an average of 97 % of the time, whereas nuclear plants averaged only 65 % and coal plants only 75 % on-line time (Figure 3). Geothermal plants are modular, and can be installed in increments as they are needed. Both baseline and peaking power can be generated. Construction time can be as little as 6 months for plants in the range 0.5 to 10 MWe and as little as 2 years for clusters of plants totalling 250 MWe or more.

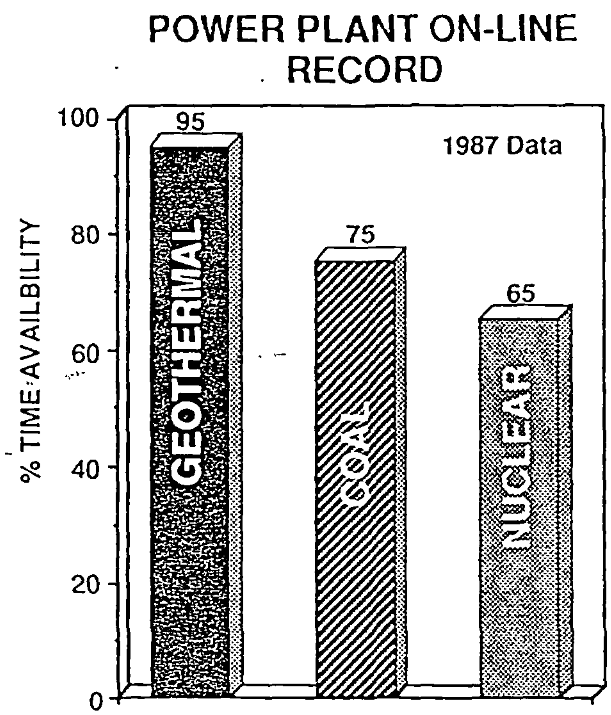


Figure 3.

Geothermal Energy Decreases our Energy Demand

No active technology for home heating and air conditioning is more efficient than the geothermal heat pump (GHP). GHPs use normal-temperature earth or groundwater for heating during the winter, cooling during the summer and supplying hot-water needs year around. The heat pump itself operates on the same principal as the home refrigerator, which is actually a one-way heat pump. The GHP, however, can move heat in either direction -- it is reversible. In the winter, heat is removed from the earth and delivered into the home or building (heating mode). In the summer, heat is removed from the home or building and delivered for storage into the earth (air-conditioning mode). On either cycle, culinary water is heated and stored, eliminating the need for a separate hot-water heater. Because electricity is used only to transfer heat, not to produce it, the

GHP will deliver 3 to 4 times more energy than it consumes. It can be effectively used over a wide range of earth temperatures.

The GHP unit sits inside the home or building, at the site of a normal gas furnace (Figure 4). In a typical installation, a loop of plastic pipe is placed in a vertical drill hole from one hundred to several hundred feet deep and the hole is backfilled with clay. A water/antifreeze solution is circulated through the loop and through the heat pump for removing heat from or rejecting heat to the ground. There is no consumptive use of groundwater whatsoever, nor is there any contact between the solution in the plastic pipe and the earth or groundwater. An alternative installation is sometimes carried out by placing the loop of plastic pipe in a horizontal trench and backfilling with soil. Either installation easily conforms to local construction and well-drilling regulations. Typical loop installations are warranted for 50 years (8).

In a 1988 survey of geothermal heat pump buyers (9), 97 % said that they were satisfied with their purchase and would buy again. Not one of the 157 randomly selected buyers refused to respond to the survey.

Earth-Coupled Heat Pump

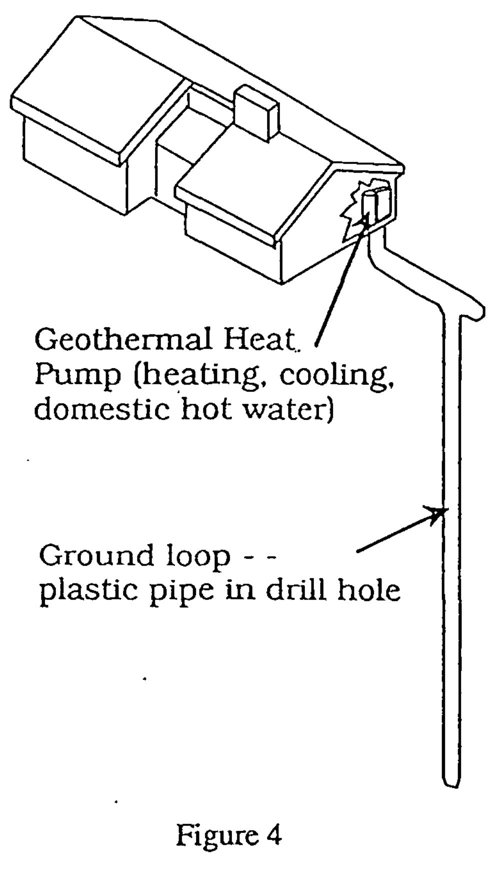


Figure 4

The U. S. lags behind other countries in taking advantage of heat-pump technology. Sweden has deferred construction of two nuclear power plants by using GHPs to reduce electrical power needs. Canadian growth in GHPs since 1986 has exceeded 50 % per year.

More than 100,000 electrically powered geothermal heat pumps have been installed in homes and buildings in the U. S. (mid-1990 figure). Additional installations are being actively promoted by investor-owned utilities and rural electrical cooperatives as a means of promoting energy efficiency and better managing demand. GHPs can cut 1 to 5 kilowatts (KW) of peak generating capacity requirement per residential installation. There are an estimated 25 million homes in the U.S. that have central air conditioning without access to natural gas (10). Replacement of these units alone with GHPs over the next several decades is not unreasonable. The savings would be 24,000 to 48,000 MWe in peak summer demand and 48,000 to 96,000 MWe in peak winter demand. This estimate illustrates what could be done in only one sector -- homes in the U. S. with electrical central air conditioning. It does not include new home construction or electrical energy used in heating and cooling buildings of the industrial or public sectors. In addition, natural-gas powered GHPs are under development and enhanced-performance units, with end-use efficiencies of 160 %, should be available within a few years.

Although the above figures give an indication of the amount of electricity and gas that could be saved through widespread use of geothermal heat pumps, the topic clearly merits a more detailed investigation. We recommend that DOE undertake a thorough examination of this technology, its R&D needs and ways to implement it quickly across the U. S.

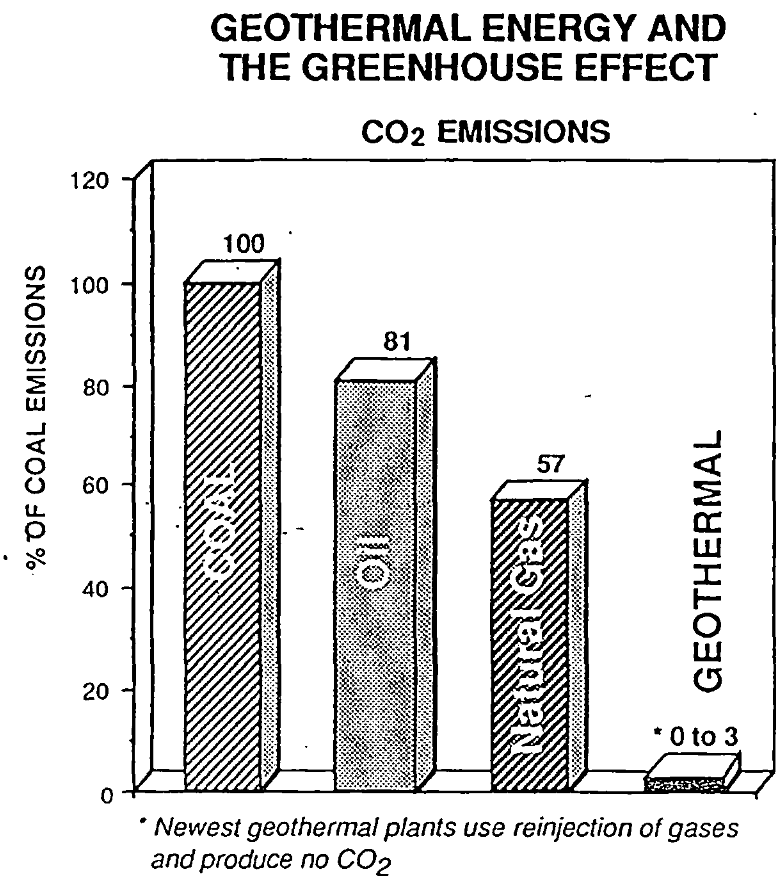
GEOTHERMAL ENERGY -- NET POSITIVE ENVIRONMENTAL IMPACT

Every major urban center and industrial complex around the world is emitting unacceptable quantities of climate- and biosphere-modifying air pollution. Certainly, the competing goals of increased energy production for continued worldwide social development and the need to mitigate release to the atmosphere of greenhouse and acid-rain gases are not compatible using today's energy mix. Strategies which allow high standards of living without fossil–fuel burning must include technologies that produce electrical energy with little or no harmful emissions.

Development of geothermal energy has a large net positive impact on the environment compared with further development of conventional energy sources. Modern geothermal power plants operating on hydrothermal resources have extremely low levels of CO_2, NO_x, SO_x and particulate emissions. The newest generation of power plants have equipment to recover the noncondensible gas from the steam and inject it back into the earth along with the spent geothermal fluid. Consequently, these plants emit only 0.3 lb of carbon per megawatt-hour (MW-hr) of electricity generated. This figure compares with 282 lb/MW-hr of carbon for a plant operating on natural gas, 418 lb/MW-hr of carbon for a plant operating on #6 fuel oil and 497 lb/MW-hr of carbon for a plant using bituminous coal (11). *Emissions of CO_2 from coal-fired generating plants are more than 1,600 times greater than emissions from modern hydrothermal power plants* (Figure 5). The advantage of geothermal energy in these comparisons is obvious.

Growing acid rain problems will increasingly limit the use of power-plant technologies incapable of low sulfur emission. Geothermal power plants have sulfur emission rates that average only about 1 percent of those from fossil–fuel alternatives. Nitrogen–oxide emissions are also much lower than those from fossil plants. The only particulate emissions from geothermal plants are those associated with evaporation of water in the cooling towers, which are typically a factor of 1,000 smaller than particulate emissions from coal, oil and biomass stacks (11).

Geothermal power plants require very little land, taking up only a few acres for plant sizes of 100 megawatts or more. Other land uses can mingle with geothermal plants with little interference or fear of accidents. Geothermal drilling, with no risk of fire, is safer than petroleum drilling, and there is less worry about the potential for environmental damage from drilling activities.



GEOTHERMAL ENERGY AND
THE GREENHOUSE EFFECT
CO2 EMISSIONS
% OF COAL EMISSIONS
120
100
80
60
40
20
0
100
81
57
* 0 to 3
COAL
Oil
Natural Gas
GEOTHERMAL
* Newest geothermal plants use reinjection of gases
and produce no CO2

Figure 5.

Sr. Karl Eduard Albrand
TECNICA Y EQUIPOS, S.A.
Avenida La Reforma 9-00, Zona 9
Edificio Plaza Panamericana Niv. 8
Guatemala City, Guatemala 01009

July 10, 1992

Dear Sr. Albrand:

Attached is USGIC's Statement of Capabilities and Interest for Construction, Operation and Maintenance of a Geothermal Power Plant in the Zunil I Geothermal Field, Guatemala. We request that you incorporate it with material you are preparing, and submit the combined package to INDE on our behalf.

We believe that USGIC can furnish the expertise, experience and equipment needed for development of geothermal resources in Guatemala. As you know, the U.S. geothermal industry has been involved in geothermal development for more than 40 years. Our member companies include some of the best of this industry. We are able to furnish complete services in: (1) exploration, drilling, well testing, reservoir engineering and assessment; (2) project feasibility and economic analysis; (3) power-plant and transmission-line design, construction and operation; and, (4) project permitting, financing and environmental control. We have been involved in the successful development of power production at numerous sites in the United States. Member companies can furnish power plants of all sizes, from a few hundred kilowatts to tens or hundreds of megawatts. Our plants operate successfully on high-temperature resources as well as those whose temperatures are as low as 103 °C.

USGIC will be happy to work with you and the Government of Guatemala to ensure the success of every geothermal project with which we are involved. One of our goals will be the training of Guatemalans in geothermal resource development and plant operation.

We believe that clean, reliable geothermal energy can play an important role in helping to furnish the power needed for continued social development in Guatemala.

Sincerely,

Gerald W. Huttrer, President
U.S. Geothermal Industries Corporation

UURI FAX

UNIVERSITY OF UTAH
RESEARCH INSTITUTE
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108-1295

Phone: (801) 524-3437
FAX: (801) 524-3453

DATE: 7-10-92

PAGE 1 OF 3

DELIVER TO: Karl Albrand

FAX: 011-502-2-311912

COMPANY Tecnica Y Equipos, S.A.

FROM: Mike Wright

******************** -COMM.JOURNAL- ************************** DATE JUL-10-1992 ****** TIME 09:42 ***** P.1

MODE = TRANSMISSION START=JUL-10 09:39 END=JUL-10 09:42

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-U OF U RESEARCH INST -

(FAX-310 V2.12)* - 8015243453- ************

MEMO TO: KARL ALBRAND

FROM: MIKE WRIGHT

SUBJECT: TRANSMITTAL LETTER

July 10, 1992

Herewith is a copy of our transmittal letter in case you want to translate it into Spanish prior to getting the final documents together for submission to INDE on 15 July 1992. We are sending our documents to you by DHL today.

TECNICA Y EQUIPOS, S.A.

Ave. La Reforma 9-00, Zona 9
Edif. Plaza Panamericana Niv. 8
Guatemala-City, Guatemala 01009
Telefax: (502-2)-311912
Tels.: (502-2)-311916/311918
Telex: 3146 TECNIQ GU

001-303-668-3074

Fax No.:	038	Date:	31.01.92	Pages:	5
To :	USGIC - Attn.: Mr. Gerald W. Huttrer, President				
From :	K. E. Albrand				
Re :	Prequalification of interested parties in geothermal exploitation by INDE, Guatemala				

cc: UURI / Dr. Wright
A-Z/GIC / J. Hanson

Dear Mr. Huttrer,

We are pleased to inform you that we received USGIC's Statement of Capabilities and Interest for Developing Geothermal Resources in Guatemala in time and wish to thank you for the confidence placed in us.

The evaluation committee of INDE received the documentations and read out the names of the different participants, in the following order:

1. U.S. Geothermal Industries Corporation
2. Morrison Knudsen / Cordon y Mérida / GEOTERMEX
3. UNOCAL (Union Oil)
4. EPN Internacional (Equipos y Petroleos Nacionales, México)
5. Perforadora y Equipos (Supposedly also a Mexican company)

None of the packages were opened and so no further details were provided.

The coordinator of the committee, Mr. Andrés Caicedo, stated that only after the evaluation process further information would be made available. As we know him very well, we might have a feedback before then.

The first three companies seem to us the most proficient ones. We do not know the other two.

We had time to re-write the covering letter in Spanish language and directed it to the President of INDE. Sorry I had to fake Mike's signature.

Changed or added sheets are attached to this fax.

We are convinced that USGIC will be shortlisted, so we should like to recommend to start work on the coming second phase. Please review with your staff what additional information must be collected and submitted. From our side we consider that the aspect of the financial capacity of the group of companies should be disclosed in a more manageable way.

Best regards,

GG/022-92

CEMENTOS PROGRESO, S. A.

15 AVENIDA 18-01, ZONA 6 - TEL. PBX 56641 TELEX 5491 CEMCAL GU - GUATEMALA.C.A.

Guatemala, 29 de Enero de 1992

Señores
U. S. Geothermal Industries Corporation
P. O. Box 2425
Frisco Colorado 80443
U. S. A.

Atn: Sr. Gerald W. Hutter, Presidente

Estimados Señores:

Por medio de la presente queremos manifestarle nuestro interés en participar como empresa nacional, conjuntamente con Ustedes, en la presentación solicitada por el Instituto Nacional de Electrificación para la integración de la Lista Corta de Empresas, que eventualmente participarán en el concurso para desarrollar proyectos de generación de electricidad a partir de recursos geotérmicos en las áreas de Moyuta, San Marcos y Tecuamburro, a través de un proceso de licitación.

Como es de su conocimiento, Cementos Progreso, S. A. es una empresa nacional que para su proceso industrial tiene necesidad de un alto consumo de energía eléctrica.

Atentamente,

CEMENTOS PROGRESO, S. A.

Ing. Carlos Springmühl
Gerente General

CSS/pes
cc file

U.S. GEOTHERMAL INDUSTRIES CORPORATION

Señor Presidente Ejecutivo
Instituto Nacional de Electrificación
7a. Ave. 2-29, Zona 9
Ciudad de Guatemala

Frisco, 28 de Enero 1992

Señor Presidente Ejecutivo:

Atendiendo la invitación para participar en la preselección de empresas, a las que posteriormente se les solicitará presentar ofertas para los proyectos de generación de electricidad a partir de recursos geotérmicos en las áreas de Moyuta, San Marcos y Tecuamburro, nos es grato someter a su consideración nuestra adjunta Declaración de Capacidad e Interés para Desarrollar Recursos Geotérmicos en Guatemala.

Estamos convencidos que USGIC puede aportar los conocimientos, experiencia y equipos necesarios para el desarrollo de recursos geotérmicos en Guatemala, dado que la industria geotérmica de Estados Unidos de América ha estado involucrada en este desarrollo desde hace más de 40 años. Las empresas que forman parte de nuestra corporación incluyen las más destacadas de esa industria.

Nuestras actividades y servicios cubren una amplia gama que van desde la exploración del campo, perforación de pozos, pruebas de pozo, ingeniería de reservorio y evaluación, factibilidad del proyecto, diseño de la casa de máquinas, hasta la realización del proyecto, incluyendo financiamiento, construcción, operación y control del medio ambiente. Hemos participado exitososamente en el desarrollo de producción de energía en numerosos sitios de los Estados Unidos de América y otras partes del mundo. Compañías miembros de nuestra corporación han suministrado plantas de generación de electricidad de todo tamaño, desde centenares de kilovatios hasta decenas de megavatios. Nuestras plantas operan satisfactoriamente en recursos con temperaturas tan bajas como 103°C.

A nosotros como USGIC nos interesa muchísimo poder demostrar nuestra capacidad a través del desarrollo de los recursos geotérmicos y contribuir a la producción de energía eléctrica en Guatemala.

Creemos que una energía limpia y confiable proveniente de recursos geotérmicos puede desempeñar un importante rol en el continuado desarrollo social de Guatemala.

Muy atentamente,

Phillip Wright, for

Gerald W. Huttrer, President
U.S. Geothermal Industries Corporation

P.O. BOX 2425 • FRISCO, CO 80443
Phone: (303) 668-3465 Fax: (303) 668-3074

INFORMACION RESUMIDA DE USGIC

1. ORGANIZACION

U.S. Geothermal Industries Corporation, es una corporación integrada por las Empresas miembros que se mencionan en nuestra presentación. En la documentación anexa, se adjunta la información detallada sobre una selección de estas Empresas.

Se adjunta el organigrama de USGIC ver figura 1.

2. CAPACIDAD FINANCIERA

La capacidad financiera de USGIC es sumamente importante, puesto que la misma se relaciona con la capacidad financiera de todas las empresas miembros que la integran.

La información financiera de algunas de las empresas miembros se adjunta en la documentación de soporte y contiene estos datos; v.g:

DAMES & MOORE	Ventas anuales:	US$ 350 mio
NABORS INDUSTRIES INC.	Ventas en 1 trimestre:	US$ 121 mio
AMERICAN LINE BUILDERS	Ventas anuales:	US$ 7.9 mio

3. EXPERIENCIA

En la presente Declaración de Capacidad e Interés se proporciona una breve descripción de cada una de las Empresas miembros seleccionadas y en la documentación de soporte, en la mayoría de los casos, se proporcionan referencias de proyectos realizados, por estas Empresas.

4. VOLUMEN ACTUAL DE TRABAJO Y CAPACIDAD OPERATIVA

Se dispone de amplia capacidad para acometer proyectos de gran magnitud, además de los proyectos que a nivel local (E.U.) y mundial se realizan en la actualidad.

5. OPCIONES PARA PARTICIPACION DE INVERSIONISTAS GUATEMALTECOS Y SUBCONTRATISTAS

USGIC ha tratado de establecer contactos con inversionistas guatemaltecos y se enorgullece que la firma CEMENTOS PROGRESO, S.A. haya comunicado su interés en participar, conjuntamente, en el desarrollo de estos proyectos.

Contactos con posibles subcontratistas, así como, con otros inversionistas se están realizando.

OPTIONS FOR NATIONAL INVESTORS AND SUBCONTRACTORS

The USGIC intends to pursue the geothermal resources addressed in the request for capabilities for compilation of a short list in conjunction with the Guatemalan firm of:

TECNICA Y EQUIPOS, S.A.
Ave. La Reforma 9-00, Zona 9
Edificio Plaza Panamericana Niv. 8
Guatemala City, Guatemala 01009
(502-2)-31916 and 311918
FAX: (502-2)-31912

It is also the intention of USGIC to address future projects in conjunction with Guatemalan investors, some of them have been already contacted. One of these companies, namely:

CEMENTOS PROGRESO, S.A.
15 Avenida 18-01, Zona 6
Guatemala City, Guatemala 01006

has indicated per attachement its interest to participate jointly with USGIC.

It is intention to seek help from Guatemalan subcontractos wherever that it possible, and to provide training to Guatemalan who work on any project we are awarded.

FOCUS ON

DRAFT

HONDURAS

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
4300 KING STREET, SUITE 400
ALEXANDRIA, VIRGINIA 22302-1508
(703) 998-3600

PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

The series is available for the following countries: Argentina, Azores (Portugal), China, Costa Rica, Ecuador, El Salvador, Ethiopia, Guatemala, Honduras, Indonesia, Jordan, Mexico, St. Lucia, Thailand.

Additional countries might be available in the future.

The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

- The *"Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities."* Final Report, August 1987. Prepared for Los Alamos National Laboratory.

- The *"Summary Report"* of the above publication.

- *"Equipment and Services for Worldwide Applications,"* U.S. Department of Energy.

- The *"Listing of U.S. Companies that Supply Goods and Services for Geothermal Explorers, Developers and Producers Internationally,"* August 1987, prepared by GRC.

Copies of these publications can be obtained from the Geothermal Technology Division of the U.S. Department of Energy. Correspondence should be addressed to:

Dr. John E. Mock
Geothermal Technology Division (GTD)
1000 Independence Avenue
U.S. Department of Energy
Washington, DC 20585
(202) 586-5340

NOTE

Data presented in this document are based on several U.S. government official publications as well as international organizations, namely:

- Background Notes (U.S. Department of State)
- Foreign Economic Trends (U.S. Department of Commerce)
- World Development Report 1987 (World Bank)
- International Data Base for the U.S. Renewable Energy Industry, May 1986 (U.S. Department of Energy)

The country's geothermal resources write-up is a revision and update of the Appendix in the "Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities." LANL, August 1987.

CONTENTS

FOCUS ON HONDURAS

Official Name: Republic of Honduras

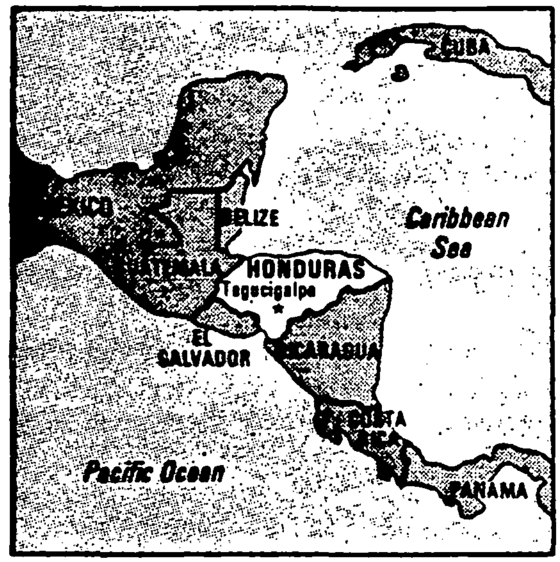
Area: 109,560 sq. km. (42,300 sq. mi.)

Capital: Tegucigalpa

Population (1985): 4.4 million

Population Growth Rate: 3.3%

Languages: Spanish



Economic Indicators:

Real GNP (1985): $3.35 billion
Real Annual Growth Rate (1985): 3.0%
Per Capita Income (1985): $815
Avg. Inflation Rate (1985): 3.4%

Trade and Balance of Payments:

(1985) Exports: $958 million; Major Markets: U.S.
(1985) Imports: $1,358 million; Major Suppliers: U.S.

(1984) Official Exchange Rate: 2 Lempira = US $1

Energy Profile: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 0.787 million ton of oil equivalent (mtoe)
  1-Yr. Growth: 1.9%

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: 66%
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: 34%
  Commercial Fuel Consumption Growth Rate (1970-1980): 4.5%

* Negligible

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: 236 MW
  Hydro: 57%
  Hydro Potential: 2,800 MW
  Steam: 0%
  Gas Turbine: 43%
  Diesel: 0%
  Other: 0%

- Electricity Sales:

  Total: 761 GWh
  Residential: 28%
  Commercial: 15%
  Industrial: 50%
  Government: 7%
  Other: *
  Average Electricity Price: 7.35 US cents/kWh

- Geothermal Power Generation Status

  Reservoir Potential (MW): Around 1,732 MW (LANL 1987 estimates)
  Temperature Range: 185° to 205°C

- Geographic Locations: Central Honduras and Western area

- Development Status: Prefeasibility studies, preliminary resource assessment

- Countries Actively Involved: U.S., Italy

- General Need for Assistance: Exploratory drilling, well testing, reservoir modelling and power generating

- International Funding:
  - $10.2 million from U.S. AID
  - $ 3 million from the Goverment of Italy and UNDP
  - $900,000 from the World Bank

* Negligible

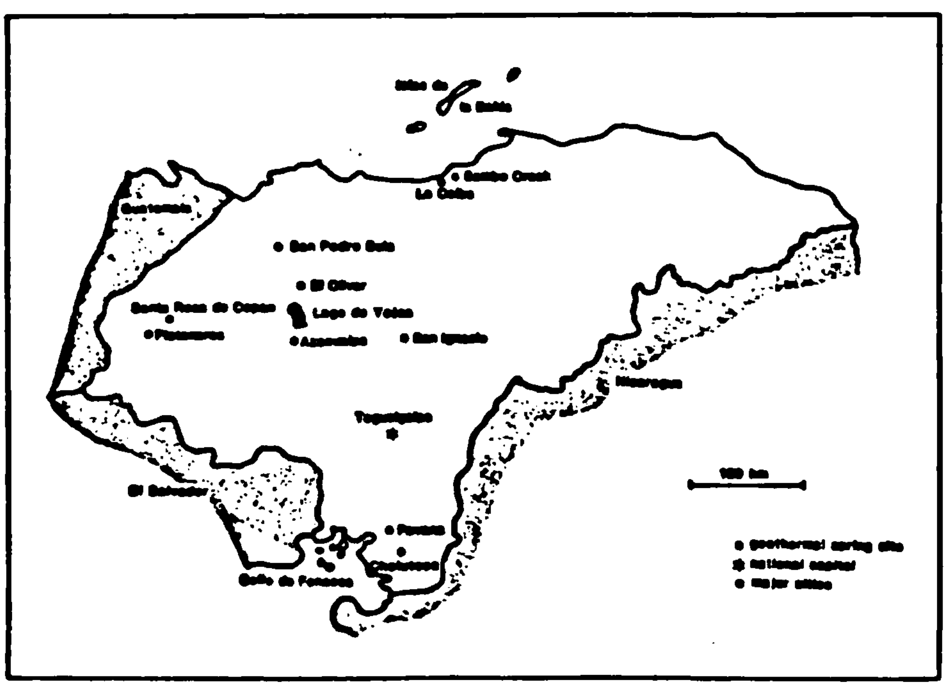
GEOTHERMAL RESOURCES

Organized geothermal investigations in Honduras began in 1976 as part of a technical mission from the United Nations. Financial difficulties prevented completion of the work and the project was not resumed until 1978. At that time, the Central American Isthmus Energy Program (PEICA) was being organized and later incorporated the UN studies.

In 1979, a nationwide hydrogeochemical sampling and reconnaissance program was performed. Along with an inventory at 128 thermal manifestations, water samples were taken at 111 locations and gas samples at 11 locations. The results of this study provided a basis for prioritizing prospective areas for more detailed exploration. In 1982, the World Bank provided $900,000 for geothermal exploration in Honduras.

Funding for geothermal studies in the next phase of work did not materialize and Honduras' national energy organization (ENEE) began surface geologic studies at selected areas. Through this work, six areas are now considered high geothermal prospects. The areas: 1) San Ignacio; 2) Platanares; 3) Azacualpa; 4) El Olivar; 5) Sambo Creek; and 6) Pavana. Geochemistry has indicated reservoir temperatures from 185^{0} to 205^{0}C for these areas. In addition to the six areas of primary interest, five other areas are considered to be of secondary interest.

In 1985, the UN Department of Technical Cooperation for Development funded a prefeasibility study in central Honduras over an area of some 10,00 sq. km. D.A.L and Geothermica Italiana Srl. are conducting the work. Funding for the project - about $3 million - is provided by the government of Italy (55%), the government of Honduras (25% in kind), and the UNDP (20%). The study is scheduled for completion at the end of this year.



Geothermal Sites in Honduras

Source: Geothermal Resources Council Bulletin, Oct. 1986

In 1986, in conjunction with this study, a joint effort began between Los Alamos National Laboratory and ENEE and is aimed at evaluating the country's geothermal energy resources. This effort is part of LANL's Central American Energy Resources Project, started in 1985 with $10.2 million from USAID. The objective of this cooperative effort is to determine the scientific and economic feasibility of developing the geothermal energy resources of Honduras for electrical power generation. Training and support to facilitate in-country expertise and surveying capabilities is also provided.

As part of this project, a 1,900-ft well was drilled in the western part of the country, near the Guatemalan border. Initial measurements show a temperature of 400°F.

Bibliography:

Di Paola, G.M., 1985, "The Role of the UN in the Field of Geothermal Resources Exploration in Developing Countries," Geothermal Resources Council (GRC) 1985 International Symposium on Geothermal Energy, International Volume, pp. 247-250.

Flores, C.W., and Mass, M.A., 1983, "Current Status of the Geothermal Project of Honduras." Latin American Seminar on Geothermal Exploration, OLADE.

Geothermal Resources Council Bulletin, December 1985, pp 11.

LANL, "Geology of the Platanares Geothermal Site Departamento de Copan, Honduras, Central America." Field Report, Central America Energy and Resource Project.

LANL, 1987, The Energy Situation in Five Central American Countries, Central American Energy and Resource Project. June 1987. (LA-10988-MS) pp 259-260.

REFERENCES

AND

KEY CONTACTS

A. Business Climate Sources of Information

The following references are suggested for timely information on the business climate in Honduras.

U.S. GOVERNMENT PUBLICATIONS

U.S. Department of Commerce

- Foreign Economic Trends (FET) and their Implications for the U.S.
- Overseas Business Reports (OBR)

U.S. Department of State

- Background Notes

NON-GOVERNMENT PUBLICATIONS

- International Series, published by Ernst and Whinney
- Businessman's Guide to......., published by Price Waterhouse and Co.
- Information Guide: Doing Business in ......, published by Price Waterhouse and Co.
- Task and Trade Guide, published by Arthur Andersen
- Task and Investment Profile, published by Touche Ross and Co.

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory:

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
- International Data Base for the U.S. Renewable Energy Industry
- Committee on Renewable Energy Commerce and Trade: CORECT's Second Year - October 1985-November 1986

California Energy Commission (CEC)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

C. KEY CONTACTS

Honduras

Mr. Jack, Arevalo
General Manager
Empresa Nacional De Energia Electrica
7th Avenue Premier Calla
Tegucigalpa, Honduras

U.S. Embassy
Avenida La Paz
Tegucigalpa, Honduras
Tel: 32-31-20
Attn: Officer in Charge
USAID Mission
Tel: 32-69-15

Agency for International Development

- Bureau for Science and Technology

Dr. James Sullivan
Director, Office of Energy
Bureau for Science & Technology
Agency for International Development
Washington, DC 20523
(703) 235-8902

- Bureau for Private Enterprise

Mr. Sean P. Walsh
Director, Office of Investment
Bureau for Private Enterprise
Agency for International Development
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Mr. Russell Anderson
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Bureau for Private Enterprise
Agency for International Development
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- Bureau for External Affairs

Ms. Rhea Johnson
Director, Office of Public Inquiries
Bureau for External Affairs
Agency for International Development
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- Bureau for Latin America/Caribbean

Mr. Terrence Brown
Director, Office of Development Resources
Bureau for Latin America and the Caribbean
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- Publications

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Bureau for External Affairs
Agency for International Development
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- Office of International Major Projects

Mr. Leo E. Engleson
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International Trade Administration
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(202) 377-2732

- Foreign Industry Sector

Mr. Les Garden
International Trade Specialist for Renewable Energy Equipment
Office of General Industrial Machinery
International Trade Administration
U.S. Department of Commerce
Washington, DC 20230
(202) 377-0556

- International Economic Policy

Mr. Peter B. Field
Director, Office of South America
Office of International Economic Policy
International Trade Administration
U.S. Department of Commerce
Washington, DC 20230
(202) 377-2436

- Office of Trade Promotion

Mr. Saul Padwo
Director, Office of Trade Promotion
International Trade Administration
U.S. Department of Commerce
Washington, DC 20230
(202) 377-1468

- Export Development

  Ms. Laverne Branch
  Latin America, Middle East and Africa
  U.S. and Foreign Commercial Service (USFCS)
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-4756

- Minority Business Development Centers

  Minority Business Development Agency
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-1936

  or contact:

  <u>Regional Offices</u>:

  Atlanta, GA (404) 881-4091
  Chicago, IL (312) 353-0182
  San Francisco, CA (415) 556-7234
  Dallas, TX (214) 767-8001
  New York, NY (212) 264-3262
  Washington, DC (202) 377-8275 or 8267

- DOC Marketing Periodicals

  Superintendent of Documents
  U.S. Government Printing Office
  Washington, DC 20402
  (202) 783-3238

<u>U.S. Department of Energy</u>

Dr. Robert San Martin
DAS/RE
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- International Lending

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811 Vermont Avenue, NW
Washington, DC 20571
(202) 566-8187

- Latin America Division

Mr. Richard D. Crafton
Vice President, Latin America Division
Export-Import Bank
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Geothermal Resources Council

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P.O. Box 1350
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(916) 758-2360

Inter-American Development Bank

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Chief
Non-Conventional Energy Section
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Washington, DC 20577
(202) 623-1978

Mr. Calvin DePass
Macroeconomist
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Inter-American Development Bank
1300 New York Avenue, NW
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(202) 623-2441

International Trade Commission

Office of Publications
International Trade Commission
701 E Street, NW
Washington, DC 20436
(202) 523-5178

Office of the U.S. Trade Representative

Mr. Fred Ryan
Director, Private Sector Liaison Division
Office of the U.S. Trade Representative
600 17th Street, NW
Washington, DC 20506
(202) 456-7140

Overseas Private Investment Corporation

- Insurance Department

Mr. John W. Gurr
Regional Manager, Latin America Division
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Overseas Private Investment Corporation
1615 M Street, NW
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- Energy Program

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- Office of Development

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Secretary
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The World Bank
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- Publications

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DEPARTMENT OF ENERGY

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5-31-94
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RUCPDC/USDOC WASHDC
RUEHC/SECSTATE WASHDC 3221
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STATE FOR ARA/CEN, ARA/ECP, ARA/EX, A/FBO/BDE/EEB
A/FBO/AM/ARA FOR BILL MOONEY
TREASURY FOR KATHERINE PARKINSON
USDOC FOR 4322/IEP/OLA/CBD/HLEE

E.O. 12356: N/A
TAGS: ENRG, AMGT, KPWR, ABLD, ALOW, ASEC, HO
SUBJECT: ELECTRICITY RATIONING TO INCREASE:
- THE WORST IS STILL AHEAD

REF: (A) 93 TEGU 1698, (B) TEGU 1250, (C) TEGU 3095

1. ON MAY 17, THE HONDURAN ELECTRICAL ENERGY COMPANY (ENEE) ANNOUNCED THAT ELECTRICITY RATIONING WOULD SOON INCREASE FROM 25 TO AT LEAST 40 HOURS WEEKLY. ENEE OPERATIONS CHIEF CARLOS GARCIA EXPLAINED THAT THE ENERGY SHORTAGE IS BECOMING MORE CRITICAL AT THE SAME TIME THAT OLDER FACILITIES AND EQUIPMENT REQUIRE SIGNIFICANTLY MORE DOWN TIME FOR MAINTENANCE. GARCIA SAID THAT HONDURAS WILL CONTINUE TO PURCHASE ELECTRICITY FROM PANAMA AND NICARAGUA, BUT THAT THESE PURCHASES ARE FAR TOO SMALL TO FILL THE GROWING GAP BETWEEN SUPPLY AND DEMAND. GARCIA NOTED THAT "THE WORST IS STILL AHEAD" IN ENERGY SHORTAGES AND THAT THE HOURS OF DAILY POWER OUTAGES WOULD INEVITABLY LENGTHEN.

2. COMMENT: THE RATIONING SCHEDULE HAS BEEN INCREASING IN RECENT WEEKS, AND IS NOW TO INCREASE FURTHER. EXPLANATIONS AND PREDICTIONS ABOUND, WITH THE MOST OPTIMISTIC COMING FROM THE PRESIDENT AND POLITICAL LEADERS AND THE MOST PESSIMISTIC FROM THE ENEE TECHNICAL STAFF. THE MAY 17 ANNOUNCEMENT WAS THE FIRST PUBLIC ADMISSION BY ENEE THAT THE ELECTRICITY SHORTAGE IS GETTING WORSE.
(DRAFTED: ECON: KMILLIKEN)
PRYCE
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#3860
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FOCUS ON
FOCUS ON
FOCUS ON
FOCUS ON

HONDURAS

A GEOTHERMAL INTERNATIONAL SERIES

Sponsored by:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

Prepared for:

LOS ALAMOS NATIONAL LABORATORY
Under Contract No. 9-X36-3652C

Prepared by:

MERIDIAN CORPORATION
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Alexandria, Virginia 22302-1508
(703) 998-3600

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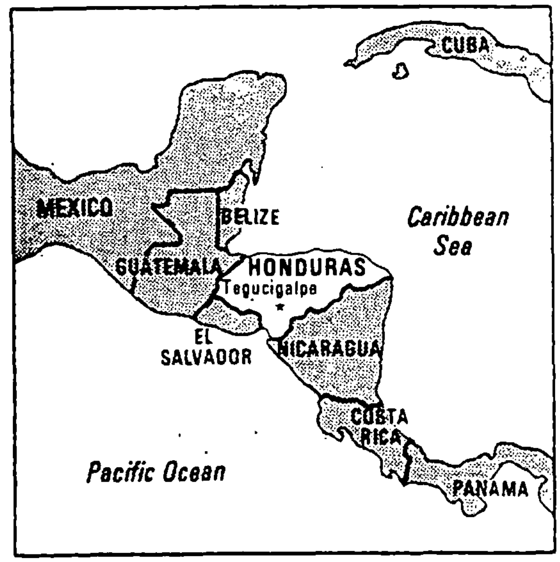
FOCUS ON

HONDURAS



<u>Official Name</u>: Republic of Honduras

<u>Area</u>: 109,560 sq. km. (42,300 sq. mi.)

<u>Capital</u>: Tegucigalpa

<u>Population (1985)</u>: 4.4 million

<u>Population Growth Rate</u>: 3.3%

<u>Languages</u>: Spanish

<u>Economic Indicators</u>:

Real GNP (1985): $3.35 billion
Real Annual Growth Rate (1985): 3.0%
Per Capita Income (1985): $815
Avg. Inflation Rate (1985): 3.4%

<u>Trade and Balance of Payments</u>:

(1985) Exports: $958 million; Major Markets: U.S.
(1985) Imports: $1,358 million; Major Suppliers: U.S.

(December 18, 1987) Official Exchange Rate: 2 Lempira = US $1

<u>Energy Profile</u>: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 0.787 million ton of oil equivalent (mtoe)
  1-Yr. Growth: 1.9%

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: 66%
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: 34%
  Commercial Fuel Consumption Growth Rate (1970-1980): 4.5%

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: 236 MW
  Hydro: 57%
  Hydro Potential: 2,800 MW
  Steam: 0%
  Gas Turbine: 43%
  Diesel: 0%
  Other: 0%

- Electricity Sales:

  Total: 761 GWh
  Residential: 28%
  Commercial: 15%
  Industrial: 50%
  Government: 7%
  Other: *
  Average Electricity Price: 7.35 US cents/kWh

- Geothermal Power Generation Status

  Reservoir Potential (MW): Around 1,732 MW (LANL 1987 estimates)
  Temperature Range: 185^{o} to $205^{o}C$

- Geographic Locations: Central Honduras and Western area

- Development Status: Prefeasibility studies, preliminary resource assessment

- Countries Actively Involved: U.S., Italy

- General Need for Assistance: Exploratory drilling, well testing, reservoir modelling and power generating

- International Funding:
  - $10.2 million from U.S. AID
  - $ 3 million from the Goverment of Italy and UNDP
  - $900,000 from the World Bank

* Negligible

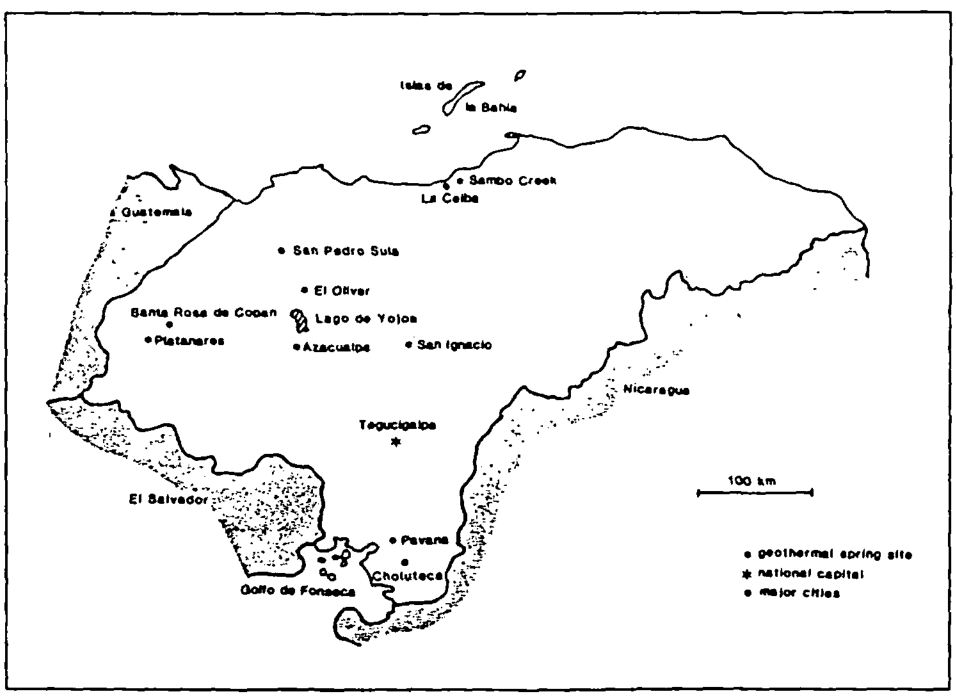
GEOTHERMAL RESOURCES

Organized geothermal investigations in Honduras began in 1976 as part of a technical mission from the United Nations. Financial difficulties prevented completion of the work and the project was not resumed until 1978. At that time, the Central American Isthmus Energy Program (PEICA) was being organized and later incorporated the UN studies.

In 1979, a nationwide hydrogeochemical sampling and reconnaissance program was performed. Along with an inventory at 128 thermal manifestations, water samples were taken at 111 locations and gas samples at 11 locations. The results of this study provided a basis for prioritizing prospective areas for more detailed exploration. In 1982, the World Bank provided $900,000 for geothermal exploration in Honduras.

Funding for geothermal studies in the next phase of work did not materialize and Honduras' national energy organization (ENEE) began surface geologic studies at selected areas. Through this work, six areas are now considered high geothermal prospects. The areas: 1) San Ignacio; 2) Platanares; 3) Azacualpa; 4) El Olivar; 5) Sambo Creek; and 6) Pavana. Geochemistry has indicated reservoir temperatures from 185^0 to 205^0C for these areas. In addition to the six areas of primary interest, five other areas are considered to be of secondary interest.

In 1985, the UN Department of Technical Cooperation for Development funded a prefeasibility study in central Honduras over an area of some 10,000 sq. km. D.A.L and Geothermica Italiana Srl. are conducting the work. Funding for the project - about $3 million - is provided by the government of Italy (55%), the government of Honduras (25% in kind), and the UNDP (20%). The study is scheduled for completion at the end of this year.



Geothermal Sites in Honduras
<u>Source</u>: Geothermal Resources Council Bulletin, Oct. 1986

In 1986, in conjunction with this study, a joint effort began between Los Alamos National Laboratory and ENEE and is aimed at evaluating the country's geothermal energy resources. This effort is part of LANL's Central American Energy Resources Project, started in 1985 with $10.2 million from USAID. The objective of this cooperative effort is to determine the scientific and economic feasibility of developing the geothermal energy resources of Honduras for electrical power generation. Training and support to facilitate in-country expertise and surveying capabilities is also provided.

As part of this project, a 1,900-ft well was drilled in the western part of the country, near the Guatemalan border. Initial measurements show a temperature of 400^{o}F.

Bibliography:

Di Paola, G.M., 1985, "The Role of the UN in the Field of Geothermal Resources Exploration in Developing Countries," Geothermal Resources Council (GRC) 1985 International Symposium on Geothermal Energy, International Volume, pp. 247-250.

Flores, C.W., and Mass, M.A., 1983, "Current Status of the Geothermal Project of Honduras." Latin American Seminar on Geothermal Exploration, OLADE.

Geothermal Resources Council Bulletin, December 1985, pp 11.

LANL, "Geology of the Platanares Geothermal Site Departamento de Copan, Honduras, Central America." Field Report, Central America Energy and Resource Project.

LANL, 1987, The Energy Situation in Five Central American Countries, Central American Energy and Resource Project. June 1987. (LA-10988-MS) pp 259-260.

REFERENCES

AND

KEY CONTACTS

A. Business Climate Sources of Information

The following references are suggested for timely information on the business climate in Argentina.

U.S. GOVERNMENT PUBLICATIONS

U.S. Department of Commerce

- Foreign Economic Trends (FET) and their Implications for the U.S.
- Overseas Business Reports (OBR)

U.S. Department of State

- Background Notes

NON-GOVERNMENT PUBLICATIONS

- International Series, published by Ernst and Whinney (New York)
- Businessman's Guide to......., published by Price Waterhouse and Co. (New York)
- Information Guide: Doing Business in ......, published by Price Waterhouse and Co. (New York)
- Task and Trade Guide, published by Arthur Andersen (Chicago)
- Task and Investment Profile, published by Touche Ross and Co. (New York)

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory (Los Alamos, New Mexico)

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
- International Data Base for the U.S. Renewable Energy Industry
- Committee on Renewable Energy Commerce and Trade: CORECT's Second Year - October 1985-November 1986

California Energy Commission (CEC) (Sacramento, California)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

C. KEY CONTACTS

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Mission Director
USAID Mission
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- Office of Trade Promotion

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  Washington, DC 20230
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- Minority Business Development Centers

  Minority Business Development Agency
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  or contact:

  Regional Offices:

  Atlanta, GA (404) 881-4091
  Chicago, IL (312) 353-0182
  San Francisco, CA (415) 556-7234
  Dallas, TX (214) 767-8001
  New York, NY (212) 264-3262
  Washington, DC (202) 377-8275 or 8267

- DOC Marketing Periodicals

  Superintendent of Documents
  U.S. Government Printing Office
  Washington, DC 20402
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THE 500 MW GEOTHERMAL PLAN

A PLAN FOR SUSTAINABLE ENERGY DEVELOPMENT
WHICH WILL REDUCE AIR POLLUTION,
INVIGORATE THE NICARAGUAN ECONOMY, AND
CEMENT U.S.-NICARAGUAN BUSINESS RELATIONSHIPS

PRESENTED BY

THE GOVERNMENT OF NICARAGUA
AT THE
SUMMIT OF THE AMERICAS
MIAMI, FLORIDA
DECEMBER 1994

CONFIDENTIAL

NICARAGUA'S CONCEPT REGARDING GEOTHERMAL ENERGY DEVELOPMENT

GOALS OF THE PROGRAM

- Diversification of energy resources.
- Substitution of ecologically compatible and sustainable energy in place of fossil fuels.
- Solution of electricity shortage problem in Nicaragua and the Central American region, which is an impediment to international investment.
- Reduction of dependence on imported fuels.
- Stimulation of the economy through private foreign investment.
- Development of energy export potential, harmonious with the Inter-American Development Bank's project of Central American Electricity inter-connection. According to the U.S. Geothermal Energy Association, Nicaragua has a 4,000 MW geothermal power potential.

These goals are to be partially implemented through the development of 500 Megawatts of geothermal power in a 10-12 year time frame.

1

THE CENTRAL AMERICAN INTERCONNECTION PROJECT

- On December 5, 1994, the Central American countries will sign an action plan, named SIEPACSA, for the construction and operation of a transmission system which will interconnect the region.

- SIEPACSA will ultimately be completed as a 500 kilovolt system, capable of carrying many hundreds of megawatts throughout the region.

- SIEPACSA will be completed in stages over the next 8-9 years, at an estimated cost of U.S. $500 million, spanning about 1680 kilometers through Central America.

- Concessionary financing will be provided by the Inter-American Development Bank and the Government of Spain. The European Investment Bank, the Eximbank of Japan, the Bank of Norway and the World Bank have expressed interest in co-financing the project.

The staged development of geothermal electricity will make it possible for Nicaragua to export part of that power to other Central American countries.

THE CURRENT SITUATION

Electricity blackouts caused by:

Drought effect on hydro-power plant availability.

Decline in Momotombo Geothermal Plant output.

Old combustion turbines providing unreliable power output.

Ongoing transition to private power, requiring:

Reorganization of the power sector.

Adequate new regulations for the private power developers.

Direction of the government to improve the situation

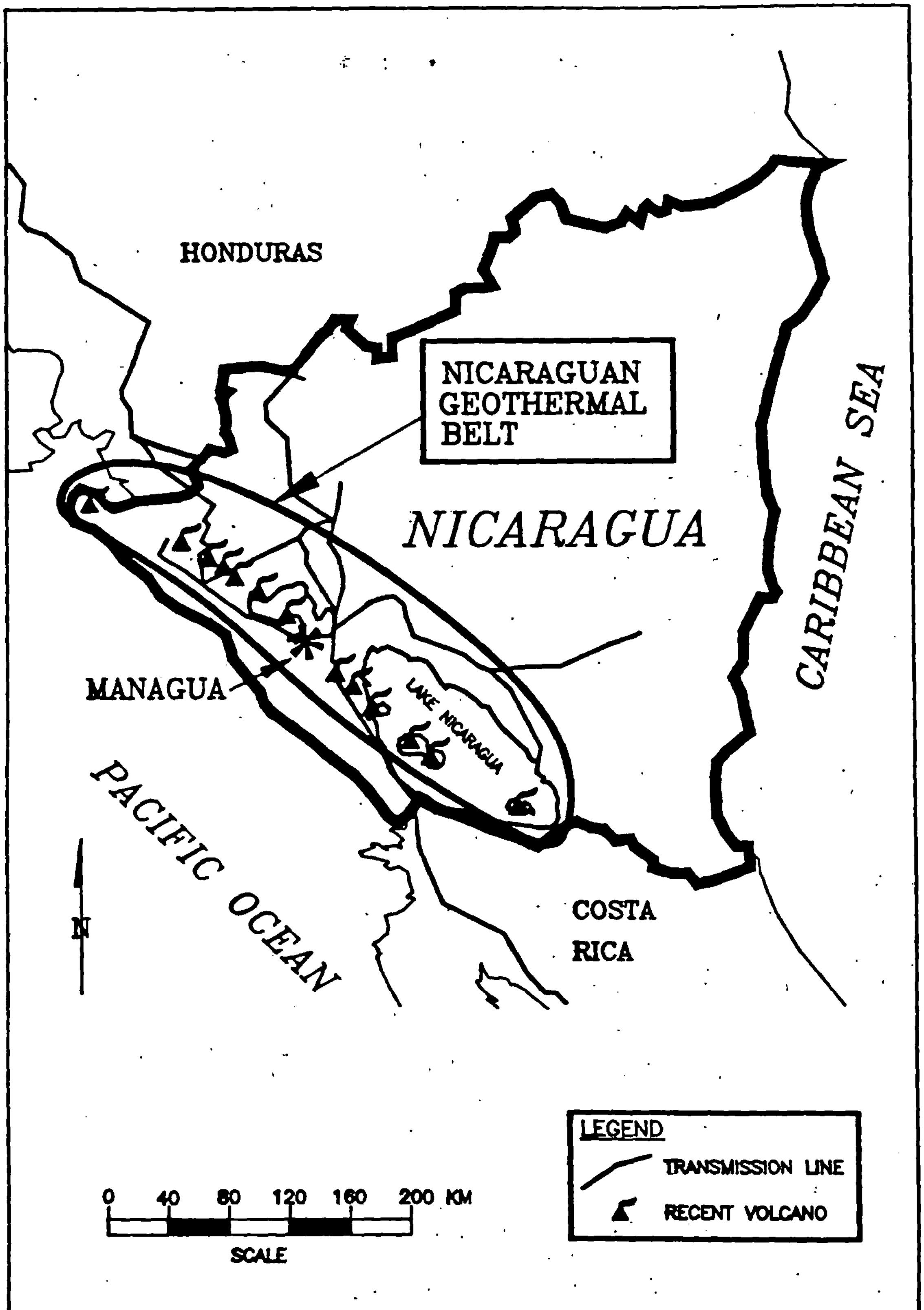
The Government of Nicaragua is seeking to develop new power sources, preferably domestic, sustainable energy, by attracting private power developers to take on that task. Geothermal energy provides one of the most attractive opportunities, because of the available geothermal resource in the country, in which it has over 20 years experience.

ECONOMIC FACTORS

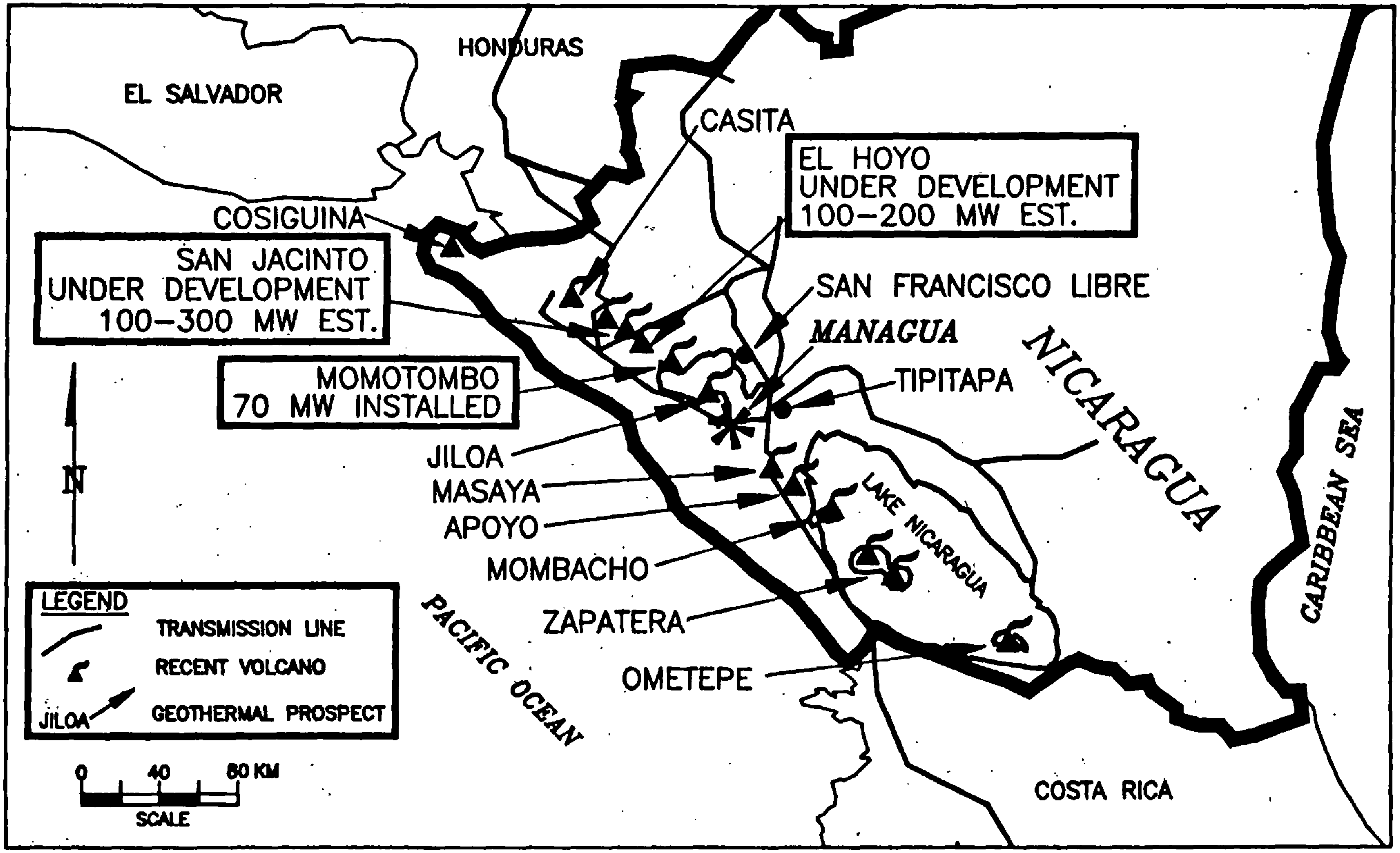
- Foreign investment, tax and other pertinent laws are in place.
- Government ready to award geothermal concessions.
- Nicaraguan Institute of Energy is being reorganized into separate generation, transmission and distribution companies.
- Power purchase agreements are being negotiated with private companies.
- Growing interest in the international geothermal community.

Examples of growing international interest:

- Partial privatization of the Momotombo geothermal plant, with the participation of a large Mexican private company, that will supply needed investment to increase output.
- Intergeoterm, a joint venture between Russian interests and Nicaraguan Institute of Energy at San Jacinto-Tizate location.
- Contract negotiations with Trans-Pacific Geothermal Corporation, a California company for a project at El Hoyo-Monte Galan location, a new private power development.

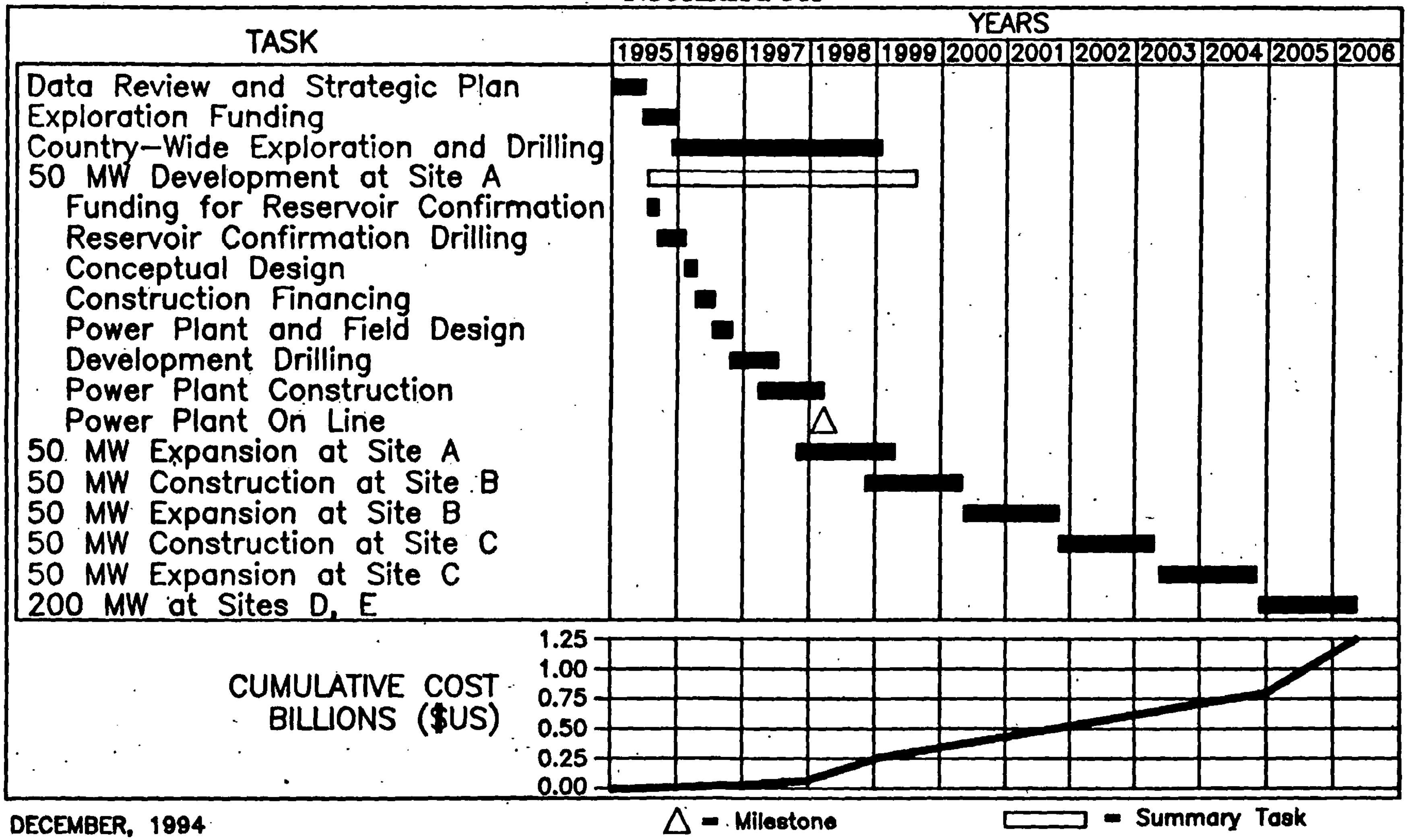


GEOTHERMAL BELT OF NICARAGUA



GEOTHERMAL PROSPECTS OF WESTERN NICARAGUA

CONCEPTUAL PLAN FOR 500 MW OF GEOTHERMAL DEVELOPMENT IN NICARAGUA



DEVELOPMENT OF THE 500 MW GEOTHERMAL PLAN WILL RESULT IN:

BENEFITS TO THE NICARAGUAN ECONOMY

- **Approximately 25% of $1.25 billion in investment in 500 MW development of geothermal power spent in direct local services ($300 million).**
- **A multiplier effect will generate about $900 million activity in the economy.**
- **Income tax on power generated.**
- **Income tax on labor and services.**
- **Increased reliability of energy supplies.**
- **Development of power export potential.**

BENEFITS TO THE U.S. ECONOMY

Should the U.S. provide loans or loan guarantees which favor U.S. industry, the direct benefits to the U.S. economy would be:

- **Direct sales of equipment and services, 75% of $1.25 billion (i.e., $940 million).**
- **Total impact on the economy of the U.S. (including the multiplier effect of 2.5), of $2.3 billion.**
- **Strengthening of commercial relationships bet...een the two countries.**

PROBLEMS IN IMPLEMENTATION

- **Geothermal resource confirmation**

  There is a need to carry out additional geo-scientific and drilling activities to increase the confidence of the international business community in the favorable economics of Nicaragua's geothermal resources.

- **Credit and investment security**

  There is an incorrect perception of the credit risk involved in private investments in Nicaragua, and lack of experience among American potential investors, that makes project financing more difficult than in some other countries around the world, even though Nicaragua is OPIC approved and there already are American and other foreign investors with considerable interests in the country.

- **External debt problem**

  Although Nicaragua is being successful in clearing its problem with debt to governments and multi-lateral lenders, the issue of debt to private banks has not been resolved as yet.

POSSIBLE SOLUTIONS TO PROBLEM OF ACCELERATED DEVELOPMENT

- **Assistance from the U.S. in geothermal resource confirmation through federal government action.**

- **Incentive loans for private companies for resource confirmation.**

- **Loan guarantees for equipment purchased in the U.S.**

- **Reduction of OPIC insurance costs for sustainable energy developments**

  Examination of the possibility of lower cost insurance for sustainable energy projects.

- **Cash-for-clean-power swaps**

  Cash contributions aimed at encouraging sustainable energy projects could be earmarked for activities that would facilitate investments by international companies.

POSITIVE IMPACTS OF THE 500 MW GEOTHERMAL PLAN ON THE GLOBAL ENVIRONMENT

Assuming that the 500 MW of geothermal power to be constructed in Nicaragua displaces and equal amount of combustion turbine facilities, the following environmental impacts will result:

- **Reduction of CO_2 emission to the atmosphere: 1.4 billion tons/year**
- **Reduction of NOx emission to the atmosphere: 1,270 tons/year**
- **Reduction of SOx emission to the atmosphere: 4,000 tons/year**
- **Reduction in oil imports 5.7 million barrels/year**

Implementation of that plan will conform to the spirit and intent of the Managua Declaration of the Central American Presidents on October 16, 1994 and the 1991 Rio Summit Agenda 21*

* Alianza para el Desarrollo Sostenible de Centro America

IMMEDIATE ACTION PROPOSAL

- **Joint study of implementation modes**

  Bilateral evaluation by joint Nicaragua-U.S. experts of legal, technical and financial mechanisms necessary to accelerate the plan, and release of report on possible approaches.

- **Analysis of impediments**

- **Development of joint action plan by the U.S. and Nicaragua to implement the 500 MW geothermal plan**

  A specific action plan would serve as a guide to the combined governmental efforts in getting the program on the road to actual implementation.

Nicaragua 5/31/94

FOR: DOFLECA

ROUTINE -- UNCLASSIFIED -- DSSCS MESSAGE -- 6572 CHARACTERS
VZCZCMSS1494
ACTION = DOE,DOE CMS(1),GTN(-),EP(4),OTHER(1)
DOE,OIN IDD(-)
INFO = ** UNASSIGNED **
MLN = 11239 DAN = 401-172573
RR RHEBDOE
DE RUEHC #4119 2280215
ZNR UUUUU ZZH ZEX
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R 150215Z AUG 92
FM SECSTATE WASHDC
TO ALL DIPLOMATIC AND CONSULAR POSTS
SPECIAL EMBASSY PROGRAM
RUEATRS/TREASURY WASHDC 6554
RUEHPH/CDC ATLANTA 8737
RUCPDIR/ALL USDOC DISTDIR
RUKLDAR/USARMY MAT COMMAND ALEXNADRIA VA//AMCMI SS//
RUWDOAA/NAVOCEANSYSCEN SAN DIEGO CA// J C SHIELDS//
RUEAHQA/HQ USAF WASHDC//XOXXI//
RUEABOA/BOLLING AFB DC/IVOA//
RUCNJVW/USDOE OKRE AL INOCCO
RUKGNHA/FAA WASHDC//ACS 400//
RULSNAA/COMNAVAIRSYSCOM WASHDC//AIR1031B//((((((
INFO RUESGU/ATO GUAM 0462
BT
UNCLAS STATE 264119

INFORM CONSULS

E.O. 12356: N/A
TAGS: OTRA, CASC' ASEC,
SUBJECT: : TRAVEL ADVISORY - NICARAGUA - CAUTTON
EZ05:

1. THE DEPARTMENT OF STATE RECOMMENDS THAT U.S. CITIZENS EXERCISE CAUTION HEN TRAVELING IN NICARAGUA. LAND MIN S IN CERTAIN RURAL AREAS MAKE OFF ROAD TRAVEL HAZADOUS, PARTICLLARLY IN THE FAR NORTH OR IN MOUNTAINOSS AREAS IN CENTRAL NICAR GUA. TRAVELERS SHOULD USE CAUTION AND CHECK WITH LOCAL AUTHORITIES AND/OR RESIDENTS TO DETERMIN IF THERE ARE AREAS KNOWN TO HAVE LAND MINES OR IF THERE ARE AREAS EXPERIENCING CIVIL UNREST OR POLITICA DEMONSTRATIONS. IN ADDITION, PERIODIC INCIDENCES OF ARMED VIOLENCE CONTINUE AND CAUTION IS ADVISED WHEN TRAVELING OUTSIDE MANAGUA. TRAVEL AT NIGHT OUTSIDE MANAGUA SHOLLD BE AVOIDED.

2. BURGLARY, PETTY THEFT AND PICKPOCKETING ARE COMMO IN CROWDED AREAS SUCH AS MARKETS AND BUSES. VISITOPS SHOULD EXERCISE CAUTION, AND SAFEG)ARD PASSPOPTS AND VALUABLES TN

HOTEL SAFES RATHEP THAN CARRYING THEM ON THEIR PERSON. NICARAGUAN LA DOES NOT REQUIRE FOREIGNEPS TO CAPRY PASSPORS AT ALL TIMES.

3. BORDER CROSSINGS SHOULD ONLY BE MADE AT THE ENTRY

POINTS AT LAS MANOS, EL ESPINO AND GUASA'LE ON THE B ER ITH HONDURAS, AND AT PENAS BANCAS ON THE COSTA RICAN BORDER. THE DEPARTMENT OF STATE DISCOURAGES .S. CITIZENS FROM CROSSTNG THE GU F OF FONSECA BY FERPY BETWEEN POTOSI, NICARAGUA AND LA UNION, EL SALVADOR.

4. PRIVATE BANKS ARE NOW OPERAING IN NICAR GAA AND CASH OR TRAVELER'S CHECKS MAY BE EXCHANGED AT AUTHORZED EXCHANGE FACILITIES (CASAS DE CAMBIO). THE EXCHANGE WILL B PARTIALLY IN LOCAL CURRNCY. THE U.S. EMPASSY CANNOT EXCHANGE CHECKS. THE UNOFFICIAL SALE OR PURCHAS OF LOCAL CURRENCY IS A VIOLATION OF NICARAGUAN LA AND MAY RESULT IN PROSECUTION. CREDIT CARDS ARE NOT ACCEPTED AT MOST HOTELS AND RESTAURANTS.

5. U.S. CITIZENS ARE ENCOURAGED TO SEEK THE LATEST TRAVEL INFORMATION AND REGISTER ITH THE CONSULAR SECTION OF THE AMERICAN EMBASSY LOCATED AT KILOMETER 4-1/2, CARRETERA SUR, MANAGUA, TELEPHONE 666-010.

6. REVIEW DATE: JANUARY 31, 1993.

7. THIS REPLACES THE ADVISORY DATED DECEMBER 20, 1991 AND OFFERS UPDATED INFORMATION ON THE CRIME SITUATION, THE OPENING OF PRIVATE BANKS, AND CUPRENCY EXCHANGE.
KANTER
BT
#4119

NNNN

WORKING PAPERS

FOCUS ON

ST. LUCIA

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
4300 KING STREET, SUITE 400
ALEXANDRIA, VIRGINIA 22302-1508
(703) 998-3600

PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

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The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

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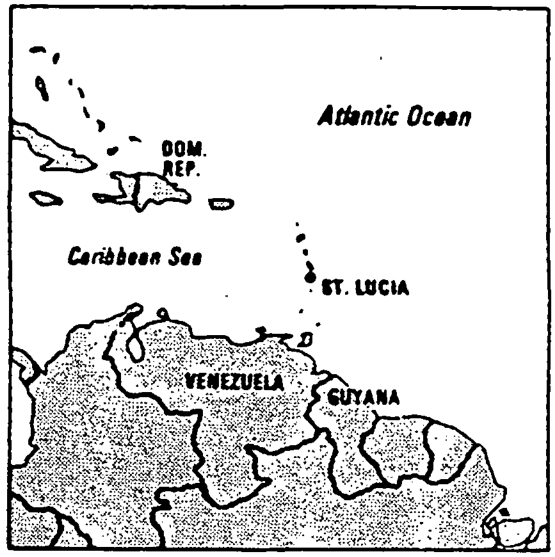
Dr. John E. Mock
Geothermal Technology Division (GTD)
1000 Independence Avenue
U.S. Department of Energy
Washington, DC 20585
(202) 586-5340

CONTENTS PAGE

FOCUS ON

ST. LUCIA



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Capital: Castries

Population (1985): 136,000

Population Growth Rate: 1.8%

Languages: English (official), a french Patois is common throughout the country

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GNP Per Capita Income (1985): $1,240
Inflation Rate (1986): 28.1% change from 1980 base year

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Official Exchange Rate: Eastern Caribbean $2.7 = U.S. $1

Energy Profile: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 0.058 million ton of oil equivalent (mtoe)
  1-Yr. Growth: *

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: *
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: *
  Commercial Fuel Consumption Growth Rate (1970-1980): *

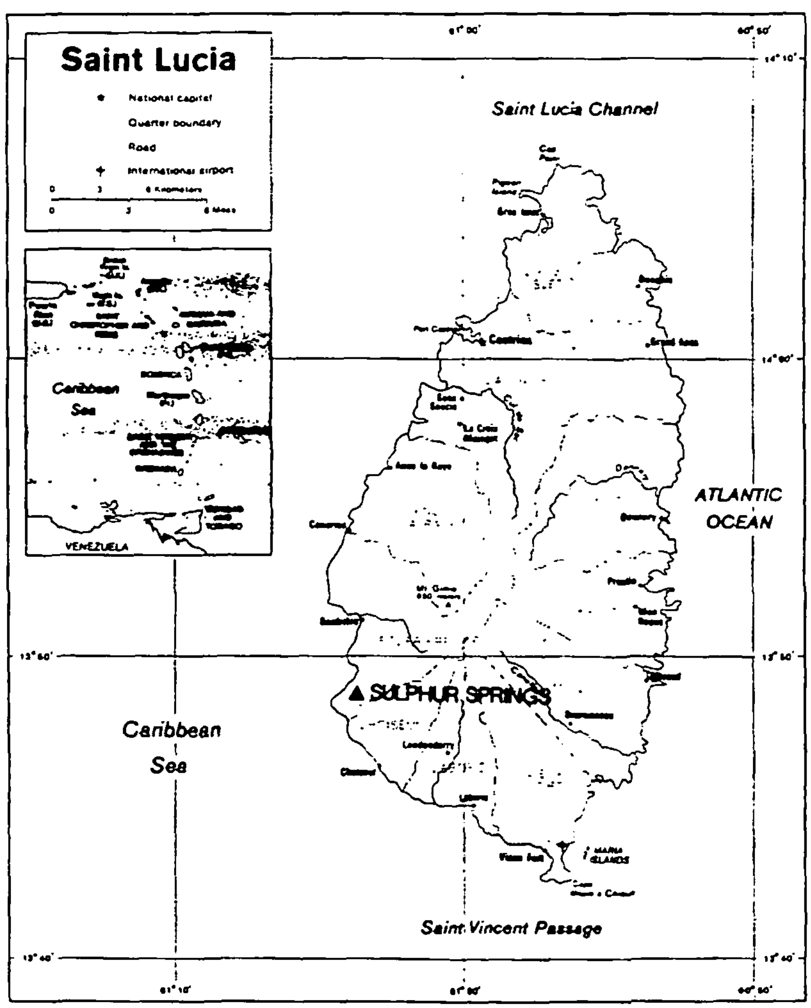
* Not available

GEOTHERMAL RESOURCES

St. Lucia, of the Lesser Antilles island arc, is an independent country of the Eastern Caribbean Commonwealth. An initial comprehensive geothermal resource exploration program at St. Lucia was conducted by the United Kingdom's Ministry of Overseas Development in the early 1970's, followed by engineering testing in 1976. An evaluation of existing information, including recommended drilling areas, was later completed in 1982 by Aquater (Italy). In 1984, Los Alamos National Laboratory (LANL) implemented a geological, geophysical, hydrogeochemical, and engineering investigation including life-cycle cost estimates and recommendations for future exploratory work.

St. Lucia is part of a 10 million year old, migrating volcanic chain where pre-caldera cones and domes of predominantly andesitic composition began forming 2.5 million years ago. Recent daditic eruptions, beginning 250,000 years ago, occurred mainly in the Petit and Gros Pitons areas. The eruption of the Choiseul Pumice resulted in the formation of the Qualibou Caldera at about 39,000 to 32,000 years ago. The latest (32,000 to 20,000 years ago) magmatic activity, centered around Belfond, created ten phreatic rhyodacitic vents in the southern part of the caldera.

Two regional northeasterly trending faults border the Qualibou Caldera. These regional faults and ring structures, associated with formation of



▲ Geothermal Resources

Goff, F., and Buataza, F.D., 1984, "Hydrogeochemistry of the Qualibou Caldera Geothermal System, St. Lucia, West Indies," Geothermal Resources Council Transactions, Vol. 8, pp. 377-382.

Barthelmy, A., 1986, "Special Requirements of Island Developing Countries for Geothermal Development." UN Workshop on the Development and Exploitation of Geothermal Energy in Developing Countries, Iceland-Italy, September 1986.

REFERENCES

AND

KEY CONTACTS

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory:

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
- International Data Base for the U.S. Renewable Energy Industry
- Committee on Renewable Energy Commerce and Trade: CORECT's Second Year - October 1985-November 1986

California Energy Commission (CEC)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

- Bureau for Latin America/Caribbean

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(703) 780-4780
(703) 780-1177

October 21, 1992

Mr. Marshall Reed
DOE, C-122
Washington, D.C. 20585

Dear Mr. Reed:

As we discussed yesterday, I am enclosing a copy of the paper I wrote, with Los Alamos, on St. Lucia's geothermal potential. No need to comment, unless you wish to.

I am also enclosing a copy of the charts I used in 1981 in briefing Prime Minister Eugenia Charles of Dominica on my study of her island's geothermal potential. She received it with enthusiasm and gave its implementation a high priority, to follow major road building and hydroelectric power development programs. These have now been completed.

I am now informed that Prime Minister Charles is close to signing an agreement with USGIT under which they would split the $1.6 million cost of a detailed geological survey and an exploratory drilling program. If results are promising, USGIT would build and operate a 5 MW power plant in the Soufriere field at the southern end of the island and sell the electricity to DOMLEC (Dominica's utility company) for US$0.07/kwh. USGIT expects to recover all its costs plus a reasonable return on its investment after 15 years of such operation, and they would then turn the plant over to Dominica.

Dominica is now seeking loans or grants for their $800,000 half of the cost of the exploratory program. I would appreciate any comments you might give me which would help advance the prospects for this promising project.

With best regards, I am,

Sincerely,

William B. Taylor, P.E.

Enclosures

AN ANALYSIS OF
DOMINICA'S GEOTHERMAL ENERGY POTENTIAL

BY

WILLIAM B. TAYLOR, P.E.

WITH SUPPORT FROM

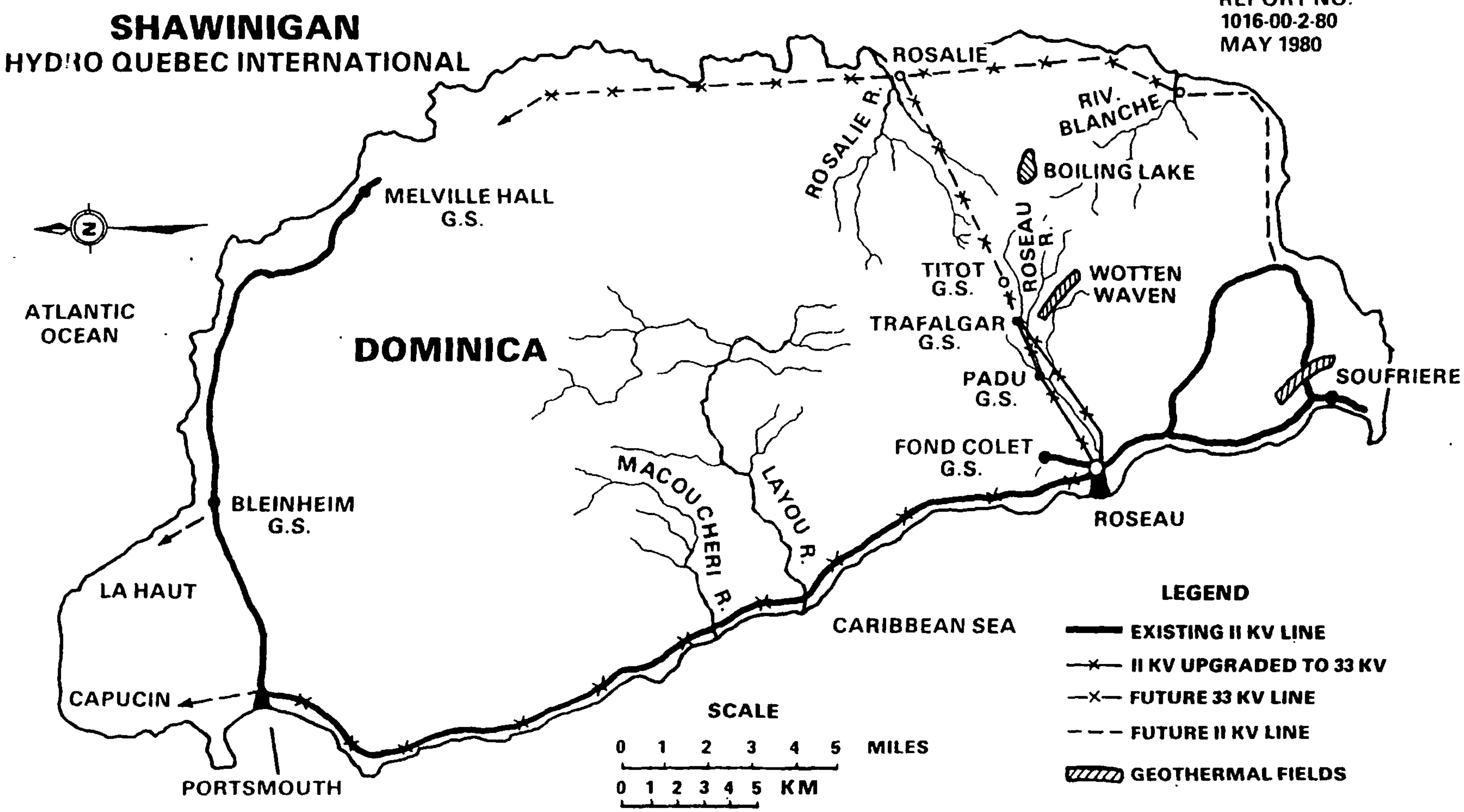
L.T.D. SURVEYING & ENGINEERING, LTD.
T.Y. LIN INTERNATIONAL, INC.
STONE & WEBSTER ENGINEERING CORPORATION

NOVEMBER 1981

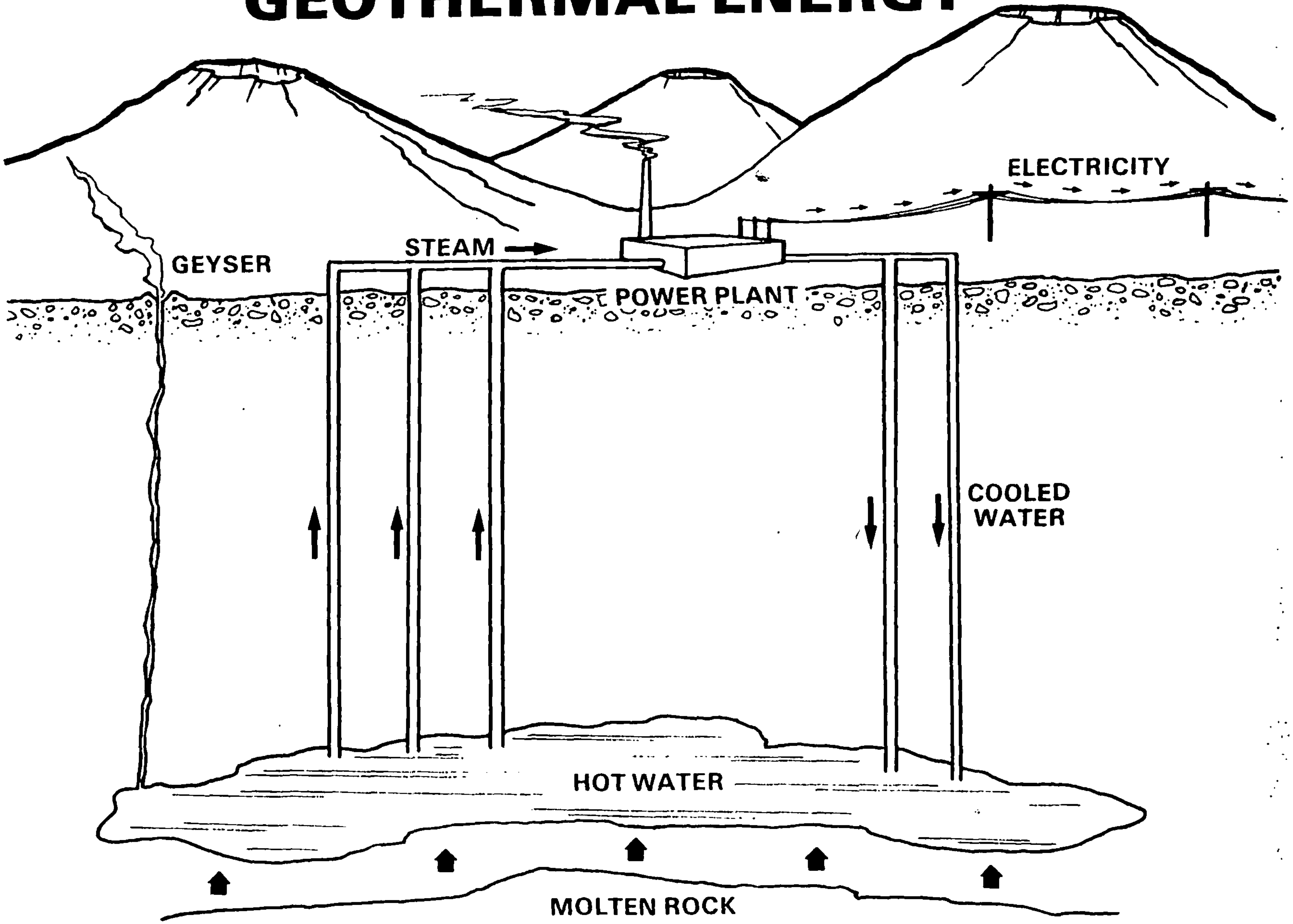
CARIBBEAN DEVELOPMENT BANK

DOMINICA ELECTRICITY SERVICES LIMITED TRANSMISSION SYSTEM

1980-1990



GEOTHERMAL ENERGY



UNDP'S "EVALUATION OF DOMINICA'S NATURAL RESOURCES, 1969":

- "...THE CHANCES FOR FINDING ECONOMIC QUANTITIES OF NATURAL STEAM FOR POWER GENERATION IN DOMINCA ARE EXCELLENT..."
- "...RECENT VOLCANISM AND THE GEOLOGICAL STRUCTURE ASSOCIATED WITH THE VOLCANOES SUGGEST THE PRESENCE OF A LARGE, SHALLOW HEAT SOURCE..."
- "...THE CHEMISTRY OF THE HOT SPRINGS INDICATES THE POSSIBILITY OF PRODUCING STEAM WITHOUT AN ASSOCIATED LIQUID PHASE..."
- "...IT MAY BE THE CHEAPEST SOURCE OF POWER IN THE CARIBBEAN REGION..."

DR. JAMES R. McNITT
UNDP GEOLOGIST
(NOW V-P, GEOTHERMEX, INC.)

US GEOLOGICAL SURVEY'S "RESOURCE APPRAISAL OF DOMINICA, 1978":

- "...NATURAL DEPOSITS OF COPPER, PUMICE, LIMESTONE AND CLAYS MAY BE SUFFICIENT TO JUSTIFY LONG-TERM INDUSTRIAL DEVELOPMENT..."
- "...A VERY GOOD POTENTIAL FOR GEOTHERMAL POWER EXISTS ON THE ISLAND..."
- "...A STUDY OF THE COMPARATIVE COSTS OF DEVELOPMENT OF HYDROELECTRIC POWER VS. GEOTHERMAL POWER IS NEEDED..."

JAMES E. CASE
GEOLOGIST
USGS

FRENCH "GEOTHERMAL STUDIES IN DOMINICA, MAY 1980":

- ONE DOMINICAN GEOTHERMAL WELL CAN PROBABLY PRODUCE 5 TO 10 MW. THIS IS MUCH STRONGER THAN IN GUADELOUPE, WHERE 3 WELLS ARE REQUIRED TO PRODUCE 6 MW.

- DOMINICA'S SOUFRIERE AND WOTTEN WAVEN FIELDS COULD PRODUCE 50 TO 100 MW EACH; BOILING LAKE COULD PRODUCE MUCH MORE.

- A THOROUGH GEOTECHNICAL MEASUREMENT PROGRAM, WITH EXPLORATORY DRILLINGS, AND A 5 MW PILOT PLANT ARE NEEDED TO DEFINE AND PROVE OUT THE RESOURCE.

JACQUES VARET
GEOLOGIST
BUREAU DE RECHERCHES
GEOLOGIQUES ET MINERALES (B.R.G.M.)
ORLEANS, FRANCE

REQUIRED DOMINICAN GEOTHERMAL EXPLORATION PROGRAM

MEASUREMENT PHASE: ($660,000 AND 1 YEAR, PER GEOTHERMEX, INC.)

- GEOLOGICAL ANALYSIS OF THE 3 FIELDS, INCLUDING PETROGRAPHY AND MINERALOGY.
- GEOCHEMICAL ANALYSES OF WATERS AND GASES SAMPLED AT EACH FIELD.
- GEOPHYSICAL MEASUREMENTS TO DEFINE PRECISELY THE LOCATION, DEPTH AND CHARACTERISTICS OF REQUIRED TEST BORINGS.
- BORINGS, MEASUREMENTS AND ANALYSIS OF THE RESULTS AT PROMISING SITES IN THE 3 FIELDS.

PILOT PLANT PHASE: ($4 MILLION AND 2 YEARS, PER B.R.G.M., FRANCE)

- DRILL UP TO 3 PRODUCTION WELLS AT THE BEST SITE.
- INSTALL A SKID-MOUNTED, 5 MW, WELL-HEAD GEOTHERMAL STEAM TURBINE-GENERATOR.
- OPERATE PILOT PLANT TO OBTAIN DESIGN & COST DATA FOR 100 MW PLANTS.
- CONNECT 5 MW PILOT PLANT INTO DOMLEC'S SYSTEM AND SELL ELECTRICITY AT 6 CENTS PER KILOWATT-HOUR (60% OF DOMLEC'S CURRENT PRICE) TO PAY BACK TOTAL COST OF EXPLORATION PROGRAM IN 3 YEARS.

CONCEPT FOR A DOMINICAN GEOTHERMALLY-POWERED INDUSTRIAL COMPLEX

- THREE GEOTHERMAL STEAM POWER PLANTS, ONE EACH AT SOUFRIERE, WOTTEN WAVEN AND BOILING LAKE, TOTALLING 300 MW ELECTRIC POWER GENERATING CAPACITY.

- EACH POWER PLANT TO INCLUDE:
  - 100 MW STEAM TURBINE-GENERATING CAPACITY
  - 25 GEOTHERMAL STEAM SUPPLY WELLS & 10 RE-INJECTION WELLS*
  - STEAM DISTRIBUTION SYSTEM TO CONNECT THE WELL FIELD AND THE POWER PLANT.

- ONE OR MORE ENERGY-INTENSIVE INDUSTRIAL PLANTS, SUCH AS TO:
  - PROCESS FOREIGN BAUXITE TO PRODUCE ALUMINUM
  - MANUFACTURE CEMENT FROM LOCAL MATERIALS
  - MANUFACTURE AMMONIA AND SYNTHETIC FERTILIZER FROM SEA WATER AND LOCAL MATERIALS

*ASSUMES PRIOR EXPLORATION AND DRILLING CONFIRMS RESERVOIR TEMPERATURES OF ABOUT 500°F.

DOMINICAN GEOTHERMAL POWER PLANT (100 MW) COST ESTIMATES*

CAPITAL COSTS (4 YEARS TO DESIGN & CONSTRUCT):	
• STEAM TURBINE POWER PLANT, INCLUDING STEAM DISTRIBUTION FROM THE GEOTHERMAL WELLS	$ 80 MILLION
• GEOTHERMAL WELLS (35 @ ≤$1 MILLION/WELL)	35 MILLION
TOTAL	$115 MILLION
OPERATING COSTS (FOR 30 YEARS):	
• REPLACEMENT WELLS (35 @ ≤$1 MILLION/WELL)	$ 35 MILLION
• O & M PERSONNEL, REPLACEMENT PARTS AND MATERIAL @ $100,000 PER YEAR	3 MILLION
TOTAL, 30 YEARS	$ 38 MILLION
AVERAGE	$1.3 MILLION/YEAR
COST OF GENERATING ENERGY	
ASSUMING 70% CAPACITY FACTOR, 7% INFLATION AND 10% DISCOUNT RATE	12.20 MILLS/KW-HR

* BY STONE & WEBSTER ENGINEERING CORPORATION, SEPTEMBER 1981.

PROPOSED DOMINICAN GEOTHERMAL PROGRAM

PHASE	COSTS	REVENUES	SCHEDULE
1. PROGRAM DEFINITION (SELECTION OF TYPE INDUSTRIES; CONCEPT DESIGN; COST/BENEFIT AND CASH FLOW ANALYSES)	$50,000		1982
2. EXPLORATION OF GEOTHERMAL FIELDS AT SOUFRIERÈ, WOTTEN WAVEN AND BOILING LAKE	$660,000		1982-83
3. DRILL≤3 PRODUCTION WELLS; INSTALL AND OPERATE 5 MW PILOT PLANT FOR 3 YEARS	$4 MILLION		1983-88
4. SELL PILOT PLANT'S ELECTRICITY THROUGH DOMLEC @ 6¢/KW-HR AND PAY OFF LOANS		$1.6 MILLION/YR	1985-88
5. DESIGN AND BUILD THREE 100 MW POWER PLANTS	$345 MILLION		1985-88
6. OPERATE POWER PLANTS AND SELL ELECTRICITY TO INDUSTRIAL PARTNERS @ COST OF GENERATION (12.2 MILLS/KW-HR) PLUS 20% PROFIT. (SELLING PRICE = 1.46 ¢ /KW-HR.)	$15.4 MILLION/YR	$26.9 MILLION/YR	1988-2018

FINDINGS:

- INTERNATIONAL EXPERTS RATE DOMINICA'S GEOTHERMAL POTENTIAL VERY HIGH.
- THE 300 MEGAWATT (MW) POTENTIAL EXCEEDS DOMLEC'S PROJECTION OF DOMESTIC DEMAND FOR ELECTRICITY DURING THE 1990'S BY A FACTOR OF 20.
- ENERGY-INTENSIVE INDUSTRIES (E.G., ALUMINUM, CEMENT, CHEMICALS) WOULD BE ATTRACTED TO DOMINICA BY THE CHEAP ELECTRICITY (LESS THAN 1.5 CENTS PER KILOWATT-HOUR) POSSIBLE FROM THE GEOTHERMAL FIELDS AT SOUFRIERE, WOTTEN WAVEN AND BOILING LAKE.
- FULL DEVELOPMENT OF DOMINICA'S GEOTHERMAL POTENTIAL WOULD COST ABOUT $459 MILLION OVER 30 YEARS AND COULD PRODUCE A NET INCOME OF OVER $10 MILLION PER YEAR TO DOMINICA AND SEVERAL HUNDRED JOBS FOR DOMINICANS, BEGINNING IN 1988.
- THE PRE-REQUISITE GEOTHERMAL EXPLORATION PROGRAM WOULD COST ABOUT $4.7 MILLION AND COULD BE PAID BACK IN 3 YEARS BY THE SALE OF ELECTRICITY FROM ITS 5 MW PILOT PLANT.

NEXT STEPS:

- REQUEST PROJECT PLANNING SERVICES FROM THE US STATE DEPARTMENT'S TRADE & DEVELOPMENT PROGRAM (TDP).

- APPLY FOR A $4.7 MILLION LOAN FROM INTERNATIONAL INSTITUTIONS (E.G., WORLD BANK, CDB) OR FROM PRIVATE INVESTORS FOR THE EXPLORATION AND PILOT PLANT PHASES.

- NEGOTIATE WITH POTENTIAL INDUSTRIAL PARTNERS OR CUSTOMERS FOR DEVELOPMENT OF A 300 MW, GEOTHERMALLY-POWERED INDUSTRIAL COMPLEX FOR DOMINICA.

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Washington, DC 20585
(202) 586-5340

NOTE

Data presented in this document are based on several U.S. government official publications as well as international organizations, namely:

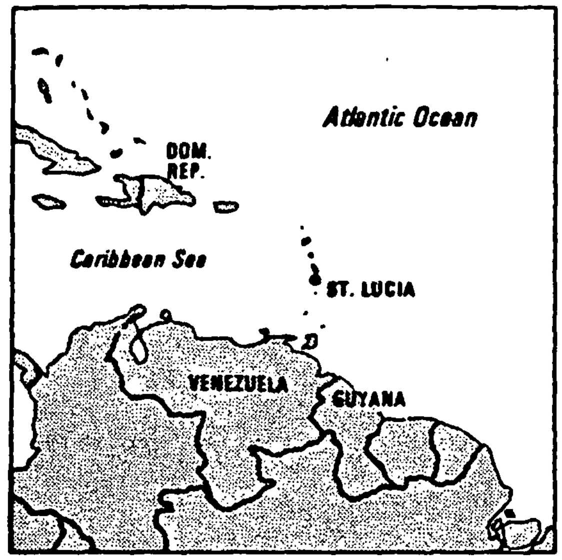
- Background Notes (U.S. Department of State)
- Foreign Economic Trends (U.S. Department of Commerce)
- World Development Report 1987 (World Bank)
- International Data Base for the U.S. Renewable Energy Industry, May 1986 (U.S. Department of Energy)

The country's geothermal resources write-up is a revision and update of the Appendix in the "Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities." LANL, August 1987.

CONTENTS

FOCUS ON

ST. LUCIA



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  1-Yr. Growth: *

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  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: *
  Commercial Fuel Consumption Growth Rate (1970-1980): *

* Not available

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: * MW
  Hydro: *
  Hydro Potential: *MW
  Steam: *
  Gas Turbine: *
  Diesel: *
  Other: *

- Electricity Sales:

  Total: * GWh
  Residential: *
  Commercial: *
  Industrial: *
  Government: *
  Other: *
  Average Electricity Price: *

- Geothermal Power Generation Status:

  Reservoir Potential (MW): Preliminary estimate of 30 MW+ (LANL 1984) at the Soufriere field.
  Temperature Range: 250°C

- Geographic Locations: Qualibou Caldera, Belfond area and Sulphur Springs Valley

- Development Status: General reconnaissance and prefeasibility studies, some recent feasibility studies.

- Countries Actively Involved: U.K., Italy, U.S.

- General Need for Assistance: Feasibility studies, exploration and and exploration drilling, reservoir modeling, financing, and commercial power production.

- International Funding:
  - $2.5 million U.N.
  - $ 3 million USAID

* Not available

GEOTHERMAL RESOURCES

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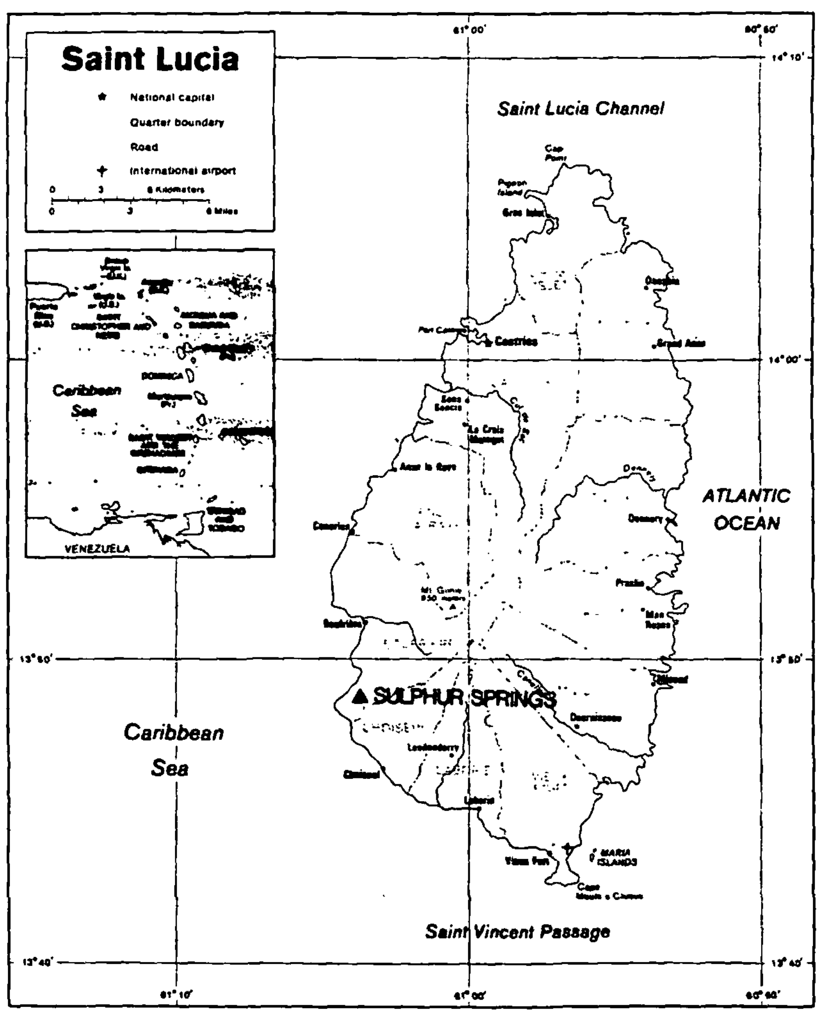

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- Publications

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FOCUS ON

ST. LUCIA

DRAFT

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
4300 KING STREET, SUITE 400
ALEXANDRIA, VIRGINIA 22302-1508
(703) 998-3600

PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

The series is available for the following countries:
Argentina, Azores (Portugal), China, Costa Rica, Ecuador, El Salvador, Ethiopia, Guatemala, Honduras, Indonesia, Jordan, Mexico, St. Lucia, Thailand.

Additional countries might be available in the future.

The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

- The *"Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities."* Final Report, August 1987. Prepared for Los Alamos National Laboratory.

- The *"Summary Report"* of the above publication.

- *"Equipment and Services for Worldwide Applications,"* U.S. Department of Energy.

- The *"Listing of U.S. Companies that Supply Goods and Services for Geothermal Explorers, Developers and Producers Internationally,"* August 1987, prepared by GRC.

Copies of these publications can be obtained from the Geothermal Technology Division of the U.S. Department of Energy. Correspondence should be addressed to:

Dr. John E. Mock
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1000 Independence Avenue
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(202) 586-5340

NOTE

Data presented in this document are based on several U.S. government official publications as well as international organizations, namely:

- Background Notes (U.S. Department of State)
- Foreign Economic Trends (U.S. Department of Commerce)
- World Development Report 1987 (World Bank)
- International Data Base for the U.S. Renewable Energy Industry, May 1986 (U.S. Department of Energy)

The country's geothermal resources write-up is a revision and update of the Appendix in the "Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities." LANL, August 1987.

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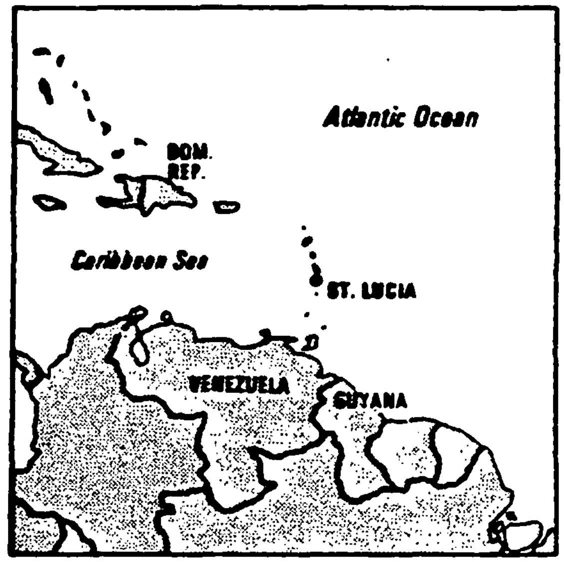
FOCUS ON

ST. LUCIA



Official Name: St. Lucia

Area: 619 sq. km (238 sq. mi.)

Capital: Castries

Population (1985): 136,000

Population Growth Rate: 1.8%

Languages: English (official), a french Patois is common throughout the country

Economic Indicators:

Real GNP (1985): $168 million
GNP Avg. Annual Growth Rate (1965-85): 2.8%
GNP Per Capita Income (1985): $1,240
Inflation Rate (1986): 28.1% change from 1980 base year

Trade and Balance of Payments:

(1982) Exports: $41.6 million; Major Markets: Caribbean Common Market (CARICOM), UK, EC, U.S.
(1982) Imports: $118 million; Major Suppliers: UK, U.S., EC, CARICOM

Official Exchange Rate: Eastern Caribbean $2.7 = U.S. $1

Energy Profile: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 0.058 million ton of oil equivalent (mtoe)
  1-Yr. Growth: *

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: *
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: *
  Commercial Fuel Consumption Growth Rate (1970-1980): *

* Not available

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: * MW
  Hydro: *
  Hydro Potential: *MW
  Steam: *
  Gas Turbine: *
  Diesel: *
  Other: *

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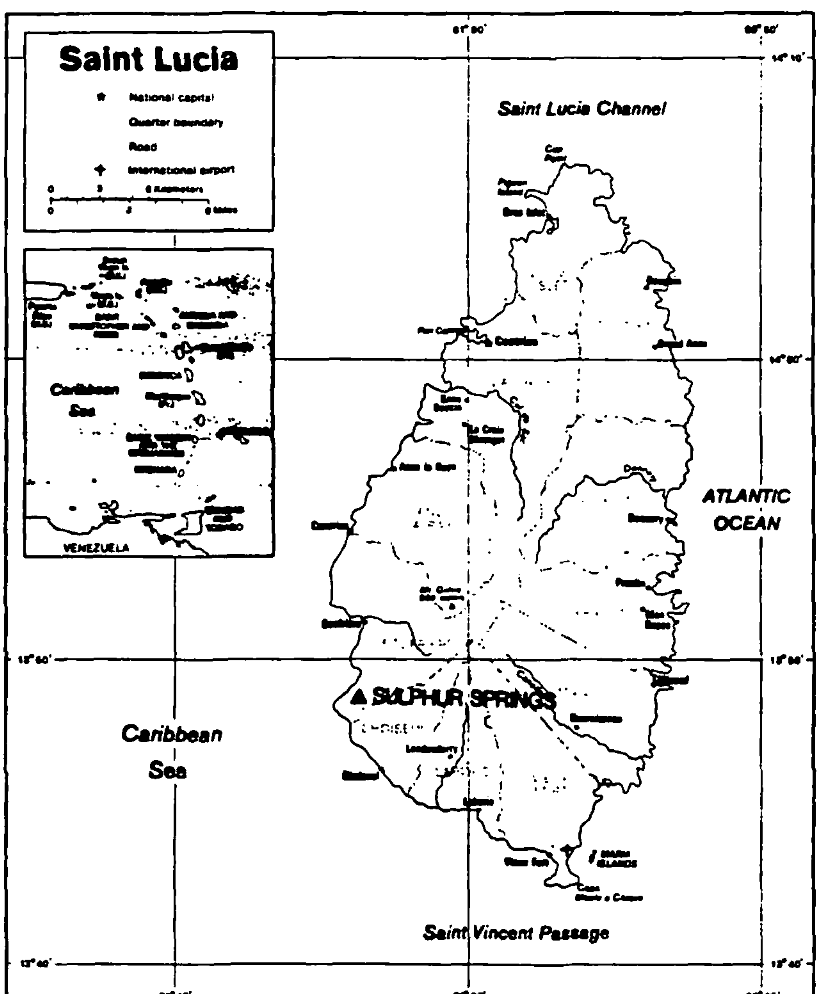

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