No. 35

REPORT
ON
THE MINERAL EXPLORATION
IN
THE RAKAH AREA, SULTANATE OF OMAN

FINAL REPORT

VOLUME Ⅲ
(MINE DEVELOPMENT)

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATIONAL AGENCY
METAL MINING AGENCY OF JAPAN

MPN
CR(3)
90-39

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PREFACE

In response to the Government of the Sultanate of Oman, the Japanese Government decided to conduct a Preliminary Feasibility Study for Mine Development Project in Rakah Area and entrusted the survey to Japan International Cooperation Agency (JICA) and Metal Mining Agency of Japan (MMAJ).

The JICA and MMAJ sent to the Sultanate of Oman a survey team for two field seasons from 1988 to 1989, headed by Mr. Takehiko Nagamatsu. The team exchanged views with the officials concerned of the Govenment of the Sultanate of Oman and conducted a field survey in the Rakah area. After the field survey, further studies were made and present reports have been prepared.

The reports consist of three volumes. The summary of the work, exploration results and the preliminary feasbility study for mine development are given in Volume I, II and III respectively.

We hope that this report will serve for the development of the project and contribute to the promotion of friendly relations between our two countries.

We wish to express our deep appreciation to the officials concerned of the Government of the Sultanate of Oman for their close cooperation extended to the team.

February, 1990

Kensuke Yanagiya
President
Japan International Cooperation Agency

Gen-ichi Fukuhara
President
Metal Mining Agency of Japan

VOLUME III

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Chapter 1 Determination of operation size

1-1 Determination of cut off grade

The cut off copper grades for both open pit mining and underground mining methods have been determined prior to the selection of the most suitable mining method and the determination of optimum operation size on Hayl as Safil and Rakah deposits.

Tentative figures have been used for the determination.

(1) Cut off grade for underground mining method

As is shown in Table 1-1, the cut off grade for underground mining method is 1.25%.

Table 1-1 Cut off grade determination for underground mining

Au price (US$/troz)		400	400	400	400	400
Cu price (US¢/lb)		80	90	100	110	120
Ore grade		Net value (US ¢/ton ore)				
Copper	Gold					
(%)	(g/t)					
1.15	0.646	−594.00	−374.95	−155.90	63.15	282.20
1.20	0.667	−528.27	−299.69	−71.12	157.45	386.03
1.25	0.688	−462.53	−224.44	13.66	251.76	489.85
1.30	0.708	−396.80	−149.18	98.44	346.06	593.68

Followings are the assumptions used in this calculation.

a. Direct operating cost

Mining cost	(US$/t ore)	10.0
Concentrator	(US$/t ore)	4.8
Cu-conc. transportation	(US$/t conc.)	10.0
Supporting	(US$/t ore)	1.8

b. Depreciation (US$/t ore) 5.7

c. Cu-concentrate

Cu grade	(%)	22.0
Cu recovery	(%)	90.0
Au recovery	(%)	60.0

d. Smelter terms

Cu T/C	(US$/t conc.)	65.0
T/C	(US¢/lb)	8.5
Recovery	(%)	96.0
Au R/C	(US$/troz)	6.0
Recovery		(g/t − 1.0) × 98.0%

(2) Cut off grade for open pit mining method

The pit design should be restricted by the maximum allowable stripping ratio which is described in the latter part of this section. The cut off grade here is the critical copper grade where the material turns to ore or to waste at the pit operation.

Therefore the mining cost and the depreciation cost have been eliminated at this calculation. The cut off grade is 0.35% which is shown in Table 1-2.

Table 1-2 Cut off grade determination for open pit mining

Au price (US$/troz)		400	400	400	400	400
Cu price (US¢/lb)		80	90	100	110	120
Ore grade		Net value (US ¢/ton ore)				
Copper	Gold					
(%)	(g/t)					
0.25	0.086	−344.87	−297.25	−249.63	−202.01	−154.39
0.30	0.146	−249.96	−192.82	−135.67	−78.53	−21.39
0.35	0.206	−155.05	−88.39	−21.72	44.95	111.61
0.40	0.266	−60.15	16.04	92.23	168.43	244.62

1-2 Selection of mining method

The open pit mining method has been selected for both Hayl as Safil and Rakah deposits. Followings are the reasons for this selection.

(1) The ore bodies are situated in rather shallow place.

(2) High grade portions are situated in the upper part of the deposits.

(3) The average copper grade is relatively low and the ore reserve for the underground mining which exceeds the cut off grade is only 240,000t on the geological ore reserve basis whereas that for the open pit mining is as much as 10,000,000t or more.

(4) The high grade portions of the stockwork ore which is the major part of the deposits are not consistently existing in the ore body. Therefore it is difficult to mine the high grade portions selectively by the underground mining method. Whereas open pit mining method doesn't have such a problem owing to its low cut off grade and nature of mining method.
(5) The extremely low precipitation in the region is a suitable condition for the open pit mining method.
(6) Wide locations for the waste dumps are available adjacent to the pits.
(7) The pits can be designed within the maximum allowable stripping ratio.

1-3 Maximum allowable stripping ratio

The maximum allowable stripping ratio, one of the important parameters for open pit designing, has been determined. Table 1-3 shows the calculation results for the Hayl as Safil deposit. The assumptions used in here are average copper grade; 1.35%, gold grade; 0.63g/t, mining cost; 0.9 US$/t and 5.7 US%/t for depreciation. Other conditions are the same as that of cut off grade calculation.

Table 1-3 Maximum allowable stripping ratio for open pit mining in Hayl as Safil

Au price (US$/troz)		400	400	400	400	400
Cu price (US¢/lb)		80	90	100	110	120
Ore grade		Net value (US ¢/ton ore)				
Copper	Gold					
(%)	(g/t)					
1.35	0.630	505.07	762.21	1,019.36	1,276.50	1,533.65
Maximum allowable stripping ratio		10.1936/0.90 = 11.33				

Table 1-4 shows the maximum allowable stripping ratio for Rakah deposit. Average copper grade is 1.15%, gold grade 0.87 g/t, mining cost 1.3 US$/t and the rest are the same as Hayl as Safil calculation.

Table 1-4 Maximum allowable stripping ratio for open pit mining in Rakah

Au price (US$/troz)		400	400	400	400	400
Cu price (US¢/lb)		80	90	100	110	120
Ore grade		Net value (US ¢/ton ore)				
Copper	Gold					
(%)	(g/t)					
1.15	0.870	442.97	662.02	881.07	1,100.12	1,319.17
Maximum allowable stripping ratio		8.8107/1.30 = 6.78				

1-4 Determination of optimum operation size

The pit designs for Hayl as Safil and Rakah have been completed considering cut off grade, mining method and maximum allowable stripping ratio. The details of the pit design is described in the next section. Following the designing, two prototype operation plans, 2,000 TPD and 3,000 TPD, have been developed. The 2,000 TPD plan has 10 years mine life and the 3,000 TPD plan has 7 years mine life. An operation size which is larger than 3,000 TPD is too short in its mine life and the depreciation cost would be too heavy for the mine operation. Therefore such case has been eliminated from the determination. A financial evaluation of these prototype plans has been conducted on the range of 300 to 500 US$/troz of gold price and 80 to 150 US ¢/lb of copper price. The comparison had shown that the FIRR (Financial Internal Rate of Return) of 7 years plan was always higher than that of 10 years plan. It is shown in Table 1-5.

Consequently, in this preliminary feasibility study, the operation size has been decided to be 3,000 TPD and the mine life is to be approximately 8 years. The mine life of 8 years is a result of the final ore reserve calculation.

Fig. 1 shows the General mine layout.

Table 1-5 Summary of financial evaluation on the prototype plans

(1) IRR for 3,000 TPD, 7 YEARS PLAN

Copper Price (US¢/lb)	Gold Price (US$/troz)								
	300	350	360	370	380	390	400	450	500
80	−13.18	−11.83	−11.56	−11.30	−11.04	−10.78	−10.52	−9.26	−8.03
90	−5.64	−4.53	−4.31	−4.09	−3.87	−3.66	−3.44	−2.38	−1.35
100	0.67	1.63	1.82	2.01	2.20	2.39	2.58	3.51	4.42
110	6.19	7.06	7.23	7.40	7.57	7.74	7.91	8.75	9.58
120	11.18	11.98	12.14	12.29	12.45	12.61	12.76	13.54	14.31
130	15.78	16.52	16.67	16.81	16.96	17.11	17.25	17.98	18.70
140	20.07	20.76	20.90	21.04	21.18	21.32	21.46	22.14	22.82
150	24.11	24.77	24.91	25.04	25.17	25.30	25.43	26.08	26.73

* IRR : Internal Rate of Return

(2) IRR for 2,000 TPD, 7 YEARS PLAN

Copper Price (US¢/lb)	Gold Price (US$/troz)								
	300	350	360	370	380	390	400	450	500
80	−17.74	−16.29	−16.02	−15.74	−15.47	−15.20	−14.94	−13.67	12.47
90	−10.12	−9.10	−8.90	−8.70	−8.50	−8.31	−8.12	−7.17	−6.26
100	−4.49	−3.67	−3.51	−3.35	−3.19	−3.03	−2.88	−2.10	−1.35
110	0.11	0.80	0.94	1.08	1.21	1.35	1.48	2.15	2.80
120	4.06	4.68	4.80	4.92	5.04	5.16	5.28	5.87	6.45
130	7.57	8.13	8.24	8.35	8.46	8.57	8.68	9.21	9.75
140	10.76	11.27	11.37	11.47	11.57	11.67	11.77	12.27	12.76
150	13.70	14.17	14.27	14.36	14.45	14.55	14.64	15.11	15.56

This calculation has used tentative figures for the operating costs, therefore the results here do not agree with that of the financial evaluation in section 9 of this report.

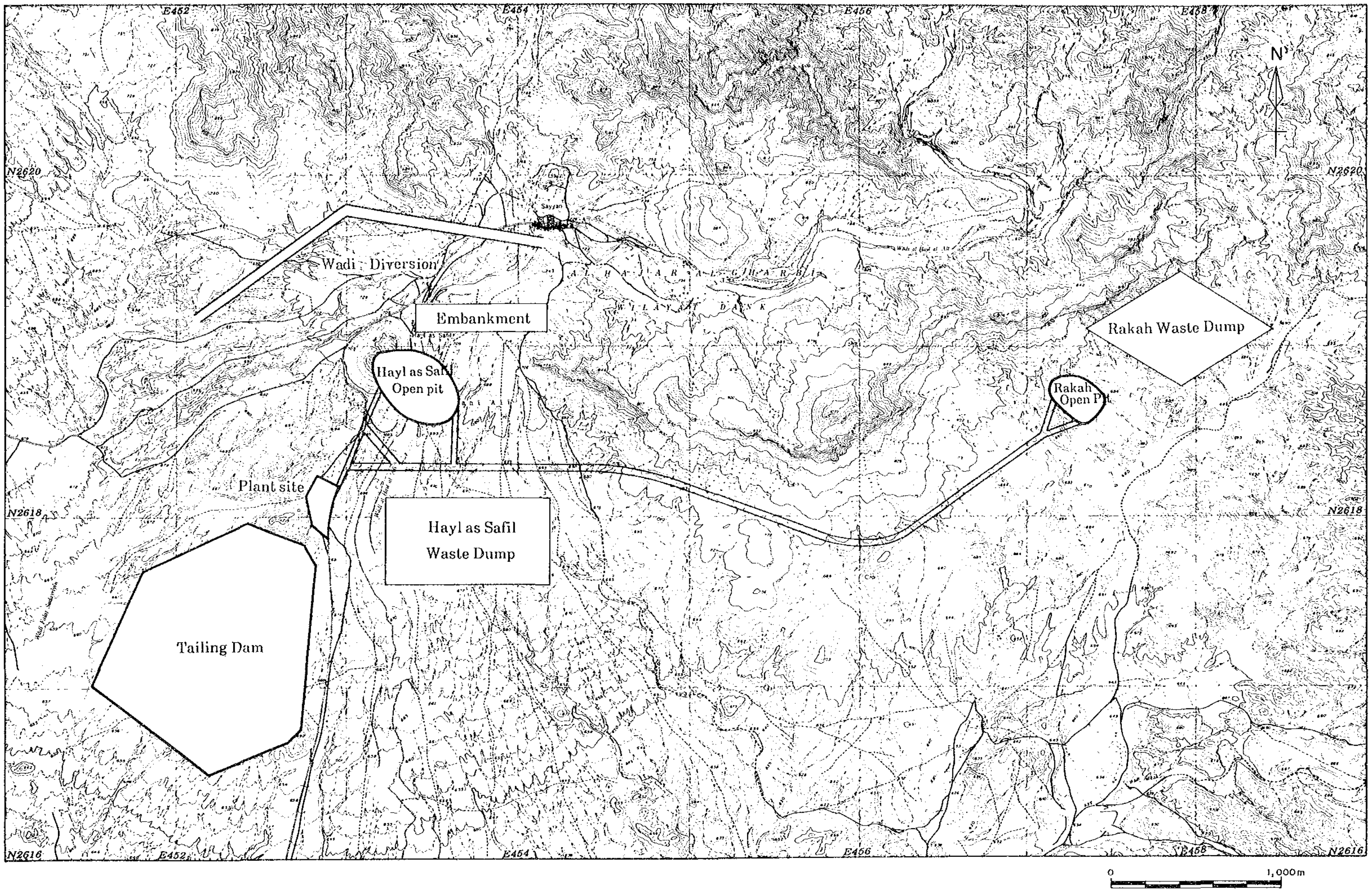

Fig. 1 General mine layout

Chapter 2 Mining

2-1 Pit design

The slope angle, 45°, is determined as a basic pit slope angle for the pit design considering extremely low precipitation, the rock strength and RQD values of the boring cores from Hayl as Safil and Rakah deposits.

The size, depth and profile of the pits have been designed so that the highest ore recovery and the lowest stripping ratio can be balanced.

The bench height has been designed to be 10m which is relatively low due to the size of heavy equipment proposed.

The stripping ratio of Hayl as Safil pit is 3.44 while its maximum allowable stripping ratio is 11.33. For Rakah pit, they are 4.17 and 6.78 respectively.

The cross sections of Hayl as Safil pit are shown in Fig. 2-1 (1) to (8). The cross section of Rakah pit are shown in Fig. 2-2 (1) to (8). The level sheets of Hayl as Safil and Rakah pits are shown in Appendix 1 and Appendix 2 respectively.

2-2 Minable ore reserve

The geological ore reserves are shown in below.

	Tonnage (t)	Cu (%)	Au (g/t)
Hayl as Safil deposit	10,553,091	1.00	0.40
Rakah deposit	4,750,736	0.99	0.88
Total	15,303,827	0.99	0.55

Based on this result, minable ore reserve has been computed by accumulating the ore blocks within the pit limit and exceeding 0.35% in copper grade. At the same time, the tonnage of the waste inside the pit is also computed. Table 2-1 and Table 2-2 show the minable ore reserves and waste tonnage of Rakah and Hayl as Safil respectively. Appendix 3 and Appendix 4 are the detailed tables of all the minable ore blocks.

The massive ore of Rakah which has been proven to be very difficult in concentrator processing is treated as waste. In the actual operation, those massive ore is to be stockpiled separately.

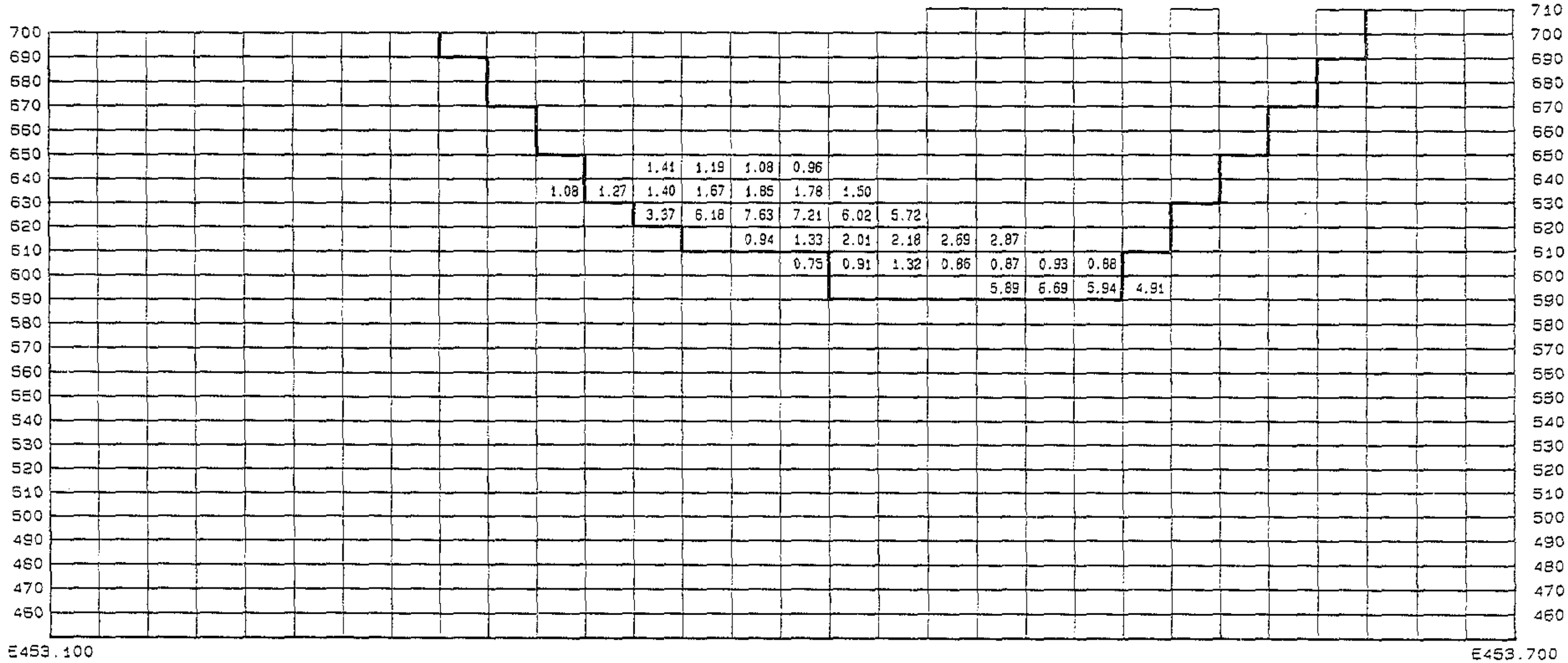

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (1)
[E-W section (N 2618.670), Pit design H 55002]

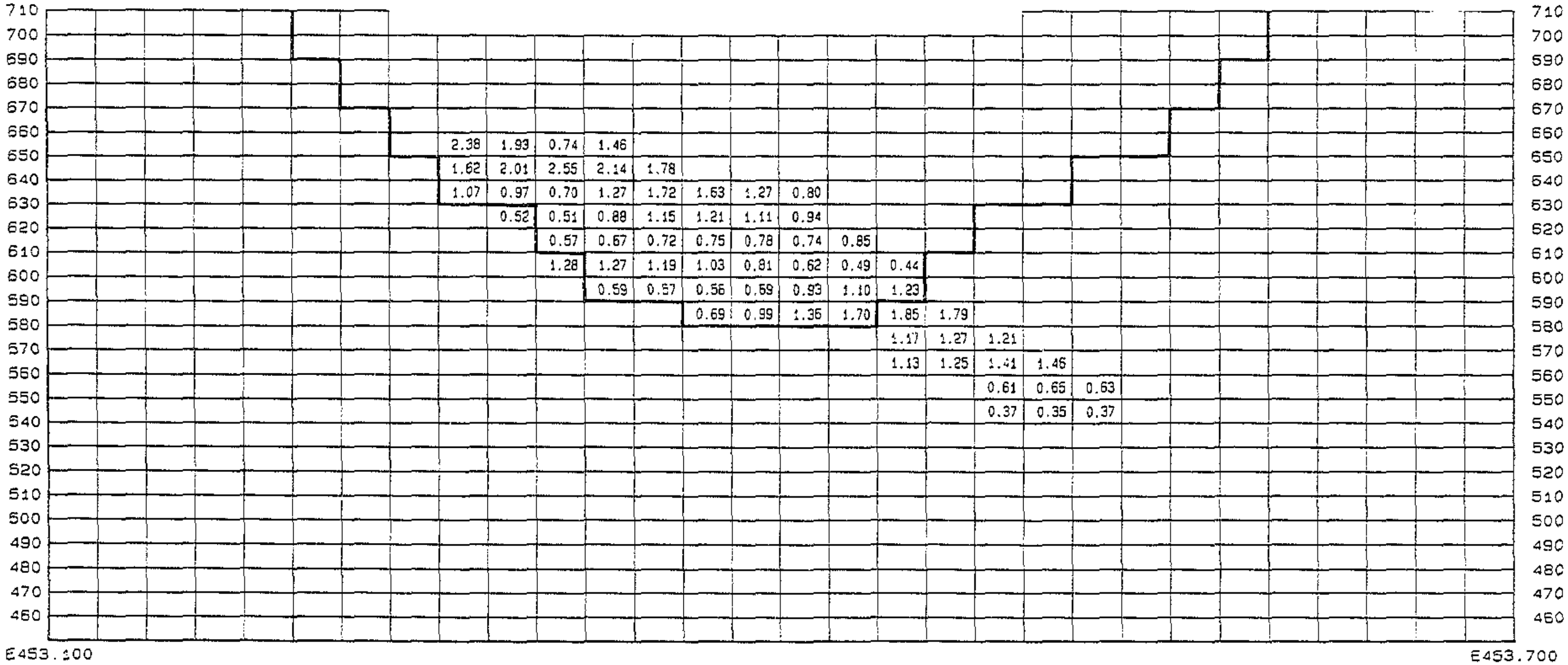

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (2)
[E-W section (N 2618.750), Pit design H 55002]

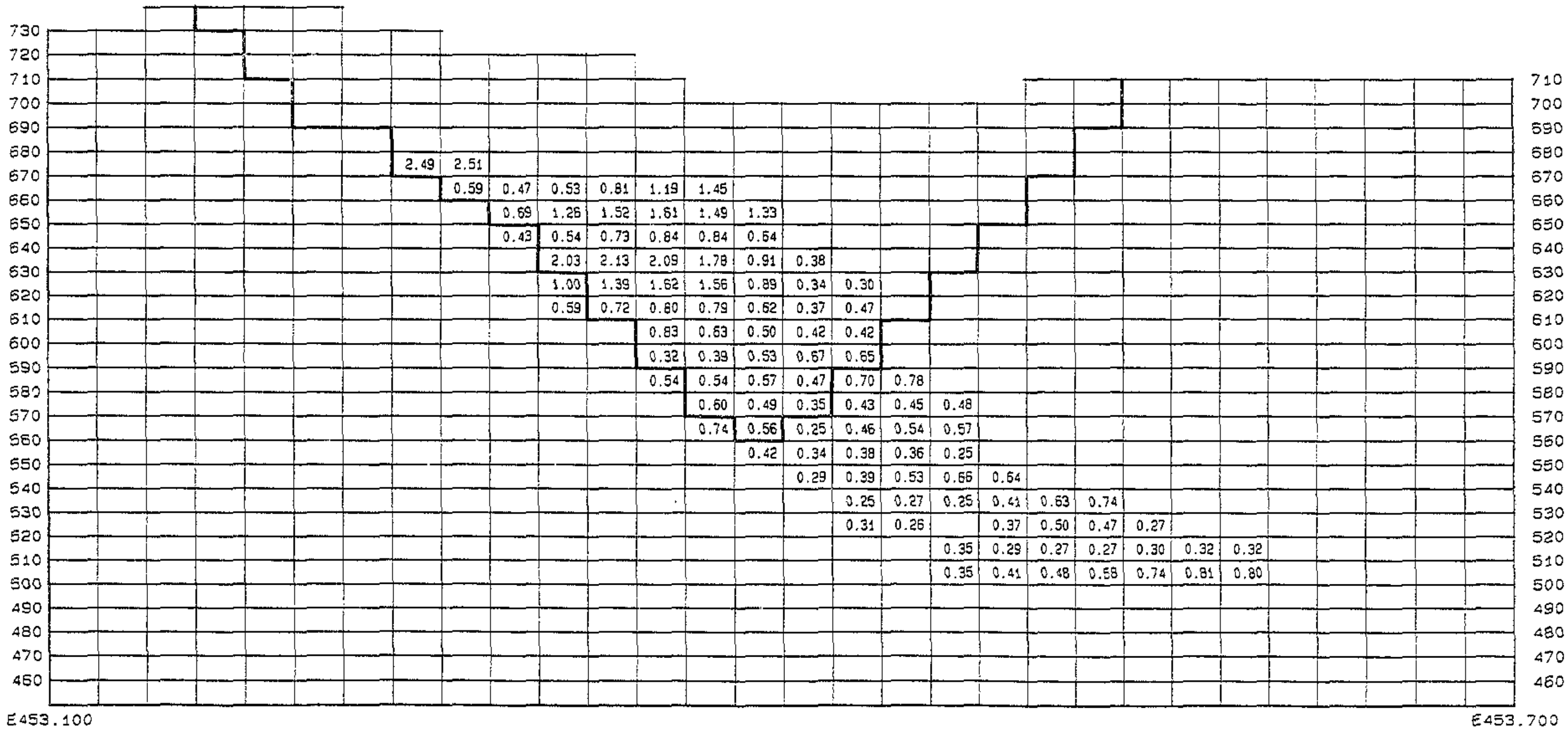

Fig. 2-1　Open pit cross section for the Hayl as Safil deposit (3)
[E-W section (N 2618.830), Pit design H 55002]

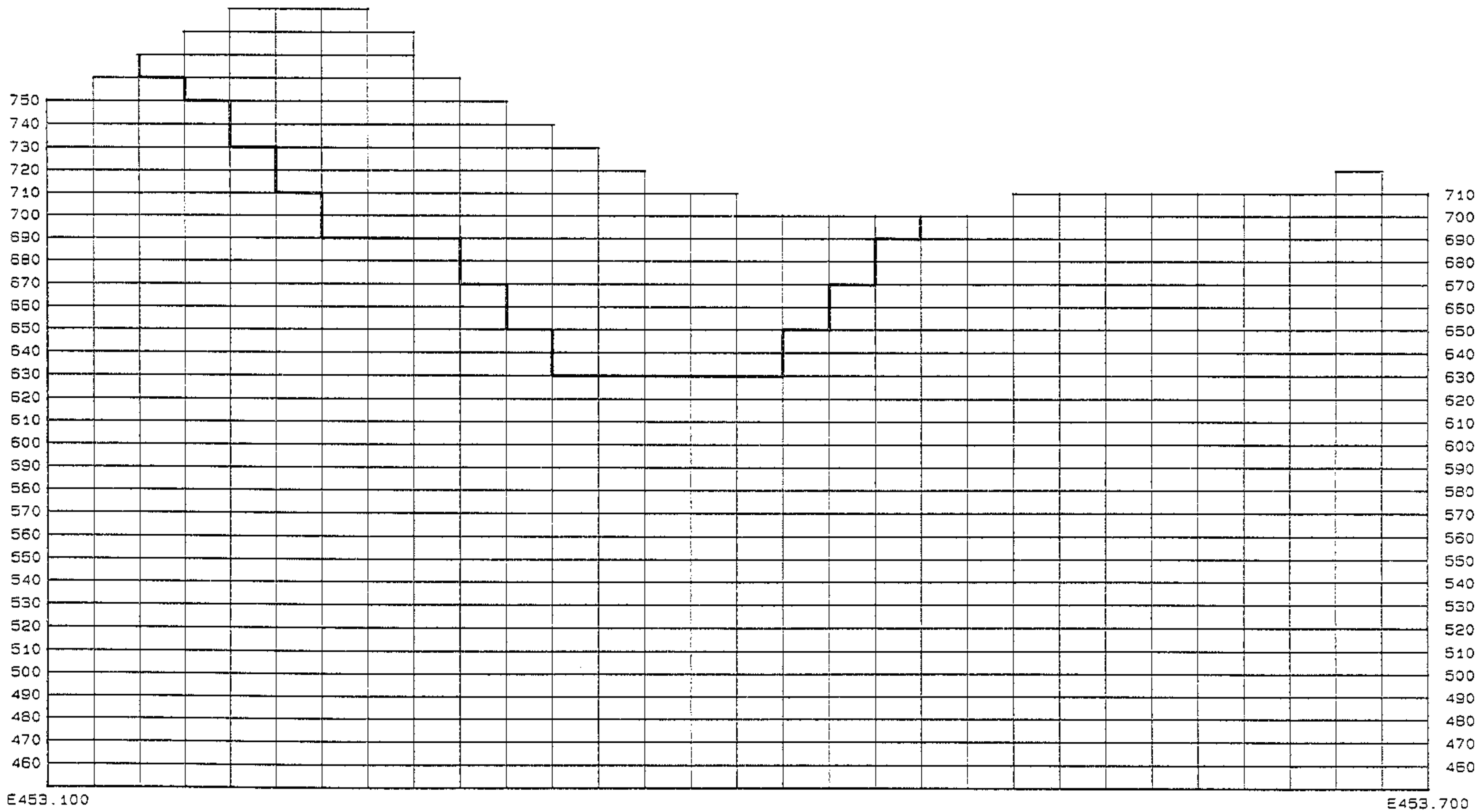

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (4)
[E-W section (N 2618.910), Pit design H 55002]

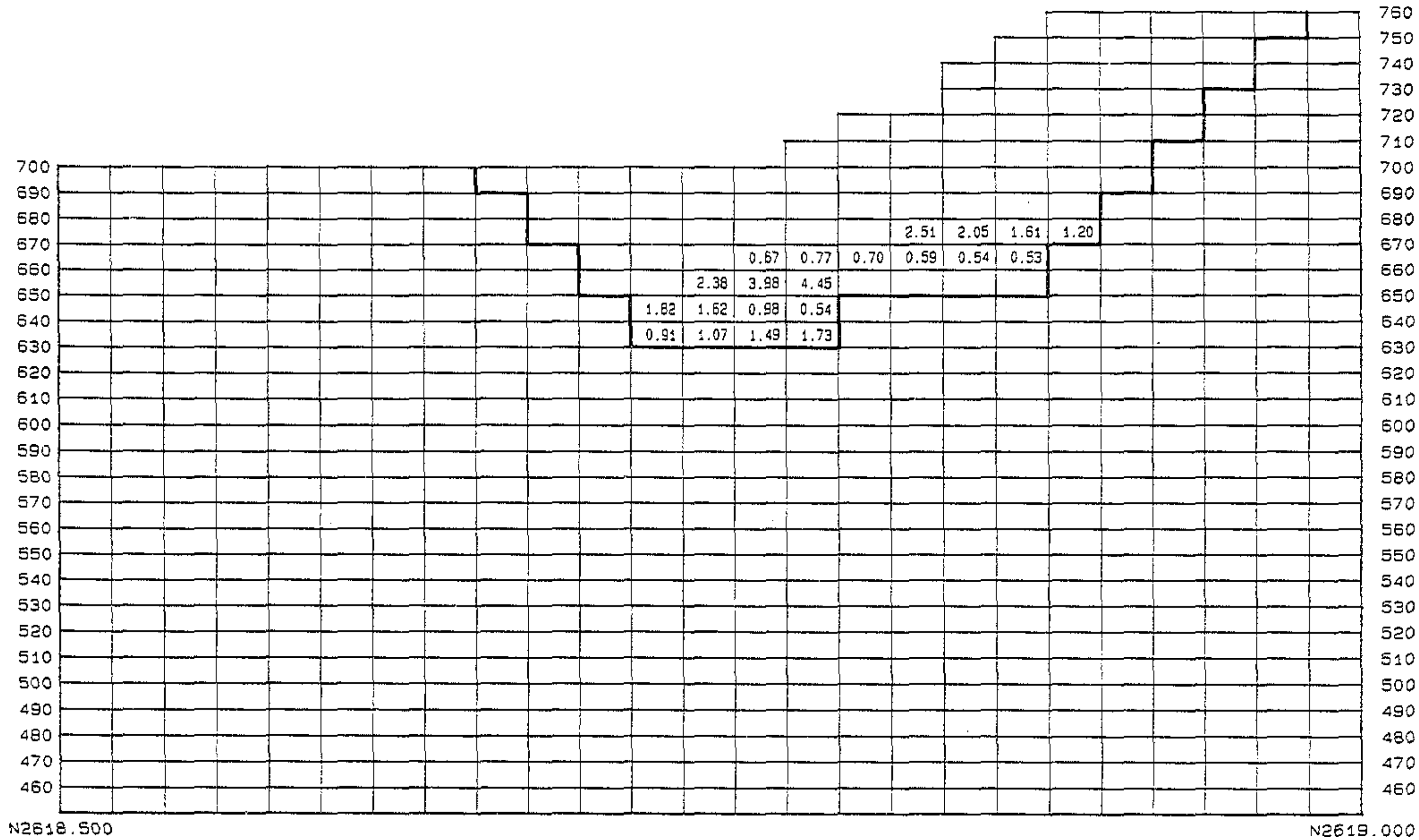

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (5)
[N-S section (E 453.270), Pit design H 55002]

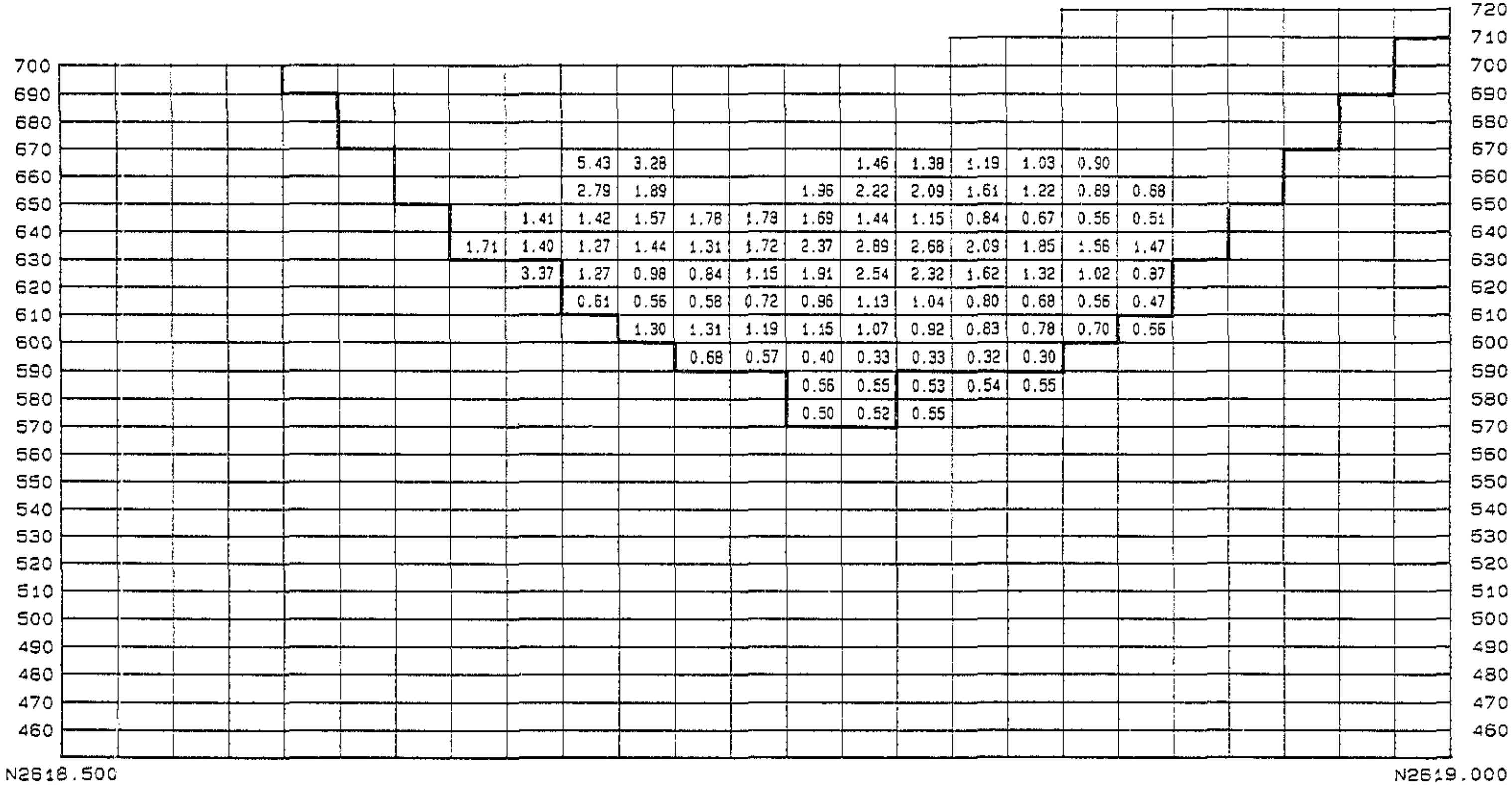

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (6)
[N-S section (E 453.350), Pit design H 55002]

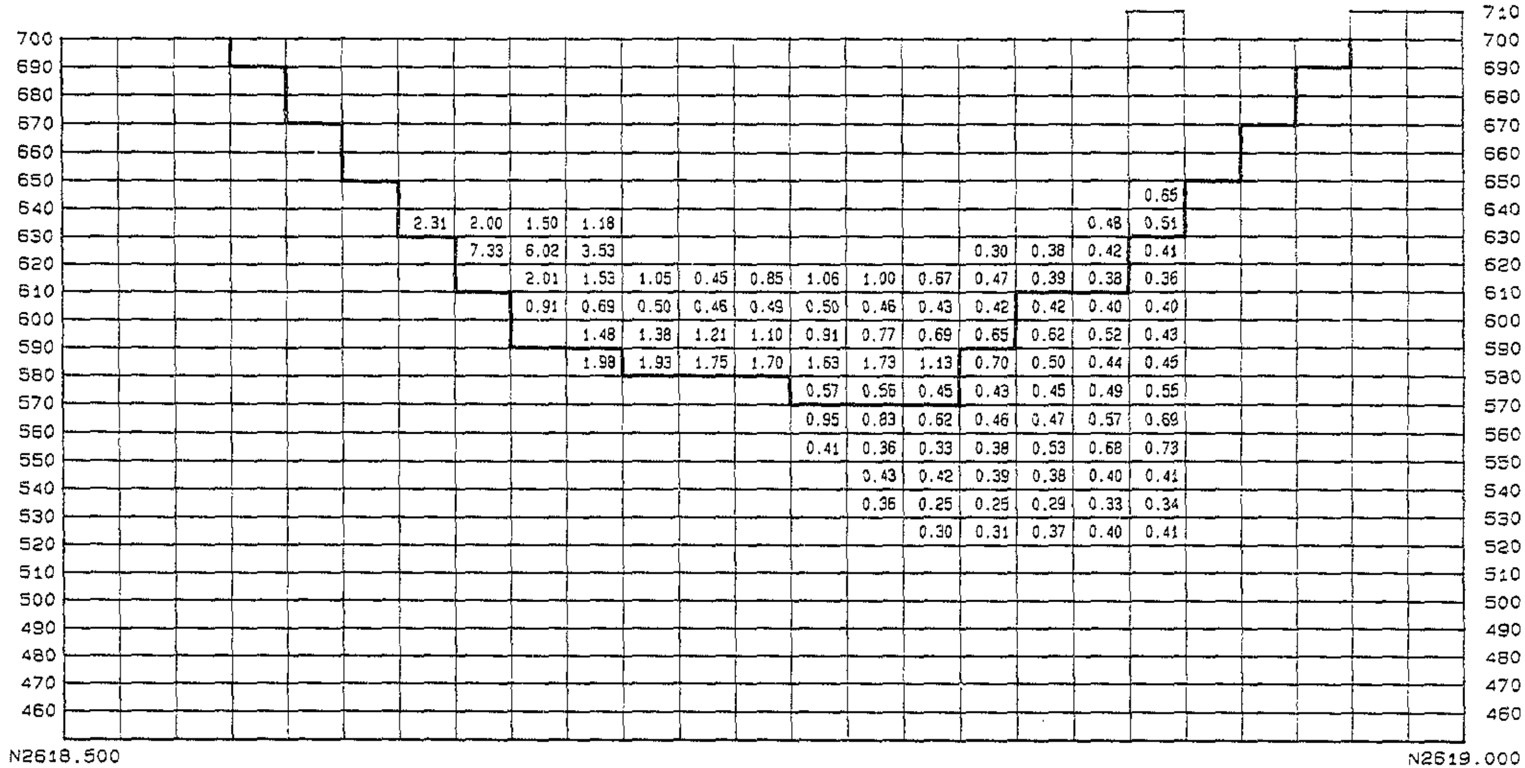

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (7)
[N-S section (E 453.430), Pit design H 55002]

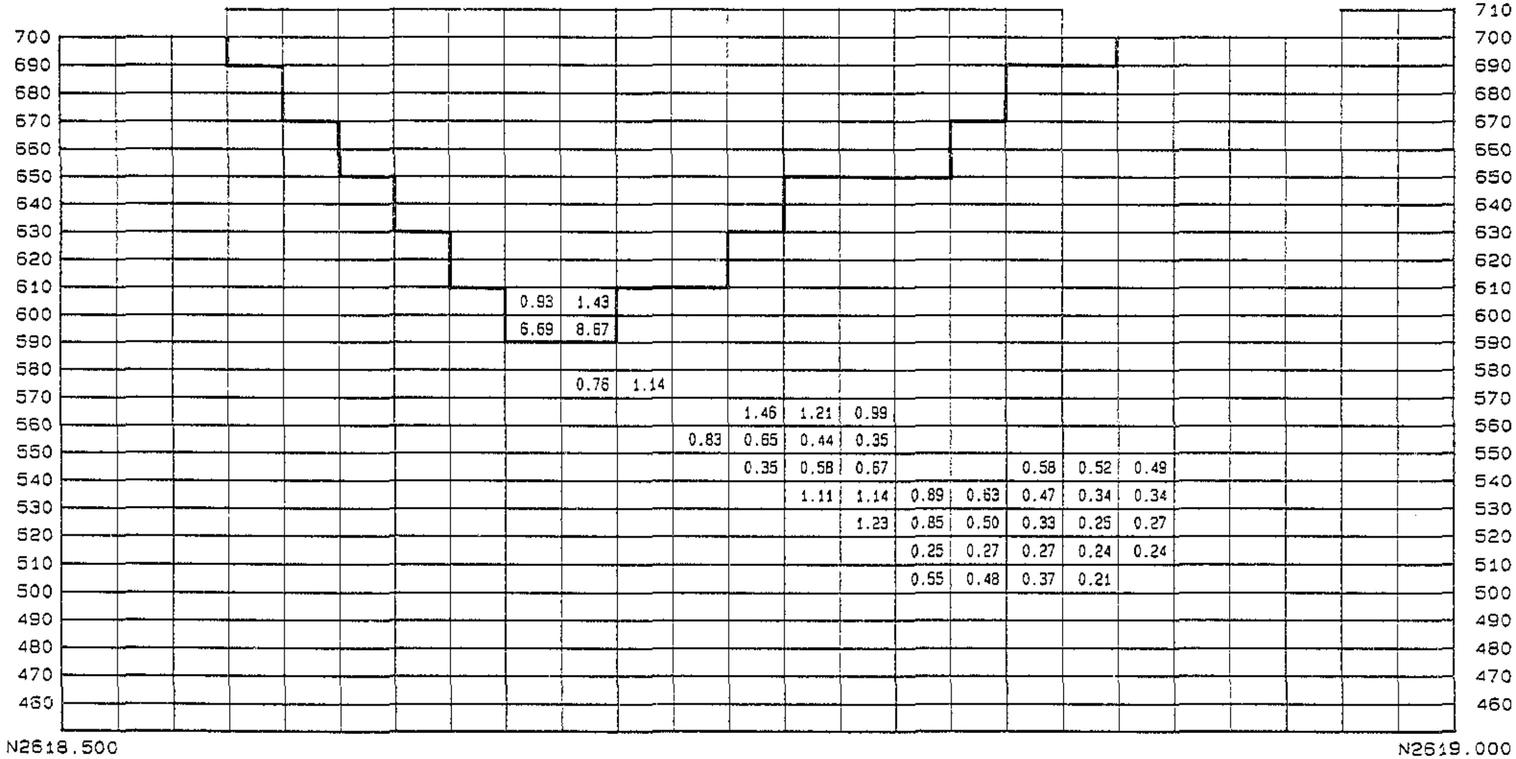

Fig. 2-1 Open pit cross section for the Hayl as Safil deposit (8)
[N-S section (E 453.510), Pit design H 55002]

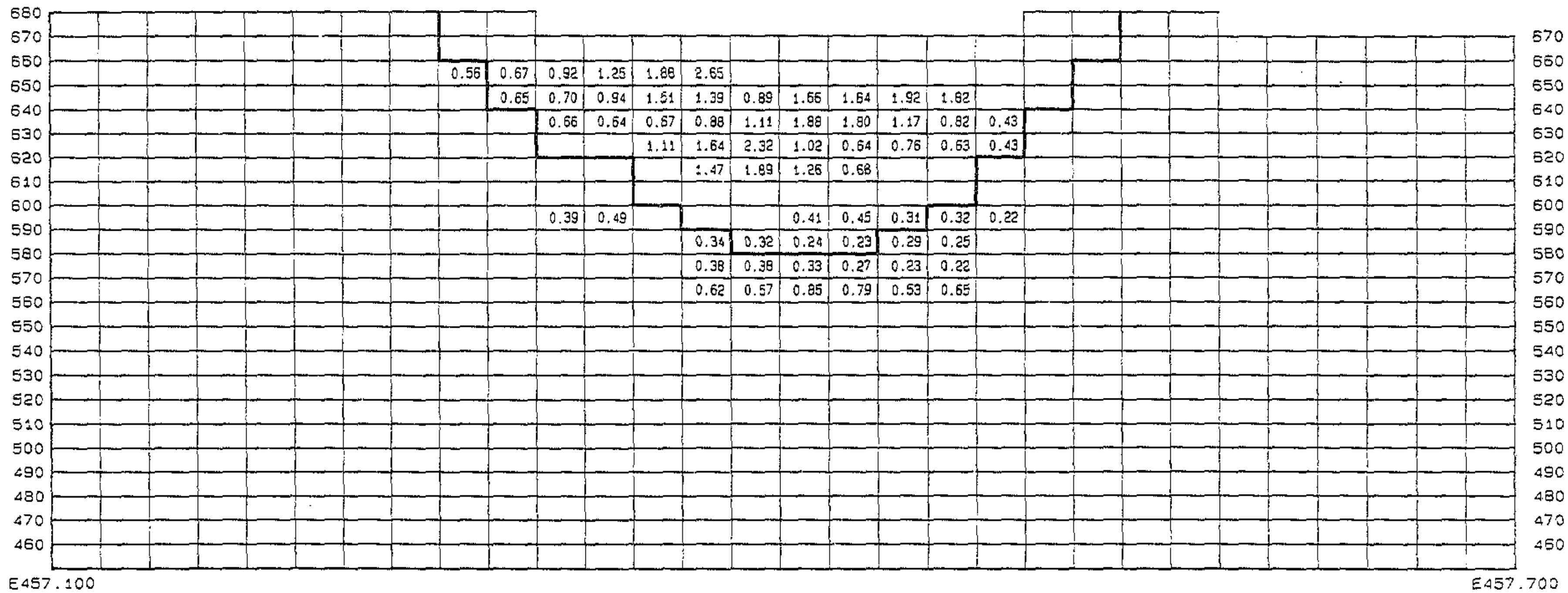

Fig. 2-2 Open pit cross section for the Rakah deposit (1)
[E-W section (N 2618.670), Pit design R 56004]

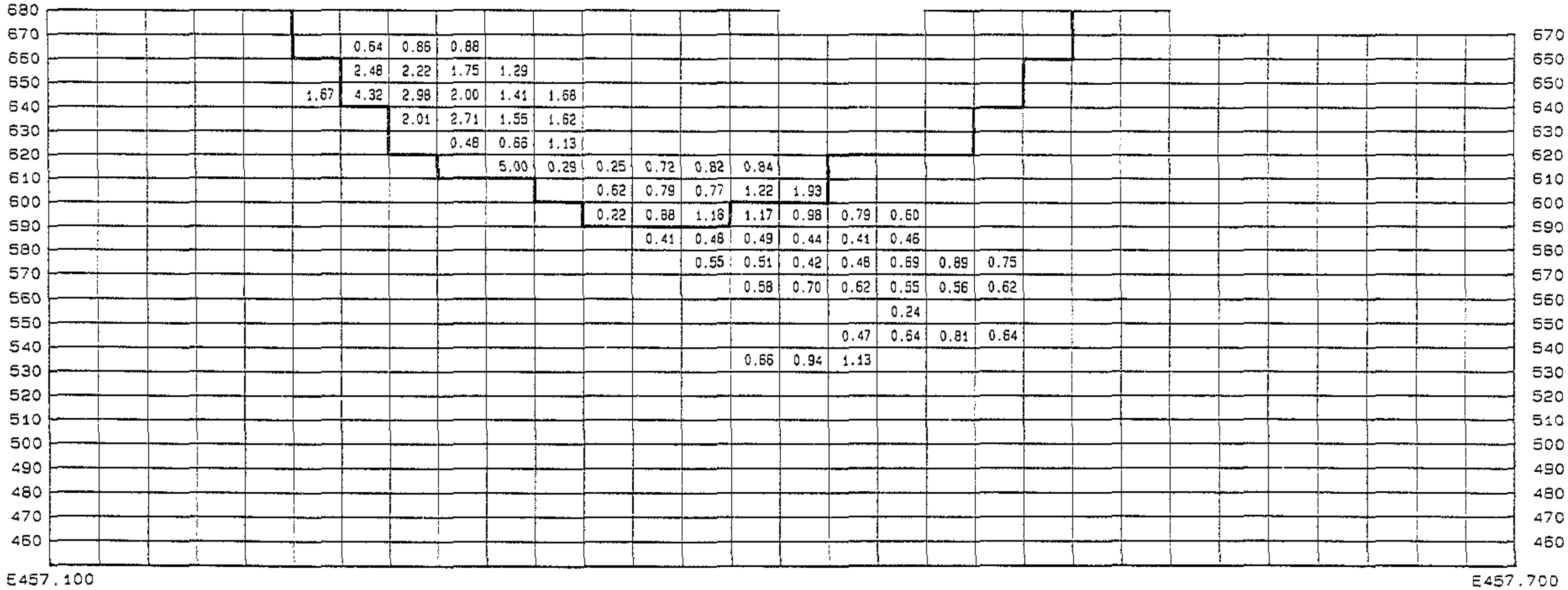

Fig. 2-2 Open pit cross section for the Rakah deposit (2)
[E-W section (N 2618.750), Pit design R 56004]

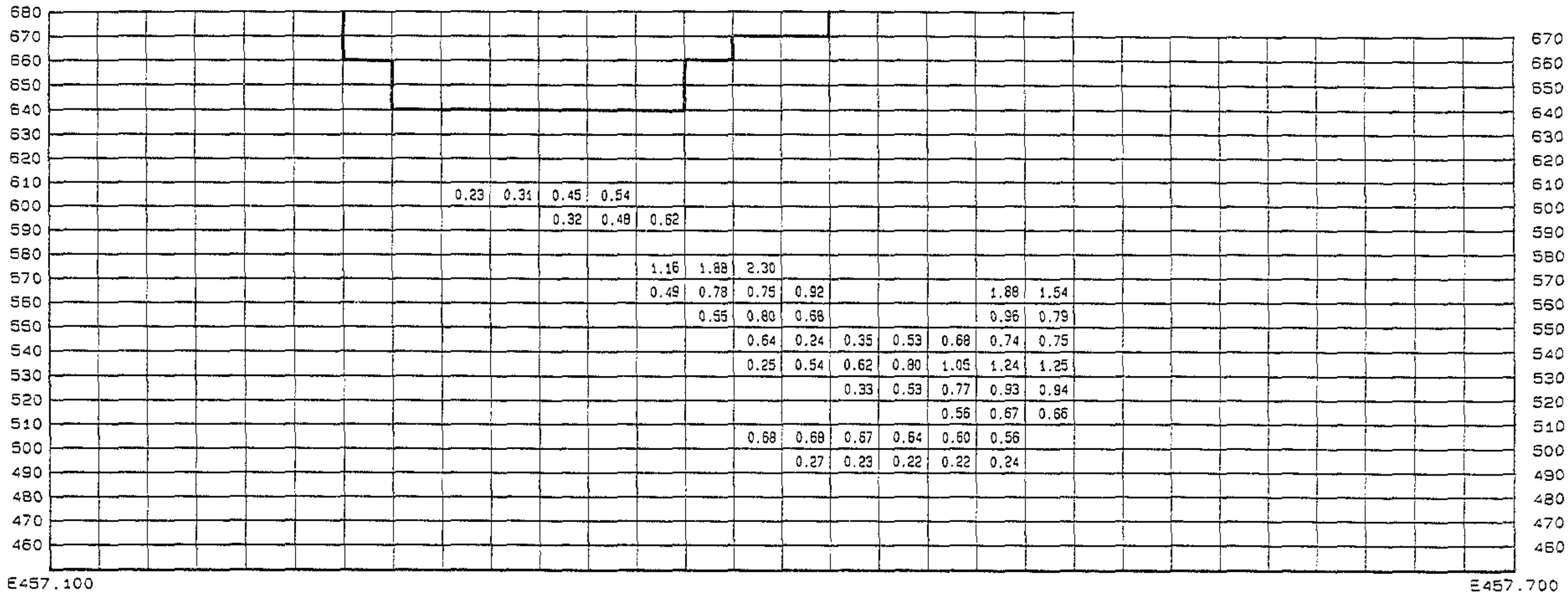

Fig. 2-2 Open pit cross section for the Rakah deposit (3)
[E-W section (N 2618.830), Pit design R 56004]

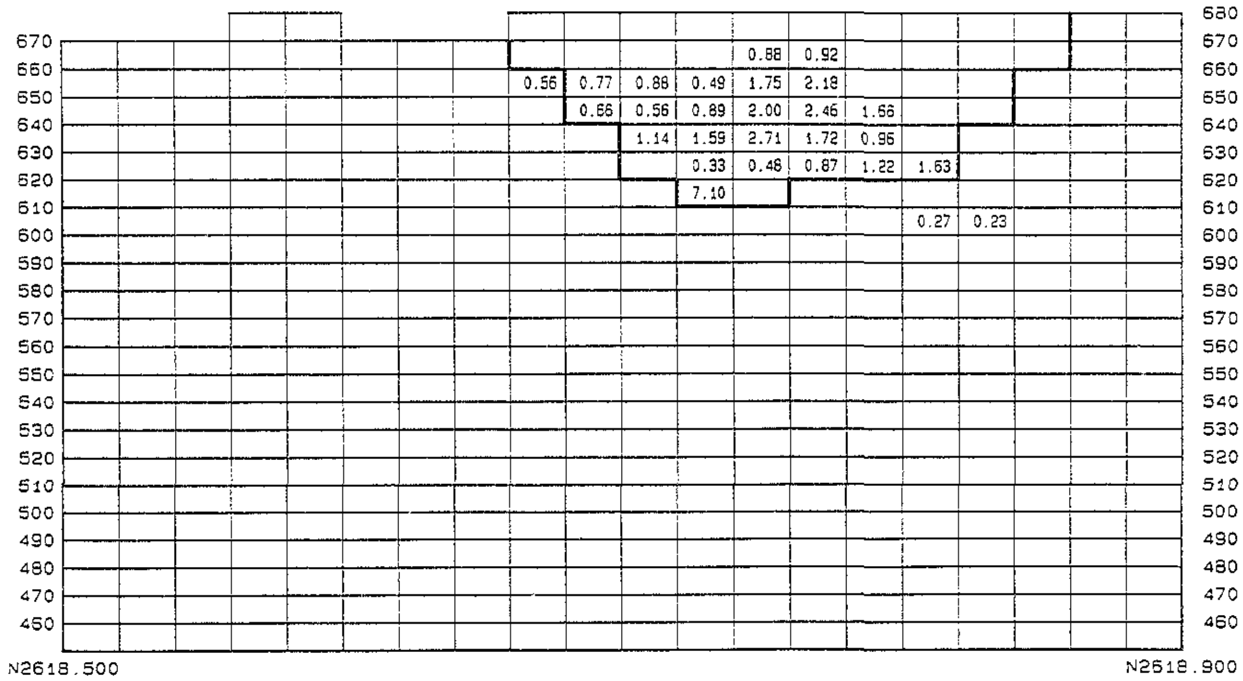

Fig. 2-2 Open pit cross section for the Rakah deposit (4)
[N-S section (E 457.270), Pit design R 56004]

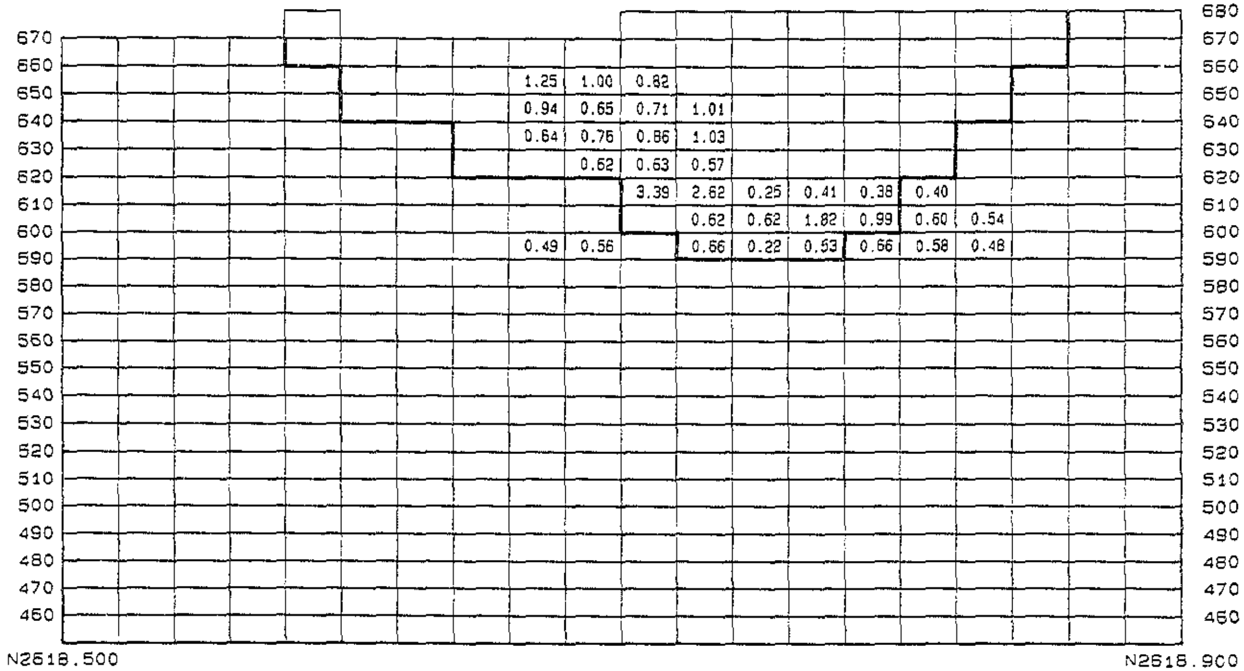

Fig. 2-2 Open pit cross section for the Rakah deposit (5)
[N-S section (E 457.330), Pit design R 56004]

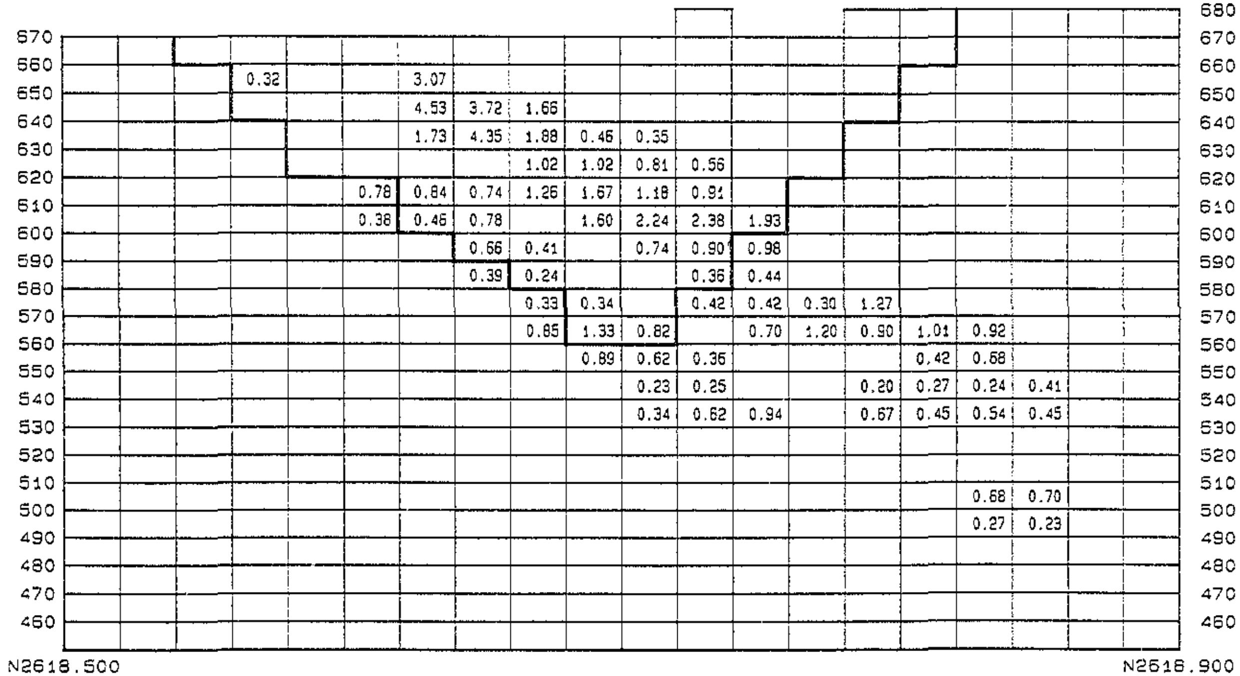

Fig. 2-2 Open pit cross section for the Rakah deposit (6)
[N-S section (E 457.410), Pit design R 56004]

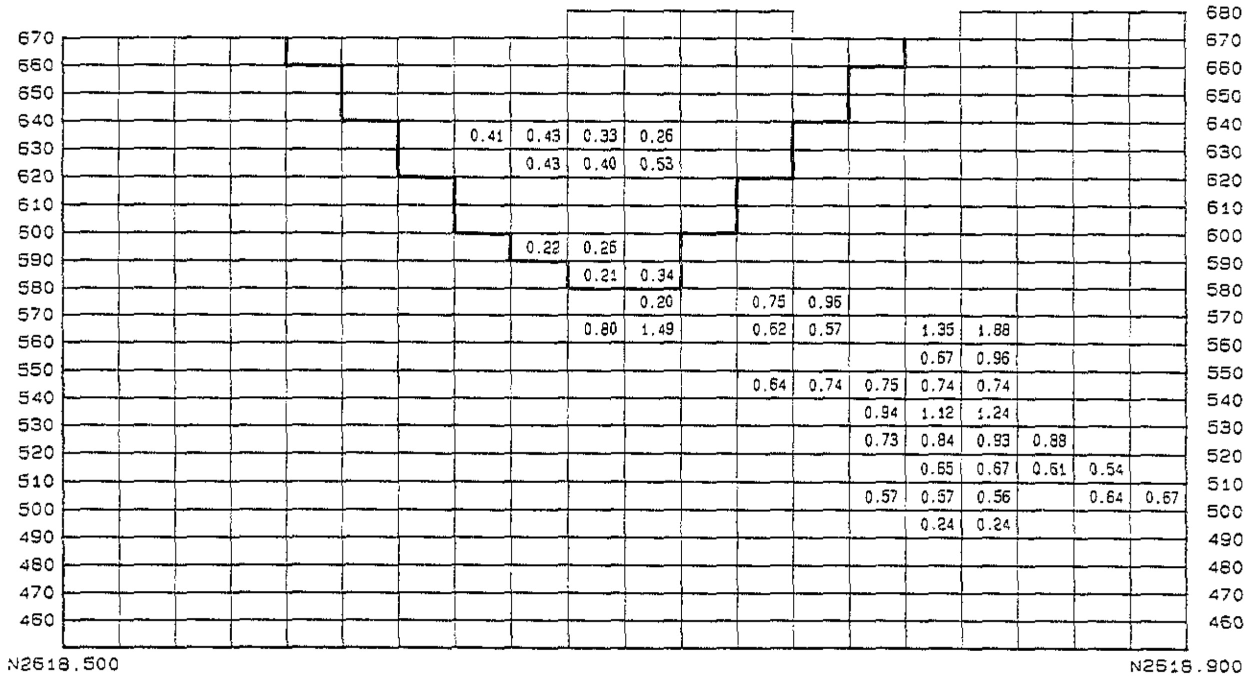

Fig. 2-2 Open pit cross section for the Rakah deposit (7)
[N-S section (E 457.490), Pit design R 56004]

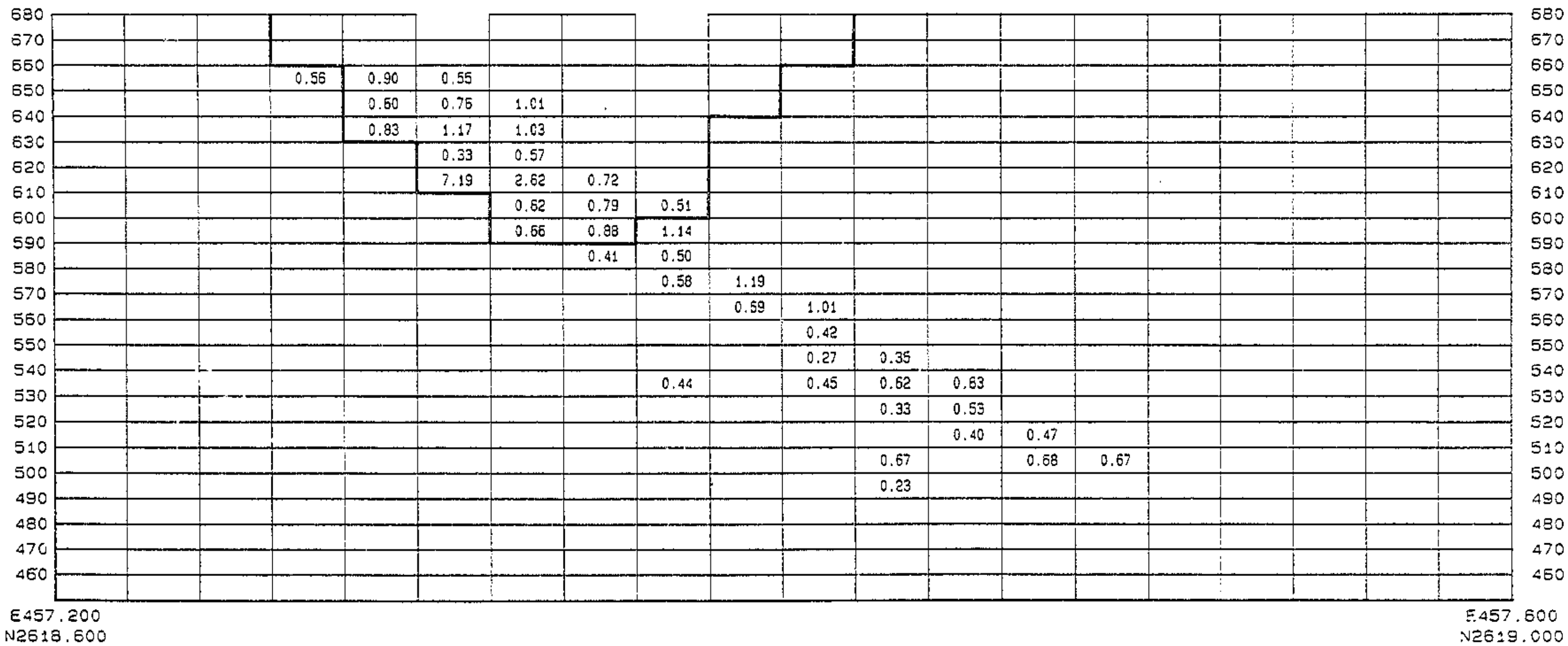

Fig. 2-2 Open pit cross section for the Rakah deposit (8)
[NE-SW section (E 457.200, N 2618.600) - (E 457.600, N 2619.000), Pit design R 56004]

Table 2-1 Summary of minable ore reserves for the Hayl as Safil deposit

Hayl as Safil — Pit design H55002 Cutoff 0.35%Cu

Level	Volume			S.W.		Tonnage			Copper		Gold		Stripping ratio
	Ore (m3)	Waste (m3)	Total (m3)	Ore (t/m3)	Waste (t/m3)	Ore (t)	Waste (t)	Total (t)	grade (%)	content (t)	grade (g/t)	content (kg)	
780	0	24.000	24.000		2.80	0	67,200	67,200					***
770	0	48.000	48.000		2.80	0	134,400	134,400					***
760	0	108,000	108,000		2.80	0	302,400	302,400					***
750	0	112,000	112,000		2.80	0	313,600	313,600					***
740	0	128,000	128,000		2.80	0	358,400	358,400					***
730	0	184,000	184,000		2.80	0	515,200	515,200					***
720	0	200,000	200,000		2.80	0	560,000	560,000					***
710	0	276.000	276.000		2.80	0	772,800	772,800					***
700	0	556,000	556,000		2.80	0	1,556,800	1,556,800					***
690	0	1,292,000	1,292,000		2.80	0	3,617,600	3,617,600					***
680	0	1,064,000	1,064,000		2.80	0	2,979,200	2,979,200					***
670	32,200	1,031,800	1,064,000	3.15	2.80	101,340	2,889,040	2,990,380	1.59	1,606.8	0.17	17.17	28.51
660	157,424	694.576	852,000	3.06	2.80	481,190	1,944,813	2,426,003	1.13	5,424.7	0.59	285.15	4.04
650	211,252	624,748	836,000	3.13	2.80	661,026	1,749,294	2,410,320	1.64	10,866.9	0.74	486.24	2.65
640	236,332	415,668	652,000	3.06	2.80	724,034	1,163,870	1,887,904	1.16	8,372.4	0.60	436.02	1.61
630	294,560	357,440	652,000	3.12	2.80	919,703	1,000,832	1,920,535	1.54	14,181.6	0.84	772.19	1.09
620	250,264	201,736	452,000	3.14	2.80	786,879	564,861	1,351,740	1.98	15,614.9	0.49	388.43	0.72
610	259,084	192,916	452,000	3.02	2.80	782,931	540,165	1,323,096	0.84	6,557.0	0.44	347.53	0.69
600	212,916	71,084	284,000	3.01	2.80	641,224	199,035	840,259	0.78	4,971.2	0.50	317.49	0.31
590	173,320	106,680	280,000	3.07	2.80	532,922	298,704	831,626	1.37	7,325.8	0.84	445.61	0.56
580	100,528	15,472	116,000	3.06	2.80	307,138	43,322	350,460	1.09	3,345.0	0.37	112.92	0.14
570	75,972	12,028	88,000	3.00	2.80	228,057	33,678	261,735	0.70	1,586.5	0.15	33.49	0.15
560	21,332	2,668	24,000	2.99	2.80	63,809	7,470	71,279	0.59	379.3	0.17	11.08	0.12
550	18,332	1,668	20,000	2.96	2.80	54,183	4,670	58,853	0.38	203.9	0.08	4.32	0.09
Total	2,043,516	7,720,484	9,764,000	3.08	2.80	6,284,436	21,617,355	27,901,791	1.28	80,436.1	0.58	3,657.64	3.44

Table 2-2 Summary of minable ore reserves for the Rakah deposit

Rakah

Pit design R56004 Cutoff 0.35%Cu

Level	Volume			S.W.		Tonnage			Copper		Gold		Stripping ratio
	Ore (m3)	Waste (m3)	Total (m3)	Ore (t/m3)	Waste (t/m3)	Ore (t)	Waste (t)	Total (t)	grade (%)	content (t)	grade (g/t)	content (kg)	
670	0	408,000	408,000		2.80	0	1,142,400	1,142,400					***
660	0	712,000	712,000		2.80	0	1,993,600	1,993,600					***
650	56,184	499,816	556,000	2.96	2.80	166,078	1,399,485	1,565,563	1.49	2,472.9	0.92	152.62	8.43
640	92,160	463,840	556,000	2.99	2.80	275,104	1,298,752	1,573,856	1.73	4,772.4	0.60	163.89	4.72
630	149,024	258,976	408,000	2.90	2.80	432,251	725,133	1,157,384	1.22	5,268.7	0.68	291.89	1.68
620	131,704	276,296	408,000	2.88	2.80	378,819	773,629	1,152,448	0.88	3,347.9	0.47	176.35	2.04
610	112,488	175,512	288,000	2.89	2.80	325,490	491,434	816,924	1.21	3,941.8	0.92	299.09	1.51
600	95,880	148,120	244,000	2.95	2.80	282,587	414,736	697,323	1.42	4,013.9	0.37	104.22	1.47
590	54,900	89,100	144,000	2.87	2.80	157,509	249,480	406,989	0.83	1,300.4	0.26	41.70	1.58
580	7,600	76,400	84,000	2.82	2.80	21,394	213,920	235,314	0.41	87.7	1.36	28.99	10.00
570	2,000	26,000	28,000	2.80	2.80	5,605	72,800	78,405	0.39	21.9	0.53	2.97	12.99
560	27,480	520	28,000	2.87	2.80	78,996	1,456	80,452	0.88	696.6	0.66	51.96	0.02
Total	729,420	3,134,580	3,864,000	2.91	2.80	2,123,833	8,776,824	10,900,657	1.22	25,924.1	0.62	1,313.68	4.13

Total minable ore reserve

Level	Volume			S.W.		Tonnage			Copper		Gold		Stripping ratio
	Ore (m3)	Waste (m3)	Total (m3)	Ore (t/m3)	Waste (t/m3)	Ore (t)	Waste (t)	Total (t)	grade (%)	content (t)	grade (g/t)	content (kg)	
H.S.	2,043,516	7,720,484	9,764,000	3.08	2.80	6,284,436	21,617,355	27,901,791	1.28	80,436.1	0.58	3,657.64	3.44
Rakah	729,420	3,134,580	3,864,000	2.91	2.80	2,123,833	8,776,824	10,900,657	1.22	25,924.1	0.62	1,313.68	4.13
Total	2,772,936	10,855,064	13,628,000	3.03	2.80	8,408,269	30,394,179	38,802,448	1.26	106,360.2	0.59	4,971.32	3.61

2-3 Mine development

2-3-1 Pre-stripping

Required amount of pre-stripping for Hayl as Safil is 12.0 million tons and that of Rakah is 3.1 million tons. The pre-stripping of Hayl as Safil is scheduled to be completed within the two years of construction period. While Rakah will be pre-stripped in the first year of operation. The heavy equipments for the pre-stripping are basically the same as those for production and will be described in the next section. Fig. 2-3 and Fig. 2-4 show the pit plan just after the completion of pre-stripping.

The gossan waste in Rakah which contains relatively high gold will be stockpiled separately.

2-3-2 Pre-stripping method

The overburden is to be ripped and dozed by bulldozers and loaded by either front end loaders or hydraulic excavators to 30t dump trucks. When blasting is required, 6 1/2" blast holes are to be drilled by DHD. AN-FO is expected as major explosive. Crawler drill is required on the steep terrain in Hayl as Safil. When the ore body is close to the drilling place, all the cutting cones should be sampled and assayed to check the copper grade. The ore mind during construction period is to be stockpiled in the appropriate place. Operation is to be carried out on three shifts 24 hours basis. Typical bench cross section and blasting pattern are shown in Fig. 2-5 and Fig. 2-6 respectively.

2-3-3 Selection of the mining equipments

The heavy equipments anticipated to be used in this project are shown in Table 2-3. The policy for selection of size, type and specification is that the priority has been given to the smaller in size and the higher in mobility considering the size of the pits and operation. The manufacturers shown in the table are recommended because their products can be expected high availability and durability in severe mining operation. Also the manufacturers have established high technical service system and efficient spare parts supply system in Sultanate of Oman. The dealer can be utilized in the omanization program. Our suggestion is that OMCO could put obligation of technical training to the dealer when purchasing heavy equipment.

2-3-4 Wadi diversion

As is shown in Fig. 1, there is a relatively large wadi just above the expected Hayl as Safil pit. Obviously it should be diverted and connected to a west adjacent one for security at a heavy rain.

Moreover a large size embankment is to be constructed on the open area between the diverted wadi and the expected Hayl as Safil pit. The construction cost of the embankment would be very

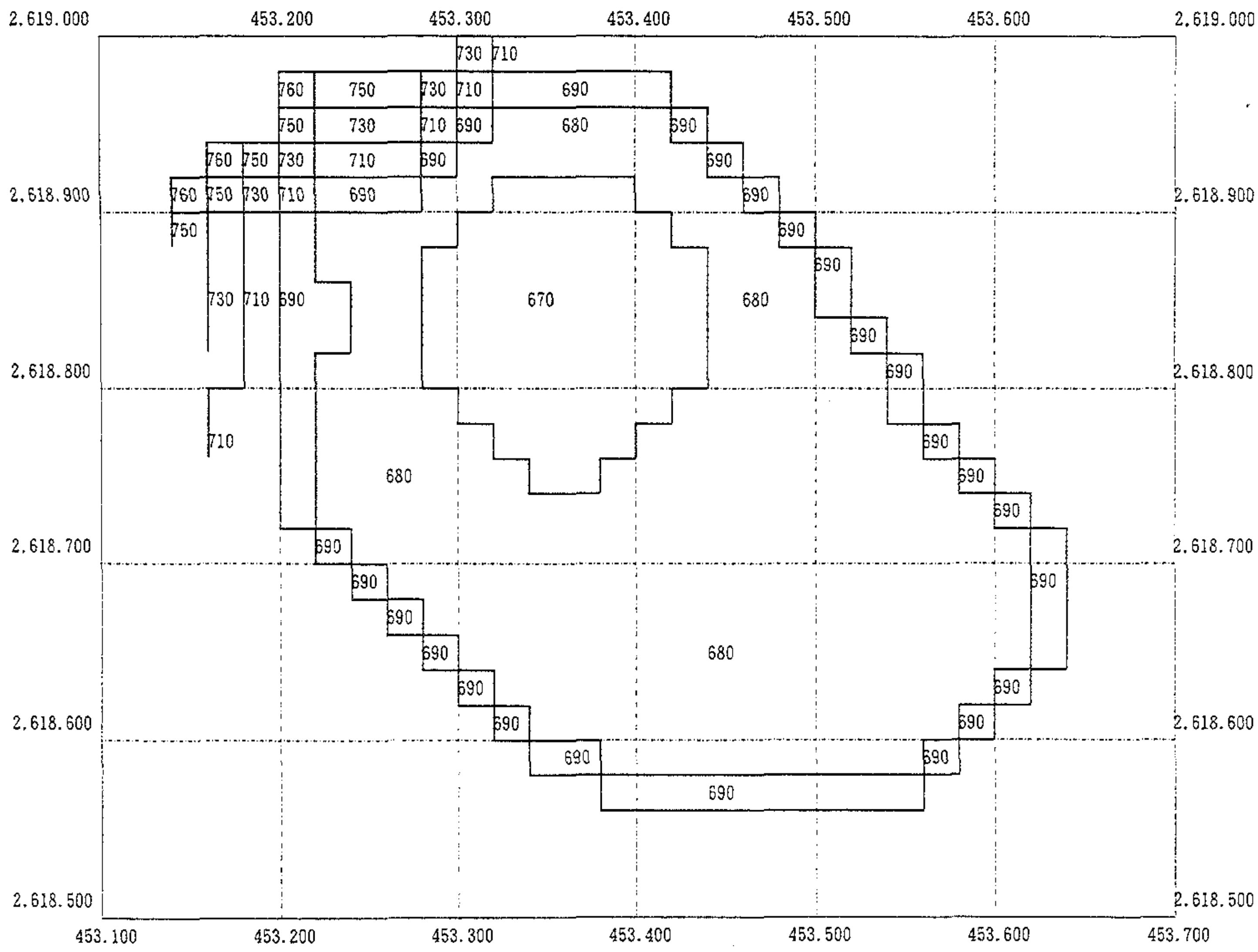

Fig. 2-3 Open pit after pre-stripping for the Hayl as Safil deposit

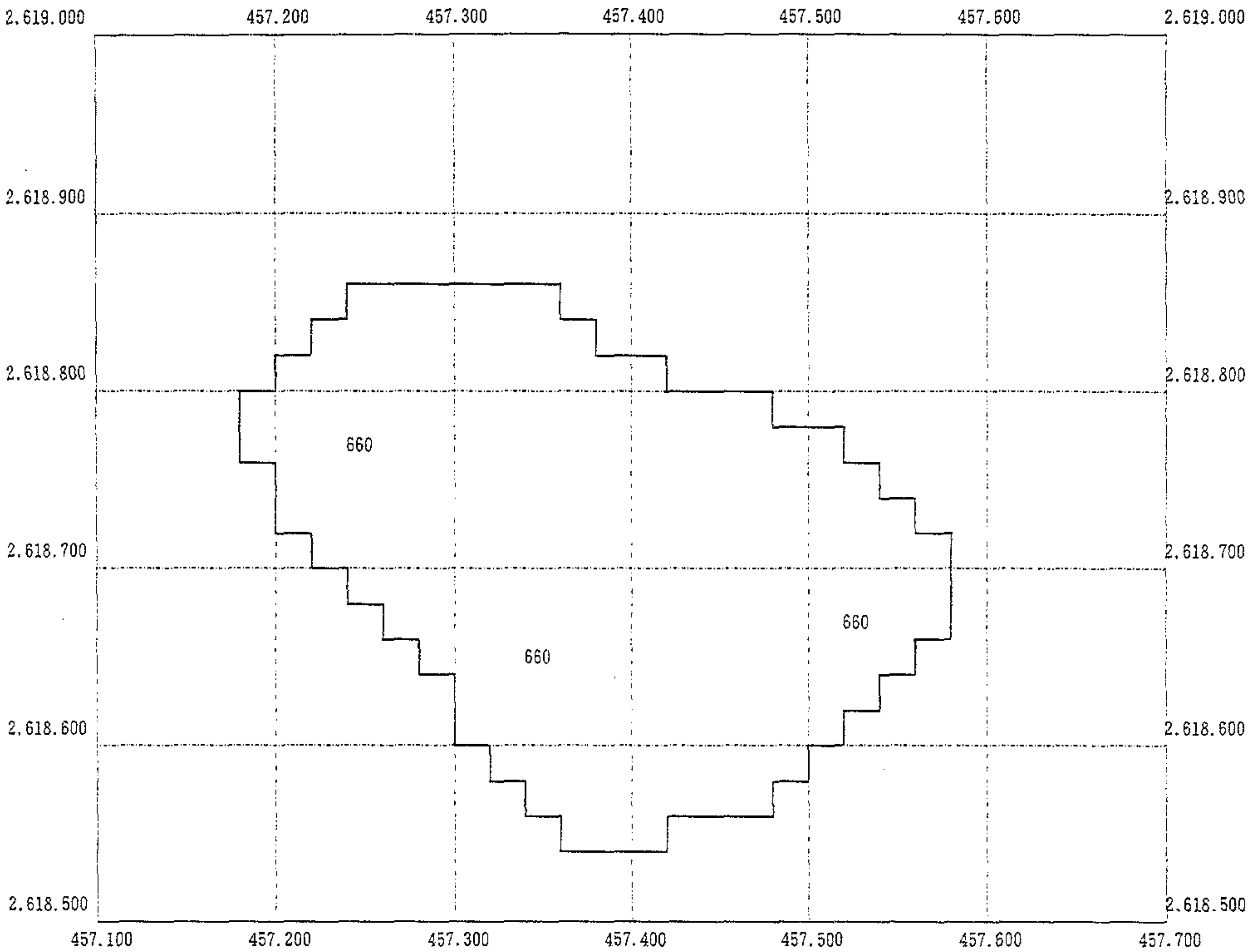

Fig. 2-4 Open pit after pre-stripping for the Rakah deposit

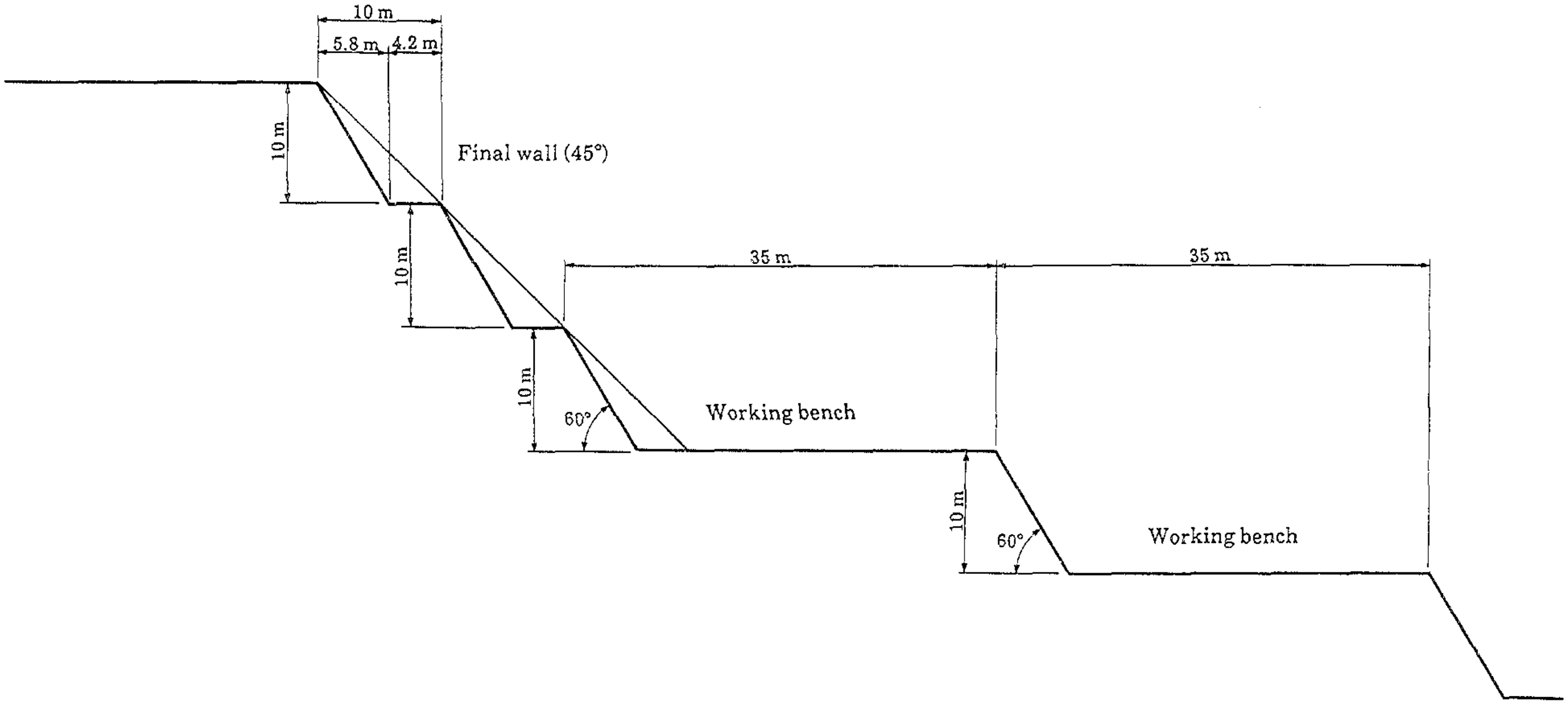

Fig. 2-5 Typical cross section of the benches

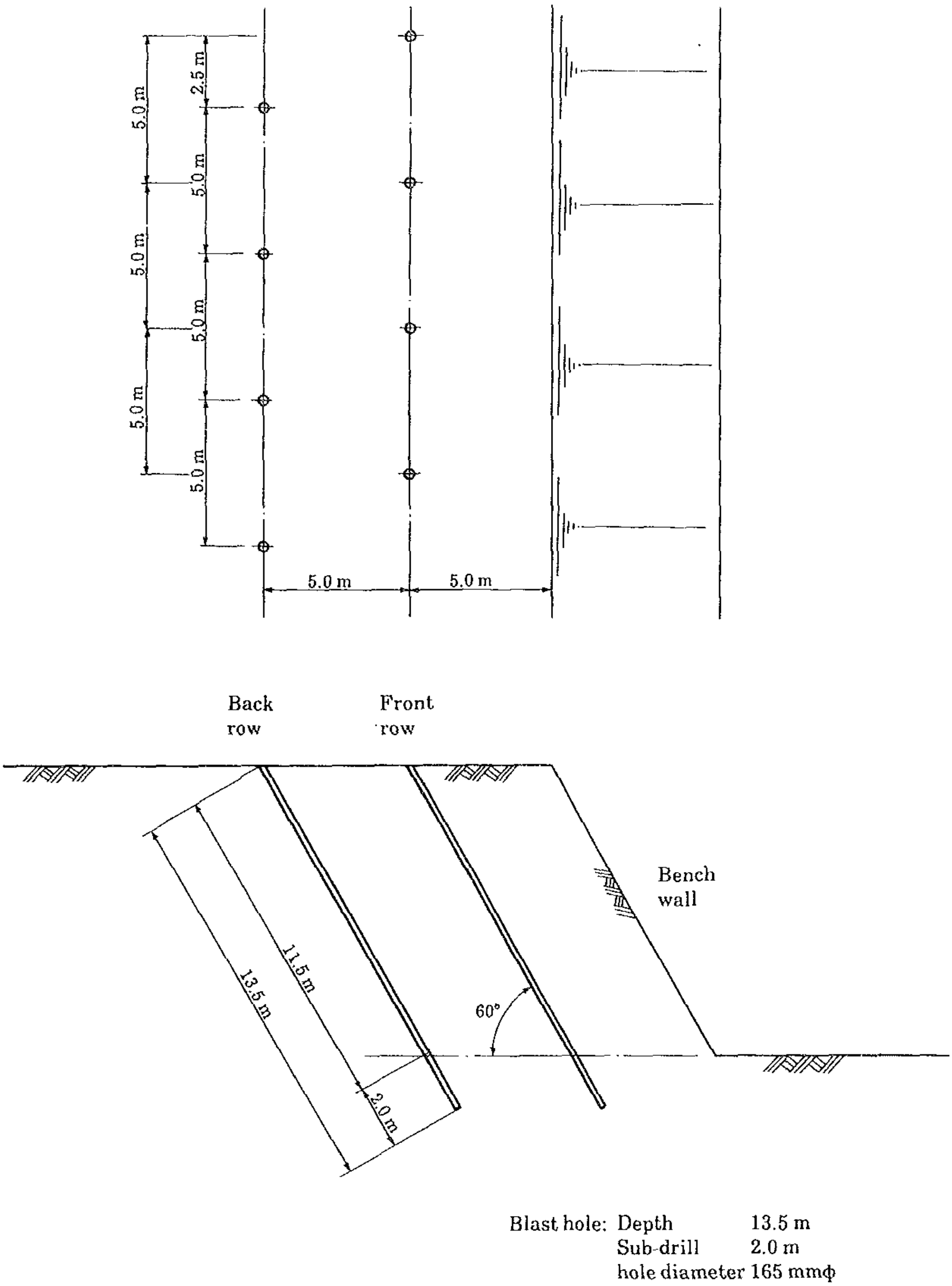

Fig. 2-6 Typical blasting pattern

Table 2-3 Proposed mining heavy equipments and main specification

Equipment	Manufacturer	Model	Operating weight (Kg)	Engine Model	Engine (flywheel) (HP)	Main specification
Drill	Ingersoll-Rand	T-4	21,800	GM12V-71N	400	Compressor HP750 DHD360 (5"-8.5")
Front End Loader	CAT	966D	19,868	CAT3306	200	Bucket 3.1 cu m (Rock V-edge with teeth)
Hydraulic Excavator	CAT	235C	42,510	CAT3306	195	Bucket 1.8 cu m (Bottom Dump)
Dump Truck	CAT	D30C	48,535	CAT3306	260	Payload 30.0 ton
Bulldozer	CAT	D7H	22,796	CAT3306	215	Blade Width 3.65 m (Straight)
Bulldozer	CAT	D6D	15,695	CAT3306	140	Blade Width 3.20 m (Straight)
Motor Grader	CAT	140G	13,540	CAT3306	150	Blade Width 3.66 m
Backhoe (Wheel type)	CAT	214	15,500	Perkins	102	Bucket 0.725 cu m (ISO Heaped)

low because the embankment can be assumed as a waste dump for the pre-stripping of Hayl as Safil pit.

2-3-5 Mining construction cost

Followings are the construction cost for the mining department.

Heavy equipment purchase	US$ 7,890,000
Pre-stripping	10,737,500
Wadi diversion	545,200
Total	US$ 19,172,700

Table 2-4 shows the mining heavy equipment purchasing schedule and Table 2-5 shows the yearly dump truck requirements.

2-4 Operating plan

2-4-1 Mining production plan

The annual mining handling volume schedule is shown in Table 2-6. In the first year, the annual ore production is 80% of the following years considering the start-up of the mine. The production is to be maintained at a level of 1,080,000 t/year on the second year and onward. The waste removal volume is scheduled to be reduced year by year.

The annual ore production plan is shown in Table 2-7. The copper grade is relatively higher in the early stage of the operation than that of the later stage.

The mining sequence of the Rakah and Hayl as Safil pits are shown in Fig. 2-7, Fig. 2-8, Fig. 2-9 and Fig. 2-10 respectively.

The massive ore which has been proven by the flotation tests to be very difficult in recovering copper is to be stock-piled independently.

2-4-2 Mining method

The mining method is basically as same as that of pre-stripping. Cuttings of all the blast holes are to be sampled and assayed. After blasting, materials are to be decided either ore or waste at hole by hole basis.

The operation is three shift a day and 24 hours basis.

Table 2-4 Purchasing schedule for mining heavy equipments

(Unit : US$1.000)

Items	Initial Investment						Additional Investment								
	Year -2			Year -1			Year 1			Year 2			Year 3		
	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount
Drill (Ingersoll-Rand T-4 class)	2	600	1.200												
Front End Loader (CAT 966 class)	2	160	320				1	160	160						
Hydraulic Excavator (CAT 235C class)	1	120	120				1	120	120				1	120	120
Dump Truck (CAT D30D class)	12	350	4.200	1	350	350									
Bulldozer (CAT D7D class)	2	230	460										1	230	230
(CAT D6D class)	1	160	160				1	160	160						
Motor Grader (CAT 140G class)	1	160	160												
Backhoe	1	80	80												
Auxiliary Equipment			840												
Total			7.540			350			440			0			350

Items	Additional Investment														
	Year 4			Year 5			Year 6			Year 7 & Year 8			Total		
	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount	Units	Price	Amount
Drill (Ingersoll-Rand T-4 class)													2	600	1.200
Front End Loader (CAT 966 class)													3	160	480
Hydraulic Excavator (CAT 235C class)													3	120	360
Dump Truck (CAT D30D class)													13	350	4.550
Bulldozer (CAT D7D class)	1	230	230										4	230	920
(CAT D6D class)	1	160	160										3	160	480
Motor Grader (CAT 140G class)	1	160	160										2	160	320
Backhoe	1	80	80										2	80	160
Auxiliary Equipment															840
Total			630			0			0			0			9.310

Table 2-5 Dump truck requirement

		Year -2	Year -1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Total
Production	(1,000t)											
Ore Hayl as Safil	(1,000t)			848.2	776.6	776.6	776.6	776.6	776.6	776.6	776.5	6,284.3
Rakah	(1,000t)			0.0	303.4	303.4	303.4	303.4	303.4	303.4	303.5	2,123.9
Total	(1,000t)			848.2	1,080.0	1,080.0	1,080.0	1,080.0	1,080.0	1,080.0	1,080.0	8,408.2
Waste Hayl as Safil	(1,000t)	6,000.0	6,000.0	1,714.6	1,759.1	2,123.1	1,637.4	849.6	631.8	643.5	258.3	21,617.4
Rakah	(1,000t)			2,136.0	1,747.7	1,028.4	1,222.3	1,019.6	578.6	447.8	596.4	8,776.8
Total	(1,000t)	6,000.0	6,000.0	3,850.6	3,506.8	3,151.5	2,859.7	1,869.2	1,210.4	1,091.3	854.7	30,394.2
Total	(1,000t)	6,000.0	6,000.0	4,698.8	4,586.8	4,231.5	3,939.7	2,949.2	2,290.4	2,171.3	1,934.7	38,802.4
Ore from Rakah	(1,000t)			0.0	303.4	303.4	303.4	303.4	303.4	303.4	303.5	2,123.9
D.T. productivity	(1,000t/y)	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9	
D.T. units	(units)	0.0	0.0	0.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	
Other materials	(1,000t)	6,000.0	6,000.0	4,698.8	4,283.4	3,928.1	3,636.3	2,645.8	1,987.0	1,867.9	1,631.2	36,678.5
D.T. productivity	(1,000t/y)	607.5	607.5	607.5	607.5	607.5	607.5	607.5	607.5	607.5	607.5	
D.T. units	(units)	9.9	9.9	7.7	7.1	6.5	6.0	4.4	3.3	3.1	2.7	
Total D.T. units	(units)	9.9	9.9	7.7	8.5	7.9	7.4	5.8	4.7	4.5	4.1	
D.T. mechanical availability		80.0%	77.5%	75.0%	72.5%	70.0%	67.5%	65.0%	62.5%	60.0%	57.5%	
D.T. units required		12	13	10	12	11	11	9	8	8	7	

Dump Truck Productivity

(1) Ore from Rakah

*Hauling distance (one way)

In-Pit	100m in ave.
Access	625m
Out-Pit	4,620m
Total	5,345m
Round trip	10,690m

*Cycle time (D.T. speed 15.0Km/hr)

Running	10,690/(15,000/60)=42.8	min
Loading	3.0	
Dumping	0.5	
Total	46.3	min

*Productivity

360x6/7x3x(8.0-1.0)x50=324,000 min/year

324,000/46.3x30=209,935 t/year

(2) Other materials

*Hauling distance (one way)

In-Pit	100m in ave.
Access	625m
Out-Pit	836m
Total	1,561m
Round trip	3,122m

*Cycle time (D.T. speed 15.0Km/hr)

Running	3,122/(15,000/60)=12.5	min
Loading	3.0	
Dumping	0.5	
Total	16.0	min

*Productivity

360x6/7x3x(8.0-1.0)x50=324,000 min/year

324,000/16.0x30=607,500 t/year

**Average outpit hauling distance for other materials.

	Tonnage	Distance
Hayl as Safil		
Ore	6,284.3	600
Waste	21,617.4	1,000
Rakah Waste	8,776.8	600
Average	36,678.5	836

Table 2-6 Mining schedule

Level	Year -2	Year -1	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7		Year 8		Total		
	Waste	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Ore	Waste	Total
H.S.	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)	(1.000t)
780	67.2																			67.2	67.2
770	134.4																			134.4	134.4
760	302.4																			302.4	302.4
750	313.6																			313.6	313.6
740	358.4																			358.4	358.4
730	515.2																			515.2	515.2
720	560.0																			560.0	560.0
710	772.8																			772.8	772.8
700	1.556.8																			1.556.8	1.556.8
690	1.419.2	2.198.4																		3.617.6	3.617.6
680		2.979.2																		2.979.2	2.979.2
670		822.4	101.3	1.066.6		800.0		200.0											101.3	2.889.0	2.990.3
660			481.2	244.8		500.0		900.0		300.0									481.2	1.944.8	2.425.0
650			265.7	403.2	395.3	346.1		700.0		300.0									661.0	1.749.3	2.410.3
640					381.3	113.0	342.7	150.9		600.0		300.0							724.0	1.163.9	1.887.9
630							433.9	172.2	485.8	328.6		300.0		200.0					919.7	1.000.8	1.920.5
620									290.8	108.8	496.1	156.1		200.0		100.0			786.9	564.9	1.351.8
610											280.5	93.5	502.4	146.7		300.0			782.9	540.2	1.323.1
600													274.2	85.1	367.0	13.9		100.0	641.2	199.0	840.2
590															409.6	229.6	123.3	69.1	532.9	298.7	831.6
580																	307.1	43.3	307.1	43.3	350.4
570																	228.1	33.7	228.1	33.7	261.8
560																	63.8	7.5	63.8	7.5	71.3
550																	54.2	4.7	54.2	4.7	58.9
S.TTL	6.000.0	6.000.0	848.2	1.714.6	776.6	1.759.1	776.6	2.123.1	776.6	1.637.4	776.6	849.6	776.6	631.8	776.6	643.5	776.5	258.3	6.284.3	21.617.4	27.901.7
Rakah																					
670				942.4		200.0														1.142.4	1.142.4
660				1.193.6		800.0														1.993.6	1.993.6
650					166.1	599.5		500.0		300.0									166.1	1.399.5	1.565.6
640					137.3	148.2	137.8	350.6		500.0		200.0							275.1	1.298.8	1.573.9
630							165.6	177.8	266.7	247.3		200.0		100.0					432.3	725.1	1.157.4
620									36.7	75.0	303.4	619.6	38.7	79.0					378.8	773.6	1.152.4
610													264.7	399.6	60.8	91.8			325.5	491.4	816.9
600															242.6	356.0	40.0	58.7	282.6	414.7	697.3
590																	157.5	249.5	157.5	249.5	407.0
580																	21.4	213.9	21.4	213.9	235.3
570																	5.6	72.8	5.6	72.8	78.4
560																	79.0	1.5	79.0	1.5	80.5
S.TTL	0.0	0.0	0.0	2.136.0	303.4	1.747.7	303.4	1.028.4	303.4	1.222.3	303.4	1.019.6	303.4	578.6	303.4	447.8	303.5	596.4	2.123.9	8.776.8	10.900.7
Total	6.000.0	6.000.0	848.2	3.850.6	1.080.0	3.506.8	1.080.0	3.151.5	1.080.0	2.859.7	1.080.0	1.869.2	1.080.0	1.210.4	1.080.0	1.091.3	1.080.0	854.7	8.408.2	30.394.2	38.802.4
	6.000.0	6.000.0	4.698.8		4.586.8		4.231.3		3.939.7		2.949.2		2.290.4		2.171.3		1.934.7				

Table 2-7 Mining annual production (1)

Level	Year 1					Year 2					Year 3					Year 4					Year 5				
	Tonnage	Grade		Content		Tonnage	Grade		Content		Tonnage	Grade		Content		Tonnage	Grade		Content		Tonnage	Grade		Content	
		Cu	Au	Cu	Au		Cu	Au	Cu	Au		Cu	Au	Cu	Au		Cu	Au	Cu	Au		Cu	Au	Cu	Au
H.S.	(1,000t)	(%)	(g/t)	(t)	(kg)	(1,000t)	(%)	(g/t)	(t)	(kg)	(1,000t)	(%)	(g/t)	(t)	(kg)	(1,000t)	(%)	(g/t)	(t)	(kg)	(1,000t)	(%)	(g/t)	(t)	(kg)
670	101.3	1.59	0.17	1,606.8	17.2																				
660	481.2	1.13	0.59	5,424.7	285.2																				
650	265.7	1.64	0.74	4,368.1	195.45	395.3	1.64	0.74	6,498.8	290.8															
640						381.3	1.16	0.60	4,409.4	229.63	342.7	1.16	0.60	3,963.0	206.4										
630											433.9	1.54	0.84	6,690.7	364.31	485.8	1.54	0.84	7,490.9	407.9					
620																290.8	1.98	0.49	5,770.5	143.54	496.1	1.98	0.49	9,844.4	244.9
610																					280.5	0.84	0.44	2,349.3	124.51
600																									
590																									
580																									
570																									
560																									
550																									
S.Ttl	848.2	1.34	0.59	11,399.6	497.77	776.6	1.40	0.67	10,908.2	520.42	776.6	1.37	0.73	10,653.7	570.69	776.6	1.71	0.71	13,261.5	551.43	776.6	1.57	0.48	12,193.7	369.40
Rakah																									
650						166.1	1.49	0.92	2,472.9	152.6															
640						137.3	1.73	0.60	2,381.9	81.80	137.8	1.73	0.60	2,390.5	82.1										
630											165.6	1.22	0.68	2,018.3	111.81	266.7	1.22	0.68	3,250.4	180.1					
620																36.7	0.88	0.47	324.4	17.09	303.4	0.88	0.47	2,681.5	141.25
610																									
600																									
590																									
580																									
570																									
560																									
S.Ttl	0.0			0.0	0.00	303.4	1.60	0.77	4,854.8	234.42	303.4	1.45	0.64	4,408.8	193.91	303.4	1.18	0.65	3,574.8	197.16	303.4	0.88	0.47	2,681.5	141.25
Total	848.2	1.34	0.59	11,399.6	497.77	1,080.0	1.46	0.70	15,762.9	754.84	1,080.0	1.39	0.71	15,062.5	764.60	1,080.0	1.56	0.69	16,836.2	748.59	1,080.0	1.38	0.47	14,875.2	510.65

Table 2-7 Mining annual production (2)

Level	Year 6					Year 7					Year 8					Total				
	Tonnage	Grade		Content		Tonnage	Grade		Content		Tonnage	Grade		Content		Tonnage	Grade		Content	
		Cu	Au	Cu	Au		Cu	Au	Cu	Au		Cu	Au	Cu	Au		Cu	Au	Cu	Au
H.S.	(1.000t)	(%)	(g/t)	(t)	(kg)	(1.000t)	(%)	(g/t)	(t)	(kg)	(1.000t)	(%)	(g/t)	(t)	(kg)	(1.000t)	(%)	(g/t)	(t)	(kg)
670																101.3	1.59	0.17	1,606.8	17.17
660																481.2	1.13	0.59	5,424.7	285.15
650																661.0	1.64	0.74	10,866.9	486.24
640																724.0	1.16	0.60	8,372.4	436.02
630																919.7	1.54	0.84	14,181.6	772.19
620																786.9	1.98	0.49	15,614.9	388.43
610	502.4	0.84	0.44	4,207.7	223.0											782.9	0.84	0.44	6.557.0	347.53
600	274.2	0.78	0.50	2,125.9	135.77	367.0	0.78	0.50	2.845.3	181.7						641.2	0.78	0.50	4.971.2	317.49
590						409.6	1.37	0.84	5.630.8	342.51	123.3	1.37	0.84	1.695.0	103.1	532.9	1.37	0.84	7.325.8	445.61
580											307.1	1.09	0.37	3.345.0	112.9	307.1	1.09	0.37	3.345.0	112.92
570											228.1	0.70	0.15	1.586.5	33.5	228.1	0.70	0.15	1.586.5	33.49
560											63.8	0.59	0.17	379.3	11.1	63.8	0.59	0.17	379.3	11.08
550											54.2	0.38	0.08	203.9	4.3	54.2	0.38	0.08	203.9	4.32
S.Ttl	776.6	0.82	0.46	6,333.6	358.79	776.6	1.09	0.68	8.476.1	524.23	776.5	0.93	0.34	7,209.7	264.91	6.284.3	1.28	0.58	80.436.0	3.657.64
Rakah																				
650																166.1	1.49	0.92	2,472.9	152.62
640																275.1	1.73	0.60	4,772.4	153.89
630																432.3	1.22	0.68	5,268.7	291.89
620	38.7	0.88	0.47	342.0	18.0											378.8	0.88	0.47	3,347.9	176.35
610	264.7	1.21	0.92	3.205.5	243.22	60.8	1.21	0.92	736.3	55.9						325.5	1.21	0.92	3,941.8	299.09
600						242.6	1.42	0.37	3.445.8	89.47	40.0	1.42	0.37	568.1	14.8	282.6	1.42	0.37	4,013.9	104.22
590											157.5	0.83	0.26	1,300.4	41.7	157.5	0.83	0.26	1.300.4	41.70
580											21.4	0.41	1.35	87.7	29.0	21.4	0.41	1.35	87.7	28.99
570											5.6	0.39	0.53	21.9	3.0	5.6	0.39	0.53	21.9	2.97
560											79.0	0.88	0.66	696.6	52.0	79.0	0.88	0.66	696.6	51.96
S.Ttl	303.4	1.17	0.86	3,547.6	261.24	303.4	1.38	0.48	4.182.0	145.34	303.5	0.88	0.46	2.674.7	140.37	2.123.9	1.22	0.62	25.924.2	1.313.68
Total	1,080.0	0.91	0.57	9,881.1	620.03	1,080.0	1.17	0.62	12,658.2	669.56	1,080.0	0.92	0.38	9.884.4	405.28	8.408.2	1.26	0.59	106,360.2	4.971.32

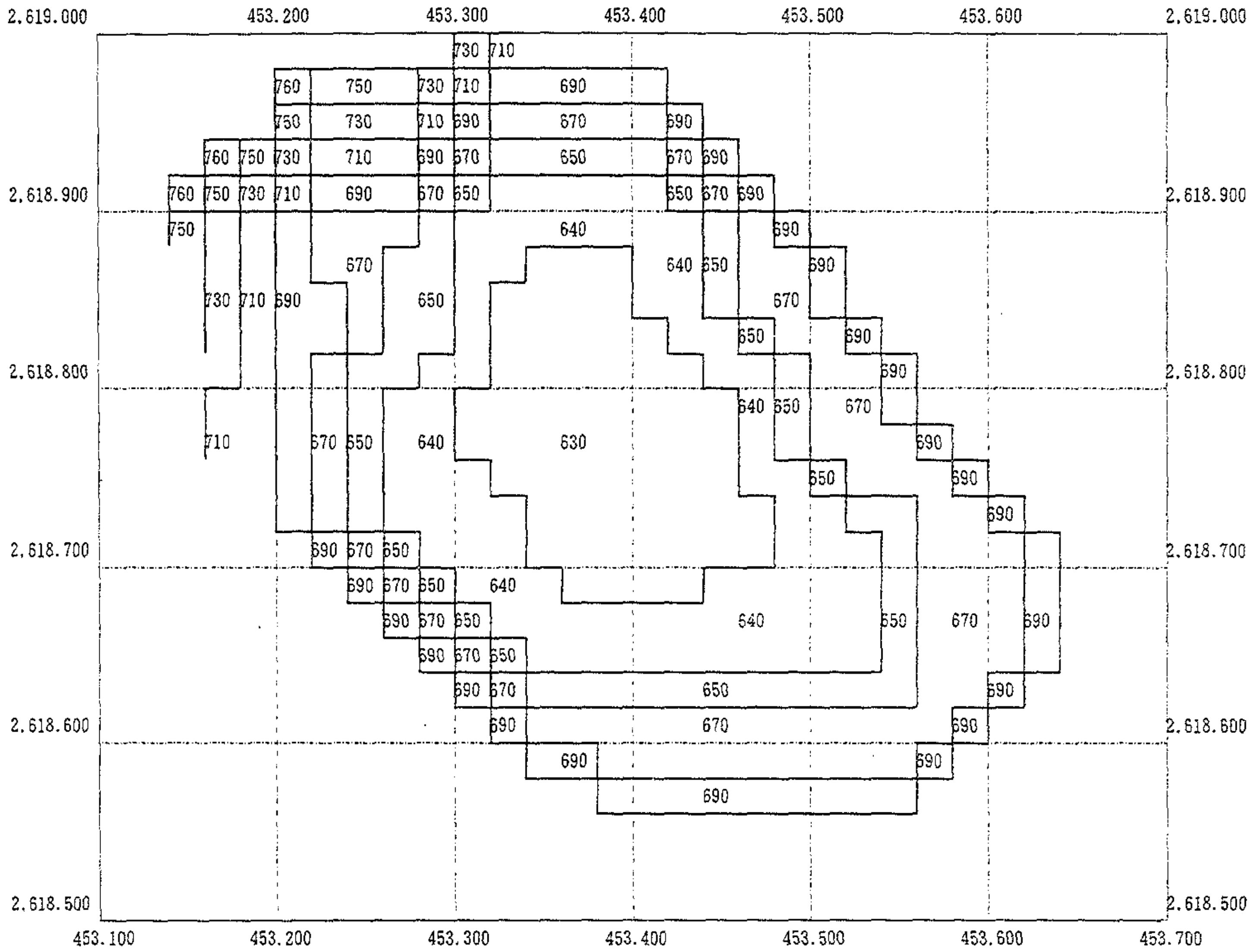

Fig. 2-7 Open pit after 3 years production for the Hayl as Safil deposit

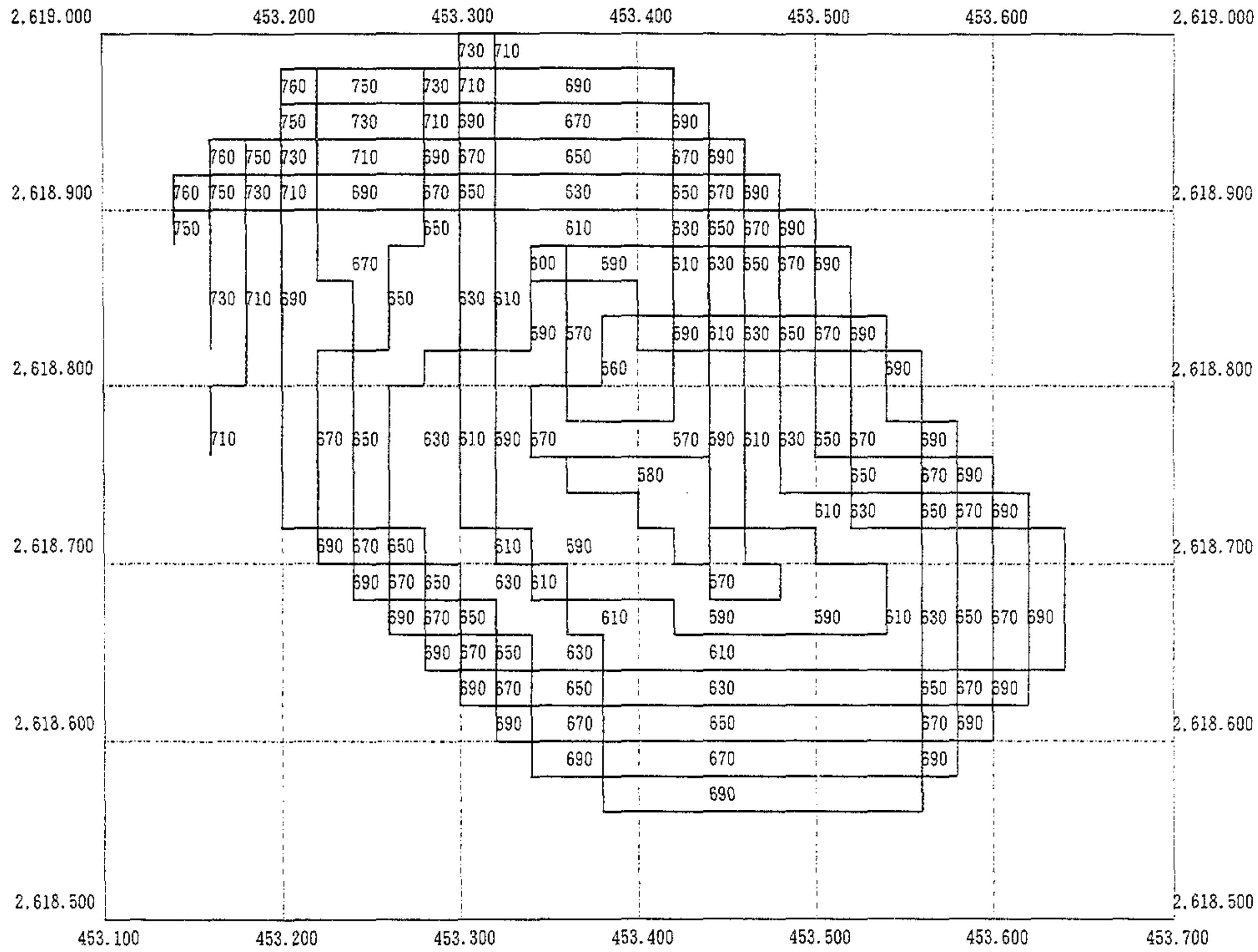

Fig. 2-8 Final pit of the Hayl as Safil deposit

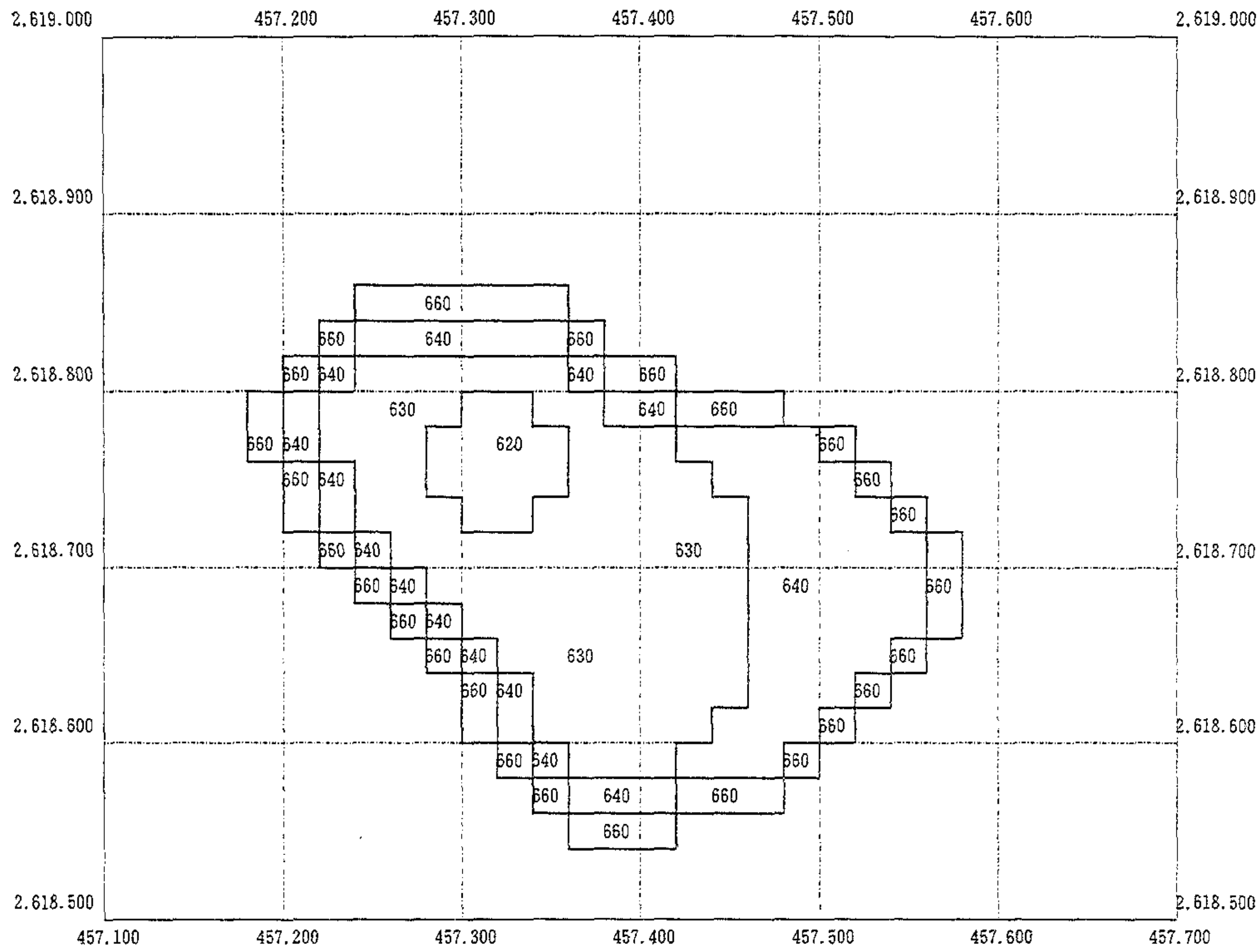

Fig. 2-9 Open pit after 3 years operation for the Rakah deposit

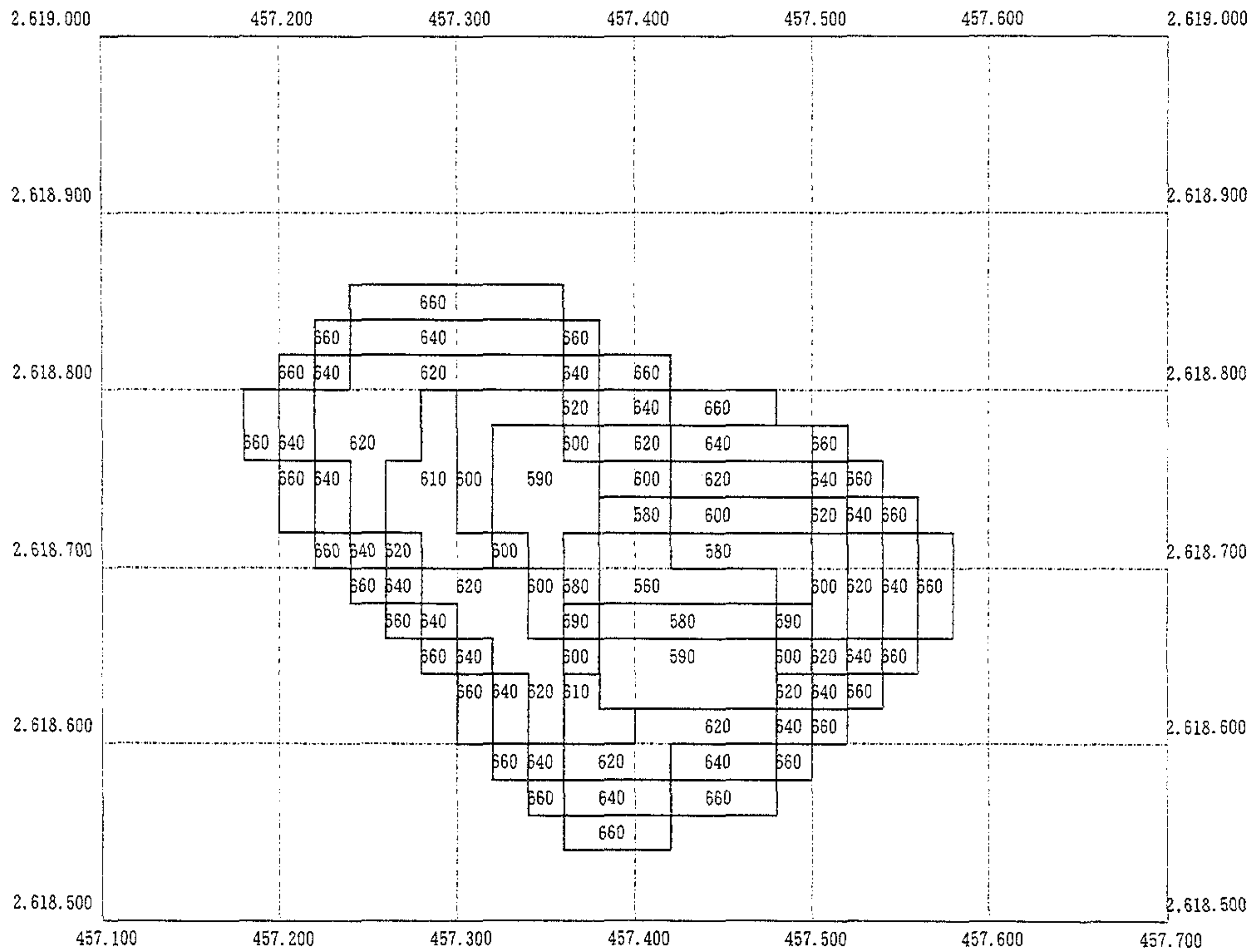

Fig. 2-10 Final pit of the Rakah deposit

2-4-3 Operating cost

Due to the difference of the hauling distance, the unit operating cost of Rakah ore and other materials (ore of Hayl as Safil and waste of both pits) are obtained independently. The unit operating cost for the Rakah ore is 153.9 US cents per ton, and that of the other materials is 112.1 US cents per ton. The details are shown in Table 2-8.

Table 2-8 Mining operation cost

	Unit Cost (US¢/t)			
	Labour	Supply	Equipment	Total
Rakah Ore				
Drill & Blast Ore	5.4	14.4	8.0	27.8
Excavation, Load & Haul	40.2	0.0	85.9	126.1
Total	45.6	14.4	93.9	153.9
Other Material				
Drill & Blast Ore	5.4	14.4	8.0	27.8
Excavation, Load & Haul	29.0	0.0	55.3	84.3
Total	34.4	14.4	63.3	112.1

2-4-4 Mining manning plan

The mining department consists from five groups which are shown below.

(1) Geological group

(2) Mine planning and survey group

(3) Operation group

(4) Heavy equipment repair shop

(5) Clerical group

The number of mining operators required for the first year's operation is shown in Table 2-9. The whole organization including all the necessary personnel is shown in Fig. 6-1 (2) of section 6 in this volume. The total manpower of mining department will be reduced year by year as the mining handling volume reduces.

Table 2-9 Mining operators manning plan

Equipment	Units	Operator		Assis-tant	Total
		I	II		
Drill	2	6		6	12
Front End Loader	2	4	3		7
Hydraulic Excavator	2	4	3		7
Dump Truck	12	20	25		45
Bulldozer	3	5	5		10
Motor Grader	1	2	2		4
Backhoe	1	1	1		2
Blasting Crew		1	1	3	5
Total		43	40	9	92

Chapter 3 Mineral processing

3-1 Metallurgical tests

The metallurgical tests were conducted on the samples of the Hayl as Safil and Rakah deposits to study the optimum condition and flotation method recovering valuable minerals in the ore. All the test works were carried out by Central Research Institute of Mitsubishi Metal Corporation.

3-1-1 Outline of test works

(1) Sample identification

All the head samples were taken from diamond drill cores performed in this project in 1988. Test works were conducted on three samples, namely stockwork ore of the Hayl as Safil deposit containing some quantity of massive ore, stockwork ore of the Rakah deposit and massive ore of the Rakah deposit. These samples are called, hereafter, Hayl as Safil ore, Rakah stockwork ore and Rakah massive ore. The details of the samples are shown in Table 3-1.

(2) Testing items

(i) Characteristics of the ore

The following test works were performed to study the characteristics of the ores.

① Chemical assays
② Mineral identification by X-ray diffraction analyses
③ Microscopical examination
④ Assays of soluble ions in the ore
⑤ Measurement of Work Index
⑥ Measurement of specific gravity

(ii) Fundamental flotation tests

The tests were performed on following two flotation methods.

(a) Copper selective flotation

This method is to recover the copper mineral selectively by depressing pyrite in rougher flotation. The following items were tested.

Table 3-1 List of samples for bench scale flotation testwork

Hayl as Safil ore (Weight 76.6 kg)

Hole No.	Depth (m) from - to	Type of ore	D.L. m	Au g/t	Ag g/t	Cu %	Zn %
MJO-A1	77.60 - 80.60	massive ore with siliceous frag	3.00	2.0	4.1	0.76	0.06
	91.70 - 95.50	stockwork ore	3.80	tr	0.3	0.85	0.17
	108.40 - 112.00	stockwork ore	3.60	0.5	2.5	0.42	0.44
	114.80 - 115.70	stockwork ore	0.90	0.6	3.1	1.38	0.69
MJO-A2	38.80 - 40.30	sulfide dominant stockwork ore	1.50	1.7	10.8	0.91	0.25
	46.10 - 48.85	stockwork ore	2.75	0.7	2.7	0.45	0.21
	49.90 - 50.80	stockwork ore	0.90	0.5	1.8	1.03	0.06
	53.80 - 63.45	stockwork ore	9.65	0.3	1.3	1.18	0.15
	86.70 - 88.70	stockwork ore	2.00	0.4	3.0	2.42	0.44
MJO-A4	81.10 - 82.50	massive ore	1.40	2.1	5.5	3.32	0.37
HS -17	59.50 - 60.20	massive ore	0.70	1.3	10.4	9.00	1.88
total			30.2	0.7	2.8	1.29	0.27

Rakah stockwork ore (Weight 69.0 kg)

Hole No.	Depth (m) from - to	Type of ore	D.L. m	Au g/t	Ag g/t	Cu %	Zn %
MJO-B2	93.00 - 96.80	stockwork ore	3.80	0.6	1.7	0.86	0.48
	141.50 - 143.40	stockwork ore	1.90	0.1	0.2	0.56	0.04
MJO-B4	49.00 - 54.70	stockwork ore	5.70	0.2	1.6	0.70	0.19
	76.00 - 80.10	stockwork ore	4.10	0.7	1.0	0.62	0.52
MJO-B5	52.80 - 55.60	stockwork ore	2.80	0.3	1.5	1.07	0.06
	62.90 - 65.70	stockwork ore	2.80	0.5	1.2	3.17	0.13
	115.10 - 117.70	stockwork ore	2.60	0.3	0.6	0.56	0.03
MJO-B6	53.70 - 57.70	stockwork ore	4.00	0.2	0.5	1.44	0.03
total			27.7	0.4	1.1	1.08	0.21

Rakah massive ore (Weight 47.8 kg)

Hole No.	Depth (m) from - to	Type of ore	D.L. m	Au g/t	Ag g/t	Cu %	Zn %
MJO-B1	35.00 - 37.00	massive ore	2.00	6.9	18.0	1.70	0.08
	37.00 - 39.00	massive ore	2.00				
	39.00 - 41.70	massive ore	2.70	12.7	26.6	2.02	0.09
	41.70 - 43.40	massive ore	1.70				
	43.50 - 45.00	massive ore	1.50	9.2	6.9	1.60	0.09
	45.00 - 46.90	massive ore	1.90				
	46.90 - 50.60	massive ore	3.70	9.2	7.0	1.30	0.15
total			15.5	9.7	14.6	1.62	0.11

① Selection of optimum grind size

② Collector screening

③ Flotation rate tests

(b) **Bulk and differential flotation**

This method is to recover copper mineral with pyrite in rougher circuit. After regrinding of bulk concentrate, the copper mineral was recovered by depressing pyrite.

The following items were tested.

① Selection of optimum grind size

② Selection of optimum pH value in rougher flotation

③ Selection of optimum pH value in cleaner flotation to separate copper mineral and pyrite.

(iii) **Overall flotation test**

The overall flotation tests which are based on the fundamental test results, were performed on the composite sample of 65/35% weight mixture of Hayl as Safil ore/Rakah stockwork ore to determine the optimum flotation method.

(3) Preparation of samples for testing

Three samples were prepared according to flowchart shown in Fig. 3-1. The samples were separately crushed to minus 12.7 mm by jaw crusher and roll jaw crusher. The product of roll jaw crusher was screened by hand at 9.52 mm and 1 kg sample was taken from screen oversize for Hardgrove grindability testing. Screen undersize and residual of oversize were crushed to minus 1.68 mm by roll crusher. The roll products were screened by hand at 1.68 mm and screen oversize returned to the roll for further size reduction.

All the samples were divided into 1 kg lot each by coning and quartering method. Each lot was packed in polyethylene bag with nitrogen gas. One lot of packed sample was used for testing of ore characteristics and other lots were provided for flotation tests.

(4) Chemical assays

Chemical assay methods of head samples or flotation products samples are shown in Table 3-2.

(5) Reagents and test machines

Reagents and test machines used in this test work are shown in Table 3-3 and Table 3-4.

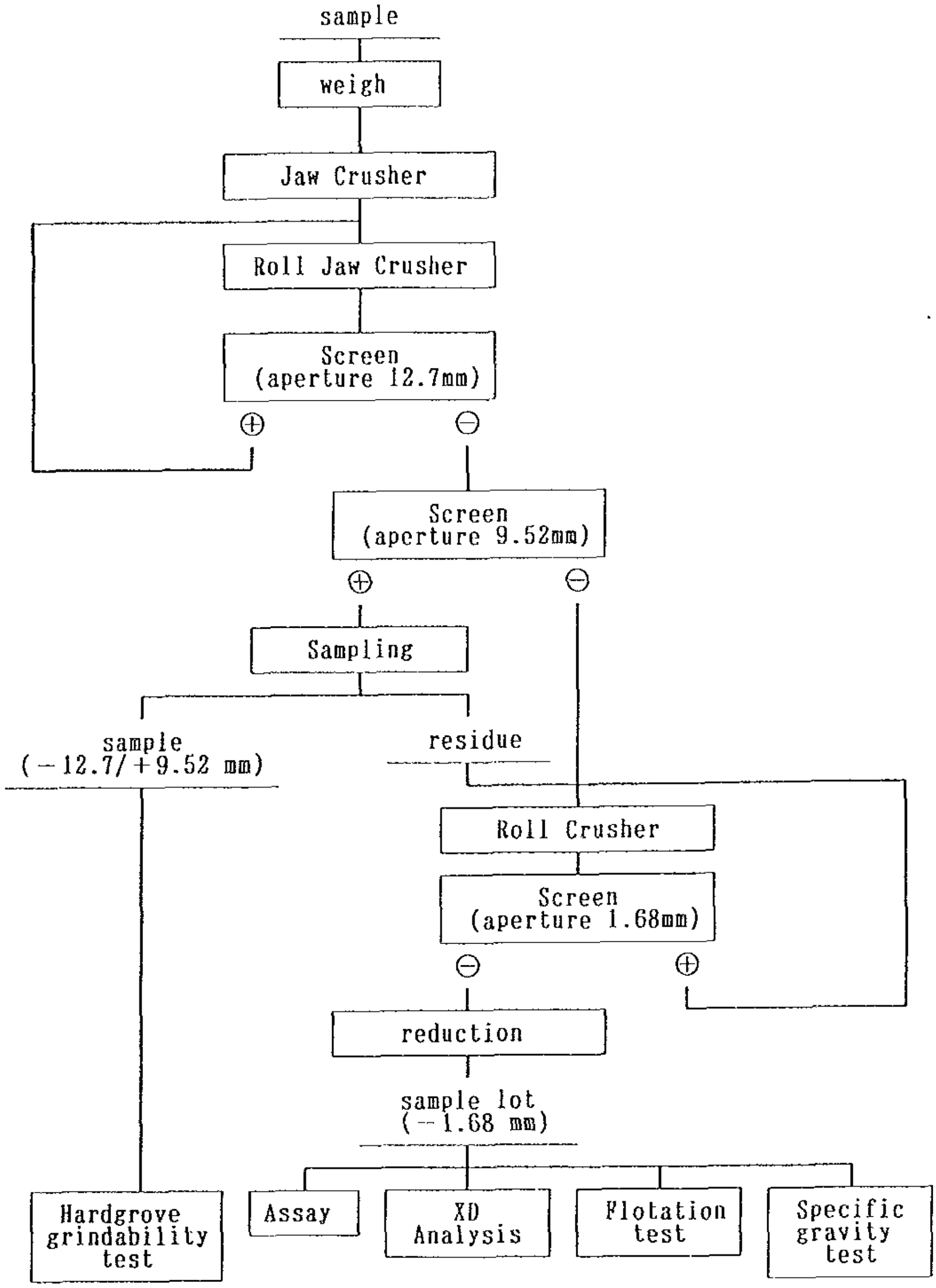

Fig. 3-1 Flowchart of sample preparation

Table 3-2 Assay method

Element	Assay method	Reference
Au,Ag	Fire assay	head sample
SiO_2	Precipitation gravimetry	
As	Absorptiometric method with AgDDC	
Fe	Permanganate titration	
S	Precipitation gravimetry	
Hg	Atomic absorption analysis	
Mo,Cd,Zn,Pb Cu,Al,Ca,Mg	ICP (Inductively coupled algon plasma emission spectrophotometer) analysis	
Au,Ag	Atomic absorption analysis	flotation product
Cu	Absorptiometric method	
Zn	Chelatometric titration	
Fe	Permanganate titration	
S	Precipitation gravimetry	

Table 3-4 List of chemicals used throughout bench scale flotation testwork

Chemical	Abbrevi-ations	Component	Manufacturer
AERO 350 Xanthate	KAX	potassium salt of amyl dithiocarbonic acid	ACC[1)]
AERO 3501 Promoter	AP3501	sodium diisoamyl dithiophoshate	ACC
AEROPHINE 3418A Promotor	AP3418	dialkyl dithiophosphinate	ACC
AERO 404 Promoter	AP404	sodium salt of mercaptobenzothiazole	ACC
AEROFROTH 65	AF65	polypropylene glycol	ACC
Slaked lime	lime	calcium hydroxide	
Sodium hydrogen	$NaHSO_3$	sodium hydrogen	Wako[2)]
Zinc sulfate	$ZnSO_4$	zinc sulfate ($ZnSO_4 \cdot 7H_2O$)	Wako

1) ACC : American cyanamid Company

2) Wako : Wako pure chemical industies, Ltd.

Table 3-3 List of test machines used in bench scale flotation testwork

Test machine	Model	Specification	Manufacturer	reference
Laboratory jaw crusher		Feed opening: 170×110mm, Open discharge setting: 27 to 20mm, 2.2KW	Otsuka Tekkou Co.,Ltd.	Sample prepa-ration
Laboratory roll jaw crusher	R-52	Feed opening: 125×50mm, Open discharge setting: 10 to 7mm, 1.5KW	Otsuka Tekkou Co.,Ltd.	
Laboratory roll crusher		Roll size: ϕ180×130mm, Discharge setting: 3 to 0.5mm, 1.5KW	Satou Seisakusho Co.	
Hardgrove grindability test machine		In conformity to JIS M8801 , 0.1KW	Yoshida Seisakusho Co.	Physical & mineralogical test
X-ray diffractometer	RAD-3C	Scintillation counter	Rigaku Co.,Ltd.	
Electron probe micro analyzer	JXA-8600M		JEOL Co.,Ltd.	
Laboratory ball mill		Cell size: ϕ150×185mm, 0.2KW	Homemade	Flotation test
Laboratory flotation machine	D-1	Denver type, Tank size: 250,500g & 1kg,1/4HP	Denver Equipment Co.	
Laboratory flotation machine		Denver type, Tank size: 200g, 0.2KW	Sugimoto Tekkou Co.	
Laboratory flotation machine		Denver type, Tank size: 100g, 0.1KW	Sugimoto Tekkou Co.	
Oven	TG100-2	Forced convection cycle type	EM Kousetsu Co.,Ltd.	
Oven	DS-42	Natural convection type	YAMATO Scientific Co.	
Balance		Weighing range: 10g - 10kg	Murayama Seisakusho Co	
Precision balance	PT3-1200D	Weighing range: 10mg - 1200g	Chuou Keiryoki Seisakusho Co.	
pH meter	HM-1k		TOA Electronics Ltd.	

(6) Water

Water for testing was supplied from the well in laboratory and distilled water was used in dissolution reagents or other precise purposes.

(7) Method of testing

(i) Work Index

Exact measurement of Work Index needs a lot of sample. Because quantity of samples was not enough to test in exact method, Work Index was estimated from the Index of Hardgrove grindability test in JIS method (Japan Industrial Standard). Work Index (Wi) is given from Hardgrove Index (Hb) using following equations of (1) and (2).

$$Wi = 400/(Hb)^{0.86} \qquad (1)$$

$$Wi = 435/(Hb)^{0.91} \qquad (2)$$

(1): given by Ishihara

(2): given by Bond

(ii) Specific gravity

Specific gravity was measured in JIS A1202 method using 50ml pycnometer.

(iii) Assays of soluble ions in ore

500 g of sample was ground for 16 minutes with distilled water 335cc. Filtrate from filtering of ground pulp was assayed for Cu, Zn and Fe.

(iv) Flotation test procedure

Grinding: 500 g of sample was ground in laboratory mill with r.p.m. 138 and a ball charge 4kg for timed period at 60% solid. In the case of Rakah massive ore, sample charge was 400 g and pulp density was 50% solid. Screen analysis of ground samples were shown in Table 3-5.

Flotation: All the rougher flotation tests were conducted in a 500 g Denver flotation test machine with an initial pulp density of 35%. The cleaning tests were conducted in 500 g or 200 g or 100 g Denver machine depending on the feed pulp quantity.

The conditioning with reagents (except those added to grind) was conducted in the flotation machine with the air valve closed.

Table 3-5 Screen analysis of ground samples

Hayl as Safil ore

SIZE FRACTION (μm)	GRINDING TIME							
	8 min.		11 min.		13 min.		16 min.	
	W%	ΣW%	W%	ΣW%	W%	ΣW%	W%	ΣW%
+1000	0.25	100.00	0.05	100.00	0.00	100.00	0.00	100.00
−1000 /+ 710	0.16	99.75	0.06	99.95	0.00	100.00	0.00	100.00
− 710 /+ 500	0.26	99.59	0.07	99.90	0.08	100.00	0.00	100.00
− 500 /+ 250	3.65	99.34	0.50	99.82	0.16	99.92	0.10	100.00
− 250 /+ 177	7.72	95.69	2.32	99.32	0.89	99.76	0.20	99.90
− 177 /+ 149	5.45	87.96	4.20	97.00	1.29	98.87	0.60	99.70
− 149 /+ 105	19.89	82.52	15.00	92.80	11.46	97.58	5.21	99.10
− 105 /+ 74	11.64	62.63	14.95	77.80	14.32	86.12	11.87	93.89
− 74 /+ 53	13.59	50.99	16.94	62.86	19.35	71.80	20.24	82.02
− 53 /+ 37	8.33	37.40	10.31	45.92	12.22	52.45	15.36	61.78
− 37	29.07	29.07	35.61	35.61	40.23	40.23	46.42	46.42
TOTAL	100.00		100.00		100.00		100.00	

Rakah stockwork ore

SIZE FRACTION (μm)	GRINDING TIME							
	9 min.		11 min.		13 min.		16 min.	
	W%	ΣW%	W%	ΣW%	W%	ΣW%	W%	ΣW%
+1000	0.59	100.00	0.00	100.00	0.00	100.00	0.00	100.00
−1000 /+ 710	0.61	99.41	0.00	100.00	0.00	100.00	0.00	100.00
− 710 /+ 500	0.86	98.79	0.60	100.00	0.20	100.00	0.06	100.00
− 500 /+ 250	6.86	97.93	1.90	99.40	0.53	99.80	0.11	99.94
− 250 /+ 177	9.04	91.07	4.57	97.50	1.82	99.26	0.36	99.83
− 177 /+ 149	5.23	82.04	3.87	92.93	2.66	97.44	0.63	99.47
− 149 /+ 105	17.93	76.81	17.07	89.06	12.56	94.78	6.80	98.84
− 105 /+ 74	9.10	58.88	10.37	72.00	10.04	82.23	8.72	92.04
− 74 /+ 53	10.12	49.78	14.68	61.62	18.51	72.18	20.24	83.31
− 53 /+ 37	7.45	39.66	9.74	46.95	9.70	53.67	12.65	63.08
− 37	32.21	32.21	37.20	37.20	43.97	43.97	50.43	50.43
TOTAL	100.00		100.00		100.00		100.00	

Rakah massive ore

SIZE FRACTION (μm)	GRINDING TIME							
	4.5 min.		6.5 min.		8.5 min.		10.5 min.	
	W%	ΣW%	W%	ΣW%	W%	ΣW%	W%	ΣW%
+1000	1.82	100.00	0.85	100.00	0.28	100.00	0.15	100.00
−1000 /+ 710	1.47	98.18	0.60	99.15	0.20	99.72	0.11	99.85
− 710 /+ 500	1.50	96.71	0.55	98.54	0.20	99.52	0.08	99.74
− 500 /+ 250	6.18	95.20	2.36	97.99	0.94	99.32	0.37	99.66
− 250 /+ 177	7.38	89.03	3.63	95.63	1.49	98.38	0.62	99.29
− 177 /+ 149	4.04	81.65	3.08	92.00	1.22	96.89	0.56	98.67
− 149 /+ 105	16.12	77.61	15.70	88.92	9.38	95.67	6.16	98.10
− 105 /+ 74	11.05	61.48	13.18	73.23	14.14	86.29	11.28	91.95
− 74 /+ 53	9.51	50.43	11.26	60.04	12.85	72.15	15.64	80.67
− 53 /+ 37	7.53	40.92	9.55	48.78	14.75	59.30	13.52	65.03
− 37	33.40	33.40	39.23	39.23	44.55	44.55	51.51	51.51
TOTAL	100.00		100.00		100.00		100.00	