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TO: David Sussman

FM: Daniel L. Carrier

RE: ANALYSIS OF CHEMICAL DATA FROM 1988
    FLOWTESTS OF GMF 68-8 AND GMF 31-17

I. SUMMARY

Fluid and non-condensible gas samples were collected during
multiple flowtests conducted on two discovery wells completed
at Glass Mountain during 1988. Fluids produced from the two
wells, GMF 68-8 and GMF 31-17, are benign, low-salinity Na-Cl
waters that contain less than 0.01% weight non-condensible gas
and 1.5 ppm H_2S.

There is no conclusive evidence that an undisturbed reservoir
sample has been collected from GMF 68-8 or GMF 31-17.
GMF 31-17 fluids produced after 13 days of production were
still enriched in calcium and silica from the dissolution of
calcium carbonate, quartz and clay by the acid job. An
undisturbed reservoir fluid was clearly not sampled during the
flowtest of that well. However, there is no indication of
contamination by injected brines, which suggests that the well
is connected to a zone of high vertical permeability. For GMF
68-8, contamination by injected fluids is clearly evidenced.
This contamination was nearly eliminated by the end of the four
flowtests. However, wellhead pressures and chemical
constituents were observed to cycle during the flowtests.
Cycling is interpreted to have resulted from a combination of
production from two feed zones with different enthalpies and
from the occurrence of flashing in the formation. The changing
salinities of the fluids due to cyclical flashing and
concentration by boiling obscures the actual reservoir
composition.

Reliable alkali geothermometer data for GMF 68-8 predict
reservoir temperatures of 477°F to 494°F. These temperatures
are about 25° cooler than static reservoir and quartz-
saturation temperatures, raising the possibility that
production occurs from a zone of recharge of shallow waters
into a previously heated reservoir. Alkali geothermometer
temperatures of 469 to 473°F for fluids produced from GMF 31-17
are also slightly less than the 475 to 485°F temperatures
measured in the productive interval of the well.

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Non-condensible gas data for GMF 68-8 indicate that the fluids produced from the well originated as meteoric waters and that they had never boiled.

II. RECOMMENDATIONS

1. In order to better characterize the reservoir, I recommend that we continue to carefully sample GMF 68-8 and GMF 31-17 during the flowtests scheduled for 1989. The same sampling program should apply to any new wells drilled in 1989.

2. In order to evaluate the reservoir dynamics of GMF 68-8, the well should be flowed and sampled for at least four weeks after the scheduled acid job or until the fluid pH returns to neutral.

3. Toward the end of the next GMF 68-8 flowtest, the well should be throttled back to minimize flashing in the formation. Samples collected under these conditions will be useful in determining the potential for silica scaling in the formation, which might occur in response to flashing in the formation.

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III.   INTRODUCTION

Geothermal production was established in the Glass Mountain
Federal Unit during the summer of 1988. Fluid and
non-condensible gas samples were collected during multiple
flowtests conducted on the two Glass Mountain wells. The
chemistry of these samples has been analyzed and the results
are presented in this report.

The main objective of this report is to characterize the
geochemistry of the Glass Mountain reservoir in its
pre-production state. However, because of the short duration
of the flowtests, or because physical processes related to
testing affected the reservoir, an undisturbed, or "baseline"
reservoir brine was never produced. Reservoir contamination
probably occurred from four sources: drilling fluids, injected
acid, injected brine and injected meteoric water. Each of
these sources is examined in the following section and
estimates made as to the amount of contaminating fluid placed
in the reservoir. Next, the chemistry of the fluids and gases
produced during the tests is described and discussed.

IV.   DRILLING AND TESTING HISTORY

A time line for the drilling and testing of GMF 68-8 and GMF
31-17 is shown in Figure 1. During drilling operations and
injection tests of the two wells, an estimated 79,000 barrels
of drilling fluids, acid, meteoric water and previously
produced and flashed brine were injected or lost into the Glass

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Figure 1: Flow chart of drilling and testing of GMF68-8 and GMF31-17.
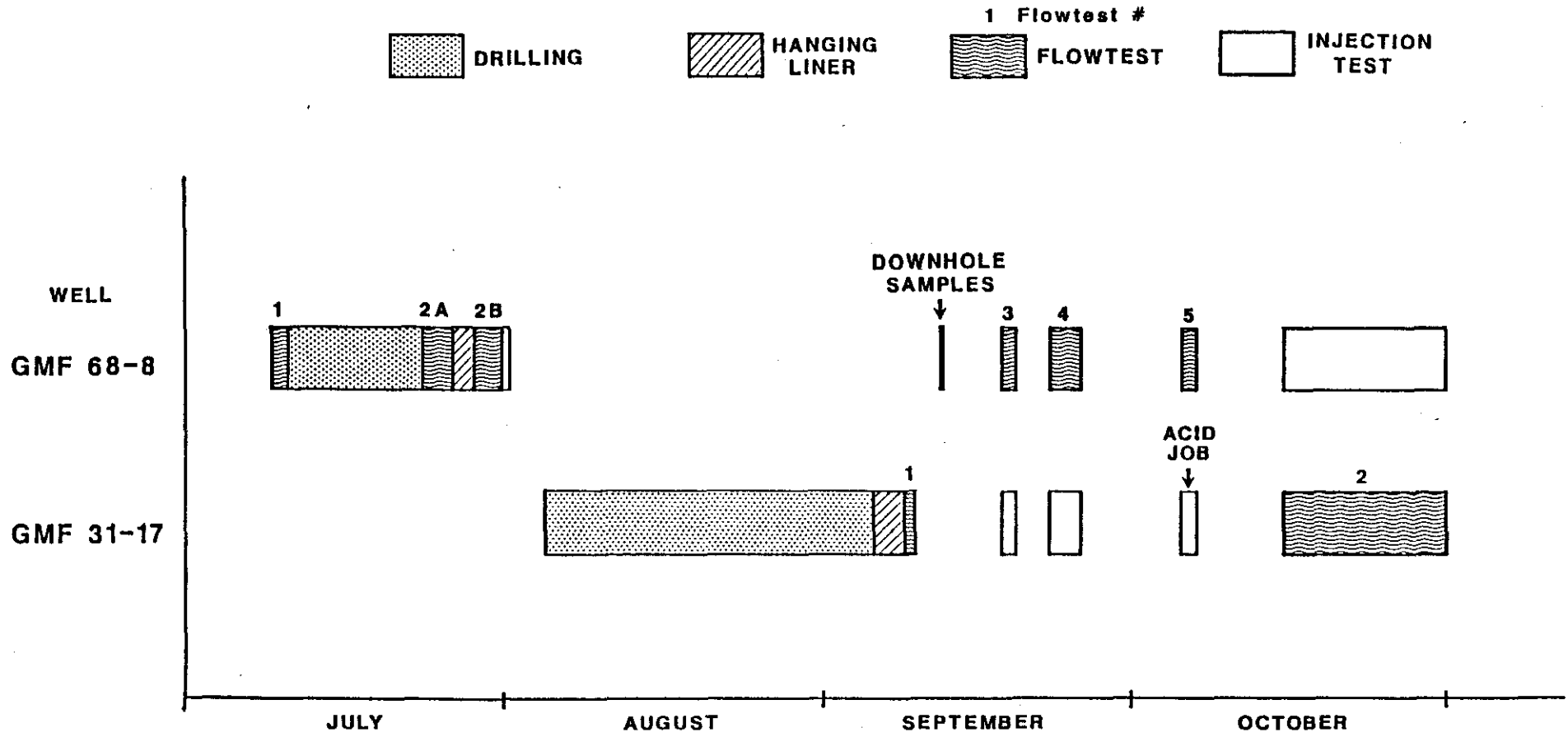
Mountain reservoir. The large volume and diversity of the injected fluids affected the chemistries of the fluid and gas samples collected throughout the flowtests. In view of the chemical contamination by the injected fluids, the drilling, injection testing, and flowtesting history of GMF 68-8 and GMF 31-17 is summarized here to facilitate the interpretation of the geochemical data. A more detailed history is presented in Appendix 1. In addition, the mass balance relationship between fluids injected or lost to the reservoir during drilling operations, and fluids produced during the flowtests are presented in Table 1. A summary of the production data is shown in Table 2.

GMF 68-8 was drilled in two parts. The well was spudded on July 19, 1985 and was completed to a total depth of 6571 feet on August 19, 1985. No flowtest was conducted at that time. The well was shut-in until July, 1988, when the site was re-occupied. After a bridge plug and liner were removed from the well, flowtest 1 began. The well flowed continuously for about 12 hours. GMF 68-8 was then deepened to 8417 feet over a period of 13 days. Flowtest 2 began after the deepening on July 23 and lasted until July 31. The initial phase of flowtest 2 was done with an open hole; however, as potentially sustainable production began, the well surged, unloaded softball-sized rocks, and bridged off. The well was cleaned out, and a liner was run to 8410 feet. Flowtest 2 resumed on July 29 and continued until July 31. Flowtest 2 ended after the well sustained a flow for eight hours. A short injection test immediately followed.

On September 11, four downhole samples were collected from GMF 68-8. Samples were collected from 3500, 6000, 6900 and 7900-foot depths in of the well.

Three additional flowtests of GMF 68-8 occurred later on during 1988. Flowtest 3 began on September 17 after the well was shut-in for 48 days to heat up. The test lasted for only 31 hours and 40 minutes because of injection pump failure and limited sump capacity. Flowtest 4 began September 22 and lasted for 66 hours. Flowtest 5 began October 5 and lasted 39 hours and 20 minutes. This time the well was flowed to provide a brine flush for the acid stimulation of GMF 31-17. No geochemical samples were collected during flowtest 5.

GMF 31-17 was spudded on August 4, 1988 and was drilled to a total depth of 8787 feet on September 5, 1988. At TD the well was washed with 100 barrels of caustic. A 7" liner was run in the hole, and on September 9 a 10.5 hour flowtest was conducted. The well produced fluids using an airlift system; however, flow was never sustained. Following flowtest 1, GMF 31-17 was used as an injector for GMF 68-8 until the end of GMF 68-8 flowtest 4. On October 6, GMF 31-17 was acidized to improve wellbore conditions. Additional meteoric water and brine from GMF 68-8 were injected into GMF 31-17 as a chaser to the acid.

TABLE 1 Mass balance relationship between fluids injected into
         the reservoir during drilling and testing and fluids
         produced from the reservoir during testing. All
         values are in barrels and are estimates.

	PUT INTO RESERVOIR (−)	PRODUCED FROM RESERVOIR (+)	RUNNING BALANCE
GMF68-8			
1988 Pre Flowtest 1			
Activities	4,800		− 4,800
Flowtest 1		5,757	957
Deepening	26,463		−25,506
Flowtest 2A		3,658	−21,848
Running Liner	587		−22,435
Flowtest		14,381	− 8,054
Injection Test	577		− 8,631
Flowtest 3		19,138	10,507
Flowtest 4		43,838	54,345
GMF31-17			
Drilling	7,360		− 7,360
Flowtest 1		2,100	− 5,260
Injection Fluids and			
Acid	39,400		−44,660
Flowtest 2		229,800	185,140

TABLE 2 Selected production data from various flowtests of GMF68-8 and GMF31-17. Taken from Rossnecht (1988).

	DAY	TIME (HRS)	WHP (PSIA)	FLOWLINE (PSIA)	TOTAL MASS (KLB/HR)	STEAM (KLB/HR)	WATER (KLB/HR)	ASSUMED ENTHALPY (BTU/LB)	% FLASH
GMF68-8 FLOWTEST									
.1	7/9/88	0155	91	78	155	37	118	495	23.8
2B	7/30/88	1740	66	50	121	27	94	470	22.3
3	9/17/88	1115	57	43	191	53	138	500	27.9
	9/17/88	1600	85	69	318	80	238	500	25.1
	9/18/88	1600	141	133	195	40	155	500	20.5
4	9/23/88	1030	85	68	320	81	240	500	25.2
	9/25/88	0715	135	124	211	44	166	500	21.1
GMF31-17 FLOWTEST									
2	10/23/88	0800	126	119	248	32	216	425	12.9
	10/28/88	0800	133	123	366	46	320	425	12.6
	10/30/88	0730	123	111	420	56	364	425	13.4

The second flowtest of GMF 31-17 began October 15 and continued to October 31. Problems with injection lines to GMF 68-8 prevented a continuous flowtest from starting until October 19. Geochemical samples were collected throughout the test.

V.   RESERVOIR CHEMISTRY

A.   INTRODUCTION

The chemical data from the flowtests of GMF 68-8 and GMF 31-17 are discussed from three perspectives: fluid chemistry, fluid geothermometry, and non-condensible gas chemistry and geothermometry. A summary of the brine analysis is shown in Table 3. Appendix 2 contains a full reporting of the data. The data are corrected for flash by estimating the fluid enthalpies from downhole temperature data and assuming a single phase liquid reservoir.

B.   FLUID CHEMISTRY

The Glass Mountain reservoir fluids are dilute Na-Cl waters containing less than 3300 ppm total dissolved solids and have a neutral pH. Chlorides range from 1400 to 1550 ppm and are comparable to the 1700 ppm measured at Broadlands (Henley and others, 1984). Average chloride contents for other fields include 2200 ppm at Wairakei (Henley and others, 1984), 4550 ppm at Tiwi (Rohrs, 1983), 6500 ppm at Awibenkok (Crecraft, personal communication) and 120,000 ppm for Sinclair 20 at the Salton Sea (Gallinatti, 1986).

The detailed characteristics of the reservoir fluids are uncertain because all produced fluids had some degree of contamination or were affected by flashing in the formation. Sampling the baseline reservoir proved to be a more difficult task than expected for both wells. Chemical signatures are observed in the data that can be attributed to the chemical or physical affects of drilling and testing on the reservoir. The specifics of the geochemistry data are discussed for each welltest below.
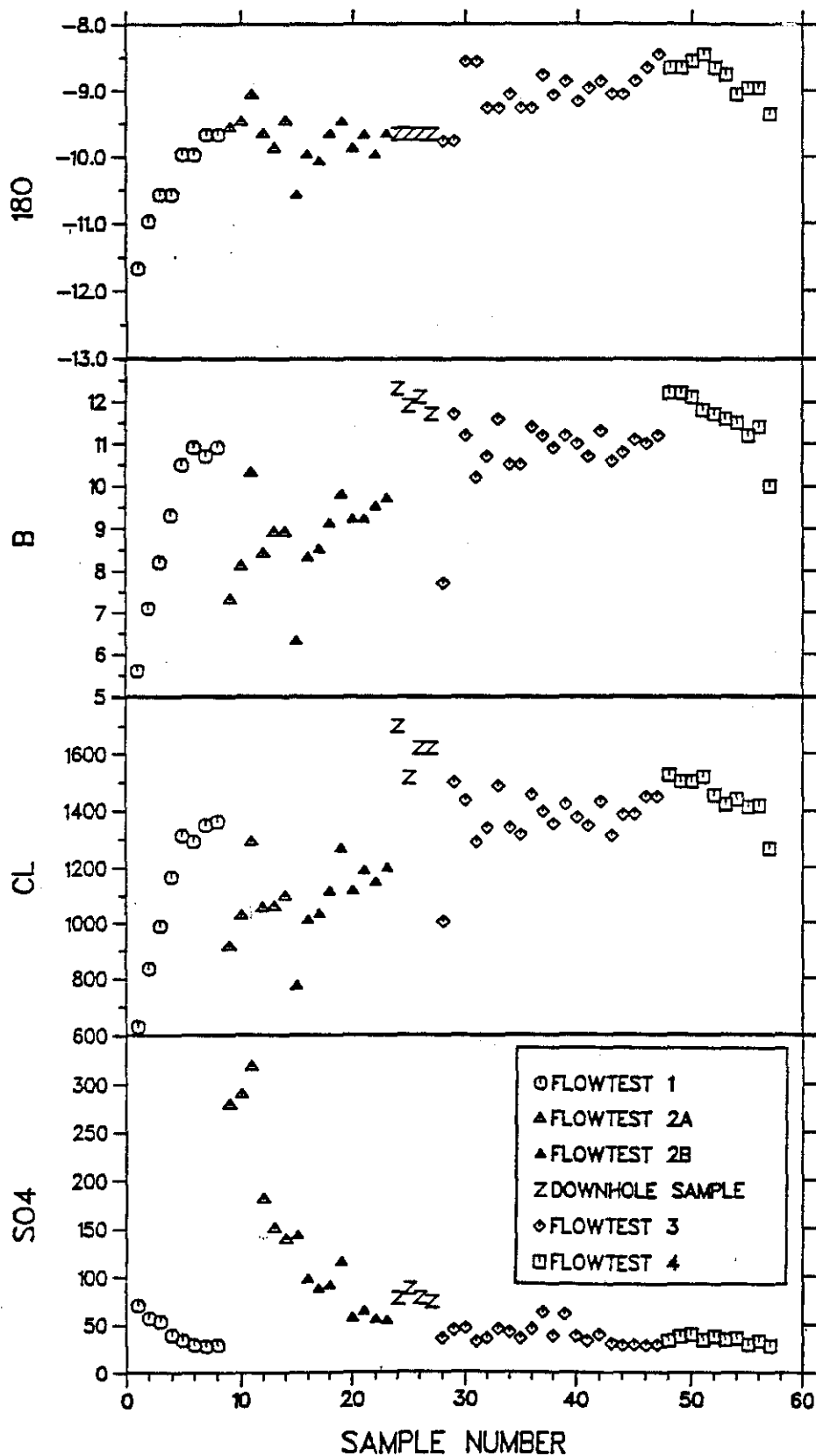
1.   GMF 68-8

Flowtest 1: Fluids produced during flowtest 1 are a combination of meteoric surface waters and reservoir fluids. The meteoric waters were introduced into the well during the removal of the cement bridge plug and 7" liner prior to the test. Fluids produced during the flowtest have a mixed reservoir-meteoric water chemistry. Plots of Cl, B, SO_4, and ^{18}O versus increasing sample number are shown in Figure 2, and illustrate the mixed reservoir-meteoric character of the fluids. Chloride, B, and ^{18}O are generally unreactive over short time periods and are easily diluted during the mixing of reservoir and meteoric waters. Figure 2 shows that as the total volume of production increased, indirectly shown here by

TABLE 3 Selected geochemical data from flowtests of GMF68-8 and GMF31-17. The complete data set is found in Appendix 2. The data are shown in ppm. PH was determined in the laboratory. S# is the sample number and is shown for comparison with data in report figures.

SAMPLE	S#	PH	NA	K	CA	MG	LI	CL	HCO3	SO4	F	B	SiO2	TDS	HR.MIN INTO FLOWTEST
GMF68-8															
FLOWTEST 1															
68-8-I-8	7	8.2	782.	126.	14.6	0.1	5.33	1348.	23.2	27.4	1.3	10.7	488.	2831	15.45
FLOWTEST 2															
68-8-IIA-5	13	7.3	749.	111.	4.8	0.1	4.35	1058.	98.3	149.8	1.1	8.9	500.	2689	N/A
68-8-IIB-8	22	8.7	725.	112.	13.4	-	4.99	1146.	37.3	55.2	1.2	9.5	488.	2602	07.35
FLOWTEST 3															
68-8-III-11	38	8.5	836.	141.	15.2	-	6.73	1353.	32.6	38.0	1.5	10.9	524.	2966	06.15
68-8-III-19	46	8.4	817.	139.	11.4	-	6.36	1448.	31.2	27.8	1.5	11.0	531.	3031	31.05
FLOWTEST 4															
68-8-IV-2	49	8.2	911.	151.	15.7	0.1	7.15	1501.	29.8	37.3	1.9	12.2	562.	3235	02.00
68-8-IV-8	55	8.4	841.	143.	12.2	0.1	6.19	1412.	26.4	28.4	1.6	11.2	476.	2962	28.00
GMF31-17															
FLOWTEST 1															
31-17-I-5	5	9.1	808.	95.	10.0	0.6	3.20	1100.	170.	162.	1.3	8.7	351.	2734.	20.15
FLOWTEST 2															
31-17-II-3	9	4.4	911.	144.	54.7	8.2	5.32	1645.	-	57.5	8.9	11.2	600.	3459.	11.30
31-17-II-20	26	5.7	848.	134.	27.1	1.2	5.10	1498.	4.4	48.0	5.6	11.0	526.	3114.	11.14
31-17-II-42	47	7.2	874.	140.	18.5	0.1	5.35	1409.	15.5	44.3	3.9	11.7	500.	3028.	28.53

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Figure 2: Concentrations of SO_4, Cl, B (all in ppm) and ^{18}O (per mil) as observed in flowtest and downhole samples from GMF 68-8. Samples from flowtest 1 display the effects of contamination by meteoric water. Samples from flowtest 2A and 2B are contaminated by drilling fluids.

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increasing sample numbers, the concentrations of Cl and B
increased. This demonstrates that the percentage of reservoir
fluids in the sample increased with time, and that the
percentage of meteoric fluids decreased with time. The same
type of relationship is observed in ^{18}O values, which become
increasingly enriched during the flowtest. The concentration
of ^{18}O in the first water sample is -11.7 per mil. This is
very close to the ^{18}O values of -13+1 per mil observed in
local surface and groundwater (Gallinatti, 1984).

The relatively high SO_4 values measured early in the first
test probably reflect contamination of the reservoir (Figure
2). Only meteoric water was used during retrieval of the plug
and there is no record of any chemicals having been introduced
into the well prior to flowtest 1; however, the first fluids
produced during flowtest 1 were observed to be "muddy." There
are three possible sources for the SO_4 contaminant in
flowtest 1: a) injection of cement fines, which contained the
SO_4 species, into the reservoir during the drilling out of
the plug; b) oxidation of H_2S in the reservoir by oxygen-rich
drilling fluids; c) oxidation of pyrite in the reservoir by
oxygen-rich drilling fluids. Oxidation of H_2S in a reservoir
by oxygen-rich drilling fluids has been observed elsewhere to
be a source of SO_4 contamination (Lovelock and Baltasar,
1983). However, since the reservoir in the GMF 68-8 area is
low in H_2S (see section on non-condensible gases), oxidation
of H_2S is probably only a minor contributor to the SO_4
content.

A baseline reservoir sample was not collected during flowtest
1. Although the variation in B, SO_4, and Cl concentrations
became small as the flowtest continued, ^{18}O values were still
increasing. When flowtest 1 finished after 12 hours of
continuous production, the ratio of produced fluid to injected
fluid was only 1.2 to 1.

Flowtest 2: In analyzing the results of flowtest 2, the
flowtest is best subdivided into flowtest 2A and 2B.
Flowtest 2A began immediately after the deepening of GMF 68-8
was completed, and lasted for three days. During this period,
fluids were airlifted for all but the last 20 minutes of the
test, when the well finally flowed on its own. However, after
20 minutes of production, the well bridged off. Flowtest 2B
began three days later after the bridges had been removed and a
7" liner had been installed.

Fluids produced during flowtest 2A were a heterogeneous
combination of drilling fluids, composed primarily of meteoric
fluids and flashed brine from flowtest 1, and of reservoir
fluids. Chloride and boron exhibited a sharp increase, then
decrease, reflecting the inhomogeneity of the drilling
contaminants in the fluids produced (Figure 2). For example,
the Cl and B concentrations are high in the injected brine and
low in meteoric water. Oxygen isotopes, however, show no

systematic change despite an increase in Cl and B. A
correlation would be expected since flashed brine is enriched
in Cl, B and ^{18}O with respect to reservoir brine, and
meteoric water is depleted in all three constituents.

Flowtest 2B fluids were a combination of drilling, meteoric,
and reservoir fluids. An estimated 590 barrels of unmixed
meteoric water had been introduced into the reservoir when the
7" liner was being run. Boron and chloride plotted against
sample number in Figure 2 show the initial effects of meteoric
contamination, and then a return to the trend observed in
flowtest 2A.

Uncontaminated baseline reservoir samples were not obtained
during flowtest 2A or 2B. By the end of flowtest 2, the ratio
of produced fluid to injected fluid was 0.67. An estimated
27,050 barrels of drilling fluid and meteoric water were lost
to the reservoir during the deepening, and only 18,050 barrels
of fluid were produced.

The best evidence for lingering contamination in the reservoir
is viewed when looking at SO_4 concentrations during the whole
of flowtest 2. The dominant source of the SO_4 is thought to
be the drilling fluids, either by direct contamination or by
oxidation of pyrite and H_2S in the reservoir. The highest
concentrations of SO_4 were produced right after drilling at
the beginning of flowtest 2. As the flowtest continued and
drilling fluids were produced, SO_4 concentrations continued
to decrease significantly. Nevertheless, they never declined
to levels reached in later flowtests (Figure 2). Since a
significant amount of mud continued being produced at the end
of flowtest 2, some degree of SO_4 contamination is likely.

Downhole Samples: Immediately following flowtest 2B, a short
injection test was conducted on July 31. The source of the
fluids for the injection test was the flashed brines produced
during flowtest 2B. Following the injection test, the well was
shut-in for 42 days. On September 11, six days prior to the
start of flowtest 3, downhole samples were collected from the
3500, 6000, 6900 and 7900-foot intervals of the well.

The chemistry of the downhole samples is more saline than the
flowtest samples for all major elements except silica (Table 3,
Figure 2). The samples were probably residual injected brine
from flowtest 2B that remained in the wellbore. The low silica
was probably in part due to SiO_2 equilibration to lower water
temperatures when the brine was in the mud pit. The
persistence of injected brine in the wellbore 42 days after
injection, however, is difficult to reconcile with TPS survey
data collected 16 days earlier suggesting intra wellbore flow
of 100 barrels/hr was occurring in well (Rossknecht, 1988).

Flowtest 3: Flowtest 3 began September 17 and ran for two
days. An uncontaminated baseline reservoir sample was probably
not sampled during flowtest 3. About 37,000 barrels of fluid
were produced in total during flowtests 2 and 3, and at least
27,000 barrels of drilling fluids are estimated to have been
lost in the well during the deepening (Table 1). The ratio of
produced fluids to lost drilling fluids is only 1.3 to 1.
Variations in SO_4 as seen in Figures 2 and 3 reflect the
lingering contamination of the drilling fluids. The variation
of SO_4, as plotted in Figure 3, do trend towards less scatter
and a decrease in contamination late in the flowtest.

In addition to the effects of contamination, there is a very
pronounced cyclicity to the fluid compositions (Figure 4).
This cycling is related to a geysering-like phenomenon that
also caused flowrates, wellhead pressures, and TDS to cycle
over a wide range. During flowtest 3 an effort was made to
sample the well when wellhead pressures were at the minima and
maxima of their cycles. The following three observations are
made. Alkali and silica geothermometers cycle in phase with
the wellhead pressure; maxima in chemical constituents, such as
Cl and B, are phase-delayed by 20 to 30 minutes with respect to
peaks in the wellhead pressure (Figure 4); and oxygen-18 cycles
in the opposite direction from the wellhead pressure. However,
only samples that were collected at the minima and maxima of
the production cycles were analyzed for isotopes. Therefore,
it cannot be determined if a phase delay did exist between
production and isotope cycles. When the well was throttled
back late in the flowtest and the wellhead (WHP) pressure
allowed to increase, the cyclic behavior of the well and
chemical constituents was considerably dampened, but not
stopped.

The in-phase character of the geothermometry and production
cycles indicates that the changes in flowrates and WHP for GMF
68-8 were associated with cyclic production from a
lower-temperature fluid and a higher-temperature fluid.
Cycling at the wellhead is positively correlated to cycling of
brine production from the deeper and hotter of the two
producing zones identified in GMF 68-8. A difference in
enthalpy between two feed zones is typical for geothermal
wells, however, and is not by itself adequate to cause cycling.

It is hypothesized that the cycling resulted from flashing in
the formation, which was deduced by Rossknecht (1988) on the
basis of down-hole flowing pressure surveys. A small increase
in production from a zone in which flashing occurs will cause
an increase in flashing and an increase in enthalpy. This can
provide a positive feedback which increases production further
and which provides the necessary drive for cycling. The
variations in salinity are also interpreted to result from
flashing in the formation. This is consistent with the linear
relationships observed in plots of B, K, Na, and Cl in
Figure 5. The salinity cycles do not result from a salinity

GMF68-8 SO4 VS HOURS OF PRODUCTION
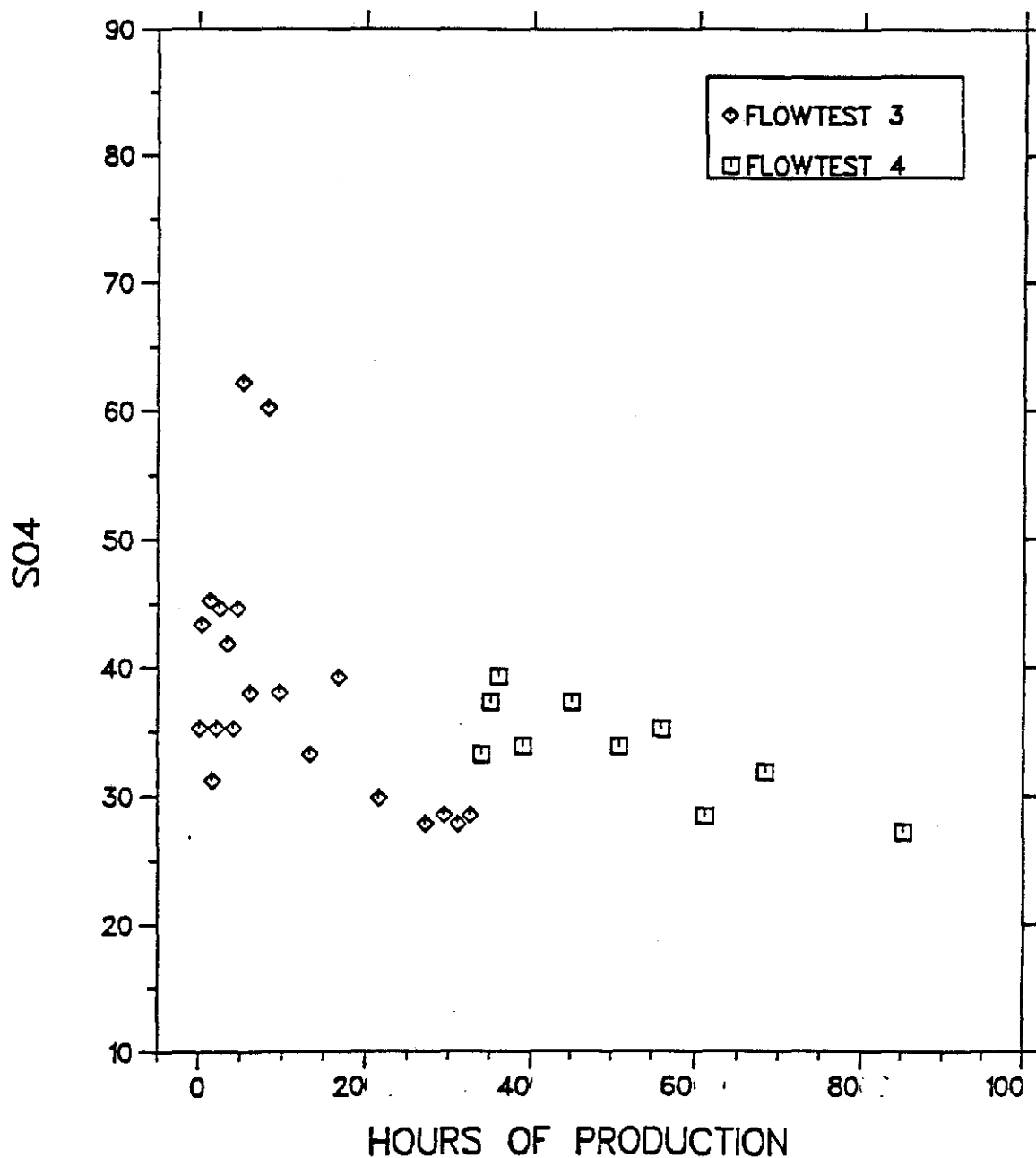
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Figure 3: The occurrence of SO_4 (ppm) in fluids produced during flowtests 3 and 4 of GMF 68-8. The SO_4 species is considered a contaminant of the drilling process. Concentrations shown here do not vary in phase with the chemical cycling observed during flowtest 3.
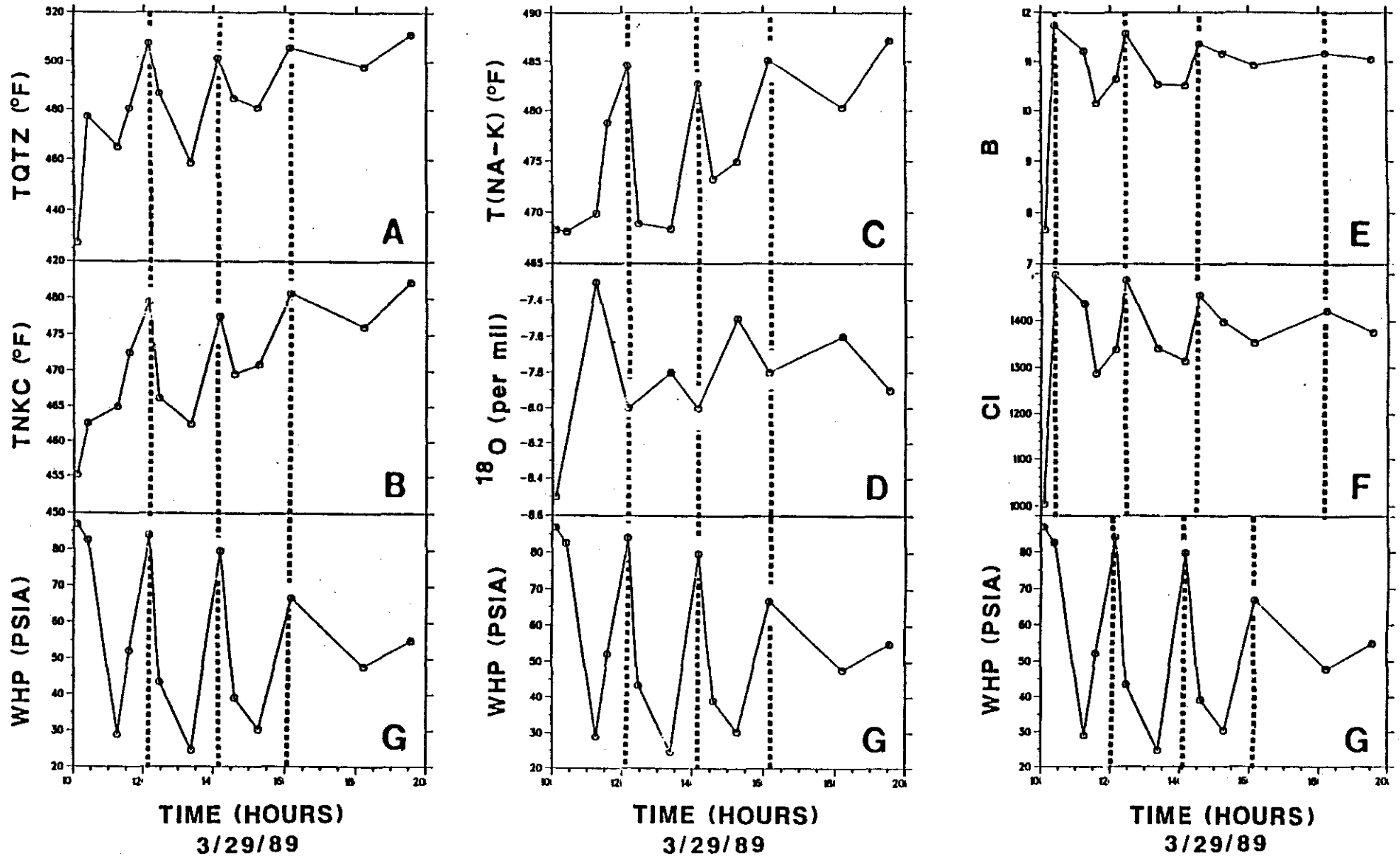
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Figure 4: Cyclical variations in WHP and chemistry for GMF68-8 during flowtest 3. Geothermometers (A-C) vary in-phase with WHP (G). Oxygen-18 (D) also appears to vary in-phase, but in an opposite direction. However, a small phase shift would not be recognized because of the sampling intervals. Chemical concentrations, as exhibited by Cl and B (E, F), peak about 30 minutes after WHP's for the two large initial cycles.

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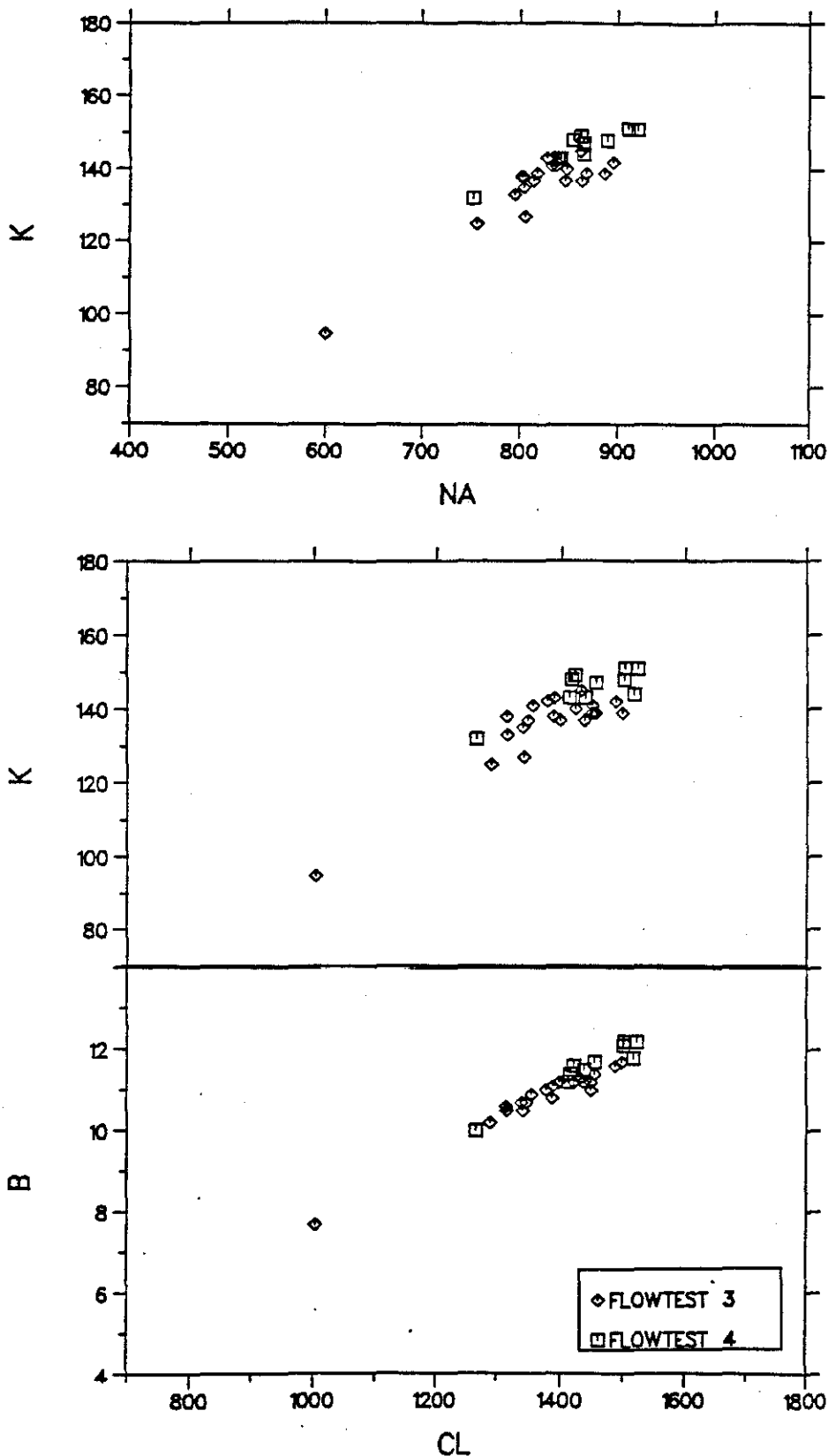
Figure 5: Shows the near linear relationships, or constant ratios, observed for concentrations of four major chemical constituents, B, K, Na, and Cl (all in ppm) produced in flowtests 3 and 4 of GMF 68-8.

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difference between the brines in the two production zones. If
this were the case, the salinity and geothermometry cycles
would be in phase with each other, in contrast to the observed
phase delay between salinity and geothermometry cycles.

The role of flashing in amplifying flow-rate perturbations and
thereby sustaining cycling, and its effects on fluid
composition are described more fully in Appendix 3.

Flowtest 4: Flowtest 4 began four days after flowtest 3 was
completed. No fluids were injected into the well during the
four-day break. Although production continued to cycle during
flowtest 4, the amplitudes of the cycles were smaller. Samples
were not collected as frequently in flowtest 4 as they were in
flowtest 3, nor were peaks or troughs of the cycles targeted
for sampling. The last sample collected during flowtest 4 is
questionable. The sample was collected while the well was
being prepared for a TPS survey. Wellhead pressures varied
during the collection of the last sample by more than 10 psig.

When the chemistry of the fluids produced in flowtest 4 is
plotted against time the data show a trend towards decreased
salinity with time. Plots of B. Cl, and ^{18}O in Figure 6
present clear examples of this trend. The ionic constituents
of the first fluids produced in flowtest 4 are 7-10% more
concentrated than the average for fluids produced during
flowtest 3. The concentrations then decrease with time.

The relatively high salinity of the fluids produced in the
initial five to 12 hours of flowtest 4 probably resulted from
flashing in the formation during flowtest 3. As reservoir
pressures recovered during the period of shut-in after flowtest
3, the concentrated brines were drawn toward the wellbore.
These enriched brines were the first fluids produced during
flowtest 4 and were rapidly depleted. Fluids produced at the
end of flowtest 4 have compositions that approach those
observed in flowtest 3.

The geochemistry of the samples collected during flowtest 4 is
probably the closest to that of the undisturbed "baseline"
reservoir. However, changing salinities of the fluids caused
by cyclical flashing and concentration by boiling make
identifying the precise baseline composition difficult. The
contamination of reservoir fluids by drilling fluids became an
insignificant factor during flowtest 4 as evidenced by the
leveling of SO_4 concentrations.

2.   GMF 31-17

The first flowtest of GMF 31-17 was of short duration and
insufficient fluid was produced for a "baseline" reservoir
sample to be collected. The flowtest was conducted while the
drilling rig was on location, and lasted only 10.5 hours.
Production was unsustainable without the use of an airlift
system. The 2100 barrels of fluid produced during flowtest 1

GMF68-8 FLOWTESTS 3 & 4

HOURS OF PRODUCTION
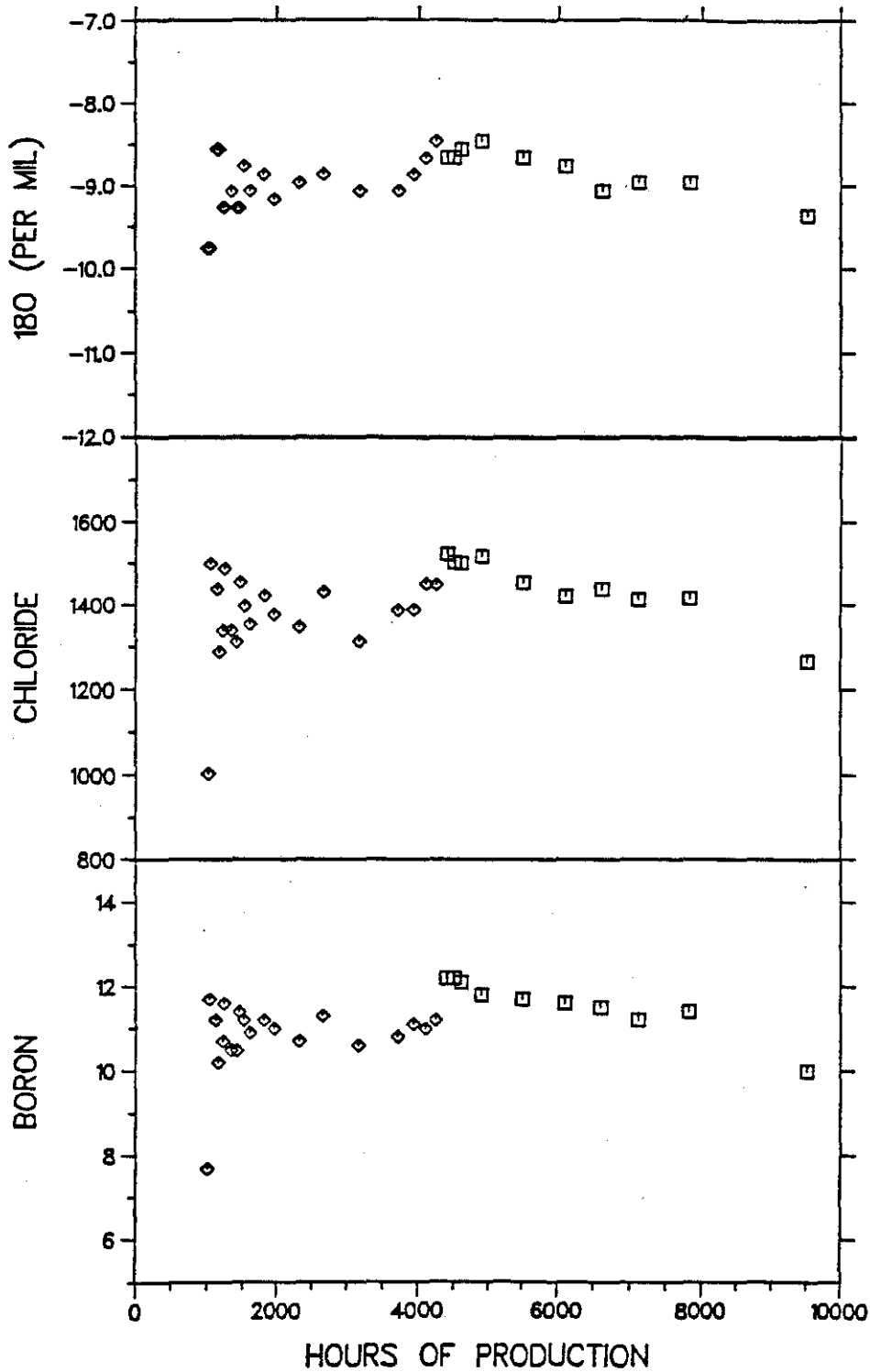
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Figure 6: Concentrations of B and Cl (in ppm) and ^{18}O (per mil) as observed in flowtest 3 and 4 of GMF 68-8. The data collected for flowtest 4 displays higher than expected salinities and ^{18}O values as compared to those observed in flowtest 3. Although there was a break of 4 days between flowtests 3 and 4, for ease of presentation the break is shown in this figure to be 1 hr and 15 mins.

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are less than 30% of the total drilling fluid lost to the well
(Table 1). The SO_4 species is again used to illustrate
reservoir contamination by drilling fluids or oxidation of
pyrite in the reservoir, and is plotted against hours of flow
in Figure 7. The plot shows initial flash-corrected SO_4
concentrations ranging from 161 to 389 ppm. During flowtest 2,
these numbers generally decrease to 50 ppm.

Between flowtest 1 and 2, drilling fluids and production fluids
from GMF 68-8 were injected into GMF 31-17. After completion
of flowtest 4 for GMF 68-8, injection into GMF 31-17 stopped,
and GMF 31-17 was subjected to an acid job. As part of the
acid stimulation, 125 barrels of 10% HCl and 250 barrels of a
12% HCl and 3% HF mixture were pumped into the well. As a
chaser to the acid, 208 barrels of fresh water and 8,640
barrels of flashed brine from GMF 68-8 were pumped into the
well. In total, over 39,400 barrels of flashed brine, meteoric
water, drilling fluids and acid were pumped into the GMF 31-17
between the first and second flowtest of the well. Flashed
brine and drilling fluids accounted for over 98% of the
injected fluids.

Flash-corrected chemical data are plotted versus time for
flowtest 2 in Figures 8, 9, 10, and 11. A constant enthalpy
corresponding to a temperature of 454°F is assumed. The data
are grouped into three categories. The first category is shown
in Figure 8, and consists of "nonreactive species" added to the
reservoir as part of the brine from GMF 68-8. Members of this
group include ^{18}O, As and B. These species are not expected
to react significantly over short time periods with the acid,
reservoir fluids, or reservoir rocks. The "nonreactive
species" were enriched in the injected brine relative to
undisturbed reservoir concentrations. The second category is
shown in Figure 9 and consists of the species introduced into
the reservoir as "acid contaminants." Members of this group
include pH, F, and Cl. These are components directly affected
by acid injection. The third category is shown in Figures 10
and 11, and consists of "reactive species" added to the
reservoir fluid as the acid reacted with the formation, casing
or cement. Members of this group include SiO_2, Ca, Fe, and
Mg.

A significant GMF 68-8 brine contribution to the GMF 31-17
reservoir due to injection is not apparent from the
distribution of the "nonreactive species" in Figure 8. Flashed
GMF 68-8 brines accounted for more than 96% of the fluid
injected into GMF 31-17, and were more concentrated in B, As
and ^{18}O (17, 6.5, and -7.5 respectively) than the fluids
produced in GMF 31-17 (11.5, 4.5, and -8.5 respectively). If
GMF 31-17 reservoir fluids had mixed with the brines then the
reservoir fluids should have shown initial enrichment in the
"nonreactive species" and then a decline toward uncontaminated
values. Only ^{18}O shows any initial enrichment, and that
occurs in just the first 24 hours of production. Boron and

31–17 SO4 VS HOURS OF FLOWTESTS
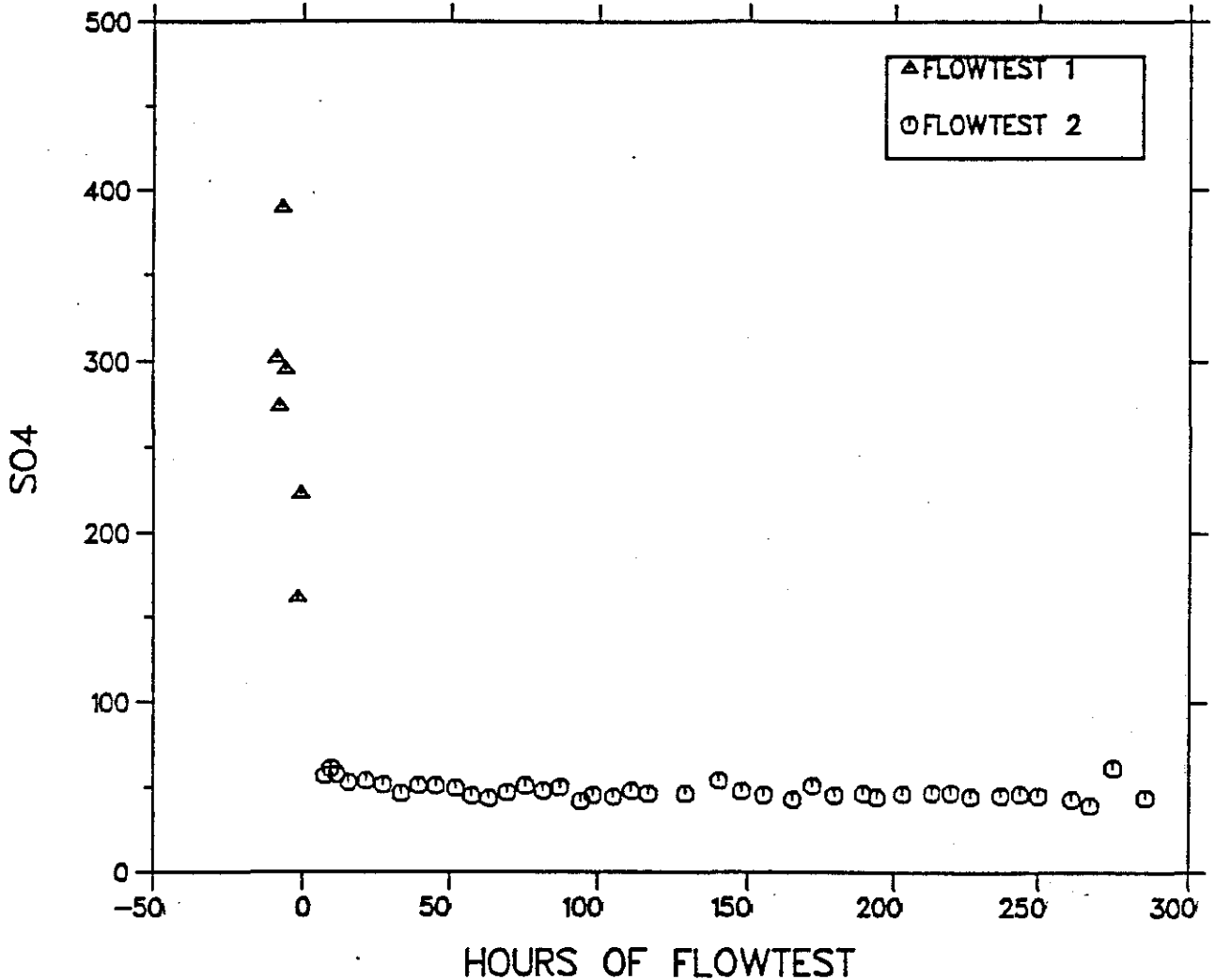
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Figure 7:   The occurrence of SO_4 (ppm) in fluids produced during
flowtests 1 and 2 in GMF 31-17 shown as an illustration of
reservoir contamination during drilling. During flowtest 2
contamination by the acid stimulation of the well was a much
greater problem than drilling related contamination.
Flowtest 2 starts at the "0" hour.
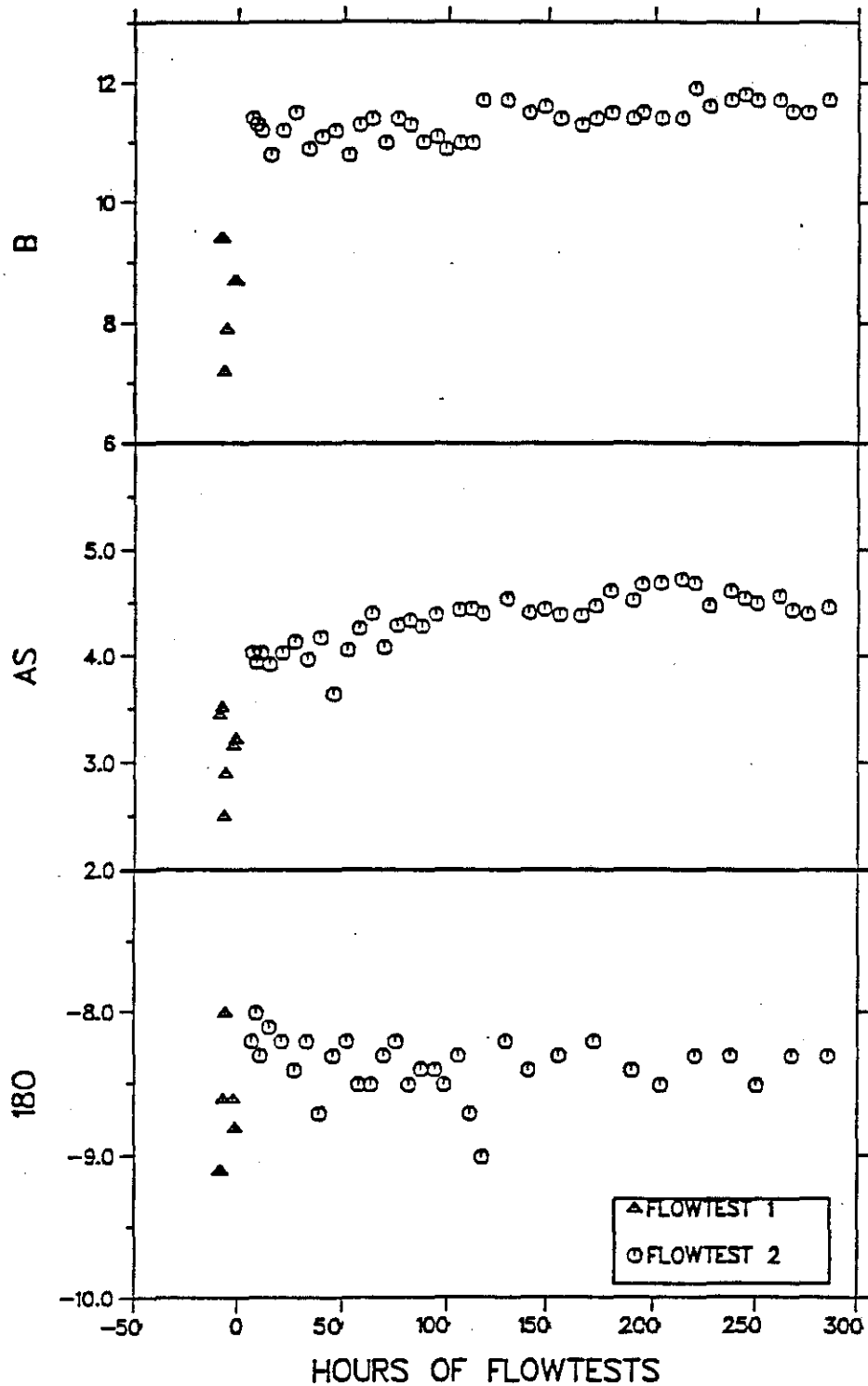
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Figure 8: The production of "nonreactive species" As, B (both in ppm) and ^{18}O (per mil) during flowtests 1 and 2 of GMF 31-17. These species do not show enrichment due to acid stimulation of the well or injection of GMF 68-8 flashed brines. Flowtest 2 starts at the "0" hour.

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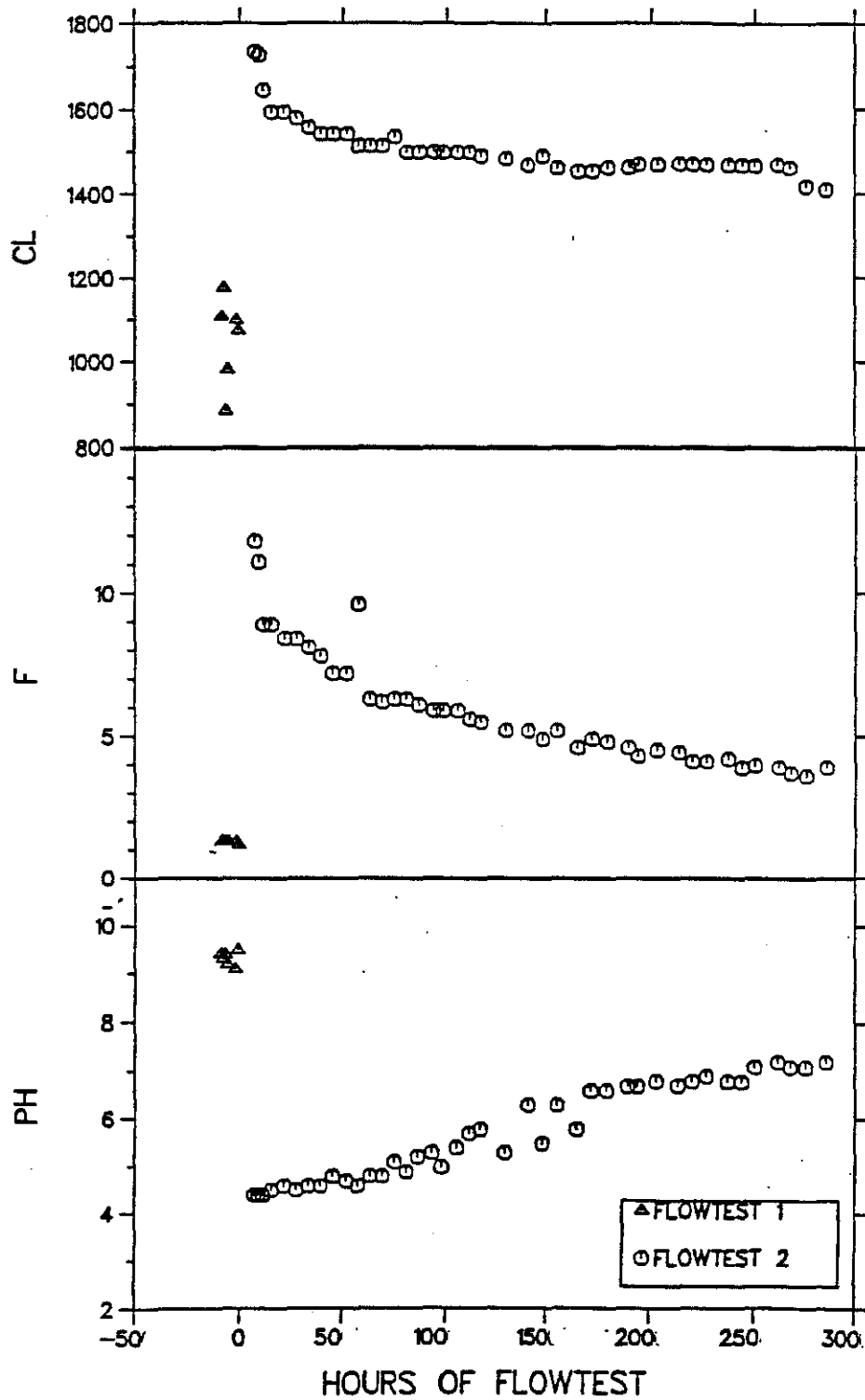
Figure 9: Production of the "acid contaminants" F, Cl (both in ppm) and H (as pH) during flowtests 1 and 2 of GMF 31-17. These species were introduced into the reservoir by the injection of HCl and HF during the acid stimulation of the well. Flowtest 2 starts at the "0" hour.

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Ctlg. No.: UCA07.2501

HOURS OF FLOWTEST
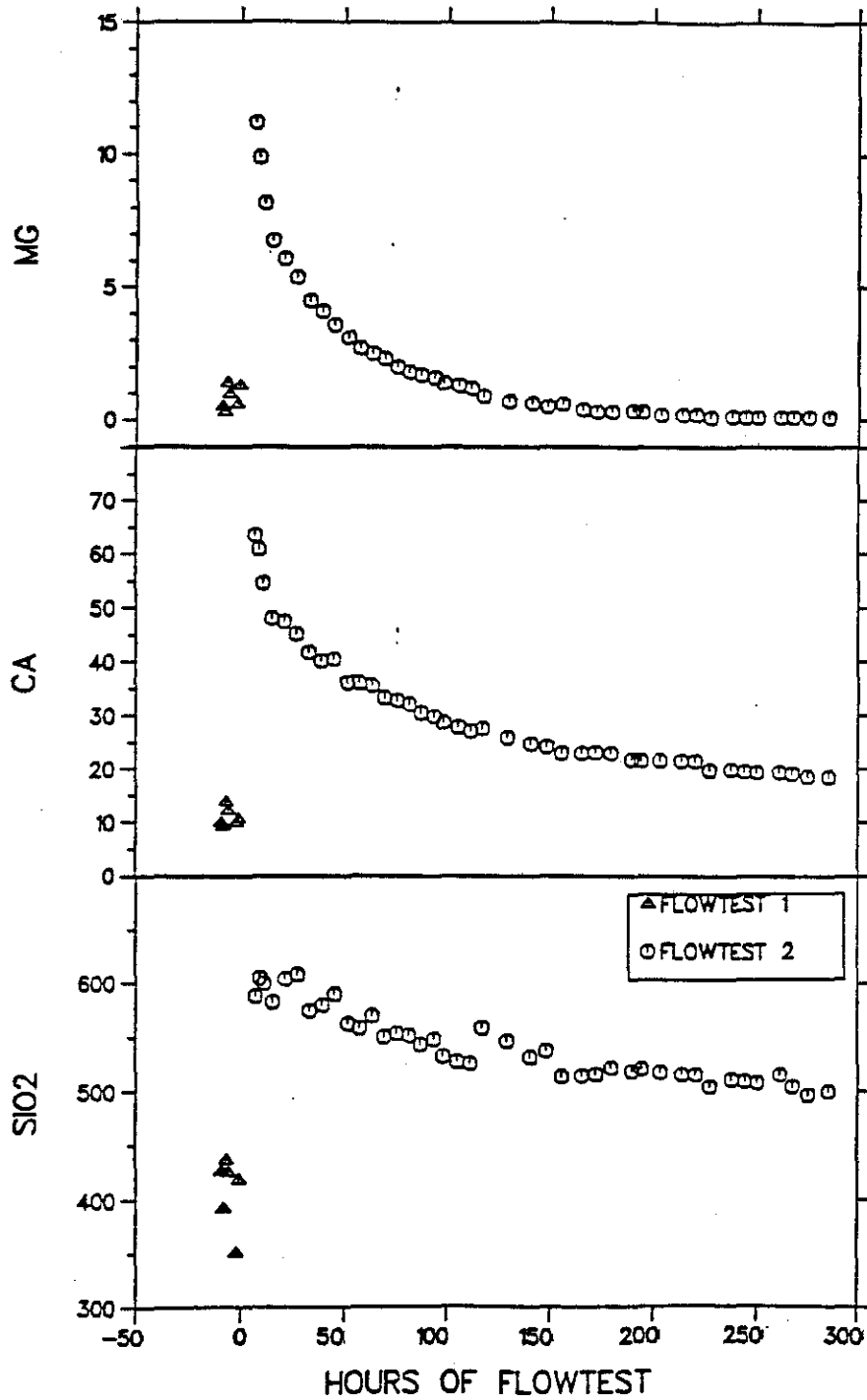
04/19/89

Figure 10: The production of the "reactive species" SiO_2, Ca, and Mg (in ppm) during flowtests 1 and 2 of GMF 31-17. These species are enriched in the brine during flowtest 2 primarily as a result of the destruction of minerals in veins and reservoir rocks, and of cement by acid used to stimulate the well. Flowtest 2 starts at the "0" hour.

DLC/mmb/5130T
Ctlg. No.: UCA07.2501

31–17 PH VS FE
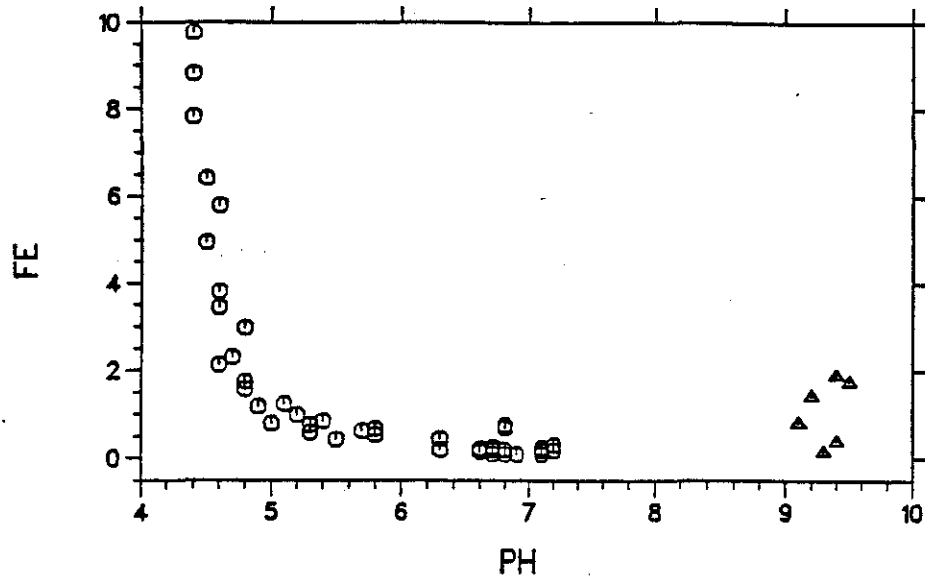
31–17 FE PRODUCTION
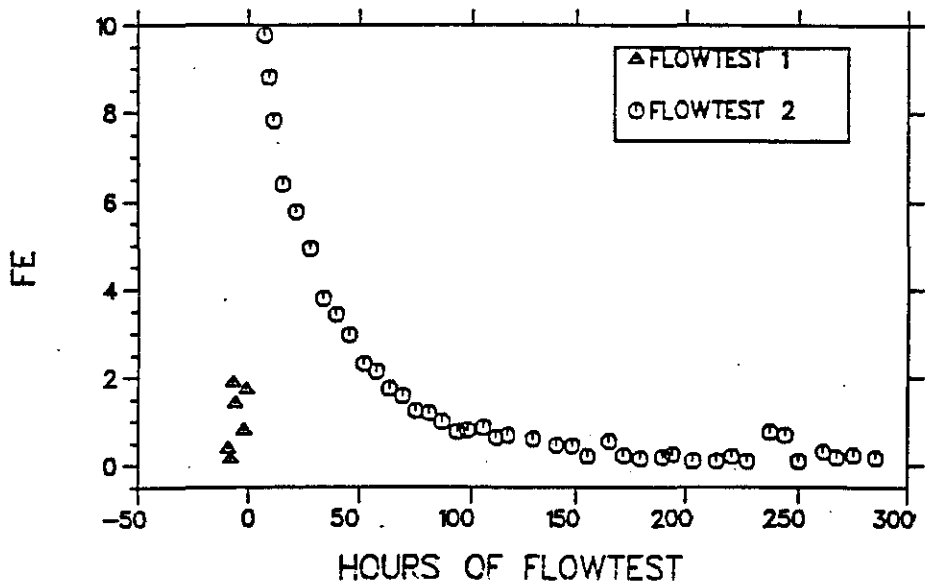

Figure 11: The production of the "reactive species" Fe (ppm) during flowtests 1 and 2 of GMF 31-17. The concentrations of Fe are greatest at the start of flowtest 2, when the pH is lowest. The low pH results from the acid stimulation of the well prior to the flowtest. The source of the Fe is the iron casing in the well. Flowtest 2 starts at the "0" hour.

arsenic actually exhibit a slight increase during most of the flowtests. This trend might be explained by a gradual heating and increase in enthalpy, which was not accounted for in the flash corrections. In any event, there is no indication of significant contamination by injected brine.

Injection and production temperature profiles indicate the 3500 to 4000-foot interval of GMF 31-17 is responsible for most of the permeability in the well. The lack of contamination by the 38,000 barrels of GMF 68-8 brine in GMF 31-17 is difficult to be explain without the existence of significant vertical permeability in the reservoir. Vertical permeability would allow the cooler, denser brines injected into the reservoir to fall away from the wellbore and into deeper parts of the reservoir, and and would result in the production of relatively uncontaminated fluids.

Although contamination by the brine is not evidenced, contamination from the acid job is readily apparent. Even after 13 days and 229,800 barrels of production (compared with 39,400 barrels injected) the reservoir fluids were still contaminated from the acid and its reaction products. The distribution of pH, F, Cl, SiO_2 and Ca in Figures 9 and 10 continued to change with time throughout the test. These relationships are explored in more detail below.

The lingering signature of acid contamination is best seen in Figure 9 plots of pH and F. Laboratory-determined pH values increased during the test from 4.4 to 7.2, and were still increasing at the end of the test. In comparison, laboratory-determined pH values for GMF 68-8 brines averaged around 8.4. Measured concentrations of F decreased during the test from 11.8 to 3.7 ppm. Fluoride concentrations during the first seven hours were probably higher, although no samples were collected and verification is not possible. Fluoride concentrations at the end of the test were still more than double the 1.5 ppm concentrations measured for GMF 68-8 fluids.

The concentrations of "reactive species" SiO_2, Ca, Mg, and Fe in Figures 10 and 11 had nearly stabilized by the end of the test. Silica and calcium were added to the reservoir probably through the destruction of minerals in veins and reservoir rocks by the acid. The SiO_2 was probably derived from the breakdown of silicate minerals by the HF. Calcium was derived from the destruction of some combination of calcite, feldspar, clays, and cement. Magnesium, is probably derived from the destruction of clays and chlorite. By the end of the test Mg had declined to nearly zero and was more characteristic of uncontaminated geothermal fluids. Iron was added to the reservoir fluids by the reaction of acid to the liner. Iron levels do not return to background conditions until the laboratory pH was greater than 6 and until 150 hours into the flowtest.

C. FLUID GEOTHERMOMETERS

1. GMF 68-8

Fluid geothermometry data for flowtest 4 of GMF 68-8 predict reservoir temperatures of 477°F to 520°F (Table 4). The alkali geothermometers probably give more reliable results (Figure 12) than the silica geothermometer because the alkali geothermometers are less sensitive to flash corrections, which are not well constrained for flowtest 4. The Na-K-Ca and Truesdell Na/K alkali geothermometers predict reservoir temperatures of 477°F to 494°F. These are significantly less than the 506°F to 520°F measured in the productive portion of GMF 68-8 after being shut-in for 10 months. The cause of the difference between the measured temperatures and the geothermometers is unknown; however the data raise the possibility that cooler fluids are being drawn into the reservoir during production. Additional chemical monitoring of the well is needed to determine whether or not this is actually the case.

Increasing alkali geothermometer temperatures for flowtest 4 fluids correlate with decreasing B and Cl concentrations in Figure 6. Since alkali geothermometers are based on ratios, they are not immediately sensitive to flash or boiling-induced enrichments. Thus, the general decrease in salinity observed for flowtest 4 waters is probably due to decreased production of brine which was concentrated by flashing in the formation. The increase in geothermometers records a relative increase of higher temperature fluids from the deeper production zone.

2. GMF 31-17

The quartz-saturation and Na-K-Ca temperatures are unreliable because there was anomalous SiO_2 and Ca in the brine from the acid job. Sodium and K show no contamination effects and therefore, only the Na/K geothermometer data are potentially reliable. The Na/K geothermometers predict reservoir temperatures of 465°F to 502°F for GMF 31-17 brines (Table 4, Figure 13) depending on whether the Fournier Na/K geothermometer or Truesdell Na/K geothermometer is used. Each is nearly constant throughout the test, but temperatures predicted by the Truesdell Na/K geothermometer are 30°F lower than the Fournier geothermometer and reach a maximum of 473°F at the end of flowtest 2. The 473°F temperature agrees best with the 475 to 485°F temperatures measured five months after the flowtest in the productive interval of GMF 31-17 at 3500 to 4000 feet.

TABLE 4   Fluid and gas geothermometers for selected samples from
          GMF68-8 and GMF31-17. The headers are as follows: S# is
          sample number in order of collection; H is assumed
          enthalpy in BTU/lb.; TQTZ is quartz-saturation temperature;
          TNKC is NA-K-CA temperature; TNKT is Truesdell NA/K
          temperature; TNKF is Fournier NA/K temperature; TDAP is
          D'Amore-Panichi gas temperature; and PDAP is pressure in
          bars based on TDAP and total CO_2.

SAMPLE	S#	H	TQTZ	TNKC	TNKT	TNKF	TDAP	PDAP
GMF68-8								
FLOWTEST 1								
68-8-I-6	5	485	486	461	469.1	499.5	510	0.14
68-8-I-8	7	490	491	472	473.4	502.7	477	0.18
FLOWTEST 2								
68-8-IIA-6	14	499	496	474	455.3	489.1	–	–
68-8-IIB-6	20	491	488	462	461.7	493.9	552	0.09
68-8-IIB-9	23	502	500	468	465.0	496.4	565	0.10
FLOWTEST 3								
68-8-III-2	29	511	477	462	468.1	498.7	–	–
68-8-III-7	34	511	458	462	468.4	499.0	–	–
68-8-III-12	39	511	498	476	480.3	507.8	406	0.58
68-8-III-18	45	511	507	489	490.6	515.5	357	0.19
68-8-III-20	47	511	500	486	486.8	512.7	–	–
FLOWTEST 4								
68-8-IV-1	48	511	513	480	477.2	505.5	–	–
68-8-IV-4	51	511	493	483	482.5	509.5	–	–
68-8-IV-6	53	511	521	491	491.8	516.4	502	0.49
68-8-IV-8	55	511	486	486	486.5	512.4	–	–
68-8-IV-9	56	511	501	491	491.1	515.9	–	0.01
68-8-IV-10	57	511	486	492	493.8	517.9	399	0.17
GMF31-17								
FLOWTEST 1								
31-17-I-3	3	454	470	413	356.3	412.0	431	0.70
31-17-I-6	6	454	463	441	397.7	444.8	–	–
FLOWTEST 2								
31-17-II-2	8	454	540	446	465.8	497.0	–	–
31-17-II-7	13	454	527	450	464.7	496.2	531	0.14
31-17-II-15	21	454	517	459	469.6	499.8	–	–
31-17-II-20	26	454	506	460	469.2	499.6	–	–
31-17-II-23	28	454	515	463	467.5	498.3	–	–
31-17-II-33	38	454	502	469	470.2	500.3	–	–
31-17-II-40	45	454	498	471	472.2	501.8	–	–
31-17-II-99	48	454	480	463	465.1	496.5	–	–
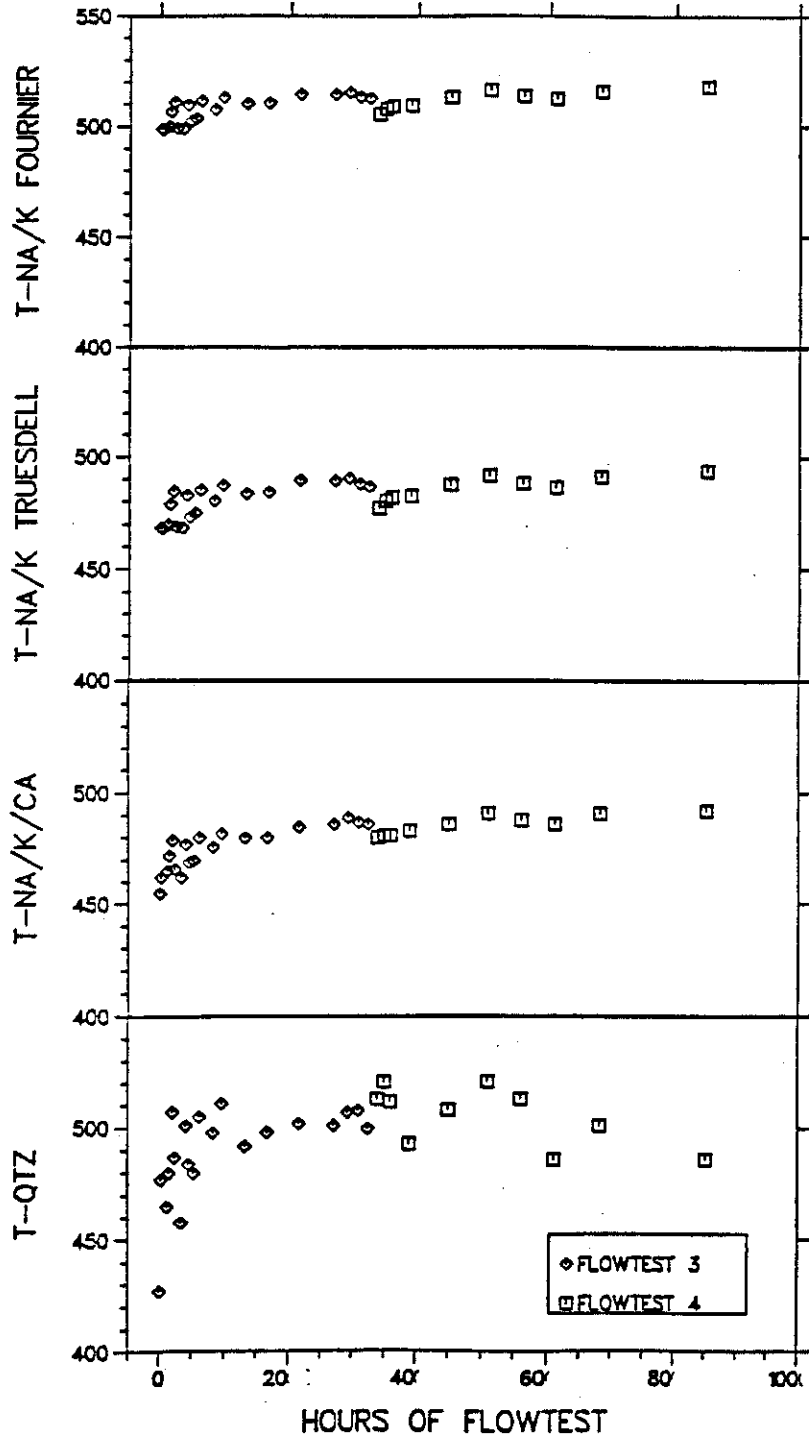
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Figure 12: Geothermometer temperatures for flowtests 3 and 4 of GMF 68-8. Although there was a break of 4 days between flowtests 3 and 4, for ease of presentation the break is shown in this figure to be 1 hr. and 15 min. Both the Na/K/Ca and Truesdell Na/K geothermometers predict temperatures less than those measured in the well during static conditions. The quartz-saturation geothermometers is of uncertain reliability because the enthalpy of the fluids is unknown and flash corrections are not precise.
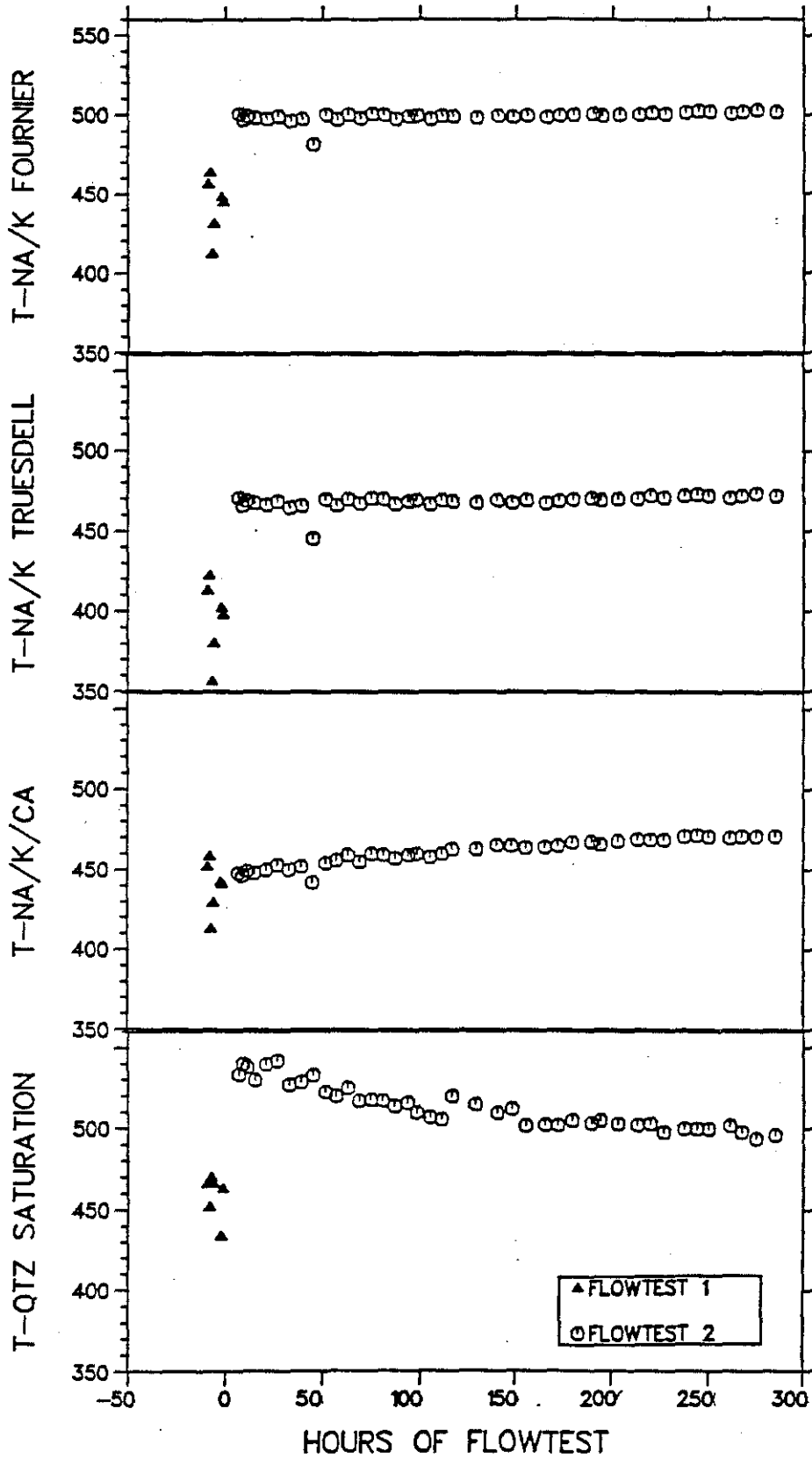
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Figure 13: Geothermometer temperatures in °F for fluids produced during flowtests 1 and 2 of GMF 31-17. The reliability of the Na/K/Ca and quartz-saturation geothermometers are both negatively impacted by the acid stimulation of the well. Flowtest 2 starts at the "0" hour.

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D. NON-CONDENSIBLE GASES

1. GMF 68-8

The data from ten non-condensible gas samples collected during
the flowtests of GMF 68-8 are shown in Table 5.
Non-condensible gases in the fluids were measured to be less
than 0.01 wt.% of the total flow in a sample collected at the
end of flowtest 4. This sample is considered to be the most
reliable sample of reservoir gas; it had the lowest air
contamination of all the samples collected from GMF 68-8, and
the brine was the least contaminated by injected fluids. The
principal gas components are CO_2, N_2, and H_2S.
Concentrations of H_2S in the sample are measured to be 1.5
ppm of the total flow, or 6 ppm of the steam. Elevated H_2
values, shown in Table 5, for flowtest 2B probably resulted
from the reaction of brine with aluminum plugs, which were part
of the 7" liner hung in the well before the flowtest.

When the CO_2 and N_2 volume percent of non-condensible gases
in GMF 68-8 are compared, N_2 levels in GMF 68-8 stand out as
being high. This primarily reflects the very low CO_2
content. The source of the N_2 in GMF 68-8 is most likely
atmospheric N_2 entrained within the natural recharge water.
N_2/Ar ratios in the air-corrected analyses (Table 5)
generally cluster around the atmospheric value of 84 (Matsuo,
et al., 1978), even for samples with less than 2% air
contamination. The N_2 concentration in the last sample for
flowtest 4, the sample with the least air or injection
contamination, is 9.7 mole ppm, which is nearly identical to
air-saturated water at 50°F and is identical to what is
observed at Cerro Prieto (Nehring and Fansto, 1979).
Therefore, the source of the N_2 is probably from the initial
air-saturation of the meteoric water which composes the
reservoir fluid. Since dissolved gases are extremely sensitive
to boiling, the observed values indicate that the reservoir
fluids had never undergone boiling prior to the flowtest.

The D'Amore-Panichi (DAP) gas geothermometer temperatures show
virtually no correlation with the fluid geothermometers (Table
5). The calculated temperatures range from 399 to 565°F and
display no clear patterns.

2. GMF 31-17

An undisturbed reservoir gas sample probably was not collected
from GMF 31-17 during either flowtest 1 or 2. Five gas samples
were collected during the flowtests and the data are shown in
Table 5. The data are disturbed by variations in the pH of the
production fluids. This is a direct result of adding caustic
to GMF 31-17 before flowtest 1, and adding acid to the well
before flowtest 2. The solubility of CO_2 and H_2S are
controlled by pH, and both gases are concentrated in higher pH
fluids. Concentrations of H_2 are also affected by the pH.
Low pH fluids in the wellbore react with the iron casing to
produce Fe^{+3} ions and H_2 gas. The DAP gas geothermometers
are useful in these conditions.

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TABLE 5 Non-condensible gas data from the flowtests of GMF68-8 and GMF31-17. Non-condensible gas data are corrected for air and reported in volume percent of dry gas. Air is reported as the percent of air in the uncorrected sample. Gas/TF is the ratio of gas to the total flow for the flash-corrected liquid. S# is sample number for comparison with the water chemistry data shown in figures, and H_2S (ppm) is for the total flow.

SAMPLE	S#	CO_2	H_2S	CH_4	H_2	N_2	NH_3	AR	AIR	GAS/TF	GAS/STM	TDAP	PDAP (BARS)	N_2/AR	H_2S(PPM)
GMF68-8															
FLOWTEST 1															
68-8-I-6	5	67.61	6.209	0.215	6.922	18.357	0.440	0.2468	4.0861	0.012	0.055	510	0.14	74.4	6.8
68-8-I-8	7	72.07	5.957	0.257	3.408	17.692	0.390	0.2299	4.9481	0.012	0.056	477	0.18	77.0	6.3
FLOWTEST 2															
68-8-IIB-6	20	50.79	1.760	0.146	30.231	16.191	0.684	0.2011	1.3400	0.009	0.030	552	0.09	80.5	1.9
68-8-IIB-9	23	52.26	2.228	0.113	27.441	17.088	0.676	0.1889	0.3450	0.011	0.036	565	0.10	90.5	2.8
FLOWTEST 3															
68-8-III-12	39	77.79	0.010	0.350	5.540	15.621	0.505	0.1802	3.0001	0.029	0.111	406	0.58	86.7	10.2
68-8-III-18	45	78.59	0.021	0.220	3.830	17.523	<0.350	0.1668	6.8301	0.008	0.041	357	0.19	105.0	2.8
FLOWTEST 4															
68-8-IV-6	53	79.52	4.441	0.320	2.371	13.083	0.130	0.1350	5.3751	0.035	0.138	502	0.49	96.9	13.1
68-8-IV-8	55	90.66	7.681	<0.341	0.155	3.153	<1.354	0.0445	1.7190	0.004	0.014	–	–	70.9	2.4
68-8-IV-9	56	79.10	3.037	<0.111	0.535	17.768	<0.252	<0.0797	44.6749	0.013	0.055	–	0.01	–	3.3
68-8-IV-10	57	90.71	2.066	0.141	1.230	6.168	<0.383	0.0706	0.2000	0.008	0.037	399	0.17	87.4	1.3
GMF31-17															
FLOWTEST 1															
31-17-I-3	3	76.90	7.260	0.800	0.384	10.199	4.350	0.1120	2.4200	0.039	0.148	431	0.70	91.1	24.0
FLOWTEST 2															
31-17-II-2	8	25.40	1.492	<0.431	1.522	65.120	6.169	0.7258	66.3913	0.005	0.019	–	–	89.7	0.8
31-17-II-7	13	38.29	2.509	0.077	5.878	51.584	0.997	0.6668	1.2500	0.020	0.077	531	0.14	77.4	5.2
31-17-II-23	28	55.95	4.166	<0.316	2.888	34.714	2.244	0.3592	1.9900	0.006	0.021	–	–	96.6	2.4
31-17-II-99	48	50.87	3.099	<0.490	0.690	43.906	1.655	0.2695	62.4512	0.002	0.015	–	–	162.9	0.6

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VII. APPENDIX I

GMF 68-8

GMF 68-8 was originally spud July 19, 1985 and completed to a
total depth of 6,571 feet on August 19, 1985. An aerated mud
system was used to drill the well from the 9 5/8" casing shoe
at 3515 feet to total depth. Drilling fluid losses to the
formation were therefore limited. The well was completed and
injection tested, but not production tested, prior to being
shut-in.

The GMF 68-8 site was re-occupied in July, 1988. Seven days
were spent removing a bridge plug, pulling the 7" liner, and
testing the well. About 4800 bbls of meteoric water were lost
in 68-8 while the liner was being pulled, and over 5757 bbls of
fluids were produced as the well was being stimulated and
tested. Production data are shown in Table 2.

GMF 68-8 was deepened to 8417 feet over a 13 day period that
began July 10 and finished July 23. A balanced mud system was
used to drill the well. Drilling fluid losses to the formation
occurred at a nearly continuous 20 to 30 barrels per hour, and
total losses are estimated to be 26,463 barrels. The greatest
losses occurred at 6750 feet and 8209 feet. Losses at 6750
feet were 200 barrels/hr. and at 8209 feet a 450 barrel loss
occurred. The drill pipe was differentially stuck at 6782,
7050 and 8399 feet. Each time the pipe was freed by
circulating air bubbles.

Eight days after drilling stopped, GMF 68-8 was stimulated into
sustained production. Extensive airlifting was required,
however, to make the well flow. The second flowtest of
GMF 68-8 began on July 23 and lasted until July 31. After
three days of airlifting fluids from the wellbore, the well
began to flow on its own. This period of flow lasted twenty
minutes, when the well surged and began to unload softball-size
rocks. These rocks first plugged the flow line, and then
bridged the wellbore and cut off the flow. Three days were
spent to clean out the bridges and running 7" liner to 8410
feet, and on July 29 the test resumed. After two days of
extensive airlifting, the well finally sustained a flow on its
own for eight hours before being shut-in July 31. Geochemical
samples were collected during both phases of the test. About
18,039 barrels of water and mud were produced during the second
flowtest. Approximately 587 barrels of water and mud were put
back into the formation while the 7" liner was being run. A
short injection test immediately followed flowtest 2B.

Three additional production tests occurred during 1988, and the
results are summarized in Table 2. On September 11, just prior
to the start of the third test, downhole samples were collected
from the 3500, 6000, 6900, and 7900-foot intervals of
GMF 68-8. The third test began September 17, lasted for
31.67 hours and produced 19,138 barrels of fluid. The test

ended early because the sump reached capacity. The fourth test
began September 22, lasted for 66 hours, and produced
43,838 barrels of fluid. The fifth and final test began
October 5, lasted 39.33 hours, and produced 21,471 barrels of
fluid. This test was run to provide a brine flush for the acid
stimulation of GMF 31-17. No geochemical samples were
collected during test five.

GMF 31-17

GMF 31-17 spud August 4, 1988 and was drilled to a total depth
of 8787 feet. The well was drilled from the 9 5/8" production
shoe at 3074 feet to total depth using a balanced mud system.
Drilling fluid losses totalled about 7360 barrels including 100
barrels of caustic used to wash the well during completion.
Three zones in the well took fluid. A 90 barrel loss occurred
at 3550 feet, a 20-40 barrel/hour loss occurred at 5352 feet,
and in the 7560 to 7880 foot interval. The drill pipe was
differentially stuck at 3694, 3820 and 5352 feet. Each time
the drill pipe was freed by circulating air bubbles.

Drilling ceased September 5, a 7" liner was run, and on
September 9 a 10.5 hour flowtest was conducted. Fluids were
produced using an airlift system; however, the well was unable
to sustain a flow. About 2100 barrels of water and mud were
produced during the test. Geochemical samples were collected
during the test.

Following the first flowtest of GMF 31-17, over 39,400 barrels
of meteoric water, acid, drilling fluids and flashed brine from
GMF 68-8 were injected into GMF 31-17 during a 15 day period.
The majority of the fluids injected were flashed brine. The
acid was injected during an acid stimulation performed on
October 6, and consisted of 125 barrels of 10% HCl and 250
barrels of a 12% HCl-3% HF mixture. To chase the acid, 208
barrels of fresh water and 8,640 barrels of flashed GMF 68-8
brine were injected into the well.

The second flowtest of GMF 31-17 began October 15 and continued
to October 31. The well was successfully induced to flow using
compressed air as an initiator. Problems with injection lines
to GMF 68-8 prevented a continuous flowtest from starting until
October 19. The well was allowed to flow continuously from
October 19 to October 31, and about 229,800 barrels of fluid
were produced. Geochemical samples were collected throughout
the test. Produced brines were all injected into GMF 68-8.

APPENDIX 2B, PART I   (Cont'd)

SAMPLE	S#	PH	NA	K	CA	MG	AS	LI	FE	CL	HCO3	SO4	F	B	SIO2	TDS	BAL
31-17-II-39	44	7.2	890.	142.	19.4	0.1	4.567	5.42	0.3025	1468.	14.0	43.5	3.9	11.7	516.	3120.	1.58
31-17-II-40	45	7.1	884.	142.	19.1	0.1	4.427	5.47	0.1771	1461.	12.5	39.8	3.7	11.5	505.	3089.	1.61
31-17-II-41	46	7.1	855.	138.	18.5	0.1	4.398	5.31	0.2287	1417.	11.1	62.0	3.6	11.5	497.	3024.	0.98
31-17-II-42	47	7.2	874.	140.	18.5	0.1	4.457	5.35	0.1771	1409.	15.5	44.3	3.9	11.7	500.	3028.	2.55
31-17-II-99	48	-	669.	104.	13.4	0.2	5.578	-	0.3719	1413.	22.3	40.2	3.7	17.1	461.	2753.	-11.90

APPENDIX 2B

PART II: Deuterium and ^{18}O values for water samples collected
from GMF 31-17 in 1988. All value are corrected
assuming a continuous flash. Enthalpy assumed for the
flash corrections is 434 BTU/lb. "S#" is the sample
number. Hour starts at "0" in flowtest 2.

S#	SAMPLE	LOCATION	D	^{18}O	HOUR	TIME
FLOWTEST 1						
1	31-17-I-1	MEDICINE LK	-95.15	-9.11	-900	0200
2	31-17-I-2	MEDICINE LK	-92.15	-9.11	-800	0330
3	31-17-I-3	MEDICINE LK	-95.15	-8.61	-700	0530
4	31-17-I-4	MEDICINE LK	-93.15	-8.01	-600	0730
5	31-17-I-5	MEDICINE LK	-95.15	-8.61	-200	2215
6	31-17-I-6	MEDICINE LK	-95.15	-8.81	-100	2400
FLOWTEST 2						
7	31-17-II-1	MEDICINE LK	-96.15	-8.21	0720	1720
8	31-17-II-2	MEDICINE LK	-93.15	-8.01	0910	1910
9	31-17-II-3	MEDICINE LK	-95.15	-8.31	1130	2130
10	31-17-II-4	MEDICINE LK	-95.15	-8.11	1540	0140
11	31-17-II-5	MEDICINE LK	-96.15	-8.21	2142	0742
12	31-17-II-6	MEDICINE LK	-96.15	-8.41	2730	1330
13	31-17-II-7	MEDICINE LK	-93.15	-8.21	3340	1940
14	31-17-II-8	MEDICINE LK	-95.15	-8.71	3935	0135
15	31-17-II-9	MEDICINE LK	-95.15	-8.31	4535	0735
16	31-17-II-10	MEDICINE LK	-96.15	-8.21	5200	1400
17	31-17-II-11	MEDICINE LK	-95.15	-8.51	5745	1945
18	31-17-II-12	MEDICINE LK	-97.15	-8.51	6325	0125
19	31-17-II-13	MEDICINE LK	-96.15	-8.31	6930	0730
20	31-17-II-14	MEDICINE LK	-95.15	-8.21	7533	1333
21	31-17-II-15	MEDICINE LK	-96.15	-8.51	8130	1930
22	31-17-II-16	MEDICINE LK	-98.15	-8.41	8708	0108
23	31-17-II-17	MEDICINE LK	-96.15	-8.41	9400	0800
24	31-17-II-18	MEDICINE LK	-94.15	-8.51	9830	1230
25	31-17-II-19	MEDICINE LK	-99.15	-8.31	10525	1925
26	31-17-II-20	MEDICINE LK	-99.15	-8.71	11140	0140
27	31-17-II-21	MEDICINE LK	-98.15	-9.01	11710	0710
28	31-17-II-23	MEDICINE LK	-98.15	-8.21	12930	1930
29	31-17-II-24	MEDICINE LK	-96.15	-8.41	14050	0650
31	31-17-II-26	MEDICINE LK	-95.15	-8.31	15530	2130
33	31-17-II-28	MEDICINE LK	-95.15	-8.21	17200	1400
35	31-17-II-30	MEDICINE LK	-95.15	-8.41	18930	0730
37	31-17-II-32	MEDICINE LK	-99.15	-8.51	20300	2100
39	31-17-II-34	MEDICINE LK	-95.15	-8.31	22000	1400
41	31-17-II-36	MEDICINE LK	-95.15	-8.31	23730	0730
43	31-17-II-38	MEDICINE LK	-97.15	-8.51	25000	2000
45	31-17-II-40	MEDICINE LK	-97.15	-8.31	26730	1330
47	31-17-II-42	MEDICINE LK	-95.15	-8.31	28530	0730

APPENDIX III   (H. R. Crecraft and D. L. Carrier)

Appendix 3 is intended to further explain the role that flashing plays in the cyclic behaviors observed during flowtest 3 of GMF 68-8. There was a pronounced cyclicity to both fluid compositions and production rates during the early part of the flowtest (Figure 4 of text). The cycling is related to a geysering-like phenomenon that occurred as a result of flashing in the formation. The following three observations are made. Alkali and silica geothermometers cycle in phase with WHP (Figure 4 in text); maxima in chemical constituents, such as Cl and B, are phase-delayed by 20 to 30 minutes with respect to peaks in the WHP; and oxygen-18 cycles in the opposite direction from WHP. During flowtest 3 an effort was made to sample the well when wellhead pressures (WHP) were at the minima and maxima of their cycles. Since isotopes were analyzed only for those samples that were collected at the minima and maxima of the production cycles, it cannot be determined if a phase delay existed between the production and isotope cycles.

It was concluded in the text that cycling of production rates and fluid chemistry were caused by flashing in the formation. Cycling resulted because, given an adequate supply of heat to a flashing fluid, an increase in production rate induces an increase in the flash. This reinforces a further increase in the production rate. During a period of increasing flash and production rates (interval 1-3, Figure A3.1), however, heat is extracted from the formation surrounding the flashing zone faster than conduction can resupply it. This causes a cooling of the rock matrix near the flashing zone. The restriction on the supply of heat to the fluid moderates and eventually reverses the continued increases in flashing and production (interval 2-4). Subsequent decreases in the flash and production rates (interval 3-5) then allow thermal recovery of the rock and pressure recovery of the fluid, and sets the stage for the next cycle.

Flow rates and wellhead pressure correlate directly to the degree of flashing in the formation and consequent steam fraction in the wellbore. This is portrayed by the correlation in curves A and B in Figure A3.1. In contrast, the pressure in the two-phase zone, and hence its temperature, vary inversely to the flow rate, as shown by curve C. This is because the pressure drawdown is greatest during maximum flow rates.

Flashing in the formation depresses the average temperature of the two-phase zone below the initial reservoir rock temperature, thereby inducing a net heat flow from the reservoir rock into the fluid. Because of the cyclicity of the temperature of the two-phase zone, the heat flux into the fluid is also cyclical. However, for a periodically changing temperature on the surface of a semi-infinite solid (e.g. the fracture walls and the reservoir rock on either side), the heat flux across that surface is phase-delayed by 1/8 of a period (Carslaw and Jaegar, 1976). Thus, there is a phase delay

between the maxima in flow rates and the maxima in the rate of heating of the fluid in the two-phase zone, as represented shown by curve D.

The addition of heat from the rock to the fluid causes a greater flash than would occur for adiabatic flashing, and consequently higher measured chemical concentrations. The variation in salinity of the air-flashed brine therefore correlates with the variation in the rate of heat addition to the fluid. This is shown by the the correlation between curves D and E in Figure A3.1.

For the two-hour cycles observed in production GMF 68-8, these phase relationships would mean that the maximum rate of heat flow to the fluid in the flash zone, and the corresponding maximum in observed salinities of flashed fluid, would occur 15 minutes after the peak in production. Given the sampling interval, this is indistinguishable with the 20 to 30 minute delay observed.

The general model presented above for the observed cycling during GMF 68-8 production tests also accounts, at least in a qualitative sense, for the cycling in geothermometers and salinities, and for the observed phase relationships among these cycles. The magnitudes of the chemical effects, however, have not been evaluated. The actual system is undoubtedly more complex. Specifically, the unrealistic assumption that there was no separation of steam and brine during flashing in the formation was made. The preferential flow of steam relative to the flow of brine, and a consequent cyclical recharge and discharge of brine from the zone of flashing, would add another variable affecting the measured salinities and would undoubtedly complicate the flashing process further. Nevertheless, the above model can provide some important constraints on the geometry of the two-phase zone as it relates to the effectiveness of heat extraction from the reservoir rock.
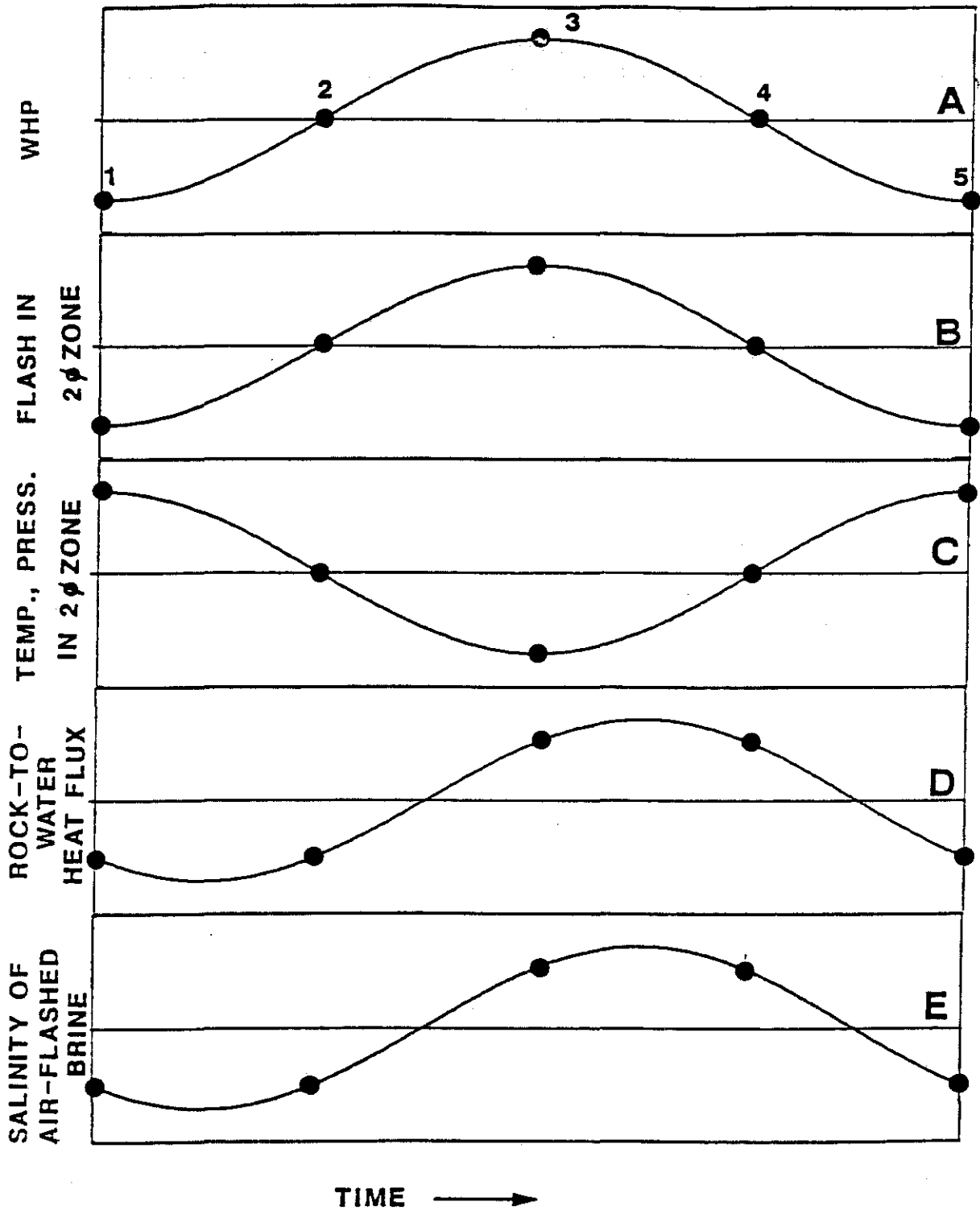
DLC/mmb/5130T
Ctlg. No.: UCA07.2501

Figure A3.1. Phase Correlations During Idealized Cyclical Production.

Cyclical variations in production and WHP (curve A) correlate directly to
variations in flashing in a two-phase zone (curve B). Temperature and hence
pressure of the two phase zone (curve C) show an inverse correlation due to
maximum draw-down during maximum flow rates. Salinities of air-flashed
brine (curve E) respond to the degree of flash at the surface, and hence to
the excess enthalpy gained by heat flow from the rock into the fluid. This
is represented (approximately) by the net rate of heat flux into the fluid
shown by curve D. Hence these two curves vary in phase. Conductive heat
flow from a solid into a surface that varies in temperature sinusoidally is
phase delayed by 1/8 phase behind the temperature variations.