ABSTRACT

HOT WATER FLOW IN RAFT RIVER RESERVOIR

Harold L. Overton

Hot mineralized water is rising along a major N-S fracture near the Crank Well in the Raft River Geothermal Reservoir. This water is distinguished by high TDS and Li, and by high Ca in the interior of the system. The water reacts with shallow meteoric water SO_4 to form gypsum on the west extremity but flows down dip to the SE (where Ca remains high). The down dip flow may be traced with shallow temperature gradients, which are excessively high where hot water flows laterally. Well logs show that the strong brines are abnormally shallow where G_t is highest, but are normal (deep) for the lower temperature gradients.

The combination of brine concentration, shallow G_t, and depth of the strongest brines shows that well No. 4 is closest to the heat source. Wells 1, 3, and 2 are farther away (in order of increasing distance). Well No. 3 is in the path of shallow down dip moving waters, and its water production causes shallow water to be drawn into the deep fractures; this causes TDS and non-reactive ions to increase with time, in the produced water.

The geothermal water is characterized by Cl/Na of 2 and Ca/SO_4 greater than 2, while the lateral meteoric water flow has 1.7 Cl/Na and near 1 Ca/SO_4. Both Li and Sr for the hot water are about double that in the mixed waters.

Both permeability and temperature should be best along the N-S line of strong brines. Injection wells should be drilled to the west of this heat source.

TABLE I

GEOCHEMICAL INDICATORS FROM WELL WATER

Raft River, Idaho

WELL	RRGE No. 1	2	3	BLM	Crank
Indicator	First, Average		Shallow/Deep/Recent	1st, Avg.	First, Avg.
Ca/SO_4	.93, .90	.91, .65	4.8/1.57/3.6	.75, 1.0	2.1, 2.4
Ca, ppm	57, 54 recent	48, 35	293/ 78 /193	52, 55	125, 130
Ca/Mg	75, 22.7	39, 61	154/ 6 /320	260, 275	417, 260
Mg	.76, 2.3	1.23, .6	1.9/ 13 /.6	.2, .2	.3, .5
Cl/Na	1.54, 1.71	1.86, 1.7	2.17/1.79/1.84	1.57,2.07	1.71, 1.77
Cl, ppm	614, 776	804, 708	4210/770/2170	880,1139	1900, 1900
Cl/SO_4	10.1, 12.9	15.2, 13	69 / 15.5/ 41	12.8, 21	31.7, 35
SO_4	61, 60	53, 54	61/ 50 / 53	69, 54	60, 54
Cl/Ca	10.8, 14.3	16.8, 20	14.4/9.9 /11.2	16.9,20.7	15.2, 14.6
TDS	1715, 1560	1852, 1267	6602/1450/4130	1720, 1640	3360,3720

NOTE:

1. The Shallow No. 3 water is most similar to the Crank water in all important respects
2. The recent produced water in No. 3 is more similar to No. 3 shallow (3986 ft.) than it was at initial production.
3. All indicators except those with Mg suggest that the recent No. 3 water is half way between the original deep and shallow waters (i.e. 50% mixing).
4. The BLM well water is somewhat like No. 1 and 2 waters, except for indicators containing Mg.

TABLE IA

Raft River Subsurface Water Characteristics

Section	T, °C	Na/Li	Ca/SO_4	Ca/Mg	Cℓ/Na	$Cℓ/SO_4$	Cℓ/Ca	TDS	B	Ca	Remarks
23 abd	29	405	1.2	19.6	1.6.1	14.4	12.2	2880	.25	107	Sys. No. 1
23 ddc	15	805	1.5	5.3	1.87	3.0	2.0	736	.07	97	Elim.
23 ddd	39	400	2.0	11.1	1.73	18.9	9.5	2400	.19	111	
24 bad	22	443	1.7	7.3	1.74	10.8	6.2	1536	.12	103	
24 bcb	24	439	1.0	8.1	1.50	10.9	10.6	2000	.20	61	Sinks
24 cad	28	416	2.1	6.9	1.89	9.1	4.4	1408	.11	126	
26 cab	24	451	.84	9.0	1.52	16.3	19.4	2496	.21	57	
27 dcc	15	646	.96	5.5	1.33	5.0	5.2	896	.05	59	Marginal
17 bcb	10	7196	1.70	6.2	1.93	5.5	3.2	1536	.14	167	Sys. No. 2
18 bcc	22	607	3.40	4.1	2.74	11.6	3.4	800	.01	98	Sys. No. 2
18 cac	15	549	2.60	4.0	2.41	9.6	3.7	1197	.05	124	Sys. No. 2
19 ccc	19	430	1.7	6.5	1.85	9.9	5.7	1856	.12	130	
29 bcc	10	6030	2.1	4.6	3.25	5.2	2.5	1408	.01	155	Elim.
RRGE-1	141	320	.93	75	1.54	10.1	10.8	1715	.2	57	
RRGE-2	147	361	.91	39	1.86	15.2	16.8	1852	.25	48	
RRGE-3 deep/shallow	148/110	430/473	1.57/4.8	6.0/154	1.79/2.17	15.5/69	9.9/14.4	1450/6602	-	78/293	
CRANK-23	93	444	2.1	417	1.71	31.7	15.2	3360	.25	125	Flowing
BLM-23		400	.75	260	1.57	12.8	16.9	1720	.15	52	

TABLE 11

TRACE GEOCHEMICAL INDICATORS

Raft River, Idaho

WELL	RRGE No. 1	2	3	BLM	Crank
Indicator			Shallow/Deep/Recent		
Na/Li	307	344	473/430/382	393	430
Li	1.48	1.21	4.1/1.0/3.1	1.4	2.5
Ca/Sr	34	34	27/ 60/ 29	41	46
Sr	1.56	1.03	11/1.3/6.7	1.35	2.8

NOTE:

1. Na/Li ratio changes at most 17% from the mean valve of 371; this subsurface water data compares with 1925 for the surface water at RR. Well No. 3 Li is approaching shallow No. 3 Li.

2. Ca/Sr ratio changes at most 55% from the mean value of 39; this compares with surface water ratio of 164. Well No 3. Sr is approaching shallow No.3 Sr.

CONCLUSIONS:

Na and Li are similar and less sensitive to T than Ca and Sr.

Present deep waters in No. 3 are a mixture of water similar to that at 4000 feet in No. 3 which is in turn closest to Crank shallow waters.

BLM water is similar to RRGE No. 1 and 2 waters.

A map on Lithium and also on TDS (Figure 1) shows that the mineralized water is rising along a N-S fracture between 23 abd and 26 cab wells (which includes the Crank well). RRGE in No. 3 cannot be directly compared with these wells because it is deep, and salinity normally increases with depth until 200°F is exceeded. Since heat is carried by moving water, a comparison of geothermal gradients allows additional analysis in three dimensions.

TABLE III

GEOTHERMAL DATA FOR RAFT RIVER WELLS

WELL	TEMP. °F	DEPTH Feet/Bit	T Surface °F	DATE Da/Mo/Yr	G_t °/h ft
No. 1	109	900/26	67 mud	1/9/75	4.7 (6.6?)
	252	4632/12¼	50	2/2/75	4.4
	286	5007/12¼	50 mean	4/6/75	4.7
No. 2	212	4247/12¼	50	5/12/75	3.8
	284	6006/12¼	50	6/27/75	3.9
No. 3	158	1404/17.5	50	3/30/76	7.7
	139	4259/12¼	50	4/17/76	---
	295	5868/8¼	50	5/2/76	4.2
No. 4	199	1900			7.8
	252	2840			7.1

NOTE: Well No. 3 has the highest G_t shallow; this indicates that convective heat is present. Since water will not flow updip at these normal pressures, water must move downdip - SSE.

The SP curves supply the following data:

TABLE IV

WELL	DEPTH Feet	MAXIMUM Salinity	MEASURED Salinity TD	FLOW INDICATION Depth
No. 1	3690	2030 ppm	1715 ppm	3700,4600
No. 2	4690	3200	1852 ppm	5200,6000
No. 3	1890	11,000	6602	3800,5400
No. 4	1700			1620

Table IV data from SP are higher than from measured data from bottom of the wells, in general. The strong brines at shallow depth in No.3 could be maintained against gravity fall by convection (due to a lateral hot water flow). Note that the strong brines do not appear in wells No.1 and 2. Strong brines are measured at the surface in the Crank well and others along the inferred N-S fracture.

Figure 2 shows that Calcium is high to the SE of RRGE No.1 and 2. Conversely Gypsum occurs in large amounts in cuttings in 1 and 2 but not in No.3. Meteoric water water bringing SO_4^{--} coming in contact with hot Ca^{++} waters would precipitate gypsum. Normal flow of meteoric water would be SE or downdip; this water mixed and chemically reacted with thermal water is found in RRGE No.1 and 2.

H_2 gas from geothermal waters would also react with SO_4^{--} near wells 1 and 2 to form sulfides. This would lower H_2 in 1 and 2 compared to No.3. Other reactions are shown in Table V, which would occur more near RRGE 1 and 2 and form permeability barriers to further mixing of meteoric and thermal waters.

Figure 3 presents a different view of the presence of Calcium. Whereas Figure 2 shows Ca^{++} as it relates to thermal production of gypsum, Figure 3 shows that calcium also reacts in the thermal zone where it does not combine with sulfate readily (gypsum probably combines mainly at the edge of the thermal zone where sulfur is in the form of sulfates rather than sulfides). Although sulfate is approximately constant in all water analyses, the sulfides are represented in these data -- as soon as temperature drops the sulfides revert to sulfates in the water samples.

Figure 3 indicates that the BLM hot well is anomalous in chloride referenced to calcium, but that Ca is high relative to Mg. This suggests a minor fracture system intersecting the main N-S mineralized zone and trending NW-SE. Calcium disappears along this minor fracture due to conversion of meteoric water carbonates to calcite and subsequent change to dolomite. This feature represents a barrier toward development of Raft River Field toward the Southwest.

A VERTICAL VIEW OF RAFT RIVER FIELD

Figure 4 is a vertical cross section of Raft River Field -- incorporating water mineralization, heat movement and well geometry.

Geothermal gradients are relatively large in the shallow zones of RRGE wells No. 1 and 3. This feature indicates shallow convection and lateral fluid movement. Data from No. 1 shallow -- 900 feet -- depths may be in error due to summertime heating of mud pits, but the anomalous shallow gradient in No. 3 is unmistakeable. Significant amounts of shallow hot water are moving along a line from the BLM well toward RRGE No. 3. This is mainly meteoric water, but becomes mineralized when it crosses the major N-S fracture system in the east part of Sections 23 and 26.

TABLE V

Reactions at Geothermal Water Interface - Raft River

$13\ H_2$	→	$26H^+ + 26e^-$	Upward-Moving Deep Water	(0.0 v)
$24e^- + 3\ Ca^{++}SO_4^{--} + 24\ H^+$	→	$3S^{--} + 12\ H_2O + 3\ Ca^{++}$	Sulfur Reduction	(-.14 v)
$S^{--} + 2\ H^+$	→	H_2S	Reduction Zone Gas	
$Fe^{+++} + e^-$	→	Fe^{++}	Reduction of Irons	(-.77 v)
$Fe^{+++} + 2S^-$	→	$FeS_2 + 2e^-$	Pyritization (probably from siderite or $Fe(OH)_2$)	
$\frac{3}{4}\ O_2 + \frac{3}{2}\ H_2O + 3e^-$	→	$3OH^-$	Meteoric Water Descent	(-.40 v)
$3\ Na_2^+\ SO_4^{--}$	→	$6\ Na^+ + 3\ SO_4^{--}$	Ions Leached by Fresh Water	
$\frac{3}{2}\ Ca^{++}Cl_2^-$	→	$\frac{3}{2}\ Ca^{++} + 3\ Cl^-$	Ions from Rising Deep Water	
$3\ Ca^{++} + 3\ SO_4^{--}$	→	$3\ Ca\ SO_4$	Gypsum Formation at Interface	
$\frac{3}{2}\ Ca^{++} + 3(OH^-) + 3\ CO_2$	→	$\frac{3}{2}\ Ca\ (HCO_3)_2$	Bicarbonate Formation at Interface	
$3\ Na^+ + 3\ Cl^-$	→	$3Na^+Cl^-\ (AQ)$	Increasing Water Salinity	

Remaining Na^+ probably neutralized by HCO_3 from $Fe\ (OH)_3$ and CO_2

RRGE wells No. 1 and 2 show that the most dense brine exists near the base of sedimentary rocks - the normal circumstance -- whereas No. 3 has the heaviest brine at about 1900 feet. Upflow of minerals occurs between wells No. 1 and 3, producing these brines. This also is indicated by H_2S gas, which is the strongest in well No. 3. The probable reactions occurring at the intersections of the two waters are shown in Table V.

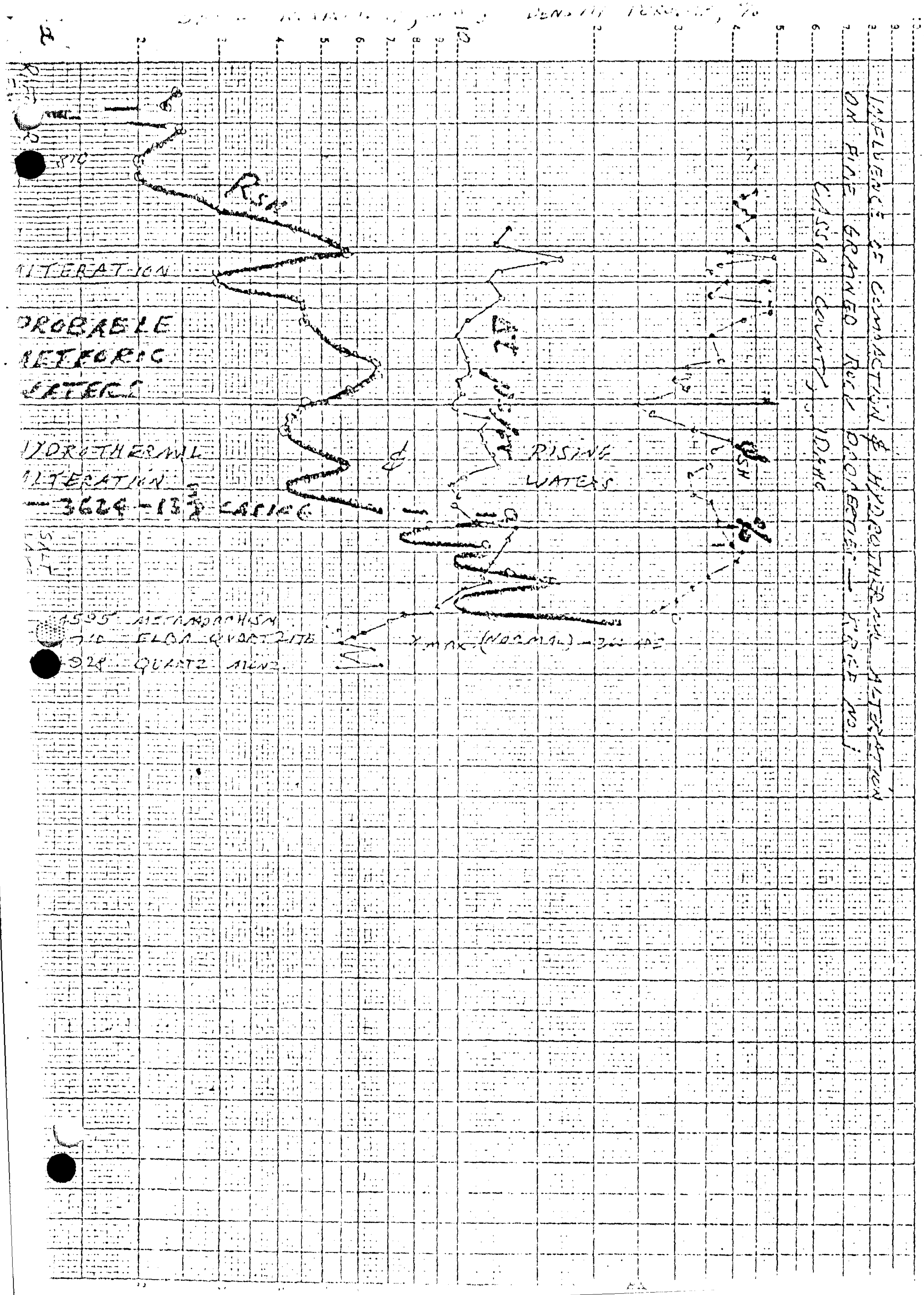
RAFT RIVER GEOTHERMAL RESERVOIR ANALYSIS - SUMMARY

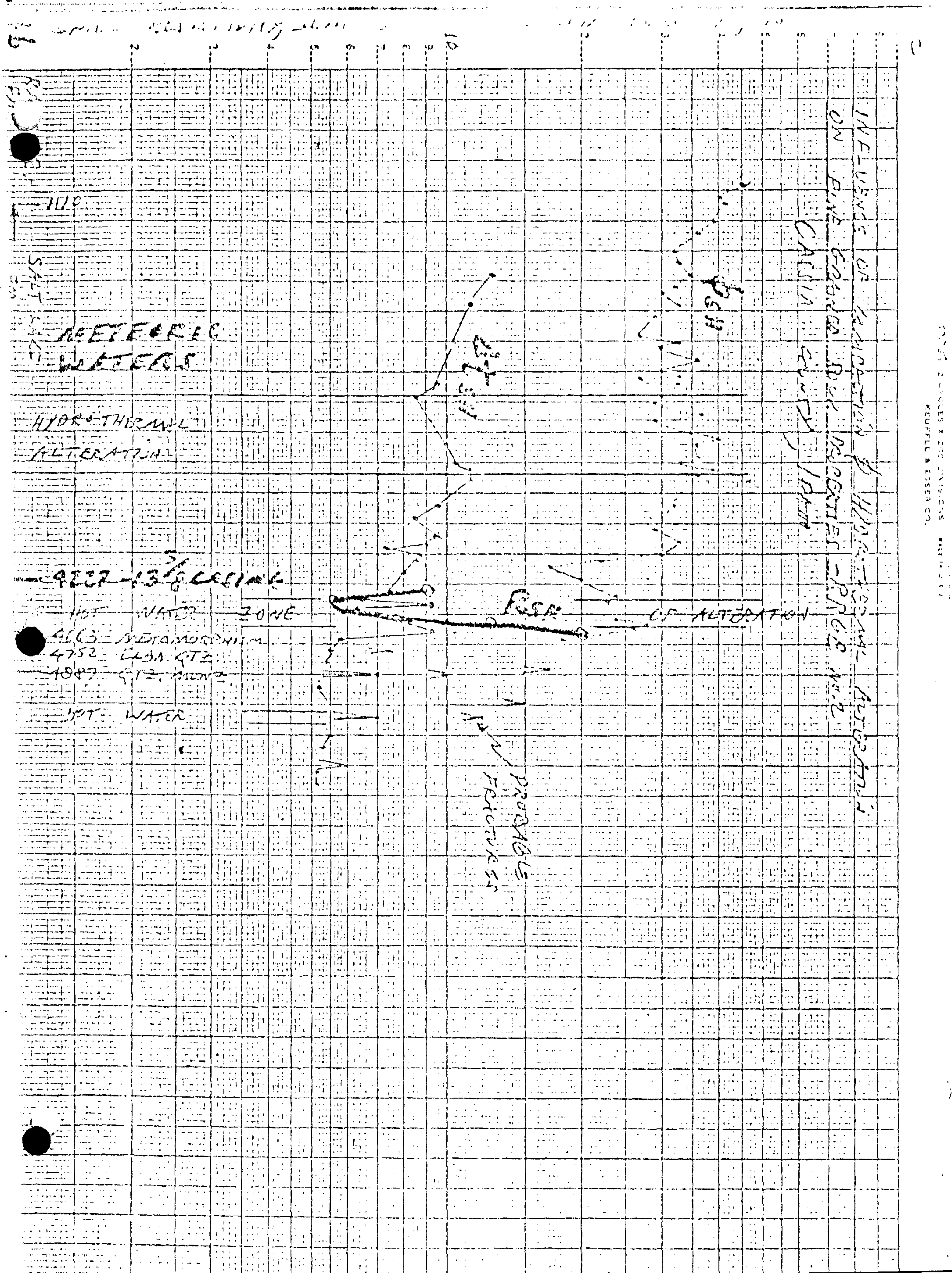
Strong brines rise along a N-S line near the Crank well from the hot basement in Raft River Geothermal Field. This vertical flow is flushed downdip towards RRGE No. 3 well by meteoric waters from the WNW, and is probably aided by a minor fracture system extending SE from the BLM well.

At the intersection of the westerly edge of the strong brines and the easterly moving meteoric waters, deep Ca^{++} combines with SO_4^{--} to form gypsum and permeability barriers. To the east of this barrier, sulfates are converted to sulfides by hydrogen from the deep waters.

Strong brines are found shallow east of the intersection of the two waters, but are found deep -- in the normal circumstance -- west of the intersection.

It is suggested that further development of the field be restricted to the major N-S fracture system existing in the eastern parts of Sections 23 and 26. Maximum temperatures and permeabilities should occur there.

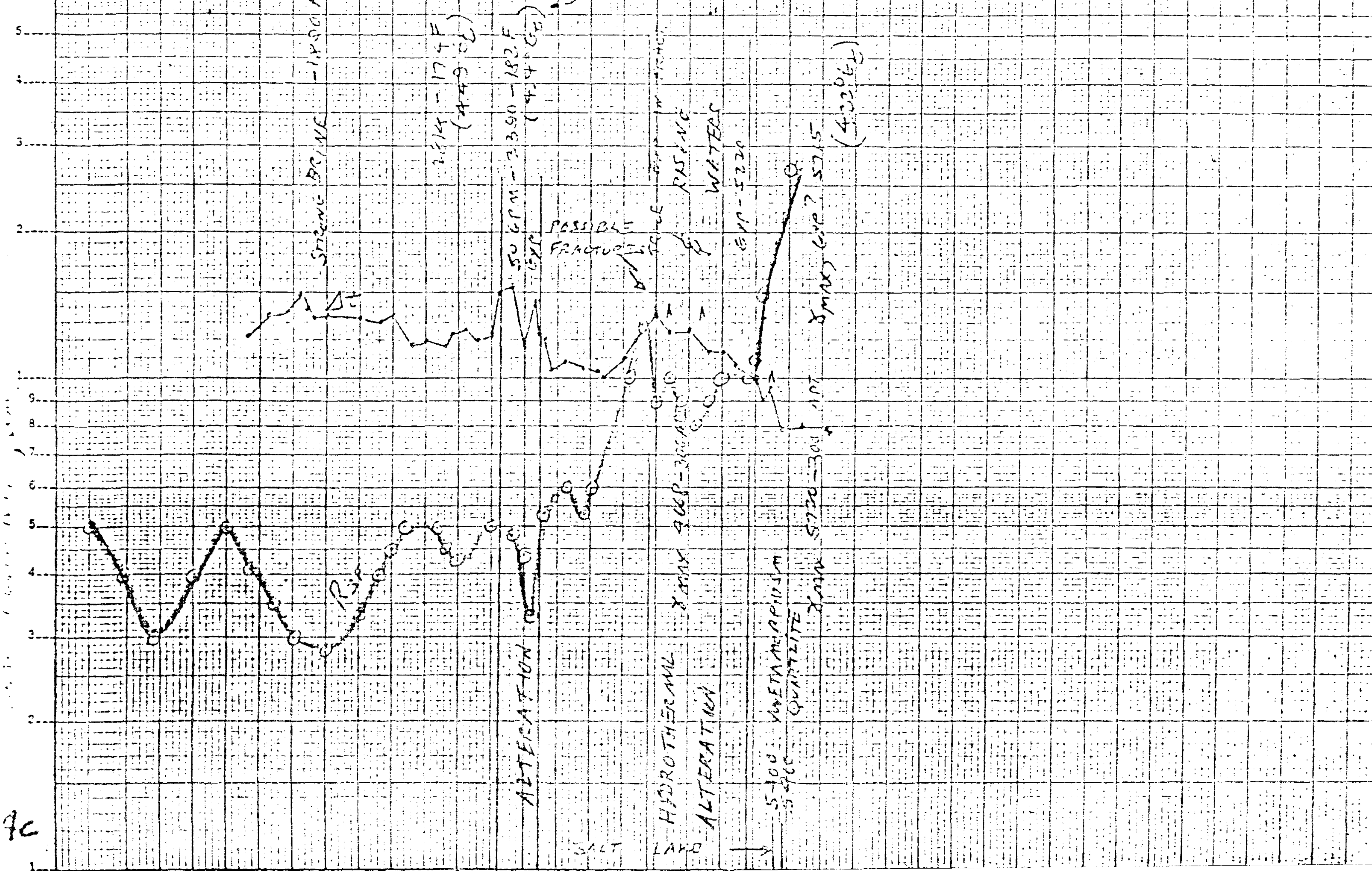

INFLUENCE OF COMPACTION & HYDROTHERMAL ALTERATION
ON FINE GRAINED ROCK PROPERTIES - PRICE NO. 1
CASSIA COUNTY, IDAHO
DENSITY POROSITY, %
RSH
ALTERATION
PROBABLE
METEORIC
WATERS
HYDROTHERMAL
ALTERATION
3624-13 CASING
RISING
WATERS
4595' METAMORPHISM
FLDR QUARTZITE
QUARTZ MINZ
KEUFFEL & ESSER CO.

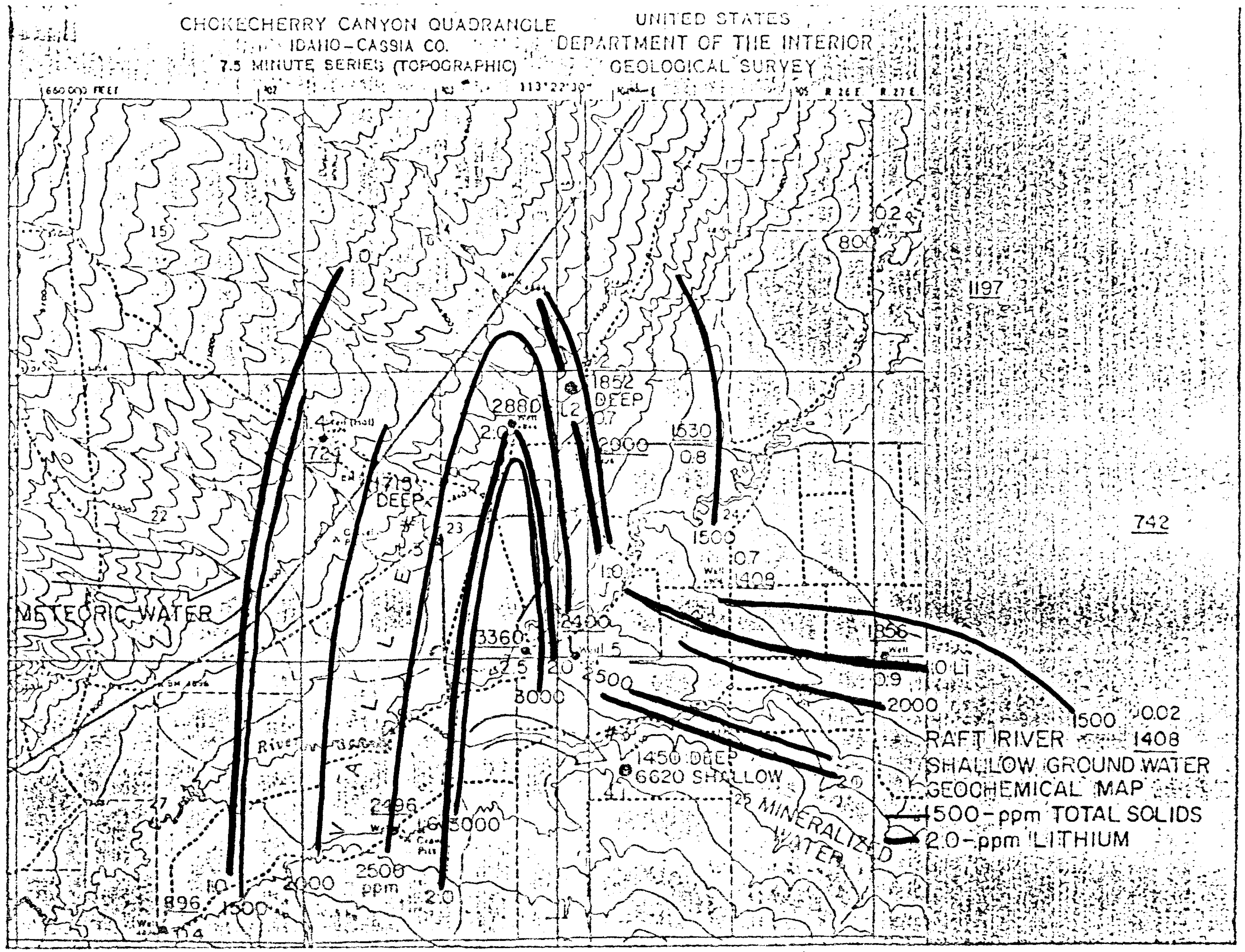


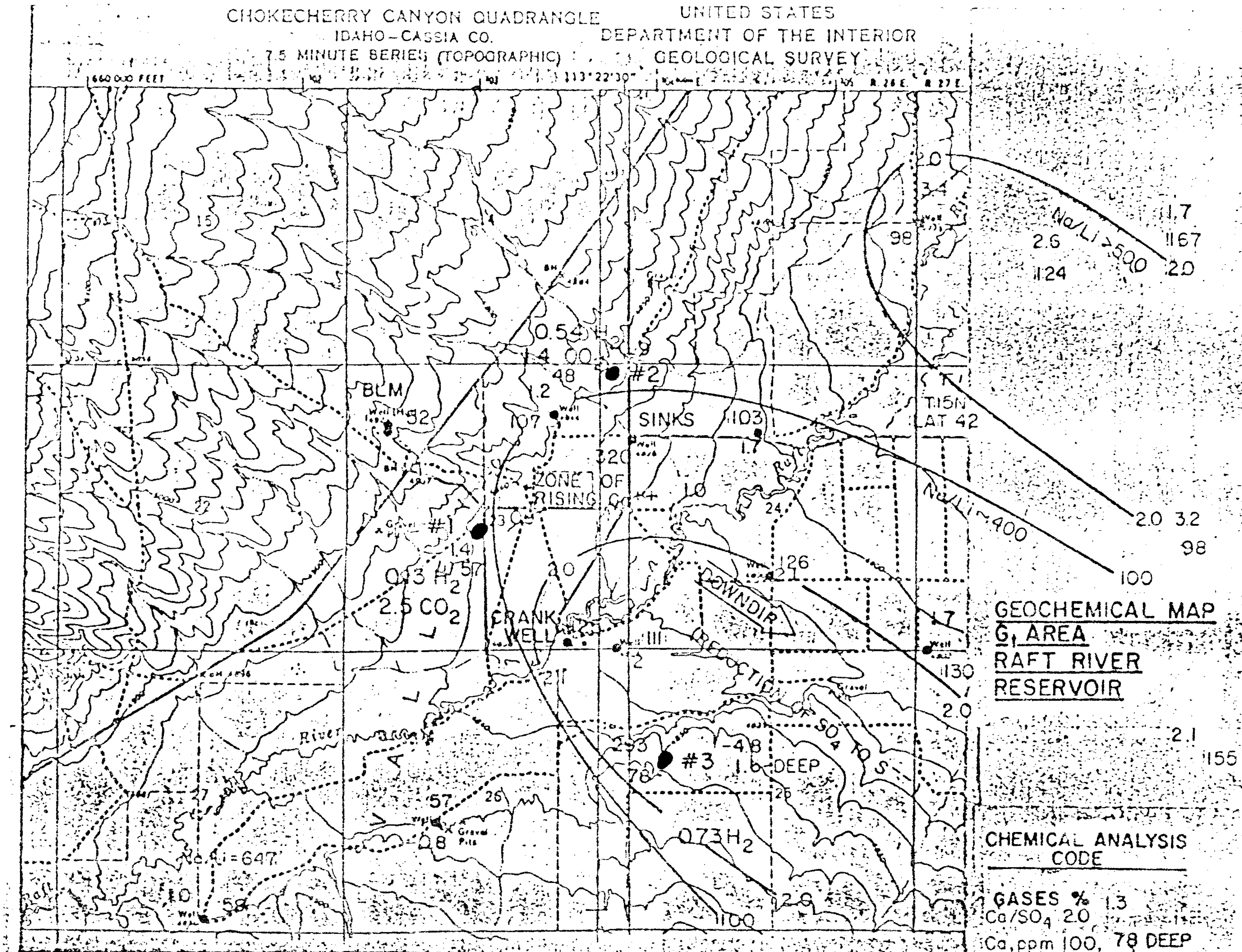
METEORIC WATERS
HYDROTHERMAL ALTERATION
13 3/8 CASING
HOT WATER ZONE
HOT WATER
BASE OF ALTERATION
PROBABLE FRACTURES

INFLUENCE OF COMPACTION & HYDROTHERMAL ALTERATION ON FINE GRAINED ROCK PROPERTIES RRGE NO 3

CASSIA COUNTY, IDAHO




CHOKECHERRY CANYON QUADRANGLE
IDAHO-CASSIA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
METEORIC WATER
MINERALIZED WATER
1852 DEEP
1715 DEEP
1450 DEEP
6620 SHALLOW
2500 ppm
RAFT RIVER
SHALLOW GROUND WATER
GEOCHEMICAL MAP
1500-ppm TOTAL SOLIDS
2.0-ppm LITHIUM

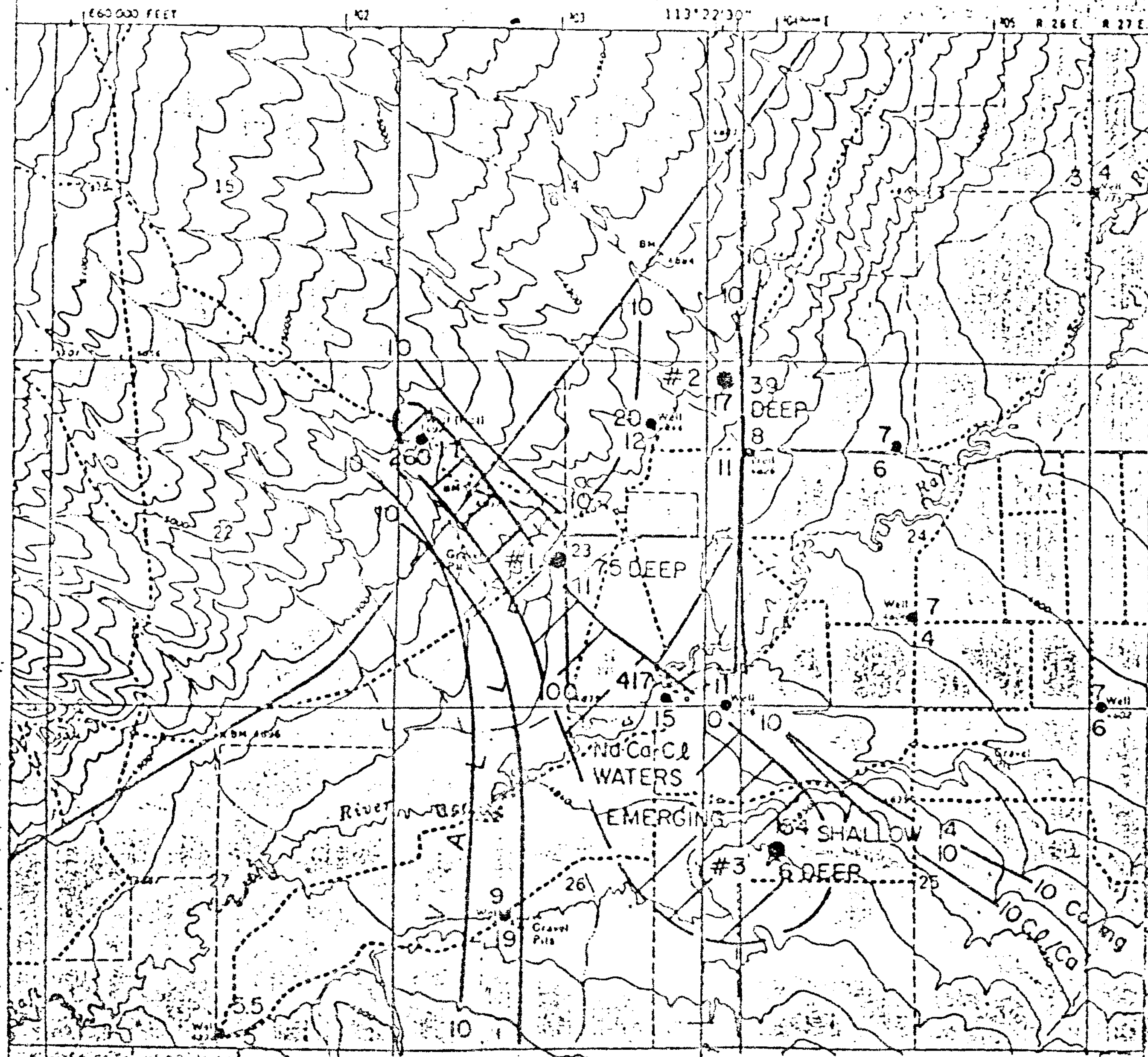


CHOKECHERRY CANYON QUADRANGLE
IDAHO-CASSIA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Na/Li >500
Na/Li ~400
BLM
SINKS
ZONE OF RISING
#1
#2
#3
CRANK WELL
DOWNDIR
DIRECTION OF SO_4 TO S
DEEP
0.54 H_2
0.3 H_2
2.5 CO_2
0.73 H_2
Na/Li=647
T15N
GEOCHEMICAL MAP
G, AREA
RAFT RIVER
RESERVOIR
CHEMICAL ANALYSIS CODE
GASES % 1.3
Ca/SO_4 2.0
Ca, ppm 100, 78 DEEP

FIG 2.

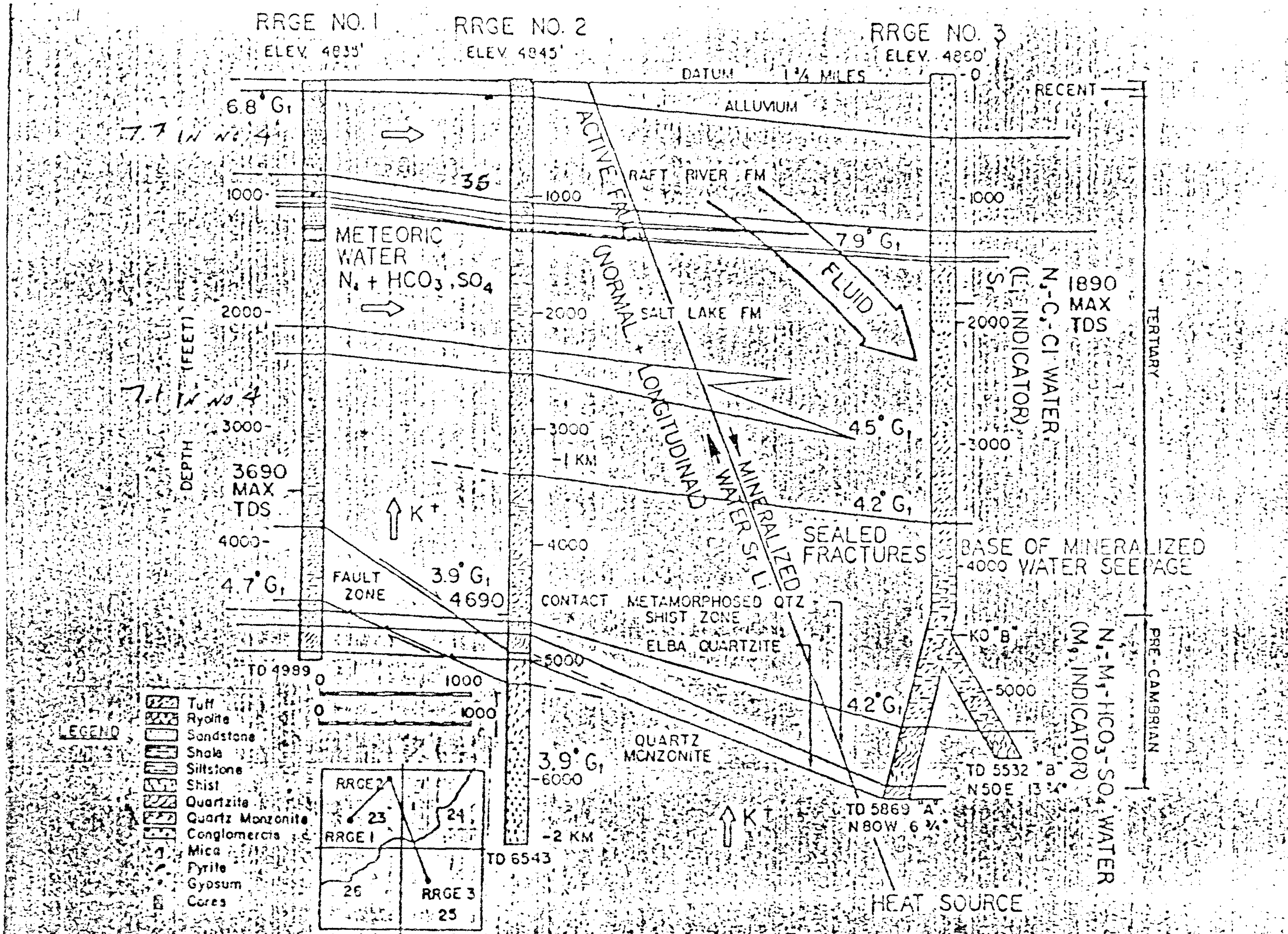
CHOKECHERRY CANYON QUADRANGLE
IDAHO-CASSIA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



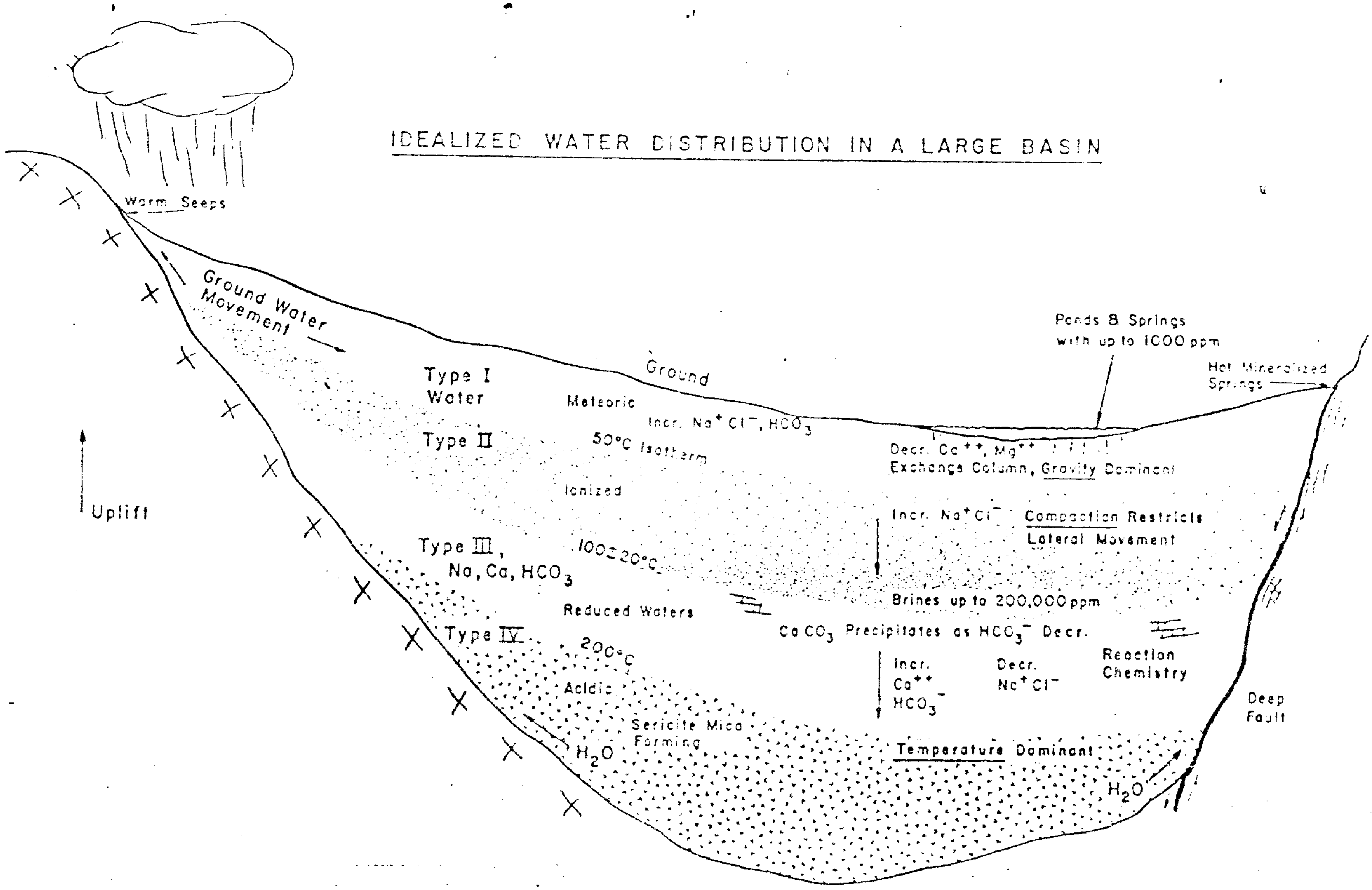
RAFT RIVER
GROUNDWATER MAP-
IONIC COMPOSITION
10-Cl/Ca RATIO
100-Ca/Mg RATIO

Fig 3



GEOCHEMICALLY-ORIENTED CROSS SECTION OF RAFT RIVER RESERVOIR

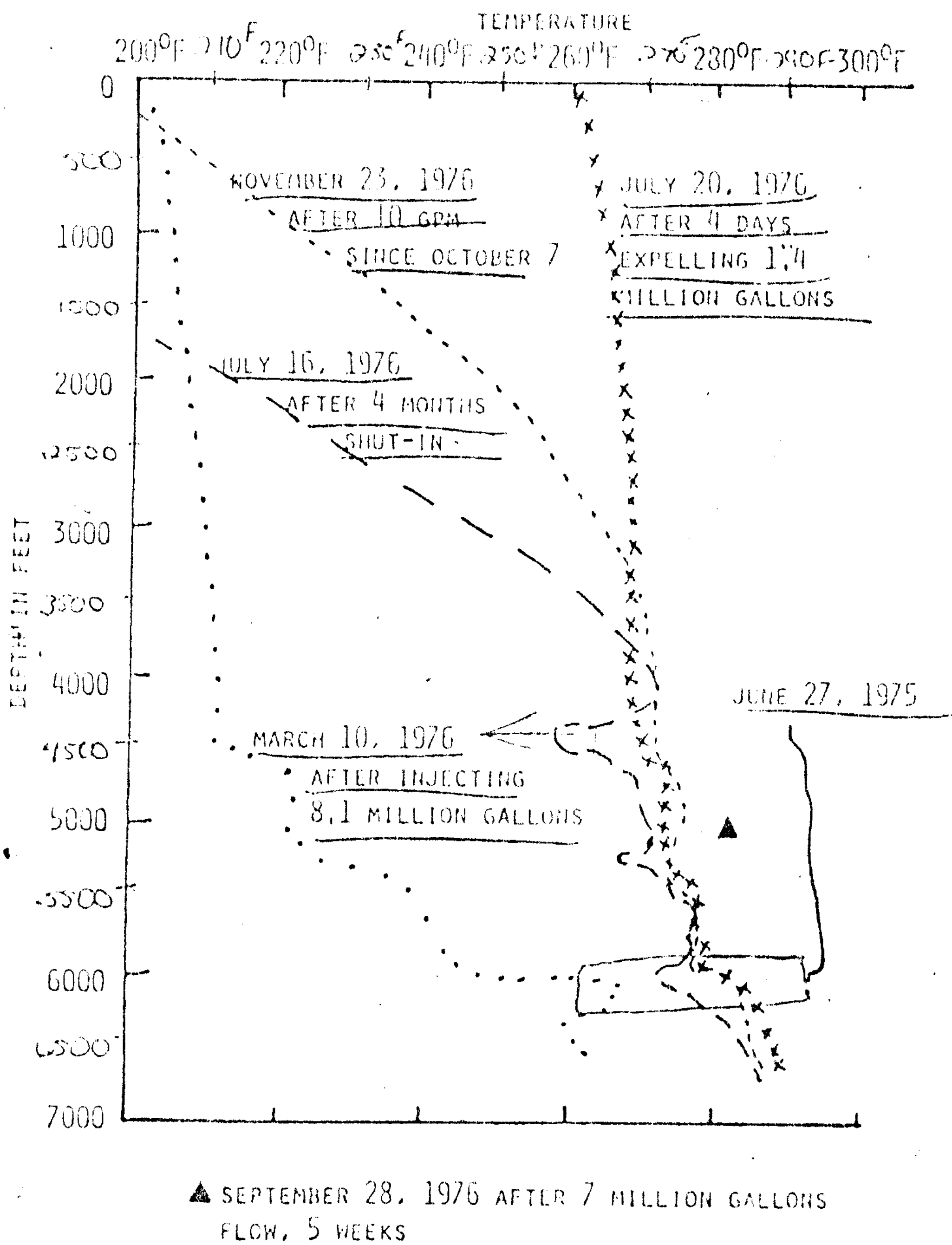
Fig 4



IDEALIZED WATER DISTRIBUTION IN A LARGE BASIN
Warm Seeps
Ground Water Movement
Uplift
Type I Water
Meteoric
Ground
Incr. Na^+ Cl^-, HCO_3
Ponds & Springs with up to 1000 ppm
Hot Mineralized Springs
Type II
50°C Isotherm
Decr. Ca^{++}, Mg^{++}
Exchange Column, Gravity Dominant
Ionized
Incr. Na^+ Cl^-
Compaction Restricts Lateral Movement
Type III, Na, Ca, HCO_3
100±20°C
Brines up to 200,000 ppm
Reduced Waters
$CaCO_3$ Precipitates as HCO_3^- Decr.
Type IV
200°C
Incr. Ca^{++} HCO_3^-
Decr. Na^+ Cl^-
Reaction Chemistry
Acidic
Sericite Mica Forming
H_2O
Temperature Dominant
H_2O
Deep Fault

Fig 5

RRGE #2 RECOVERY AFTER REINJECTION



Flow history of RRGE-2 since conclusion of the re-injection experiments in March 1976

RAFT RIVER WELLS PRODUCTION ZONES

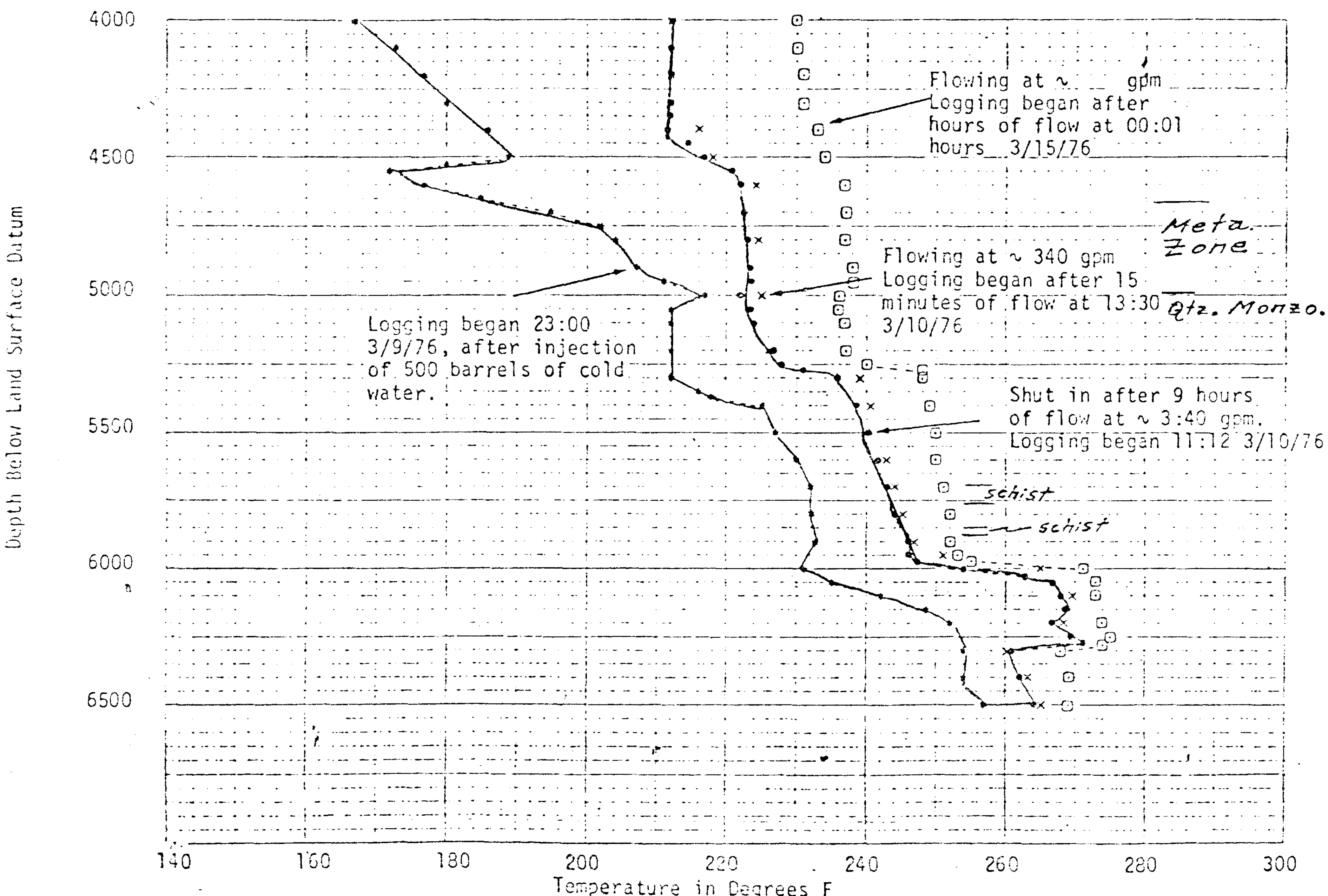
	MINOR	MAJOR	TOTAL EFFECTIVE (100% MAJOR; 25% MINOR)
RRGE-1	3,800 - 4,250	4,250 - 4,650	APPROXIMATELY 550
RRGE-2	4,650 - 4,800	4,300 - 4,575	
	4,850 - 5,000	5,175 - 5,300	APPROXIMATELY 650
	5,300 - 5,500	5,930 - 6,100	
RRGE-3	4,400 - 4,600	4,650 - 4,850	
	4,850 - 5,100	5,400 - 5,500	APPROXIMATELY 425

WELL	ROCK TYPE	SAMPLE DEPTH	WET BULK DENSITY (GM/CC)	DRY BULK DENSITY (GM/CC)	GRAIN DENSITY (GM/CC)	TOTAL POLOSITY (%)	EFF WATER POROSITY (%)	PERMEABILITY (MILLIDA
RRGE-1	Grn Tuff Siltstone	4500.5'(prod)	--	1.88	2.62	28.8	28.8	5.00
	Dk Gray Mica Slts	4518.0'	--	2.20	2.67	7.6	14.3	
	Phyllite	4687.0'	--	2,73	2.79	2.2	0.8	
RRGE-2	Gray Siltstone	3728.4'	--	2.16	2.66	18.8	13.2	
	Gray Siltstone	4223.8'	--	2.07	2,66	22.2	15.0	
	Gray Siltstone	4227.0'(cased)	2.29	2.20	2.72	19.3	17.4	0.040
	Cal Tuff Siltstone	4373.0'(prod)	--	2.28	2.67	14,5	13.6	
	Quartz Monzonite	6500.0'	--	2.57	2,64	2,7	0.8	
RRGE-3A	Grn Sand-stone-Slts	(L) 3365.0'(cased)	--	1,74	2.60	33,1	11.3	0.040
	Grn Tuff Siltstone	(U) 3365.0'(cased)	--	1.53	2,48	38.3	34.7	3.400
RRGE-3C	Gry Silty Shale (fractured)	4994.0'(prod)	--	2,31	2,70	14.4	9.1	0.001
	Gry Slst (fractured)	5273.0'(prod)	--	1.97	2,66	25.9	23.0	0.044
	Quart w/ Schist lam	5550.5'	--	2.64	2.70	2.2	1.2	

CORED SAMPLE PHYSICAL PROPERTIES

RAFT RIVER GEOTHERMAL EXPLORATION WELL NO. 2

Temperature vs Depth



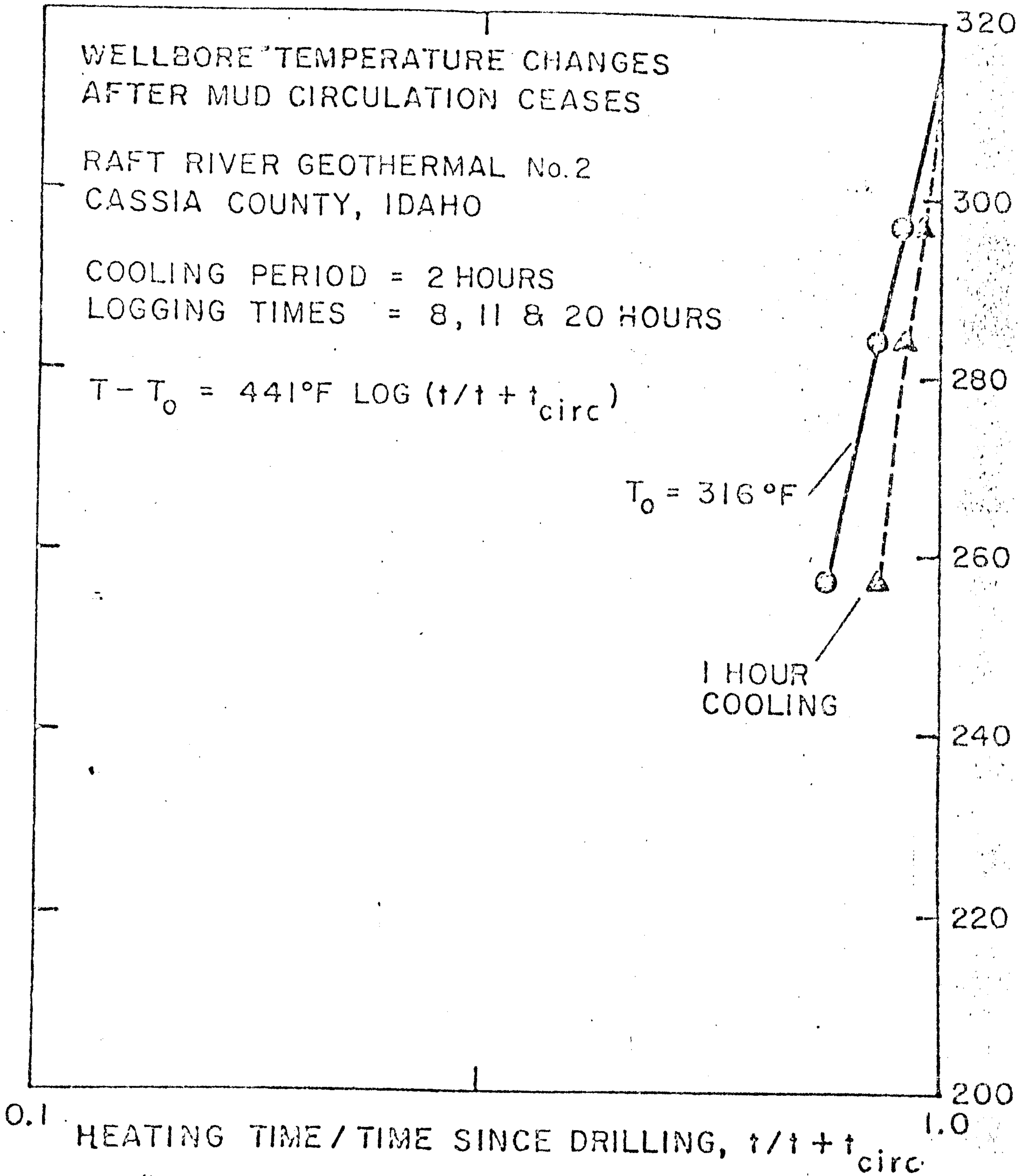

WELLBORE TEMPERATURE CHANGES
AFTER MUD CIRCULATION CEASES
RAFT RIVER GEOTHERMAL No. 2
CASSIA COUNTY, IDAHO
COOLING PERIOD = 2 HOURS
LOGGING TIMES = 8, 11 & 20 HOURS
T − T0 = 441°F LOG (t/t + tcirc)
T0 = 316 °F
1 HOUR
COOLING
320
300
280
260
240
220
200
0.1
1.0
HEATING TIME / TIME SINCE DRILLING, t/t + tcirc

Fig 6