2.3 EXPLORATORY WELL DRILLING

2.3.1 WELL AMJ-1

1. WORK ACTIVITIES

Based on the "Drilling tender document for a exploratory well in Amatitlan" which was prepared in fiscal year 1998, the international pre-bid meeting and contract negotiation was held in Guatemala City on August, 1999 for the drilling contract for the exploratory well AMJ-1. After the bidding process, Simmons Drilling International, who has much geothermal drilling experiences in Berlin geothermal field in El Salvador, was selected as a winner of the bid.

The drilling operation was started on 23rd of December 1999 and terminated on 5th February 2000 as a total depth was 1700.5m. The well testing was carried out after running 7-5/8" liner, and the rig was released on 10th of February 2000.

The well location is summarized as follows.

	Coordinates	Altitude	Total Depth
AMJ-1	X= 757,737 Y=1,593,207	1,885.00m	1,700.50m

2. DRILLING

The mobilization of the drilling equipment and rig-up were completed on December 22, 1999. After drilling of rat hole and mouse hole, drilling of the 17-1/2" hole was started at 16:30 on December 25. During the drilling of the 17-1/2" hole, two loss zones at 2m and 8m were encountered and first one was treated with LMC, another was treated with two cement plugs. Drilling was continued with 17-1/2" bit to 10m where the very hard formation was encountered. From 10m, 12-1/4" hole was drilled to 32m with normal condition. After reamed to 32m with 17-1/2" bit, reaming with 26" hole opener started from 2m. During reaming with 26" hole opener at 11.4m, a partial loss of circulation zone was encountered. The formation washout was found at the shoe of 30" conductor pipe, and a cement plug was set to prevent the cave-in hole. After reaming cement to 11.4m, the 20" casing was run to 10.8m and cemented on January 1, 2000. After waiting on cement set for 20 hours, the 30" conductor pipe and 20" conductor casing were cut and a 20" well head, 21-1/4"-2000# BOP, flow line were installed.

A 17-1/2" bit was run in hole after the opening and closing test of annular BOP. The top of cement was tagged at 7m and reaming cement started on January 3. After reaming cement and open hole to 32m with 17-1/2" bit, the drilling of the formation started with same bit. During drilling in this period, two partial loss zones were encountered at 83m and 151m, and they were treated with LCM successfully. Drilling was continued to a depth of 300.2m with 17-1/2" bit without problem. After finished drilling, a wiper trip was made to the 20" casing shoe to check hole condition. On January 9, the 13-3/8"casing was run in to a depth of 295.7m and cemented. During cementing operation, partial loss of circulation was occurred in the open hole. After waiting on cement set for 24 hours, the top cement job was carried out in the annular space between the 20" casing and 13-3/8" casing because of the falling of the top of cement. After three top cement job, the 13-3/8" casing was cut and a 13 3/8"-2000# casing head was welded to the 13-3/8" casing. A 13 5/8"-5000# annular BOP and a double ram BOP were installed on the casing head.

The pressure test of the wellhead system including BOP was carried out at 600 psig. for 15 minutes. A 12-1/4" bit was run in and tagged the top of cement at 275m on January 12. The drilling of the formation was started after reaming cement to 300.2m and continued to 807.2m without problem. After drilling to 807.2m, the first temperature and pressure logging were carried out to evaluate this interval. The 9-5/8" casing was run in to a depth of 803.3m and cemented on January 20.After waiting on cement set for 24 hours, the 9-5/8" casing was cut below the 13-3/8" casing head and a 10"-600# master valve and BOP were installed on the casing head.

The pressure test of the wellhead system was carried out at 600 psig for 15 minutes. A 8-1/2" bit was run in and tagged the top of cement at 777m on January 23. The drilling of the formation started after reaming cement to 807.2m and the first loss zone was encountered at 1011m. The loss rate was $3m^3$/hr. and drilling was continued with low viscosity mud. Several loss zones were encountered at 1,168m, 1,231m, however those were partial loss zones. Finally, a total loss zone was encountered at 1,493m. Drilling was continued with total loss, however the loss rate was gradually decreased to $20m^3$/hr.or less. After drilling to 1,700.5m with partial loss, the second logging was carried out to evaluate the well and a total depth was declared based on the results of the meeting with INDE and JICA team. After drilling to a total depth of 1,700.5m, 7- 5/8" liner, including 294.26 meters of slotted liner and 637.25 meters of blind liner, was run in and hanged from 756.9m to 1,690.0m. After setting 7-5/8" liner, three hydro-fracturing test were carried out so as to improve permeability of open hole, and a better result was obtained. The water loss test and pressure transient test was carried out with a Kuster tool on February 10. On same day, the 10" master valve was closed, finally rig was released.

3. **SUMMARY**

The results of the drilling AMJ-1 were summarized as follows.

1) Total drilling depth was 1,700.5m as compared the programmed depth of 1,500m.
2) High temperature geothermal reservoir was encountered below 1,500m.
3) Final recovery temperature of the formation was estimated around 300℃.
4) The permeability of the formation was not so high.
5) Not so many loss of circulation zones were encountered in the open hole.

2.3.2 Well AMJ-2

1. **Work Activities**

Based on the document "Drilling tender document for an exploratory well in

Amatitlan" which was prepared during the activities of the fiscal year 1999, the international pre-bid meeting and contract negotiation was held in Guatemala City on June, 2000 for the drilling contract for the exploratory well AMJ-2. After the bidding process, Perforaciones Integrales Termicas, S.A.(PITSA), who has much geothermal drilling experiences in Zunil and Amatitlan geothermal field in Guatemala, was selected as a winner of the bid.

The drilling operation was started on 26th of August 2000 and completed on 4th of November 2000. The well testing was carried out after running 7" liner, and the rig was released on 13th of February 2000.

The exploratory well, AMJ-2 was drilled at the northern slope of Mt. Cerro Chino as shown in Fig. 3-5. Well AMJ-2 was directionally drilled down to 1,705m, just beside well AMJ-1, 450m apart in WSW direction from AMF-2.

	Coordinates	Altitude	Total Depth
AMJ-2	X=757,732 Y=1,593,213	1,885.00m	1,705.00m

2. DRILLING

The mobilization of the drilling equipment and rig-up were completed on August 25, 2000. After drilling of a rat and a mouse hole, drilling of the 17-1/2" hole was started at 24:00 on August 26. During the drilling of the 17-1/2" hole, no loss zone was encountered. Drilling was continued with a 17-1/2" bit to 8m where a very hard formation was encountered. After reaming to 8m with a 26" bit, the 20" casing was run to 8m and cemented on August 27. After waiting on cement set for 24 hours, the 30" conductor pipe and 20" conductor casing were cut and a 20" well head, 21-1/4"-2000# BOP, flow line were installed.

A 12-1/4" bit was run in hole on August 29. The top of cement was tagged at 7m and continued to ream cement to 8m and drill formation to 13m with same bit. After 13m, pulled out the 12-1/4" bit to the surface to change bit to a 17-1/2". Two partial loss zones were encountered, one at 105m and the other at 156m. First one was plugged with drilled cuttings. While treating the second loss zone, the drill pipe was fallen in the hole with bit and other bottom hole assembly. Immediately the fishing tools such as over-shot, fishing basket were run in hole to recover the fish. However the some trial was resulted unsuccessfully and followed two cement plugs from the bottom to 119m to carry out side-tracking the hole. The side-track was carried out at 119m with a down-hole motor successfully. After side-track, the drilling was continued to a depth of 300m with a 17-1/2" bit without problem. On September 28, the 13-3/8"casing was run in to a depth of 293.4m and cemented. During cementing operation, partial loss of circulation was encountered. After waiting on cement set for 24 hours, the top cement job was carried out in the annular space between the 20" casing and 13-3/8" casing because of the falling of the top of cement. After two top cement job, the 13-3/8" casing was cut and a 13 3/8"-2000# casing head was welded to the 13-3/8" casing. A 13 5/8"-5000# annular BOP and a double ram BOP were installed on the casing head.

The pressure test of the wellhead system including BOP was carried out at

600 psig. for 15 minutes. A 12-1/4" bit was run in and tagged the top of cement at 271m on October 3. The drilling of the formation was started after reaming cement to 300m and continued to 385m at where the directional drilling was started. The directional drilling was smoothly proceeded to a proposed depth of 1,000m without problem. The 9-5/8" casing was run in to a depth of 996.3m and cemented on October 18.After waiting on cement set for 36 hours, the 9-5/8" casing was cut below the 13-3/8" casing head and a 10"-600# master valve and BOP were installed on the casing head. A top cement job was carried out in the annular space between the 13-3/8" casing and 9-5/8" casing because of the falling of the top of cement.

The pressure test of the wellhead system was carried out at 600 psig for 15 minutes. A 8-1/2" bit was run in and tagged the top of cement at 966m on October 22. After reaming cement to 1,000m, the drilling of the formation was continued to a depth of 1,203m at where the drill strings were stuck. Immediately extra pulling of the strings and oil-spot of the strings were conducted. The oil-spot was so effective to recover the strings successfully. The drilling was continued and the first total loss zone was encountered at 1,539m. At 1,542m, the loss rate was gradually decreased to 20m^3/hr and the drilling was continued to a total depth of 1705m with partial loss. The 7" liner, including 601.6 meters of slotted liner and 126.6 meters of blind liner, was run in and hanged from 961.1m to 1,690.2m. After setting 7" liner, three hydro-fracturing tests were carried out so as to improve permeability of open hole, and a better result was obtained. The loss rate was improved from 53m^3/hr to 126m^3/hr. The water loss test and pressure transient test was carried out with a Kuster tool from November 8 to13. On November 13, the 10" master valve was closed and the rig was released.

3. SUMMARY

The results of the drilling AMJ-2 were summarized as follows.

1) Total drilling depth was 1,705m as compared the programmed depth of 1,700m.
2) High temperature geothermal reservoir was encountered below 1,539m.
3) Final recovery temperature of the formation was estimated around 300℃.
4) The permeability of the formation was higher than that of AMJ-2.
5) Total drilling days were 80days as compared the programmed days of 70days. The main reason of delay was considered as carried out fishing operations.
6) Not so many loss of circulation zones were encountered in the open hole.

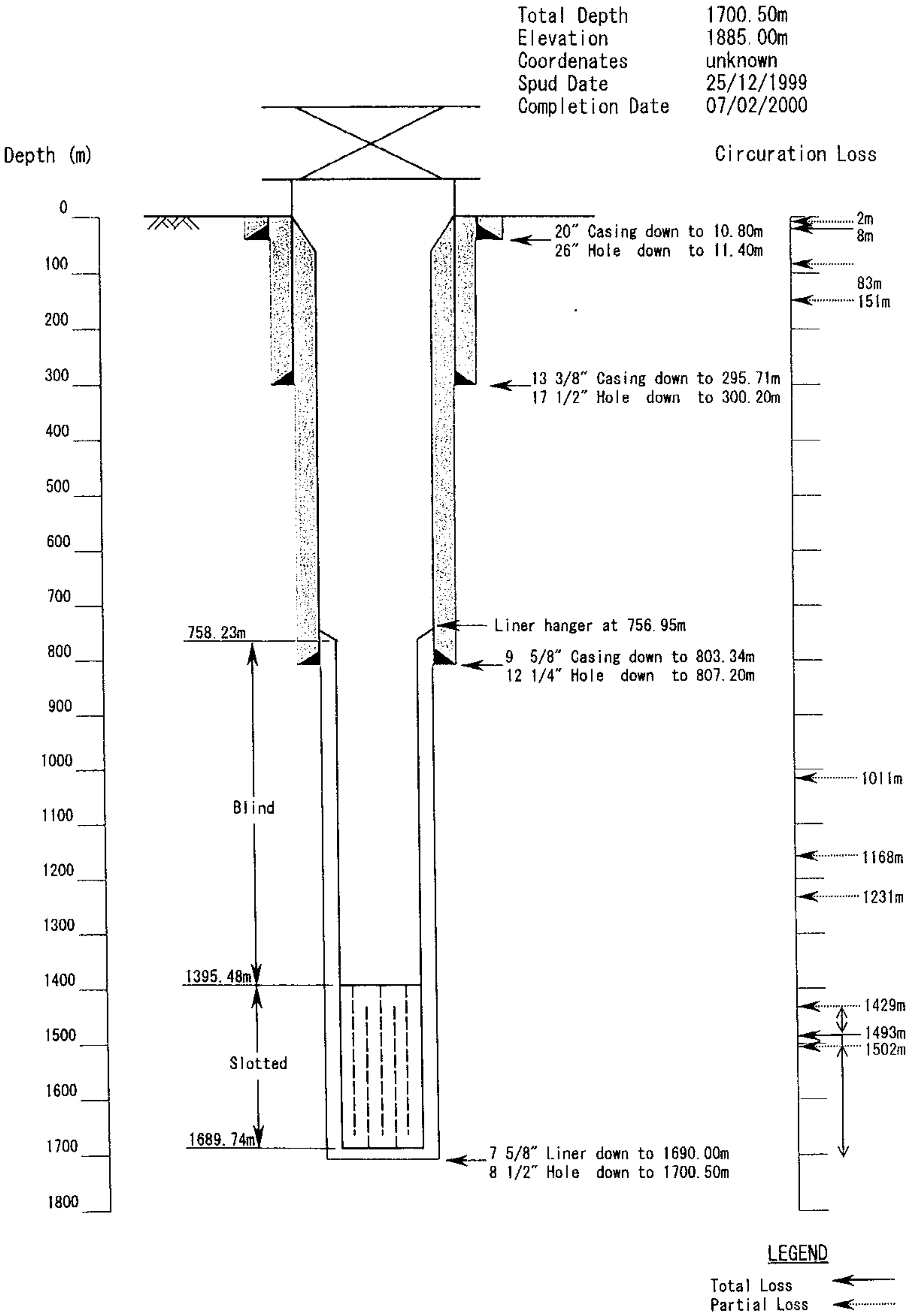

Fig. 2-3-1 AMJ-1 Well Completion Diaglam

AMJ-1号井　坑井仕上げ図

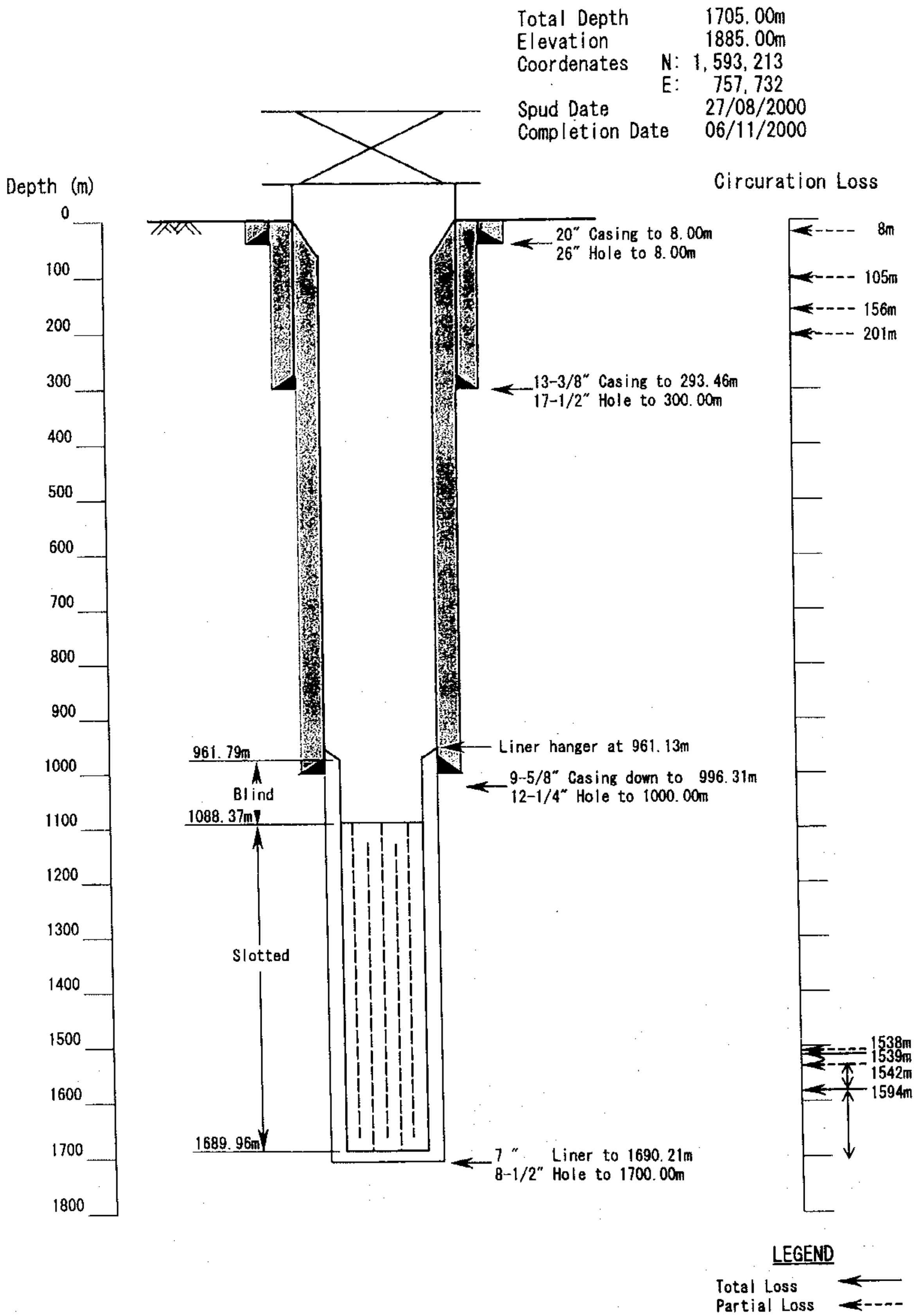

Fig. 2-3-2 AMJ-2 Well Completion Diagram

AMJ-2号井　坑井仕上げ図

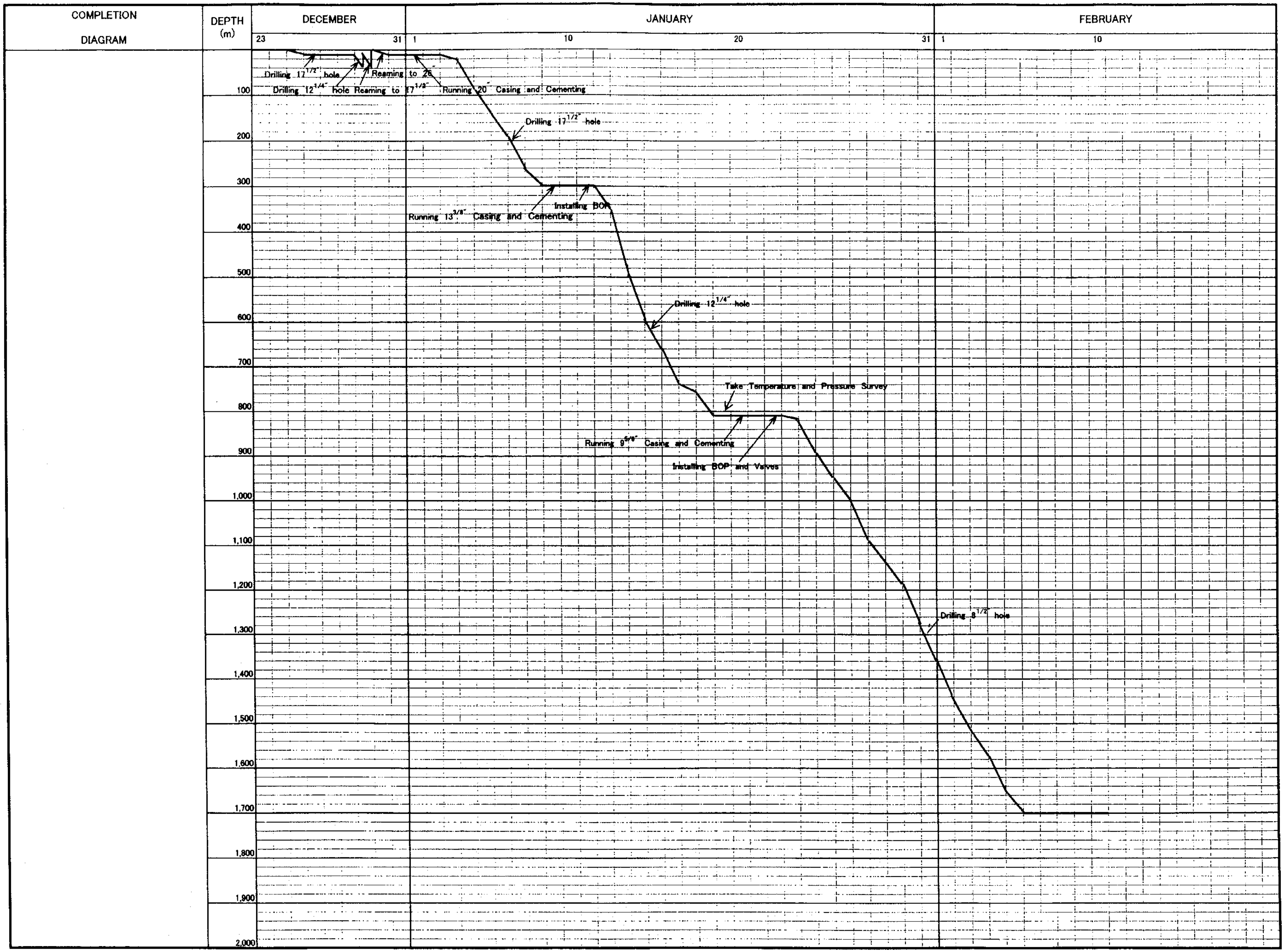

Fig. 2-3-3 AMJ-1 Well Drilling Diagram

AMJ-1号井　掘削実績

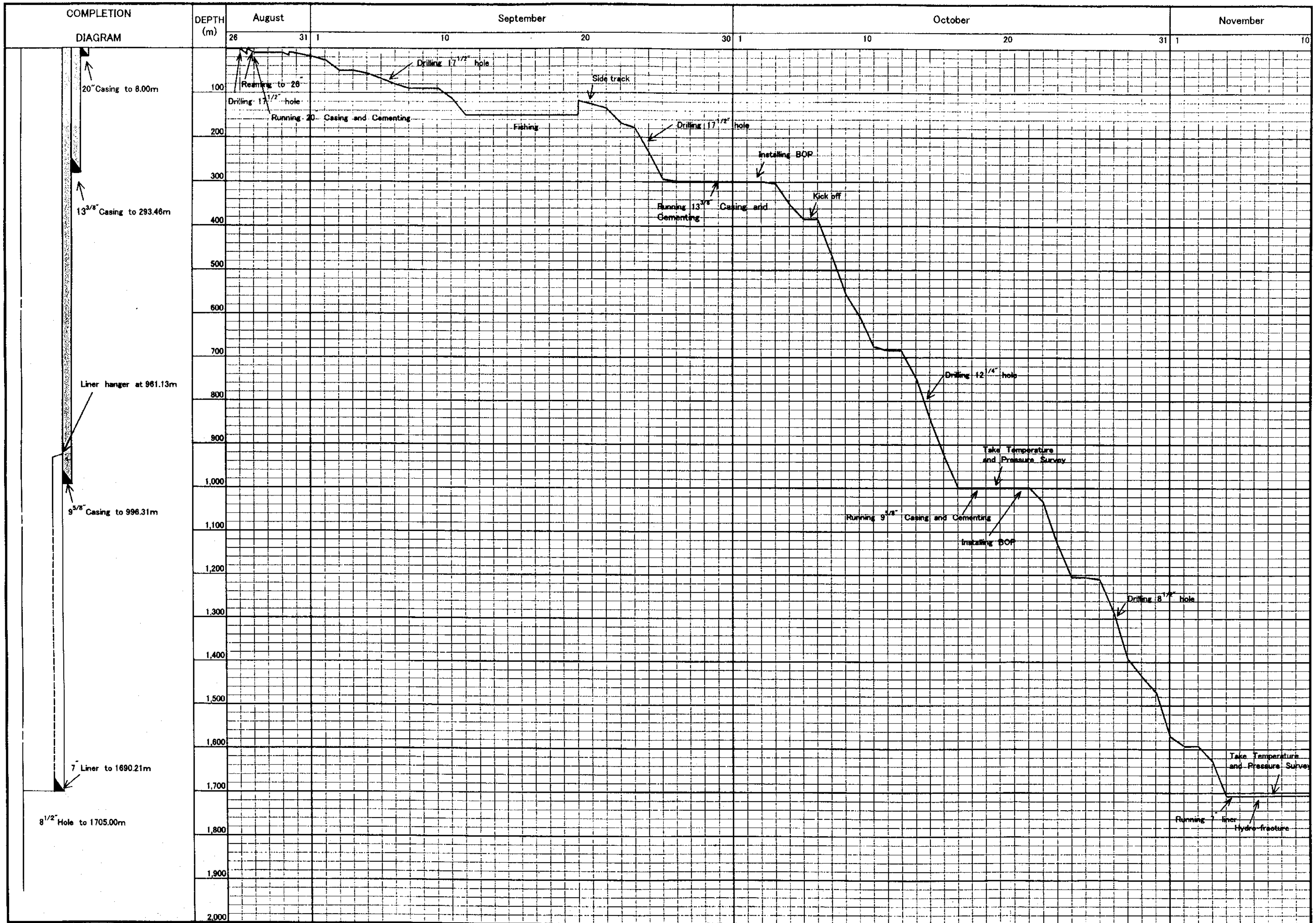

Fig. 2-3-4 AMJ-2 Well Drilling Diagram

AMJ-2号井　掘削実績

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
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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 №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 №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 №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 FROM	DEPTH TO	DEPTH TOTAL	DRILLING HOURS	DRILLING RATE	BIT WOB	BIT RPM	DEV (°)	PUMP P. P	PUMP SPM	MUD SG	MUD VIS	MUD IN	MUD OUT	DULL GRADING T	DULL GRADING B	DULL GRADING G	REMARKS
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	I	
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	I	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	I	
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	I	
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	I	
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	I	
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	I	
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	I	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	I	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

1. Objective and Analytical Items

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.

2. Analytical Results

Through the examination of cuttings at naked eye and microscope and the measurement of age dating, X-ray diffraction and fluid inclusion, each result regarding Well AMJ-1 and AMJ-2 is described in the Progress Report No.2, the Interim Report and the Final Report of Amatitlan Geothermal Development Project in detail (refer to Fig. 2-4-1, Fig. 2-4-2 and Fig. 2-4-3).

3. Integration

Features of hydrothermal alteration and hydrogeological implications 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 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. **Fluid geochemistry**

   Results of chemical and isotopic analyses of discharge fluids from the wells AMJ-1 and AMJ-2 with the results of field measurement are shown in Table 2-4-1 and 2-4-2.

   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. 2-4-4. 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. 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. 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.

2. **Reservoir connection with the existing production wells**

   According to the chemical monitoring data of the existing wells AMF-1 and AMF-2, 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 changes of fluid chemistry were relatively gradual. One of the reasons for the slow response could be the low permeability in the reservoir around the well AMJ-1.

3. **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. 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.

   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.

2. Pressure-temperature surveys and water loss tests

To fulfill the first objective static temperature and pressure surveys as well as water loss tests were carried out on wells AMJ-1 and AMJ-2. To achieve the third objective, series of pressure and temperature surveys at different standing times were performed.

3. Multiple-rate test and transient test

a. Field procedure

To fulfill the second objective a maximum injection, multiple-rate injection and fall-off tests were conducted so as to estimate the near well hydraulic properties.

Using the results of the multiple-rate injection test the *injectivity index*, was estimated.

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.

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.

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 a maximum injection rate of 75 m^3/h was recorded.

b. Water Loss Temperature Survey

In Fig. 2-4-5 the temperature profile obtained during the water loss temperature test is depicted together the temperature profiles at 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

Three rates were set to 30, 50 and 70 T/H to be injected during 45 minutes respectively and a *injectivity index, I.I* of 1.27 T/H per ksc was estimated indicating either low permeability of the well or temporarily damage by drilling operations.

Table 2-4-1 shows the results of the matching process applied to Horner 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 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

Fig. 2-4-6 depicts profiles obtained during the several Pressure–Temperature surveys.

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. 2-4-6). 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

The maximum injection rate accepted by the wells was 126.456 T/H, therefore, the injection rates and injection times were set as follows: 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.

The form of this pressure-time curve indicates a multi-feed zone. 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. 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.

The *injectivity index, I.I* was estimated in 4.44 T/H per ksc which is a fairly good value for a common geothermal well. The temperature logs (refer to Fig. 2-4-6) 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 2-4-2 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

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.

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. 2-4-5 and Fig. 2-4-6 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

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. 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.

10. Flow Tests.

Wells were flow tested using the Lip Pressure and Weir method and arrays as those depicted in Fig. 2-4-7.

a. Well AMJ-1

First flow test

The well characteristics curve is depicted in Fig. 2-4-8

Second Flow Test

The well characteristics curve is depicted in Fig. 2-4-9. These figures depict a good improvement in flowing characteristics

b. Well AMJ-2

First Flow Test

The well characteristics curve is depicted in Fig. 2-4-10

Second Flow Test

The well characteristics curve is depicted in Fig. 2-4-11. These figures depict a good improvement in flowing characteristics

11. Borehole dynamic surveys

Fig. 2-4-5 shows these results for well AMJ-1 and Fig. 2-4-6 for well AMJ-2.

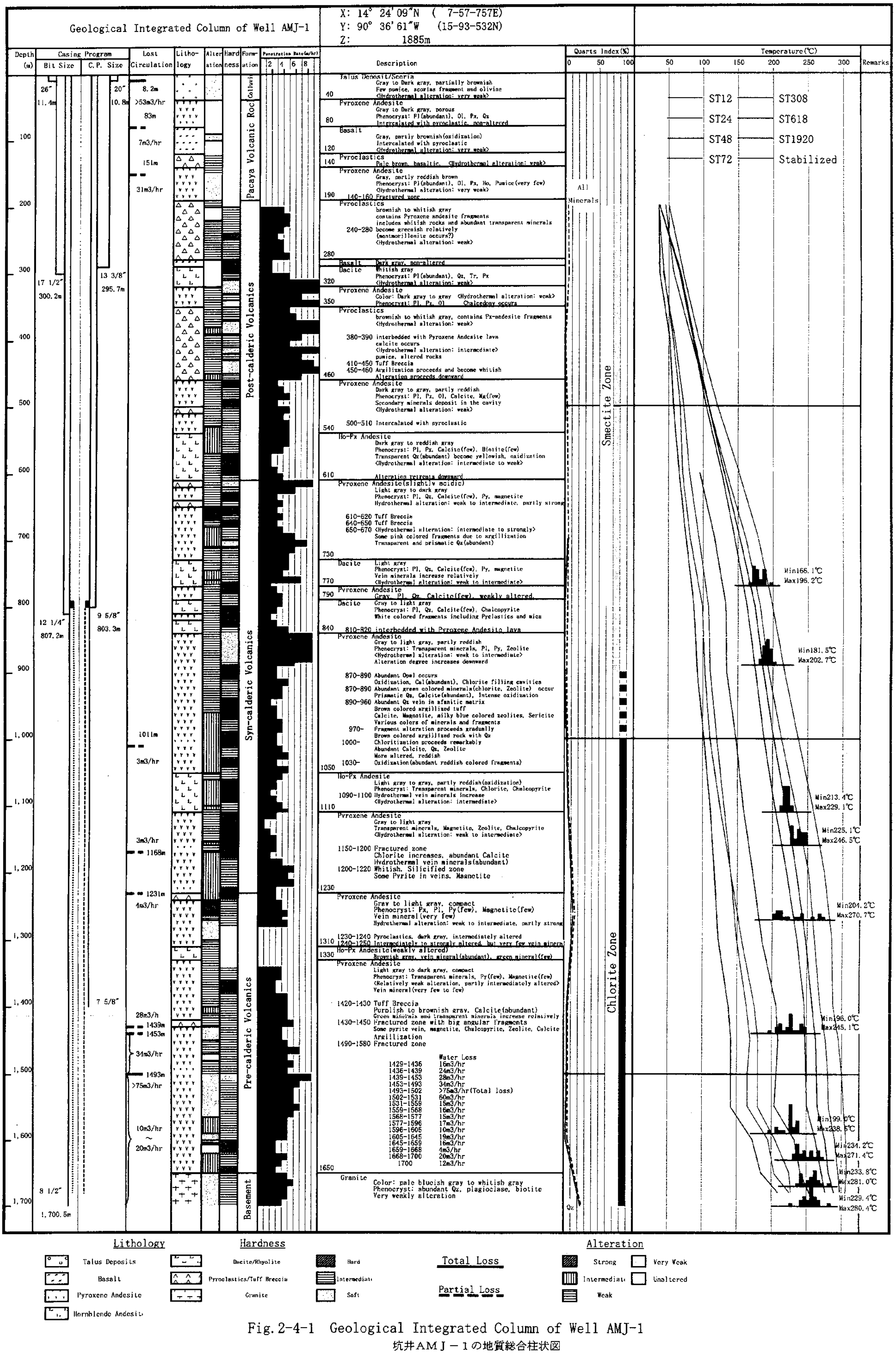


Fig.2-4-1 Geological Integrated Column of Well AMJ-1

坑井AMJ－1の地質総合柱状図

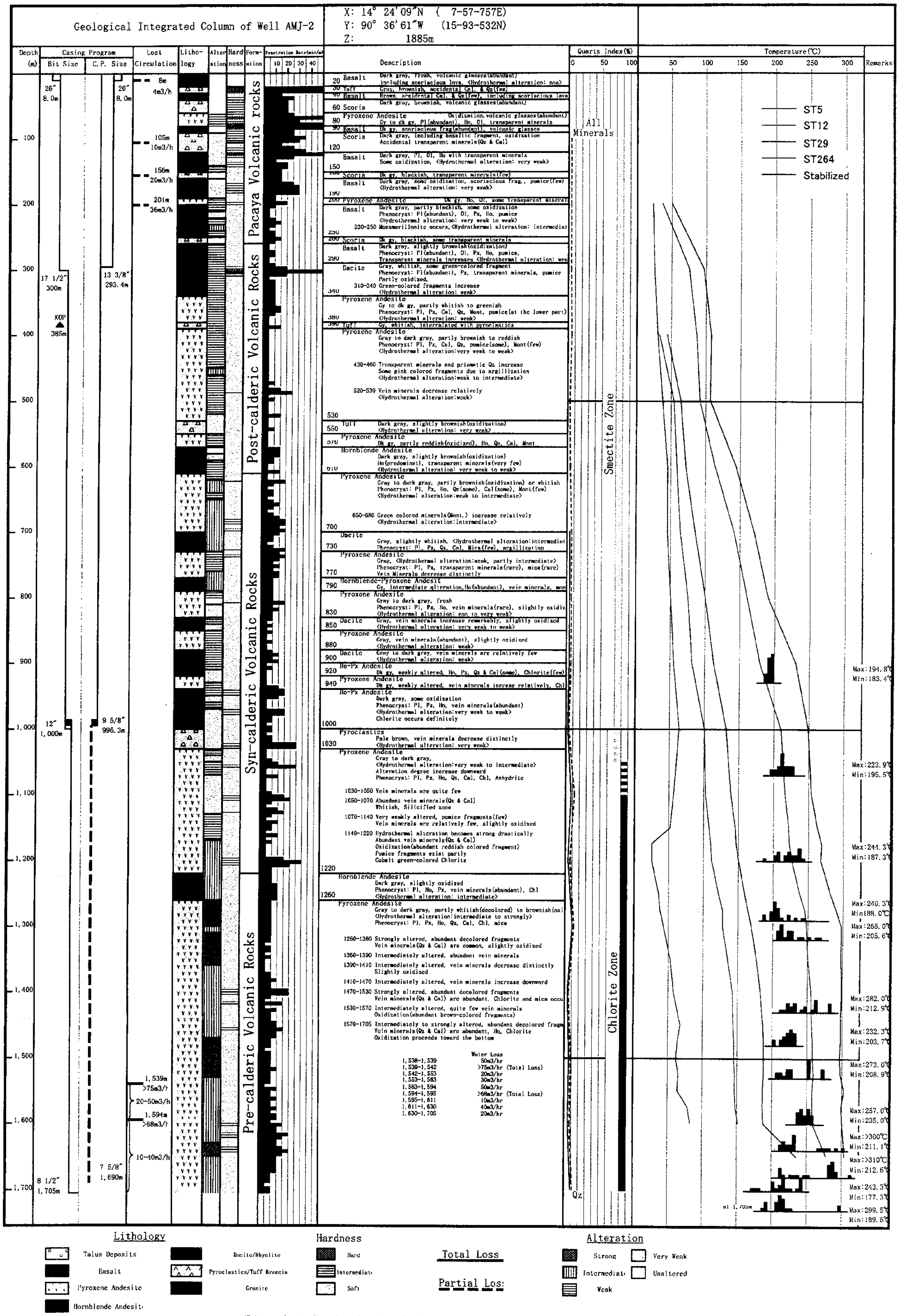


Fig. 2-4-2 Geological Integrated Column of Well AMJ-2

AMＪ－2号井の地質総合柱状図

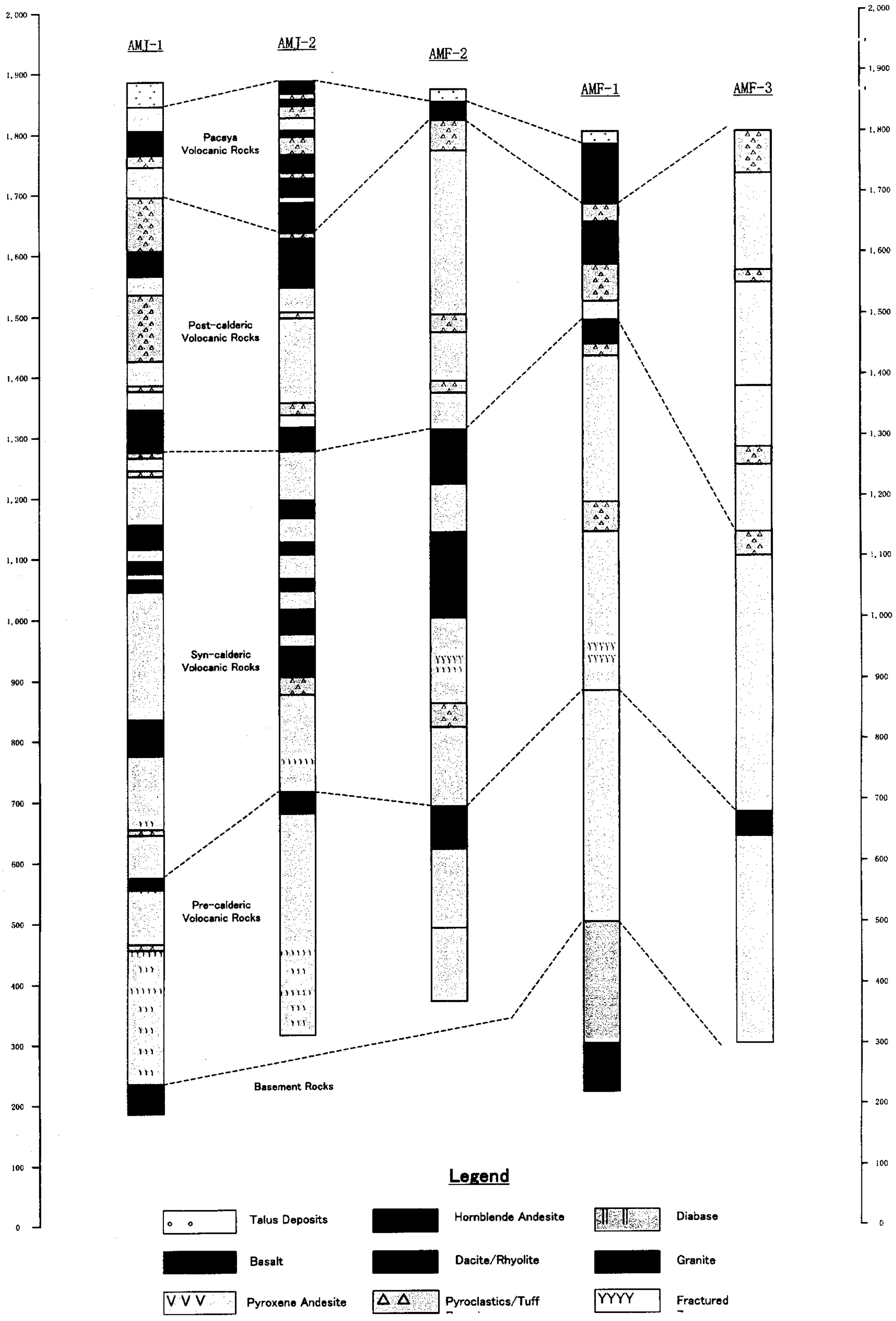


Fig. 2-4-3 Correlation of Geothermal Columns in Amatitlan Geothermal Field

アマティトラン地熱地域の地質柱状対比図

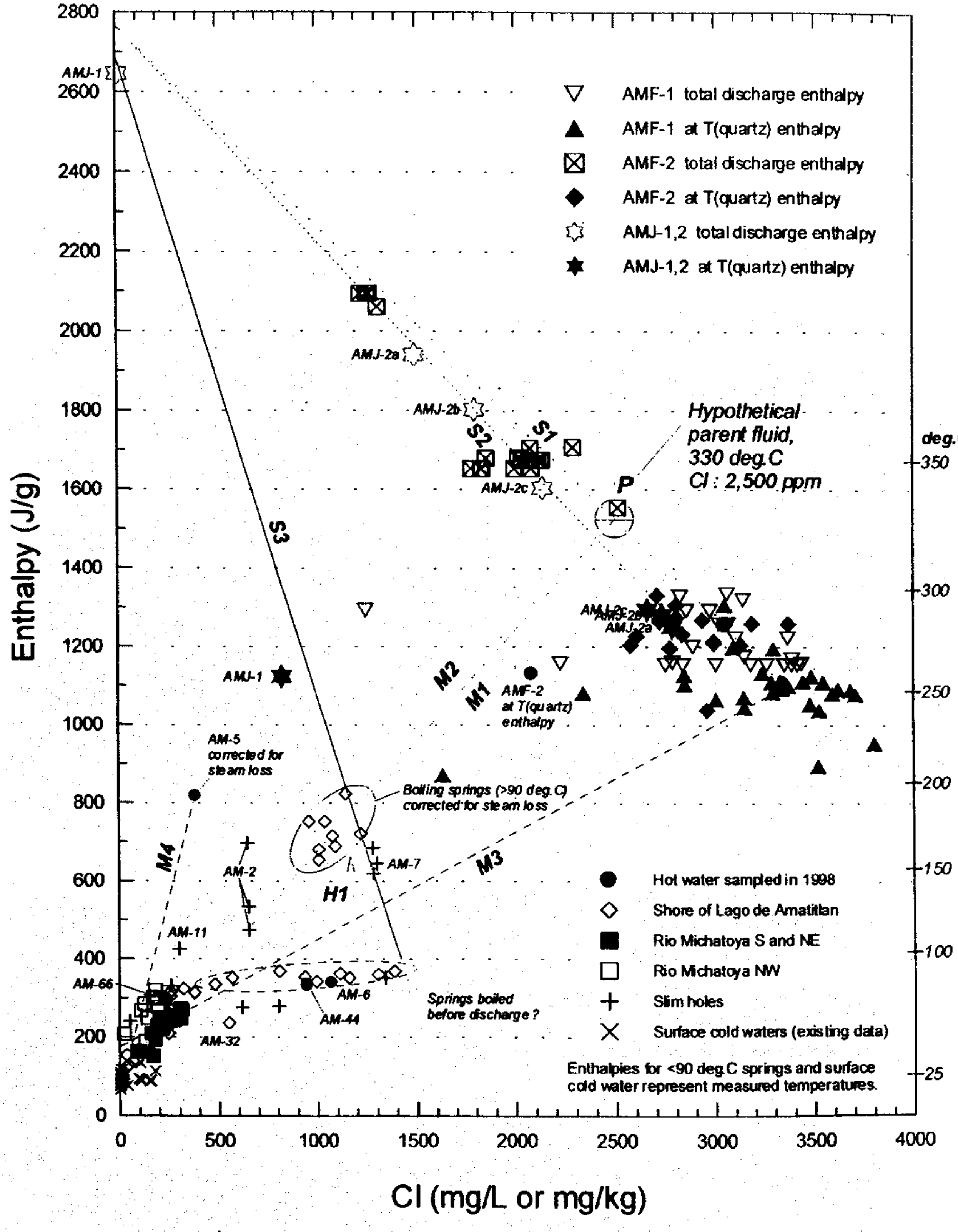


Fig.2-4-4 Enthalpy versus Cl diagram

エンタルピー—Cl 相関図

Fig.2-4-5　坑井 AMJ-1 温度検層(1,700 m)

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

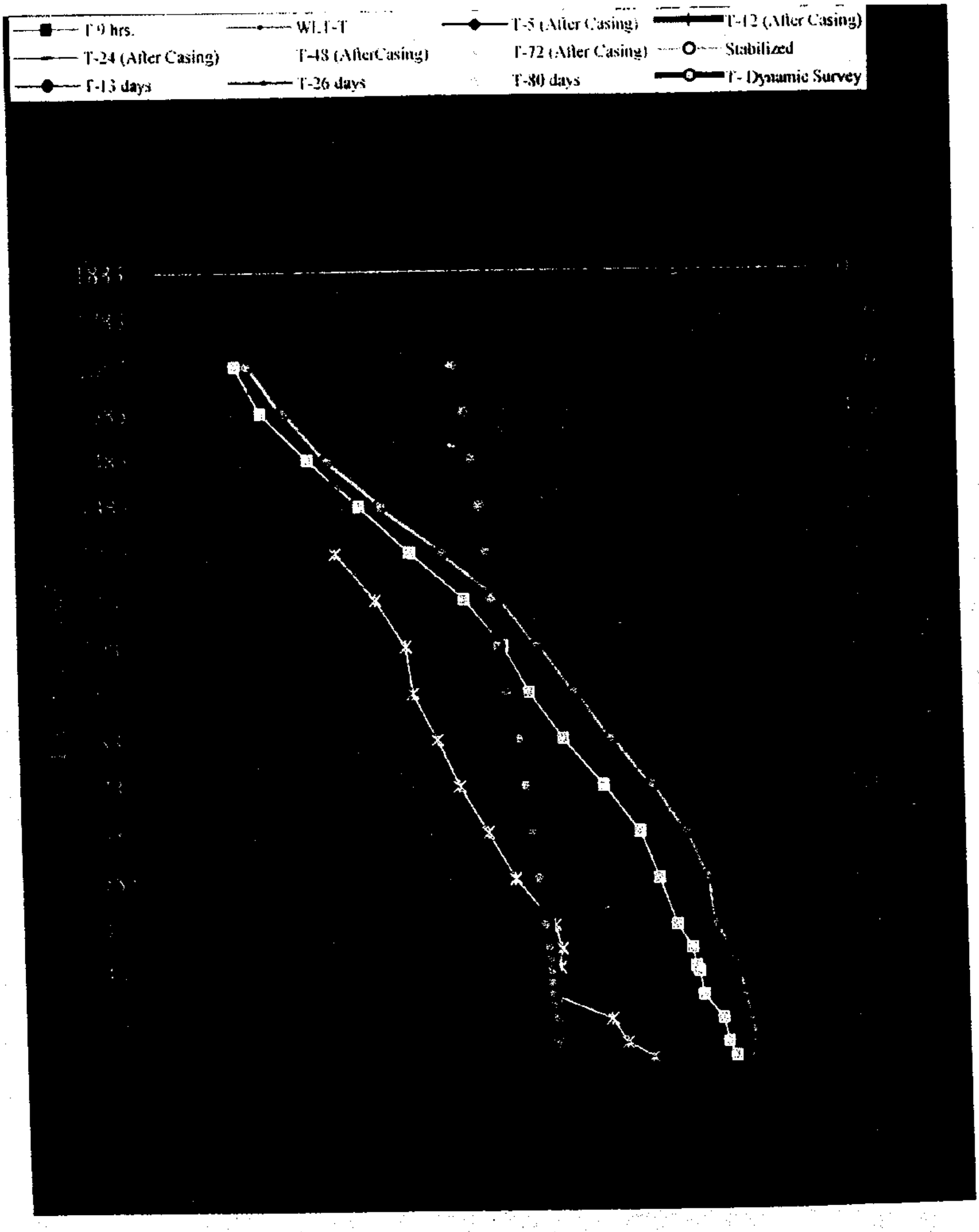


Fig.2-4-5　坑井 AMJ-1 温度検層(1,700 m)

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

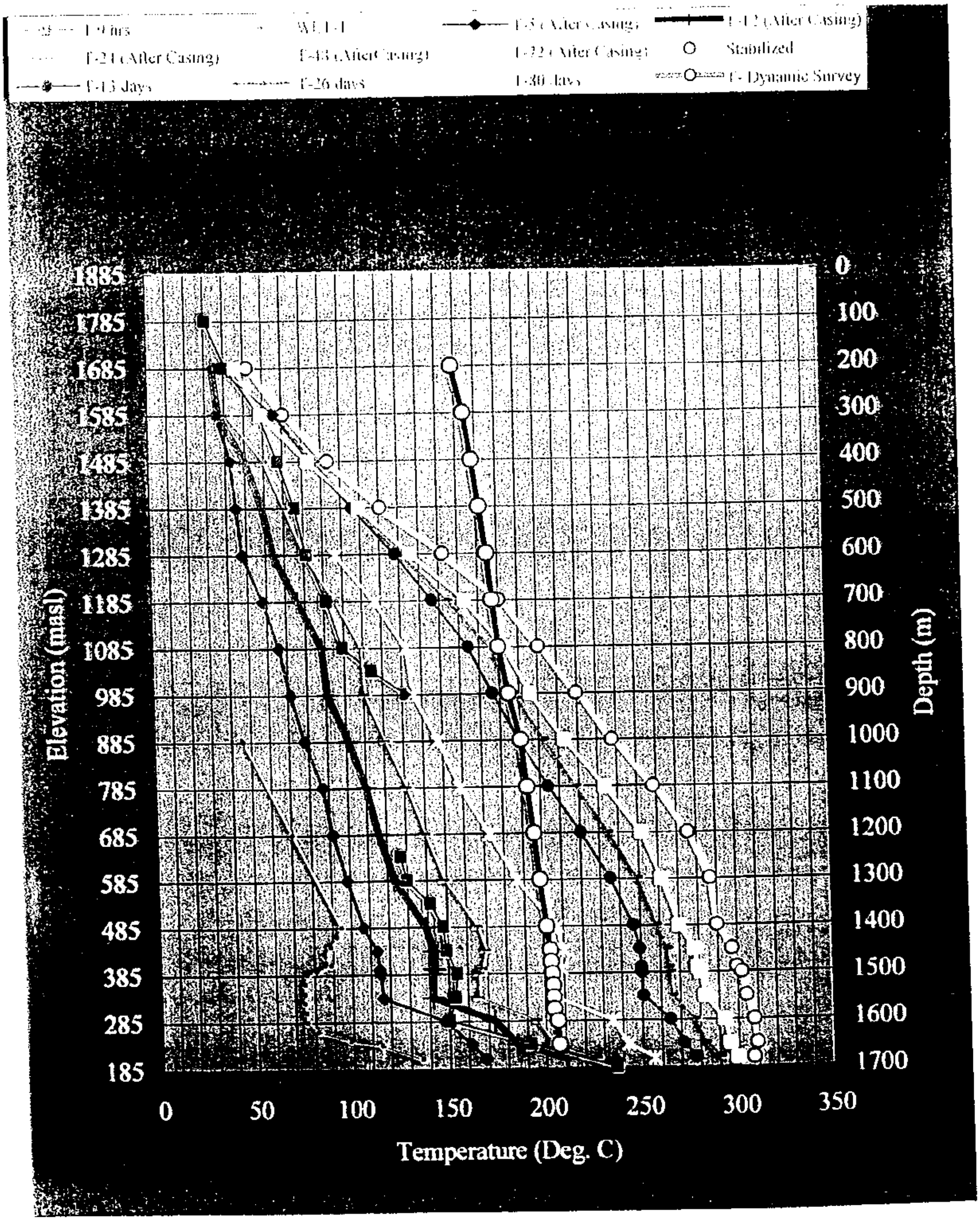


Fig.2-4-6　坑井 AMJ-2 温度検層(1,700m)

Well AMJ-2: Static temperature profiles

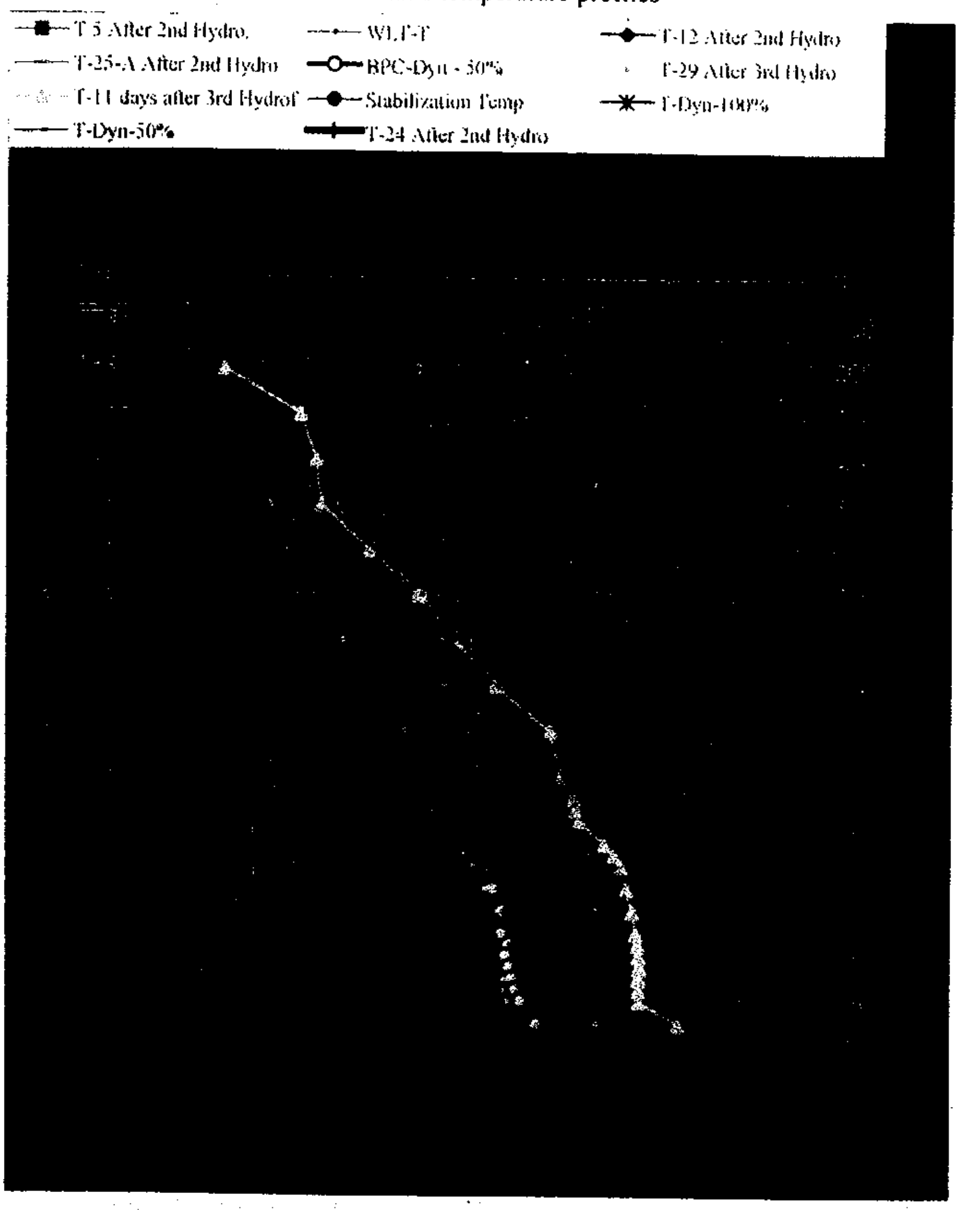
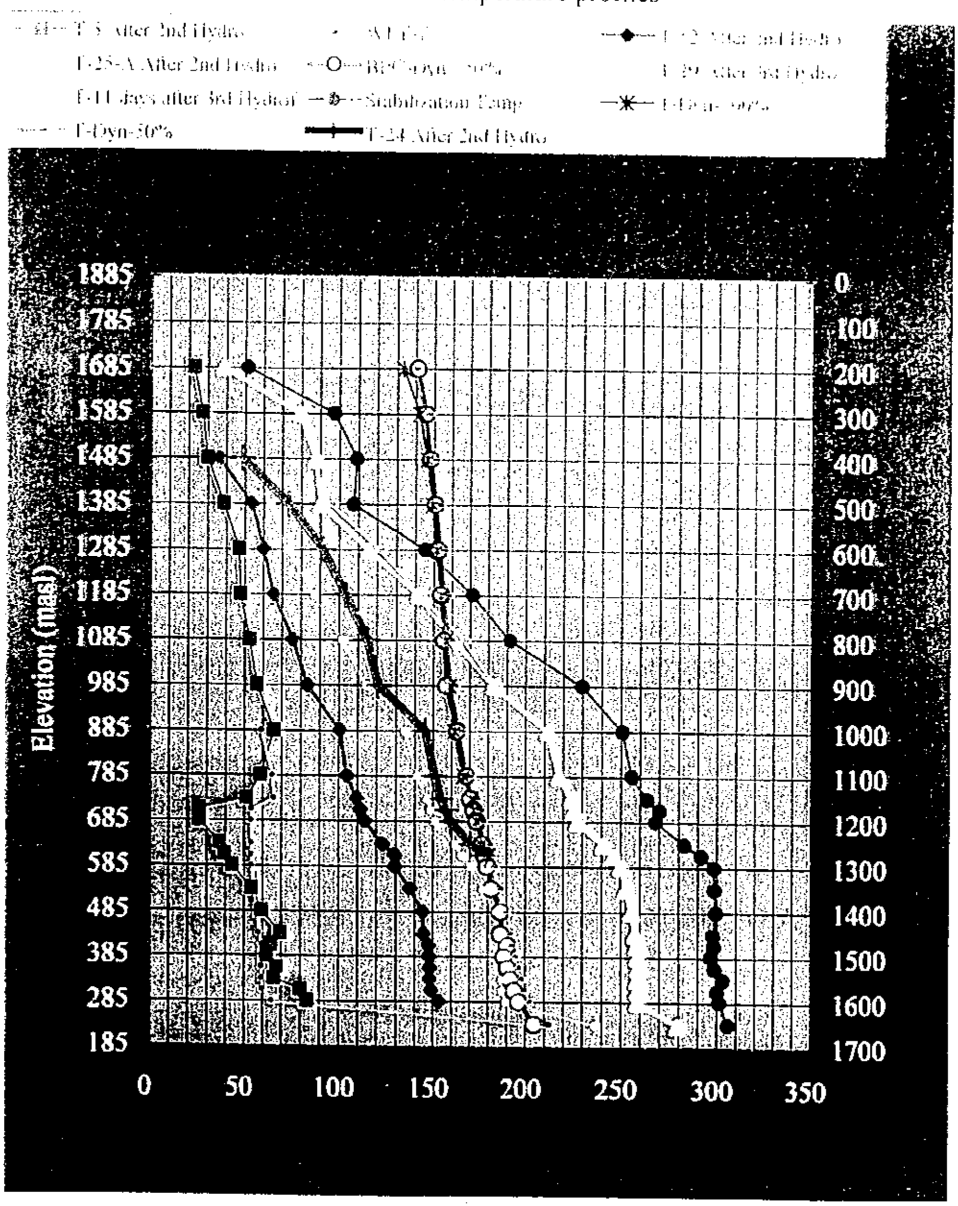


Fig.2-4-6　坑井 AMJ-2 温度検層(1,700m)

Well AMJ-2: Static temperature profiles



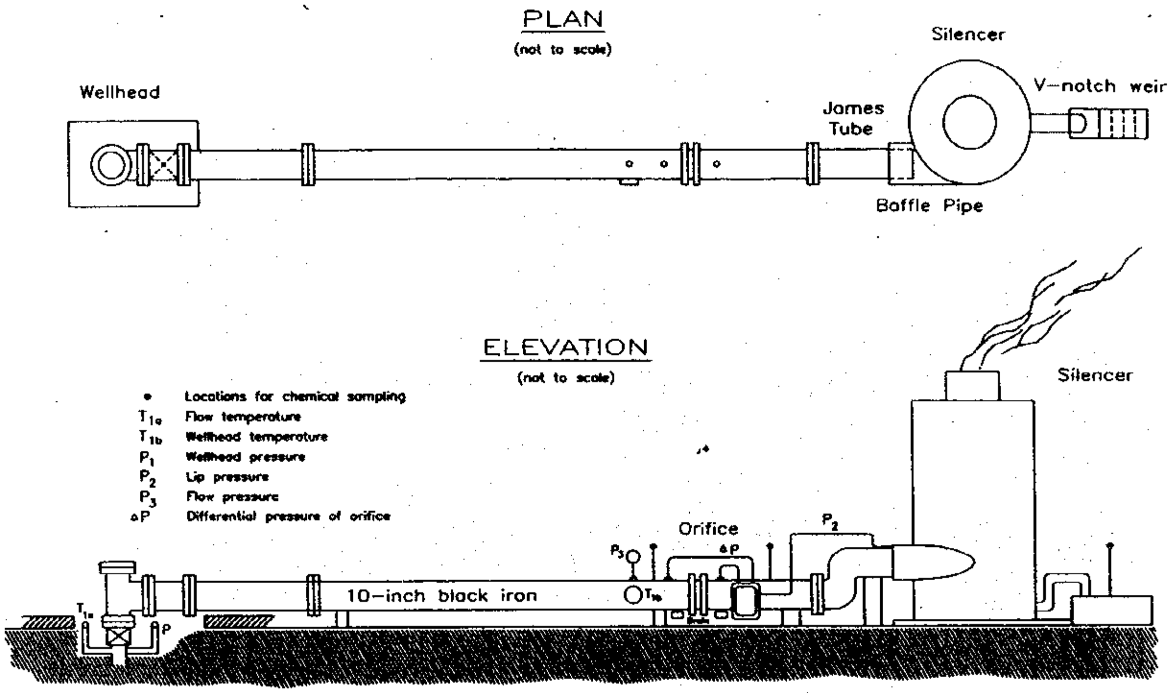


Fig.2-4-7 Well setup for the "James" Lip Pressure Method

リッププレッシャー法試験設備

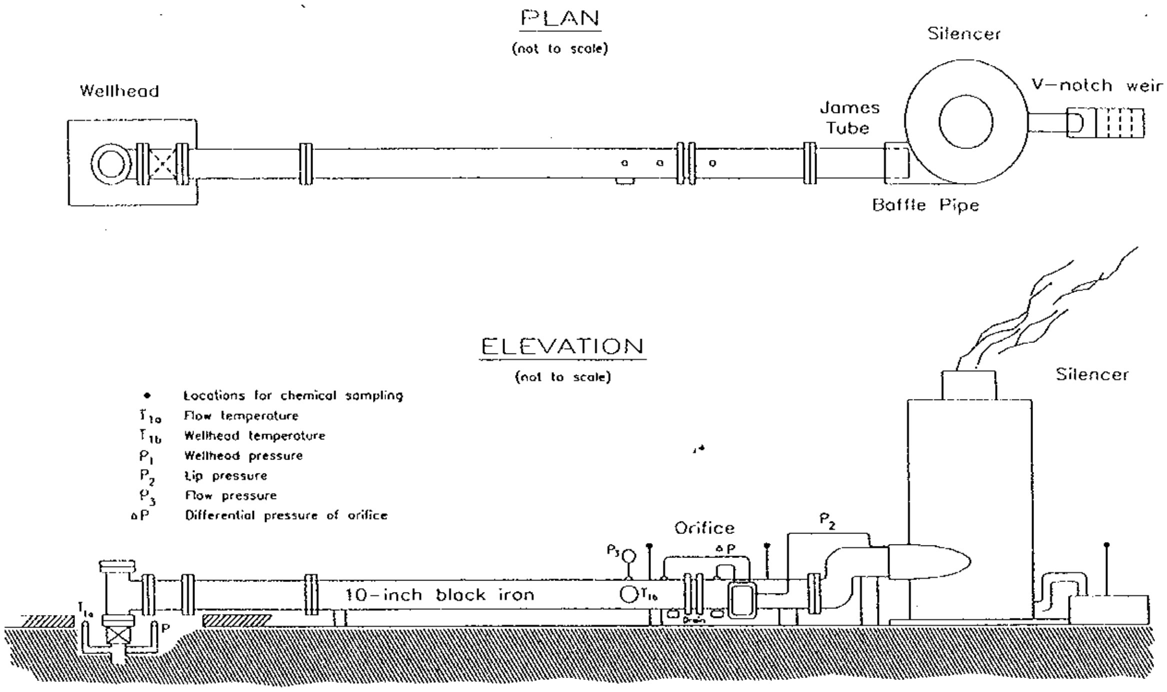
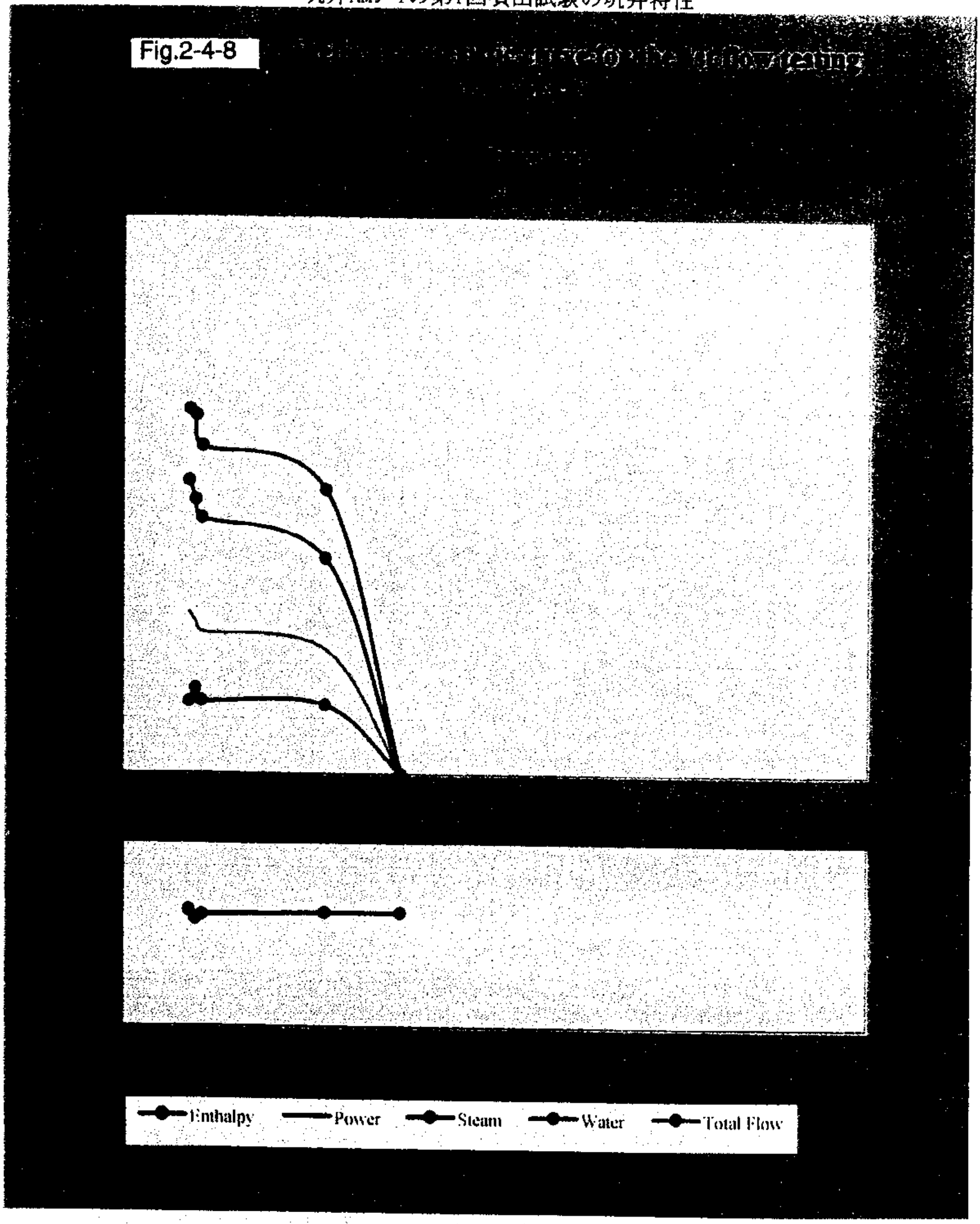
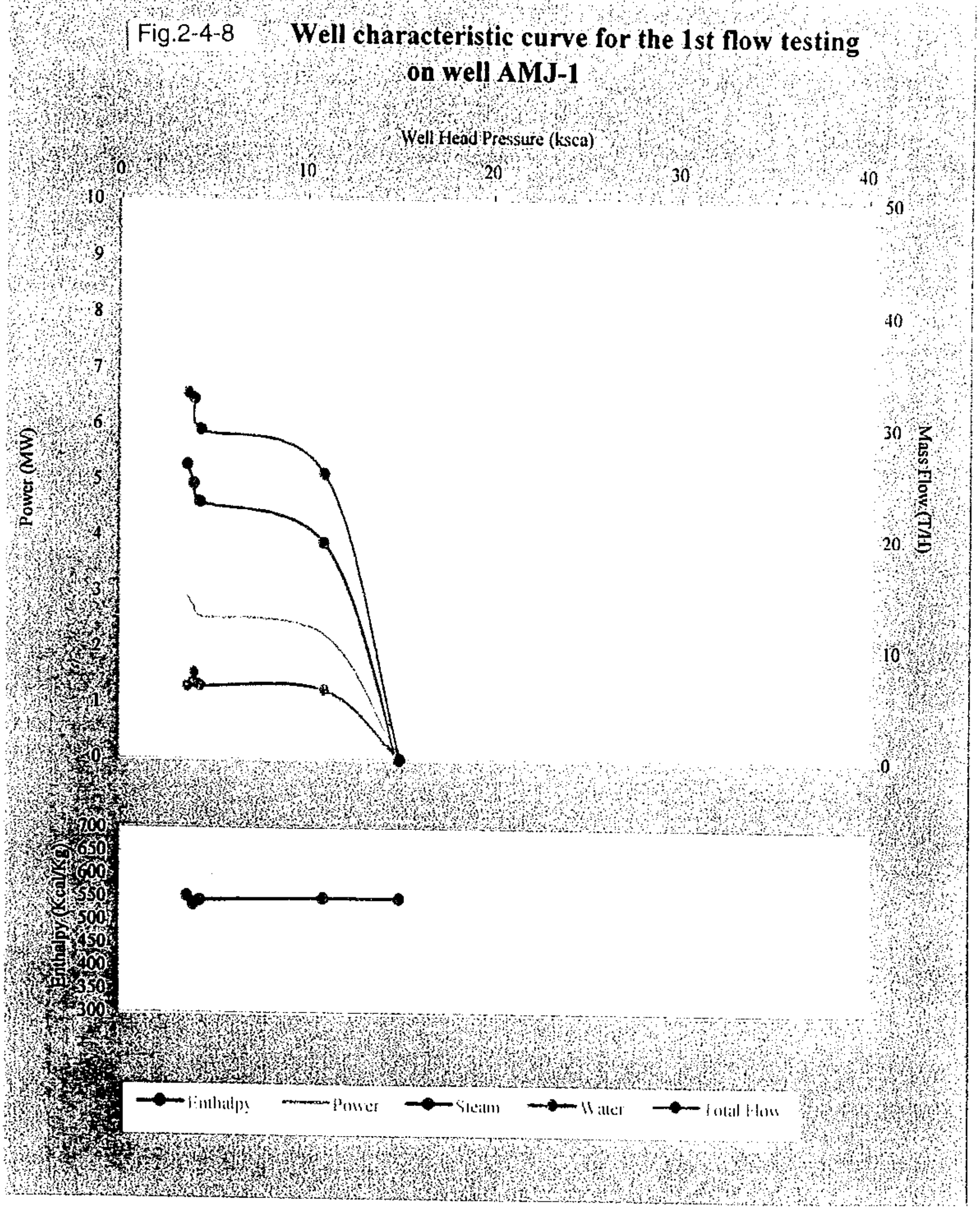


Fig.2-4-7 Well setup for the "James" Lip Pressure Method
リッププレッシャー法試験設備

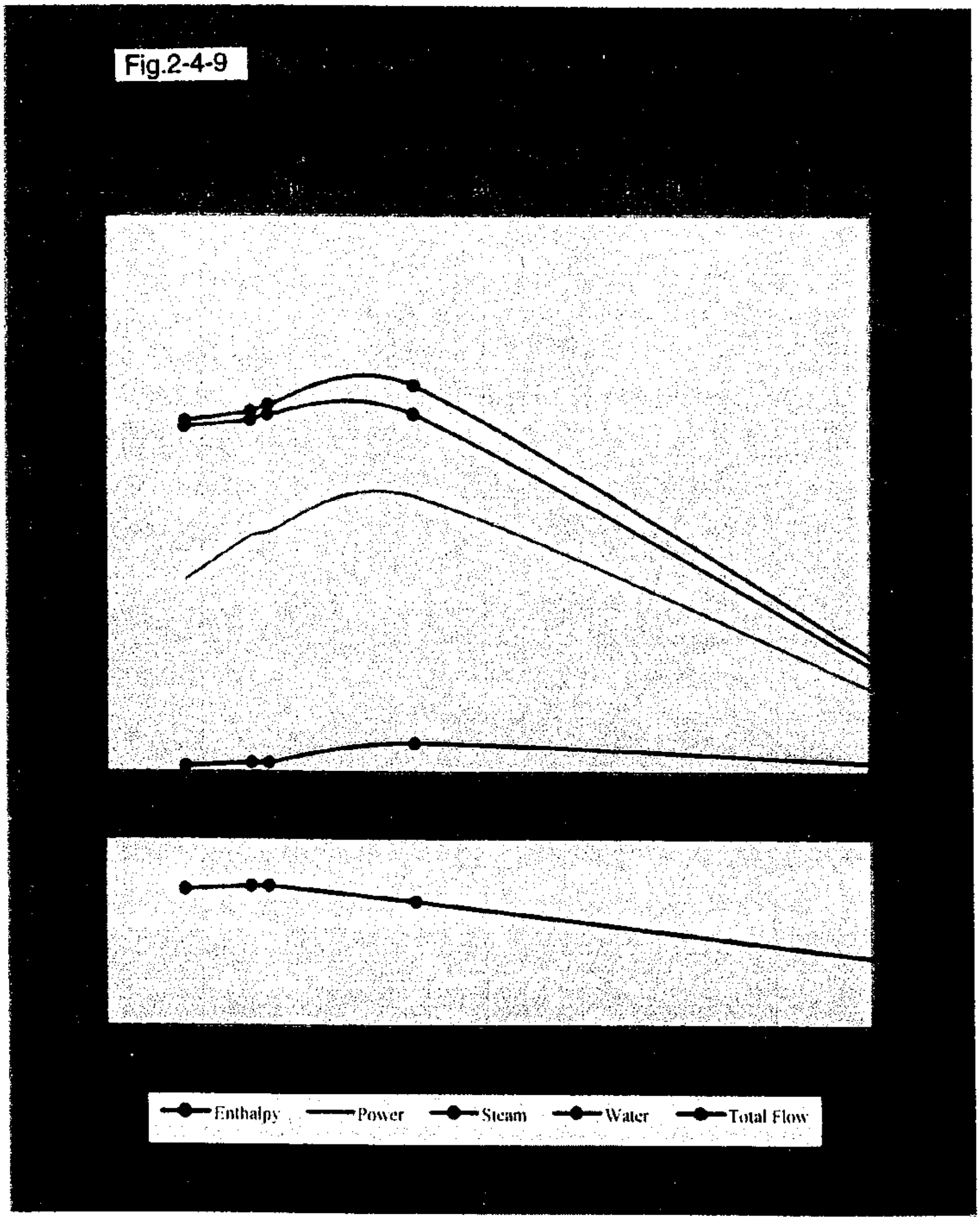
坑井AMJ-1の第1回噴出試験の坑井特性



坑井AMJ-1の第1回噴出試験の坑井特性

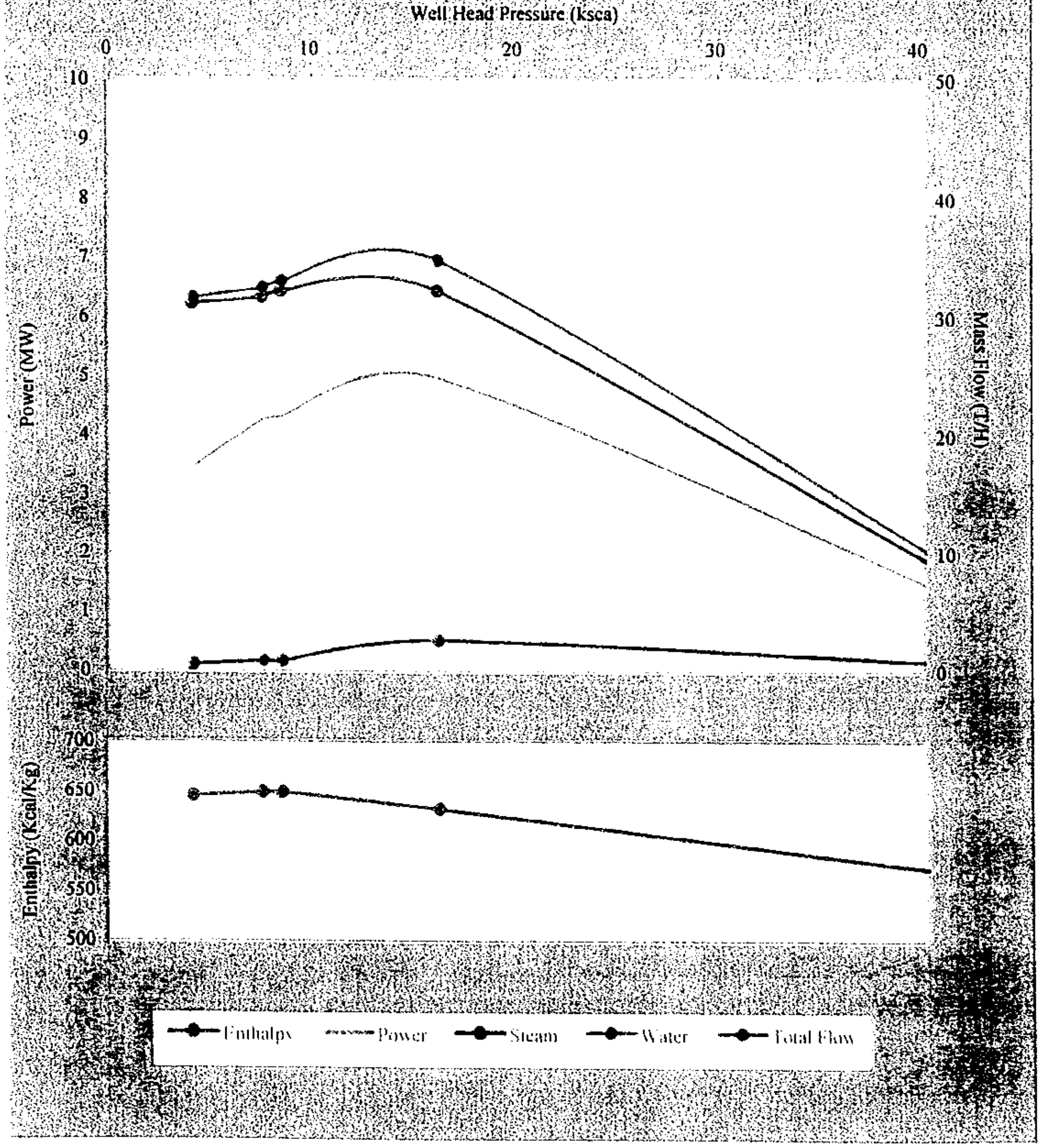


坑井AMJ-1の第2回噴出試験の坑井特性

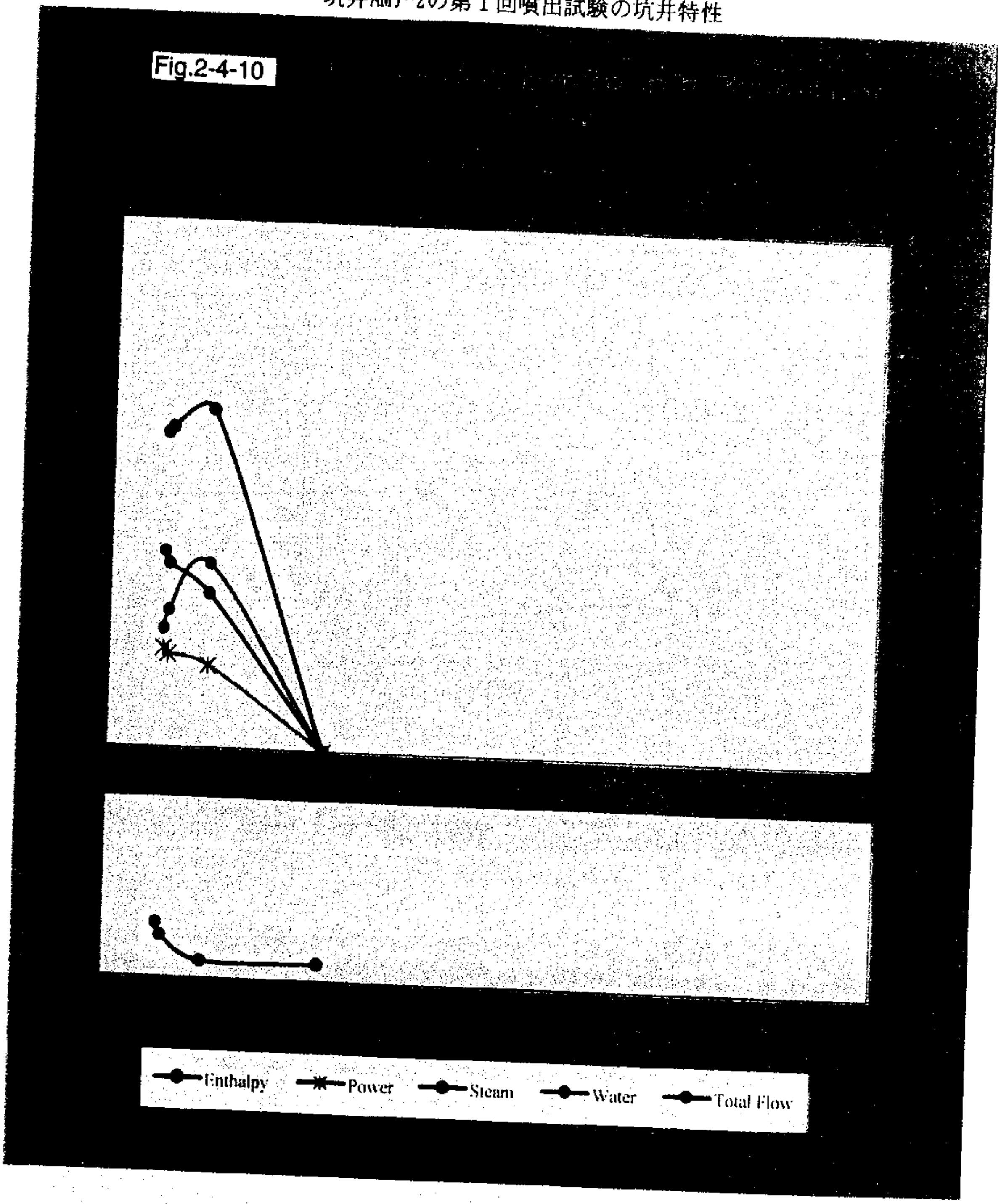


坑井AMJ-1の第2回噴出試験の坑井特性

Fig.2-4-9 **Well characteristic curve for the 2nd. flow testing on well AMJ-1**

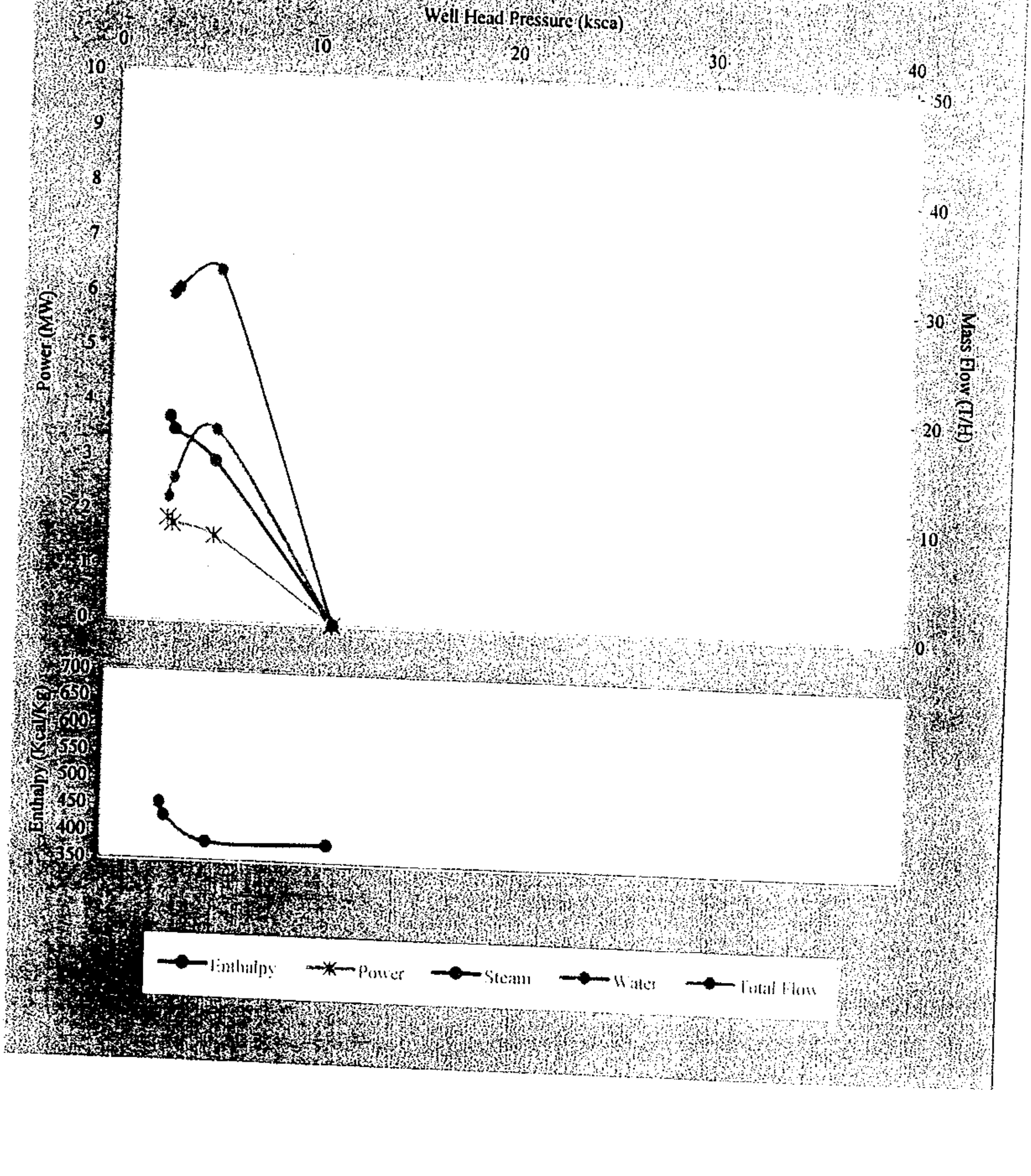


坑井AMJ-2の第１回噴出試験の坑井特性

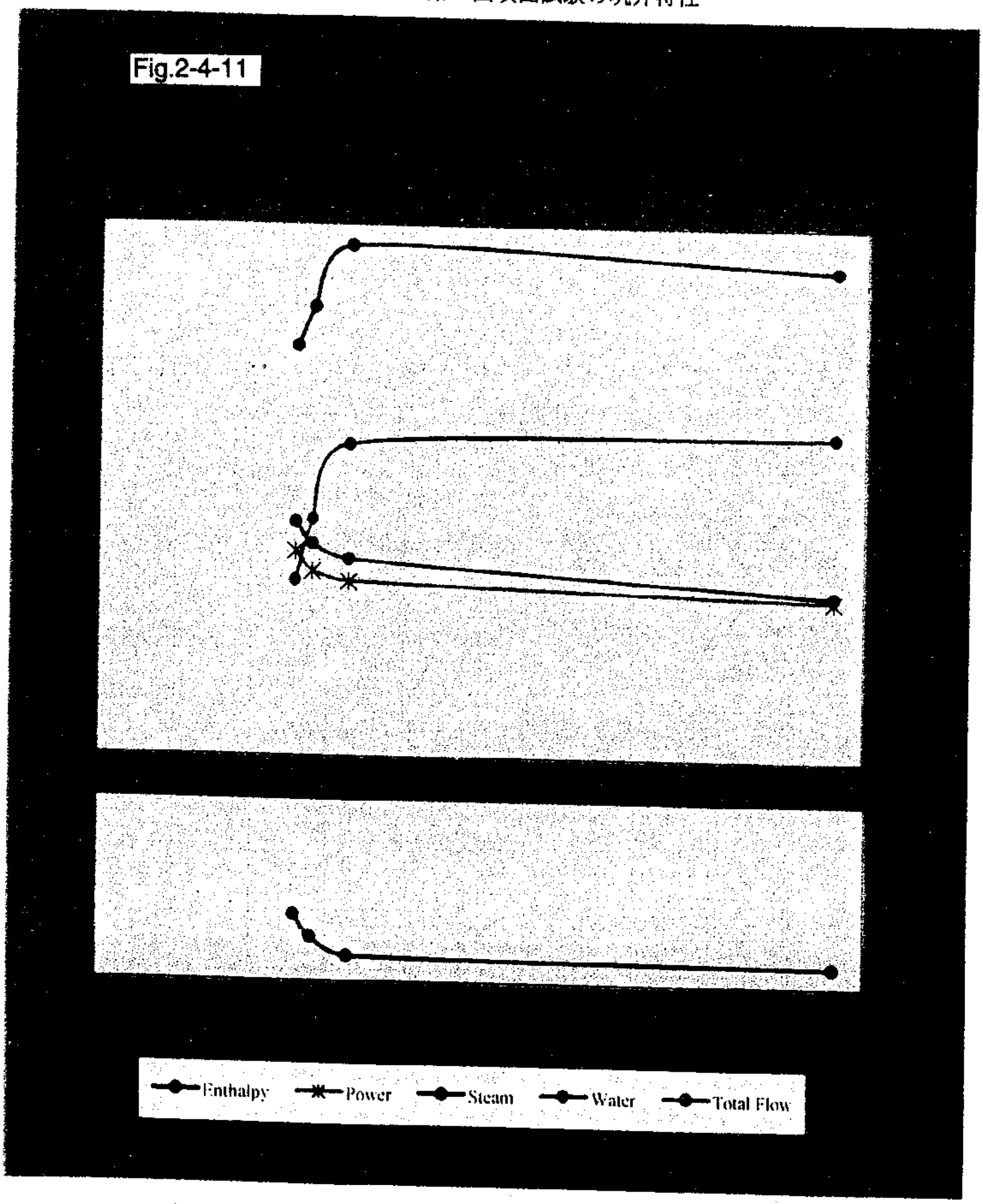


坑井AMJ-2の第1回噴出試験の坑井特性

Fig.2-4-10 **Well characteristic curve for the 1st flow testing on well AMJ-2**



坑井AMJ-2の第２回噴出試験の坑井特性



坑井AMJ-2の第２回噴出試験の坑井特性

Fig.2-4-11 **Well characteristic curve for the 2nd. flow testing on well AMJ-2**

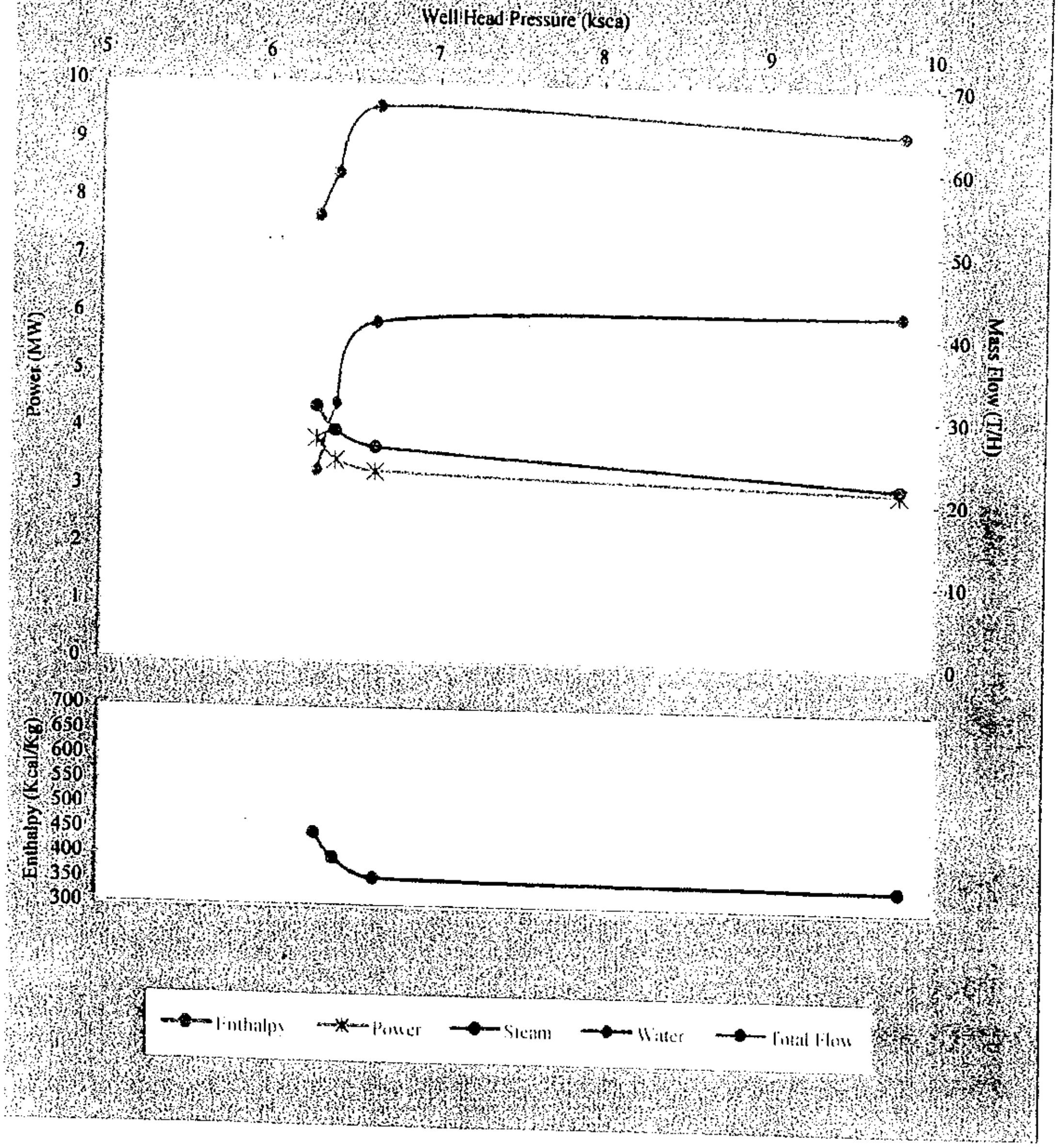


Table2-4-1 Result of chemical and isotope analyses of hot water samples
熱水試料の化学・同位体分析結果表

NAME	AMJ-1		AMJ-2a		AMJ-2b		AMJ-2c		AMF-2(1998)	
DATE	Nov/25/2000		Nov/27/2000		Nov/28/2000		Nov/29/2000		Oct/22/1998	
W.H.P.(psi)	700		29		33		64		32.7atg	
SAMPLING POINT	silencer muffler		weir box		weir box		weir box		sampling separator	
WATER-TEMP. (℃)	84		90		90		90		<60	
pH(18℃)	7.95		7.57		7.56		7.55		5.25	
EC (μS/cm)	4230		13700		13800		13400		9030	
TSM (mg/L)	3230		9440		9500		9370		6150	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Na	760	33.06	2540	110.48	2520	109.61	2510	109.17	1630	70.90
K	132	3.38	523	13.38	524	13.40	531	13.58	345	8.82
Ca	10.3	0.51	73.3	3.66	72.5	3.62	67.1	3.35	39.1	1.95
Mg	0.071	0.01	0.117	0.01	0.086	0.01	0.071	0.01	0.018	0.00
total cation		36.95		127.52		126.63		126.11		81.67
Cl	1220	34.41	4480	126.35	4500	126.91	4420	124.66	2970	83.76
SO_4	28.2	0.59	39.3	0.82	36.7	0.76	32.6	0.68	11.7	0.24
HCO_3	137	2.25	55	0.90	54	0.88	49	0.80	37	0.61
CO_3	n.d.	0.00	n.d.	0.00	n.d.	0.00		0.00	n.d.	0.00
total anion		37.24		128.07		128.56		126.14		84.61
	mg/L		mg/L		mg/L		mg/L		mg/L	
Li	1.35		19.5		18.7		18.3		9.90	
Fe	0.26		0.50		0.22		0.38		0.16	
Al	0.35		0.38		0.15		0.20		0.58	
Sr	0.14		0.45		0.41		0.37		0.36	
F	0.79		1.98		2.07		1.91		0.49	
B	42.0		75.6		77.1		74.1		45.9	
Br	5.1		17.9		18.1		17.8		10.1	
I	0.74		0.99		0.91		0.96		1.52	
As	3.56		8.69		8.64		8.41		5.39	
Hg	-		<0.0005		<0.0005		<0.0005		0.0009	
T-CO_2	111		134		174		139		68	
H_2S	-		<0.04		<0.04		<0.04		3.76	
T-SiO_2	765		1030		1100		1130		745	
$\delta D(H_2O)$ (‰)	-25		-33		-36		-36		-46	
$\delta^{18}O(H_2O)$ (‰)	1.5		-1.1		-1.3		-1.6		-3.7	
$\delta^{18}O(SO_4)$ (‰)	-		0.8		2.0		2.0		1.1	
$\delta^{34}S(SO_4)$ (‰)	-		10.7		11.5		12.0		15.8	
$\delta^{13}C(HCO_3)$ (‰)	-		-16.9		-22.8		-22.4		-5.2	
Tritium (T.U.)	-		<0.3		<0.3		<0.3		<0.3	
$\delta D(H_2O)^*$ (‰)	-		-42		-42		-43		-	
$\delta^{18}O(H_2O)^*$ (‰)	-		-2.3		-2.3		-2.5		-	
NOTE									separated from steam at 0.8atg	

n.d.: not determined
*: sampled at sampling separator

Table2-4-2 Result of chemical and isotope analyses of gas samples
ガス試料の化学・同位体分析結果表

NAME		AMJ-1a	AMJ-1b	AMJ-1c	AMJ-2a	AMJ-2b	AMJ-2c	AMF-2(1998)
DATE		Nov/19/2000	Nov/20/2000	Nov/21/2000	Nov/27/2000	Nov/28/2000	Nov/29/2000	Oct/22/1998
W.H.P.	psi	200	110	46	29	33	64	32.7atg
SAMPLING POINT		sampling separator	sampling separator	sampling separator	sampling separator	sampling separator	sampling separator	sampling separator
SEPARATED PRESSURE	barG	2.4	1.3	1.4	0.5	0.7	0.5	0.8atg
GAS CONTENT	vol%	0.98	1.02	0.97	0.52	0.62	0.58	0.84
GAS CONTENT	wt%	2.28	2.41	2.29	1.22	1.46	1.36	2.01
GAS COMPOSITION								
CO_2	vol%	89.9	93.8	92.5	88.3	90.6	87.6	96.8
H_2S	vol%	2.80	3.90	5.30	9.30	6.90	10.1	2.01
Residual gas	vol%	7.3	2.4	2.2	2.4	2.5	2.3	1.2
RESIDUAL GAS COMPOSITION								
N_2	vol%	75.3	59.8	53.4	73.0	68.1	64.8	71.1
H_2	vol%	n.d.	n.d.	7.44	8.46	12.5	13.9	17.8
CH_4	vol%	7.42	35.5	34.3	12.3	11.7	11.0	8.67
C_2H_6	vol%	-	-	-	-	-	-	0.37
O_2	vol%	16.4	3.94	4.22	5.32	6.80	9.18	1.68
Ar	vol%	0.84	0.78	0.58	0.92	0.80	1.07	0.34
He	vol%	0.0072	0.021	0.023	0.019	0.019	0.018	0.053
Ne	vol%	0.0015	0.00074	0.00051	0.0012	0.00080	0.0027	0.0007
$^3He/^4He$	$\times 10^{-6}$	10.37±0.13	10.31±0.14	10.45±0.15	10.46±0.14	10.52±0.12	10.44±0.09	10.64±0.09
$^4He/^{20}Ne$		44	18	68	21	23	23	123
$\delta^{13}C(CO_2)$	‰	-6.8	-8.4	-7.4	-6.8	-6.9	-5.9	-3.0
$\delta^{13}C(CH_4)$	‰	-30.5	-30.4	-30.4	-27.4	-27.6	-26.5	-33.1
$\delta D(H_2)$	‰	n.d.	n.d.	-379	n.d.	-409	-493	-485
$\delta D(CH_4)$	‰	-208	-221	-227	-196	-205	-187	-227
$\delta^{34}S(H_2S)$	‰	2.5	1.6	1.0	1.4	1.4	1.4	n.d.
CONDENSED WATER CHEMISTRY								
pH	20℃	6.20	5.85	5.66	5.03	5.03	5.00	-
Na	mg/L	0.902	0.408	0.402	0.380	0.093	0.112	-
Cl	mg/L	1.20	0.54	0.56	0.64	0.12	0.16	-
SO_4	mg/L	1.5	1.2	0.8	1.3	0.8	1.3	-
As	mg/L	0.014	0.013	0.012	0.006	0.031	0.016	-
Hg	mg/L	0.0009	0.0011	<0.0005	<0.0005	<0.0005	<0.0005	-
$\delta D(H_2O)$	‰	-56	-55	-54	-59	-59	-60	-67
$\delta^{18}O(H_2O)$	‰	-3.8	-3.4	-3.3	-6.1	-6.1	-6.6	-7.7

n.d.: not determined due to low concentration of CH_4, H_2 and H_2S

Table2-4-3 Results of the curve matching and hydraulic properties for well AMJ-1

坑井 AMJ-1 の坑井試験結果

h/MU	4.54E-10	m3/Pa.s	Phi*c*h	1.09E-04	m/Pa	Skin Factor	0.9		WB Storage	30	
kh	4.59E-14	m3	kh	4.59E+01	mdarcy-m	Viscosity	0.0001011	Pa.s	Spec. Vol	0.00101	m3/k
k	2.53E-16	m2	Phi*Ct	6.003E-07	1/Pa	Stabilization Temp. 1600m	264.53	C	Injection Temp.	25	C
h	1.82E+02	M									

Table2-4-4 Results of the curve matching and hydraulic properties for well AMJ-2

坑井 AMJ-2 の坑井試験結果

R=k 'MU	2.84E-09	m3/Pa.s	STO= Phi*c*h	5.85E-06	m/Pa	Skin Factor	-0.5		WB Storage	0	
kh	5.52E-14	m3	kh	5.39E+01	mdarcy-m	Viscosity	1.943E-05	Pa.s	Spec. Vol	0.001013	m3/kg
k	5.66E-15	m2	Phi*Ct	6.003E-07	1/Pa	Stabilization Temp. 1600m	279.28	C	Injection Temp.	50	C
h	9.75E+00	M									

2.5 Geothermal Conceptual Model

2.5.1 Geological Structure

2.5.2 Heat Source

2.5.3 Temperature Distribution

2.5.4 Geochemical Model

2.5.5 Conceptual Model

2.5 GEOTHERMAL CONCEPTUAL MODEL

From geo-scientific surveys such as geological reconnaissance, geochemical and geophysical survey, and various well surveys, the geothermal conceptual model in the Amatitlan area was prepared and updated.

The geological result allowed the identification of the basement structure, faults system and the dacitic intrusion controlling the geothermal activity present in the Amatitlan field. In addition, the comprehensive analysis of rock age and hydrothermal alteration permitted the disclosure of the volcanic activity associated to the heat source and to the geothermal activity of the area.

In addition to review the chemistry of thermal springs and the fumarolic activity, the geochemical analysis for geothermal fluids from wells AMJ-1 and AMF-2 permitted the estimation on the up-flow pathways, the characteristics and the pattern of geothermal fluids. Finally a geochemical model was constructed.

The uplifted zone of basement, the altered area, the extent of geothermal reservoir and resistivity structure was estimated from the gravity, magnetic and MT survey. This information were compared and reviewed with the result of well survey (shown to Fig.2-5-1, Fig.2-5-2 and Fig.2-5-3).

2.5.1 Geological structure

An uplift zone related to faults in N-S and NE-SW direction, by a system of calderas and by a dacitic intrusion characterizes the geological structure in the Amatitlan geothermal field.

1. Uplift Zone related to Faults in N-S and NE-SW Direction

N-S trending uplift zone of 1.5 – 2.0 km width was estimated in the center of the surveyed area from the results of the geological and gravity surveys.

This uplift zone is partly bent in NE-SW direction between Cerro Hoja de Queso and well AMF–2. Water loss circulation at the depth of 1594m in well AMJ-2 may correspond to the fault associated to the west edge of this uplift zone. At this depth, reservoir temperature over 280°C was confirmed by logging conducted in wells AMF–1 and AMF–2. The extension and distribution of fumaroles and alteration zones are parallel to this uplift zone. As shown to Fig.2-5-3, dacite intrusion occurs along the fracture zone along the west end of this uplifted zone. A part of this intrusion was confirmed by the cuttings analysis of well AMF-2.

It was confirmed by drilling of wells AMF–1 and AMF-4 that basement rock forms a relative upheaval at an altitude of 400 – 500 m compared than the low elevation, about 230m in altitude, of well AMJ-1 basement. Generally, the uplift zone of poorly permeable granite basement is likely to correspond to the upflow zone of geothermal fluids in typical geothermal fields.

2. A System of Calderas

INSIVUMEH (1978), OLADE (1982) AND Roldan (1993) report to exist three delineated calderas around the study area. The geothermal activity in Amatitlan area is considered to be associated to the southern rims of these calderas. These calderas rims are traced from the following faults-systems

(Fig.2-5-1):

a. An outermost caldera

The outer and oldest caldera is passing beneath Cerro Grande and north Cerro Chino and reaches to east Volcan de Agua through the valley along Rio Michatoya. The meteoric water may infiltrate into at the shallow zone in the study area due to no geothermal features along caldera lineation on the surface.

b. A middle caldera

The second oldest caldera forms the wall facing southeast shore of Lago de Amatitlan. Between well AMJ-1 and AMJ-2, through EL Cedro and San Vicente Pacaya, the caldera outline ends up to Jalpatagua fault. Water loss circulation around 1,140m depth of well AMJ-2 may correspond to the fault associated to this caldera rim.

The MT survey shows the low resistivity zone with NW-SE extension near wells AMJ-1, AMJ-2, AMF-2 and El Cedro. In addition, as mentioned below, the high anomaly of temperature distribution bent toward northwest direction along middle caldera rim. The fact indicates that fractured zone developed along this middle caldera is highly permeable.

c. An innermost caldera

This caldera is estimated as the youngest one from the previous reports and passes through Cerro Hoja de Queso, near well AMF-4 and north San Vicente Pacaya. Since water loss circulation was reported around 1,000m depth of well AMF-4, the cold water might percolate along faults and fractures associated to this youngest caldera rim. In contrast, the low temperature zone extends over at the northeastern part of the study area. This suggests that Lago de Amatitlan water is supposed to infiltrate along the permeable zone relevant to this caldera rim.

In addition, a relatively small caldera, Luguna Caldera, was recognized at the west of Laguna de Calderas. Water loss circulation around 1,539m depth of well AMJ-2 may result from the fault associated to the rim of Luguna Caldera. Since the extension and distribution of fumaroles and alteration zones are similar to the shape of this caldera rim, this caldera rim is anticipated to be the up-flow zone of high temperature fluids from the greater depth.

3. Intrusion of Dacite

Dacite intrusion was confirmed to exist around well AMF-2 by well geology. Since this intrusion is similar to the dacitic domes near south shore of Lago de Amatitlan in petrological characteristics and age, it was pointed out that this intrusive activity certainly happens at the same age of dome formation (West JEC and Telectro, 1995). It is possible that these intrusion bodies are distributed along the west side of the uplift zone estimated by gravity survey beneath Laguna Caldera (Fig.2-5-2 and Fig.2-5-3).

According to fluid inclusion analysis of cuttings, the homogenization temperature shows the bimodal distribution below 1,100m depth of wells AMJ-2, AMF-1 and AMF-2. It is thought that the deeper portion around these wells may be reheated and the temperature increased by newly activated hydrothermal events.

In other words, when the dacitic magma rose and shaped the intrusion, the fracture zone developed around the intrusion and then possibly becomes a path of geothermal fluid flow.

2.5.2 Heat source

It is obvious from the result of age determination that the center of the volcanic activities has migrated from north to south in Amatitlan area. It is recognized that the hydrothermal activity also has migrated in the same direction. This series of volcanic activities continues from the late Pleistocene (0.7Ma) to present. The regional heat source for Amatitlan geothermal system is interpreted and associated to a series of this magmatism, including recent activities of Volcan de Pacaya, which was erupted on January 17, 2000, with large scaled Strombolian type.

In additions, it is estimated that the dacitic magma intruded along faults related to west edge of the basement upheaval zone and to caldera rim in the age of 3-6 ka and the dacite rock body exists inside Laguna Caldera. Furthermore, it is highly possible that this dacite body itself plays a role of the direct heat sources in Amatitlan geothermal system.

2.5.3 Temperature Distribution

The temperature distribution map was made on the basis of logging data and homogenization temperature of fluid inclusions from 6 wells drilled in the survey area.

a. The highest temperature in the study area is observed around the bottom of well AMF-2. The temperature above 300°C was confirmed around the top of the basement consisting of granite porphyry. At the altitude of 200m, the maximum temperature of 320℃ was recorded by logging measurement.

b. The reversal phenomenon of underground temperature appears near 500m altitude of well AMF-3 and a isothermal line of 200℃ at same elevation extends towards the north in the tongue shape (refer to Fig.2-5-3). This fact suggests that high temperature fluid flows laterally toward the north along the uplifted basement zone.

c. The isothermal line is bent toward the northwest from the surrounding area of well AMJ-1. Low resistivity area indicated by MT survey has a harmonious elongation along the middle caldera rim. According to the geochemical analysis, lateral flow of high temperature fluid was reported to reach to Rio Michatoya in same direction. From these evidences, the fractured zone developed along this middle caldera is highly permeable and plays a role of fluid passage.

d. Around well AMF-4, slight anomaly of relatively low temperature extends in ESE direction. Meteoric water or underground cold water at shallow portion of this well may percolate along fault associated to the innermost caldera rim. This estimation is harmonious to the depth of water loss circulation encountered around 1,000m depth of well AMF-4.

In conclusion, underground temperature in the study area has a center around the dacite intrusion body beneath the westward of Laguna de Calderas and decreases concentrically. The temperature distribution has, in general, an appearance with fluid flow reflected geological structure relevant to the uplifted basement structure and a series of caldera rims.

2.5.4 Geochemical Model

Based on the geochemical interpretation regarding the reservoir fluids, the geochemical model of the Amatitlán geothermal field was reconstructed (Fig.2-5-4).

The geothermal reservoirs tapped by the wells AMJ-1, AMJ-2, AMF-1 and AMF-2 may compose a single hydrothermal system. Although the discharge fluid from the wells is only steam at the AMJ-1 and including excess steam at the AMJ-2 and AMF-2, the system is essentially a liquid dominated. All of these reservoir fluids are possibly derived from a common parent fluid of ca.330℃ and ca.2,500mg/L in Cl. The origin of the reservoir fluid is basically considered to be deep circulated meteoric water with minor magmatic fluid. The meteoric water is possibly a mixture of high altitude precipitation of the south side and low altitude water from north and northeast sides including the lake water of Lago de Amatitlán. According to Cl/B ratios in discharged water, the main reservoir host rock is believed to be volcanic rocks and not the basement granite.

The main upwelling zone is thought to be close to the wells AMF-2 and AMJ-2, since the highest fluid temperature (290-300 ℃) is estimated by the geothermometries for these wells. The ascent of the deep hot fluid is likely accompanied by partial boiling, providing the reservoir fluids slightly higher in Cl (ca.2,700mg/L) than the parent fluid. Further boiling during the fluid ascent may produce the fluid fed at the shallower depth of the well AMJ-2, which is relatively cool (<280℃) and relatively high in steam fraction and in Cl (>2,800mg/L). Possibly larger part of the high temperature fluid flows laterally northeastward with further boiling and steam separation, producing the reservoir of the well AMF-1. A part of the steam separated from the fluid ascends to shallow part to make the fumaroles at Calderas. The fluid at the reservoir of the well AMF-1 is affected more by the steam separation which yields temperature decline to around 250℃ and enrichment of Cl up to around 3,300mg/L. The fluid ascended at Calderas flows laterally toward mainly north and northeast directions with dilution by cool groundwater, and finally discharges at the south shore of Lago de Amatitlán.

2.5.5 Conceptual model

The model of geothermal system in the Amatitlan area is considered to be hydrothermal convection system resulted from meteoric water originated in southern highland and Lago de Amatitlan (shown in Fig.2-5-1, Fig.2-5-2, and Fig.2-5-3). This system is thought to be directly heated by dacitic intrusion beneath the westward of Laguna de Calderas and is regionally affected to upflowing heat and gases from the remained magma after the volcanism continuing from Late Pleistocene (0.7Ma) to Recent, such as dacitic domes, the intrusion, repeated eruption of Volcan de Pacaya, etc.

Recharged meteoric water is considered to flow toward the north or the northeast upon the granitic basement rocks. The flowing meteoric water is heated by conductive heat from the remained magma and changes to neutral chloride type hot water by interaction with surrounding rocks. This hot water contains upflowing gases from basement rocks and rises up to 300-340℃. This deep water is supposed to be parental fluid in the Amatitlan geothermal systems.

The ascent of the deep hot fluid is reserved mainly along faults related to west edge of the NE-SW trending basement upheaval, faults formed Laguna Caldera rim at the west of Laguna de Calderas, and fracture zone developed around the intrusion by the dacitic magma rise.

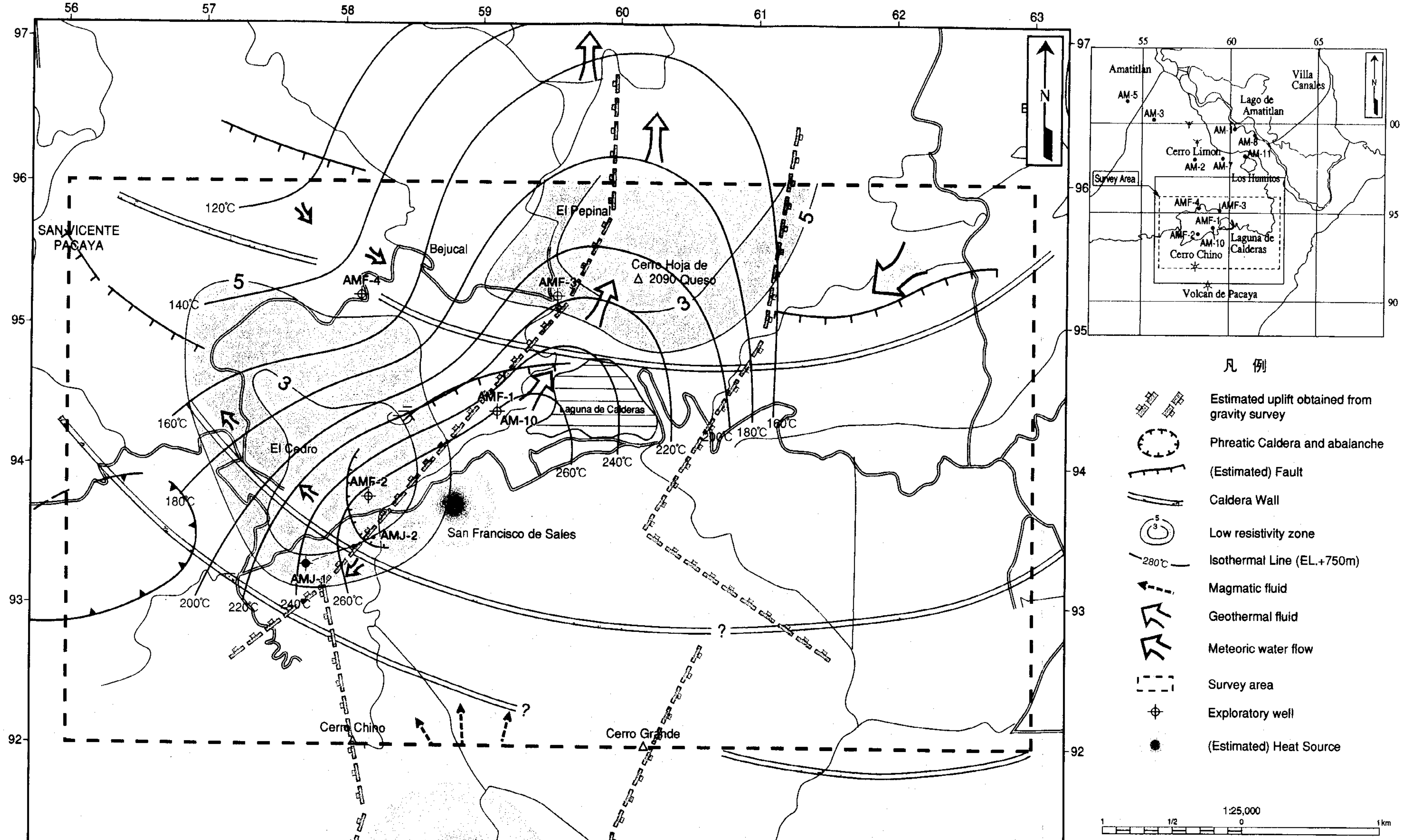
At the altitude of 500m beneath well AMF-2, the geothermal fluid is 290-300℃ in temperature and 2,700mg/l in Cl content. This hot fluid is vertically flowing up through the NE-SW trending fault and yields fumaroles and altered zones at the west-wall of Laguna Caldera. Horizontally, this fluid reaches to well AMF-1 along the NE-SW fault under boiling and yields to the water-dominated reservoir with relatively low enthalpy and high salinity tapped by this well.

Boiling accompanied with the upflow of geothermal fluids results in silica depreciation and hydrothermal alteration in the shallow part. It leads to form the cap-rock in the geothermal reservoir. This hydrothermal alteration portion was identified by the MT measurements as a low resistivity anomaly. In the area beneath and surrounding wells AMF-1 and AMF-2, there is a two-phase reservoir coexisting steam and liquid just below this cap-rock. From the distribution of this low resistivity anomaly, the hydrothermal alteration portion possibly extends towards the north with a banded-shape. Geochemical analysis suggests that the hot water is gradually diluted by meteoric water during its travel towards the north. Finally, the temperature decreases and it forms the hot spring aquifer adjacent to the shore of Lago de Amatitlan.

On the contrary, it seems that the cap-rock will be with difficulty extend toward the west due to the less development of the alteration zone around wells AMJ-1 and AMJ-2.

The phenomenon of temperature decline downward was recognized at well AMF-3. This suggests that the Lago de Amatitlan water may be percolating at elevation between 0-500m towards the southwest and be cooling the underground temperature at the northeastern part of the study area.

Dacite intrusion beneath the eastward of well AMF-2 is similar to dacite domes adjacent to Lago de Amatitlan in the zircon crystal form and the geological age. The fact is in high possibility that dacitic magma intruded in the same age (3-6ka) as dacite domes were formed at Cerro Limon and Cerro Duranzno.



Amatitlan Geothermal Development Project	
地熱構造モデル（平面図）	
Geothermal Structual Model	
JICA-WEST JEC	Fig. 2-5-1

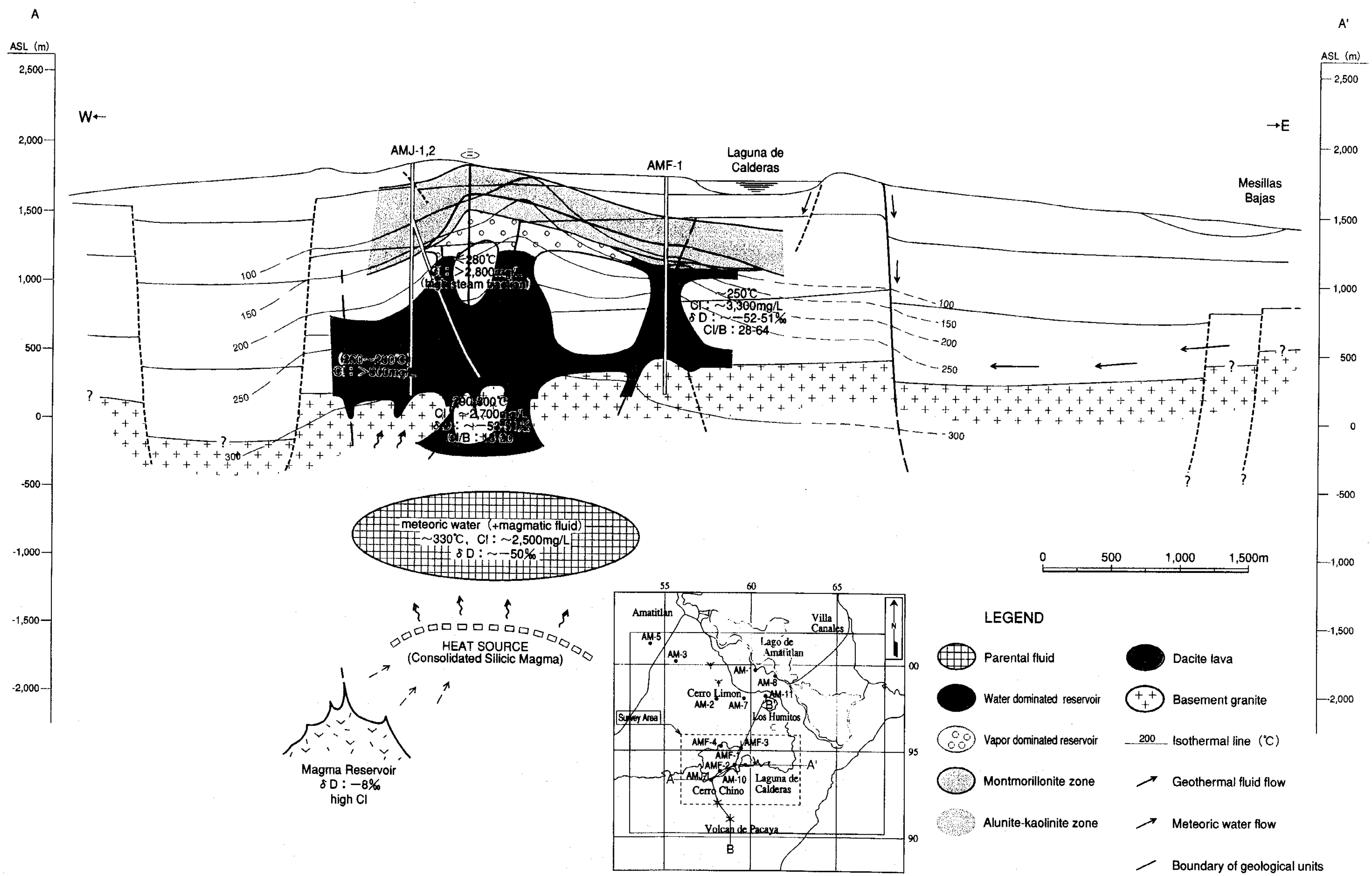


Fig. 2-5-2 Conceptual model of the Amatitlan Geothermal Area (A-A')
地熱構造モデル（A-A'断面図）

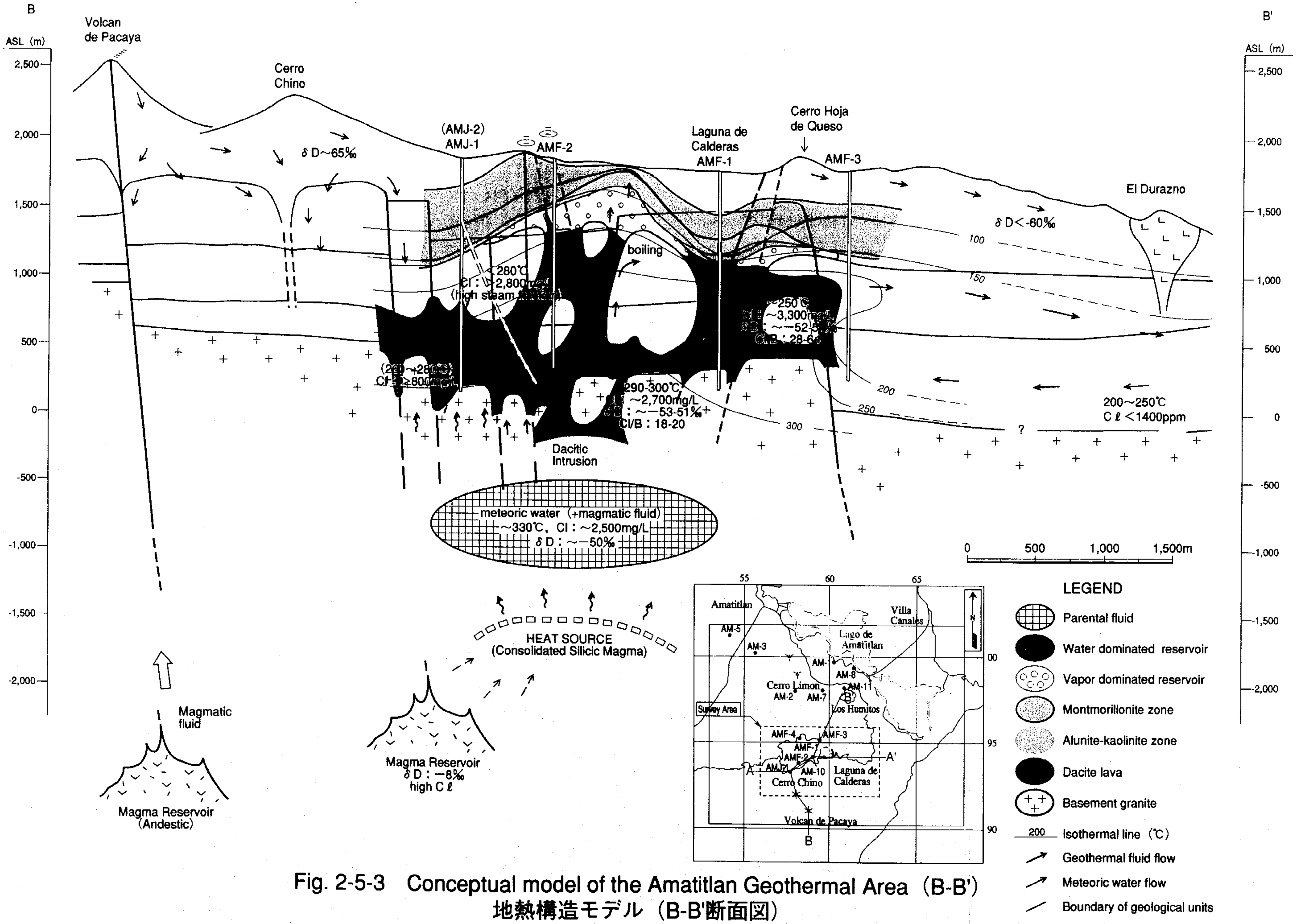
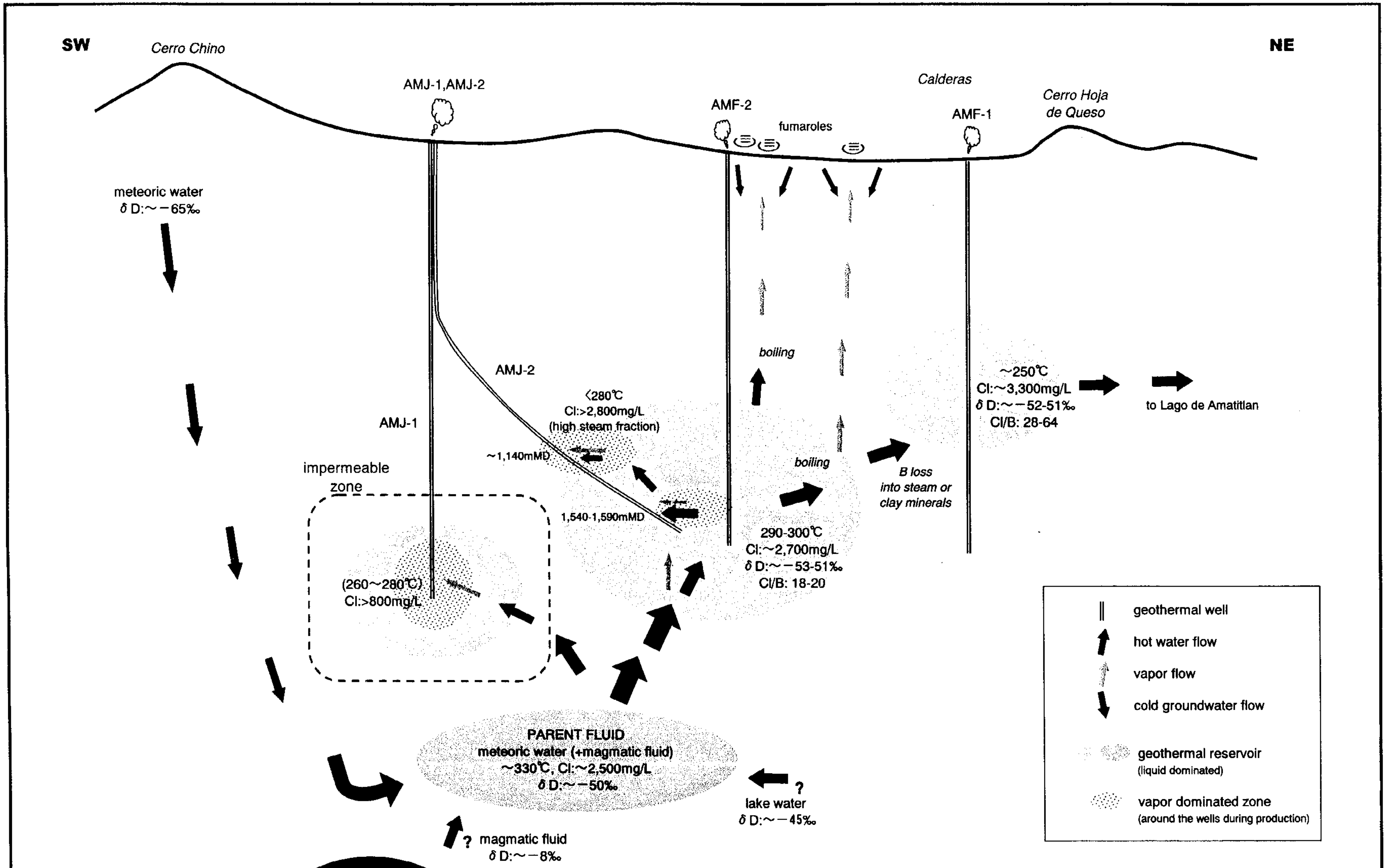


Fig. 2-5-3 Conceptual model of the Amatitlan Geothermal Area (B-B')
地熱構造モデル（B-B'断面図）



Amatitlan geothhermal development project

熱水系地化学モデル

Geochemical model of hydrothermal system

JICA-WEST JEC | Fig. 2-5-4

3 DEVELOPMENT PROGRAM

3.1 Resource Assessment

3.2 Development Plan of Power Plant

3.3 Envionmental Impact Assessment

3.4 Economical and Financial Evaluation

3.1 Resource Assessment

3.1.1 Numerical Model

3.1.2 Natural State Calibration

3.1.3 History Matching Calibration

3.1.4 Forecasting and Field Potential

3.1.5 Results of Forecasting