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GEYSERING DISCHARGE OF A GEOTHERMAL WELLBORE AT ZUNIL, GUATEMALA

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ABSTRACT

Within two hours after discharge began, for a production test in 1989 of well ZCQ-4, pressure variations changed from approximately sinusoidal to a cycle of sudden and complex peak discharge pressures, to 9 bar, separated by irregular pressure declines to 5 bar. Initial cycle periods of 42 minutes evolved to 150 minutes by day 20 of continuous testing, when three of four surge peaks were well separated. Chemical signatures of fluids discharged with pressure surges were distinctive. When combined with downwell pressure measurements, assignments can be made for elevations of fluid entry points. The variety of chemical signatures indicates a scarcity of interzone connectivity. These constrained discharges are suspected to derive from altered rubble zones between layered volcanic rocks.

SETTING: Geothermal exploration of the Zunil area began in 1973 with a regional study by Instituto Nacional de Electrificaci6n (INDE). Reconnaissaince geology, geophysics, and geochemistry, assisted by the Japan International Cooperation Agency (JICA) led to drilling eleven temperature gradient holes. These were followed by six deep geothermal wells, drilled in 1980-81 and subsequently tested with assistance of Electroconsult. Four of these deep wells produce neutral sodium chloride fluids with geothermometer temperatures in the general range of 240 to 280°C. In 1987, a contract to develop and engineer a 15 Mw power plant was awarded to MK Engineers, MK Ferguson Co., and Cordon y Merida Ings. Retesting of the wells was necessary and partial results for ZCQ-3, -4, -5, and -6 are reported by Menzies, et al (1990). A geologic summary is provided by Foley, et al (1990).

Lithologies at Zunil are a basement of granodiorite overlain unconformably by lava flows and ash-flow tuffs associated with a proposed caldera (Foley, et al, 1990). Volcanic rocks range in age from Tertiary to Pleistocene and involve four volcanic sequences, each with multiple flows and/or tuffs. The six deep wells all penetrate the volcanic series and intersect the granodiorite at elevations of 1090 to 1270 m ASL. Elevation differences are suspected due partly to faults. These faults are also suspected to channel upflow of hot fluids, although current production zones are variously within the volcanics and the rubble zone at the top of the granodiorite.

Surface elevation at ZCQ-4 is 2117 m ASL and granodiorite was encountered at 1140 m. The completion interval includes three of the four volcanic sequences. Prior to studies in 1989, ZCQ-4 was tested on five occasions between March 1981 and September 1985. The apparent power potential of ZCQ-4 is the largest among the Zunil wells, 5.7 Mw, including considerable excess enthalpy, (Menzies, et al, 1990), but marred by severe pressure surges. Surges were present as early as 1982, substantially in the form found by 1989 testing, but described only as a graph. A brief description of the 1989 surging is available (Menzies, et al, 1990).

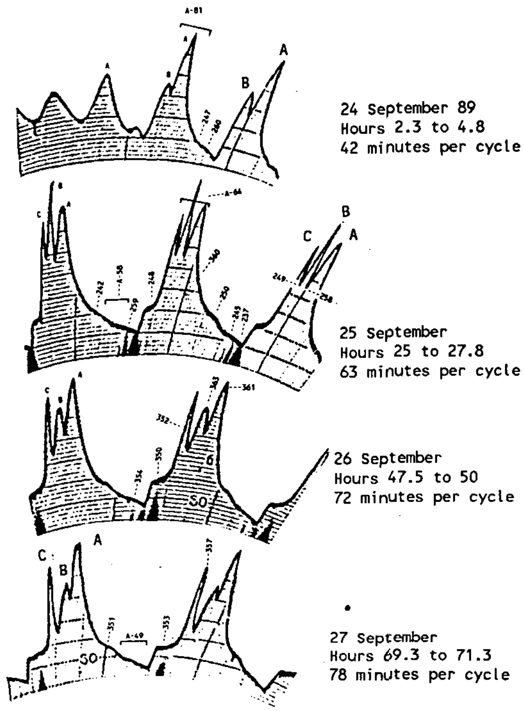
The surging is important because its persistence and chemical variety indicate poor vertical connectivity among producing zones, surprising in view of suspected fluid production control through the field by northwest and northeast-trending faults. Geysering also complicates evaluation of the well's power potential and depletion forecasts. The relative independence of the geysering zones makes it impractical to interpret downwell pressure measurements in the usual way. Also, production zones experience different ratios of times for discharge/recharge. Furthermore, the chemical compositions of the production zones do not appear to stabilize, complicating forecasts of scaling tendencies, fluid enthalpy, etc. Severity of the surging makes the well an impractical supply to a power plant. Selection of a best remedial method requires good understanding of the sources and causes of the surging.

EVOLUTION OF PRESSURE CYCLING: Figure 1 shows the evolution of the pressure cycling during the first four days. The figure is a composite of parts of Barton chart records of flowline pressures. Trough-to-peak pressure excursions amounted to more than 50 percent of the scale range of the Barton chart, nominally 5 to 9 bars pressure in the flowline. Corresponding flowline temperatures are 160 to 182 C. Time interval between similar points on the cycles was initially about 42 minutes, but increased to 78 minutes per cycle by about the 70th hour. Peaks were labeled "A", "B"... in order of their appearance in the record. The relative intensities of the peaks shifted during the first few days, but the general features of the cycling were otherwise similar. By day 16, the pressure cycling had evolved to a period of 120 minutes and the peaks that had earlier been clustered into a group became well separated and individually narrow.

On day 17, a unique pressure drop with an associated pressure spike (peak D) was "inserted" during one cycle, at a chart location just preceding the highest pressure surge (Figure 2). It occurred with increasing regularity during the next two weeks and by day 34 it was a part of all cycles. Cycles without the D-peak were 120 minutes long, those with it were 150 minutes.

This cycling of identifiable surges was also observed in 1982, but with longer cycle periods; 185 versus 120 minutes without, and 208 versus 180 minutes with "D". The longer periods in 1982 may be related to the longer preceding time of discharge, more than three months, compared to one month for Figure 2. Absence of the "D" peak three months into the 1982 record suggests it may have been waning. Similarity of the cycling pattern of March 1982 and October 1989 indicates that the number and relative potency of feed zones to ZCQ-4 has not changed in any substantial way.

FIGURE 1: PRESSURE CYCLING IN ZCQ-4
INITIAL EVOLUTION IN 1989



GASES IN DISCHARGE FLUIDS

A syringe method of gas sampling (modified after Michels, 1978) was used to obtain a series of twenty-three gas measurements during a 90-minute time interval. The intent was to use natural CO_2 as a tracer for individual production zones. Figure 3 shows the gas-sampling events in relation to the pressure variations taken from the Barton record of the same time. Also shown in Figure 3 are pressures derived from the temperatures measured in the steam separator at the times of sample collection, showing that the separator fairly tracks the flowline. Resolving the narrow pressure peaks is not perfect due to the discontinuous measurements of time for the sampling events.

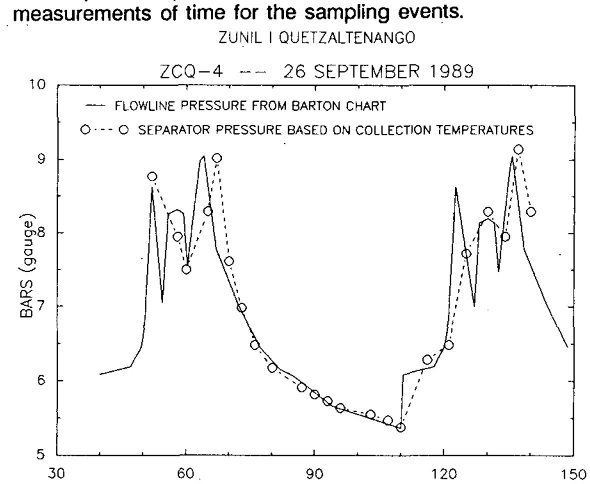
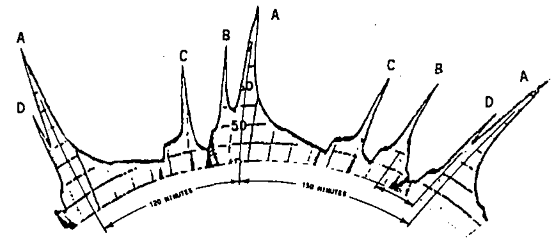


FIGURE 3: SAMPLING FOR CO2 DURING PRESSURE SURGES

FIGURE 2: PRESSURE CYCLING IN ZCQ-4
CONTINUED EVOLUTION IN 1989



DAY 17: MIXED CYCLES

PEAK "D" IS ABSENT FROM THE LEFT SIDE CYCLE

The resulting CO_2 concentrations in steam are plotted versus time in Figure 4. This complicated behavior emphasizes composition contrasts among fluids which mix in proportions that vary through the pressure cycle. For example, if the discharge were a single fluid of stable composition, decreases in flowline pressure would signal an increased steam fraction diluting the CO_2 concentration. However, between 75 and 110 minutes in the figure, CO_2 content increases during pressure decline, following "A". This signals a reversal of dominance between two input fluids of different gas content.

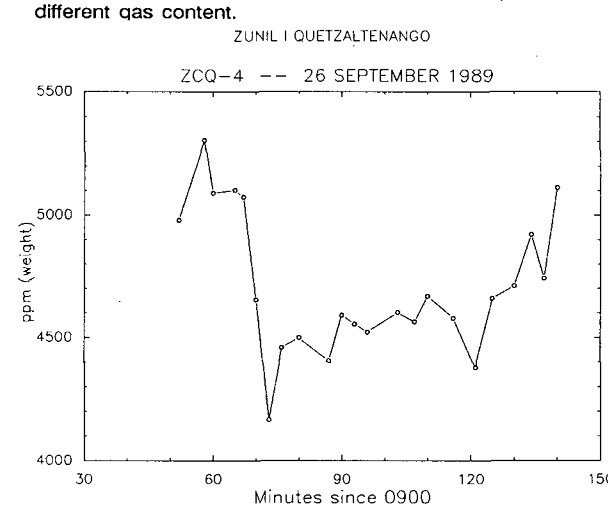


FIGURE 4: CO2 IN STEAM

Figure 5 shows CO_2 concentration (total discharge basis) plotted versus separator pressure. Lines connect data points in a time sequence which covers slightly more than one pressure cycle. The diagonal, elongated pattern of plotted points from pressure of 5.4 to 7 bars indicates a fluid mixture of two components. Similarly, the elongate pattern between 8 and 9.5 bars indicates another two-component mixture. Because these two indicators are displaced in pressure and relate to specific parts of the pressure cycling, they indicate at least four production zones contributing CO_2 to the ZCQ-4 discharge.

BRINE COMPOSITIONS Correlation of the pressure cycle with the brine sampling followed a different procedure. Samples were taken at the times of certain events in cycles of different days. In the early test days, pressure surges were not well separated, so sample contrasts reflect mutual contamination as well as day-to-day differences. Samples were taken also of the discharges during pressure minima.

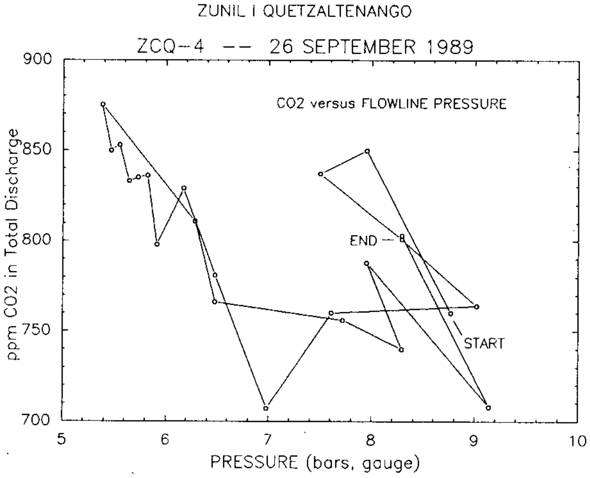


FIGURE 5: CO2 IN THE PRESSURE CYCLE

The extended cycle periods of the last test days permitted a better sampling of individual surges and of the pressure minima between them. These are compared in Table 1, which is arranged with higher quartz temperatures toward the left side and ranked concentrations of components based on the "A" surge composition.

TABLE 1: COMPOSITION OF SURGE BRINES

SURGE	A	D	C	B
SEPTEMBER 1989				
T-qtz	252		242	248
Chloride	1120		1167	1170
Sodium	675		701	691
Silica	480		439	464
Potassium	113		111	116
Bicarbonate	40.7		37.2	37.9
Sulfate	33.6		35.7	33.7
Boron	31.9		32.9	32.3
Calcium	19.0		22.0	19.6
Arsenic	8.55		7.53	9.33
Lithium	6.29		6.69	6.45
Ammonium	.51			.54
Antimony	.81			.66
Strontium	.18		.63	.19
OCTOBER 1989				
SURGE	A	D	C	B
T-qtz	258	248	245	241
Chloride	1011	1196	1249	1207
Sodium	604	706	724	689
Silica	509	465	451	431
Potassium	117	119	118	116
Bicarbonate	52.6	41.8	45.6	45
Sulfate	26.3	30.5	35.5	31.1
Boron	26.0	31.0	32.7	30.5
Calcium	14.7	20.5	23.5	20.2
Arsenic	6.66	6.89	7.80	6.87
Lithium	5.42	6.19	6.48	5.96
Bromide	4.51	6.36	5.56	5.81
Fluoride	1.25	1.38	1.34	1.31
Ammonium	.66		.76	.70
Antimony	.62		.64	1.28
Strontium	.13	.18	.22	.18

Brine compositions, obtained for a 244-day period of testing in 1983, are suspected to represent weir samples (CyM-MKF, 1989). Apparently, no attempt was made to sample according to pressure variations. Concentrations in 1983 are mostly higher than in 1989, by factors up to 3.4 beyond the effect of steam losses. Figure 6A shows persistently increasing concentrations that all begin at values greater than the 1989 counterparts.

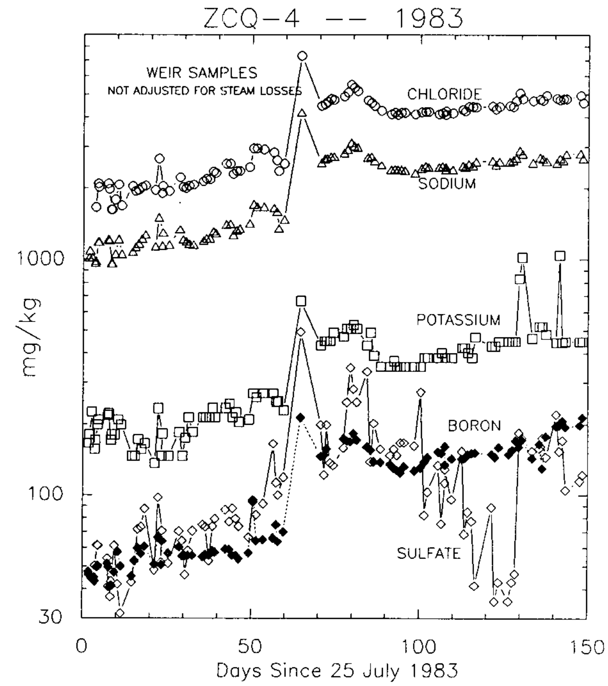


FIGURE 6A: MAJOR COMPONENTS versus TIME

These 1983 data show significant symptoms of being evapo-concentrated, for example, the Cl/Na ratio varies little, 1.733±.048. More general indications are shown in Figure 6B, a log-log plot of chloride versus other selected components. In a log-log plot evapo-concentration yields scatter fields with unit slope. A reference line is included in the figure. The observed data largely falls on parallel trends of nearly unit slope. Fine structures within scatter areas indicate other features of mixing with production zones, but will not be considered further, here.

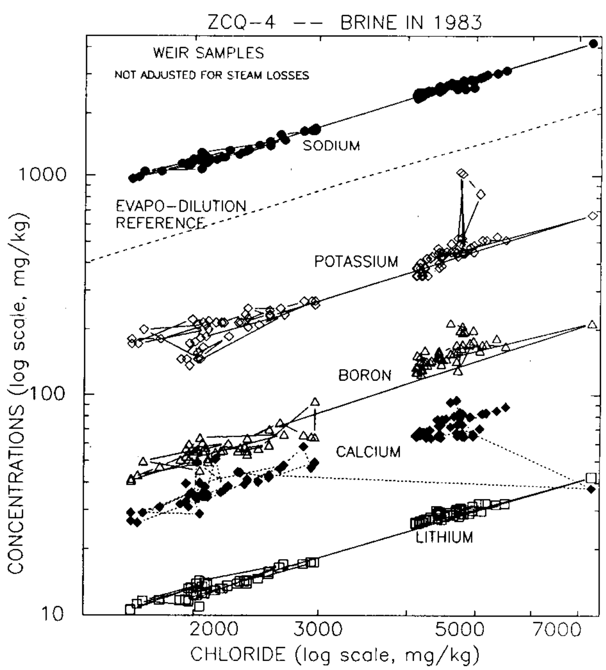


FIGURE 6B: TEST FOR EVAPO-CONCENTRATION

GEYSER ACTION IN ZCQ-4

The pressure surges of Figure 2 are mirrored in the shallower parts of the wellbore, but occur inverted at deeper levels. Temperature and pressure tools were suspended at 415 meters and recorded data through approximately one full cycle (four surges) (Pruett Industries, 1989). There, variations in pressure were essentially like the surface variations and temperature correspondences indicate that the instruments were in two-phase (brine-steam) conditions. Subsequently, the instruments were lowered to 800 meters for an additional period. There, the pressure-temperature values indicated that most of the time, conditions were one-phase liquid. Figure 7 shows results for both depths. *[The time axis for the 800-meter record has been displaced 150 minutes (one cycle) in Figure 7 in order to align events with the 415-meter record.]* This shows that low-pressure events at 800 meters are exactly one pressure cycle away from the high-pressure events measured at 415 meters, yielding two views of the same causal factors.

After the pressure reversal, the plot again follows a path approximately parallel to the vapor pressure curve. This segment represents increasing pressure on a two-phase system. Mismatch with the vapor pressure curve can be assigned jointly to thermal inertia of the temperature gauge and to a (plausible) component of CO_2 pressure. At pressures above 18 bars, the trend diverges from the two-phase invariant, indicating that the single-phase liquid level has risen enough to surround the instruments. The temperature at that point, about 204°C, is much less than the static temperature at that depth (253°C) measured earlier (Pruett Industries, 1989).

Pressure, indicated in Figure 8, continues to rise, in the single-phase condition, to the position marked END (of the measured record) at about 28 bars. The trend extends to the START (of the measured record) at about 31.5 bars, single phase), which completes the cycle. The nineteen plotted points (after START) show oscillations of pressure during a steady increase of temperature and include geyser events C, B, and D.

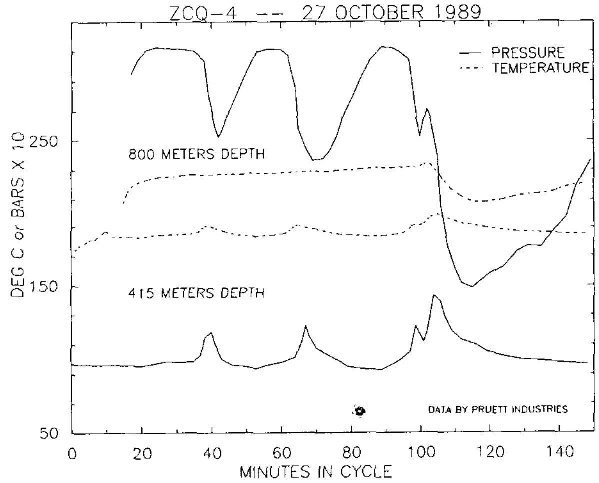


FIGURE 7: CYCLE CONDITIONS IN WELLBORE

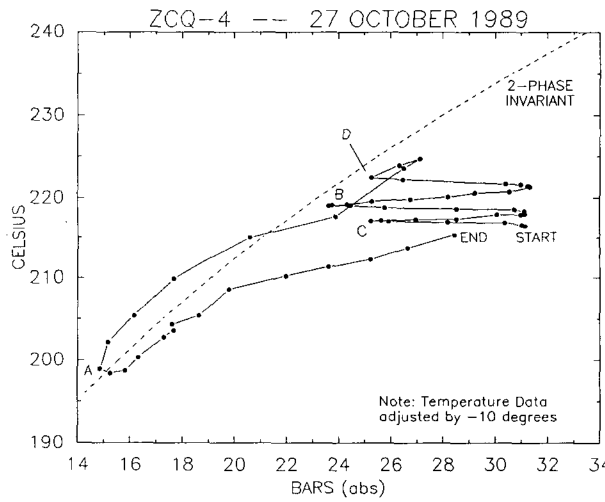


FIGURE 8: CYCLE CONDITIONS AT 800 METERS DEPTH

Local pressure minima at 800 m represent discharges from a liquid column of different heights above the instruments and each minimum represents a geyser-like discharge that yields a pressure maximum in the two-phase zone of the upper wellbore and surface equipment. The most severe pressure minimum at 800 m corresponds to the largest pressure surge at the surface. This geyser action is driven from below 800 meters. Insight about this action can be deduced by recasting the data from 800 m as a plot of temperature versus pressure.

For a two-phase watery system, true pressure-temperature coordinates cannot exist above the vapor-liquid line, shown dashed in Figure 8. Data from known two-phase (vapor-liquid) systems which plot above that line are defective, but may be explained or adjusted. Considerable raw data for Figure 8 did plot (initially) in the forbidden region. Accordingly, all temperature data were arbitrarily reduced by 10 degrees, before plotting as shown. This adjustment places several data coordinates close to the vapor pressure line, corresponding to two-phase conditions at those times.

Five plotted points in the left side of the graph, slightly above the two-phase invariant line, are suspected to represent changing two-phase conditions at 800 meters which occur faster than the Kuster temperature gauge can follow (thermal inertia). This leg of the plot, at pressures less than 24 bars, represents a geyser-like discharge driven from below.

In Figure 8, pressure following the last peak, near 27 bars, decreases with decreasing temperature. This is interpreted as boiling, suspected to originate below 800 meters and triggered by the (measured) pressure minimum due to "D". Mismatch with the vapor pressure curve, about 3 degrees, or 1.7 bar, could be due to CO_2 pressure or to effects of liquid from the lower part of the wellbore beginning to move upwardly, past the instruments. Subsequently, the pressure falls below 24 bars, apparently in two-phase conditions, completing the cycle with a geyser-like discharge, driven from below 800 meters depth.

GEYSER DYNAMICS AND INTERPLAY: A time interval of about 30 minutes occurs between the maximum temperature and the graph point (near 20 bar, Fig. 8) where single-phase liquid reappears at 800 meters. Of the four pressure maxima per cycle (Figure 2) only peak "A" has an uninterrupted discharge that long. Geothermometers of surge "A" correspond to zones below 850 meters, hence, it seems clear that the geyser discharge from below 800 meters is due to surge "A". The three pressure maxima for 800 meters in Figure 7, are relatively flat-topped peaks of the same magnitude. Because Figure 8 indicates single-phase liquid present at those times the pressure magnitude at 800 meters can be considered in two components; the weight of overlying single-phase liquid plus the vapor pressure at the top of the one-phase column, where two-phase conditions begin.

The periodically lower pressures at 800 meters represent events that reduce the height of the liquid column. The local pressure minimum corresponding to surge "B" is at a higher pressure than for "C", indicating a higher elevation for the top of the liquid column during "B" events than for "C" events.

The "D" peak of the surface pressure record (Figure 2) is a short-lived pressure minimum in Figure 7 where it appears to trigger the "A" surge. It seems that "D" does not reach its potential minimum before being overpowered by "A". Thus, its depth is not precisely calculable. Since the quartz temperature for D is higher than all others, except "A", elevation of "D" input can be inferred to be between those of "C" and "A".

The top of the one-phase liquid surges up and down in the wellbore during cycling. Its highest elevation is indicated by the three local pressure maxima that have equal magnitude. This limiting level is interpreted as a persistent steam entry, overpowering waning surges from below.

Geyser actions end with collapse of flash-cooled liquid toward the well bottom, after geysering feeder channels become so depleted they no longer overpower the shallow, persistent steam entry. Stagnant liquid, fallen in the wellbore, rewarms from rock heat. A new geyser event begins when a temperature-driven increase in vapor pressure can lift the overlying part of the liquid column of the wellbore, overpowering other current inputs.

GEYSER ELEVATIONS: Elevations of geyser inputs above 800 m depth can be estimated from liquid pressure gradient for the column (0.0832 bar/meter for liquid of 204-224°C), and H_2O vapor pressure at (the temperature of) the top of the liquid column. The minimum temperature at 800 meters, 204°C, observed when fluid falls down after the "A" geyser event, suggests conditions at the persistent steam entry when it overpowers the waning surge. From steam tables, 204°C corresponds to 16.0 bar(g). Table 2 shows relevant data and results. This sequence of depths is in agreement with the sequence of quartz temperatures derived for the fluids of individual surges (Table 2).

The maximum feasible depth for flash initiation in the "A" source can be estimated, based on its quartz temperature, gas content, and maximum pressure at 800 meters. Geyser action can begin when the warming of liquid by rock heat increases vapor pressure of one-phase liquid to the local wellbore pressure.

TABLE 2: DEPTHS OF INITIATION FOR GEYSER EVENTS

Surge	A	D	C	B	M
P-800	2-phase	<24.5	22.9	24.5	30.5
P net	---	<8.5	6.9	8.5	14.5
Liquid height	---	<102	82	102	174
Depth	<1072	>698	718	698	626
T qtz	258	248	246	241	[205]

From the maximum pressure at 800 meters, 30.5 bg, hydraulic pressure increases down the liquid column. There is a depth, below which, fluid at A-like temperatures cannot boil. That limiting depth is given by vapor pressure of A-type fluid, which has two components, water vapor (steam table) and CO_2. Using 850 ppm as the CO_2 content and CO_2 solubility given by Ellis and Golding (1963), yields 1.78 bar as the CO_2 pressure component; total vapor pressure at 258°C is 44.4 bg. Other values and results are given in Table 3.

Since "A" was functioning prior to the appearance of "D" in the surface pressure record, "A" clearly is capable of self-triggering. Alternatively, surge "D" yielding a local pressure minimum in the liquid column could trigger an "A" surge before the liquid temperature/pressure of "A" reaches the requirement for self-triggering. Thus, two plausible depths for the "A" zone can be computed. One is based on the liquid column with top at the persistent steam entry (626 m), the other with top of the liquid column lower, but not deeper than the entry for surge "D". Maximum depths for these two mechanisms are 977 and 1072 m, for "A" self-trigger and "D" trigger, (Table 3). The shallower "maximum" depth seems more plausible. The actual depth of "A" could be less than indicated in Table 3. A shallower depth also allows geysering to begin at a fluid temperature lower than the original wellbore temperature at that depth. The cycle period depends partly on heat transfer between rock and residual, partly flashed water in the parts of the channels nearest the wellbore.

CONSIDERATIONS OF ENTHALPY: The increasing time period for cycles represents depletion of rock heat. In terms of heat conduction, the temperature gradient in the rock away from the fluid flow channels decreases with time (repetition of cycles). If the mass of liquid heated in the channels were the same in successive cycles, and if the starting temperatures were similar, then increasing increments of time are needed for conductive heat to raise temperatures to the requirements for geysering. The rate of change of cycle period versus fluid production could yield information about the porosity structure in the rock.

The maximum temperature reached during this cycle (224°C at 800 meters) is much below all the geothermometer temperatures for quartz (235-258°C) and Na/K (244-274°C), as well as below the static temperature for the depth (252°C). This low measured temperature indicates that liquid which fills the wellbore after the geyser discharge derives from partially boiled liquids that fell from above. This includes the last-delivered liquid from the deep zone, which failed to get high enough in the wellbore to be incorporated with discharge from the subsequent dominant production.

After the geyser action, wellbore fluid at 800 meters is essentially static. The increase from lowest single-phase temperature (204°C) to the temperature at the start of the geyser (224°C) must be due to heat flow into the wellbore from adjacent rocks. This extra heating can be expressed later, during boiling, and is equivalent to about 2.5 percent steam, in addition to what might be expected from a simple adiabatic release, starting at T_{quartz} of the previous cycle.

Heat absorbed by residual liquids, after they fall back during the last stages of geysering, appears modest to small in amount. However, pickup of heat by hotter fluids, arriving to recharge channels near the wellbore, would be negligible.

TABLE 3: MAXIMUM DEPTH OF THE "A" GEYSER

	Self-Trigger	"D"-Trigger
P-800	30.5	24.5
$(P_{H2O})_{258}$	44.4	44.4
$(P_{CO2})_{850}$	1.78	1.78
$Gradient_{224-258}$	.0796 b/m	.0796
Increment	197 m	272 m
Depth	997	1072

Thus, the main part of a geyser discharge probably incorporates negligible rock heat. Further interpretation in this regard might be useful when forecasting the extent that rock heat could be recovered by the cycling discharge of ZCQ-4. The extension of cycle time from the initial 42 minutes to 150 minutes (after 34 days of discharge) would seem to be mostly due to mining of rock heat near the wellbore. Detailed analysis of the changes in cycle periods and masses of discharged fluids could yield quantitative calculations about the dimensions of the rock mass involved.

The energy output from the well can be obtained by summing the outputs of the separate discharges (Table 4). Between the surge events, discharge is mainly steam. Boundaries between surge and interlude discharges can be defined in the surface pressure record. On the pressure traces for waning surges, distinct, flattened segments occur near the 48 percent Barton scale dimension (Figure 2). They generally separate contrasting local slopes of pressure change. These are marked in Figure 2 and are referenced in Table 4 as time boundaries between elements of the discharge record.

TABLE 4: DISCHARGE ENERGY DETAIL -- ZCQ-4

Discharge	Minutes	deg C	j/g
D	0-8	248	1073
A	8-42	258	1124
M1	42-82	205	2793
C	82-105	246	1061
M2	105-115	205	2793
B	115-132	241	1042
M3	132-150	205	2793
Time average enthalpy:			1860

The model on which Table 4 is based considers a geysering discharge to dominate the wellbore pressure regime so that all other (potential) feed zones are blocked, until the surge subsides. Thus, single-phase liquid enthalpy values are appropriate during surges. Rock heat is negligible, as described earlier, and indepéndent steam zones are inoperative.

During interludes, the "steam" zone at 626 m depth discharges mainly steam, with some liquid derived partly, perhaps mostly, from the previous surge. This steam zone may be related to the zone which discharged highly evaporated water in 1983 (Figs. 6A, -B), implying connection to substantial open space where boiling can accomodate phase separation most of the time. Liquids in the 1989 surges do not show significant evapo-concentration.

The time average enthalpy given in Table 5 does not accurately represent the well's energy potential. The required mass average enthalpy cannot be calculated because rate measurements have not been resolved for the individual surges.

The model of Table 4 differs from that of Menzies, et al (1990) who do not recognize surge "D". They further simplified their enthalpy/energy model by considering only two modes; 1380 j/g for "A" and 2510 j/g for the remainder of the cycle. Both correspond to mixed-phase inputs to the wellbore. Using James Tube/weir data, they obtained discharge rates of 12 and 37 kg/sec for "A" and "other", respectively. Using the same data as were involved with Figures 2 and 7 of this report, they selected 24 minutes as the duration of "A", versus 34 minutes used in Table 4. The difference may be due to identifications of apparent boundaries. For this report, the choice was mainly influenced by "flattened" parts of the Barton pressure record (Fig. 2), described earlier, and suspected due to discharge of liquid from the steam zones, received as an injection from the surge fluids.

CONCLUSIONS: At least five inflow zones participate with well ZCQ-4. Three are prominent geysers and a minor fourth geyser appears to trigger the largest, although the largest functioned mainly by self-triggering during the first twenty days of testing.

Geysering requires a kind of switching mechanism to periodically initiate discharge after a depleted zone has been (partly) regenerated. In this case, the "switch" is related to enthalpy transfer from rock to stagnant water in the wellbore and nearby feeder fractures. The cycle period increased with time, suggesting that heat had been mined near the wellbore. The amount of heat mined per cycle may be small, associated mainly with the liquid in the wellbore that is relatively stagnant between surge events. Additional rock heat would be mined near the fluid flow pathways away from the well, also consistent with a lengthening cycle period.

Road cuts and gullies in the area show extensive hydrothermal alteration at interfaces between layered volcanic rocks. Since the surge liquids have distinctive geothermometer temperatures, it is reasonable to suspect that fluids feeding the well are similarly confined to interlayer spaces. Failure of surges to fuse over time indicates their ultimate sources are not well connected beyond the vicinity of the wellbore. Thus, fault connections, if any, must be relatively impermeable or remote.

Gas sampling at close intervals of time (23 in 90 minutes) was effective for making early identification of the complex discharge. Four end-menber compositions were indicated.

Brine sampling showed contrasts among the surge fluids, but all were dilute compared with earlier testing. For example, the highest chloride concentrations encountered in 1989 were near 1250 ppm (reservoir basis) versus >5500 ppm in 1983. Those high concentrations are due largely to evapo-concentration, indicating that the boiling space in some volcanic rocks provides for extensive separation of steam from liquid. Those spaces probably connect to the shallowest production zone in ZCQ-4, which yields mainly steam. The circumstances which enable discharge of residual liquids were not encountered in the 1989 testing. They may be technically unusual and significant to operations.

Downwell measurements of pressure for full cycles at multiple depths were essential for exposing details of the geyser mechanism. However, the chemical data most clearly shows the individuality of inflow zones. Neither kind of data is adequate, alone, for a useful study of this phenomena.

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