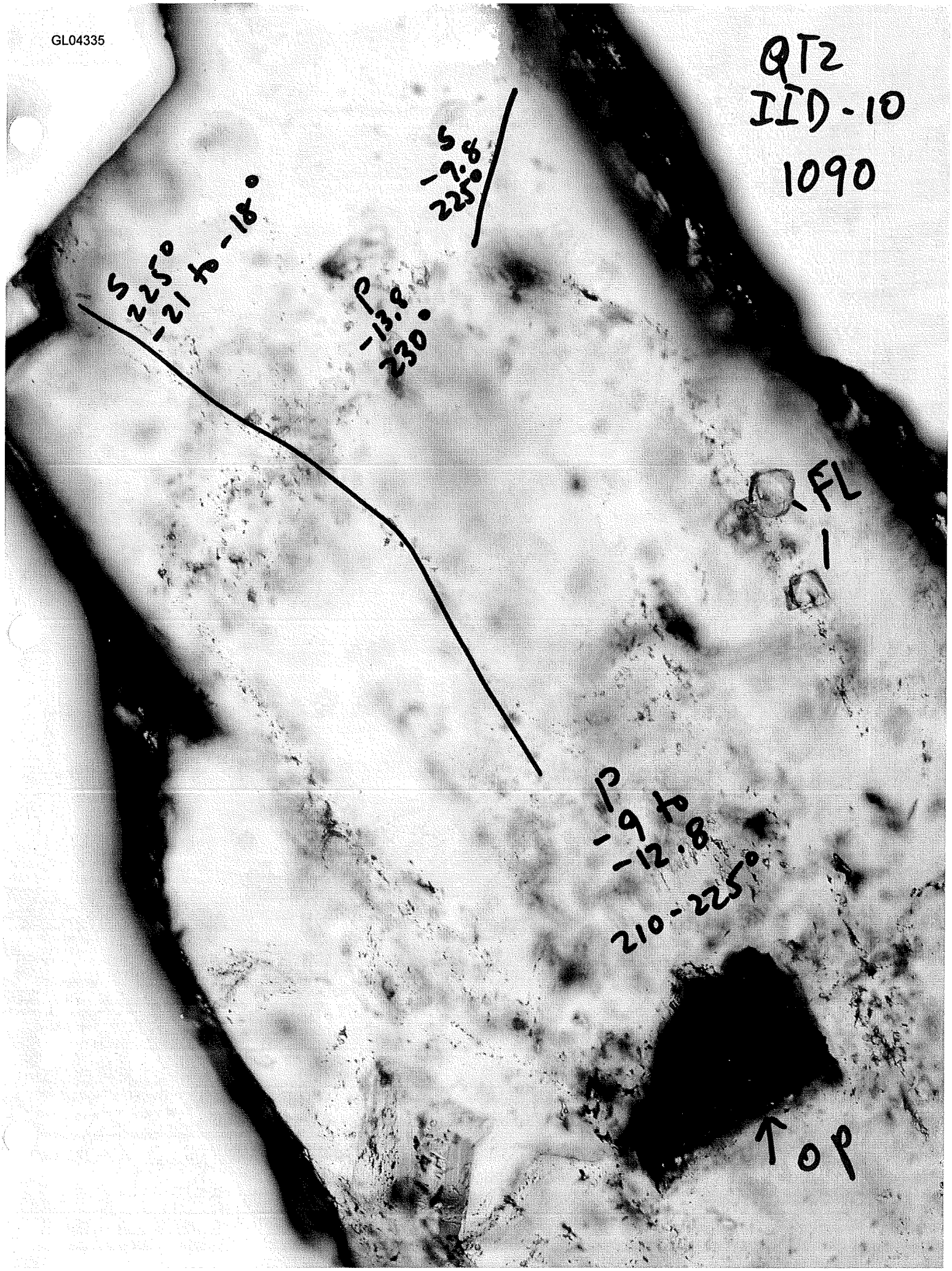
SSGF Sphalerite

GL04335


QT2
IID-10
1090
S
-7.8
225°
S
225°
-21 to -18°
P
-13.8
230°
FL
1
P
-9 to
-12.8
210-225°
↑ op

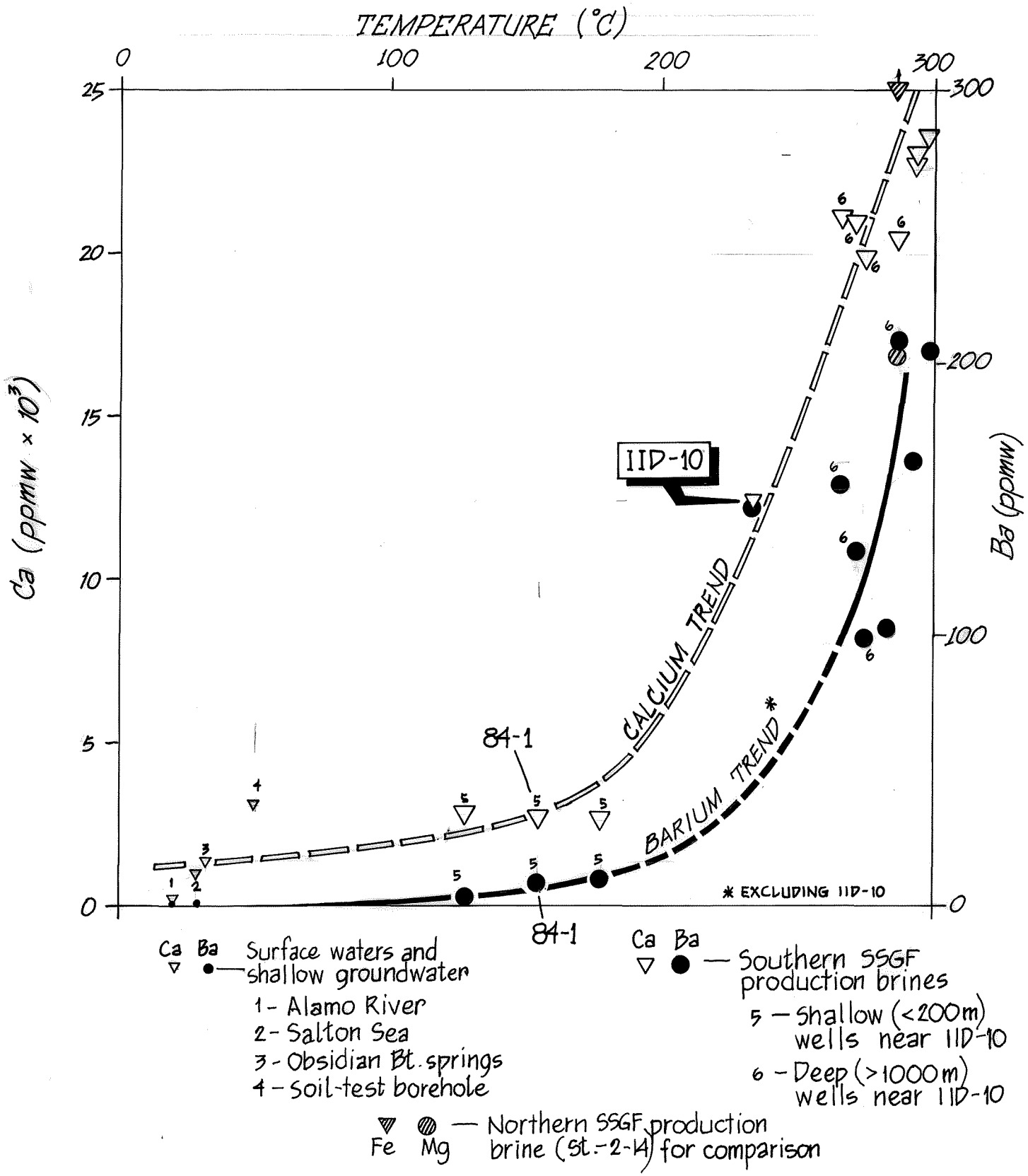
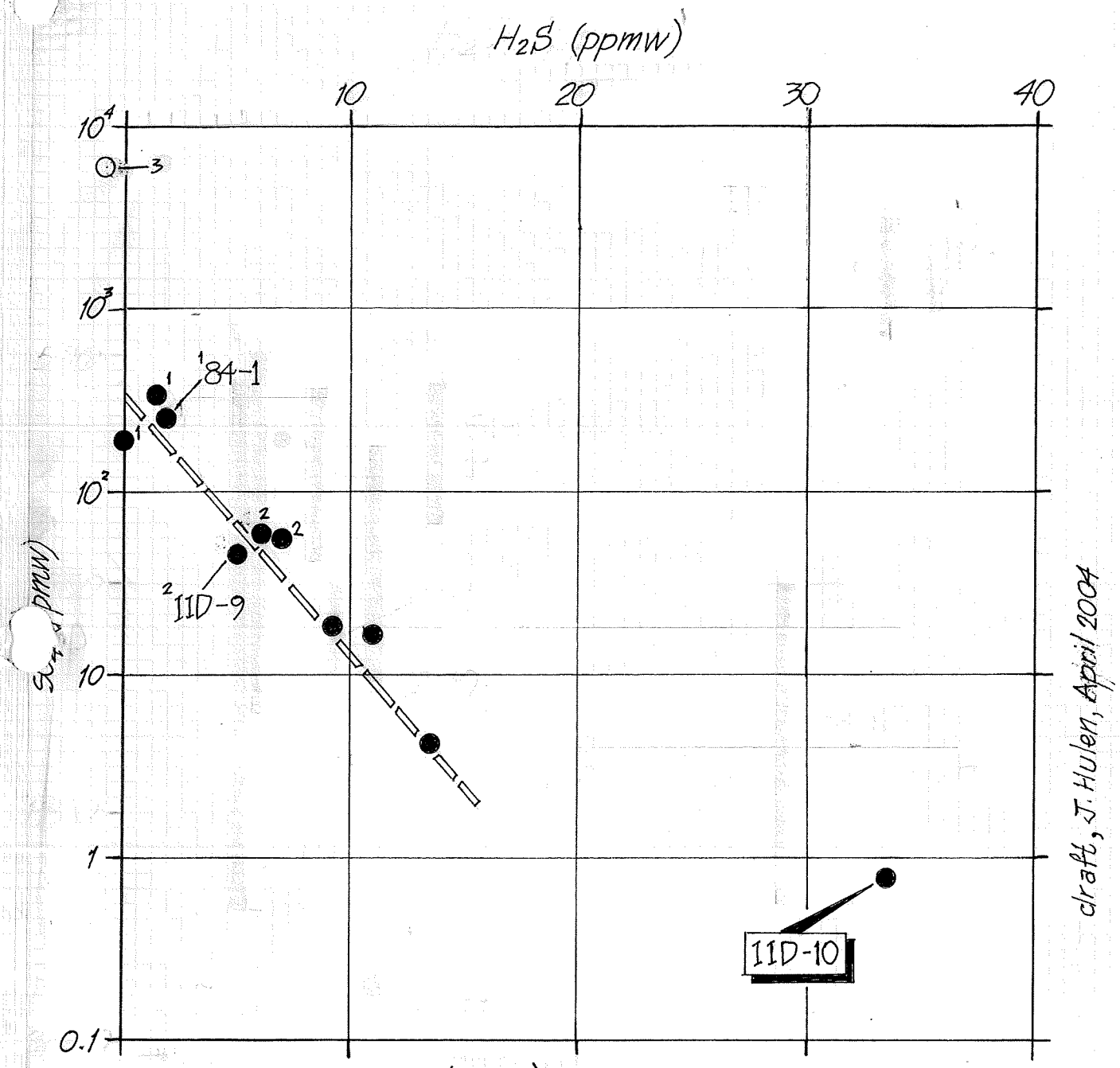


Figure 6. Plot of temperature vs. calcium and barium for waters and brines of the southern Salton Sea geothermal field and vicininity.

JBH04206

molal = moles per kg of solvent

Grade	DEPOSIT or DEPOSIT TYPE	STRUCTURAL SETTING	SIZE & GEOMETRY	VERTICAL RANGE of MINRLZN	HOST ROCKS	TEMP. of MINRLZN.	SALINITY	FLUID SOURCE & evidence	SULFIDE SULFUR SOURCE & evidence	LEAD SOURCE & evidence	ALTERATION	VEIN or "ORE" M	GANGUE
	Pb-Zn-Cu-Fe (Salton Sea, general (sparse minrlzn., not really a deposit)		"curvi-tabular" ≥50 km³	~1000 m	lacustrine, fluvial, deltaic mds—ss.			Meteoric (Colo. R.) (δ)	altn. of sed. sulfate	basin-fill seds. (wall rocks)	calc-silicate qtz-adularia albite-chl.-ser.	I GN, SP II CPY	I CAL, II HM
m: 3-12% sp 0.5-1% gn	MD-10 Gn-Sp	"Pull-apart basin" strike-slip flts. w/ dilational jogs normal faults gentle folding	steeply-dipping tabular veins subhorizontal stratabound (in ss.)	~100 m (300-400 m present depth	"	(170-230°C) (sp) (170-260°C) (all vn. minrls.	14.5-20 wt.%	meteoric (δ)			Calcite dissolution Adularization Silicification CHL & CH/SM	SP δ GN δ	BA δ, AN δ, QTZ δ, CH/SM, CH [hm] δ ≡ undersaturated
	Silver/base metal (Creede, Colqui, Peru)	"structurally complex volcanic environments"	2-3 km L	Creede 250-400 m (Prob. formed at 300-600 m depth	Silicic to intermediate-comp. volcanics	200-300°C Creede 190-285°C (most sp @ 240-260°C	5-12 wt% Creede (4-12)	(δ) meteoric — $\delta^{34}S \cong 0‰$ 0.02 molal H_2S	leaching of wall rocks	wall rocks	silicification "near vein" sericite around silica ± kf, chl. the above package encased in propylic alteration sericitic "cap"	SP, GN, sulfosalts, CPY, I SP δ GN δ	AD, CHL, QTZ, PY BA δ, FL δ, RC δ ↳ 10-20% of amethyst-vein ores
	McArthur Zn-Pb-Ag	"Broad basinal folds" to tight folds		exhalite		no fluid inclusions (almost colloidal sulfides)	← see					SP, GN, cpy	PY, only a trace of barite
	MVT-type deposits					50-225°C (avg. 120°C) 2	15-30 wt.%	connate oil-field brines (petroleum common, free & fluid-incl.) brines react w/ silicates upon warming and become acid (pH 4-5) ↓ dissolve carbonate rocks				SP > GN (>5:1)	



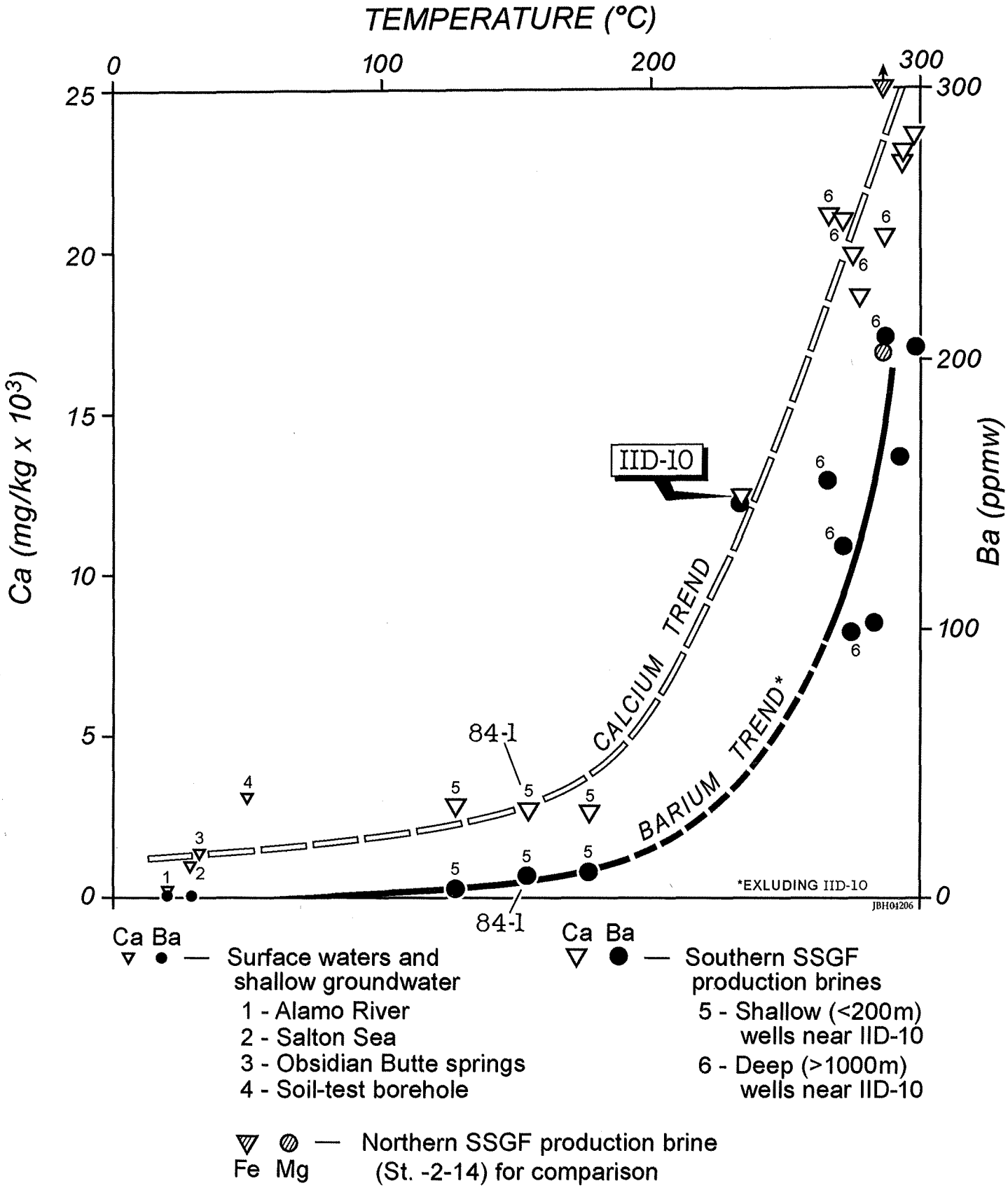
1 – Shallow (<200 m) wells near 11D-10

2 – Deep (>1000 m) wells near 11D-10

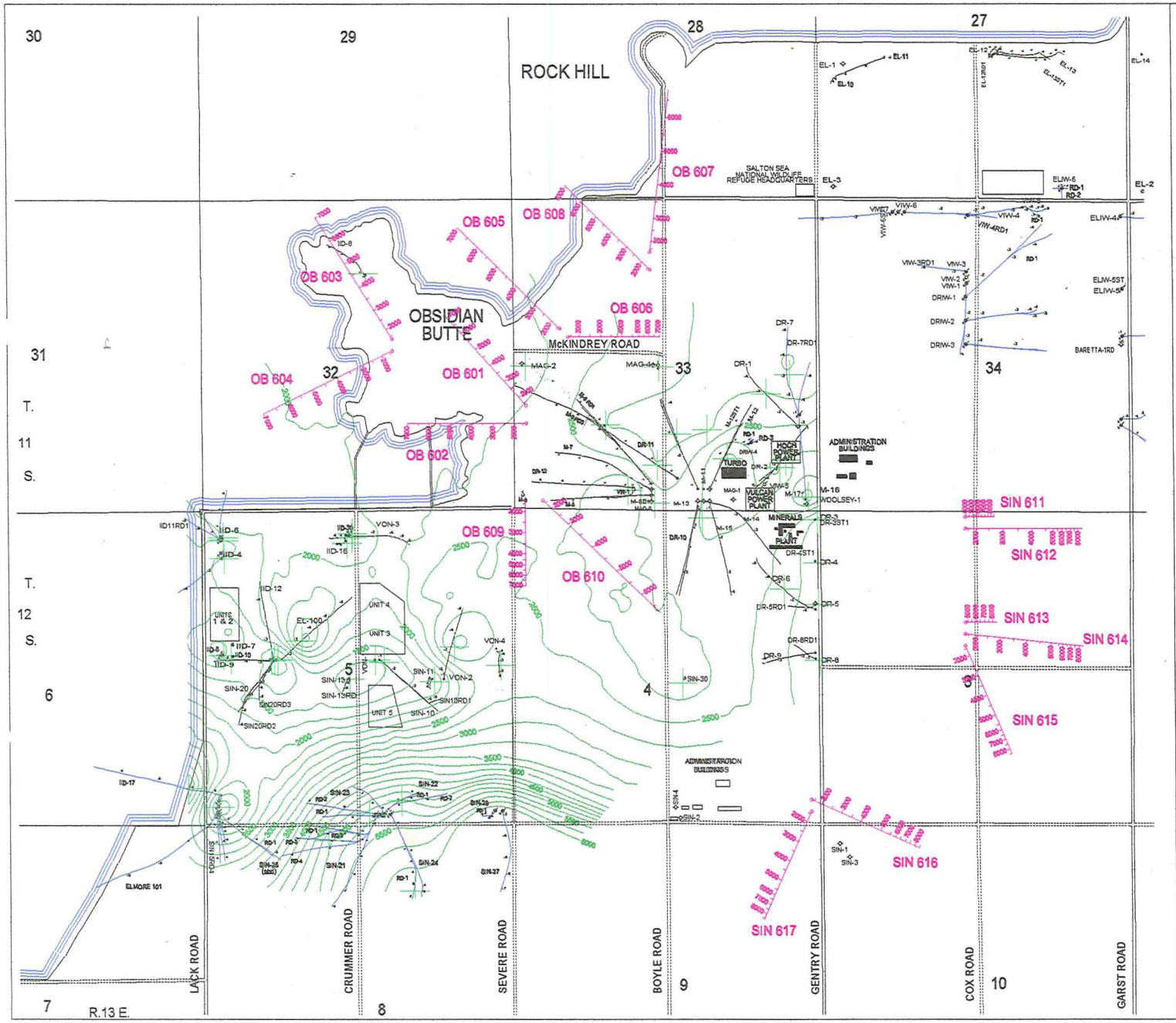
3 – Salton Sea, Obsidian Butte springs, ~~15-m water well~~ (sulfate only; no H_2S analyses), for comparison

Figure 7. Plot of H_2S vs. SO_4 for production brines of the southern Salton Sea geothermal field

JBH 04207



G5 ai.10 502304 JBH04206



SALTON SEA GEOTHERMAL AREA

N

UNIT 6 WELL COURSE DEPTHS IN TVD

First Trace Epidote

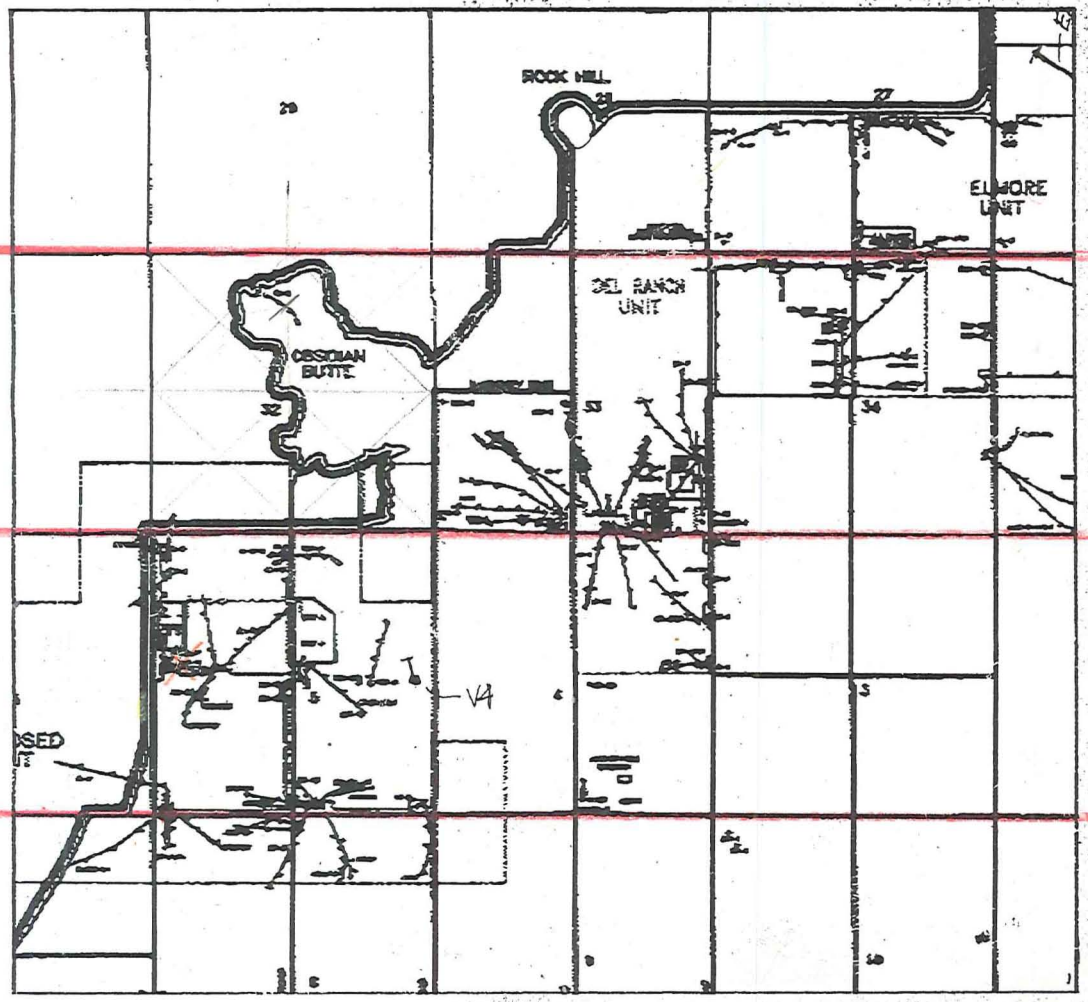
Haenggi/Pulka Data Set

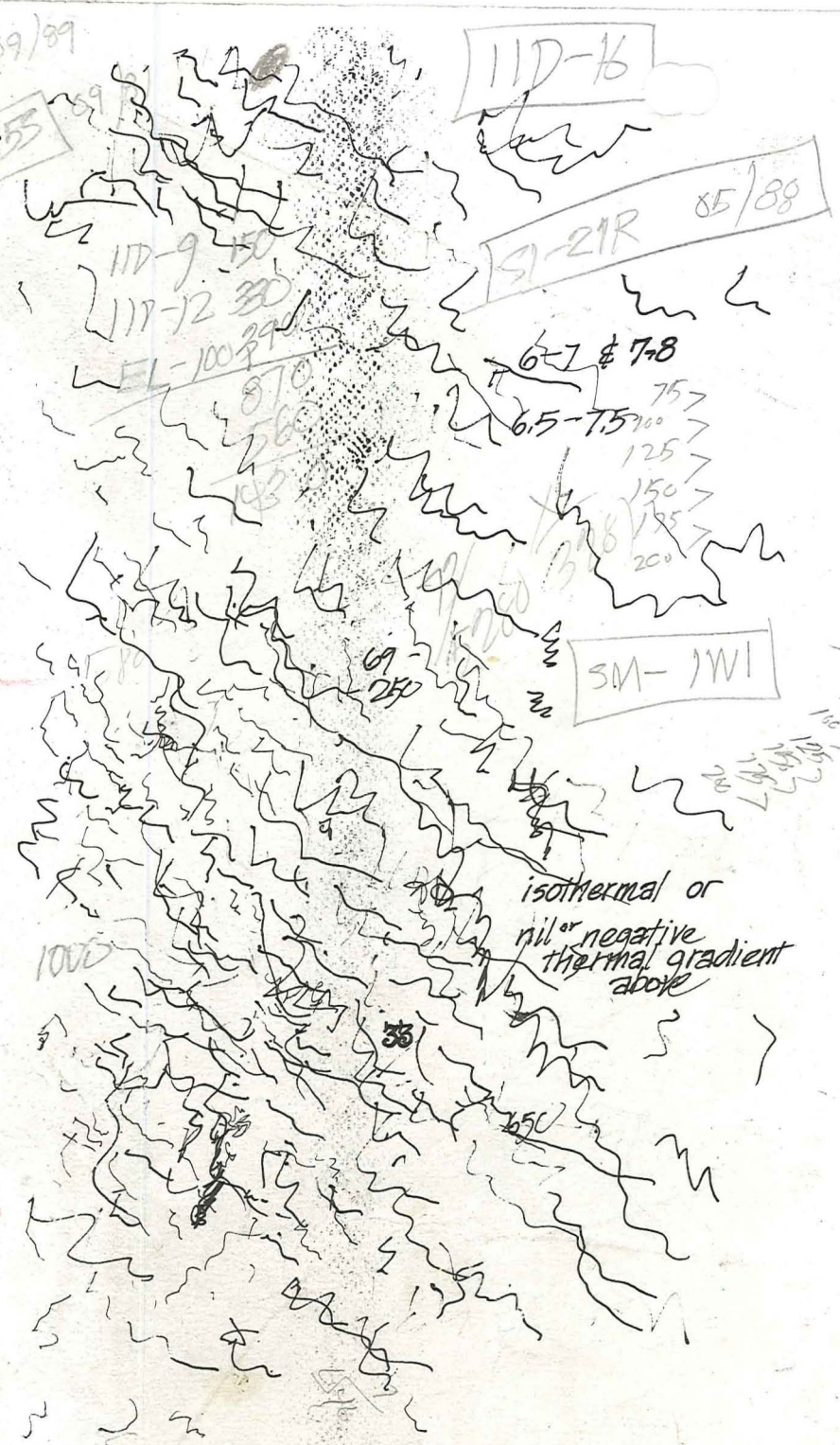
FP 7/12/02

Gthx-Bse.dc

Data Points

A-1v


ROCK HILL
ELMORE UNIT
DEL RANCH UNIT
OBSIDIAN BUTTE
29
28
27
26
32
33
34
5
4
3
2
1
10
11
12
ASED

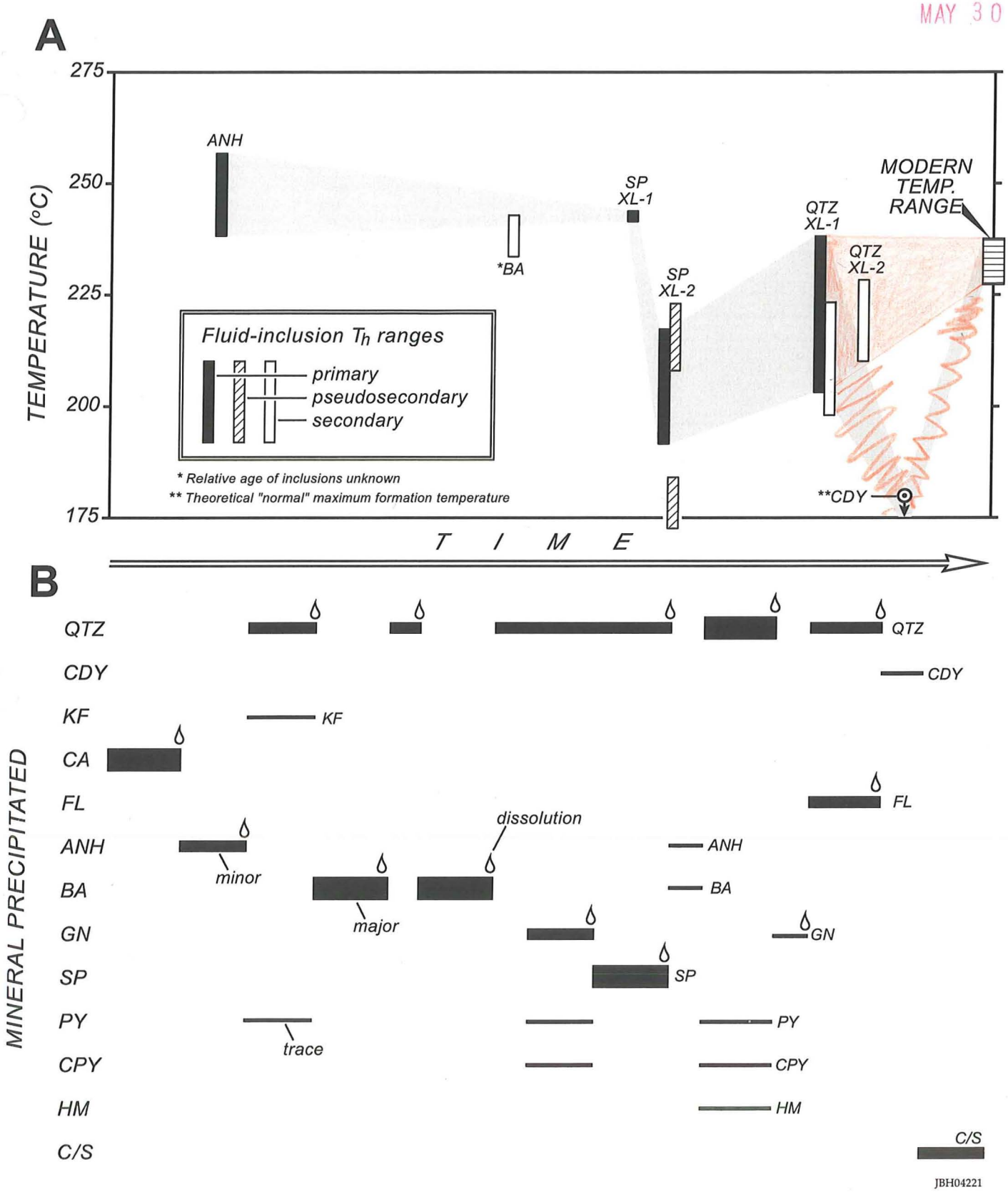

IID-16
SI-21R 05/88
IID-9 150
IIT-12 330
EL-100 390
870
6-7 & 7-8
6.5-7.5
75
100
125
150
175
200
SM-1W1
69
250
1000
33
650
isothermal or
nil or negative
thermal gradient
above

AQUEOUS SPECIES	CONCENTRATION (ppmw) IN BRINE FROM:						
	The Salton Sea (n=2)	Soil-test borehole (n=1)	Well [1] 84-1 (n=6)	Well [1] IID-10 (n=2)	Well [1] IID-9 (n=4)	Well [1] IID-5 (n=3)	Well [1,2] St.-2-14 (n=1)
Ag	< 0.2	—	—	< 0.6	0.2	< 0.2	—
As	< 0.1	< 0.1	< 0.1	6.3	8.6	5.7	—
B	8.6	6.3	49.9	165	277	295	257
Ba	0.1	—	7.4	146	130	215	202
Br	8	—	53.8	58.8	65.8	95.2	—
Ca	904	3,040	2,676	12,359	20,857	20,347	27,048
Cl	15,050	28,900	67,429	83,779	122,816	119,690	153,410
CO_2	211	1,330	3,120	6,517	676	1,479	1,945
Cu	< 0.1	—	—	< 0.8	5.3	1.5	—
F	1.8	—	1.5	3.8	8.3	0.8	—
Fe	0.1	0.3	9.3	83	574	519	1,548
H_2S	—	—	2	33.6	5.1	8.6	11.3
I	—	—	—	4	12.1	6	—
K	198	99	702	6,428	11,253	12,207	16,736
Li	3.2	—	15.7	89	154	156	193
Mg	1,242	3,210	268	51.9	81.2	44.3	37
Mn	0.1	—	—	342	683	766	1,397
Na	10,910	10,400	40,904	39,951	51,014	50,777	52,843
NH_4	—	—	163	281	343	334	325
Pb	< 0.1	—	< 0.4	6.7	61.5	71.5	98
SO_4	8,473	2,700	240	< 0.1	47.5	—	—
SiO_2	11	28	61	294	459	418	380
Sr	17.2	—	76.7	217	356	360	409
Zn	< 0.1	—	(n=2) 0.3	117	245	267	514
Σspecies	37,038	49,914	115,781	143,933	210,190	207,884	257,353
Rptd. TDS	38,331	54,600	123,982	137,366	221,001	215,575	255,396
OTHER DATA: [3] pH	8.5	7.3	—	—	6.0	6.0	5.5
OTHER DATA: [4] $\delta^{18}O$	−1.0	− 7.9	−1.8	(n=3) +0.4	—	+1.1	+ 0.7
OTHER DATA: [4] δD	− 38.0	− 87.5	−51.7	(n=3) −66.8	—	−76.3	−77.4
OTHER DATA: [5] Temp.	28°C	~50°C	154°C	237°C	271°C	287°C	286°C
OTHER DATA: Depth	Near-surface	15 m	[6] 84 m	[6] 332 m	[6] 1,137 m	[6] 765 m	[6] 1,871 m

1. Flash-corrected 2. Northern SSGF, for comparison 3. At wellhead 4. ‰ (SMOW) 5. Static, in reservoir 6. Mid-point of production interval

Table 2. Chemical compositions of selected waters and brines from the southern Salton Sea geothermal field.

JEFF
MAY 30 2004
130P



STRAY THOUGHTS

If "gas cap" provides H_2S for ZnS, then the Imperial CO_2 field should be a good place to find ZnS (SP) mineralization.

ELEMENT or COMPOUND in RESERVOIR BRINE, avg. ppmW(n)

WELL	Mg	Zn	Pb	Cu	Fe	SO_4	Ba
04-1 (81-87 m) [184°C]	268	0.3 (2)	<0.1 (2)	ND	7 (8)	242.4 (8) (0.005)	17 (8)
85-1 93-99 m ~~75~~ (128°C)	511	1.0 (2)	<0.5 (2)	2.5 (2)	14.9 (2)	320.5 (2) (0.002)	4 (2)
85-2 92-98 m (176°C)	197.4	~~bdl~~ ~~~1.0?~~ ~~(17)~~ → 1.5 (17)	~1.0? (17)	2.7 (3)	5.4 (18)	176.9 (18) (0.005)	8.2 (17)
11D-5 D-5	44.3	267 (3)	72 (3)	1.5 (3)	519	ND	216 (3)
SIN-13	67.6	257 (7)	48 (7)	1.7 (7)	323 (7)	4.0 (4) (3.1)	97 (7)
YON-1 683-1196	31.3	310 (7)	75 (7)	2.5 (7)	876 (7)	17.4 (7) (0.54)	204 (7)
SIN-15	45.2	299 (5)	63 (5)	0.9 (5)	911 (5)	ND	162 (5)

11D-5

WELL	% FLASH	$\delta^{18}O$ sep brine	$\delta^{18}O$ stm	δD sep brine	δD stm	$\delta^{18}O$ ~~sep~~ res brine	δD res. brine
[illegible]-1	1.8 (98.2)	-1.77	-5.35	-51.5	-61.5	-1.83	-51.68
84-2	0 (100)					-1.75	-64.20
~~85-1~~ 85-2	~~1.42 (95.58)~~	~~-1.89~~ ~~-0.42~~	~~-3.57~~	~~-48.7~~			
~~85-2~~	4.42 (95.58)	-0.21	-3.37	(-49.56)	(-53.84)	-0.35	-49.74
11D-5	9.3 (90.7)	+1.27	~~-0.61~~ -0.61	-77	-69	+1.09	-76.3
11D-10	17.4 (82.6)	+0.68	-1.52	-68.9	-62.1	+0.30	-67.7
~~11D-8~~ 11D-12	10.9 (89.1)	+1.13	-0.81	-76.5	-64.7	+0.93	-75.2
51-15	9.7 (90.3)	+1.75	-0.13	-76	-69.2	+1.57	-75.3
51-20	7.2 (92.8)	+1.30	-0.65	-74	-62.8	+1.16	-73.2
11D-9	(8.1)	(91.9)					
Salton Sea						-5.4	-61.8
~~11D-12~~ SIN-13	16.0 (84.0)	+1.19	-0.61	-76.7	-69	+0.90	-75.5
~~[illegible]~~							
VON-1	8.1 (91.9)	+1.97	+0.~~177~~ 18	-77.7	-64.4	+1.82	-76.6
St. 2-4	21.0 (79.0)	+0.81	+0.39	-79.4	-69.6	+0.72	-77.4

WELL	PROD. INTERVAL (m) & T RANGE (°C)	AVG. RESERV. BRINE TDS (wt%) (n)	TOTAL GAS IN BRINE ppmw (n) whole gas	TOTAL GAS IN BRINE ppmw (n) Σ gases	COMPONENT GASES IN BRINE, ppmw (n) CO_2	H_2S	NH_3	Ar	N_2	CH_4	H_2	molar N_2/Ar
84-1	81-87 m (154°C)	~~11.79~~ 12.40	~~3000~~ 3000 (7)	3191 (7)	2988 (7)	1.86 (7) (0.06%)	189 (7)	ND	2.0 (1)	9.69 (7)	0.27 (7)	ND
85-1	93-99 m (128°C)	13.05	500	493	492 (2)	0.06 (2) (0.01%)	ND	ND	0.44 (2)	0.47 (2)	0.05 (2)	ND
85-2	92-98 m (176°C)	12.88 (18)	447 (29)	716 (18)	541 (18)	1.48 (18) (0.02%)	170 (18)	0.039 (12)	2.11 (12)	1.27 (12)	0.10 (17)	77 12
TD-5	574-955 m (243-~~297~~ 287°C)	21.56 (3)	1560 (3)	1880 (1)	1499 (1)	8.6 (1) (0.46%)	360 (1)	ND	5.7 (1)	6.71 (1)	0.09 (1)	ND
SIN-13	569-868 m (252-274°C)	19.24 (7)	6406 (8)	6412	6005 (7) ~~7893 (5)~~	13.7 (7) (0.21%)	353 (7)	2.465 (2)	13.5 (2)	23.38 (4)	0.45 (4)	bad anal.? 7.8
VON-1	~~683-1196 m~~ 989-1196 m (298°C)	22.58 (7)	1530 (7)	2029	1650 (7)	9.4 (7) (0.46%)	364 (7)	0.014 (6)	2.09 (6)	~~3.16 (5)~~ 3.68 (6)	0.06 (6)	213
SIN-15	1000-1838 m (267-293°C)	23.14 (5)	3108 (5)	3467	3038 (5)	29.1 (5) (0.84%)	367 (5)	2.37 (5)	12.01 ~~(5)~~ (4)	18.1 (4)	0.76 (4)	7.2 bad anal.(?)

gas analyses considered "questionable"

(ppmw) in water or brine)

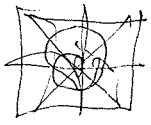
		Zn	Pb	Cu	Fe	SO_4	Ba
Alamo River		0.02	0.01	0.01	0.05	960	0.12
Salton Sea		0.03 (1)	<0.1	0.08 (1)	0.1 (2)	8299 (2)	0.07 (1)
Unit 3 soil borehole	(depth 50 ft) (15.2 m)	NN	ND	ND	0.3 (1)	2700 (1)	ND
Obsidian Butte springs		<0.3	<0.5	<0.1	1.1 (2)	6253 (3)	<1.3 (3)
shallow rehole near SIN-2	(depth 2 ~~215~~ 5') (65.5 m)	ND	ND	ND	0.3	107	ND
IID-9 grout hole	(139 m)	ND	ND	ND	170	1000	ND

SURFACE WATERS	PRODUCTION INTERVAL (m) & TEMP RANGE (°C)	AVG. BRINE TDS (wt%)(n)	TOTAL GAS in SOL (ppm/vol)	INDIVID. GASES IN BRINE ppm/vol (n)							molar N_2/Ar
				CO_2	H_2S	NH_3	Ar	N_2	CH_4	H_2	
Alamo River	20°C	0.3 (1)	205?	205 (1) "(ΣCO_2)"	—	—	ND	—	—	—	ND
Salton Sea	20°C	3.75 (2)	207?	207 (2) "(ΣCO_2)"	—	—	ND	—	—	—	ND
Unit 3 soil borehole	~~31.5°C~~ 27°C	5.46 (1)	1330?	1330 (1) "(ΣCO_2)"	—	—	ND	—	—	—	ND
Obsidian Butte Springs	31.5°C	4.20 (3)	247?	247 (3) (ΣCO_2)	—	—	ND	—	—	—	ND
Shallow borehole near SIN-2	ND	3.68 (1)	ND	—	—	—	ND	—	—	—	ND
IID-9 Grout Hole	ND	? 16.00 (1)	270?	270 (1) "(ΣCO_2)"	—	—	ND	—	—	—	ND
RR-1	2021– ~~2486~~ 2468m. [338–347]	26.8~~6~~ ~~(1)~~ (4)									

ELEMENT IN RESERVOIR BRINE, ppm
or COMP! avg. (n)

	Mg	Zn	Ba	Pb	Fe	Cu	Fe	SO4	H2S/gpm	Ba
IN-20 266°C 21,052	80.6	245 (21)		59 (21)		4.8 (21	508 (21)	52.7 (21)	0.13	153 (21)
IID-10	51.9	117 (2)	146	67 (2)	83	<0.08 (2)	83 (2)	<0.08 (2)	ND	145 (2)
St. 2-14	37	514 (3)	202	98 (3)	1,548 (4)	2.1 (1)	~~140 (2)~~	NA		~~274 (5)~~ check
~~Magma-11~~		~~321 (1)~~		~~69 (1)~~		NA	~~582 (1)~~	~~120 (1)~~		~~183 (1)~~
Magma-1										
779-852m						ND	170	ND		Bad data (49-762)
570-588m						ND	93	ND		
323-701m		256 (8)		44 (8)		0.9 (8)	188 (9)	ND		
SIN-10 22,594 701-1262 m	35.4	304 (4)		75 (4		2.4 (4)	922 (4)	15 (4)	0.74	204 (4)
Elmore-1		ND		65 (1)		3.2 (1)	~~1422 (3)~~ (1)	ND		ND
IID-9	81.2	245 (3)	130	61 (4)		5.3 (4)	574 (4)	47.8 (4)	0.10	130 (4)
IID-12										
495-1375m	58.4	~~584~~ (3) 261 (3)		62		6.5 (3)	629 (3)	26.1 (3)		100 (3)
495-1321m		257 (10)		58 (10)		2.9 (10)	560 (10)	42.6 (9)		163 (11)
495-1284m		246 (3)		59 (3)		2.6 (3)	536 (3)	41.7 (3)	0.4	168 (3)

MgCl



Mg, ~~Ba~~

WELL	PRODUCTION INTERVAL (m) & temp range	AVG. RESERVOIR BRINE TDS WT% (n)	TOTAL GAS IN BRINE ppmw (μ) whole gas	TOTAL GAS IN BRINE ppmw (μ) Σ of 4	GASES IN BRINE, ppmw (n) CO_2	H_2S	NH_3	Ar	N_2	CH_4	H_2	(molar) N_2/Ar
SIN-20 ✓	671-701m (265-266°C)	21.40 (2)	1414 (17)	1919 (20)	1540 (20)	7.0 (20) (0.36%)	364 (18)	0.079 (14)	2.83 (18)	4.71 (18)	0.074 (18)	67.3
IID-10	201-463m (223-232°C)	13.73 (2)	7000 (2)	6907 (2)	6517 (2)	33.6 (2) (0.49%)	331 (2)	0.075 (2)	9.2 (2)	15.3 (2)	0.48 (2)	172.8
State 2-14	1865-1877m (286°C)	25.47 (5)	2747 (2)	2377	1945 (3)	11.3 (3) (0.48%)	391 (3)	0.497 (3)	24.46 (3)	1.74 (3)	3.36 (3)	72.8
Magma-11	1064m (300°C)	21.32 (1)	ND	ND	1000	ND						
Elmore-100	1320m											
Magma-1	779-802 263-264	15.50 (1) DST	ND	ND	ND							
get T from papers & LLL logs	570-588 (246-249°C)	3.81 (1) DST	ND	ND	ND							
	~~458~~-701 ~~(182-262°C)~~ 227	17.14 (9)	ND	ND	ND							107.5 (2)
SIN-10	701-1262 (278-293°C)	21.98	1360	1841	1426 (5)	11.2 (5) (0.61%)	401 (4)	0.002 (3)	0.836 (3)	1.85 (3)	0.09 (3)	596.9 (3)
Elmore-1	1446-2168 (345-362°C)	19.62 (5) ✓ (2)	4350 (5)	>4168	4168 (4)	Bad Data						
IID-9	559-1715m (520)	22.10 (4)	593 (4)	1051	676 (4)	5.1 (4) (0.48%)	368 (4)	0.009 (1)	0.92 (1) 1.18 (3)	3.88 (4)	0.12 (4)	143 67.1 173 ★
IID-12	495-1375 267-287°C	21.85 (3)	593 (3)	974 (3)	616 (3)	1.72 (2)	354 (3)	ND	1.75 (2)	1.48 (2)	0.09 (2)	ND
	495-1321	20.61 (7)	658 (9)	1110 (9)	697 (9)	5.32 (9)	404 (9)	0.042 (9)	2.68 (9)	0.91 (9)	0.01 (9)	91
	495-1284 267-287°C	20.19 (3)	697	1205 (3)	(857) (3)	5.71 (3) (0.48)	357 (3)	0.018 (3)	1.32 (3)	1.99 (3)	0.03 (3)	104.7

★ from "any gas analysis"

Freckman, 1978 (?)

		δD
ELMORE 1 —	325,000 ppm TDS	NA
SINC. 4 —	266,560 ppm TDS casing ? Temp. ?	466.

$\delta^{18}O = +1.43‰$ $\delta D = ?$

assume ~1100 m. prod. casing

so: 1100 – 1617 m ≡ 252 – 297°C

Moore and Adams, 1988

- HD-9 & HD-11 studied
- 3 mineral zones, each well:
  - I/S zone (0 – 221/241 m)
  - chl/cal ($\frac{221}{241}$ – $\frac{616}{789}$ m)
  - chl-ep-cal ($\frac{616}{789}$ – $\frac{1646}{1292}$ m) TP?
- $\boxed{\text{CH/SM only in well HD-9}}$
- SPHALERITE present
  - paragenesis:
    - ANH – SP
    - BAO – QTZ – GN (& SP? implied?)

(ss matrix) $\frac{AN}{CA}$ O – $\left.\begin{matrix}\frac{KF}{QTZ}\\ SP\end{matrix}\right\}$ – $\left.\begin{matrix}\frac{QTZ}{ba}\\ \frac{hm}{ch}\\ \frac{sp}{gn}\end{matrix}\right\}$

McKibben & Elders, 1985

1. "At depths <500-700 m, ore minerals occur mainly as fgr. diss & cmtng stratiform Fe sulfides

2. Metamorphic mineralization

   200-300°C

   - rex/zn & overgrowth of (diagenetic) pyrite → progressive development of coarse porphyroblasts

   - local "polyphase" porphyroblasts (qtz + calcite) surrounded by rim of sp + qtz + cal surr. by pyrrhotite (po)

   - pyrite porphyroblasts loc. replaced partially by po, cpy, sp

3. vein mineralzn.

   mostly in mds/sltst

   (1) $S^{=}$-$CO_3^{=}$
   - cpy-(sp)-CAL-EP ± kf, py, qtz, (gn)
   - (sp)-cpy-CAL ± gn, kf, (ep)
   - po-(sp)-cal-cpy ± gn
   - (sp)-cpy-cal ± ep, (po)
   - CAL ± sp, cpy, po, (gn)

   (2) HM-silic-$S^{=}$-$SO_4^{=}$
   - HM-EP-ANH ± (py), (cpy), (cal)
   - HM-QTZ-CPY ± py

McKibben et al. (1988) (GRC)

δS data ⟹ H_2S in SSGF brine generated by partial hydrothermal reduction of $SO_4^=$ derived from dissoln of lacustrine ~~CO_3~~ sulfate minerals.

SSGF brines very deficient in S
— availability of reduced sulfur is the major limitation on sulfide deposition.

"Reduction and H_2S generation could be promoted by interaction of reduced, thermally upwelling hypersaline reservoir brines with evaporific in less saline, higher elevation formation fluids."

(para)

AN MECHANISM INVOLVED IN SULFIDE PRECIPITATION IS COOLING AND DILUTION OF H_2S & METAL-BEARING HYPERSALINE BRINE. Process could be enhanced by H_2S production through reduction of $SO_{4(aq)}^=$ in higher-elev. lower-salinity brines.