Table. 2-3-1 Rig Time Distribution on Well AMJ-1

坑井 AMJ-1 の掘削時間分析

Operation	26″ hole	17-1/2″ hole	12-1/4″ hole	8-1/2″ hole	Total
Rig up and Rig-down	61:00	—	—	14:30	75:30
Drill actual	96:45	94:00	105:30	231:45	528:00
Reaming and drill out cement	4:30	8:15	8:00	9:00	29:45
Coring	—	—	—	—	—
Condition mud and circulate	10:30	7:00	11:45	23:15	52:30
Trips	14:30	17:15	18:45	53:15	103:45
Lubricate rig	—	1:15	1:00	1:15	3:30
Repair rig	7:45	0:45	0:30	1:45	10:45
Cut off drilling line	—	—	—	2:00	2:00
Deviation survey	—	1:00	1:30	2:30	5:00
Wire line logs and hydro-fracturing	—	—	25:45	44:00	69:45
Run casing and cement	6:15	18:15	22:00	15:15	61:45
Wait on cement	54:15	44:00	36:00	—	134:15
Nipple up BOP	19:30	9:30	20:30	—	49:30
Test BOP	—	0:15	1:00	0:30	1:45
Drill stem test	—	—	—	—	—
Plug back	6:30	—	—	—	6:30
Squeeze cement	—	—	—	—	—
Fishing	—	—	—	4:30	4:30
Stand by	—	—	17:45	43:30	61:15
Totals	281:30	201:30	270:00	447:00	1200:00

Table 2-3-2 Rig Time distribution on Well AMJ-2

坑井 AMJ-2 の掘削時間分析

Operation	26″ hole	17-1/2″ hole	12-1/4″ hole	8-1/2″ hole	Total
Rig-up and Rig-down	24:00		3:45		27:45
Drill actual	16:00	235:45	152:30	161:00	565:15
Reaming and drill out cement	—	25:45	35:15	18:00	79:00
Coring	—	—	—	—	—
Condition mud and circulation	—	27:00	10:45	7:45	45:30
Trip	4:00	65:00	71:00	58:45	198:45
Lubricate rig	—	1:00	2:00	1:30	4:30
Repair rig	—	41:00	69:45	36:00	146:45
Cut off drilling line	—	—	1:00	—	1:00
Deviation survey	—	1:00	5:45	8:00	14:45
Wire line logs	—	—	5:30	—	5:30
Run casing and cement	4:00	63:45	30:15	20:00	118:00
Wait on cement	24:00	107:00	52:30	—	183:30
Nipple-up BOP	11:00	30:00	10:30	—	51:30
Test BOP	—	—	6:00	0:45	6:45
Drill stem test	—	—	—	—	—
Plug back	—	11:15	—	—	11:15
Squeeze cement	—	—	—	—	—
Fishing	—	143:00	—	60:30	203:30
Stand by	—	82:30	—	6:15	88:45
Total	83:00	834:00	456:30	378:30	1752:00

Table. 2-3-3 Drilling Equipment for Well AMJ-1

坑井 AMJ-1 の掘削設備

Item	Description	
Mast	Make: DRECO, Type: Cantilever, Model: M13621-800	
Substructure	Make: DRECO, Type: Box on Box, Capacity: 500,000lbs	
Crown Blocks	Shieves: 55″ ×1(first line), 42″ ×5	
Hook Blocks	Make: NATIONAL, Model: 545G350, Rating: 350ton	
Drawworks	Make: NATIONAL, Model: 80UE, Drive: GE 752(1000HP)	
Rotary Table	Make: NATIONAL, Model: C-275, Size: 27-1/2″	
Swievel	Make: NATIONAL, Model: P-400, Rating: 400ton	
Pipe Spinner	Make: SPINNER HAWK, Model: J29	
Kelly Bushing	Make: DEN CON, Type: R-H	
Tongs	Make: BLOOM VOSS, Type: 100	
Hydraulic Winch	Make: BRADEN, Model: PD12C, Rating: 6ton	
Wire Line Unit	Home make, Wire Line Size: 9mm	
Mud Pumps	No,1 Pump	Make:NATIONAL, Model:9-P-100, Drive:GE752
	No,2 Pump	Make:NATIONAL, Model:9-P-100, Drive:GE752
Shaker	Make: BRANT, Type: Tandem	
Desander	Make: SWACO, Model: 30839	
Desilter	Make: SWACO, Model: 30856	
Blowout Preventers	Annular	Make: HYDRILL, Size: 21-1/4″ , WP: 2000psi Make: SHAFFER, Size: 13-5/8″ , WP: 5000psi
	Pipe Ram	Make: SHAFFER, Size: 13-5/8″ , WP: 5000psi
	Shear Ram	Make: SHAFFER, Size: 13-5/8″ , WP: 5000psi
Cooing Tower	Home make	
Engines	Make: CATERPILLAR, Model: D398(910HP), 3ea	
Generators	Make: BROWN BOVERI, Model: 718, 800kw, 600volts, 3ea	
Tanks	Home make, Mud Tank 1100bbls,2ea, Water Tank 600bbls,3ea	

Table 2-3-4 Drilling Equipment for Well AMJ-2

坑井 AMJ-2 の掘削設備

Item	Description	
Mast	Make: IDECO, Model: HFM138-550, Height: 138ft	
Substructure	Make: IDECO, Type: Box on Box, Capacity: 550,000lbs	
Crown Blocks	Make: IDECO, 6Sheaves, Capacity: 350ton	
Hook Blocks	Make: National IDEAL, Model: 540G250, Capacity: 497,200lbs	
Drawworks	Make: Wilson, Model: Super Mogul 42, Rating: 800HP	
Drawworks Engines	Make: Detroit Diesel, Model: 12V71, Rating: 550HP, 2ea	
Rotary Table	Make: National IDEAL, Model: C-275, Size: 27-1/2″	
Swivel	Make: IDECO, Capacity: 200ton	
Kelly	Type: Hexagonal 5-1/4″	
Hydromatic Break	Make: PARMAC, Model: D631228	
Tongs	Make: BJ, Size: 4-1/2″ ～13-3/8″	
Mixing Pump	Make: Mission Magnum, Model: 6-8R	
Mud Pumps	No,1 Pump	Make: IDECO, Model: MM600, Drive: 16V71
	No,2 Pump	Make: IDECO, Model: MM600, Drive: 16V71
Shaker	Home make, Type: Tandem	
De-sander	Make: SWACO	
De-silter	Make: SWACO	
Blowout Preventers	Annular	Make: HYDRILL, Size: 13-5/8″ , WP: 5000psi
	Pipe Ram	Make: SHAFFER, Size: 13-5/8″ , WP: 3000psi
	Shear Ram	Make: SHAFFER, Size: 13-5/8″ , WP: 3000psi
Cooing Tower	Home make, with fan and 7.5HPmotor	
Tanks	Home make, Mud Tank : 40kl, 3ea, Water Tank : 18kl, 2ea	

Table. 2-3-5　Drift-angle Survey Data of Well AMJ-1

坑井 AMJ-1 の傾斜測定記録

Date	Measured depth	Drift-angle	Remarks
Jan. 4, 2000	39 m	0° 45′	17-1/2″ hole
Jan. 5, 2000	102 m	0° 50′	17-1/2″ hole
Jan. 6, 2000	152 m	0° 45′	17-1/2″ hole
Jan. 8, 2000	247 m	0° 15′	17-1/2″ hole
Jan.13, 2000	355 m	1° 00′	12-1/4″ hole
Jan.13, 2000	456 m	0° 45′	12-1/4″ hole
Jan.14, 2000	552 m	0° 50′	12-1/4″ hole
Jan.15, 2000	650 m	1° 00′	12-1/4″ hole
Jan.17, 2000	753 m	0° 45′	12-1/4″ hole
Jan.24, 2000	869 m	1° 00′	8-1/2″ hole
Jan.26, 2000	964 m	1° 00′	8-1/2″ hole
Jan.28, 2000	1068 m	1° 00′	8-1/2″ hole
Jan.29, 2000	1163 m	0° 50′	8-1/2″ hole
Jan.30, 2000	1257 m	0° 45′	8-1/2″ hole
Feb. 1, 2000	1352 m	0° 45′	8-1/2″ hole
Feb. 5, 2000	1512 m	0° 30′	8-1/2″ hole
Feb. 5, 2000	1652 m	0° 10′	8-1/2″ hole

Table. 2-3-6 AMJ-2 Directional Drilling Data

坑井AMJ-2の傾斜掘り実績

WELL NAME	AMJ-2

KOP[m]	ELEVAION	Directinal Angle
0.00	1885.00	N65° E. True North

	M.D 測定深度	C.L 測定間隔	DR.A 傾斜角度 [度].[分]	DIR.A 傾斜方向 [度].[分]	VE.D 垂直深度 m	T.V.D 垂直深度計 m	EL 標高 m	C.D 偏距 m	HOL.DIR 坑底方位 [度].[分]	T.D 坑底偏距 m
1	204.00	204.00	0.30	N 57.00 E	203.99	203.99	1681.01	1.78	N 57.00 E	1.78
2	290.00	86.00	0.45	N 72.00 E	85.99	289.98	1595.02	1.13	N 62.48 E	2.88
3	385.00	95.00	1.30	N 74.30 E	94.97	384.95	1500.05	2.49	N 68.13 E	5.34
4	413.00	28.00	3.00	N 79.00 E	27.96	412.91	1472.09	1.47	N 70.32 E	6.79
5	441.00	28.00	4.42	N 74.00 E	27.91	440.82	1444.18	2.29	N 71.25 E	9.08
6	469.00	28.00	6.36	N 73.00 E	27.81	468.63	1416.37	3.22	N 71.50 E	12.29
7	497.00	28.00	8.00	N 74.30 E	27.73	496.36	1388.64	3.90	N 72.28 E	16.19
8	524.00	27.00	9.24	N 71.18 E	26.64	523.00	1362.00	4.41	N 72.13 E	20.60
9	551.00	27.00	10.48	N 66.12 E	26.52	549.52	1335.48	5.06	N 71.02 E	25.63
10	582.00	31.00	12.48	N 65.18 E	30.23	579.75	1305.25	6.87	N 69.49 E	32.48
11	611.00	29.00	14.18	N 65.18 E	28.10	607.85	1277.15	7.16	N 69.00 E	39.62
12	637.00	26.00	14.48	N 65.18 E	25.14	632.99	1252.01	6.64	N 68.28 E	46.25
13	666.00	29.00	15.18	N 62.48 E	27.97	660.96	1224.04	7.65	N 67.40 E	53.87
14	696.00	30.00	16.45	N 66.00 E	28.73	689.69	1195.31	8.65	N 67.26 E	62.51
15	724.00	28.00	17.00	N 65.00 E	26.78	716.47	1168.53	8.19	N 67.09 E	70.69
16	752.00	28.00	17.00	N 66.00 E	26.78	743.24	1141.76	8.19	N 67.02 E	78.88
17	800.00	48.00	10.00	N 66.00 E	47.27	790.51	1094.49	8.34	N 66.56 E	87.21
18	827.00	27.00	17.30	N 67.00 E	25.75	816.26	1068.74	8.12	N 66.57 E	95.33
19	855.00	28.00	17.30	N 67.00 E	26.70	842.97	1042.03	8.42	N 66.57 E	103.75
20	884.00	29.00	18.00	N 69.00 E	27.58	870.55	1014.45	8.96	N 67.07 E	112.71
21	914.00	30.00	19.45	N 69.00 E	28.24	898.78	986.22	10.14	N 67.16 E	122.84
22	950.00	36.00	22.00	N 68.00 E	33.38	932.16	952.84	13.49	N 67.20 E	136.32
23	979.00	29.00	24.00	N 69.00 E	26.49	958.65	926.35	11.80	N 67.28 E	148.11
24	1019.00	40.00	25.15	N 71.00 E	36.18	994.83	890.17	17.06	N 67.50 E	165.15
25	1057.00	38.00	26.45	N 68.00 E	33.93	1028.77	856.23	17.10	N 67.51 E	182.25
26	1095.00	38.00	28.45	N 68.00 E	33.32	1062.08	822.92	18.28	N 67.52 E	200.53
27	1123.00	28.00	29.45	N 69.00 E	24.31	1086.39	798.61	13.89	N 67.56 E	214.42
28	1152.00	29.00	31.00	N 67.00 E	24.86	1111.25	773.75	14.94	N 67.53 E	229.36
29	1181.00	29.00	31.30	N 68.00 E	24.73	1135.98	749.02	15.15	N 67.53 E	244.51
30	1217.00	36.00	33.00	N 68.00 E	30.19	1166.17	718.83	19.61	N 67.54 E	264.11
31	1273.00	56.00	33.30	N 68.00 E	46.70	1212.87	672.13	30.91	N 67.54 E	295.02
32	1330.00	57.00	33.15	N 67.00 E	47.67	1260.53	624.47	31.25	N 67.49 E	326.27
33	1377.00	47.00	33.30	N 68.00 E	39.19	1299.73	585.27	25.94	N 67.50 E	352.21
34	1414.00	37.00	33.30	N 68.00 E	30.85	1330.58	554.42	20.42	N 67.50 E	372.63
35	1488.00	74.00	34.30	N 67.00 E	60.99	1391.57	493.43	41.91	N 67.45 E	414.54
36	1595.00	107.00	34.30	N 67.00 E	88.18	1479.75	405.25	60.61	N 67.40 E	475.15
37	1650.00	55.00	34.30	N 67.00 E	45.33	1525.07	359.93	31.15	N 67.37 E	506.30
38	1705.00	55.00	34.30	N 67.00 E	45.33	1570.40	314.60	31.15	N 67.35 E	537.45
39										
40										
41										
42										
43										
44										
45										
46										
47										
48										

Table. 2-3-7 Record of the loss of circulation zones of Well AMJ-1

坑井 AMJ-1 の逸水層記録

Date	Depth	Loss rate	Treatment
Dec.25, 1999	2 m	$9m^3$/hr	Drilled with LCM mud
Dec.26, 1999	8 m	> 53 m^3/hr	Set cement plug
Jan. 5, 2000	83 m	7 m^3/hr	Drilled with LCM mud
Jan. 6, 2000	151 m	31 m^3/hr	Drilled with LCM mud
Jan.27, 2000	1011 m	3 m^3/hr	Drilled with mud
Jan.29, 2000	1168 m	3 m^3 · /hr	Drilled with mud
Jan.30, 2000	1231 m	4 m^3/hr	Drilled with mud
Feb. 1, 2000 ~Feb. 2, 2000	1429 m ~ 1493 m	16 m^3/hr ~ 34 m^3/hr	Drilled with mud
Feb. 2, 2000	1493 m ~ 1502 m	> 75 m^3/hr	Drilled with low vis mud
Feb. 2, 2000	1502 m ~ 1531 m	60 m^3/hr	Drilled with low vis mud and water
Feb. 3, 2000 ~Feb. 5, 2000	1531 m ~ 1700 m	4 m^3/hr ~ 20 m^3/hr	Drilled with low vis mud

Table 2-3-8 Record of the loss of circulation zones of Well AMJ-2

坑井 AMJ-2 の逸水層記録

Date	Depth	Loss Rate	Treatment
Aug.29, 2000	8 m	$4m^3/hr$	Drilled with mud
Sep.10, 2000	105 m	$10m^3/hr$	Drilled with mud
Sep.22, 2000	156 m	$20m^3/hr$	Drilled with LCM mud
Sep.24, 2000	201 m	$36m^3/hr$	Drilled with LCM mud
Oct.31, 2000	1538 m ～ 1539 m	$50m^3/hr$	Drilled with low vis mud
Oct.31, 2000	1539 m ～ 1542 m	$>75m^3/hr$	Drilled with low vis mud
Oct.31, 2000	1542 m ～ 1553 m	$20m^3/hr$	Drilled with low vis mud
Oct.31, 2000	1553 m ～ 1563 m	$30m^3/hr$	Drilled with low vis mud
Nov. 1,2000	1563 m ～ 1594 m	$50m^3/hr$	Drilled with low vis mud
Nov. 1,2000	1594 m ～ 1595 m	$>68m^3/hr$	Drilled with low vis mud
Nov. 3,2000	1595 m ～ 1611 m	$10m^3/hr$	Drilled with low vis mud
Nov. 4,2000	1611 m ～ 1630 m	$40m^3/hr$	Drilled with low vis mud
Nov. 4,2000	1630 m ～ 1705 m	$20m^3/hr$	Drilled with low vis mud

Table. 2-3-9 Hydro-fracturing Data of Well AMJ-1

坑井 AMJ-1 のハイドロフラクチャリング記録

Date		Injection rate	pump pressure	Total Volume	Remarks
Run No.1 Feb.8, 2000	9:50	75 m^3/hr	0→250psi	367 m^3	Run in hole with DP Pump through DP
	10:10	113 m^3/hr	450psi		
	10:30	150 m^3/hr	580psi		
	10:50	165 m^3/hr	680psi		
	11:00	161 m^3/hr	650psi		
	11:30	159 m^3/hr	650psi		
	12:00	161 m^3/hr	640psi		
	12:25	161 m^3/hr	630psi		
Run No.2 Feb.9, 2000	1:10	162 m^3/hr	0→450psi	293 m^3	Pump through DP
	1:20	155 m^3/hr	530psi		
	1:30	161 m^3/hr	580psi		
	1:40	159 m^3/hr	590psi		
	2:00	161 m^3/hr	610psi		
	2:20	161 m^3/hr	630psi		
	2:40	161 m^3/hr	630psi		
	3:00	160 m^3/hr	630psi		
Run No.3 Feb.9, 2000	18:05	135 m^3/hr	0→ 50psi	188 m^3	Pump through kill line Check loss rate:75 m^3/hr
	18:15	131 m^3/hr	50psi		
	18:25	159 m^3/hr	50psi		
	18:35	158 m^3/hr	50psi		
	18:45	143 m^3/hr	50psi		
	19:00	158 m^3/hr	50psi		
	19:10	157 m^3/hr	50psi		
	19:20	158 m^3/hr	50psi		

Table 2-3-10 Hydro fracturing Data of Well AMJ-2

坑井 AMJ-2 のハイドロフラクチャリング記録

Date		Injection rate	Pump pressure	Total Volume	Remarks
Run No.1 Nov.7, 2000	12:10	132m^3/hr	0psi	126m^3	Run in hole with DP Pump through DP
	12:20	70m^3/hr	0psi		
	12:30	139m^3/hr	0→250psi		
	12:40	139m^3/hr	0～250psi		
	12:50	139m^3/hr	0～250psi		
	13:00	139m^3/hr	0～250psi		
	13:10	139m^3/hr	0～250psi		
Run No.2 Nov.7, 2000	18:30	152m^3/hr	0psi	127m^3	Pump through DP
	18:40	152m^3/hr	0psi		
	18:50	152m^3/hr	0→100psi		
	19:00	152m^3/hr	0～100psi		
	19:10	152m^3/hr	0～100psi		
	19:20	152m^3/hr	0～100psi		
Run No.3 Nov.9, 2000	8:00	152m^3/hr	0psi	152m^3	Pump through DP Check loss rate:126m^3/hr
	8:10	152m^3/hr	0psi		
	8:20	152m^3/hr	0→250psi		
	8:30	152m^3/hr	0～250psi		
	8:40	152m^3/hr	0～200psi		
	8:50	152m^3/hr	0～100psi		
	9:00	152m^3/hr	0～100psi		

Table. 2-3-11 Cementing Data of Well AMJ-1

坑井 AMJ-1 のセメンティング記録

Primary cementing(casing cementing)

Date	Casing size	Set depth	Materials	Specific gravity	Remarks
Jan. 1, 2000	20″	10.8	Cement "A" 64sacks Calcium Chloride 2%	1.80	30 % excess volume
Jan. 9, 2000	13-3/8″	295.7	Cement "H" 632sacks Silica Flour 35% Halad-22A 0.5% CFR-2 0.2%	1.80	50 % excess volume
Jan.20, 2000	9-5/8″	803.3	Cement "H" 667sacks Silica Flour 35% Halad-22A 0.5% CFR-2 0.2% HR-12 0.25%	1.80	50% excess volume

Secondary cementing(top job cementing)

Date	Casing annuls	Materials	Specific gravity	Remarks
Jan.10, 2000	20″ - 13-3/8″	Cement "A" 200sacks	1.80	Run in 1″ pipe
Jan.11, 2000	20″ - 13-3/8″	Cement "H" 244sacks	1.80	Run in 1″ pipe
Jan.11, 2000	20″ - 13-3/8″	Cement "A" 45sacks Calcium Chloride 3%	1.80	Set from surface
Jan.21, 2000	13-3/8″ - 9-5/8″	Cement "H" 274sacks Silica Flour 35% Halad-22A 0.5% CFR-2 0.2% HR-12 0.25%	1.70	Set from surface

Secondary cementing (plug-back cementing)

Date	Drilling depth	Materials	Specific gravity	Remarks
Dec.26, 1999	8 m	Cement "A" 21sacks	1.80	Plug for loss zone
Dec.27, 1999	9 m	Cement "A" 85sacks	1.80	Plug for loss zone
Dec.31, 1999	32 m	Cement "A" 215sacks	1.80	Plug for loss zone

Table 2-3-12 Cementing Data of Well AMJ-2

坑井 AMJ-2 のセメンティング記録

Primary cementing (Casing cementing)

Date	Casing size	Set depth	Materials	Specific gravity	Remarks
Aug.27, 2000	20″	8.00	Cement "A" 2,000kg Calcium Chloride 2%	1.80	50%excess volume
Sep.30, 2000	13-3/8″	293.46	Cement "H" 30,000kg Silica Flour 35% Halad-22A 0.5% CFR-2 0.2%	1.80	70%excess volume
Oct.18, 2000	9-5/8″	996.31	Cement "H" 40,000kg Silica Flour 35% Halad-22A 0.5% CFR-2 0.2% HR-12 0.2%	1.75	80%excess volume

Secondary cementing (top job cementing)

Date	Casing annuls	Materials	Specific gravity	Remarks
Sep.30, 2000	20″ - 13-3/8″	Cement "H" 10,000kg	1.80	Set from surface
Oct. 1, 2000	20″ - 13-3/8″	Cement "H" 5,000kg	1.80	Set from surface
Oct.21, 2000	13-3/8″ -9-5/8″	Cement "H" 10,000kg	1.80	Set from surface
Oct.21, 2000	13-3/8″ -9-5/8″	Cement "A" 935kg	1.75	Set from surface

Secondary cementing (Plug-back cementing)

Date	Drilling depth	Materials	Specific gravity	Remarks
Sep.16, 2000	156 m	Cement "A" 5,000kg	1.80	Plug for side-track
Sep.17, 2000	156 m	Cement "A" 5,000kg	1.80	Plug for side-track

Table. 2-3-13 Bit Record of Well AMJ-1

坑井 AMJ-1 のビット記録

Well Name AMJ-1 Field Amatitlan Spudding Date Dec.25, 1999 Drawworks NATIONAL 80 UE Mud Pump NATIONAL 9-P-100 Mud Type Bentonite/Polymer

No	SIZE	MAKE	TYPE	IADC	SERIAL	NOZZLE	DEPTH			DRILLING		BIT		DEV	PUMP		MUD				DULL GRADING			REMARKS
							FROM	T O	TOTAL	HOURS	RATE	WOB	RPM		P. P	SPM	SG	VIS	IN	OUT	T	B	G	
1	17-1/2	SEC	S84	515	500432	Open	0	10	10	41:00	0.24	2/8	40/60	–	50	60	1.01	38	–	–				Pilot hole
2RR	12-1/4	SEC	M89F	637	657078	Open	10	32	22	13:15	1.66	6/8	60	–	50	60	1.02	40	–	–				Used, Pilot hole
1RR	17-1/2	SEC	S84	515	500432	Open	10	32	22	9:30	2.32	6/8	60/70	–	50	60	1.03	40	–	–				Pilot hole
1RR	17-1/2	SEC	S84	515	500432	Open	0	11	11	34:00	0.32	2/6	40/50	–	50	60	1.03	42	–	–				W/Hole Opener
1RR	17-1/2	SEC	S84	515	500432	Open	32	195	163	67:45	2.41	20/30	50/70	3/4°	50	80	1.04	44	20	21				
3RR	17-1/2	SEC	S86	535	493546	Open	195	300	105	32:45	3.21	15/30	40/80	1/4°	50	80	1.04	43	21	23				Used
4	12-1/4	SEC	S86F	537	652707	3×20	300	659	359	70:30	5.09	14/18	80/100	1°	400	130	1.06	41	38	44	2	3	I	
5	12-1/4	SEC	S84F	517	122551	3×20	659	807	148	35:00	4.23	16/22	80/100	3/4°	500	130	1.06	43	42	47	2	2	I	
6	8-1/2	SEC	S84	515	568527	Open	807	932	125	37:00	3.38	16/18	80/85	1°	250	105	1.06	38	41	47	4	8	I	
7RR	8-1/2	SEC	MG89 TF	627	559050	Open	932	1002	70	23:00	3.04	16/18	60/65	1°	350	105	1.06	38	41	48	2	2	I	Used
8	8-1/2	SEC	MG89 TF	627	574859	Open	1002	1129	127	40:30	3.14	20	65	7/8°	375	110	1.06	38	43	50	2	2	I	
9	8-1/2	SEC	MG89 TF	627	574864	Open	1129	1276	147	45:30	3.23	20/24	65	3/4°	400	110	1.07	38	46	53	2	2	I	
10	8-1/2	SEC	MG89 TF	627	574862	Open	1276	1500	224	46:00	4.87	18/24	65	3/4°	400	110	1.04	38	28	36	2	2	I	Loss circulation
11	8-1/2	SEC	MG89 TF	627	574865	Open	1500	1700	200	40:00	5.00	18/24	65	1/2°	400	110	1.02	34	45	53	4	8	I	TD

Table 2-3-14 Bit Record of Well AMJ-2

坑井 AMJ-2 のビット記録

Well Name AMJ-2 Field Amatitlan Spudding Date Aug.27, 2000 Drawworks Wilson Super Mogul 42 Mud Pump IDECO MM600 Mud Type Bentonite/Polymer

No	SIZE	MAKE	TYPE	IADC	SERIAL	NOZZLE	DEPTH			DRILLING		BIT		DEV	PUMP		MUD				DULL GRADING			REMARKS
							FROM	TO	TOTAL	HOURS	RATE	WOB	RPM	(°)	P. P	SPM	SG	VIS	IN	OUT	T	B	G	
1	17-1/2	SEC	S85F	527	496665	Open	0 m	8 m	8 m	12:00	0.67	2 t	50	--	0	40	1.05	50	—	—	—	—	—	Pilot hole
2	26	VAREL	-	215	--	Open	0	8	8	4:00	2.00	2	50	--	0	40	1.04	55	—	—	—	—	—	Ream hole
3	12-1/4	SEC	S85F	527	656533	Open	8	13	5	15:25	0.32	2	50	-	0	40	1.04	55	—	—	—	—	—	Used. Pilot hole
1RR	17-1/2	SEC	S85F	527	496665	Open	13	156	143	100:47	1.42	7	60	-	0	45	1.05	60	—	—	—	—	—	
4	17-1/2	VAREL	--	517	154882	3×18	156	300	144	51:40	2.79	4	60	-	300	55	1.04	50	—	—	—	—	—	
5	12-1/4	VAREL	--	517	157856	3×16	300	385	85	18:07	4.69	10	65	1	500	50	1.03	45	—	--	1	1	1	
6	12-1/4	VAREL	-	517	157769	3×16	385	682	297	38:45	7.66	8	60	15	700	60	1.08	40	—	—	2	2	1	KOP 385m
7	12-1/4	VAREL		517	157772	3×18	682	875	193	35:30	5.44	18	70	17	500	60	1.10	40	—	48	2	3	1	
5RR	12-1/4	VAREL	--	517	157856	3×18	875	1000	125	19:00	6.58	14	60	24	500	60	1.11	50	—	60	2	2	1	
8	8-1/2	VAREL	-	537	152569	3×14	1000	1203	203	38:40	5.25	7	70	31	600	60	1.05	42	—	54	1	2	1	
9	8-1/2	VAREL	--	537	151809	3×16	1203	1434	231	43:20	5.33	10	60	33	300	60	1.09	43	—	58	2	3	1	
10	8-1/2	VAREL	-	537	152579	3×16	1434	1542	108	20:00	5.40	7	75	34	400	60	1.12	40	—	60	2	2	1	
11	8-1/2	VAREL		537	152568	3×16	1542	1595	53	9:54	5.35	7	75	34	500	60	1.09	40	—	—	1	1	1	Loss circulation
12	8-1/2	VAREL	---	537	152572	3×16	1595	1705	110	28:12	3.90	5	80	34	300	60	1.02	40	—	—	2	4	1	Loss circulation

Table. 2-3-15 List of Used Materials of Well AMJ-1

坑井 AMJ-1 の使用資材一覧表

Bit and Hole Opener

26″ hole opener, with conventional cones	1 unit
17-1/2″ , with conventional cones, classification 5-1-5	1 unit
17-1/2″ , with conventional cones, classification 5-3-5 (used)	1 unit
12-1/4″ , with conventional cones, classification 5-1-7	1 unit
12-1/4″ , with conventional cones, classification 5-3-7	1 unit
12-1/4″ , with conventional cones, classification 6-3-7 (used)	1 unit
8-1/2″ , with conventional cones, classification 5-1-5	1 unit
8-1/2″ , with conventional cones, classification 6-2-7	4 unit
8-1/2″ , with conventional cones, classification 6-2-7 (used)	1 unit

Mud materials

Bentonite (100lbs)	3018 sacks
Caustic Soda (50lbs)	121 sacks
Sodium Bicarbonate (100lbs)	24 sacks
Tannathin (50lbs)	65 sacks
Polypack (50lbs)	9 sacks
Resinex CMC (50lbs)	70 sacks
Sodium Carbonate (100lbs)	13 sacks
Kwik-Seal (40lbs)	57 sacks
Saw-Dust (40lbs)	120 sacks
Cottonseed-Hulls (40lbs)	37 sacks
Nut-Plug (80lbs)	20 sacks
Lime (16kg)	53 sacks

Cement materials

Cement "A" (94lbs)	630 sacks
Cement "H" (94lbs)	1817 sacks
Silica Flour (100lbs)	517 sacks
Calcium Chloride (110lbs)	3 sacks
Halad 22A (50lbs)	15 sacks
CFR-2 (50lbs)	6 sacks
HR-12 (50lbs)	5 sacks

Well Head Equipment

Well head for 13-3/8″ casing	1 unit
Expansion spool of 33″ height	1 unit
Master valve, 10″ ANSI600, WKM	1 unit
Bleed-off valve, 3″ series 2000	2 unit

Casing and Accessories

Conductor pipe, 30″ OD, 1/8″ thickness	10.00meters
Casing 20″ , 94 lbs/ft, BTC	24.29meters
Casing 13-3/8″ , 61 lbs/ft, BTC	303.60meters
Casing 9-5/8″ , 40 lbs/ft, BTC	811.20meters
Casing 7-5/8″ , 26.4 lbs/ft, Hydril FJP, Blind	637.25meters
Casing 7-5/8″ , 26.4 lbs/ft, Hydril FJP, Slotted	294.26meters
Float shoe for 20″ casing	1 unit
Float shoe for 13-3/8″ casing	1 unit
Float shoe for 9-5/8″ casing	1 unit
Guide shoe for 7-5/8″ casing	1 unit
Float collar for 13-3/8″ casing	1 unit
Float collar for 9-5/8″ casing	1 unit
Cementing plug for 20″ casing	1 unit
Cementing plugs for 13-3/8″ casing, top and bottom	1 unit
Cementing plugs for 9-5/8″ casing, top and bottom	1 unit
Centralizers for 13-3/8″ casing	8 unit
Centralizers for 9-5/8″ casing	20 unit
Liner hanger, 9-5/8″ ×7-5/8″	1 unit

Table 2-3-16 List of Used Materials of Well AMJ-2

坑井 AMJ-2 の使用資材一覧表

Bit and Hole Opener

26″ , with conventional cones, classification 2-1-5	1 unit
17-1/2″ , with conventional cones, classification 5-1-7	1 unit
17-1/2″ , with conventional cones, classification 5-2-7	1 unit
12-1/4″ , with conventional cones, classification 5-1-7	3 unit
12-1/4″ , with conventional cones, classification 5-2-7 (used)	1 unit
8-1/2″ , with conventional cones, classification 5-3-7	5 unit

Mud materials

Bentonite (100lbs)	4484 sacks
Caustic Soda (50lbs)	77 sacks
Sodium Bicarbonate (100lbs)	56 sacks
Tannathin (50lbs)	110 sacks
Polypack (50lbs)	138 sacks
Poly-plus (18L)	267 cans
Thermex (200L)	6 drums
Kwik-Seal (40lbs)	25 sacks
Nut-Plug (80lbs)	182 sacks
Pipe-Lax (200L)	2 drums

Cement materials

Cement "A"	12,935 kg
Cement "H"	95,000 kg
Silica Flour	33,250 kg
Calcium Chloride	240 kg
Halad 22A	475 kg
CFR-2	190 kg
HR-12	80 kg

Well Head Equipment

Well head for 13-3/8″ casing	1 unit
Expansion spool of 33″ height	1 unit
Master valve, 10″ ANSI600, WKM	1 unit
Bleed-off valve, 3″ series 2000	2 unit

Casing and Accessories

Conductor pipe, 30″ OD, 1/8″ thickness	10.00meters
Casing 20″ , 94.0 lbs/ft, BTC	11.83meters
Casing 13-3/8″ , 54.5 lbs/ft, BTC	300.15meters
Casing 9-5/8″ , 40.0 lbs/ft, BTC	1001.75meters
Casing 7″ , 29.0 lbs/ft, BTC, Blind	126.58meters
Casing 7″ , 29.0 lbs/ft, BTC, Slotted	601.59meters
Float shoe for 20″ casing	1 unit
Float shoe for 13-3/8″ casing	1 unit
Float shoe for 9-5/8″ casing	1 unit
Guide shoe for 7″ casing	1 unit
Float collar for 13-3/8″ casing	1 unit
Float collar for 9-5/8″ casing	1 unit
Cementing plug for 20″ casing	1 unit
Cementing plugs for 13-3/8″ casing, top and bottom	1 unit
Cementing plugs for 9-5/8″ casing, top and bottom	1 unit
Centralizer for 13-3/8″ casing	8 unit
Centralizer for 9-5/8″ casing	25 unit
Liner hanger, 9-5/8″ ×7″	1 unit

2.4 Well Survey

2.4.1 Well Geology

2.4.2 Well Geochemistry

2.4.3 Completion Testing and Bore hole Surveys

2.4 WELL SURVEY

2.4.1 Well Geology

A study on the petrology and mineralogy of cuttings from the exploratory wells AMJ-1 and AMJ-2 was done to clarify the geological and geothermal structures of the Amatitlan geothermal field. Firstly, all cuttings samples from wells were naked eye examined. Secondly, representative samples selected were analyzed through microscopic observation, Zircon crystal morphology, Age determination, X-ray diffraction analysis, and Fluid inclusion analysis in the laboratory.

1. Microscopic Observation and Preparation of Geological Column

A polarizing petrography microscope was used to study the textural classification, volume of crystal content, mineral paragenesis, alteration degree, occurrence of secondary minerals. With the result of other laboratory analyses, the geological column around wells AMJ-1 and AMJ-2 was constructed. Although the granite basement was confirmed below the depth of 1,650m at AMJ-1 vertical well, AMJ-2 directional well did not reach to the basement in the period of the drilling, which drilling depth is 1,705m and vertical depth is 1,570.4m (refer to Fig. 2-4-1 and Fig. 2-4-2).

a. Colluvium

Cuttings of the first 40 meters from well AMJ-1 show talus deposits of basaltic and andesitic fragment, scoria and pumice, gray to dark gray in color. The fragments are hardly altered, but partly brownish color showing the signs of weathering and oxidization.

b. Pacaya volcanic rocks

This unit is composed mainly of basaltic lava and pyroxene andesite interbedded with thin pyroclastic layers.

Dark gray colored basaltic lava is subject to partly oxidization with reddish brown color. There are abundant plagioclases, some augite, few hornblende and transparent minerals as phenocryst in an intersertal matrix of plagioclase laths. The fragment is mostly unaltered in spite of the occurrence of calcite and volcanic glasses.

Pyroxene andesite is gray to dark gray in color; partly brownish resulted in oxidization. Phenocryst consists of abundant plagioclase, some hornblende, olivine, few transparent minerals and rare pumice. Alteration degree is none to very weak.

Pyroclastic layers consist of tuff and scoria with the thickness of 10-30m. Each layer includes basaltic fragments and transparent minerals as calcite and quartz.

c. Post-calderic volcanics

This unit is composed of basaltic lava, pyroclastic layers, dacitic rock, and andesite lava with the thickness of 400-500m except well AMF-1, some 200m.

Basaltic lava, 10-30m in thickness, is the uppermost layer of Post-calderic volcanics. The lava is dark gray and frequently observed with oxidized reddish tints in porous zone. Fragments are mostly unaltered except for fine secondary minerals in cavities. The texture is vesicular and contains phenocrysts such as plagioclase, pyroxene, hornblende and pumice in an intergranular matrix of plagioclase laths.

Cuttings from pyroclastic layers contain pyroxene andesite fragments and poorly sorted pumiceous deposits. In well AMJ-1, two thick layers, some 100m in thickness, are brown to whitish gray in color. Abundant transparent minerals and greenish smectite are found in these rocks. Argillization proceeds downward. Despite of partial oxidization, alteration degree is generally very weak.

Dacitic rock is pale gray, partly brownish gray owing to the oxidization. There are several phenocrysts containing abundant plagioclase, rare hornblende and few augites in hyaloophitic or intergranular texture. Occurrence of minerals, such as quartz, calcite and smectite results from the weak hydrothermal alteration.

Andesite lava can be divided into two groups: pyroxene andesite and hornblende andesite. Pyroxene andesite is gray to dark gray and its phenocrysts consist of mainly plagioclase, pyroxene, olivine, pumice and alteration minerals are calcite, quartz, and smectite. Hornblende andesite appearing at the lowermost part of Post-calderic volcanics is dark gray to reddish. Phenocrysts contain plagioclase, hornblende, but transparent mineral is very few. Alteration degree is weak to very weak.

d. Syn-calderic volcanics

This formation is made up mainly of andesite lava, dacite, and partly interbedded with pyroclastic deposit and 500-700m in thickness.

Andesite lava is separated into pyroxene andesite and subordinate hornblende andesite with several layers of tuff breccias of 10-30m in thickness. Phenocrysts among lava consist of mainly plagioclase and subordinately pyroxene, hornblende, pyrite, volcanic glasses, mica and transparent minerals such as, calcite and quartz in intersertal and intergranular matrix. In well AMJ-1, opal occurs at 870-890m and chlorite occurs below the depth of 900m. Intermediate and strong alteration was observed in 1,200-1,230m and the silicified zone corresponds to the bottom of this strongly altered zone. In well AMJ-2, chloritization proceeds remarkably below 1,000m depth. At 1,050-1,070m, alteration degree becomes relatively strong with occurrence of the silicified zone.

Hornblende is slightly gray to dark gray, partly reddish due to oxidization. Plagioclase, hornblende, pyroxene, transparent minerals including quartz and chlorite appear in intergranular texture. The degree of alteration is weak to very weak.

Dacite lava consists of several layers of 20-50m, light gray to dark gray and is composed of abundant plagioclase, some quartz and poor calcite as phenocrysts in intergranular matrix. The cuttings are weakly to intermediately altered. Argillization occurs partly especially in well AMJ-

2.

Tuff breccias are interbedded at 1,000-1030m in well AMJ-2 with pale brown color. Cuttings include some hydrothermal vein minerals in the very weak alteration.

e. Pre-calderic volcanics

This formation is composed of pyroxene andesite lava and hornblende andesite and 400-500m in thickness.

Pyroxene andesite is gray to dark gray, compact lava and is mainly observed abundant plagioclase, pyroxene, hornblende, and few pyrites in an intersertal matrix of plagioclase laths. Alteration degree is generally weak except following parts. Especially, hydrothermal vein minerals are relatively abundant at the uppermost part of this formation and around 1630m in AMJ-1 and at 1,360-1,390m, 1,470-1,530m and below 1,570m depth in well AMJ-2.

Hornblende andesite, dark gray in color, is subject to partly oxidization and includes abundant plagioclase, some hornblende, pyroxene and vein minerals in an intersertal texture. This zone is altered weakly to intermediately.

f. Basement rocks

The geological basement of the Amatitlan geothermal area is composed of granitic rocks that intruded during the Tertiary (WJEC and TELECTRO, 1995) and which underlies volcanic rocks. Basement rocks crop out in the western area of the Amatitlan caldera (Eggers, 1971).

This intrusive rock was encountered by wells AMJ-1 and AMF-1 at the altitude of 200-400m. The basement is made of granite porphyry, pale bluish gray to whitish gray in color and consists of large quartz minerals, subordinate plagioclase and chlorite. This unit is very weakly altered and has few vein minerals (refer to Fig. 2-4-3).

2. Zircon Crystal Morphology

Zircon ($ZrSiO_4$) occurs as subordinate mineral in various kinds of igneous rocks. Morphology of zircon crystal corresponds with the conditions of magma at which consolidated to form the original rocks. This morphologic characteristic is effective to do the geological correlation and to estimate the origin of the sedimentary rocks and the altered rocks.

Collected from wells AMJ-1 and AMJ-2 and outcrops including West JEC and Telectro (1995), the integrated analysis of zircon morphology was done.

From Pacaya Volcanic Rocks, zircon crystal morphology was analyzed from basaltic lava of well AMJ-2 and andesite outcrop lava. These rocks show the index of 8549 and 7439 in crystal type respectively with short to middle prisms.

Dacite, pyroxene andesite and pyroclastic rock from Post-Calderic Volcanics were measured all over the Amatitlan geothermal field. Each rock has different characteristic crystal pattern. The pattern of dacite rock has a comparatively constant index with 7449 and 7549, while that of pyroxene andesite shows the various indexes of 6439, 7449, 7539, 8439 and 8539 with 100-dominant type. In contrast, pyroclastic rock was in indexes of 6439, 7429 and 7449 with 100-dominant type.

Syn-Calderic Volcanics was investigated from only 1 sample of well AMJ-1 and shows 6559 index with 100-dominant type.

Hornblende andesite (1 rock) and pyroxene andesite (4 rocks) were analyzed from Pre-Calderic Volcanics. The former sample shows 7449 index and 110-dominant to 100 dominant type with not abundant zircon crystal. The other was observed in several indexes of 5449, 6329, 6549 and 7559 with 100-dominant, 100-intermediate, 110-dominant type with short to middle prisms.

The zircons in granitic Basement Rock were found with 4349 index from well AMJ-1 and with 7439 index from the outcrop at the eastern side of Lago de Amatitlan.

Although, most of the volcanic rocks in Amatitlan geothermal field shows 100-dominant type with short to middle prisms as the above results, zircon content are free or few in basalt of Pacaya Volcanic Rocks, all rocks of Syn-Calderic Volcanics and hornblende andesite of Pre-Calderic Volcanics except pyroclastic rocks. This may suggest not proceeding to the crystallization differentiation of magma (refer to Table 2-4-1).

3. Age determination

The thermo-luminescence (TL) dating method and the fission track (FT) method were applied for in age determination. Though quartz is generally utilized in TL method, the dating was conducted by feldspar from cuttings in well AMJ-1 and by pyroxene, particularly in augite, from those in well AMJ-2 due to the lack of quartz.

In order to estimate the volcanic and alteration activity in Amatitlan geothermal area, eruptive age and hydrothermal alteration date was reviewed and integrated by comparing with the dating data from all samples.

a. Dating of volcanic rocks

TL dating datum of samples from the outcrop near well AMF-1 and Pacaya Volcanic Rocks of wells AMJ-1 and AMJ-2 show very recent age, 4-11ka. These samples were hardly altered and their TL date indicates the volcanic eruption age. This fact suggests that Pacaya Volcano starts the volcanic activity at the beginning of Holocene (about 10ka) and a series of dacite domes adjacent to Lago de Amatitlan appeared in this period. Samples of Post-Calderic Volcanics were collected from several outcrops and cuttings of wells AMJ-1 and AMJ-2 and their FT age shows 80-1,160 ka. These dates correspond to late Pliocene to Pleistocene.

Rock dating of Syn-Calderic Volcanics was conducted from only well AMJ-1 and its FT dating result was 1,140->3,600ka. The fact suggests that Amatitlan Caldera had been shaped before late Pliocene.

From cuttings sampled from wells AMJ-1 and AMJ-2, the age of Pre-Calderic Volcanics was measured and shows 2,690-14,100ka, which is Miocene to Pliocene. These results are slightly older than the existing report.

Although granite, formed the basement in Amatitlan geothermal field, was not dated from well AMJ-1 and AMJ-2, West JEC and Telectro (1995) mention that this basement is 15.2 Ma in age by FT dating

b. Dating of alteration

In the Amatitlan geothermal area, it is thought that at least 3 times of hydrothermal alteration activities took place after the formation of the Amatitlan Caldera.

The oldest hydrothermal activity is located around north El Pepinal, north of well AMF-3, and was 35-46 (55?) ka in age.

The second activity shows the occurrence near the outcrop of eastern side of fumaroles altered zone, where is located at northern rim of Laguna de Calderas and was dated on 16ka.

The latest activity occurred in 3-5ka beneath the western part of the same fumaroles zone. Cuttings of Post Calderic Volcanic of well AMJ-1 and AMJ-2 show the same TL age.

The fact indicates that the geothermal activities migrated towards the south or southern west together with the migration volcanism. In addition, because of the value of 6.1 ka for the dacite domes of Cerro Limon, it is highly possible that the hydrothermal alteration activity is associated to the formation of the dome of Cerro Limon.

4. X-Ray Diffraction Analysis

In order to elucidate on the characteristics of hydrothermal alterations, all cuttings sampled from wells AMJ-1 and AMJ-2 were examined with a polarized microscope and an X-ray diffractometer.

The naked eye examination of samples indicates that hydrothermal alteration in Well AMJ-1 appears below the depth of 700m, where pyrite and quartz are visible in fractures and cavities. An alteration zone with quartz veins was found from 730m to 770m. A silicified zone with vein minerals was occurred from 1,200m to 1,220m and it possibly acts as conduit for hydrothermal fluids. Due to the alteration diminution, vein minerals decrease, in contrast, below 1260m in spite of chloritization procedure. The X-ray diffraction analysis of the cuttings from Well AMJ-1 identified various types of alteration minerals. They were mostly of neutral to alkaline types. Of silica minerals, tridymite was detected at 300-700m and quartz exists below 700m. Kaolinite, an acidic type of clay minerals, was not found at all depths. Of the alumina-clay minerals, smectite occurs in the range from 200m to 800m, except around 300m. It converts to chlorite below 900m, through a transitional zone. Chlorite appears at greater depth. Relic feldspar was detected in all the cuttings analyzed. Table 2-4-3 shows the result of X-ray diffraction analysis done of Well AMJ-1.

While, to cuttings of well AMJ-2, the same naked eye examination and X-ray diffraction analysis was done. Hydrothermal alteration in Well AMJ-2 begins from the depth of 700m, where pyrite and quartz are visible in fractures and cavities. A silicified zone with vein minerals was found from 1,050m to

1,070m and it possibly acts as conduit for hydrothermal fluids. Due to the alteration diminution, vein minerals decrease at the depth between 1,070-1,140m, despite of occurrence of chlorite minerals. Below 1,140m, the chloritization procedure strengthens in the intermediately to strongly altered condition down to the bottom of well AMJ-2. From the X-ray diffraction analysis, various types of alteration minerals were identified from cuttings from Well AMJ-2. They were mostly of neutral to alkaline types. Of silica minerals, tridymite was detected at 300m and quartz exists at 400m and below 700m. Kaolinite, was found between 900-1,100m in depth. Of the alumina-clay minerals, smectite occurs in the range from the surface to 1,000m. Transitional zone from smectite to chlorite is around the depth of 1,100m. Chlorite increases downward. Table 2-4-4 shows the result of X-ray diffraction analysis done of Well AMJ-2.

5. Fluid Inclusion Analysis

Fluid inclusions are micron-sized cavities filled with the fluid trapped during mineral precipitation or during subsequent fracturing. Information on the temperature of trapping and on the composition of the inclusion fluids is derived from phase changes occurring in inclusions during heating and freezing. Homogenization temperature (Th) and ice-melting point (IMP) of fluid inclusions were measured through the cuttings from the lower portion of wells where hot water is estimated to reserve.

a. Measurement of Homogenization Temperature

Regarding well AMJ-1, the distribution of Th values of fluid inclusions above 1,160m depth represents that the lowest Th of inclusions corresponds to the measured temperature. On the contrary, the measured temperatures at the deep portion of this well are close to the highest homogenization temperature resulting from fluid inclusion thermometry, as well as the fact found in Wells AMF-2 and AMF-4. This indicates that the geothermal system at depth is still under the heating up process (refer to Fig. 2-4-1).

While on well AMJ-2, homogenization temperature of fluid inclusions shows the bimodal distribution below 1,100m in depth, as well as wells AMF-1 and AMF-2. It is thought that the deeper portion of well AMJ-2 may be reheated and increase some 50℃ by newly activated hydrothermal event (refer to Fig. 2-4-2).

b. Measurement of Ice-Melting Point

Regarding well AMJ-1, since the measured minerals are quartz contained in pyroxene andesite or hornblende andesite except in granite, almost all these quartz are generated from the hydrothermal quartz veins. Though the content of the dissolved salinity of each inclusion varies from 0.0 to 2.6wt% in NaCl equivalent, there is no distinct difference of physical and chemical characteristics because of the moderate concentration of Th and IMP (refer to Fig. 2-4-4).

While on the AMJ-2, since all of the measured minerals are quartz contained in pyroxene andesite rocks, these quartz are generated from the hydrothermal quartz veins. The content of the dissolved salinity of each inclusion varies from 0.0 to 2.2wt% in NaCl equivalent. There is no distinct difference of physical and chemical characteristics because of the moderate concentration of Th and IMP (refer to Fig. 2-4-5).

6. Hydrothermal Alteration and Implications around wells AMJ-1 and AMJ-2

Through the examination of cuttings at naked eye and microscope and including the analytical results of X-ray diffraction and fluid inclusion, features of hydrothermal alteration around wells AMJ-1 and AMJ-2 could be disclosed and with this, the geothermal system could be constructed.

1) In spite of comparatively higher permeability of the deeper part of both wells, alteration degree is very weak and vein minerals are not abundant. Quartz index depicted in Fig. 2-4-1 and Fig. 2-4-2 is low. It may result in the very recent geothermal system. However, the homogenization temperature of fluid inclusions shows the bimodal distribution below 1,100m in depth of well AMJ-2, as well as wells AMF-1 and AMF-2. It is thought that the deeper portion surrounding these wells may be reheated by newly activated hydrothermal event.

2) At shallow depths around both wells, the presence of a low resistivity zone was detected by the MT survey. In contrast, the geological studies on cuttings reveal that the smectite occurrence is scarce and the altered argillization zone is not well developed. Accordingly, the possibility of having a cap rock confining a reservoir is not anticipated in. This low resistivity zone might be caused by weakly altered pyroclastic deposit.

3) Transition from smectite zone to chlorite zone was found around 900-1,000m in depth, where a correspondence between measured temperature and homogenization temperature is confirmed. The constituents of alteration minerals suggest that these minerals had been formed by a present geothermal activity.

4) Although it is generally under the low degree of alteration in well AMJ-1, vein minerals such as quartz and calcite increase moderately from 1,100m to 1,300m in depth. Water loss circulation was encountered between these depths and it indicates the possible presence of geothermal fluids with the temperature of 220-240℃ estimated from fluid inclusions thermometry.

While, at the depth between 1,400m and 1,550m is located the main permeable zone of well AMJ-1 with scarce vein minerals and weak alteration. This permeable zone seems to reserve the geothermal fluids different from that at the shallower zone. Reservoir temperatures is relatively high, at 250-280℃, but its permeability is lower compared than well AMF-2. It suggests that the deeper permeable portion of well AMJ-1 may be formed very recently.

Both shallower permeable portion and deeper permeable portion have the possibility to connect with the secondary structural feature associated to the NE trending fault system developed in the western edge of the horst structure around wells AMF-1 and AMF-2.

5) In well AMJ-2, vein minerals such as quartz and calcite were found from 1,140m to 1,220m in depth, where the hydrothermal alteration proceeds distinctly. Loss circulation was recognized at the same portion after the hydro-fracturing test. From the existing geological structure map, this portion corresponds to Laguna Caldera Rim developed in WNW-ESE trend. The promising geothermal reservoir is highly expected to exist along this caldera Rim.

The remarkable higher permeable zone of well AMJ-2 is located between 1,530m to 1,600m. Total loss circulation occurred at the depth of 1,539m and 1,594m and partial water loss continued at the range of 20-50m^3/hr until the bottomhole. This deeper permeable portion of well AMJ-2 corresponds to the structural fracture associated to the west boundary of upheaval zone and forms the regional fault that induced total loss circulation. Reservoir temperature is supposed to be within 280-300℃ by fluid inclusions thermometry.

In addition, on drilling at the deeper portion of well AMJ-2, some chemical material for water loss protection was found from the reinjection tank of the 5Mw power plant adjacent to Laguna de Calderas. Since this plant was distributed from wells AMF-1 and AMF-2, fluid conduit exists between AMJ-2 and these wells.

6) From the constitution of alteration minerals and hydrothermal vein minerals, the neutral-typed geothermal fluids seems to reserve in the Amatitlan geothermal area.

7) In synthesis on the above-mentioned, owing to the low development of hydrothermal alteration, the presence of the cap rock, which overlies the targeting geothermal resources, is not anticipated at the shallow depth beneath wells AMJ-1 and AMJ-2. It seems that the reservoir tapped by well AMF-2 will be with difficulty in the extension toward the west.

2.4.2 Well geochemistry

The geochemical investigation on the well discharge fluids is aimed to ascertain that the fluids are appropriate for the future power generation and to assess the geothermal fluid behavior in the reservoir and its extension. The results of the well geochemical interpretation is utilized to reevaluate and improve the hydro-geochemical model which was constructed in the previous survey, and would be basic information for geothermal development of the Amatitlán field.

1. Procedure

The geochemical sampling and analysis of hot water and gas of the well discharge was carried out on three samples discharged at the different well head pressure condition in each wells AMJ-1 and AMJ-2. However, only one hot water sample was taken in the flow test of the well AMJ-1 due to the steam dominated discharge. Major and minor chemical and isotope analyses on the hot water, gas and steam condensate were carried out in Japan. The numbers of collected fluid samples are as below.

①AMJ-1

Hot water	:	1 samples	(WHP: 700psi)
Gas	:	3 samples	(WHP: 200, 110, 46psi)
Steam condensate	:	3 samples	(WHP: ditto)

②AMJ-2

Hot water	:	3 samples	(WHP: 29, 33, 64psi)
Gas	:	3 samples	(WHP: ditto)
Steam condensate	:	3 samples	(WHP: ditto)

Discharged hot water from the well AMJ-2 was sampled at the weir-box, but the sample for hydrogen and oxygen isotope was also taken from the sampling mini-separator. Regarding hot water from the well AMJ-1, a water sample was collected at outlet of the muffler-silencer connected with the flowline at a high well head pressure condition (700psi) after the flow rate measurement, since water discharge from this well was not recognized at relatively low well head pressure condition. Gas and steam condensate was sampled through the mini-separator and a spiral tube water cooler.

Chemical and isotopic analysis on components shown in below was carried out in Japan.

①Hot water: TSM, Na, K, Li, Ca, Mg, Fe, Al, Cl, SO_4, T-CO_2, HCO_3, F, B, Br, I, As, T-SiO_2, Sr, H_2S, Hg, $\delta D(H_2O)$, $\delta\,^{18}O(H_2O)$, $\delta\,^{18}O(SO_4)$, $\delta\,^{34}S(SO_4)$, $\delta\,^{13}C(HCO_3)$, Tr

(A part of the components was not analyzed for the water sample from the well AMJ-1.)

②Gas: N_2, H_2, CH_4, C_2H_6, O_2, Ar, He, Ne, $^3He/^4He$, $^4He/^{20}Ne$, $\delta\,^{13}C(CO_2)$, $\delta\,^{13}C(CH_4)$, $\delta D(H_2)$, $\delta D(CH_4)$, $\delta\,^{34}S(H_2S)$

③Steam condensate: Na, Cl, SO_4, As, Hg, $\delta D(H_2O)$, $\delta\,^{18}O(H_2O)$

Using the chemical and isotope analyses of this survey and the existing data, geochemical interpretation on the geothermal fluid behaviors in the Amatitlán production field, which including not only the wells AMJ-1 and AMJ-2 but also the wells AMF-1 and AMF-2, was conducted. New chemical data on the wells AMF-1 and AMF-2 collected during the continuos production of these wells (from February 1999 to September 2000) were presented by INDE.

2. Results of interpretation

Results of the chemical and isotopic analyses with the results of field measurement are shown in Table 2-4-5 and 2-4-6.

a. Fluid geochemistry

The discharged hot water from the wells AMJ-1 and AMJ-2 is neutral Cl type as same as water of the wells AMF-1 and AMF-2 in Calderas based on major anion classification. Chloride concentration in reservoir water of the well AMJ-2 is close to the well AMF-2 (2,660-2,780mg/L and 2,560-3,470mg/L, respectively) indicating their reservoir connection. The hot water of the well AMJ-1 is slightly higher in HCO_3 ratio though classified in Cl type and relatively low in reservoir Cl concentration (826mg/L), implying the water is contributed by steam condensate water which probably mixed at the silencer muffler.

An enthalpy versus Cl diagram on the geothermal fluids in the Amatitlán field is shown in Fig. 2-4-6. In this diagram, the reservoir waters of the wells AMF-1, AMF-2 and AMJ-2 seem to be derived from a common parent fluid with steam separation (S1 and S2). The AMJ-2 hot water is not distinguished from the AMF-2. The degree of the steam separation is larger in AMF-1 water relative to in AMF-2 and AMJ-2. Assuming the parent fluid (P) of 330℃ and 2,500mg/L in Cl along the line S1 permits to explain the mixing into hot spring waters of the south shore of Lago de Amatitlán and also Río Michatoya (mixing lines M1 and M2). The Cl concentration of reservoir fluid of the well AMJ-1 is unfortunately not known due to the nearly steam only discharge and the steam condensate contamination in the water sample. However, the moderately high in Cl concentration (1,220mg/L in raw analysis) even in the water sample contaminated by steam condensate and the similarities of water and gas chemistry to the other three wells suggest that the hot water having a Cl concentration probably comparable with the water of the other wells exists in the reservoir of the well AMJ-1. The nearly single vapor phase discharge of this well may result from low permeability and high temperature in its reservoir. The reservoir water of the well AMJ-1 is believed to be derived also from the common parent fluid.

The fluid samples of the well AMJ-2 collected at the different discharge conditions in three steps represent some variations in their chemistries. Variation diagrams of physical (discharge enthalpy) and chemical properties against the well head pressure on the well AMJ-2 are shown in Fig. 2-4-7. The chemical variations are explained by mixing of two kinds of fluid in the well borehole, and the ratio of their inflow rate may change with the well head pressure.

b. Reservoir connection with the existing production wells

The chemical trend diagrams of the existing wells, AMF-1 and AMF-2, are shown in Fig. 2-4-8 and Fig. 2-4-9. The data of the water and gas chemistries and geochemical temperatures represent significant variations, and some of them are possibly due to the inconsistent sampling and the analytical error. However, some of the variations, i.e. increase of Mg and Fe in water and O_2 in non-condensable gas, are considered to be caused by the drilling (and the injection test) of the well AMJ-1. Although degree of the increase of Mg and Fe does not correspond in the two wells, these trends, especially the apparent increase of Fe in the well AMF-2, are believed to indicate contamination of the mud water used in the drilling of the well AMJ-1. The increase of O_2 may suggest a contribution of air dissolved in the mud water (and cool fresh water used in the injection test).

From the evidences mentioned above, the reservoirs of the well AMJ-1 and the two existing wells are thought to have some connection between themselves. The connection, however, is inferred not so significant, because the increases of Mg and Fe were not observed until after three months or more of the completion of the AMJ-1 drilling, and because their increasing rates were relatively slow. One of the reasons for the slow response could be the low permeability in the reservoir around the well AMJ-1.

c. Fluid suitability for power generation

The discharged water of the well AMJ-2 sampled at atmospheric pressure is quite high in silica concentration ranging 1,030-1,130mg/L, which reaches 3.1-3.4 times of saturation concentration of amorphous silica. Therefore, continuous utilization of the AMJ-2 discharge fluid for power plant with making the hot water open to atmospheric pressure may yield silica scaling in the water pipeline and reinjection well. Consequently, the closed reinjection system in which the separated water remains in high pressure is recommended. If the separated water remains in high pressure, the degree of over-saturation of amorphous silica is able to be lowered. Alternatively, even in a case of making the hot water open to atmospheric pressure, the reinjection system using the retention pond is possibly effective to reduce the silica scaling. The retention of separated hot water accelerates silica polymerization in the hot water and prevents scale formation.

In the case of geothermal power generation using condensing turbines, the non-condensable gas content in steam sometimes affect severely the costs of plant construction. In general, if the gas content exceeds about 10 wt% or so, condensing machines become uneconomic owing to the high power absorbed by the gas exhaustion process. The non-condensable gas contents in discharged steam from the wells AMJ-1 and AMJ-2, which are normalized content in steam separated from hot water at the pressure of 5 atG, are lower than 2.5 wt%. Therefore, the non-condensable gas in steam of the wells AMJ-1 and AMJ-2 will not affect severely the costs of plant construction.

2.4.3 Completion testing and borehole surveys

1. Objectives and settings

The objectives of the completion tests applied to wells AMJ-1 and AMJ-2 were:

a. To estimate the position of main production zones in order to define the portions of blank and slotted 7 5/8" liners.

b. To assess the global hydraulic properties of the production zones

c. To estimate fluid temperature and pressure at the main production zones.

To fulfill the first objective, pressure and temperature surveys as well as water loss tests were programmed. To fulfill the second objective, a maximum injection test and a multiple-rate injectivity test with measurement of the transient fall-off were conducted. To achieve the third objective, series of pressure and temperature surveys at different standing times were performed.

2. Pressure-temperature surveys and water loss tests

Table 2-4-7shows the specifications for all static temperature and pressure surveys done on both wells. The specifications for water lost test on wells AMJ-1 and AMJ-2 are shown in Table 2-4-8 and Table 2-4-9 respectively.

3. Multiple-rate test and transient test

a. Field procedure

Multiple-rate injection and fall-off tests to estimate the gross near well hydraulic properties were carried out. First a maximum injection test was carry out. Depending on the maximum injection rate accepted by the well being tested three different injection rates were set as well as the injection duration. After the injection of the third rate ceased, the fall-off transient was recorded. Table 2-4-10 and Table 2-4-11 summarize the specifications for these tests on wells AMJ-1 and AMJ-2 respectively.

Using the results of the multiple-rate injection test the *injectivity index, I.I* – the simplest crude gauge of the total permeability of the well and expressing the rate of mass the well is able to accept per each ksc (kg/cm^2) of build up- was estimated. This value is the slope of the line best representing the linear alignment of the step mass flow rate to the stabilized pressure. The *I.I* is also an early crude indicator of the productivity of the well.

b. Data processing

The fall-off data was used to estimate the *flow capacity* or "kh/μ" coefficient, the *transmissivity* or "kh" coefficient and the *storativity* (or the porosity-compressibility-thickness, "φch" coefficient). These values represent an average of the global hydraulic properties of the reservoir. The *skin factor* (S) and the *well storage coefficient* (Cd) representing the global hydraulic properties of the portion of the reservoir near the well were obtained from the information of the pressure buildup during injection. The "kh" coefficient measures how the permeable zone can deliver fluid mass. The "Storativity" measures how effectively the reservoir rocks can store fluid before allowing it to permeate. The "Skin effect" measures the degree of improvement (negative value) or damage (positive value) suffered by the feed zones during drilling operations; the "wellbore storage coefficient, Cd" indicates the degree of early time variation of the mass flow into the formation during injection.

A computer curve matching procedure was utilized to fit field data to theoretical curves. The formulation utilized to reproduce pressure variations during injection and fall-off is a rearrangement of that common to the well testing engineering.

$$\Delta P = Pd * \left[\sum_{n=1}^{N} q_n \left\{ Sf_{n-1} * \left(\left(E_i\left(\frac{Td}{t - t_{n-1}}\right) + 2 * S \right) - Sf_n \left(E_i\left(\frac{Td}{t - t_n}\right) + 2 * S \right) \right) \right\} \right] \quad 1)$$

Where:

$$Pd = -\frac{1}{4\pi TR} \qquad 2)$$

$$Td = \frac{STO}{2TR} * r_w^2 \qquad 3)$$

$$STO = \phi ch \qquad 4)$$

$$TR = \frac{kh}{\mu} \qquad 5)$$

$$E_i(x) = \int_x^{\infty} \frac{1}{y} e^{-y} dy \qquad 6)$$

$$Sf_n = 1 - \frac{d\left(E_i\left(\frac{Td}{t - t_n}\right)\right)}{dt} \qquad 7)$$

ΔP : Pressure change (Pa)

TR : Flow capacity

STO : Storativity

Sf : Sand face rate

S : Skin factor

Ei(x): Exponential integral (well function)

t_n : Duration of the nth injection rate (s)

t : Elapsed time since injection started

q : Injection rate (m^3/s)

k : Permeability (m^2)

h : Reservoir thickness (m)

μ : Viscosity (Pa.s)

φ : Porosity

c : Compressibility (Pa^{-1})

4. Well AMJ-1

Pre-completion pressure and temperature surveys were carried out on January 21, 2000 after the drilling operations reached 800m and before the 9-5/8" casing was cemented. This well was drilled 200m below the 1500m originally programmed. Once this depth was reached, the borehole was prepared for 5h, 12h, 24h and 48h recovery temperature and pressure surveys at open hole. Completion tests were carried out as scheduled, from February 7 to 15, 2000.

Fig 2-4-10 shows the temperature during drilling.

a. Hydrofracturing and checking of the maximum loss rate

To clean the well of mud and cuttings left in the loss zones during drilling and to improve the permeability two days (February 8 through 9) of hydrofracturing operations were carried out. After refilling tanks, water was injected to measure the maximum injection rate. This rate resulted in 75 m^3/h.

b. Water Loss Temperature Survey

In Fig. 2-4-11 the temperature profile obtained during the water loss temperature test is depicted together the temperature profiles at different standing times, Fig. 2-4-12 depicts the corresponding pressure profiles at these different standing times. The temperature profile for the water loss test indicates that below the plain casing (1,400m) the temperature reveals the effects of the two days of hydrofracturing. At 1,460m there is a water entrance with the most conspicuous mark at a depth of 1,600m. These places were identified during drilling as moderate loss zones. In general, no big loss zone is identified from this test. Comparatively, the largest seams to be that around 1,600m depth.

c. Multiple-rate test and transient test

1) Field procedure

Following, the multiple-rate injection and fall-off tests to estimate the gross hydraulic properties of the reservoir near well AMJ-1 were carried out. Since the maximum injection rate accepted by the wells was 75 T/H and the remaining water in tanks was 300 m^3, the three rates were set to 30, 50 and 70 T/H to be injected during 45 minutes respectively. Fig. 2-4-13 depicts the pressure at the depth of the instrument vs. the injection flow rate.

Using the results of the multiple-rate injection test the *injectivity index, I.I* of 1.27 T/H per ksc was estimated, which is a small value for a common geothermal well. This indicates either low permeability of the well or temporarily damage by drilling operations.

Table 2-4-12 shows the results of the matching process applied to Hörner presentation of Fall-Off data. The estimated hydraulic properties of the reservoir were; Flow capacity value (kh/μ) = 4.54E-10 m^3/Pa.s, Storativity (φch) = 1.09E-04 m/Pa, Skin Factor = 0.9, and Wellbore Storage = 30. Considering a reservoir temperature of 264.53°C and pressure of 93.97 ksc (latest recovery values at 1600m depth where the tool was set during the test), the viscosity of reservoir fluids is 0.0001011 Pa.s, thus the transmissivity (kh) value was calculated in 45.9 mdarcy-m. As interpreted from the injectivity index value, the permeability of the reservoir seems to be low, however the storativity value is high.

From the equation $\varphi c_t = 10.5 * P^{-1.66}$ and the value of storativity resulted from the matching process, the acting thickness of the reservoir resulted in 182m (confirming the water lost test results).

2) Interpretation

The calculated hydraulic properties around well AMJ-1 reasonably reproduced the fall-off portion indicating that for long elapsed time the reservoir was acting with flow capacity and storativity values as those resulting from the matching process. However, using these values of flow capacity and storativity, the calculated and measured values of pressure build up during injection did not match, except for the for the first injection rate.

The fact of a large storativity value led to the interpretation that a possible steam or two-phase saturated reservoir were present in the vicinities of the drilled area and that in general the initial "flow capacity" of the reservoir is low.

5. Well AMJ-2

a. Period of testing

Completion tests for well AMJ-2 were carried out as scheduled, from November 8 to 16, 2000.

b. Hydrofracturing and checking of the maximum loss rate

To clean the well of mud and cuttings left in the loss zones during drilling and to improve the permeability one day of hydrofracturing operations was carried out. The first hydrofracturing ended with a maximum injection test that indicated a value of 53T/H. After refilling tanks a second hydrofracturing operation with its corresponding maximum injection tests were carried out. This rate resulted in 106 T/H. Then a third hydrofracturing and maximum injection tests were done. The rate after this trial was 126.47 m^3/h indicating the activation of a permeable zone not detected or sealed by drilling operations.

c. Static temperature and pressure surveys

The depths of the stops for the static P/T surveys were set to 200, 300, 400, 500, 600, 700, 800, 1000, 1100, 1150, 1175, 1200, 1250, 1275, 1300, 1350, 1400, 1450, 1475, 1500, 1525, 1550, 1575, 1600 and 1625m. All stations had stops of 5 minutes except for stations at 1000 and 1500m. Fig. 2-4-14 depicts profiles obtained during the several Pressure–Temperature surveys. Fig. 2-4-15 depicts the corresponding pressure profiles at these different standing times

d. Water Loss-Temperature Survey

For the water loss test the cooling effects of hydrofracturing were clear below the plain casing (1,000m). At a depth of 1,200m the temperature profile indicates a water loss area (refer to Fig. 2-4-14). Another and more conspicuous water loss zone was recorded at a depth of 1,600m. Only the second loss zone was identified during drilling. As result of these water loss-temperature tests only moderate loss zone were identified and the largest seams to be that around 1,600m depth.

e. Multiple-rate test and transient test

1) Field procedure

Multiple-rate injection and fall-off tests were carried out. Since the maximum injection rate accepted by the wells was 126.456 T/H and the Maximum water in tanks was 200 m^3, the following rates and times were set to carry out the test; 62T/H during 15 minutes, 82T/H during 30 minutes, 112T/H during 30 minutes and 127T/H during 15 minutes. After the injection of the fourth rate ceased, the fall-off transient was recorded during 10 hours. Fig. 2-4-16 depicts the pressure variation recorded at 900m depths during the injection and fall-off tests.

The form of this pressure-time curve indicates is a multi-feed zone well and thus produced a pressure build-up curve of different features. The initial part (corresponding to the first two injection flow rates), seems to be the response of a low flow capacity feed zone, while the part corresponding to the two final injection flow rates seem to be the response of a higher flow capacity zone. The end of the fall-off (where the curve should become progressively flat) shows pressure values lower than those when the test was commenced. This was caused by the suction of the inertia of the injected mass into the high transmisivity zone of the well. There is no theory to interpret multi-feed zones wells. However in order to have average values of hydraulic properties and to compare to those of well AMJ-1, this information was processed using single feed zone procedures.

Using the pressure build-up results of the multiple-rate injection test the *injectivity index, I.I* was estimated in 4.44 T/H per ksc. The value of the I.I is a fairly good value for a common geothermal well, indicating either a low permeability of the well or temporarily affects on the permeability due to drilling operations. The temperature logs (refer to Fig. 2-4-14) indicates two permeable zones. One at 1,600m depth, corresponding to a zone where total loss was experienced during drilling, and the other at 1,200m depths corresponding to a zone where no total loss during drilling was experienced. It is believed that this is one of the zones activated by the hydrofracturing operations.

Table 2-4-13 shows the results of the matching process applied to a Horner representation f the Fall-Off data. The estimated average hydraulic properties of the reservoir feeding well AMJ-2 were as follows; Flow capacity value (kh/μ) = 2.84E-9 m^3/Pa.s, Storativity (φch) = 5.85E-06 m/Pa, Skin Factor = -0.5, and Wellbore Storage = 0. The injection temperature was 50°C and pressure of 40 ksc (values at 900m depth where the tool was set during the test), the viscosity of reservoir fluids is 0.001013 Pa.s, thus the transmisivity (kh) value was calculated in 53.9 mdarcy-m which is a fairly low value. The storativity value 5.85E-6 m/Pa is also a low value.

2) Interpretation

The matching results reasonably reproduced the initial part of the build-up curve and for a very short time, with the fall-off curve. This indicates that for short periods the reservoir acted with average transmisivity and storativity values as those resulting from the matching process. However, using these values, the calculated and measured pressure build up values did not match.

It seems that during the initial times of injection the only acting feed zone was the lower one (low transmisivity) and that, as the injection proceeded (water level within the well rose), the upper feed zone at 1200m started to act. The explanation to this fact could be in the pressure of the upper feed zone. While the water level above the upper zone was not high enough, the fluid produced by this zone continued to flow with the injected fluid towards the lower feed zone and when the water level rose enough to overcome this pressure, the upper feed zone started to accept injection fluid.

However, for the later injection times, the measured pressure build –up curve is flatter than the calculated one. This indicates an improved flow capacity (kh/μ) value, an improved storativity (φch) of the upper feed zone. Nevertheless, if the controlling improved parameter were only the transmisivity (kh/μ), the measured curve would be not as flat as is it was recorded. This means that the (φch) value was increase. To have a storativity value increased, the compressibility (c) should be the parameter of higher value. This might indicate that the upper feed point is mostly steam.

As injected water entered into the upper feed zone, condensation of steam occurred enhancing even further the flatness of the pressure build-up curve. After the injection ceased, the void left by the condensed steam permitted the inflow of water into the upper zone and this is the reason for the steep drop of pressure in the fall-off curve even to values lower than the pressure values when the test was initiated. As time proceeded, the steam regained its position within the permeable zone and the pressure started gradually to rise.

6. Heating up borehole surveys on both wells

Once the Injection and fall-off tests were completed heating up, pressure and temperature recovery surveys. Fig. 2-4-11 and Fig. 2-4-14 show the results of these measurements for wells AMJ-1 and AMJ-2 respectively.

7. Flow and Interference tests on Wells AMJ-1 and AMJ-2

A program to flow test wells AMJ-1 and AMJ-2 was devised. Well AMJ-1 was tested two times. The first time was during the third term of services in Guatemala carried out from June 10 to July 9, 2000. Well AMJ-2 was tested also two times, one during the fourth term of services in Guatemala carried out from November 2 to December 5, 2000 and the second time by INDE from February 5 to February 9, 2000.

8. Well Stimulation

a. Well AMJ-1

After the heating up surveys, the well was allowed to build up pressure, however there was not gas release after completion testing. The compressor in the INDE's drilling rig was used to compress the well to 500 PSIG. The procedure was repeated several times and finally fluids were produced at 11:00 AM of June 23, 2000. After the testing the well showed very high wellhead pressure with gas release. To keep the wellhead pressure to controllable levels, the well was constantly bled though the 2" kill line valve until it was close. The well was left to build-up pressure (controlling the pressure through the kill line) until the well was opened for production testing at 17:00 on November 18, 2000.

b. Well AMJ-2

This well also did not show any gas release after the completion and heating up tests. It was necessary to interconnect this well to AMJ-1 in order to warm up and build up pressure. The pressure was let to build-up to 600 PSIG and the main valve was opened for first discharge at 14:45 of November 23, 2000. The well was opened for second flow testing on February 5, 2000 following the same pressure build up procedure.

9. Recording interference pressure in wells AMF-1, AMF-2, AMF-3 and AMF-4

INDE is continuously monitoring downhole pressures in wells AMF-3 and AMF-4 and wellhead pressures in wells AMF-1 and AMF-2.

Only during the drilling of well AMJ-2, drilling fluids were detected in the reinjection pond near the ICA-CFE power plant. This indicates communication between well AMJ-2 and either or both wells AMF-1 and AMF-2. However none of the pressure recordings on wells AMF-1, AMF-2, AMF-3 and AMF-4 showed apparent pressure interference effects during the discharge of wells AMJ-1 and AMJ-2.

10. Flow Tests.

Wells were flow tested using the Lip Pressure and Weir method and arrays as those depicted in Fig. 2-4-17. The empirical equation in this method relates the enthalpy of the two phases fluid, the mass flow rate to the lip pressure measured at the end of the discharge pipe. In this equation the lip pressure is the only known value. However, using an atmospheric separator and a weir, the mass flow of the water separated at atmospheric conditions can be calculated measuring the water level in the weir. Considering an isoenthalpic expansion and a numerical root finding procedure the production enthalpy and the total mass flow (at well head conditions) were calculated. The input values were, weir height, size of discharge pipe and thermodynamic properties of water. These calculations are done for stable readings of the lip pressure and water height.

The relationship between total mass flow rate and enthalpy is provided by the following empirical equation which is validated for 75, 150 and 200 mm diameter discharge pipes and an enthalpy range from 130 to 680 kcal/kg :

$$W_{tp} = \frac{1.053\, p_c^{0.96}\, d_c^2}{h_t^{1.102}} \qquad 8)$$

where: P_c = lip pressure at end of discharge pipe (ksca),

d_c = diameter of discharge pipe (mm)

This equation can be solved simultaneously with equation for the water mass flow in the wair:

For the weir method, the water flow from the atmospheric silencer was measured using a 90° V-notch weir. For this type of weir, the water flow rate is proportional to $h^{2.5}$, where h is the head above the weir notch. This is a general relationship and each weir has a different discharge coefficient

$$W_w = 4.93x\,10^{-5}\,\rho.h^{2.5} \qquad 9)$$

depending primarily on the angle of the notch. For the 90° V-notch weir:

where:

W_w = water flow rate (tons/ hour),

ρ = water density at weirbox temperature (kg/m^3),

h = head of water above weir notch (cm).

The steam fraction (x') at atmospheric pressure is given by:

$$x' = \frac{h_t - h'_w}{h'_s - h'_w} \qquad 10)$$

where:

h_t = total fluid enthalpy (kcal/kg),

h'_w = water enthalpy at atmospheric pressure (kcal/kg),

h'_s = steam enthalpy at atmospheric pressure (kcal/kg).

From a mass balance on the atmospheric silencer:

$$W_{tp} = \frac{W_w}{(1-x')} = \frac{W_w(h'_s - h'_w)}{(h'_s - h'_t)} \qquad 11)$$

This last equation provides a relationship between total mass flow rate and enthalpy that can be solved simultaneously with the lip pressure relationship (equation 8) to give the total mass flow rate and enthalpy. The power produced from the well (at wellhead conditions and 7 ksca of separation pressure) is calculated here, considering Single Flash technology with condenser pressure set at 0.12 ksca.

a. Well AMJ-1

First flow test

The mass flow, enthalpy and power produced from the well is graphically depicted in Fig. 2-4-18. The well characteristics curve is depicted in Fig. 2-4-19

Second Flow Test

The mass flow, enthalpy and power produced from the well is graphically depicted in Fig. 2-4-20. The well characteristics curve is depicted in Fig. 2-4-21. These figures depict a good improvement in flowing characteristics

b. Well AMJ-2

First Flow Test

The mass flow, enthalpy and power produced from the well is depicted in Fig. 2-4-22. The well characteristics curve is depicted in Fig. 2-4-23

Second Flow Test

The mass flow, enthalpy and power produced from the well is depicted in Fig. 2-4-24. The well characteristics curve is depicted in Fig. 2-4-25. These figures depict a good improvement in flowing characteristics

11. Borehole dynamic surveys

As wells attained Lip Pressure stability for a valve opening, borehole pressure and temperature survey in flowing conditions were done (refer to Table 2-4-15). Fig. 2-4-16 shows these results for well AMJ-1 and Fig.2-4-18 for well AMJ-2.

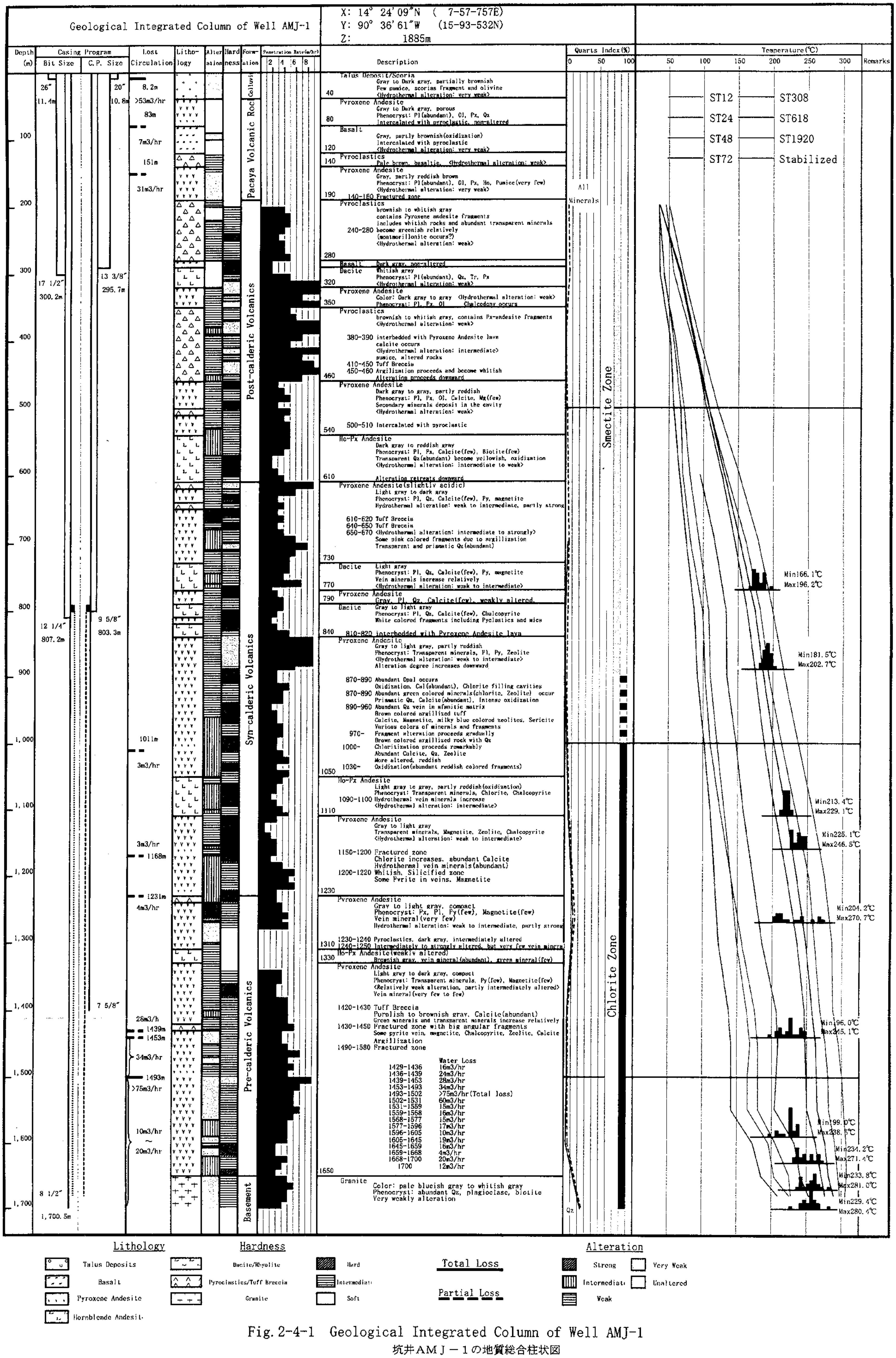


Fig. 2-4-1 Geological Integrated Column of Well AMJ-1
坑井ＡＭＪ－１の地質総合柱状図

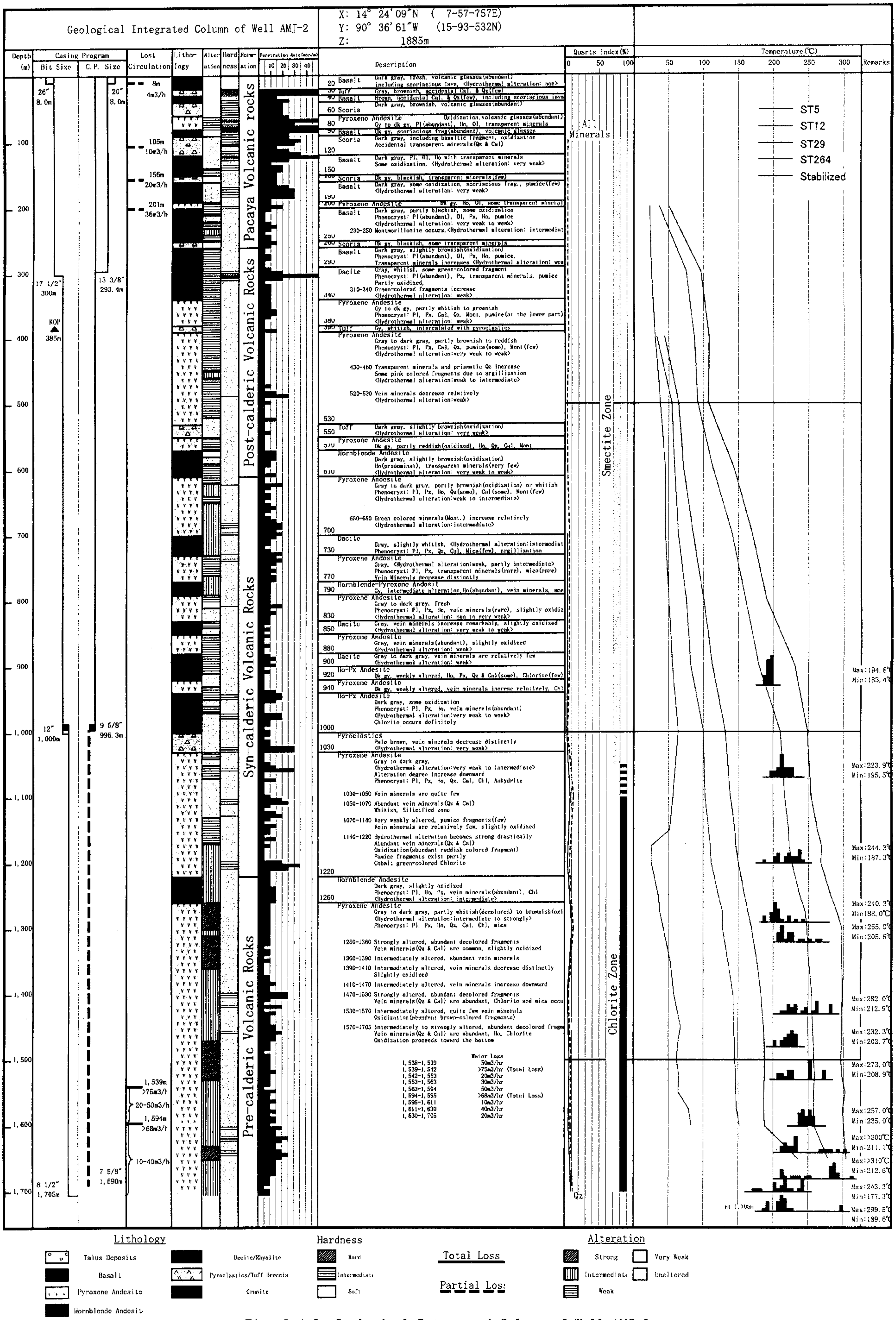


Fig. 2-4-2 Geological Integrated Column of Well AMJ-2

AMJ－2号井の地質総合柱状図

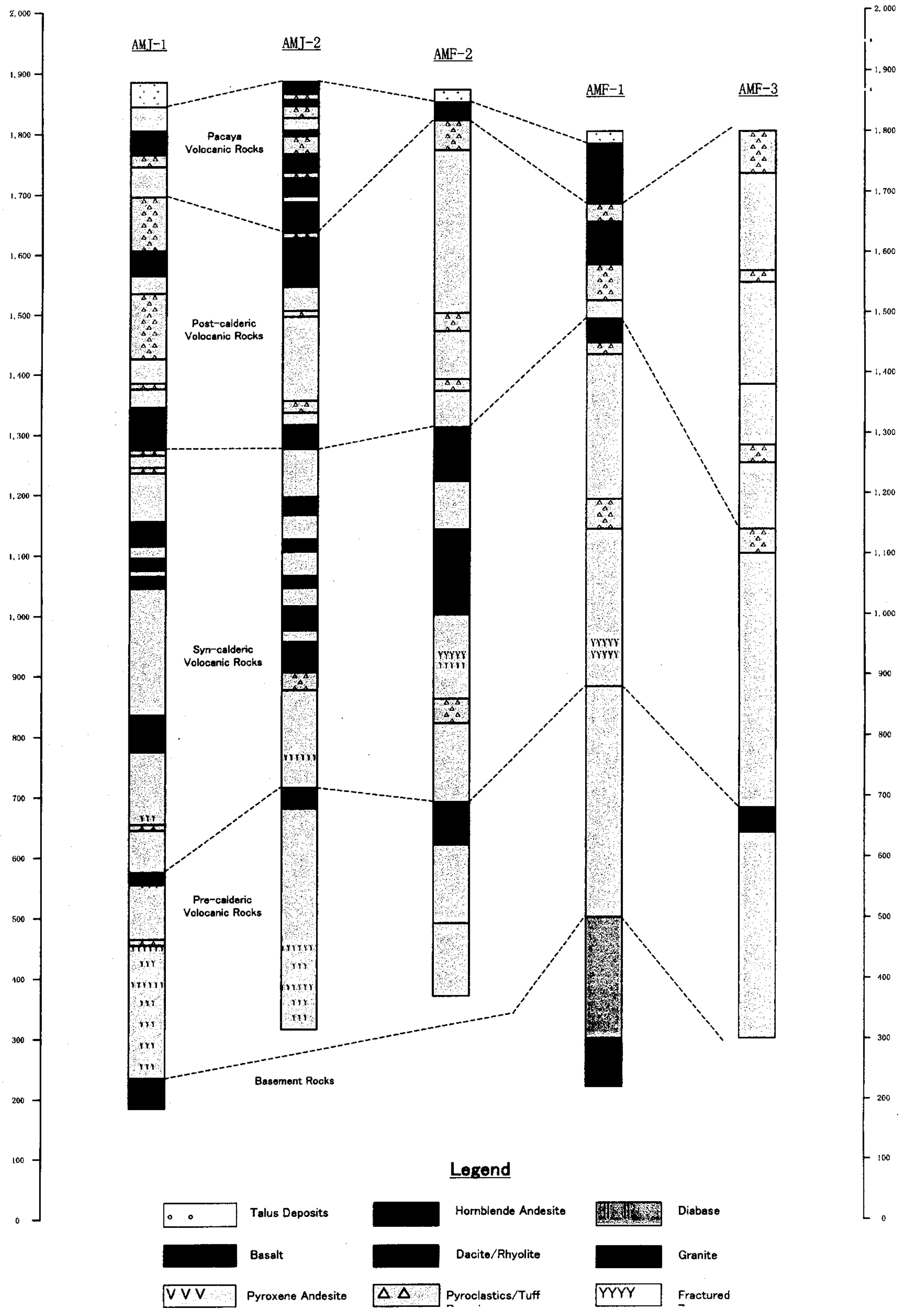


Fig. 2-4-3 Correlation of Geothermal Columns in Amatitlan Geothermal Field

アマティトラン地熱地域の地質柱状対比図

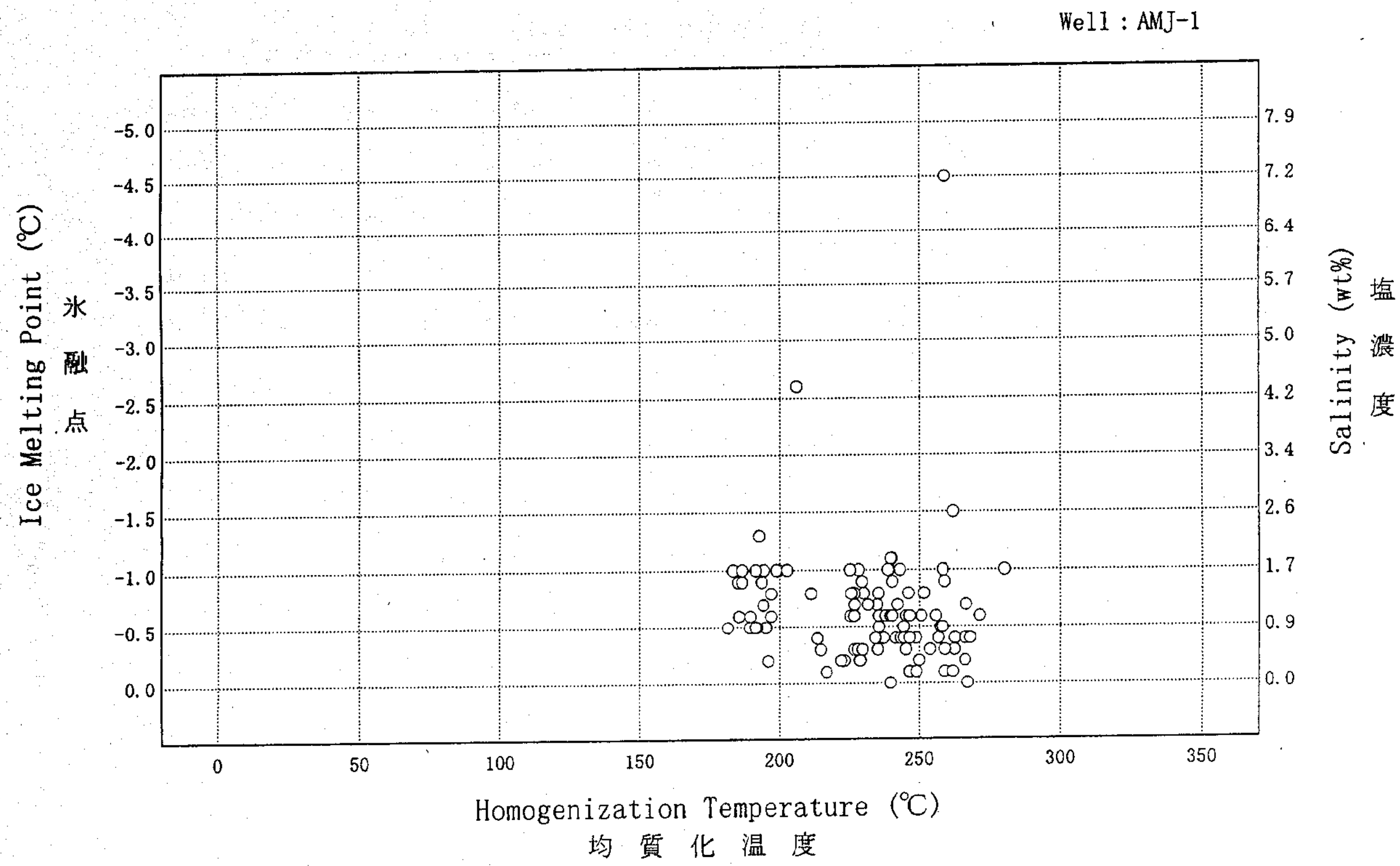


Fig. 2-4-4 Homogenization temperature vs. melting point of fluid inclusion from well AMJ-1

流体包有物の均質化温度ー氷融点関係図

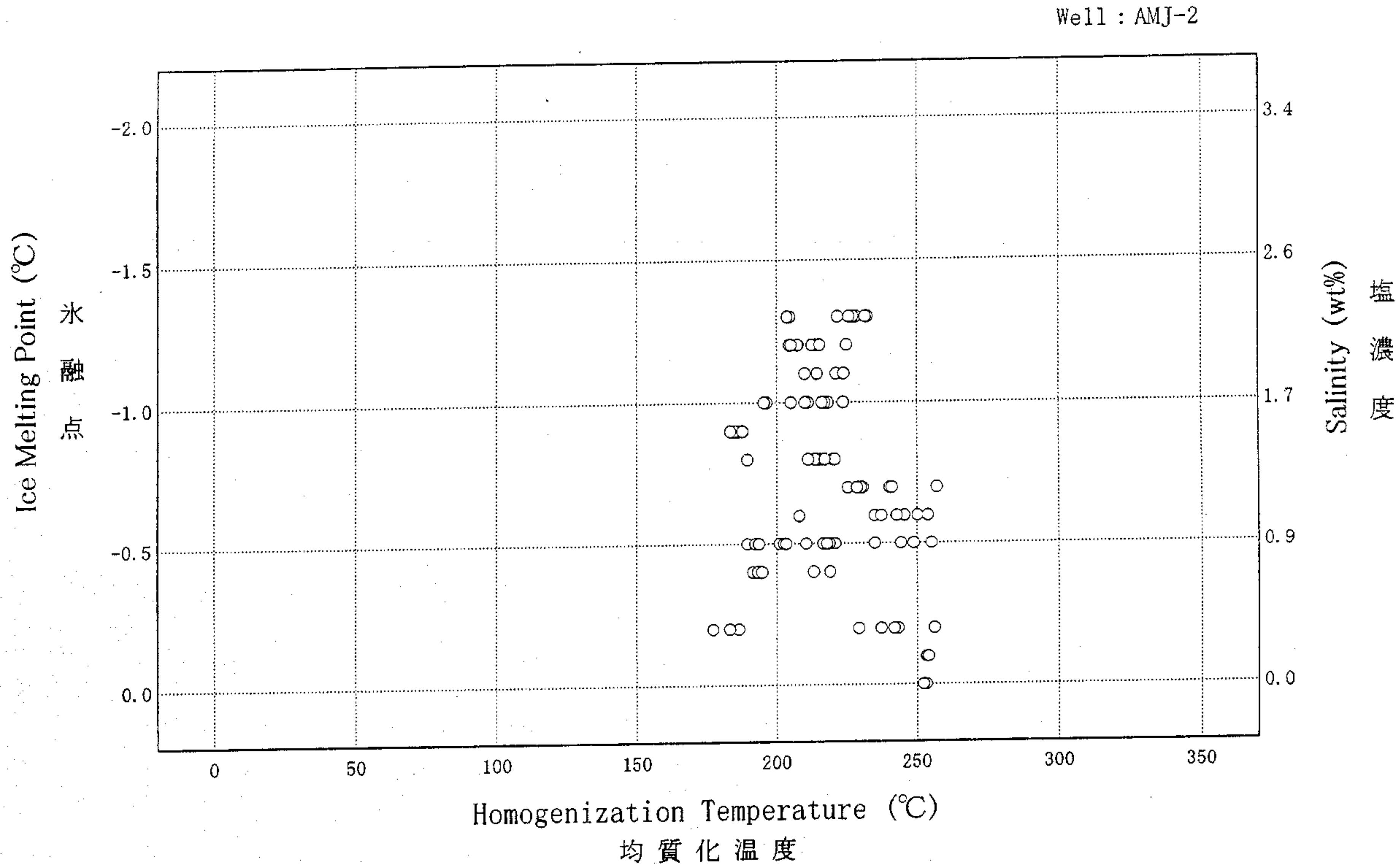


Fig. 2-4-5 Homogenization Temperature vs. Ice Melting Point of fluid inclusion from Well AMJ-2
流体包有物の均質化温度ー氷融点関係図

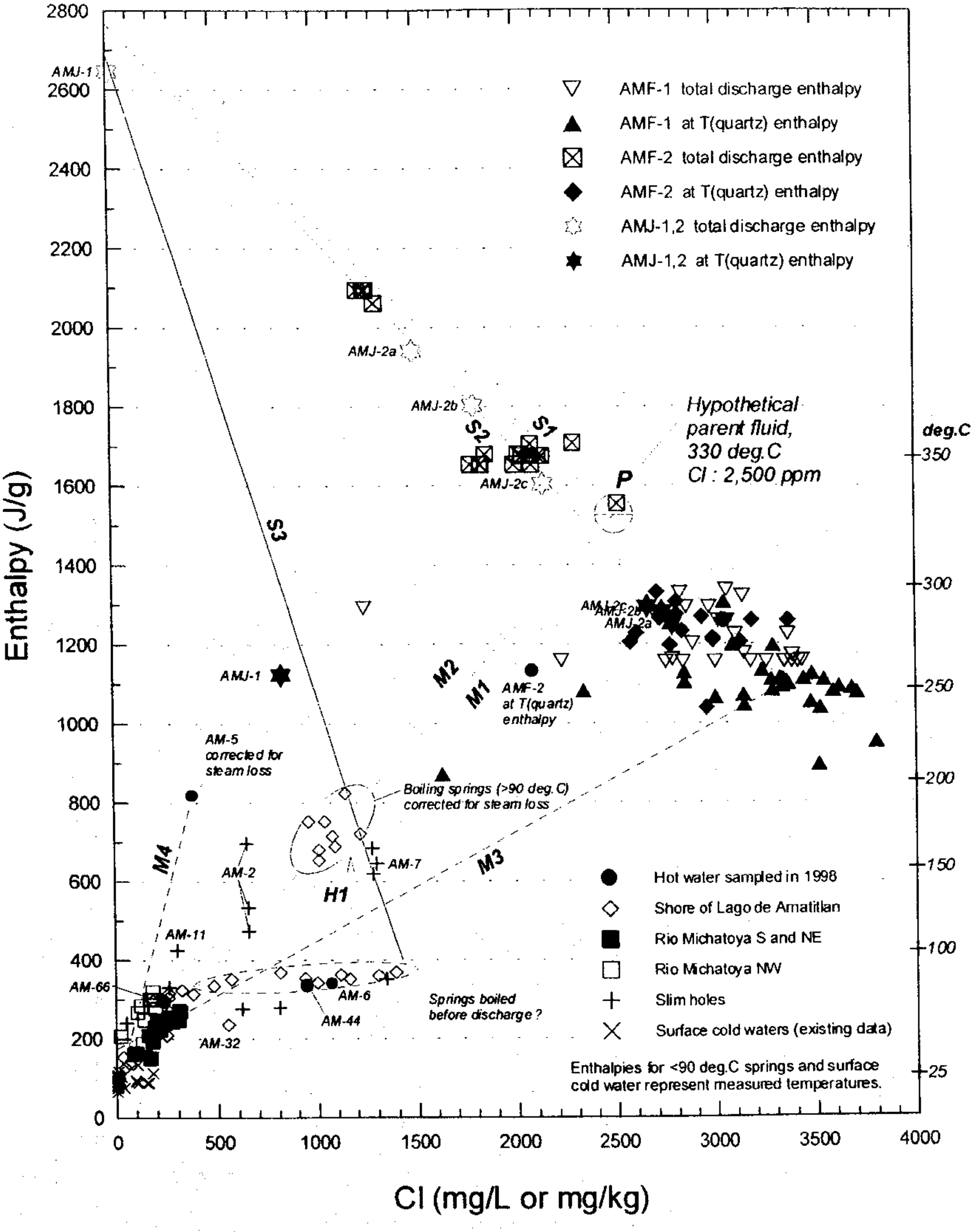


Fig. 2-4-6 Enthalpy versus Cl diagram

エンタルピー－Cl 相関図

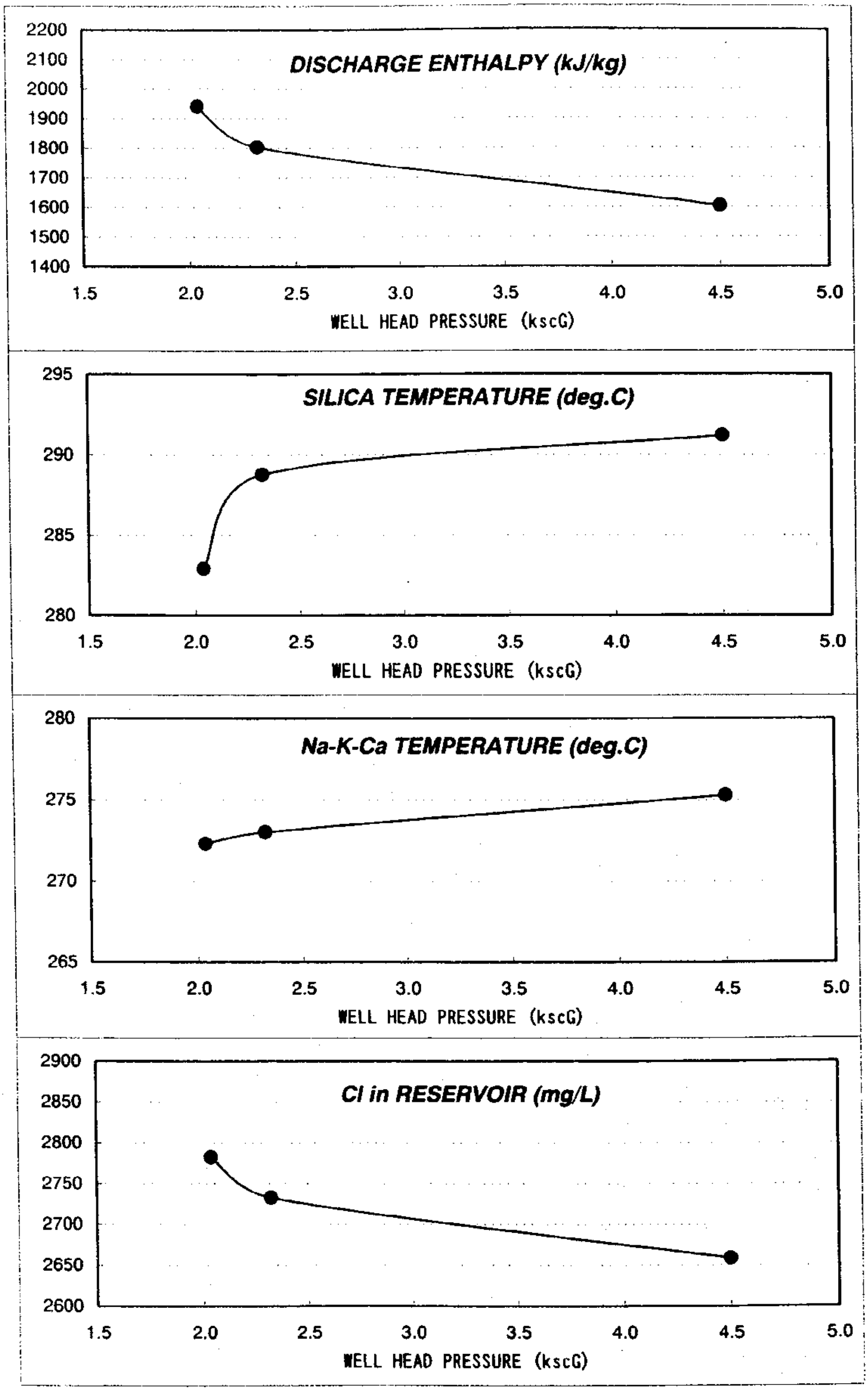


Fig. 2-4-7 Variation diagram of water chemistry of the well AMJ-2

AMJ-2熱水化学特性変化図

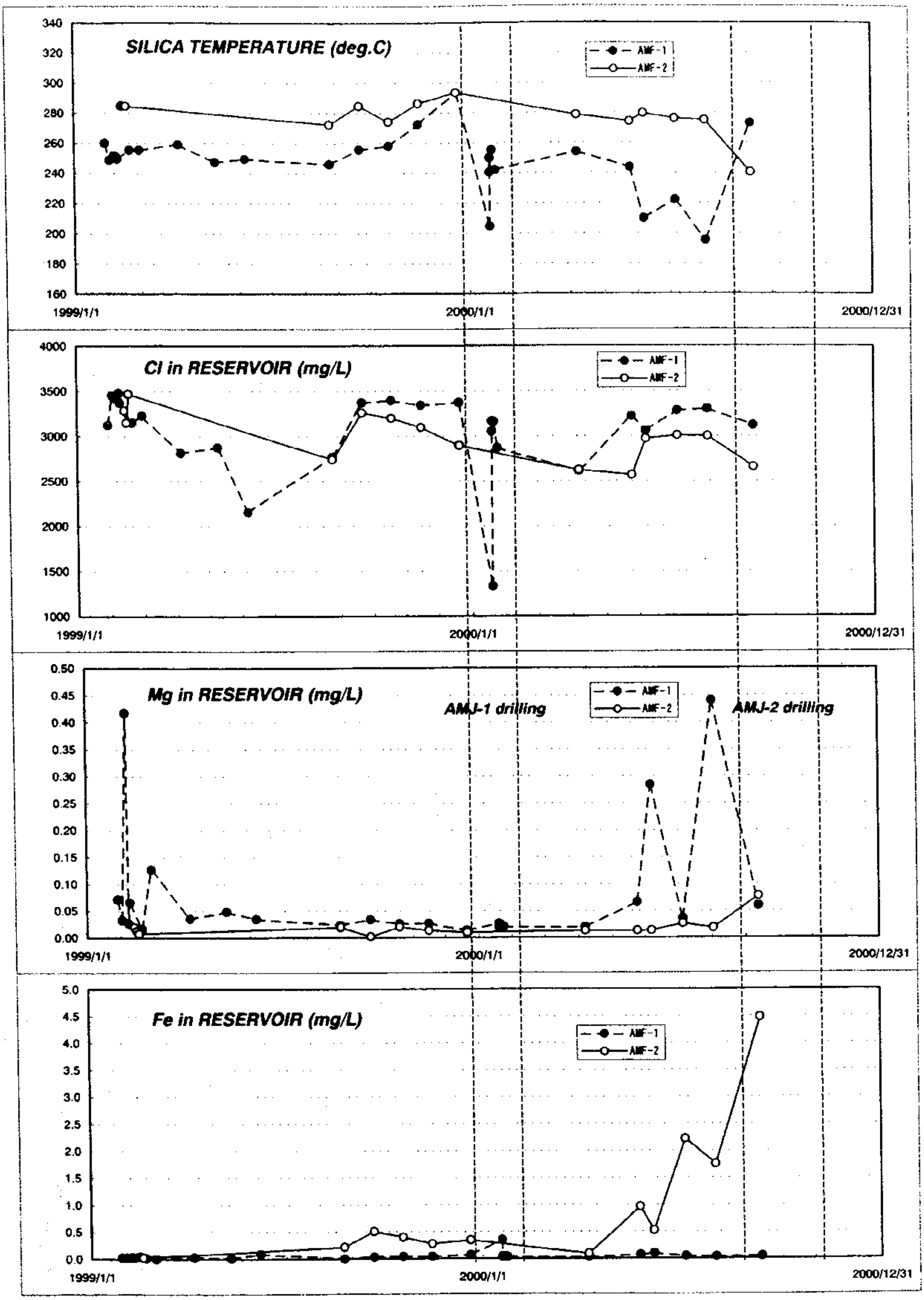


Fig. 2-4-8 Trend diagram of monitoring data on water chemistry of the wells AMF-1 and AMF-2

AMF-1及びAMF-2の熱水化学特性に関するモニタリングデータ経時変化図

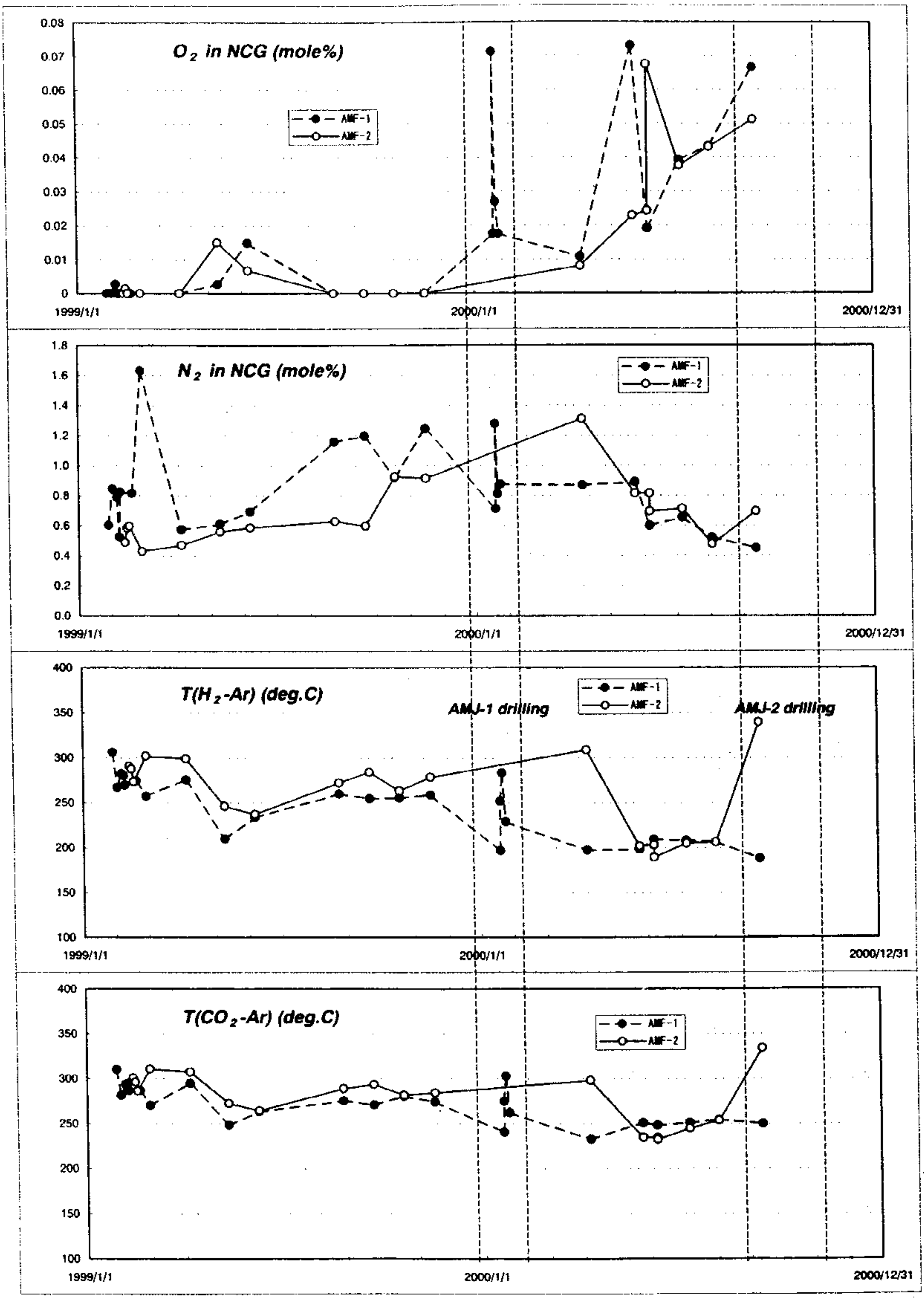
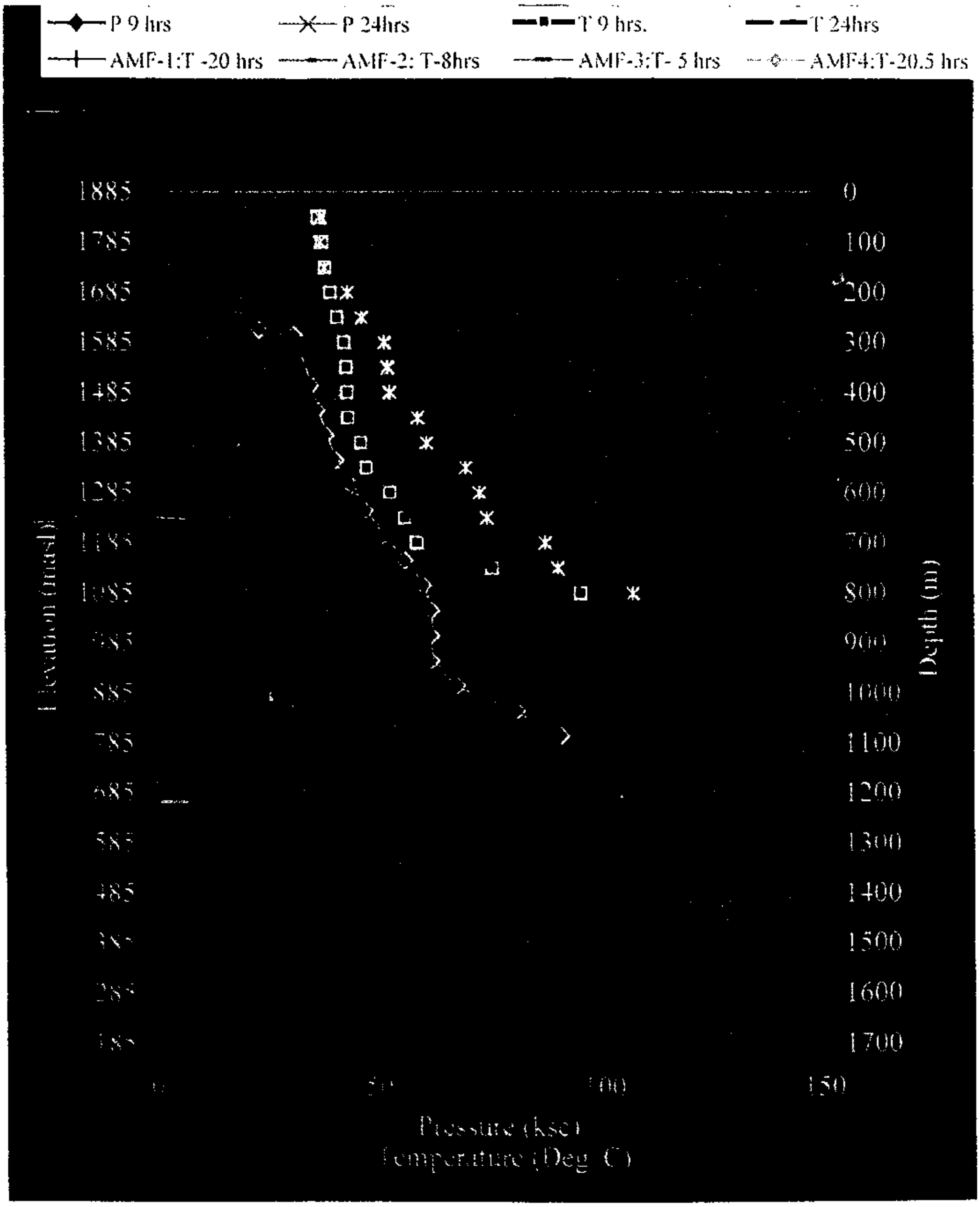


Fig. 2-4-9 Trend diagram of monitoring data on gas chemistry of the wells AMF-1 and AMF-2

AMF-1及びAMF-2のガス化学特性に関するモニタリングデータ経時変化図

Fig. 2-4-10坑井 AMJ-1 温度圧力検層(800 m)

Well AMJ-1 Temperature – Pressure Surveys: 800 m



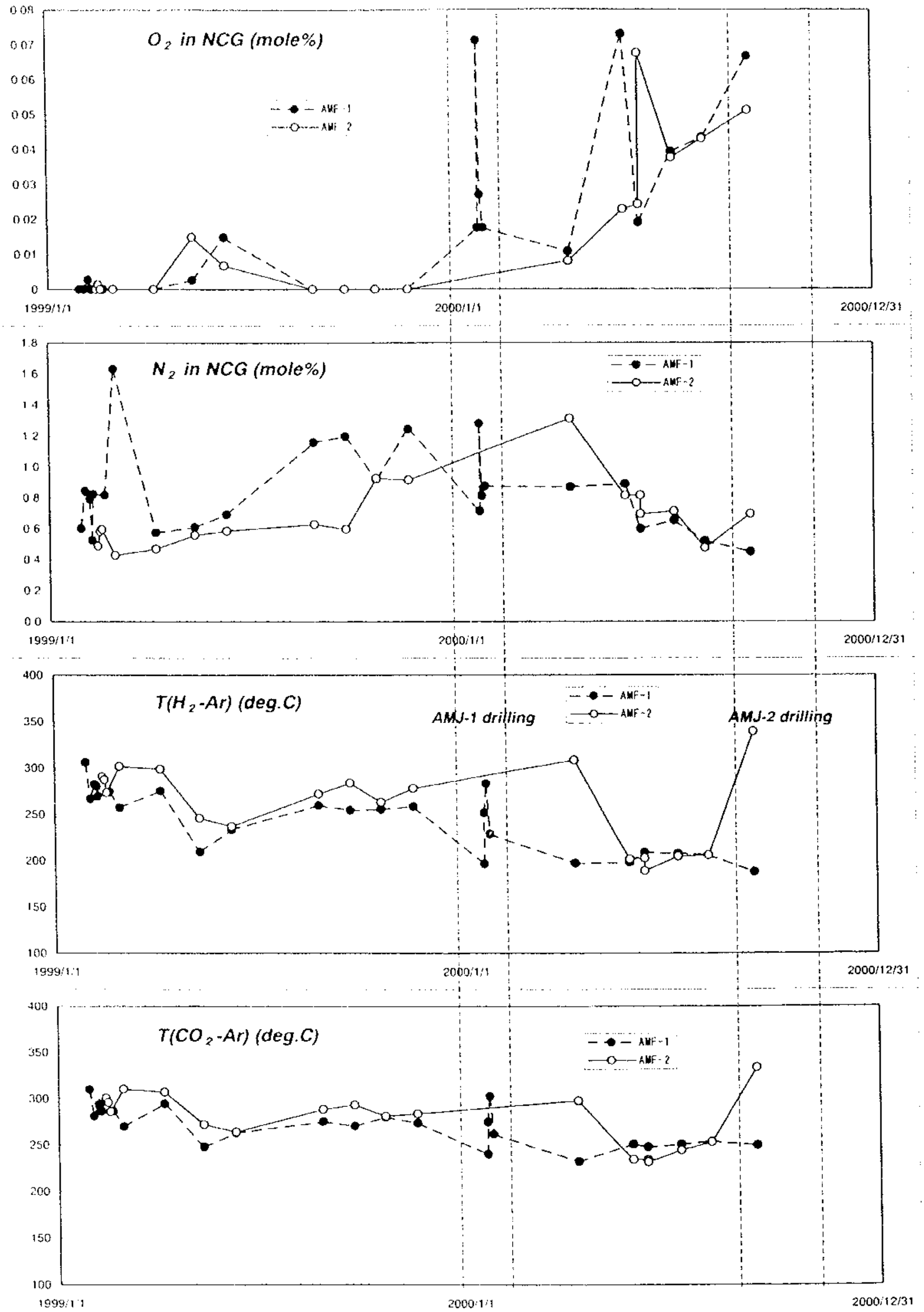


Fig. 2-4-9 Trend diagram of monitoring data on gas chemistry of the wells AMF-1 and AMF-2

AMF-1及びAMF-2のガス化学特性に関するモニタリングデータ経時変化図

Fig 2-4-10坑井 AMJ-1 温度圧力検層(800 m)

Well AMJ-1 Temperature - Pressure Surveys: 800 m

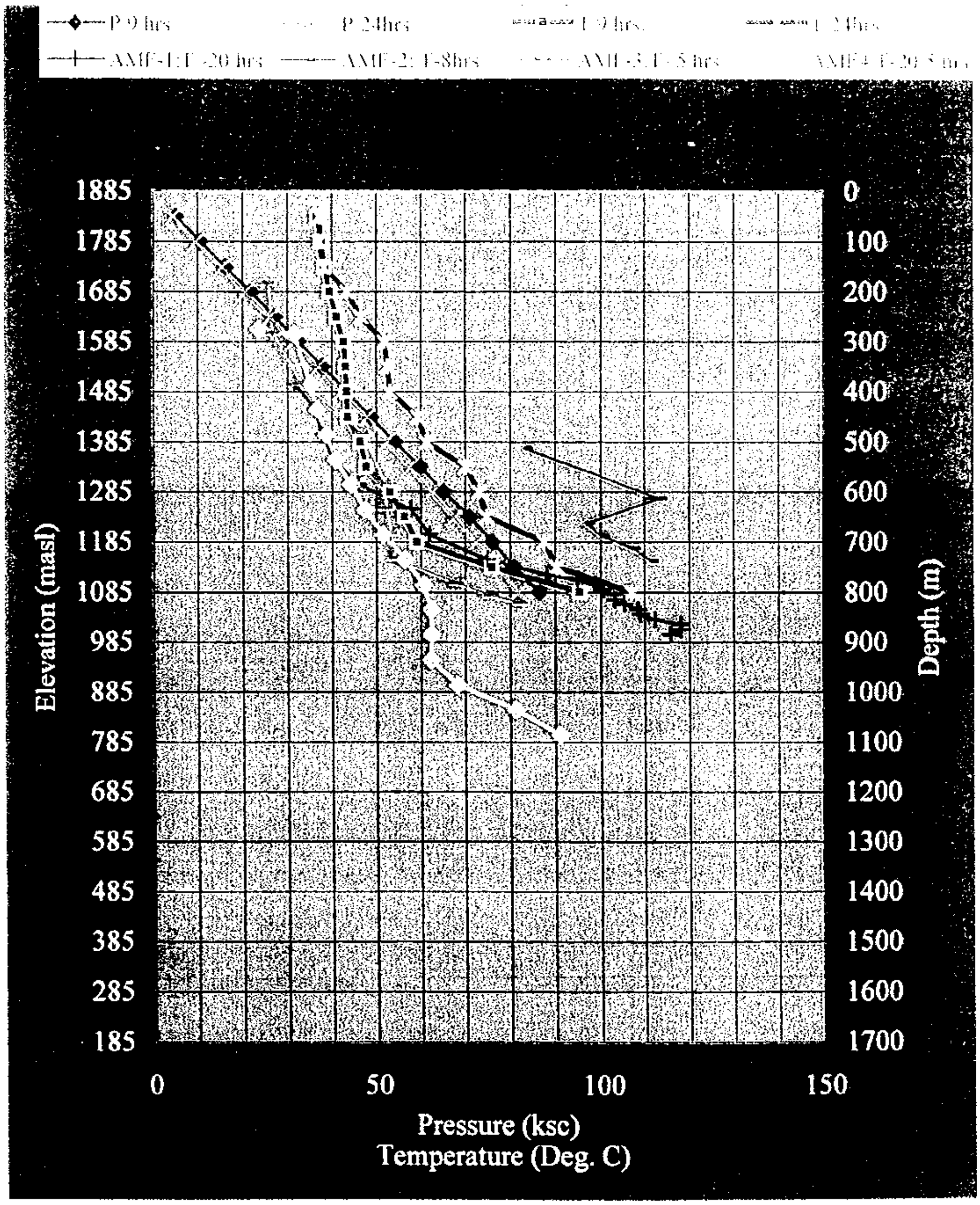


Fig. 2-4-11　坑井 AMJ-1 温度検層(1,700 m)

Well AMJ-1 Temperature Build up Surveys: 1,700 m

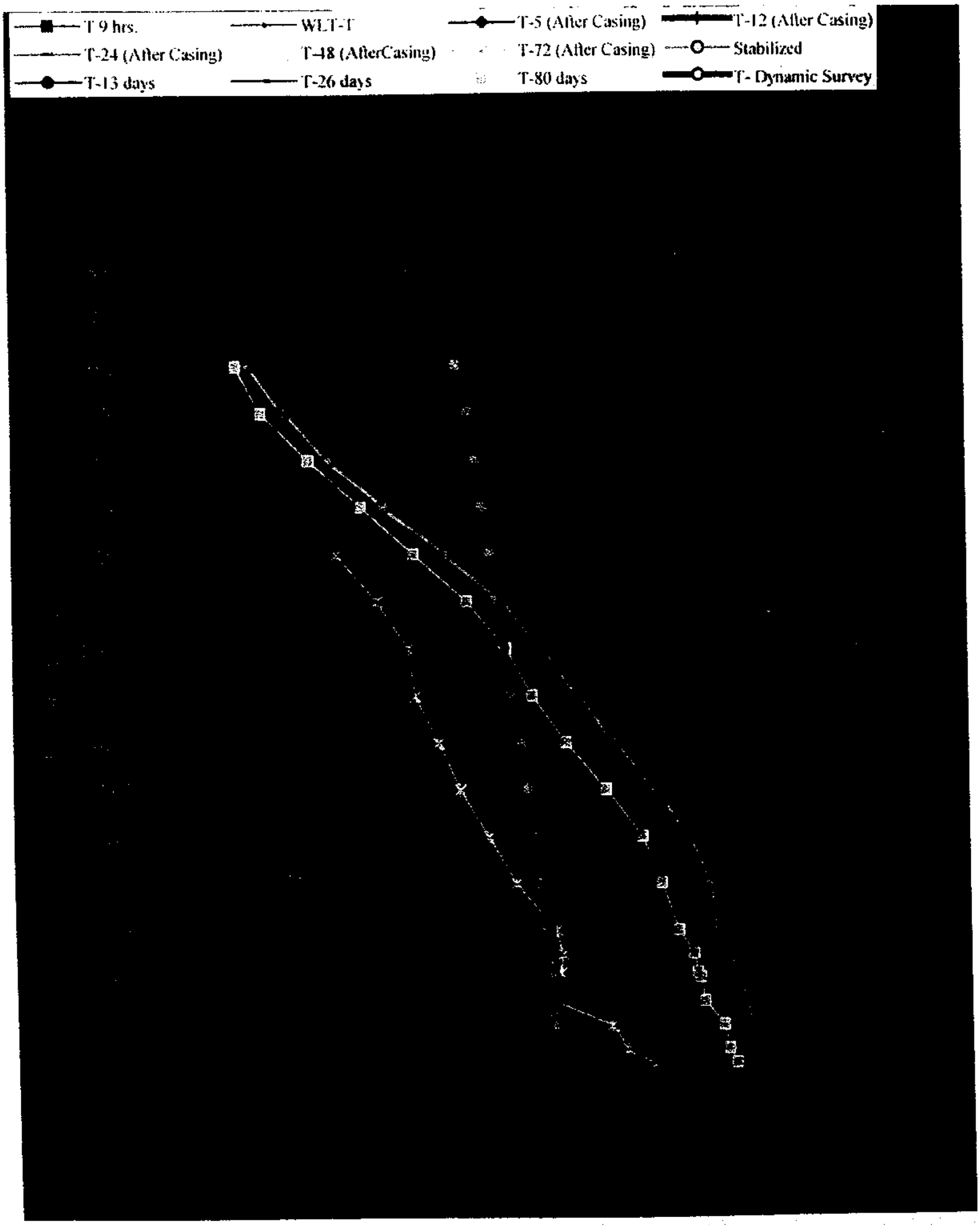


Fig. 2-4-12坑井 AMJ-1 圧力検層(1,700 m)

Well AMJ-1 Pressure Build up Surveys: 1,700 m

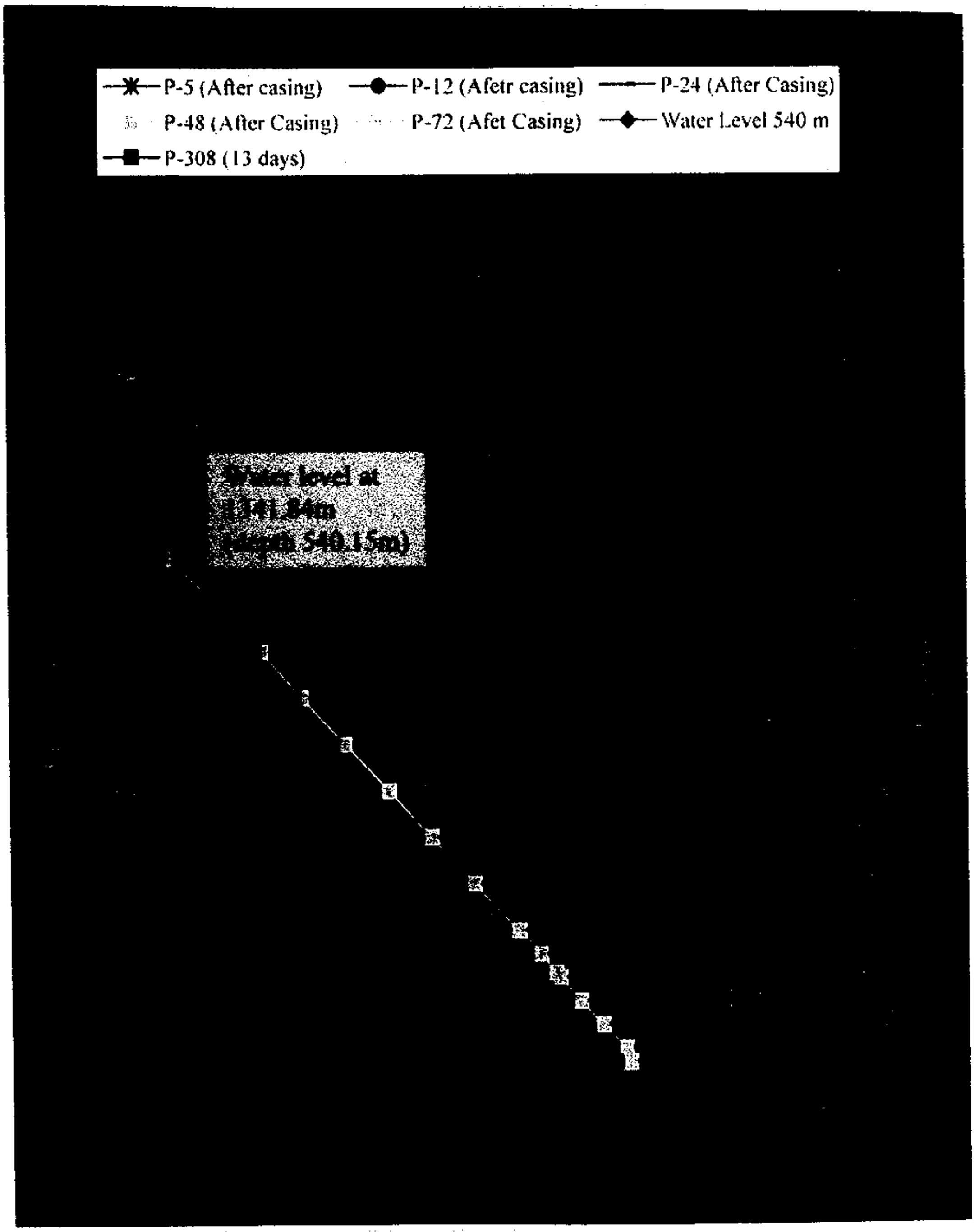


Fig. 2-4-11 坑井 AMJ-1 温度検層(1,700 m)

Well AMJ-1 Temperature Build up Surveys: 1,700 m

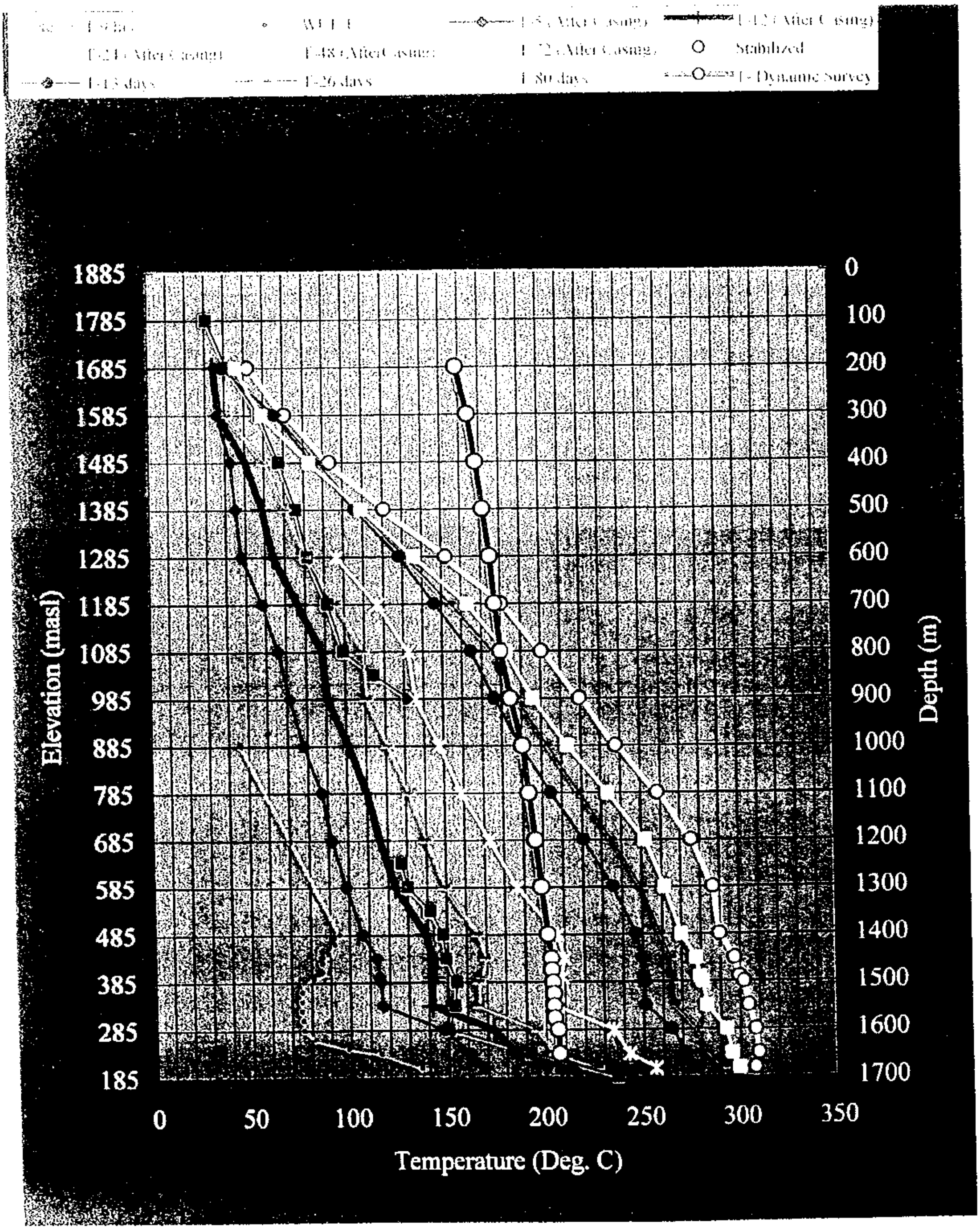


Fig. 2-4-12 坑井 AMJ-1 圧力検層(1,700 m)

Well AMJ-1 Pressure Build up Surveys: 1,700 m

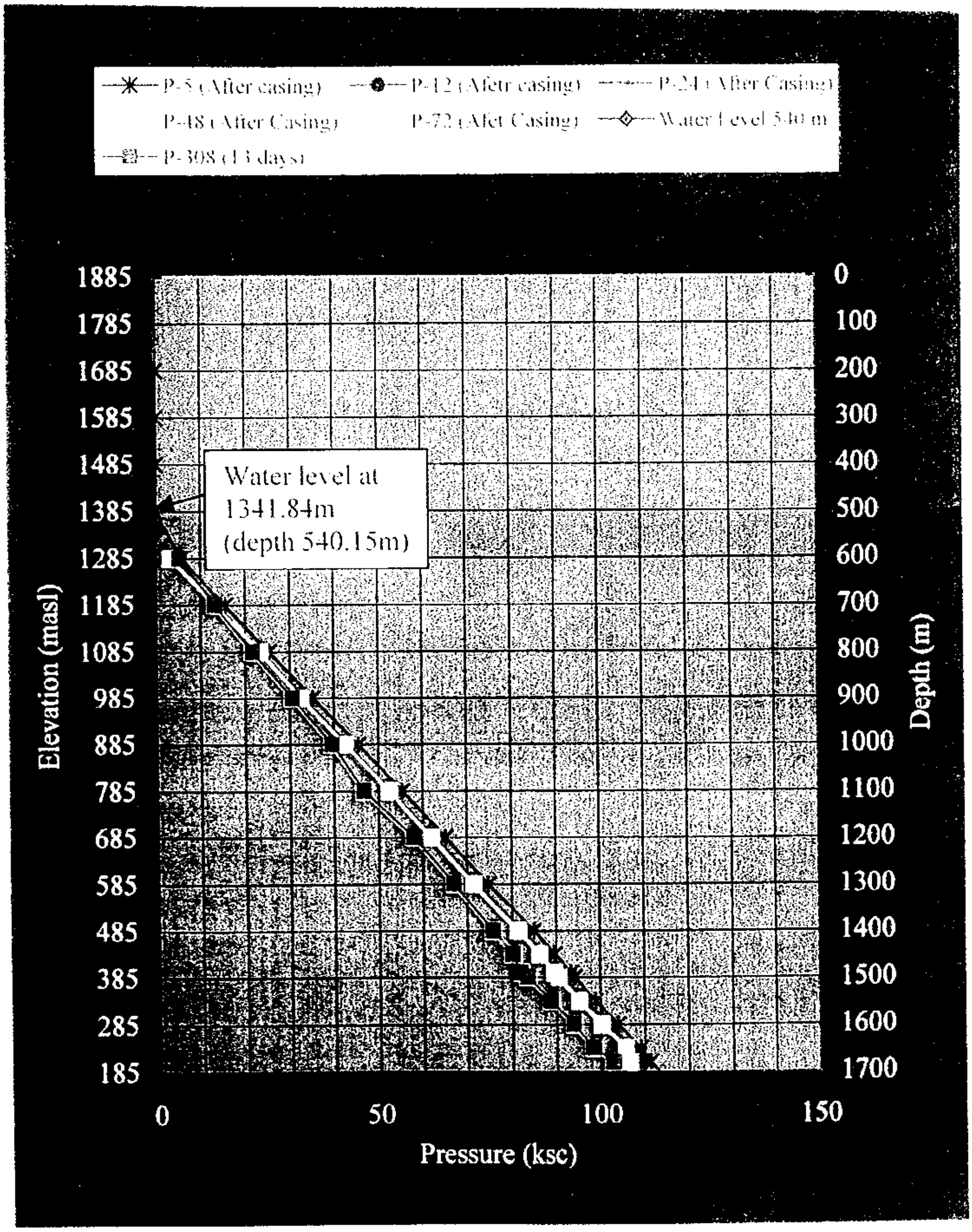


Fig. 2-4-13坑井 AMJ-1 注水試験記録

Flow Rate and Pressure Data during Injectivity Tests: Well AMJ-1

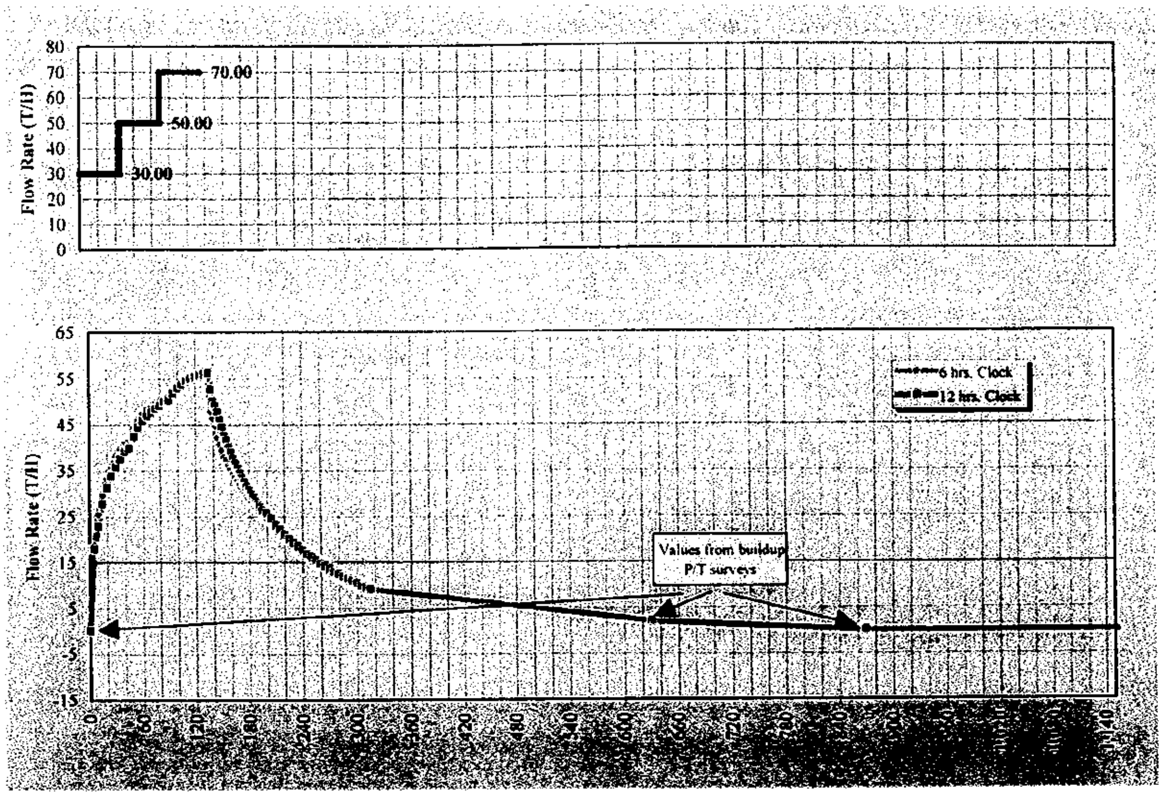


Fig 2-4-13坑井AMJ-1注水試験記録

Flow Rate and Pressure Data during Injectivity Tests: Well AMJ-1

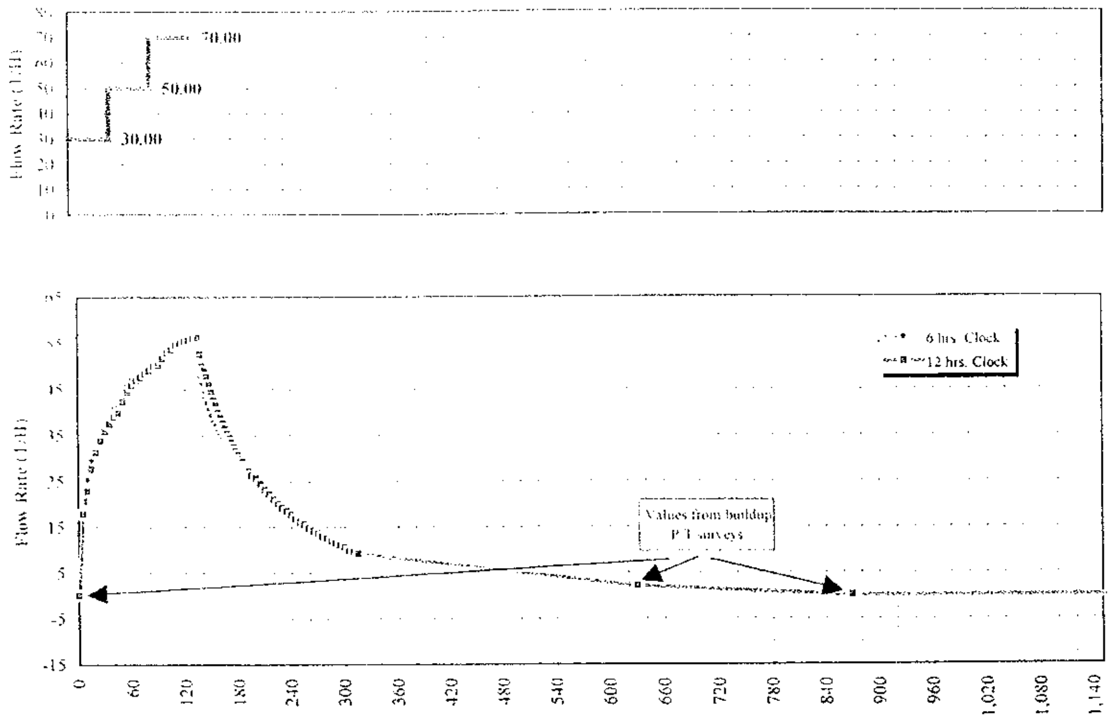


Fig. 2-4-14坑井 AMJ-2 温度検層(1,700m)

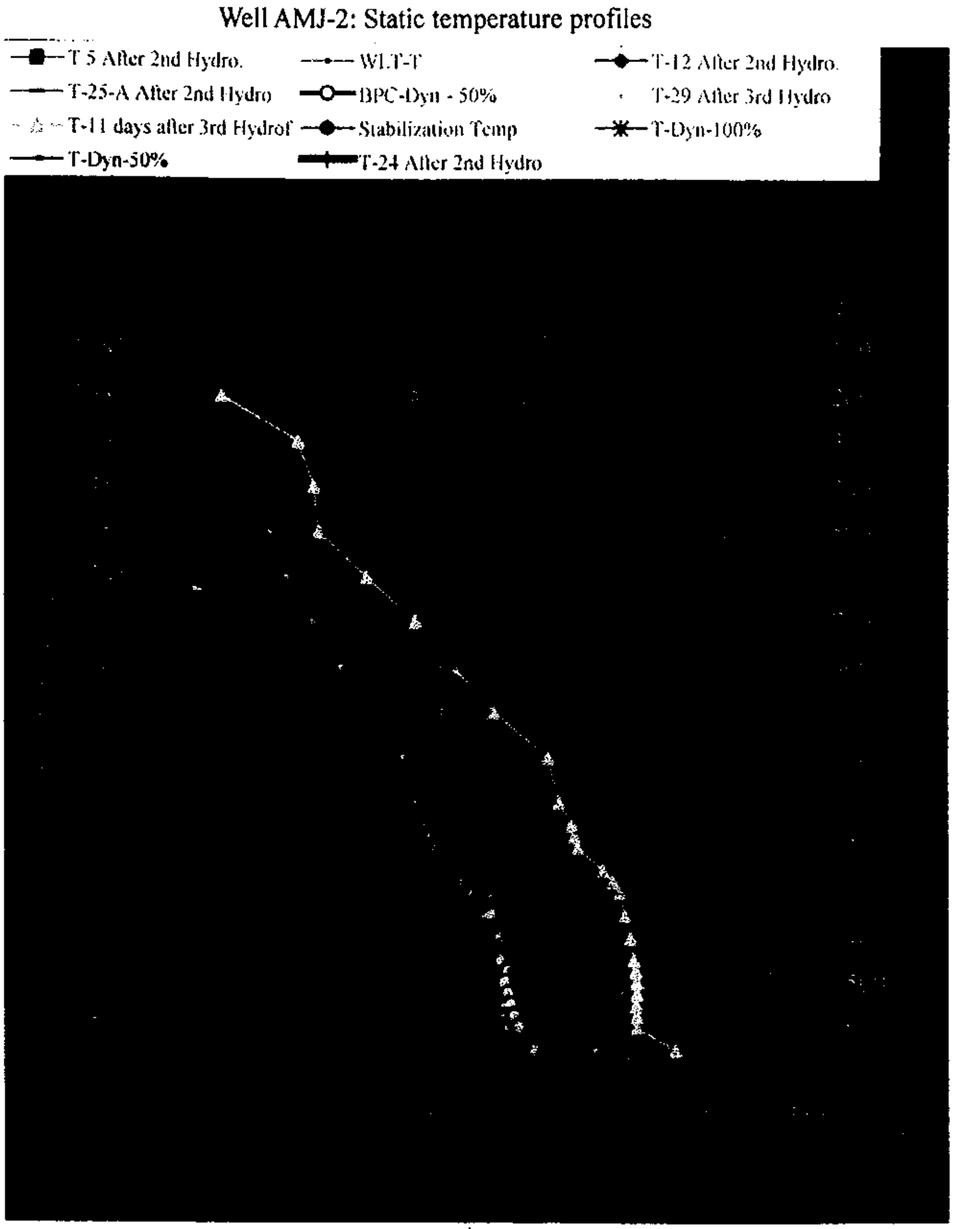


Fig 2-4-14坑井 AMJ-2 温度検層(1,700m)

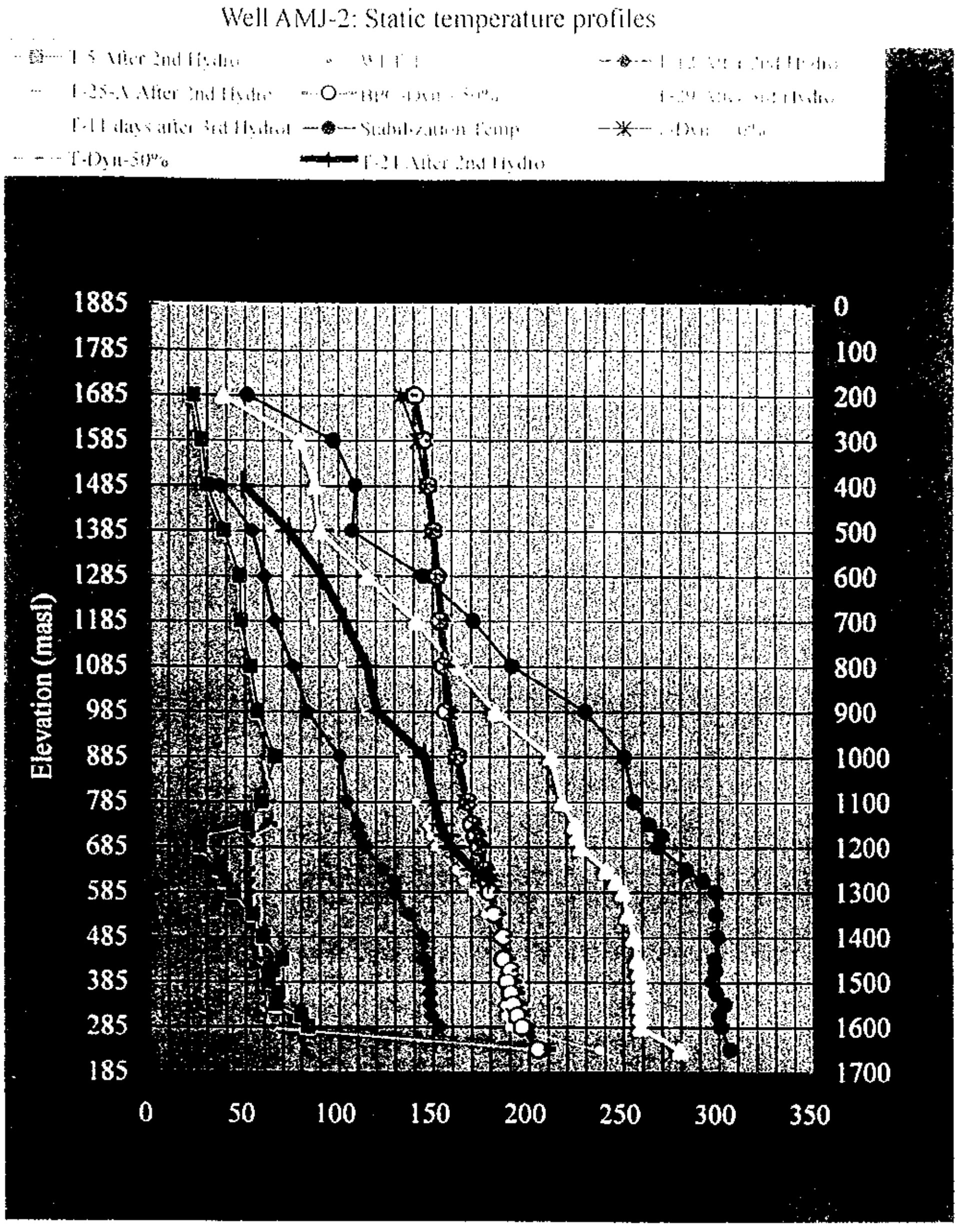


Fig. 2-4-15坑井AMJ-2圧力検層(1,700m)

Well AMJ-2: Static pressure profiles

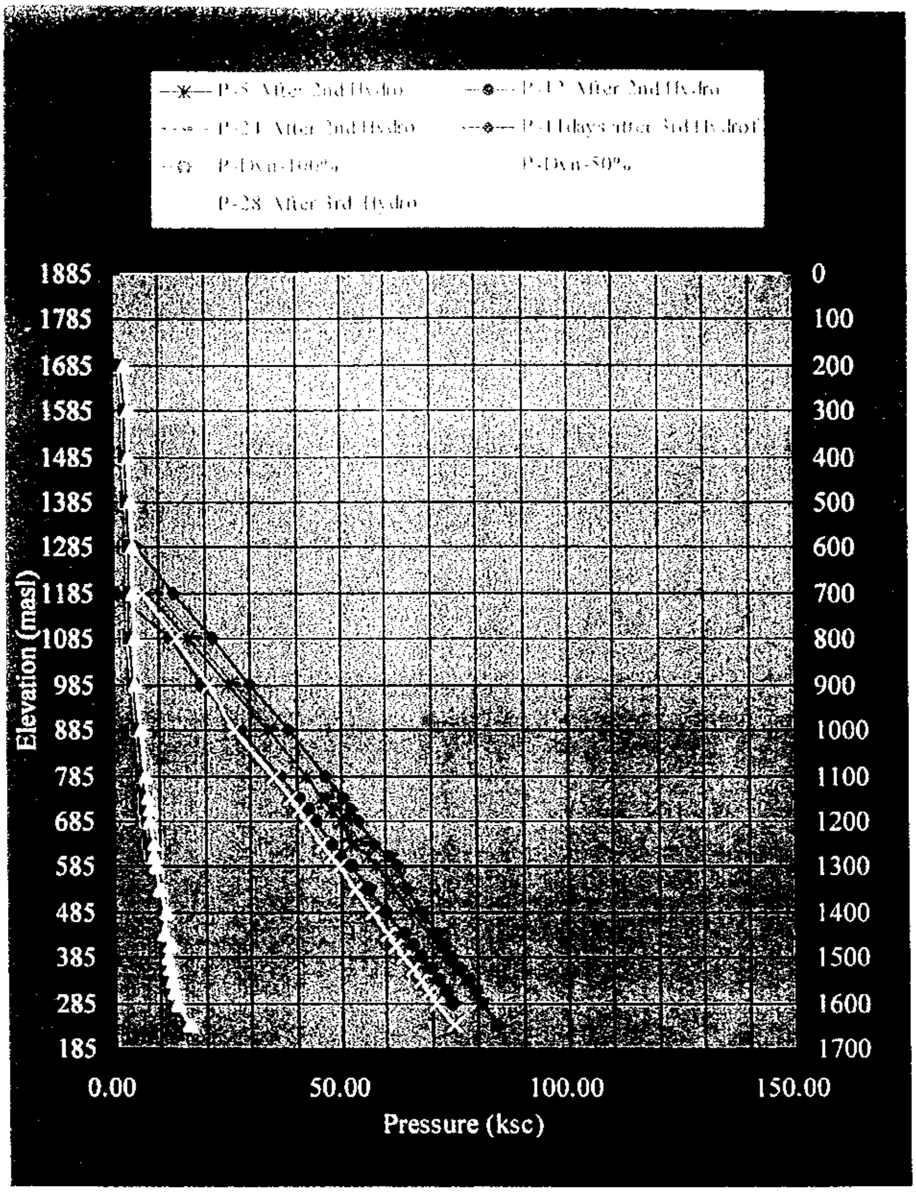


Fig. 2-4-15坑井 AMJ-2 圧力検層(1,700m)

Well AMJ-2: Static pressure profiles