TOPOGRAPHIC MAP OF PIT IN YEAR 41

I \ J	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
2	0	0	0	0	0	0	0	2	2	2	4	2	2	2	2	2	2	2	2	2	2	2	0	0	0
4	0	0	0	0	2	2	2	4	4	4	6	4	4	2	2	2	2	2	2	2	2	0	0	0	0
6	0	0	0	2	2	4	4	6	6	6	8	8	4	4	2	2	2	2	2	2	0	0	0	0	0
8	0	0	2	2	4	6	6	8	8	8	8	8	6	6	4	4	4	2	2	2	0	0	0	0	0
10	0	2	2	4	6	6	8	10	10	10	10	10	8	8	6	6	6	4	4	4	2	0	0	0	0
12	0	2	4	6	6	8	10	12	12	10	10	10	12	10	8	8	8	6	6	6	4	2	0	0	0
14	2	4	4	6	8	10	12	12	14	12	12	12	14	10	10	10	10	8	8	8	6	4	2	0	0
16	2	4	6	8	10	12	12	12	12	14	14	14	14	12	12	14	12	12	12	10	8	6	4	2	0
18	4	6	8	10	10	12	14	12	10	12	14	14	14	16	14	14	14	14	12	12	10	6	4	2	0
20	6	6	8	10	10	12	14	14	12	14	14	14	14	14	14	14	14	12	12	12	10	6	4	2	0
22	6	6	6	8	8	10	12	14	14	14	14	12	12	12	12	14	14	10	10	10	8	6	4	2	0
24	6	8	8	8	8	8	10	12	14	14	12	10	10	12	10	14	12	10	10	8	6	4	2	0	0
26	6	8	8	6	6	8	8	10	12	12	10	8	8	10	10	10	10	8	6	6	4	2	0	0	0
28	6	6	6	6	6	6	8	8	10	10	8	8	6	8	10	10	8	6	4	4	4	0	0	0	0
30	6	6	6	6	6	6	6	6	8	8	6	6	4	6	8	8	6	6	2	4	0	0	0	0	0

FIG. 7.4 (CONTINUED)

The capital requirements (CR) listed in the cash flow are the development expenditures for the combination of plant facilities selected from Table 7•1 to exploit the example deposit• Recall that these capital requirements were discounted to the first year to make up the entry: pit = 7m tons/yr•, concentrator = 1•7m tons/yr•, refinery = 20t tons/yr• and overall recovery efficiency = 95%•

The last column lists the loan capital repayments (LR)• All entries are in millions of cash units•

The total present value (-5•39) of the cash flow in Table 7•18 is not identical with the corresponding present value of the production targets for the preceding plant combination• (See Table 7•9•) Obviously, this must be so, if the mining conditions are such that the production targets cannot be met•

The cash flow analysis is the ultimate measure of any open pit mining solution's worth• That solution resulting from the input mining proposal which yields the greatest profitability, is the obvious choice for exploiting the user's deposit• Note that this solution for the example deposit is unprofitable with a negative total present value and a discounted cash flow yield less than the opportunity cost of investment capital• However, it is possible that the deposit could be made profitable with a different mining proposal and better scheduling and proportioning of the loan and equity capital•

7• 4 AN INVALID SOLUTION

An invalid solution of the MP Programme is illustrated in Table 7•19• This table was generated by the Programme for the example deposit with the following plant capacities:

1) Pit = 5•0m tons per year•

2) Concentrator = 3m tons per year, and

3) Refinery = 20t tons per year•

Recall from Subsection 6•7•2 that an invalid solution arises when the simulated waste plus ore production exceeds the

YR	REV	INT	TAX	OB	CFI	ECAP	CF	PV	LC	CR	LR
1	0•59	•0	0•0	2•61	-2•02	11•0	-13•02	-5•39	0•0	7•1	0•0
2	0•56	•0	0•0	2•53	-1•97	4•2	-6•22	7•19	0•0	5•6	0•0
3	0•68	•0	0•0	2•78	-2•10	0•0	-2•10	13•99	0•0	5•5	0•0
4	2•14	•56	0•0	3•33	-1•75	0•0	-1•75	17•21	7•5	6•5	0•0
5	2•93	•81	0•0	1•59	0•53	0•0	0•53	20•34	3•2	7•6	0•0
6	2•26	•81	0•0	1•42	0•03	0•0	0•03	21•43	0•0	7•5	0•0
7	2•08	•81	0•0	1•51	-0•24	0•0	-0•24	23•11	0•0	0•0	2•0
8	2•31	•66	0•0	1•26	0•37	0•0	0•37	25•20	0•0	0•0	2•0
9	3•33	•51	0•0	1•49	1•33	0•0	1•33	26•84	0•0	0•0	2•0
10	3•84	•36	0•0	1•50	1•98	0•0	1•98	27•65	0•0	0•0	2•0
11	2•52	•21	0•0	1•35	0•96	0•0	0•96	27•83	0•0	0•0	2•0
12	2•32	•06	0•0	1•32	0•94	0•0	0•94	29•15	0•0	0•0	0•7
13	2•67	•0	0•0	1•74	0•93	0•0	0•93	30•54	0•0	0•0	0•0
14	4•02	•0	1•2	1•34	1•43	0•0	1•43	32•05	0•0	0•0	0•0
15	3•68	•0	1•0	0•38	2•30	0•0	2•30	33•19	0•0	0•0	0•0
16	6•51	•0	1•9	0•21	4•41	0•0	4•41	33•54	0•0	0•0	0•0
-	-	-	-	-	-	-	-	-	-	-	-
25	4•79	•0	1•4	0•66	2•78	0•0	2•78	26•96	0•0	0•0	0•0
26	8•79	•0	2•6	0•0	6•18	0•0	6•18	26•33	0•0	0•0	0•0
27	5•89	•0	1•7	0•14	4•06	0•0	4•06	22•26	0•0	0•0	0•0
28	2•96	•0	0•8	0•40	1•79	0•0	1•79	19•98	[illegible]	0•0	0•0
29	3•59	•0	1•0	0•12	2•50	0•0	2•50	19•79	0•0	0•0	0•0
30	4•23	•0	1•2	0•03	3•03	0•0	3•03	18•87	0•0	0•0	0•0
31	2•97	•0	0•8	0•01	2•19	0•0	2•19	17•35	0•0	0•0	0•0
32	3•27	•0	0•9	0•0	2•40	0•0	2•40	16•55	0•0	0•0	0•0
33	3•03	•0	0•8	1•01	1•23	0•0	1•23	15•47	0•0	0•0	0•0
34	5•81	•0	1•7	0•0	4•14	0•0	4•14	15•43	0•0	0•0	0•0
35	3•70	•0	1•0	0•0	2•70	0•0	2•70	12•58	0•0	0•0	0•0
36	3•93	•0	1•1	0•01	2•84	0•0	2•84	10•89	0•0	0•0	0•0
37	3•76	•0	1•0	0•13	2•61	0•0	2•61	8•92	0•0	0•0	0•0
38	3•26	•0	0•9	0•27	2•13	0•0	2•13	7•02	0•0	0•0	0•0
39	4•79	•0	1•4	0•0	3•44	0•0	3•44	5•46	0•0	0•0	0•0
40	3•24	•0	0•9	0•0	2•38	0•0	2•38	2•45	0•0	0•0	0•0
41	0•29	•0	0•0	0•0	0•29	0•0	0•29	0•27	0•0	0•0	0•0

DISCOUNTED CASH FLOW YIELD=6•24%

TABLE 7•18

total pit capacity, as it has in the third, fourth, fifth
years, etc. This is due to the fact that the production
targets have been computed from an inadequate pit capacity.

SIMULATED PIT PRODUCTION SCHEDULE(FOURTH ITERATION CYCLE)

YR	OVERBURDEN M TONS	STRIPPING COSTS M CASH UNITS	ORE M TONS	REVENUE M CASH UNITS
1	2•53	1•25	1•27	0•68
2	2•06	1•40	1•27	0•51
3	6•62	3•41	1•27	1•06
4	5•49	2•69	1•27	1•66
5	2•25	1•12	1•41	2•20
6	4•64	2•45	2•25	3•30
7	1•55	0•78	2•25	2•62
8	1•55	0•79	2•25	3•19
9	1•13	0•60	2•25	5•07
10	5•49	2•65	2•11	3•05
11	6•62	3•48	1•97	1•84
12	5•49	2•95	1•97	3•09
13	5•35	2•90	1•97	2•56
14	0•28	0•15	1•97	4•53
15	1•69	1•02	1•97	7•26
16	0•84	0•53	2•53	11•35
17	0•56	0•20	2•96	6•90
18	1•27	0•77	2•96	8•01
19	0•14	0•09	2•96	5•97
20	4•22	2•85	2•96	7•85
21	0•14	0•03	2•96	12•24
22	1•13	0•57	2•96	8•79
23	1•97	1•22	2•96	6•50
24	0•99	0•43	3•04	5•99
25	0•0	0•0	2•96	6•61
26	0•0	0•0	2•96	8•93
27	0•28	0•18	2•96	7•61
28	0•56	0•27	2•96	5•49
29	2•12	1•07	2•96	7•88
30	4•85	3•26	1•18	1•00

TOTAL REVENUE=154•24 MILLION CASH UNITS

TOTAL NUMBER OF PIT INCREMENTS=6

TABLE 7•19

CHAPTER 8 THE MINE PLAN PROGRAMME

The MP Programme is made up of three modules which are needed for the different computations in the various iteration cycles of the open pit mining solution. The computations within the iterative solution are varied by calling different modules. The construction of these modules is illustrated in Table 8.1. Each module is created by including the appropriate calling programme and four subroutines. The calling programmes and subroutines are stored individually in a partitioned data set. There is one module per cycle for the execution of the first two cycles of the iterative solution. The third module is used to execute all additional cycles.

Having divided the MP Programme in this way, it became possible to exclude some time consuming operations in the first two iteration cycles. The excluded operations are not needed because they are refinements unnecessary to the initial accuracy. The large computer time per cycle also made it advantageous to segment the computations for increased control of the solution and to achieve a minimum time loss from computer failures. The results of each iteration cycle are stored on a magnetic disk. If there is a failure in the solution, it is unnecessary to restart the Programme from the beginning. The user merely is required to retrieve the results of the previous cycle and proceed.

8. 1 JOB CONTROL LANGUAGE

The MP Programme is executed in the three job steps illustrated in Fig. 8.1 through 8.3. Note that certain entries in the figures are written in lower case letters. These entries name that which is to be replaced in their position. The label of the disk pack on which the partitioned, direct access and sequential data sets reside is substituted for 'disk pack label'. The position of the source decks and data sets within the control cards is indicated with explanatory phrases• The remaining substitutions are explained in the following description of the job steps:

JOB STEP 1:

The calling programmes and subroutines are compiled, link -edited and stored individually in a partioned data set• The control cards illustrated in Fig• 8•1 are used repetitively to load the source deck of cards for each member of the partitioned data set• The names of the calling programmes and subroutines, as listed in Table 8•1, are substituted, in turn, for the internal name of the LKED•SYSLMOD card's DSNAME parameter•

```
---------------------------------------------------------------------
|                                                                   |
|                    |           MP PROGRAMME               |      |
|                     ---------------------------------------      |
|                    | MODULE 1 | MODULE 2 | MODULE 3 |             |
|                     ---------------------------------------      |
|  CALLING PROGRAMMES| MAIN1     | MAIN2      | MAIN3       |       |
|                    |           |            |             |       |
|         SUBROUTINES|   COG1    |   COG2---|----->          |       |
|                    |   COGSUB-|----->----|----->          |       |
|                    |   PD-----|----->----|----->          |       |
|                    |   SUBPD--|----->----|----->          |       |
|                     ---------------------------------------      |
|                                                                   |
|                          TABLE 8• 1                               |
|                                                                   |
---------------------------------------------------------------------
```

JOB STEP 2:

The second job step creates one of the three modules (MP1, MP2 or MP3) by including the appropriate members of the partioned data set• The modules are made up by executing the control card list in Fig• 8•2 with the following substitutions:

1) 'n' and 'nn' are replaced with '1' to create the module MP1 which computes the first iteration cycle,

2) 'n' and 'nn' are replaced with '2' to create the module

```
(job card)
// EXEC FORTHCL,PARM.LKED=NCAL
//SYSIN DD *
(source card deck for the calling programmes and subroutines, in turn)
/*
//LKED.SYSLMOD DD DSNAME=PROGMP(name),DISP=(NEW,KEEP),UNIT=SYSDA,        X
//              VOLUME =SER=disk pack label,SPACE=(CYL,(20,1,20))
//
```

The preceding control cards are used to load the first member of the partioned data set only. The 'LKED.SYSLMOD' card must be replaced by the following card to compile the remaining data set members or to recompile any of these members:

```
//LKED.SYSLMOD DD DSNAME=PROGMP(name),DISP=OLD,VOLUME=SER=disd pack label
```

FIG. 8.1 COMPILATION AND LINK-EDIT JOB STEP

```
(job card)
// EXEC PGM=IEWL,PARM='MAP',REGION=150K
//SYSPRINT DD SYSOUT=A
//SYSUT1 DD UNIT=SYSDA,VOLUME=SER=disk pack label,SPACE=(TRK,(50,10))
//SYSLIB DD DSNAME=SYS1.FORTLIB,DISP=SHR
//SYSLMOD DD DSNAME=PROG(MPn),DISP=(NEW,KEEP),UNIT=SYSDA,                X
//               VOLUME=SER=disk pack label,SPACE(CYL,(10,1,10))          X
//               DCB=(RECFM=U,BLKSIZE=3625)
//A DD DSNAME=PROGMP,DISP=OLD,VOLUME=SER=disk pack label,UNIT=SYSDA
//SYSLIN DD *,DCB=BLKSIZE=80
 ENTRY MAIN
 INCLUDE A(MAINn)
 INCLUDE A(CO[illegible])
 INCLUDE A(COGSUB)
 INCLUDE A(PD)
 INCLUDE A(SUBPD)
/*
//
```

The 'DISP' parameter must be changed to 'OLD', and the 'DCB' and 'SPACE' parameters deleted on the 'SYSLMOD' card for any executions of this job step after the first, as follows:

```
//SYSLMOD DD DSNAME=PROG(MPn),DISP=OLD,UNIT=SYSDA,VOLUME=SER=disk pack label
```

FIG. 8.[illegible] CREATION OF MODULES JOB STEP

MP2 which computes the second iteration cycle, and

3) 'n' is replaced by '3' and 'nn' by '2' to create the module MP3 which computes all iteration cycles from the third one on.

JOB STEP 3:

The module created in the second job step is executed by the job control cards listed in Fig. 8.3. The module number 'n' is replaced by the one created in the second step.

Each module required an average of thirty three minutes to execute a solution for a grid system with 13,500 grid -intersections on the International Business Machines Corporation's IBM 360/50 computer.

8. 2 PREPARATION OF THE PROGRAMME FOR EXECUTION

The steps needed to implement the MP Programme are listed below. The Programme can be prepared for execution by using these steps to locate the comments within the Programme listing which describe any required modifications.

STEP 1:

The dimensions must be specified for the FORTRAN arrays, sequential data sets and direct access data sets. These dimensions are

A) defined in Section 8.8 for the specification statements of the arrays,

B) given for the sequential data sets in Section 8.1, and

C) given for the direct access data sets in Section 8.1 for the SPACE parameters and in Subsection 8.3.2 for the DEFINE FILE statement.

STEP 2:

The grid system is already defined for the preceding Programmes in the Model. However, the maximum number of grid co-ordinates NI, NJ and NK in the I, J and K co-ordinate

```
(job card)
//JOBLIB DD DSNAME=PROG,DISP=(OLD,PASS),UNIT=2311,VOLUME=SER=disk pack label
//A EXEC PGM=MPn,TIME=30,REGION=550K
(sequential and direct access data sets--see the list below)
//GO.FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=133,BUFNO=1)
//GO.FT05F001 DD *
(punched card input data)
/*
//
```

The sequential and direct access data sets required for the three modules (MP1 , MP2, and MP3) are:

1) For the first module (MP1):

```
//GO.FT10F001 DD DSNAME=CMODEL,DISP=OLD,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT11F001 DD DSNAME=UPDATE,DISP=(NEW,KEEP),UNIT=2311,                  X
//                 VOLUME=SER=disk pack label,SPACE=(CYL,(3,1)),            X
//                 DCB=(RECFM=VB,LRECL=8,BLKSIZE=3204)
//GO.FT12F001 DD DSNAME=ORERES,DISP=(NEW,KEEP),UNIT=2311                   X
//                 VOLUME=SER=disk pack label,SPACE=(CYL,(3,1))             X
//                 DCB=(RECFM=VB,LRECL=12,BLKSIZE=3544)
//GO.FT13F001 DD DSNAME=EQGRAD,DISP=(NEW,KEEP),UNIT=2311,                  X
//                 VOLUME=SER=disk pack label,SPACE=(CYL,(1,1))             X
//                 DCB=(RECFM=VB,LRECL=10,BLKSIZE=3204)
```

2) For the second module (MP2):

```
//GO.FT11F001 DD DSNAME=UPDATE,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT12F001 DD DSNAME=ORERES,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT13F001 DD DSNAME=EQGRAD,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
```

(continued--next page)

FIG. 8.3 EXECUTION JOB STEP

```
//GO.FT14F001 DD DSNAME=UPDATE2,DISP=(NEW,KEEP),UNIT=2311,                 X
//              VOLUME=SER=disk pack label,SPACE=(CYL,(2,1)),              X
//              DCB=(RECFM=VB,LRECL=12,BLKSIZE=3544)
//GO.FT15F001 DD DSNAME=ORERES2,DISP=(NEW,KEEP),UNIT=2311                  X
//              VOLUME=SER=disk pack label,SPACE=(TRK,(2,1)),              X
//              DCB=(RECFM=VB,LRECL=12,BLKSIZE=2404)
//GO.FT16F001 DD DSNAME=PRICES,DISP=(NEW,KEEP),UNIT=2311                   X
//              VOLUME=SER=disk pack label,SPACE=(TRK,(1,1)),              X
//              DCB=(RECFM=VB,LRECL=32,BLKSIZE=3204)
```

3) For the third module (MP3):

```
//GO.FT13F001 DD DSNAME=EQGRAD,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT14F001 DD DSNAME=UPDATE2,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT15F001 DD DSNAME=ORERES2,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
//GO.FT16F001 DD DSNAME=PRICES,DISP=SHR,UNIT=2311,VOLUME=SER=disk pack label
```

FIG. 8.3 (CONTINUED)

rections, respectively, are required as part of the MP Programme's input data.

STEP 3:

The appropriate number of FORTRAN variables must be created for each recoverable mineral reported by the Grade Prediction Programme. This modification only is required for the calling programmes. The variables and their location in the programmes are described in the comments of Subsection 8.3.2.

STEP 4:

A factor 'GS' is selected to scale the mineral grades up to integer values. Recall from Section 6.3 that the integer mineral values are used for the subscript 'M' of 'ORERES'. Additionally, a mineral grade increment 'GI' is selected to limit the size of subscript 'M'. This increment groups all minerals occurring in the same grade interval into one class. A balance must be made between accuracy and the ORERES array size. The scale factor 'GS' must be large enough to avoid INTEGER truncation. In contrast, the grade increment 'GI' must be small enough that subscript 'M' of ORERES does not become excessively large. 'GI' and 'GS' are input data to the MP Programme.

STEP 5:

The initial assumption for the subscript 'N' of 'ORERES' is given by the user. (See Subsection 6.3.1 for a description of how this is done.) This assumption is located in the calling programme MAIN1. (Subsection 8.3.2)

STEP 6:

Any geologic or physical features, legal boundaries and costing situations which may affect the following operations or variables must be simulated:

A) T-S net cash value distribution,

B) design of the final pit surface,

C) the tonnage factors, and

D) pit production simulation.

There is a comment at those places in the Programme lists where the simulation of these features is required.

STEP 7:

The variable 'D' in the cone expressions for the final pit surface design and waste mining simulation routines must be dependant on the pit wall-angles, if these angles vary. The relationship between 'D' and the pit wall-angles is explained further in the comments in the lists of subroutines PD and SUBPD.

STEP 8:

The ore excavation sequence programmed in subroutine PD must be tailored to the user's requirements. The desired number of ore working faces per bench and the number of exposed ore benches, and the direction of their advance is simulated as explained in Subsection 6.7.1.

8. 3 CALLING PROGRAMMES

A verbal description of the first calling programme's computational sequence is presented in Subsection 8.3.1. It is then listed in the next Subsection with comments to explain some of its features. The last two Subsections contain the lists of the other calling programmes with comments explaining how they differ from those preceding them.

8. 3. 1 COMPUTATIONAL SEQUENCE OF MAIN1

LINES 001 - 007

Specification statements.

LINES 008 - 054

Input statements.

LINES 059 - 080

DO loop 11 computes:

A) an equivalent mineral grade 'EQGRAD' to represent all the deposit's recoverable minerals, and

B) the initial assumption for the T-S mineral distribution.

LINES 083 - 093

The first estimate of the unit production costs is computed.

LINE 094

The following values are supplied by the nested subroutines COG1 and COGSUB for the selected plant combination:

A) the annual cut-off grades 'CUTOFF' and production targets 'MIN, CON, QREF';

B) the overall recovery efficiency 'YIELD', and

C) an average 'AVEG' of the annual cut-off grades 'CUTOFF'.

LINES 095 - 158

These computations execute the first estimate of the T-S net cash value distribution 'VAL' and the second estimate of the average unit production costs 'Z, C, R'. At this point in the solution, it is not know when the grid-blocks are mined. Consequently, it is assumed that they are mined in the first year 'T' and, in addition, their equivalent mineral contents are compared with the average cut-off grade 'AVEG'.

LINE 151

The following computations are executed by the nested subroutines PD and SUBPD:

A) the final pit surface is designed and

B) the pit production is simulated.

LINES 152 - 159

The annual revenue is totalled 'PNEW' and the number of pit increments computed 'MAXN'. These results are printed out to assist the user in monitoring the solution.

LINES 160 - 179

The second estimate of the T-S mineral distribution 'ORERES' is computed with the grid-block excavation times 'YR' from the pit production simulation in subroutine PD.

LINES 180 - 185

The results of the first module 'MP1' are stored on a disk pack for future use. The T-S mineral distribution 'ORERES' and the grid-block excavation times 'YR' are used to update the iterative solution. The remaining data (TOPO, EQGRAD, IGRAD1, IGRAD2) are stored for rapid access rather than being recalculated in the other modules.

LINES 186 - 209

Yearly topographic maps are printed to illustrate the pit production simulation.

8. 3. 2 A LIST OF MAIN1

----------------------------COMMENT----------------------------

The example deposit has two recoverable minerals 'GRAD1' and 'GRAD2' whose present selling prices are 'S1' and 'S2', respectively. The following lines must be modified, if the user's deposit contains a different number:

```
MAIN1 : LINES 004, 005, 021-022, 036-038, 047,
             071-072, 091-092, 124-126, 142 and
             184;
MAIN2 : LINES 004, 005, 016-017, 040, 049-050,
             090-092, 108 and 117;
MAIN3 : LINES 004, 005, 016-017, 046-047, 049,
             052, 091-093, 109 and 118.
```

```
001      DOUBLE PRECISION CAP(3,3,3),CONCAP(3),REFCAP(3),
        1MINCAP,ORERES(99,20),F(99),MIN(99),Q6(20),
        2Q7(65,20),Q8(65,20),Q9(65,20),Q10(65,20),
```

```
         3Q11(65,20),Q12(3,3,3),Q14(99),POLD,PNEW,DABS,FIXC,
         4Q14A(99)
002       REAL MILC(2),INFRC,INFRP,MINC
003       INTEGER CUTOFF(99),ONE/1/,TWO/2/,GI
004       INTEGER*2 TOPO(13500),YR(13500),PITINC,SURFC(30),
         1Q33(13500),Q34(13500),Q35(13500),T,SCORK(750),
         2IGRAD1(30,25,18),IGRAD2(30,25,18),EQGRAD(30,25,18),
         3AVEG
005       DIMENSION OB(2),OR(2),OBCI(2),ORCI(2),REFC(2),
         1PITANG(2),WRKANG(2),SLOPE(2),WSLOPE(2),S1(99),
         2S2(99),TONF(2),REC(3),E(99),C(99),R(99),PROFIT(99),
         3CAPOB(99),WASTE(99),VAL(13500)
006       COMMON ORERES,CONCAP,REFCAP,MINCAP,F,Q6,Q7,Q8,Q9,
         1Q10,Q11,Q12,MIN,Q14,Q14A,CAP,PITANG,WRKANG,SLOPE,
         2WSLOPE,S1,D,C,R,E,TONF,PROFIT, CAPOB,WASTE,REC,
         3VAL,GS,NI,NJ,NK,NBLKS,MAXN,MAXG,CUTOFF,L,Q33,Q34,
         4Q35,SURFC,TOPO.YR
------------------------COMMENT----------------------------
```

ii = NK*NJ*NK: jj = 4*(number of recoverable minerals)•

```
-----------------------------------------------------------
007       DEFINE FILE 10( ii , jj ,L,IJ)
------------------------COMMENT----------------------------
```

The scale factor 'GS' and grade increment 'GI' (Line 011) are given by the user to set up the subscript 'M' of 'ORERES' in lines 037, 076 and 177 as explained in Step 4, Section 8•2•

```
-----------------------------------------------------------
008          READ (5,15) NI,NJ,NK,GS
009       15 FORMAT (3I3,F7•1)
010          NBLKS=NI*NJ*NK
011          GI=5
012          READ (5,1051) (SCORK(N),N=1,750)
013     1051 FORMAT (30I2)
014          DO 210 LOC=1,NBLKS
015          TOPO(LOC)=0•0
016          VAL(LOC)=0•0
017      210 YR(LOC)=0
018          DO 260 K=1,NK
019          DO 260 J=1,NJ
020          DO 260 I=1,NI
021          IGRAD1(I,J,K)=0
022          IGRAD2(I,J,K)=0
```

```
 260 EQGRAD(I,J,K)=0
     DO 1054 K=1,NK
     N=0
     DO 1054 J=1,NJ
     DO 1054 I=1,NI
     N=N+ONE
     LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
     FIND (10'LOC)
     IF (SCORK(N)-K) 1055,1053,1053
1055 II=I
     GO TO 1056
1053 II=0
1056 TOPO(LOC)=II
     READ (10'LOC) GRAD1,GRAD2
     IGRAD1(I,J,K)=GRAD1*GS
     IGRAD2(I,J,K)=GRAD2*GS
1054 CONTINUE
     READ (5,60) (((CAP(I,J,K),I=1,3),J=1,3),K=1,3)
  60 FORMAT (3F12•1)
     READ (5,61) (OB(I),OR(I),OBCI(I),ORCI(I),MILC(I),
    1REFC(I),PITANG(I),WRKANG(I),I=1,2)
  61 FORMAT (5F6•3,F7•3,2F7•4)
     DO 63 I=1,2
     SLOPE(I)=(SIN(PITANG(I))/COS(PITANG(I)))**2•
  63 WSLOPE(I)=(SIN(WRKANG(I))/COS(WRKANG(I)))**2•
     READ (5,1) MAXN,S1(1),S2(1),D,INFRC,INFRP,TONF(1),
    1TONF(2)
   1 FORMAT (I2,2F8•2,F5•2,2F6•3,2F9•1)
     READ (5,2) (CONCAP(I),I=1,3),(REFCAP(J),J=1,3),
    1(REC(K),K=1,3)
   2 FORMAT (3F11•1/3F9•1/3F5•2)
     READ (5,3) MINCAP
   3 FORMAT (F11•1)
     READ (5,12) MINC,CONC,FIXC
  12 FORMAT (2F5•2,F10•1)
     DO 4 NN=1,20
     DO 4 M=1,99
   4 ORERES(M,NN)=0•0
     MAXG=0
```

------------------------COMMENT------------------------

Among other things, DO loop 11 executes the initial assumption for 'ORERES', as explained in Subsection 6•3•1• and Step 5, Section 8•2•

```
059        DO 11 N=1,MAXN
060        K1=4*N
061        K2=K1-TWO
062    73  DO 11 K=K2,K1
063        DO 11 J=1,NJ
064        DO 11 I=1,NI
0065        LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
066        IF (TOPO(LOC)) 11,11,5
```

------------------------COMMENT---------------------------

The example deposit has two tonnage factors 'TONF' one for each side of the tenth grid-level• The following four statements select the appropriate tonnage factor for the 'ORERES' computations• These statements are modified as explained in Subsection 6•3•1, if the user's deposit requires different tonnage factors• Additionally, the modification must be repeated each time tonnage is involved in a computation•

(SEE: MAIN1: LINES 110, 120 & 173;
      MAIN2: LINES 076, 086 & 144;
      MAIN3: LINES 077, 087 & 145;
      PD: LINES 118 & 143; AND
      SUBPD: LINE 050•)

```
067     5 IF (K-10) 6,6,7
068     6 MM=ONE
069       GO TO 8
070     7 MM=2
```

------------------------COMMENT---------------------------

The following two statements must be modified to calculate an equivalent mineral grade for each secondary mineral reported in the user's deposit, as explained in Subsection 6•3•2•

```
071     8 X=(S2(1)/S1(1))*IGRAD2(I,J,K)
072       EQGRAD(I,J,K)=IGRAD1(I,J,K)+IFIX(X)
073       IF (EQGRAD(I,J,K)-GI) 9,9,10
074     9 M=ONE
075       GO TO 70
076    10 M=EQGRAD(I,J,K)/GI
077    81 IF (MAXG-M) 80,80,70
078    80 MAXG=M
```

```
   70 OREPES(M,N)=OREPES(M,N)+TONF(MM)
   11 CONTINUE
      WRITE (6,220) MAXG
  220 FORMAT (1X,' MAXG=',I4)
      DO 13 N=1,99
      T=N
      X=(1.+INFRC)**T
      Y=(1.+INFRP)**T
      E(N)=X*MINC
      C(N)=X*CONC
      R(N)=X*REFC(1)
      F(N)=X*FIXC
      S2(N)=Y*S2(1)
      S1(N)=Y*S1(1)
   13 CONTINUE
      CALL COG (AVEG,YIELD)
      T=ONE
      LC=0
      MC=0
      SUME=0
      SUMC=0
      SUMR=0
```

-------------------------COMMENT-----------------------------

DO loop 34 computes the T-5 net cash value distribution. This routine, and its duplicates in MAIN1 and MAIN2 must be tailored to the user's desired cost structure, as explained in Subsection 6.5.2.

```
      DO 34 K=1,NK
      DO 34 J=1,NJ
      DO 34 I=1,NI
      LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
      IF (TOPO(LOC)) 34,34,14
   14 M=ONE
   16 IF (EQGRAD(I,J,K)-AVEG) 19,23,23
   19 LC=LC+ONE
      REV=0.0
      IF (K-10) 20,20,21
   20 N=ONE
      GO TO 22
   21 N=TWO
   22 X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**K)
      SUME=SUME+X
      COST=(X+(F(N)/MIN(N)))*TONF(N)
```

```
      GO TC 33
   23 LC=LC+ONE
      MC=MC+ONE
      IF (K-10) 24,24,25
   24 N=ONE
      GO TC 26
   25 N=TWC
   26 I1=IGRAD1(I,J,K)
      I2=IGRAD2(I,J,K)
      REV=((FLOAT(I1)/GS*S1(M))+(FLOAT(I2)/GS*S2(M)))*
     1TONF(M)*YIELD
      X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**M)
      Y=(OR(N)+(K*ORCI(N)))*((1.+INFRC)**M)
      SUME=SUME+X
      IF (IGRAD2(I,J,K)) 27,27,28
   27 NN=ONE
      GO TC 29
   28 NN=TWO
   29 Z=(MILC(NN))*((1.+INFRC)**M)
      SUMC=SUMC+Y-X+Z
      IF (ABS(((66.3*I)-(277.5*J)-(37.525*K)+3274.075)
     1/288)-3.0) 30,30,31
   30 NN=ONE
      GO TC 32
   31 NN=TWO
   32 W=(REBC(NN))*((1.+INFRC)**M)
      SUMR=SUMR+W
      COST=(Y+Z+(W*YIELD*((FLOAT(I1+I2))/GS))+(F(M)/
     1MIN(M)))*TONF(N)
   33 VAL(LOC)=REV-COST
   34 CONTINUE
      IF (SUME) 36,36,35
   35 E(T)=SUME/LC
   36 IF (SUMC) 38,38,37
   37 C(T)=SUMC/MC
      R(T)=SUMR/MC
   38 CONTINUE
      CALL PD
      PNEW=0.0
      DO 39 N=1,L
   39 PNEW=PROFIT(N)+PNEW
      WRITE ( 6,222) PNEW
  222 FORMAT (1X,' TOTAL REVENUE=',F14.1)
      MAXN=(L-ONE)/5+ONE
      WRITE (6,221) MAXN,L
  221 FORMAT (1X,' MAXN=',I4,'L=',I4)
```

```
      DO 41 M=1,99
      DO 41 N=1,20
   41 ORERES(M,N)=0.0
      DO 48 K=1,NK
      DO 48 J=1,NJ
      DO 48 I=1,NI
      LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
      IF (TOPO(LOC)) 48,48,42
   42 IF (YR(LOC)) 48,48,51
   51 PITINC=(YR(LOC)-ONE)/5+ONE
  231 IF (K-10) 43,43,44
   43 MM=ONE
      GO TO 45
   44 MM=TWO
   45 IF (EQGRAD(I,J,K)-GI) 46,46,71
   46 M=ONE
      GO TO 47
   71 M=EQGRAD(I,J,K)/GI
   47 ORERES(M,PITINC)=ORERES(M,PITINC)+TONF(MM)
   48 CONTINUE
      WRITE (11) (TOPO(N),YR(N),N=1,NBLKS)
      END FILE 11
      WRITE (12) ((ORERES(M,N),M=1,MAXG),N=1,MAXN)
      END FILE 12
      WRITE (13) (((EQGRAD(I,J,K),IGRAD1(I,J,K),
     1IGRAD2(I,J,K),I=1,NI),J=1,NJ),K=1,NK)
      END FILE 13
   50 WRITE (6,201)
  201 FORMAT (' ANNUAL PIT OUTLINE')
      DO 211 N=1,NJ
  211 SURFC(N)=0
      DO 100 N=1,L
      WRITE (6,202) N
  202 FORMAT ('1',' TOPOGRAPHIC MAP OF MINE IN YEAR',I3)
      DO 100 I=1,NI
      DO 104 J=1,NJ
      M=0
      K=ONE
  151 IF (K-NK) 154,154,175
  154 LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
      IF (TOPO(LOC)) 152,152,105
  105 IF (YR(LOC)) 175,175,190
  190 IF (YR(LOC)-N) 152,152,175
  152 M=K
      K=K+ONE
      GO TO 151
```

```
175 SURFC(J)=M
104 CONTINUE
    WRITE (6,203) (SURFC(LEVEL),LEVEL=1,NJ)
100 CONTINUE
203 FORMAT ('0',30I3)
 49 STOP
    DEBUG TRACE,SUBTRACE,SUBCHK
    END
```

8. 3. 3 A LIST OF MAIN2

The comments within the list describe how MAIN2 differs from MAIN1.

```
001      DOUBLE PRECISION CAP(3,3,3),CONCAP(3),REFCAP(3),
        1MINCAP,OPERES(99,20),F(99),MIN(99),Q6(20),
        2Q7(65,20),Q8(65,20),Q9(65,20),Q10(65,20),
        3Q11(65,20),Q12(3,3,3),Q14(99),POLD,PNEW,DABS,FIXC,
        4Q14A(99)
002      REAL MILC(2),INFRC,INFRP,MINC
003      INTEGER CUTOFF(99),ONE/1/,TWO/2/,GI
004      INTEGER*2 TOPO(13500),YR(13500),PITINC,SURFC(30),
        1Q33(13500),Q34(13500),Q35(13500),P,SCORK(750),
        2IGRAD1(30,25,18),IGRAD2(30,25,18),EQGRAD(30,25,18),
        3AVEG
005      DIMENSION OB(2),OR(2),OBCI(2),ORCI(2),REFC(2),
        1PITANG(2),WRKANG(2),SLOPE(2),WSLOPE(2),S1(99),
        2S2(99),TONF(2),REC(3),E(99),C(99),R(99),PROFIT(99),
        3CAPOB(99),WASTE(99),VAL(13500)
006      COMMON OPERES,CONCAP,REFCAP,MINCAP,F,Q6,Q7,Q8,Q9,
        1Q10,Q11,Q12,MIN,Q14,Q14A,CAP,PITANG,WRKANG,SLOPE,
        2WSLOPE,S1,D,C,R,E,TONF,PROFIT, CAPOB,WASTE,REC,
        3VAL,GS,NI,NJ,NK,NBLKS,MAXN,MAXG,CUTOFF,L,Q33,Q34,
        4Q35,SURFC,TOPO,YR
----------------------COMMENT---------------------------
```

The input data of line 007 are required from the results of the first module MP1:

A) the maximum equivalent mineral grade 'MAXG' reported in the user's deposit by MAIN1 and

B) the mine's life span 'L' reported by the subroutine COG1.

```
      READ (5,62) MAXG,L
   62 FORMAT (2I3)
      READ (5,4) NI,NJ,NK,GS
      NBLKS=NI*NJ*NK
    4 FORMAT (3I3,F7.1)
      GI=5
      DO 260 K=1,NK
      DO 260 J=1,NJ
      DO 260 I=1,NI
      IGRAD1(I,J,K)=0
      IGRAD2(I,J,K)=0
  260 EQGRAD(I,J,K)=0
      DO 210 LOC=1,NBLKS
      VAL(LOC)=0.0
      YR(LOC)=0
  210 CONTINUE
      READ (5,60) (((CAP(I,J,K),I=1,3),J=1,3),K=1,3)
   60 FORMAT (3F12.1)
      READ (5,61) (OB(I),OR(I),OBCI(I),ORCI(I),MILC(I),
     1REFC(I),PITANG(I),WRKANG(I),I=1,2)
   61 FORMAT (5F6.3,F7.3,2F7.4)
      DO 63 I=1,2
      SLOPE(I)=(SIN(PITANG(I))/COS(PITANG(I)))**2.
   63 WSLOPE(I)=(SIN(WRKANG(I))/COS(WRKANG(I)))**2.
```

------------------------COMMENT--------------------------

The total number of pit increments 'MAXN' reported by the preceding iteration cycle is required to modify the input of the following 'READ' statement.

```
      READ (5,1) MAXN,S1(1),S2(1),D,INFRC,INFRP,TONF(1),
     1TONF(2)
    1 FORMAT (I2,2F8.2,F5.2,2F6.3,2F9.1)
      READ (5,2) (CONCAP(I),I=1,3),(REFCAP(J),J=1,3),
     1REC(K),K=1,3)
    2 FORMAT (3F11.1/3F9.1/3F5.2)
      READ (5,3) MINCAP
    3 FORMAT (F11.1)
      READ (5,12) MINC,CONC,FIXC
   12 FORMAT (2F5.2,F10.1)
```

------------------------COMMENT--------------------------

The two data sets 'YR' and 'ORERES' are used to update the iterative solution. The data sets 'EQGRAD', 'IGRAD1', 'IG-RAD2' and 'TOPO' are read form the disk pack where they were stored rather than being recalculated.

```
--------------------------------------------------------------------
038        READ (11) (TOPO(N),YR(N),N=1,NBLKS)
039        READ (12) ((ORERES(M,N),M=1,MAXG),N=1,MAXN)
040        READ (13) (((EQGRAD(I,J,K),IGRAD1(I,J,K),
          1IGRAD2(I,J,K),I=1,NI),J=1,NJ),K=1,NK)
041        DO 13 N=1,99
042        T=N
043        X=(1.+INFRC)**T
044        Y=(1.+INFRP)**T
045        E(N)=X*MINC
046        C(N)=X*CONC
047        R(N)=X*REFC(1)
048        F(N)=Y*FIXC
049        S2(N)=Y*S2(1)
050        S1(N)=Y*S1(1)
051     13 CONTINUE
052        CALL COG (AVEG,YIELD)
-------------------------COMMENT--------------------------------------
```

DO loop 38 has been added to this module to make the first estimate of the time dimension for the T-S net cash value distribution 'VAL' and the average unit production costs 'E', 'C' and 'R'.

```
--------------------------------------------------------------------
053     92 DO 38 T=1,L
054        LC=0
055        MC=0
056        SUME=0
057        SUMC=0
058        SUMR=0
059        DO 34 K=1,NK
060        DO 34 J=1,NJ
061        DO 34 I=1,NI
062        LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
063        IF (TOPO(LOC)) 34,34,14
-------------------------COMMENT--------------------------------------
```

The time dimension 'T' and grid-block excavation time 'YR' were added to DO loop 34 with the statements in Lines 064, 066 and 068 - 073. Note that the time is assumed to be the first year for any grid-blocks whose pit production has not been simulated in the first module 'MP1'. This assumption eventually becomes redundant as the solution converges.

```
 14 IF (YR(LOC)) 15,15,17
 15 M=ONE
    IF (T-M) 16,16,34
 16 IF (EQGRAD(I,J,K)-AVEG) 19,23,23
 17 IF (YR(LOC)-L) 18,18,261
261 M=ONE
    GO TO 16
 18 IF (T-YR(LOC)) 34,262,34
262 M=T
    IF (EQGRAD(I,J,K)-CUTOFF(T)) 19,23,23
 19 LC=LC+ONE
    REV=0.0
    IF (K-10) 20,20,21
 20 N=ONE
    GO TO 22
 21 N=TWO
 22 X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**M)
    SUME=SUME+X
    COST=(X+(F(M)/MIN(M)))*TONF(N)
    GO TO 33
 23 LC=LC+ONE
    MC=MC+ONE
    IF (K-10) 24,24,25
 24 N=ONE
    GO TO 26
 25 N=TWO
 26 I1=IGRAD1(I,J,K)
    I2=IGRAD2(I,J,K)
    REV=((FLOAT(I1)/G5*S1(M))+(FLOAT(I2)/G5*S2(M)))*
   1TONF(N)*YIELD
    X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**M)
    Y=(OR(N)+(K*ORCI(N)))*((1.+INFRC)**M)
    SUME=SUME+X
    IF (IGRAD2(I,J,K)) 27,27,28
 27 NN=ONE
    GO TO 29
 28 NN=TWO
 29 Z=(MILC(NN))*((1.+INFRC)**M)
    SUMC=SUMC+Y-X+Z
    IF (ABS(((66.3*I)-(277.5*J)-(37.625*K)+3274.075)
   1/288)-3.0) 30,30,31
   1-3.0) 30,30,31
 30 NN=ONE
    GO TO 32
 31 NN=TWO
```

```
   32 W=(REFC(NN))*((1.+INFRC)**M)
      SUMR=SUMR+W
      COST=(Y+Z+(W*YIELD*((FLOAT(I1+I2))/GS))+(F(M)/
     1MIN(M)))*TONF(N)
   33 VAL(LOC)=REV-COST
   34 CONTINUE
      IF (SUME) 36,36,35
   35 E(T)=SUME/LC
   36 IF (SUMC) 38,38,37
   37 C(T)=SUMC/MC
      R(T)=SUMR/MC
   38 CONTINUE
```

-------------------------COMMENT----------------------------

The re-evaluated unit production costs are stored on a disk pack by the following statement to replace previous estimates.

```
      WRITE (16) (E(T),C(T),R(T),S2(T),S1(T),F(T),T=1,L)
      END FILE 16
      WRITE (6,240)
  240 FORMAT ('1',' AVERAGE UNIT PRODUCTION COSTS')
      WRITE (6,241)
  241 FORMAT ('0','  E',1X,'  C',2X,'  R',3X,'REF')
      WRITE (6,242) (T,E(T),C(T),R(T),T=1,L)
  242 FORMAT (I3,2F5.2,F7.3)
      CALL PD
      PNEW=0.0
      DO 39 N=1,L
   39 PNEW=PROFIT(N)+PNEW
      WRITE ( 6,222) PNEW
      MAXN=(L-ONE)/5+ONE
  222 FORMAT (1X,' TOTAL REVENUE=',F14.1)
      WRITE (6,221) MAXN,L
  221 FORMAT (1X,' MAXN=',I4,'L=',I4)
      DO 41 M=1,99
      DO 41 N=1,20
   41 ORERES(M,N)=0.0
      DO 48 K=1,NK
      DO 48 J=1,NJ
      DO 48 I=1,NI
      LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
      IF (TOPO(LOC)) 48,48,42
   42 IF (YR(LOC)) 48,48,51
   51 PITINC=(YR(LOC)-ONE)/5+ONE
```

```
 231 IF (K-10) 43,43,44
  43 MM=ONE
     GO TO 45
  44 MM=TWO
  45 IF (EQGRAD(I,J,K)-GI) 46,46,71
  46 M=ONE
     GO TO 47
  71 M=EQGRAD(I,J,K)/GI
  47 ORERES(M,PITINC)=ORERES(M,PITINC)+TONF(MM)
  48 CONTINUE
```

-----------------------COMMENT---------------------------

Additional external data sets are created by the following four statements to store the updated variables 'YR' and 'ORERES' for the next iteration cycle• The T-S net cash value distribution 'VAL' is stored for informational purposes only• The 'TOPO' data set is stored rather than being recalculated for each module•

```
     WRITE (14) (TOPO(N),YR(N),VAL(N),N=1,NBLKS)
     END FILE 14
     WRITE (15) ((ORERES(M,N),M=1,MAXG),N=1,MAXN)
     END FILE 15
  50 WRITE (6,201)
 201 FORMAT (' ANNUAL PIT OUTLINE')
     DO 211 N=1,NJ
 211 SURFC(N)=0
     DO 100 N=1,L
     WRITE (6,202) N
 202 FORMAT ('1',' TOPOGRAPHIC MAP OF MINE IN YEAR',I3)
     DO 100 I=1,NI
     DO 104 J=1,NJ
     M=0
     K=ONE
 151 IF (K-NK) 154,154,175
 154 LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
     IF (TOPO(LOC)) 152,152,105
 105 IF (YR(LOC)) 175,175,190
 190 IF (YR(LOC)-N) 152,152,175
 152 M=K
     K=K+ONE
     GO TO 151
 175 SURFC(J)=M
 104 CONTINUE
     WRITE (6,203) (SURFC(LEVEL),LEVEL=1,NJ)
```

```
  100 CONTINUE
  203 FORMAT ('0',30I3)
   49 STOP
      DEBUG SUBTRACE,SUBCHK
      END
```

8• 3• 4 A LIST OF MAIN 3

After the first two iteration cycles, only one module 'MP3' is used to compute the remaining cycles of the iterative solution• The comments listed in this Subsection describe how MAIN2 was modified to form MAIN3 for these computations:

```
       DOUBLE PRECISION CAP(3,3,3),CONCAP(3),REFCAP(3),
      1MINCAP,ORERES(99,20),F(99),MIN(99),Q6(20),
      2Q7(65,20),Q8(65,20),Q9(65,20),Q10(65,20),
      3Q11(65,20),Q12(3,3,3),Q14(99),POLD,PNEW,DABS,FIXC,
      4Q14A(99)
       REAL MILC(2),INFRC,INFRP,MINC
       INTEGER CUTOFF(99),ONE/1/,TWO/2/,GI
       INTEGER*2 TOPO(13500),YR(13500),PITINC,SURFC(30),
      1Q33(13500),Q34(13500),Q35(13500),T,SCORK(750),
      2IGRAD1(30,25,18),IGRAD2(30,25,18),EQGRAD(30,25,18),
      3AVEG
       DIMENSION OB(2),OR(2),OBCI(2),ORCI(2),REFC(2),
      1PITANG(2),WRKANG(2),SLOPE(2),WSLOPE(2),S1(99),
      2S2(99),TONF(2),REC(3),Z(99),C(99),R(99),PROFIT(99),
      3CAPOB(99),WASTE(99),VAL(13500)
       COMMON ORERES,CONCAP,REFCAP,MINCAP,F,Q6,Q7,Q8,Q9,
      1Q10,Q11,Q12,MIN,Q14,Q14A,CAP,PITANG,WRKANG,SLOPE,
      2WSLOPE,S1,D,C,R,Z,TONF,PROFIT, CAPOB,WASTE,REC,
      3VAL,GS,NI,NJ,NK,NBLKS,MAXN,MAXG,CUTOFF,L,Q33,Q34,
      4Q35,SURFC,TOPO,YR
-------------------------COMMENT---------------------------
```

The mine's life span 'L' reported by the results of the preceding iteration cycle's subroutine COG2 is required to modify the input of the following statement•

```
-----------------------------------------------------------
       READ (5,62) MAXG,L
    62 FORMAT (2I3)
       READ (5,4) NI,NJ,NK,GS
       NBLKS=NI*NJ*NK
     4 FORMAT (3I3,F7•1)
       GI=5
```

```
013         DO 260 K=1,NK
014         DO 260 J=1,NJ
015         DO 260 I=1,NI
016         IGRAD1(I,J,K)=0
017         IGRAD2(I,J,K)=0
018     260 EQGRAD(I,J,K)=0
019         DO 210 LOC=1,NBLKS
020         VAL(LOC)=0.0
021         YR(LOC)=0
022     210 CONTINUE
023         READ (5,60) (((CAP(I,J,K),I=1,3),J=1,3),K=1,3)
024      60 FORMAT (3F12.1)
025         READ (5,61) (OB(I),OR(I),OBCI(I),ORCI(I),MILC(I),
           1REFC(I),PITANG(I),WRKANG(I),I=1,2)
026      61 FORMAT (5F6.3,F7.3,2F7.4)
027         DO 63 I=1,2
028         SLOPE(I)=(SIN(PITANG(I))/COS(PITANG(I)))**2.
029      63 WSLOPE(I)=(SIN(WRKANG(I))/COS(WRKANG(I)))**2.
------------------------COMMENT---------------------------
```

The total number of pit increments 'MAXN' reported by the preceding iteration cycle is required to modify the input of the following 'READ' statement.

```
----------------------------------------------------------
030         READ (5,1) MAXN,S1(1),S2(1),D,INFRC,INFPP,TONF(1),
           1TONF(2)
031       1 FORMAT (I2,2F8.2,F5.2,2F6.3,2F9.1)
032         READ (5,2) (CONCAP(I),I=1,3),(REFCAP(J),J=1,3),
           1REC(K),K=1,3)
033       2 FORMAT (3F11.1/3F9.1/3F5.2)
034         READ (5,3) MINCAP
035       3 FORMAT (F11.1)
036         READ (5,12) MINC,CONC,FIXC
037      12 FORMAT (2F5.2,F10.1)
------------------------COMMENT---------------------------
```

The unit production costs and selling prices estimated by DO loop 13 are replaced by overwriting them with the more accurate ones read in from the preceding iteration cycle (Line 052). However, the values read in from data set 16 have only been computed for the mine's life span 'L' of the preceding iteration cycle. Therefore, DO loop thirteen is required to estimate these costs for any years exceeding the previous cycle's mine life 'L', if the mine life of the current cycle exceeds that of the previous cycle. This estimate becomes redundant as the solution converges•

```
------ ---------------------------------------------------------
       DO 13 N=1,99
       T=N
       X=(1•+INFRC)**T
       Y=(1•+INFRP)**T
       E(N)=X*MINC
       C(N)=Y*CONC
       R(N)=X*REFC(1)
       F(N)=X*FIXC
       S2(N)=Y*S2(1)
       S1(N)=Y*S1(1)
    13 CONTINUE
------------------------COMMENT---------------------------
```

The following external data sets (13, 14, 15, & 16) are read into internal storage• The unit production costs and prices, excavation times and the T-S mineral distribution from the preceding iteration cycle are used to update the solution• The remaining data sets are constant for all iteration cycles•

```
----------------------------------------------------------------
       READ (13) (((EQGRAD(I,J,K),IGRAD1(I,J,K),
      1IGRAD2(I,J,K),I=1,NI),J=1,NJ),K=1,NK)
       READ (14) (TOPO(N),YR(N),VAL(N),N=1,NBLKS)
       READ (15) ((ORERES(M,N),M=1,MAXG),N=1,MAXN)
       READ (16) (E(T),C(T),R(T),S2(T),S1(T),F(T),T=1,L)
       CALL COG (AVEG,YIELD)
    92 DO 38 T=1,L
       LC=0
       MC=0
       SUME=0
       SUMC=0
       SUMR=0
       DO 34 K=1,NK
       DO 34 J=1,NJ
       DO 34 I=1,NI
       LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
       IF (TOPO(LOC)) 34,34,14
    14 IF (YR(LOC)) 15,15,17
    15 M=ONE
       IF (T-M) 16,16,34
    16 IF (EQGRAD(I,J,K)-AVEG) 19,23,23
    17 IF (YR(LOC)-L) 18,18,261
```

```
  261 M=ONE
      GO TO 16
   18 IF (T-YR(LOC)) 34,262,34
  262 M=T
      IF (EQGRAD(I,J,K)-CUTOFF(T)) 19,23,23
   19 LC=LC+ONE
      REV=0.0
      IF (K-10) 20,20,21
   20 N=ONE
      GO TO 22
   21 N=TWO
   22 X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**M)
      SUME=SUME+X
      COST=(X+(F(M)/MIN(M)))*TONF(N)
      GO TO 33
   23 LC=LC+ONE
      MC=MC+ONE
      IF (K-10) 24,24,25
   24 N=ONE
      GO TO 26
   25 N=TWO
   26 I1=IGRAD1(I,J,K)
      I2=IGRAD2(I,J,K)
      REV=((FLOAT(I1)/GS*S1(M))+(FLOAT(I2)/GS*S2(M)))*
     1TONF(N)*YIELD
      X=(OB(N)+(K*OBCI(N)))*((1.+INFRC)**M)
      Y=(OR(N)+(K*ORCI(N)))*((1.+INFRC)**M)
      SUME=SUME+X
      IF (IGRAD2(I,J,K)) 27,27,28
   27 NN=ONE
      GO TO 29
   28 NN=TWO
   29 Z=(MILC(NN))*((1.+INFRC)**M)
      SUMC=SUMC+Y-X+Z
      IF (ABS(((66.3*I)-(277.5*J)-(37.625*K)+3274.075)
     1/288)-3.0) 30,30,31
     1-3.0) 30,30,31
   30 NN=ONE
      GO TO 32
   31 NN=TWO
   32 W=(REFC(NN))*((1.+INFRC)**M)
      SUMR=SUMR+W
      COST=(Y+Z+(N*YIELD*((FLOAT(I1+I2))/GS))+(F(M)/
     1MIN(M)))*TONF(N)
   33 VAL(LOC)=REV-COST
   34 CONTINUE
```

```
112       IF (SUME) 36,36,35
113    35 E(T)=SUME/LC
114    36 IF (SUMC) 38,38,37
115    37 C(T)=SUMC/MC
116       R(T)=SUMR/MC
117    38 CONTINUE
```

-------------------------COMMENT---------------------------

The external data sets--'YR' only of 14, 15 and 16 (Lines 118 and 155 - 158)--used to update the solution are the same for all iteration cycles from the third on. Therefore, the obsolete data is lost when the current updating information is over-written on the same data sets. The 'VAL' data set is updated for informational purposes only. The 'TOPO' data set is stored rather than being recalculated for each iteration cycle.

```
118       WRITE (16) (E(T),C(T),R(T),S2(T),S1(T),F(T),T=1,L)
119       END FILE 16
120       WRITE (6,240)
121   240 FORMAT ('1',' AVERAGE UNIT PRODUCTION COSTS')
122       WRITE (6,241)
123   241 FORMAT ('0','  E',1X,'  C',2X,'  R',3X,'REF')
124       WRITE (6,242) (T,E(T),C(T),R(T),T=1,L)
125   242 FORMAT (I3,2F5.2,F7.3)
126       CALL PD
127       PNEW=0.0
128       DO 39 N=1,L
129    39 PNEW=PROFIT(N)+PNEW
130       WRITE ( 6,222) PNEW
131       MAXN=(L-ONE)/5+ONE
132   222 FORMAT (1X,' TOTAL REVENUE=',F14.1)
133       WRITE (6,221) MAXN,L
134   221 FORMAT (1X,' MAXN=',I4,'L=',I4)
135       DO 41 M=1,99
136       DO 41 N=1,20
137    41 OBERES(M,N)=0.0
138       DO 48 K=1,NK
139       DO 48 J=1,NJ
140       DO 48 I=1,NI
141       LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
142       IF (TOPO(LOC)) 48,48,42
143    42 IF (YR(LOC)) 48,48,51
144    51 PITINC=(YR(LOC)-ONE)/5+ONE
145   231 IF (K-10) 43,43,44
```

```
 43 MM=ONE
    GO TO 45
 44 MM=TWO
 45 IF (EQGRAD(I,J,K)-GI) 46,46,71
 46 M=ONE
    GO TO 47
 71 M=EQGRAD(I,J,K)/GI
 47 ORERES(M,PITINC)=ORERES(M,PITINC)+TONF(MM)
 48 CONTINUE
    WRITE (14) (TOPO(N),YR(N),VAL(N),N=1,NBLKS)
    END FILE 14
    WRITE (15) ((ORERES(M,N),M=1,MAXG),N=1,MAXN)
    END FILE 15
 50 WRITE (6,201)
201 FORMAT (' ANNUAL PIT OUTLINE')
    DO 211 N=1,NJ
211 SURFC(N)=0
    DO 100 N=1,L
    WRITE (6,202) N
202 FORMAT ('1',' TOPOGRAPHIC MAP OF MINE IN YEAR',I3)
    DO 100 I=1,NI
    DO 104 J=1,NJ
    M=0
    K=ONE
151 IF (K-NK) 154,154,175
154 LOC=NJ*NI*(K-ONE)+NI*(J-ONE)+I
    IF (TOPO(LOC)) 152,152,105
105 IF (YR(LOC)) 175,175,190
190 IF (YR(LOC)-N) 152,152,175
152 M=K
    K=K+ONE
    GO TO 151
175 SURFC(J)=M
104 CONTINUE
    WRITE (6,203) (SURFC(LEVEL),LEVEL=1,NJ)
100 CONTINUE
203 FORMAT ('0',30I3)
 49 STOP
    DEBUG SUBTRACE,SUBCHK
    END
```

8. 4 SUBROUTINES COG1 AND COG 2

A verbal description of subroutine COG1's computational sequence follows in Subsection 8.4.1. Then, it is listed in the next Subsection. The last Subsection contains a list of COG2 with comments to explain how it differs from COG1.

8. 4. 1 COMPUTATIONAL SEQUENCE OF COG1

LINES 001 - 008

Specification and input statements.

LINES 009 - 052

Ratios of ore : pit material 'R1', refined product : pit material 'R2' and refined product : ore 'R3' are calculated for each grade increment 'M' and pit increment 'N' of 'ORERES'.

LINES 053 - 056

Subroutine 'COGSUB' is called to compute the following information for the combination of plant capacities (MINCAP, CONCAP, REFCAP, REC) named by (I,J,K):

A) the annual cut-off grades 'CUTOFF';

B) the annual production targets 'MIN', 'CON' and 'QREF'; and

C) the overall recovery efficiency 'YIELD'.

It is not necessary to compute the plant combination yielding the maximum present value for the rough computations of the first iteration cycle. Therefore, any plant combination (I,J,K) is selected. The plant combination yielding the maximum present value is selected later by replacing this subroutine with subroutine 'COG2' in subsequent iteration cycles.

LINES 057 - 069

These statements execute printer output used to monitor the solution as described and illustrated in Section 7•2•

LINES 070 - 073

An average 'AVEG' of the annual cut-off grades 'CUTOFF' is computed•

8• 4• 2 A LIST OF COG1

```
001       SUBROUTINE COG (AVEG,YIELD)
002       DOUBLE PRECISION MAT(20),ORERES(99,20),
         WASTE(65,20),ORE(65,20),REF(20),DFLOAT,PROD(65,20),
         2R1(65,20),R2(65,20),R3(65,20),PVMAX,PV(3,3,3),
         3CAP(3,3,3),Q2(3),Q3(3),Q4,Q5(99),MIN(99),CON(99),
         4QREF(99),P(99)
003       INTEGER CUTOFF(99),ONE/1/,SUM1,SUM,GI
004       INTEGER*2 AVEG,Q33(13500),Q34(13500),Q35(13500),
         1Q37(30),Q38(13500),Q40(13500)
005       DIMENSION REC(3),Q16(2),Q17(2),Q18(2),Q19(2),
         1Q20(99),Q22(99),Q23(99),Q24(99),Q25(2),Q26(99),
         2Q27(99),Q28(99),Q29A(13500)
006       COMMON ORERES,Q2,Q3,Q4,Q5,MAT,ORE,PROD,R1,R2,R3,PV,
         1MIN,CON,QREF,CAP,Q16,Q17,Q18,Q19,Q20,Q21,Q22,Q23,
         2Q24,Q25,Q26,Q27,Q28,REC,Q29A,GS,NI,NJ,NK,NBLKS,
         3MAXN,MAXG,CUTOFF,L,Q33,Q34,Q35,Q37,Q38,Q40
007       L=0
```

------------------------COMMENT--------------------------

'GI' is given by the user and is equal to 'GI' in Line 011 of 'MAIN1'•

```
008       GI=5
009       DO 351 N=1,20
010       MAT(N)=0
011       REF(N)=0•0
012       DO 351 M=1,65
013       PROD(M,N)=0•0
014       WASTE(M,N)=0•0
015       ORE(M,N)=0•0
016       R1(M,N)=0•0
017       R2(M,N)=0•0
018       R3(M,N)=0•0
019   351 CONTINUE
020       DO 308 N=1,MAXN
021       DO 308 M=1,MAXG
```

```
 308 MAT(N)=MAT(N)+ORERES(M,N)
     DO 309 N=1,MAXN
     WASTE(1,N)=ORERES(1,N)
     IF  (MAT(N)-WASTE(1,N))  2,2,3
   2 ORE(1,N)=ORERES(1,N)
     GO TO 4
   3 ORE(1,N)=MAT(N)-WASTE(1,N)
   4 DO 309 M=2,MAXG
     WASTE(M,N)=WASTE(M-1,N)+ORERES(M,N)
 309 ORE(M,N)=MAT(N)-WASTE(M,N)
     DO 310 N=1,MAXN
     REF(N)=ORERES(1,N)*(GI/GS)
     DO 310 M=2,MAXG
 310 REF(N)=REF(N)+(DFLOAT(M*GI)/GS)*ORERES(M,N)
     DO 311 N=1,MAXN
     PROD(1,N)=REF(N)
     DO 311 M=2,MAXG
     IF  (ORE(M,N))  311,311,1
   1 PROD(M,N)=PROD(M-1,N)-(DFLOAT(M*GI)/GS)*ORERES(M,N)
 311 CONTINUE
     DO 312 N=1,MAXN
     DO 312 M=1,MAXG
     R1(M,N)=ORE(M,N)/MAT(N)
 312 R2(M,N)=PROD(M,N)/MAT(N)
     DO 353 N=1,MAXN
     DO 353 M=1,MAXG
     IF  (ORE(M,N))  354,354,355
 354 R3(M,N)=0
     GO TO 353
 355 R3(M,N)=PROD(M,N)/ORE(M,N)
 353 CONTINUE
     I=ONE
     J=ONE
     K=ONE
 314 CALL COGSUB (I,J,K,P)
     WRITE (6,6)
   6 FORMAT ('1','DISCOUNTED PROFITS FROM THE PRODUCTION
    1TARGETS OF EACH PLANT COMBINATION')
     WRITE (6,5)  (((PV(II,JJ,KK),II=1,3),JJ=1,3),KK=1,3)
   5 FORMAT  (3F13.1)
     YIELD=REC(K)
     WRITE (6,7)
   7 FORMAT ('1','CUT-OFF GRADES & TARGETS FOR THE PLANT
    1COMBINATION YIELDING THE GREATEST EXCESS OF PRESENT
    2VALUE OVER CAPITAL COST')
     WRITE (6,8) PV(I,J,K),Q2(I),Q3(J),REC(K)
```

```
065     8 FORMAT ('0','PRESENT VALUE=',F13•1,'CONCENTRATOR CA
         1PACITY=',F11•1,'REFINERY CAPACITY=',F9•1,'OVERALL R
         2ECOVERY EFFICIENCY=',F5•2)
066       WRITE (6,9)
067     9 FORMAT ('0',' YR  COG',4X,'MIN',8X,'CON',8X,'REF',
         1'PROFIT')
068       WRITE (6,10) (N,CUTOFF(N),MIN(N),CON(N),QREF(N),
         1P(N),N=1,L)
069    10 FORMAT (I3,I5,3F10•1,F13•1)
070       SUM=0
071       DO 165 N=1,L
072   165 SUM=SUM+CUTOFF(N)
073       AVEG=SUM/L
074       RETURN
075       DEBUG SUBTRACE,SUBCHK
076       END
```

8•4• 3 A LIST OF COG2

```
001       SUBROUTINE COG (AVEG,YIELD)
002       DOUBLE PRECISION MAT(20),ORERES(99,20),
         WASTE(65,20),ORE(65,20),REF(20),DFLOAT,PROD(65,20),
         2R1(65,20),R2(65,20),R3(65,20),PVMAX,PV(3,3,3),
         3CAP(3,3,3),Q2(3),Q3(3),Q4,Q5(99),MIN(99),CON(99),
         4QREF(99),P(99)
003       INTEGER CUTOFF(99),ONE/1/,SUM1,SUM,GI
004       INTEGER*2 AVEG,Q33(13500),Q34(13500),Q35(13500),
         1Q37(30),Q38(13500),Q40(13500)
005       DIMENSION REC(3),Q16(2),Q17(2),Q18(2),Q19(2),
         1Q20(99),Q22(99).Q23(99),Q24(99),Q25(2),Q26(99),
         2Q27(99),Q28(99),Q29A(13500)
006       COMMON ORERES,Q2,Q3,Q4,Q5,MAT,ORE,PROD,R1,R2,R3,PV,
         1MIN,CON,QREF,CAP,Q16,Q17,Q18,Q19,Q20,Q21,Q22,Q23,
         2Q24,Q25,Q26,Q27,Q28,REC,Q29A,GS,NI,NJ,NK,NBLKS,
         3MAXN,MAXG,CUTOFF,L,Q33,Q34,Q35,Q37,Q38,Q40
007       L=0
008       GI=5
009       DO 351 N=1,20
010       MAT(N)=0
011       REF(N)=0•0
012       DO 351 M=1,65
013       PROD(M,N)=0•0
014       WASTE(M,N)=0•0
015       ORE(M,N)=0•0
016       R1(M,N)=0•0
017       R2(M,N)=0•0
```

```
      R3(M,N)=0.0
  351 CONTINUE
      DO 308 N=1,MAXN
      DO 308 M=1,MAXG
  308 MAT(N)=MAT(N)+ORERES(M,N)
      DO 309 N=1,MAXN
      WASTE(1,N)=ORERES(1,N)
      IF (MAT(N)-WASTE(1,N)) 2,2,3
    2 ORE(1,N)=ORERES(1,N)
      GO TO 4
    3 ORE(1,N)=MAT(N)-WASTE(1,N)
    4 DO 309 M=2,MAXG
      WASTE(M,N)=WASTE(M-1,N)+ORERES(M,N)
  309 ORE(M,N)=MAT(N)-WASTE(M,N)
      DO 310 N=1,MAXN
      REF(N)=ORERES(1,N)*(GI/GS)
      DO 310 M=2,MAXG
  310 REF(N)=REF(N)+(DFLOAT(M*GI)/GS)*ORERES(M,N)
      DO 311 N=1,MAXN
      PROD(1,N)=REF(N)
      DO 311 M=2,MAXG
      IF (ORE(M,N)) 311,311,1
    1 PROD(M,N)=PROD(M-1,N)-(DFLOAT(M*GI)/GS)*ORERES(M,N)
  311 CONTINUE
      DO 312 N=1,MAXN
      DO 312 M=1,MAXG
      R1(M,N)=ORE(M,N)/MAT(N)
  312 R2(M,N)=PROD(M,N)/MAT(N)
      DO 353 N=1,MAXN
      DO 353 M=1,MAXG
      IF (ORE(M,N)) 354,354,355
  354 R3(M,N)=0
      GO TO 353
  355 R3(M,N)=PROD(M,N)/ORE(M,N)
  353 CONTINUE
```

-----------------------COMMENT---------------------------

The annual cut-off grades 'CUTOFF' and production targets 'MIN' 'CON' and 'QREF' are calculated for all plant combinations (I,J,K) rather than just the single trial combination selected in subroutine 'COG1'.

```
      DO 314 I=1,3
      DO 314 J=1,3
      DO 314 K=1,3
```

```
056  314 CALL COGSUB (I,J,K,P)
057        WRITE (6,6)
058      6 FORMAT ('1','DISCOUNTED PROFITS FROM THE PRODUCTION
          1TARGETS OF EACH PLANT COMBINATION')
059        WRITE (6,5) (((PV(II,JJ,KK),II=1,3),JJ=1,3),KK=1,3)
060      5 FORMAT (3F13.1)
```

-----------------------COMMENT---------------------------

The plant combination yielding the greatest present value of the profits that would result from its production targets less its capital cost 'CAP' is chosen to exploit the given deposit between Lines 061 and 070.

```
061        PVMAX=PV(1,1,1)-CAP(1,1,1)
062        DO 162 LL=1,3
063        DO 162 M=1,3
064        DO 162 N=1,3
065        IF (PVMAX-PV(LL,M,N)+CAP(LL,M,N)) 161,162,162
066    161 PVMAX=PV(LL,M,N)-CAP(LL,M,N)
067        I=LL
068        J=M
069        K=N
070    162 CONTINUE
```

-----------------------COMMENT---------------------------

The cut-off grades 'CUTOFF' and production targets 'MIN', 'CON' and 'QREF' are recalculated (Line 071) for the plant combination yielding the maximum present value.

```
071        CALL COGSUB (I,J,K,P)
072        YIELD=REC(K)
073        WRITE (6,7)
074      7 FORMAT ('1','CUT-OFF GRADES & TARGETS FOR THE PLANT
          1combination yielding the greatest excess of present
          2value over capital cost')
075        WRITE (6,8) PV(I,J,K),Q2(J),Q3(J),REC(K)
076      8 FORMAT ('0','PRESENT VALUE=',F13.1,'CONCENTRATOR CA
          1pacity=',f11.1,'refinery capacity=',f9.1,'overall r
          2ecovery efficiency=',f5.2)
077        WRITE (6,9)
078      9 FORMAT ('0',' YR  COG',4X,'MIN',8X,'CON',8X,'REF',
          1'profit')
079        WRITE (6,10) (N,CUTOFF(N),MIN(N),CON(N),QREF(N),
          1p(n),n=1,1)
```

```
080    10 FORMAT (I3,I5,3F10.1,F13.1)
081       SUM=0
082       DO 165 M=1,L
083   165 SUM=SUM+CUTOFF(M)
084       AVEG=SUM/L
085       RETURN
086       DEBUG SUBTRACE,SUBCHK
087       END
```

8. 5 SUBROUTINE COGSUB

8. 5. 1 COMPUTATIONAL SEQUENCE OF COGSUB

LINES 001 - 007

Specification and input statements.

LINES 008 - 029

Computation of the balancing cut-off grades 'GMC', 'GRM' and 'GRC'.

LINES 030 - 234

An implicit loop in which the optimum cut-off grades 'CUTOFF' and production targets 'MIN' 'CON' and 'QREF' are computed. This is a trial and error computation because the present value 'V' is unknown in the economic cut-off grade expressions (LINES 044 - 046). These computations converge on 'V'.

The implicit loop is divided into two parts, Lines 047 - 113 and Lines 014 - 207, in both of which many of the computations are duplicated for two different situations. The first part computes the cut-off grades and targets for annual production coming entirely from the material within a single pit increment 'N' of 'ORERES'. The second part performs the same computations for annual production straddling two pit increments.

LINES 044 - 046

The economic cut-off grades 'GM', 'GC' and 'GR' are computed for the year 'L'.

```
   10 FORMAT (I3,I5,3F10.1,F13.1)
      SUM=0
      DO 165 M=1,L
  165 SUM=SUM+CUTOFF(M)
      AVEG=SUM/L
      RETURN
      DEBUG SUBTRACE,SUBCHK
      END
```

8. 5 SUBROUTINE COGSUB

8. 5. 1 COMPUTATIONAL SEQUENCE OF COGSUB

LINES 001 - 007

Specification and input statements.

LINES 008 - 029

Computation of the balancing cut-off grades 'GMC', 'GRM' and 'GRC'.

LINES 030 - 234

An implicit loop in which the optimum cut-off grades 'CUTOFF' and production targets 'MIN' 'CON' and 'QREF' are computed. This is a trial and error computation because the present value 'V' is unknown in the economic cut-off grade expressions (LINES 044 - 046). These computations converge on 'V'.

The implicit loop is divided into two parts, Lines 047 - 113 and Lines 014 - 207, in both of which many of the computations are duplicated for two different situations. The first part computes the cut-off grades and targets for annual production coming entirely from the material within a single pit increment 'N' of 'ORERES'. The second part performs the same computations for annual production straddling two pit increments.

LINES 044 - 046

The economic cut-off grades 'GM', 'GC' and 'GR' are computed for the year 'L'.

LINES 047 - 077

The optimum cut-off grade 'G' is chosen from the balancing cut-off grades (GMC, GRM, GRC) and the economic cut-off grades (GM, GC, GR) for the year 'L'.

LINES 078 - 111

The plant production targets 'QM', 'QC' and 'QR' are computed for the year 'L'.

LINES 112 - 113

The year 'L' and pit increment 'N' are controlled with these statements by comparing the cumulative quantity of material 'SUMQM' produced from, the current pit increment 'N' to the total material 'MAT' contained in that pit increment.

LINES 114 - 117

The production targets (QM, QC, QR) are adjusted for the first part of production years 'L' that straddle two pit increments 'N'.

LINES 118 - 120

The plant capacities (MINCAP, CONCAP, REFCAP) are scaled down to compute the cut-off grades and production targets for the remaining fractional part of the production year 'L' from the next pit increment 'N'.

LINES 121 - 205

The cut-off grades 'G' and production targets 'QM', 'QC', and 'QR' are calculated for the second part of production years 'L' that straddle two pit increments 'N'. These computations are executed in a similar manner to those between Lines 047 and 111.

LINES 206 - 208

The year 'L' and pit increment 'N' are controlled with these statements.

LINES 209 - 224

The subscript 'N' is deleted from the cut-off grade 'G' and production targets 'QM', 'QC' and 'QR'. These data sets (CUTOFF, MIN, CON, QREF) are supplied to the other subroutines through the COMMON statement.

LINES 225 - 230

The annual profit 'P' and its present value 'SUMPV' are computed.

LINE 231

The trial and error computations for the cut-off grades and production targets are controlled with this statement by testing the convergence of the present value 'SUMPV' in successive cycles. If the computations have not converged, the subroutine returns for another trial; otherwise it exits.

8. 5. 2 A LIST OF COGSUB

```
001       SUBROUTINE COGSUB (I,J,K,P)
002       DOUBLE PRECISION CONCAP(3),REFCAP(3),MINCAP,V(99),
         1SUMQM(20),R1(65,20),R2(65,20),R3(65,20),P(99),
         2QM(99,20),QC(99,20),QR(99,20),F(99),MAT(20),
         3ORE(65,20),PROD(65,20),MIN(99),CON(99),QREF(99),
         4SUMPV(99),PV(3,3,3),S1,S2,S3,U1,U2,U3,OREG,PRODG
002       DOUBLE PRECISION QM2,DABS,DFLOAT,Q1(99,20),
         1Q15(3,3,3)
003       INTEGER G(99,20),ONE/1/,CUTOFF(99),GI
004       INTEGER*2 GMC(20),GRM(20),GRC(20),GM(99),GC(99),
         1GR(99),GMC1(99),GRC1(99),GRM1(99),GMC2(99),
         2GRM2(99),GRC2(99),IFIX,Q33(13500),Q34(13500),
         3Q35(13500),Q37(30),Q38(13500),Q40(13500),Y
005       DIMENSION C(99),S(99),R(99),E(99),REC(3),Q16(2),
         1Q17(2),Q18(2),Q19(2),Q25(2),Q26(99),Q27(99),
         2Q28(99),Q29A(13500)
006       COMMON Q1,CONCAP,REFCAP,MINCAP,F,MAT,ORE,PROD,R1,
         1R2,R3,PV,MIN,CON,QREF,Q15,Q16,Q17,Q18,Q19,S,D,C,R,
         2E,Q25,Q26,Q27,Q28,REC,Q29A,GS,NI,NJ,NK,NBLKS,MAXN,
         3MAXG,CUTOFF,L,Q33,Q34,Q35,Q37,Q38,Q40
-------------------------COMMENT----------------------------
```

'GI' is given by the user and is equal to 'GI' in Line 011 of 'MAIN1'.

```
888 GI=5
    DO 160 L1=1,99
160 V(L1)=0*0
900 S1=CONCAP(I)/MINCAP
    S2=REFCAP(J)/MINCAP
    S3=REFCAP(J)/CONCAP(I)
    DO 6 N=1,MAXN
    SUMQM(N)=0
    GMC(N)=0
    DO 2 M=1,MAXG
    IF (DABS(R1(M,N)-S1)-*02) 1,1,2
  1 GMC(N)=M*GI
  2 CONTINUE
    GRM(N)=0
    DO 4 M=1,MAXG
    IF (DABS(R2(M,N)-S2)-*00010) 3,3,4
  3 GRM(N)=M*GI
  4 CONTINUE
    GRC(N)=0
    DO 6 M=1,MAXG
    IF (DABS(R3(M,N)-S3)-*00015) 5,5,6
  5 GRC(N)=M*GI
  6 CONTINUE
 52 DO 151 L1=1,99
    CUTOFF(L1)=0
    P(L1)=0*0
    DO 151 N=1,20
    QM(L1,N)=0*0
    QC(L1,N)=0*0
    QR(L1,N)=0*0
    G(L1,N)=0
151 CONTINUE
    L=0
    N=0
998 N=N+1
    SUMQM(N)=0
 10 L=L+ONE                     ((S(L)-R(L))*REC(K)))*GS
    GM(L)=(C(L)/((S(L)-R(L))*REC(K)))/CONCAP(I))/((S(L)-
    GC(L)=((C(L)+(F(L)+(D*V(L)))/CONCAP(I))/((S(L)-
   1R(L))*REC(K)))*GS
    GR(L)=(C(L)/(S(L)-R(L)-(F(L)+(D*V(L)))/REFCAP(J))*
   1REC(K))*GS
    IF (GM(L)-GMC(N)) 12,11,11
 11 GMC1(L)=GM(L)
    GO TC 70
```

```
   12 IF (GC(L)-GMC(N)) 13,13,14
   13 GMC1(L)=GC(L)
      GO TO 70
   14 GMC1(L)=GMC(N)
   70 IF (GM(L)-GRM(N)) 16,15,15
   15 GRM1(L)=GM(L)
      GO TO 71
   16 IF (GR(L)-GRM(N)) 17,17,18
   17 GRM1(L)=GR(L)
      GO TO 71
   18 GRM1(L)=GRM(N)
   71 IF (GR(L)-GRC(N)) 20,19,19
   19 GRC1(L)=GR(L)
      GO TO 72
   20 IF (GC(L)-GRC(N)) 21,21,22
   21 GRC1(L)=GC(L)
      GO TO 72
   22 GRC1(L)=GRC(N)
   72 IF (GMC1(L)-GRM1(L)) 102,105,101
  101 IF (GRC1(L)-GMC1(L)) 104,105,105
  102 IF (GRC1(L)-GMC1(L)) 105,105,103
  103 IF (GRM1(L)-GRC1(L)) 107,106,106
  104 IF (GRM1(L)-GRC1(L)) 106,106,107
  105 G(L,N)=GMC1(L)
      GO TO 73
  106 G(L,N)=GRC1(L)
      GO TO 73
  107 G(L,N)=GRM1(L)
   73 T1=MAT(N)/MINCAP
      IF (G(L,N)) 153,154,153
  154 OREG=ORE(1,N)
      PRODG=PROD(1,N)
      GO TO 117
  153 DO 118 M=1,MAXG
      IF (G(L,N)-M*GI) 113,112,111
  111 IF (G(L,N)-MAXG*GI) 118,112,116
  118 CONTINUE
  116 OREG=0
      PRODG=0
      GO TO 117
  112 OREG=ORE(G(L,N)/GI,N)
      PRODG=PROD(G(L,N)/GI,N)
      GO TO 117
  113 IF (G(L,N)-GI) 116,114,115
  114 OREG=ORE(1,N)
      PRODG=PROD(1,N)
```

```
      GO TO 117
  115 OREG=ORE(M,N)+(((DFLOAT(M*GI)-DFLOAT(G(L,N)))/GI)
     1*(ORE(M-1,N)-ORE(M,N)))
      PRODG=PROD(M,N)+(((DFLOAT(M*GI)-DFLOAT(G(L,N)))/GI)
     1*(PROD(M-1,N)-PROD(M,N)))
  117 T2=OREG/CONCAP(I)
      T3=PRODG/REFCAP(J)
      IF (T1-T2) 501,502,502
  501 IF (T2-T3) 506,505,505
  502 IF (T1-T3) 506,504,504
  504 T=T1
      GO TO 74
  505 T=T2
      GO TO 74
  506 T=T3
   74 QM(L,N)=MAT(N)/T
      QC(L,N)=OREG/T
      QR(L,N)=PRODG/T
      SUMQM(N)=SUMQM(N)+QM(L,N)
      IF (MAT(N)-SUMQM(N)) 23,996,10
   23 QM2=QM(L,N)+(MAT(N)-SUMQM(N))
      QC(L,N)=(QM2/QM(L,N))*QC(L,N)
      QR(L,N)=(QM2/QM(L,N))*QR(L,N)
      QM(L,N)=QM2
      E2=MINCAP-QM(L,N)
      C2=CONCAP(I)-QC(L,N)
      P2=REFCAP(J)-QR(L,N)
      U1=C2/E2
      U2=P2/E2
      U3=P2/C2
      N=N+1
      IF (MAXN-N) 43,130,130
  130 GMC2(N)=0
      DO 25 M=1,MAXG
      IF (DABS(R1(M,N)-U1)-.02) 24,24,25
   24 GMC2(N)=M*GI
   25 CONTINUE
      GRM2(N)=0
      DO 27 M=1,MAXG
      IF (DABS(R2(M,N)-U2)-.0001) 26,26,27
   26 GRM2(N)=M*GI
   27 CONTINUE
      GRC2(N)=0
      DO 29 M=1,MAXG
      IF (DABS(R3(M,N)-U3)-.00015) 28,29,29
   28 GRC2(N)=M*GI
```

```
      GO TO 217
  213 IF (G(L,N)-GI) 214,214,215
  214 OREG=ORE(1,N)
      PRODG=PROD(1,N)
      GO TO 217
  215 OREG=ORE(M,N)+(((DFLOAT(M*GI)-DFLOAT(G(L,N)))/GI)
     1*(ORE(M-1,N)-ORE(M,N)))
      PRODG=PROD(M,N)+(((DFLOAT(M*GI)-DFLOAT(G(L,N)))/GI)
     1*(PROD(M-1,N)-PROD(M,N)))
  217 T2=OREG/C2
      T3=PRODG/P2
      IF (T1-T2) 601,602,602
  601 IF (T2-T3) 606,605,605
  602 IF (T1-T3) 606,604,604
  604 T=T1
      GO TO 79
  605 T=T2
      GO TO 79
  606 T=T3
   79 QM(L,N)=MAT(N)/T
      QC(L,N)=OREG/T
      QR(L,N)=PRODG/T
      SUMQM(N)=QM(L,N)
      IF (MAT(N)-SUMQM(N)) 23,996,10
  996 IF (MAXN-N) 43,43,998
   43 DO 45 M=1,L
      MIN(M)=0*0
      CON(M)=0*0
      QREF(M)=0*0
      SUMG=0
      NUM=0
      DO 49 N=1,MAXN
      IF (G(M,N)) 49,49,44
   44 NUM=NUM+ONE
      SUMG=SUMG+G(M,N)
      MIN(M)=MIN(M)+QM(M,N)
      CON(M)=CON(M)+QC(M,N)
      QREF(M)=QREF(M)+QR(M,N)
   49 CONTINUE
      CUTOFF(M)=SUMG/NUM
   45 CONTINUE
      DO 46 M=1,L
   46 P(M)=(S(M)-R(M))*QREF(M)-C(M)*CON(M)-E(M)*MIN(M)-
     1F(M)
      DO 47 M=1,L
      SUMPV(M)=0*
```

```
      DO 47 Y=M,L
   47 SUMPV(M)=SUMPV(M)+P(Y)/((1.+D)**(Y-M+1))
      IF (DABS(SUMPV(1)-V(1))-1000000.0) 53,48,48
   48 DO 51 M=1,L
   51 V(M)=SUMPV(M)
      GO TO 52
   53 PV(I,J,K)=V(1)
      RETURN
      DEBUG SUBTRACE
      END
```

8. 6 SUBROUTINE PD

8. 6. 1 COMPUTATIONAL SEQUENCE OF PD

LINES 001 - 006

Specification and input statements.

LINES 007 - 067

Design of the final pit surface.

LINE 019

The grid-blocks (X,Y,Z) with a positive net cash value 'VAL' are selected, in turn, to form the base of the semi-cone closures of the Lerchs - Grossman algorithm(9).

LINES 020 - 057

The grid-blocks (I,J,K) required to expose the base grid -block (X,Y,Z) are labelled by storing their location in the array 'ICL'. Any grid-blocks (I,J,K) included in the pit 'IP' or a previous test are not included.

LINES 058 - 067

The net cash values 'VAL' of the grid-blocks within the semi-cone closure 'ICL' are totaled. If this total 'SUM' is positive, the semi-cone closure 'ICL' is included in the pit 'IP'; otherwise, it is excluded.

LINES 068 - 086

A topographic map of the final pit surface is printed by these statements.

LINES 087 - 136

An implicit loop which simulates ore production from the pit.

LINES 128 & 132

Subroutine SUBDD is called to simulate the pit's waste production.

LINES 137 - 169

Schedules for the annual revenue, costs, ore production and waste production are computed and printed. Additionally the excavation times for ore 'IOR' and waste 'IWA' are combined into one array 'YR'.

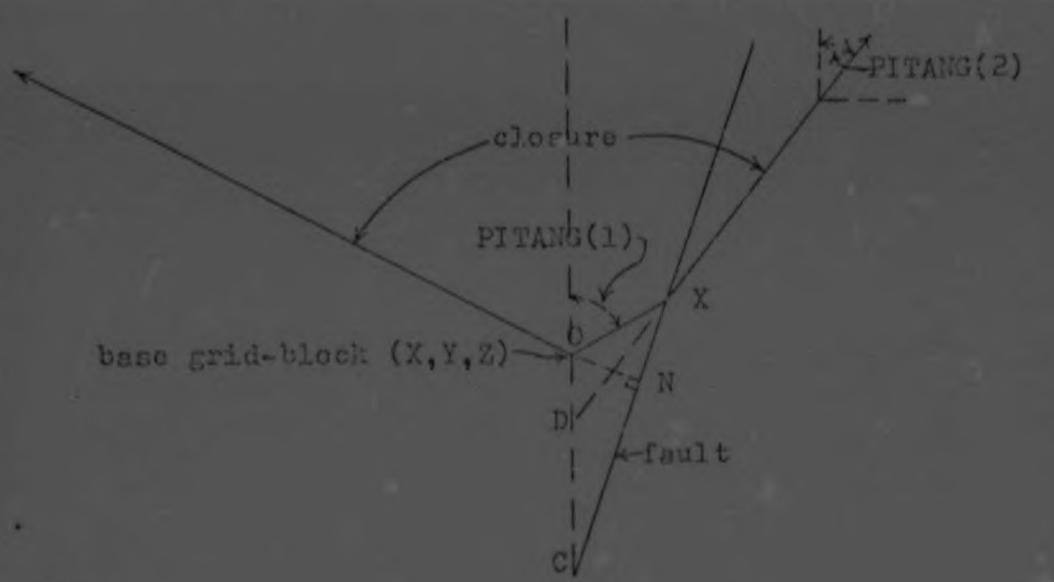
8. 6. 2 A LIST OF PD

```
001        SUBROUTINE PD
002        DOUBLE PRECISION MAT(99),ORE(99),SUM,SORE,SWASTE,
          1DNEW,DOLD,DABS,Q1(99,20),Q2(3),Q3(3),Q4,Q5(99),
          2Q6(20),Q7(65,20),Q8(65,20),Q9(65,20),Q10(65,20),
          3Q11(65,20),Q12(3,3,3),Q15(3,3,3),Q14A(99)
003        INTEGER Q31(99),Q30,ONE/1/,TWO/2/
004        INTEGER*2 IP(13500),IWA(13500),ICL(13500),
          1IOR(13500),TOPO(13500),YR(13500),SURFC(30),X,Y,Z,
          2A,B
005        DIMENSION VAL(13500),PITANG(2),SLOPE(2),TONF(2),
          1WSLOPE(2),PROFIT(99),CAPOB(99),WASTE(99),Q17(2),
          2Q20(99),Q22(99),Q23(99),Q24(99),Q29(3)
006        COMMON Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10,Q11,Q12,MAT,
          1ORE,Q14A,Q15,PITANG,Q17,SLOPE,WSLOPE,Q20,Q21,Q22,
          2Q23,Q24,TONF,PROFIT,CAPOB,WASTE,Q29,VAL,GS,NI,NJ,
          3NK,NBKLS,Q30,MAXG,Q31,L,IWA,IP,IOR,SURFC,TOPO,YR
007        DO 4 N=1,NBLKS
008        YR(N)=0
009        IP(N)=0
010        IWA(N)=0
011      4 IOR(N)=0
012        DO 200 N=1,NBLKS
013    200 ICL(N)=0
014        IC=0
```

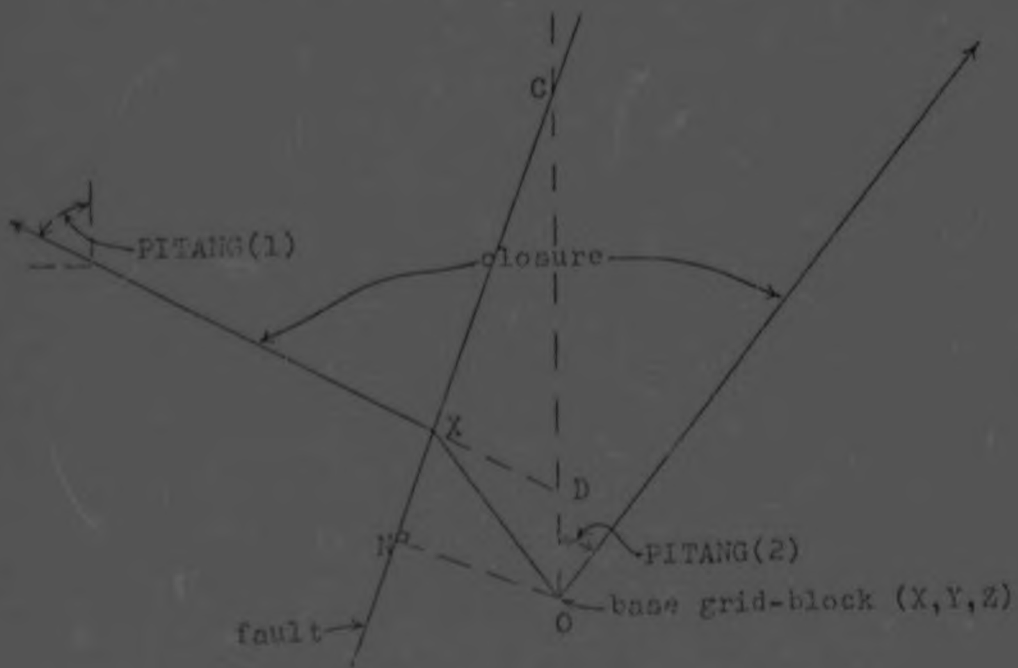
```
015       DO 20 Z=1,NK
016       DO 20 Y=1,NJ
017       DO 20 X=1,NI
018       LOC=NJ*NI*(Z-ONE)+NI*(Y-ONE)+X
019       IF (VAL(LOC)) 20,20,2
-------------------------COMMENT--------------------------
```

The constants (X,Y,D) of the cone expression in Line 51 are given by the grid co-ordinates of the base grid-block (X,Y,Z)• However, the constant 'D' must respond to variable safe wall-angles• For example, the given deposit (See Section 7•1) is divided into two zones by a fault (Line 020) either side of which has a different safe wall-angle 'PITANG'• The constant 'D' is adjusted to construct the overlapping cones required for the closures• The following statements (Lines 020 - 026 and 032 - 050), along with Fig• 8•4, demonstrate how this is accomplished for the example deposit• These statements must be tailored to the user's requirements•

```
----------------------------------------------------------
020     2 FAULT=(66•3*X)-(277•5*Y)-(37•625*Z)+3274•075
021       IB=0
022       OC=ABS(Z-(((66•3*X)-(277•5*Y)+3274•075)/37•625))
023       IF (OC) 210,210,211
024   211 ON=ABS(FAULT/288)
025       C=(ON/OC)
026       NOC=ATAN(SQRT(1•-(C*C))/C)
027   210 DO 240 K=1,NK
028       IF (K-Z) 8,8,288
029     8 DO 14 J=1,NJ
030       DO 14 I=1,NI
031      M=NJ*NI*(K-ONE)+NI*(J-ONE)+I
032       IF ((66•3*I)-(277•5*J)-(37•625*K)
         1+3274•075) 101,101,102
033   101 IS=TWO
034       IF (FAULT) 103,103,104
035   103 D=Z
036       GO TO 108
037   104 XOC=3•14159-PITANG(1)
038       OX=ON/COS(XOC-NOC)
039       OD=(OX*SIN(PITANG(1)-PITANG(2)))/SIN(PITANG(2))
040       D=Z+OD
041       GO TO 108
042   102 IS=ONE
043       IF (FAULT) 106,105,105
```



A. A BASE GRID-BLOCK ABOVE THE FAULT



B. A BASE GRID-BLOCK BELOW THE FAULT

FIG. 8.4 CROSS-SECTIONS OF OVERLAPPING CONES USED AS CLOSURES

```
  105 D=Z
      GO TO 108
  106 XOC=PITANG(2)
    1 OX=ON/COS(ABS(NOC-XOC))
    5 OD=(OX*SIN(PITANG(1)-PITANG(2)))/SIN(3•14159-
     1PITANG(1))
      D=Z-OD
  107 IF (D) 14,14,108
  108 CONE=SLOPE(IS)*(K-D)*(K-D)-((2*J-2*Y)**2)-((I-X)
     1**2)
      IF (CONE) 14,12,12
   12 IF (IP(M)) 13,13,14
   13 IB=IB+ONE
      ICL(IB)=M
   14 CONTINUE
  240 CONTINUE
  283 IF (IB) 20,20,174
  174 SUM=0
      DO 15 M=1,IB
   15 SUM=SUM+VAL(ICL(M))
      IF (SUM) 18,18,16
   16 DO 17 M=1,IB
   17 IP(ICL(M))=ICL(M)
   18 DO 19 M=1,IB
   19 ICL(M)=0
   20 CONTINUE
      WRITE (6,99)
   99 FORMAT ('1',' OPTIMUM PIT SURFACE')
      DO 220 N=1,NJ
  220 SURFC(N)=0
      DO 97 X=1,NI
      DO 96 Y=1,NJ
      M=0
      Z=ONE
   91 IF (Z-NK) 87,87,92
   87 LOC=NJ*NI*(Z-ONE)+NI*(Y-ONE)+X
      IF (TOPO(LOC)) 88,88,89
   89 IF (IP(LOC)) 92,92,88
   88 M=Z
      Z=Z+ONE
      GO TO 91
   92 SURFC(Y)=M
   96 CONTINUE
   97 WRITE (6,98) (SURFC(N),N=1,NJ)
   98 FORMAT ('0',30I3)
------------------------COMMENT--------------------------------
```

The following ore excavation sequence (Lines 088 - 114) illustrates a simulation for one working face that advances in opposite directions on alternate benches parallel to the I co-ordinate axes. This simulation must be tailored to the user's requirements, as described in Subsection 6.7.1.

```
-------------------------------------------------------------
087    26 L=ONE
088       J=0
089       I=0
090       K=0
091       SORE=0
092       SWASTE=0
093    31 ISIGN=ONE
094       GO TO 33
095    32 ISIGN=-ONE
096    33 K=K+ONE
097       IF (K-NK) 34,34,160
098    34 N=K-((K/2)*2)+ONE
099       GO TO (35,36),N
100    35 B=-ONE
101       GO TO 37
102    36 B=ONE
103    37 J=J+B
104       IF (J-NJ) 38,39,32
105    38 IF (J-ONE) 31,39,39
106    39 N=J-((J/2)*2)+ONE
107       GO TO (40,41),N
108    40 A=(-ONE)*ISIGN
109       GO TO 42
110    41 A=ISIGN
111    42 I=I+A
112       IF (I-NI) 43,43,37
113    43 IF (I-ONE) 37,44,44
114    44 MC=750*(K-ONE)+30*(J-ONE)+I
115       IF (IOR(MC)) 130,130,42
116   130 IF (IP(MC)) 42,42,110
117   110 IF (VAL(MC)) 42,42,45
118    45 IF (K-10) 46,46,47
119    46 M=ONE
120       GO TO 48
121    47 M=2
122    48 SORE=SORE+TONF(M)
123       IF (ORE(L)-SORE) 50,50,49
124    49 IOR(MC)=L
125       GO TO 42
```

```
   50 IF (SORE-ORE(L)-(TONF(M)/2.)) 51,51,60
   51 IOR(MC)=L
      CALL SUBPD (SORE,M,K)
      SORE=0
      L=L+ONE
      GO TO 42
   60 CALL SUBPD (SORE,M,K)
      L=L+ONE
      SORE=TONF(M)
      IOR(MC)=L
      GO TO 42
  160 DO 69 N=1,99
      PROFIT(N)=0.0
      CAPOB(N)=0.0
      ORE(N)=0.0
   69 WASTE(N)=0.0
      DO 253 Z=1,NK
      IF (Z-10) 71,71,72
   71 II=ONE
      GO TO 73
   72 II=TWO
   73 DO 86 Y=1,NJ
      DO 86 X=1,NI
      M=NJ*NI*(Z-ONE)+NI*(Y-ONE)+X
      IF (TOPO(M)) 86,86,260
  260 IF (IP(M)) 86,86,180
  180 IF (IOR(M)) 181,181,83
  181 IF (IWA(M)) 182,182,84
  182 IWA(M)=L
   84 YR(M)=IWA(M)
      CAPOB(IWA(M))=CAPOB(IWA(M))+VAL(M)
      WASTE(IWA(M))=WASTE(IWA(M))+TONF(II)
      GO TO 86
   83 YR(M)=IOR(M)
      PROFIT(IOR(M))=PROFIT(IOR(M))+VAL(M)
      ORE(IOR(M))=ORE(IOR(M))+TONF(II)
   86 CONTINUE
  253 CONTINUE
      WRITE (6,250)
  250 FORMAT ('1',' SIMULATED PIT PRODUCTION SCHEDULE')
      WRITE (6,251)
  251 FORMAT ('0',' YR OVERBURDEN STRIPPING COSTS ORE
     1 REVENUE')
      WRITE (6,252) (N,WASTE(N),CAPOB(N),ORE(N),
     1PROFIT(N),N=1,L)
  252 FORMAT (I3,4F13.1)
```

```
170       RETURN
171       END
```

8. 7 SUBROUTINE SUBPD

8. 7. 1 COMPUTATIONAL SEQUENCE OF SUBPD

LINES 001 - 006

Specification and input statements.

LINES 007 - 066

The grid-blocks required to expose the ore production of year 'L' are identified with the semi-cone set (Lines 024 - 061) and labelled by storing their location in the array 'IKA'.

LINE 008

The appropriate minimum working wall-angle 'WSLOPE' is selected.

LINES 011 - 066

DO loop 58 increases the working wall-angle 'WORKSL' in
increments 'STEP' between its minimum 'WSLOPE' (Line 14) and
its maximum '35.0' (Line 15) until the overburden 'SWASTE'
within the waste closure approximates the waste production
target 'MAT - ORE'. Then, the accuracy of the working
wall-angle 'WORKSL' is increased by splitting the increment
'STEP', changing its sign and repeating the computations
within the smaller tolerance. The computations are termi-
nated when the overburden within the waste closure equals
the waste production target. The termination can also occur,
if the working wall-angle 'WORKSL' reaches the maximum or
minimum limits without satisfying the waste production
target. The maximum woring wall-angle 'WORKSL=35' in Line 15
is a practical upper limit imposed to prevent the computa-
tions from going to infinity.

LINES 024 - 061

DO loop 56 identifies the ore grid-blocks 'IOE' that form

```
   29 CONTINUE
      IF (GM(L)-GMC2(N)) 31,30,30
   30 GMC1(L)=GM(L)
      GO TO 75
   31 IF (GC(L)-GMC2(N)) 32,32,33
   32 GMC1(L)=GC(L)
      GO TO 75
   33 GMC1(L)=GMC2(N)
   75 IF (GM(L)-GRM2(N)) 35,34,34
   34 GRM1(L)=GM(L)
      GO TO 76
   35 IF (GR(L)-GRM2(N)) 36,36,37
   36 GRM1(L)=GR(L)
      GO TO 76
   37 GRM1(L)=GRM2(N)
   76 IF (GR(L)-GRC2(N)) 39,38,38
   38 GRC1(L)=GR(L)
      GO TO 77
   39 IF (GC(L)-GRC2(N)) 40,40,41
   40 GRC1(L)=GC(L)
      GO TO 77
   41 GRC1(L)=GRC2(N)
   77 IF (GMC1(L)-GRM1(L)) 202,205,201
  201 IF (GRC1(L)-GMC1(L)) 204,205,205
  202 IF (GRC1(L)-GMC1(L)) 205,205,203
  203 IF (GRM1(L)-GRC1(L)) 207,206,206
  204 IF (GRM1(L)-GRC1(L)) 206,206,207
  205 G(L,N)=GMC1(L)
      GO TO 78
  206 G(L,N)=GRC1(L)
      GO TO 78
  207 G(L,N)=GRM1(L)
   78 T1=MAT(N)/E2
      IF (G(L,N)) 155,152,155
  152 OREG=ORE(1,N)
      PRODG=PROD(1,N)
      GO TO 217
  155 DO 218 K=1,MAXG
      IF (G(L,N)-K*GI) 216,212,211
  211 IF (G(L,N)-MAXG*GI) 218,212,216
  218 CONTINUE
  216 OREG=0
      PRODG=0
      GO TO 217
  212 OREG=ORE(G(L,N)/GI,N)
      PRODG=PROD(G(L,N)/GI,N)
```

the base of the semi-cone set. DO loops 19, 22 and 9 identify the grid-blocks that satisfy the semi-cone closure.

LINE 052

Note that any ore grid-blocks are excavated as well, if they satisfy the semi-cone set.

8. 7. 2 A LIST OF SUBPD

```
001        SUBROUTINE SUBPD (SORE,M,K)
002        DOUBLE PRECISION SORE,SWASTE,Q1(99,20),Q2(3),Q3(3),
          1Q4,Q5(99),Q6(20),Q7(65,20),Q8(65,20),Q9(65,20),
          2Q10(65,20),Q11(65,20),Q12(3,3,3),MAT(99),ORE(99),
          3Q15(3,3,3),Q14A(99),DNEW,DOLD,DABS
003        INTEGER Q31(99),ONE/1/,TWO/2/
004        INTEGER*2 IOR(13500),IP(13500),IWA(13500),
          1TOPO(13500),X,Y,Z,Q37(30),Q40(13500)
005        DIMENSION WRKANG(2),VAL(13500),TONF(2),Q16(2),
          1Q18(2),WSLOPE(2),Q20(99),Q22(99),Q23(99),Q24(99),
          2Q26(99),Q27(99),Q28(99),Q29(3)
006        COMMON Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10,Q11,Q12,MAT,
          1ORE,Q14A,Q15,Q16,WRKANG,Q18,WSLOPE,Q20,Q21,Q22,
          2Q23,Q24,TONF,Q26,Q27.Q28,Q29,VAL,GS,NI,NJ,NK,
          3NBLKS,Q30,MAXG,Q31,L,IWA,IP,IOR,Q37,TOPO,Q40
077        STEP=5.0
008        WORKSL=WSLOPE(M)-STEP
009        IF (MAT(L)-ORE(L)) 121,59,121
010    121 DNEW=SORE-MAT(L)
011        DO 56 II=1,3
012     52 DOLD=DNEW
013        WORKSL=WORKSL+STEP
014        IF (WORKSL-WSLOPE(M)) 59,140,140
015    140 IF (WORKSL-35.0) 53,53,59
016     53 SWASTE=0
017        DO 171 Z=1,NK
018        DO 171 Y=1,NJ
019        DO 171 X=1,NI
020        N=NJ*NI*(Z-ONE)+NI*(Y-ONE)+X
021        IF (IWA(N)-L) 171,173,171
022    173 IWA(N)=0
023    171 CONTINUE
024        DO 56 Z=1,NK
025        IF (K-Z) 232,54,54
026     54 DO 56 Y=1,NJ
027        DO 56 X=1,NI
```

```
028       N=NJ*NI*(Z-ONE)+NI*(Y-ONE)+X
029       IF (IOR(N)-L) 56,55,56
030    55 DO 19 KK=1,NK
031       IF (KK-Z) 2,2,56
032     2 DO 22 J=1,NJ
033       DO 9 I=1,NI
034       N=NJ*NI*(KK-ONE)+NI*(J-ONE)+I
035       IF (TOPO(N)) 9,9,10
036    10 IF (IOR(N)) 1,1,9
037     1 IF (IP(N)) 9,9,3
038     3 IF (IWA(N)) 4,4,9
------------------------COMMENT----------------------------
```

The constants (X,Y,D) of the cone expression in Line 47 are given by the grid co-ordinates of the base grid-blocks (X,Y,Z). However, the constant 'D' must respond to variable working wall-angles. For example, the given deposit (See Section 7.1) is divided into two zones by the tenth grid-level (Line 039) either side of which has a different minimum working wall-angle 'WRKANG'. The constant 'D' is adjusted to construct the overlapping cones required for the closure. The following statements (Lines 039 - 046), along with Fig. 8.5, demonstrate how this is accomplished for the example deposit. These statements must be tailored to the user's requirements.

```
-----------------------------------------------------------
039     4 IF (Z-10) 14,14,15
040    14 D=Z
041       GO TO 16
042    15 IF (KK-10) 17,14,14
043    17 CO=Z-10.
044       CX=SQRT(WORKSL)*CO
045       CD=CO-CX*(COS(WRKANG(1))/SIN(WRKANG(1)))
046       D=Z-CD
047    16 IF (WORKSL*(KK-D)*(KK-D)-((2*J-2*Y)**2)-((I-X)
         1**2)) 9,5,5
048     5 IF (KK-10) 6,6,7
049     6 MM=ONE
050       GO TO 8
051     7 MM=TWO
052     8 IF (VAL(N)) 11,11,12
053    11 IWA(N)=L
054       SWASTE=SWASTE+TONF(MM)
055       GO TO 9
056    12 IOR(N)=L
```

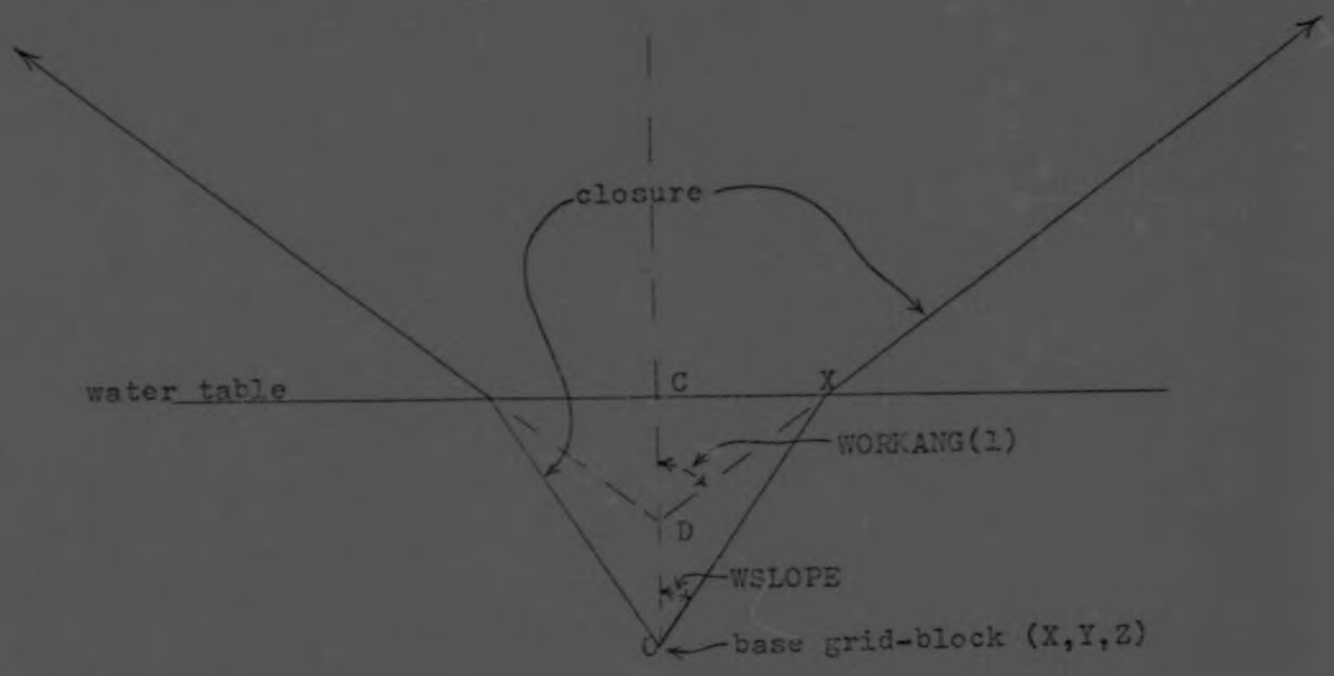


FIG. 8.5 A CROSS-SECTION OF OVERLAPPING CONES USED AS A CLOSURE

```
      SORE=SORE+TONF(MM)
    9 CONTINUE
   22 CONTINUE
   19 CONTINUE
   56 CONTINUE
  232 DNEW=SWASTE-MAT(L)+SORE
      IF (DABS(DNEW)-TONF(M)) 59,57,57
   57 IF (DOLD*DNEW) 58,52,52
   58 STEP=-0.5*STEP
   59 SWASTE=0
   23 RETURN
      END
```

8. 8 GLOSSARY

The format of this glossary follows the same pattern as those of Chapters 4 and 5. Wherever a variable name appears twice in the glossary, it is the result of using the same name for two different applications in the MP Programme. The brackets which follow their definitions list the subroutines in which the given definition is applicable. Note also that any variables appearing in the specification statements of the form 'Qnn', where 'nn' is an identifying number, are only necessary to match the 'COMMON' statements. For this reason, they do not appear in the glossary. The glossary is not complete; it does not contain the variables used to facilitate programming.

AVEG - (I*2) the average cut-off grade over the pit's life span.

C(i) - (R) the annual concentration costs per input ton. See Subsection 6. 1. 2 for a rigorous definition;

i - year.

CAP(i,j,k) - (D) the total capital cost of each possible plant combination discounted to the first year at the opportunity cost of investment capital 'D';

i - concentrator identification number
j - refinery identification number
k - overall recovery efficiency identification number.

CAPOB(i) - (R) the annual cost of stripping overburden;

i - year.

CON(i) - (D) the annual production target for the concentrator in input tons;

i - year.

CONCAP(i) - (D) the plant capacity of all possible concentrators in input tons;

i - concentrator identification number.

CUTOFF(i) - (I) the annual cut-off grades scaled up by the grade scale factor 'GS' to integer value;

i - year.

D - (R) the opportunity cost of investment capital (MAIN1-3, COG1, 2 and COGSUB).

D - (R) a constant used to define the semi-cone closures (PD & SUBPD).

E(i) - (R) the annual excavation costs per ton of pit output. See Subsection 6.1.2 for a rigorous definition;

i - year.

EQGRAD(i,j,k) - (I*2) the total equivalent mineral content at each grid-intersection;

i,j,k - I, J and K grid co-ordinates, respectively.

F(i) - (D) the fixed plus administrative costs per year;

i - year.

FIXC - (D) a variable used to transfer the fixed costs 'F' from the card reader to internal storage.

G(i,j) - (I) the annual cut-off grades in each pit increment. They are scaled up to integer values with the grade scale factor 'GS';

i - year
j - pit increment.

GM(i), GC(i), GR(i) - (I*2) the annual economic cut-off grades for the pit, concentrator and refinery, respectively. They are scaled up to integer values with the grade scale factor 'GS';

i - year.

GMC(i), GRM(i), GRC(i) - (I*2) the balancing cut-off grades for each pit increment between mine and concentrator, refinery and mine, and refinery and concentrator, respectively. They are scaled up to integer values with the grade scale factor 'GS';

i - pit increment.

GI - (I) the class interval for the increments in the T-S mineral distribution 'ORERES'.

GRAD1, GRAD2 . . . GRADn - (R) variables used to transfer the proportional mineral grades of the 'n' minerals reported in the user's deposit from external to internal storage.

GS - (R) a scale factor used for converting proportional mineral grades to integers so that they may be used as subscripts in arrays.

ICL(i) - (I*2) a pointer used to indicate the grid-blocks in a test closure of the Lerchs-Grossman graph algorithm;

i - grid-block identification number.

IGRAD1(i,j,k), IGRAD2(i,j,k) . . . IGRADn(i,j,k) - (I * 2) the mineral grades of the 'n' minerals reported in the user's deposit at each grid-intersection. They are scaled up to integer values with the grade scale factor 'GS';

i,j,k - I,J and K grid co-ordinates, respectively.

INFRC, INFRP - (R) the interest rates for the time inflation of costs and selling prices, respectively.

IOR(i) - (I*2) the excavation year of the ore grid-blocks;

i - grid-block identification number.

IP(I) - (I*2) a pointer for the grid-blocks within the final pit surface;

i - grid-block identification number.

IWA(i) - (I*2) the excavation year of the overburden grid-blocks;

i - grid-block identification number.

L - (I) the mine's life span.

LOC - (I) the subscript for certain indicator arrays. It is computed to locate specific members of uni-dimensional arrays used to store three-dimensional data sets.

MAT(i) - (D) the total material in each pit increment measured in tons (COG1 - 2 and COGSUB);

i - pit increment.

MAT(i) - (D) the annual pit production target, ore plus overburden, in tons (PD and SUBPD);

i - year.

MAXG - (I) the maximum equivalent mineral grade 'EQGRAD' reported in the user's deposit.

MAXN - (I) the total number of pit increments.

MILC(i) - (R) the milling cost per input ton for each recoverable mineral of the example deposit. See Section 7.1.

i - mineral identification number.

MIN(i) - (D) the annual pit production target, ore plus overburden, in tons;

i - year.

MINC - (R) a variable used to transfer the initial assumption of the excavation cost per ton 'E' from the card reader to internal storage.

MINCAP - (D) the pit capacity, ore plus overburden, per year measured in tons.

NBLKS - (I) the total number of grid-intersections or grid-blocks.

NI, NJ, NK - (I) the maximum I,J and K grid co-ordinates, respectively.

OB(i) - (R) the overburden stripping cost per ton on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

OBCI(i) - (R) the increased cost of overburden stripping per grid-level per ton on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

OR(i) - (R) the ore excavation cost per ton on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

ORCI(i) - (R) the increased cost of ore excavation per grid-level per ton on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

ORE(i,j) - (D) the available ore tonnage, in pit increments, for the range of cut-off grades from zero to the maximum reported mineral grade 'MAXG' (COG1 - 2 and COGSUB);

i - integer cut-off grade increment
j - pit increment.

ORE(i) - (D) this variable has two different definitions in the PD subroutine. Firstly, it is used as the production target for the concentrator. Then, it becomes the total simulated ore production in each year. Both data sets are measured in tons of concentrator input(PD);

i - year.

ORERES(i, j) the data set for the T-S mineral distribution;

i - integer mineral grade increment
j - pit increment.

P(i) - (D) the annual profits estimated from the production targets 'MIN', 'CON' and 'QREF';

i - year.

PITANG(i) - (D) the safe pit wall-angles on each side of the fault given for the example deposit. See Section 7.1. The angles are measured in radians from vertical.

i - pit zone identification number.

PITINC - (I*2) the pit increment.

PNEW - (D) the total revenue over the mine's life span.

PROD(i, j) - (D) the tonnage, in each pit increment, of refined product available at any cut-off grade;

i - integer cut-off grade increment
j - pit increment.

PROFIT(i) - (D) the annual revenue from the simulated pit production;

i - year.

PV(i, j, k) - the total present value of the annual profits 'P' estimated from the production targets 'MIN', 'CON' and 'QREF' for each combination of the given plant capacities;

i - concentrator identification number
j - refinery identification number
k - overall recovery efficiency identification number.

PVMAX - (D) the present value of the combination of plant capacities yielding the maximum present value.

QC(i, j), QM(i, j), QR(i, j) - (D) the annual plant production targets for each pit increment in tons for the concentrator pit and refinery, respectively;

i - year
j - pit increment.

QREF(i) - (D) the annual production target for the refinery;

i - year.

R(i) - (R) the annual cost of refining per ton of product;

i - year.

R1(i,j), R2(i,j), R3(i,j) - (D) the ratios, in each pit increment, of ore 'ORE' to pit material 'MAT', refined product 'PROD' to pit material and refined product to ore, respectively, for the range of cut-off grades from zero to the maximum reported mineral grade 'MAXG';

i - integer cut-off grade increment
j - pit increment.

REC(i) - (R) the proportional overall recovery efficiency for each combination of plant capacities;

i - overall recovery efficiency identification number.

REFC(i) - (R) the refining cost per ton of product for the concentrates originating from either side of a zone surrounding the fault given for the example deposit. See Section 7.1.

i - pit zone identification number.

REFCAP(i) - (D) the plant capacity of the refinery in output tons per year;

i - refinery identification number.

S(i) - (R) the annual selling price per product ton of the primary material;

i - year.

S1(i), S2(i), . . . Sn(i) - (R) the annual selling price per product ton of the 'n' minerals reported in the user's deposit (MAIN1 - 3, PD, SUBPD):

i - year.

S1, S2, S3 - (D) the ratio of concentrator capacity 'CONCAP' to the pit capacity 'MINCAP', refinery capacity 'REFCAP' to pit capacity and refinery capacity to concentrator capacity, respectively, (COGSUB).

SLOPE(i) - (T) this variable is used to define the semi-cone closures of the final pit surface design routine. It is equal to the tangent squared of 'PITANG'.

i - pit zone identification number.

SORE - (D) cumulative total of the simulated ore production in any given year and measured in tons.

SUMPV(i) - (D) the present value of the future profits 'P' in each year;

i - year.

SUMQM(i) - (D) the cumulative total of the annual pit production targets 'QM' in each pit increment;

i - pit increment.

SWASTE - (D) the cumulative total of the simulated overburden production in any given year.

T1, T2, T3, T - (R) the time periods required to process a given amount of pit material at the optimum cut-off grade 'G' for the pit, concentrator and refinery, and the maximum of the three, respectively.

TONF(i) - (R) the total weight of the grid-blocks on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

TOPO(i) - (I*2) an indicator array for the given deposit's surface topography:

i - grid-intersection identification number.

V(i) - (D) the present value of the future profits 'P' in each year;

i - year.

VAL(i) - (R) the T-S net cash value distribution;

i - grid-block identification number.

WASTE(i,j) - (D) the tonnages of overburden in each pit increment for the range of cut-off grades from zero to the maximum reported mineral grade 'MAXG' (COG1 - 2);

i - integer cut-off grade increment
j - pit increment.

WASTE(i) - (R) the total simulated overburden production in tons for each year (MAIN1 - 3, PD, SUBPD);

i - year.

WORKSL - (R) this variable is used to define the semi-cone sets of the overburden production simulation. It is the current value of the working wall-angle.

WORKANG(i) - (R) the minimum pit wall-angle at which the excavation equipment can work on each side of the tenth grid-level of the example deposit. See Section 7.1.

i - pit zone identification number.

WSLOPE(i) - (R) this variable is equal to the tangent squared of 'WRKANG';

i - pit zone identification number.

YR(i) - (I*2) the excavation year of each mined grid-block.

i - grid-block identification number.

YIELD - (R) the overall recovery efficiency of the combination of plant capacities yielding the maximum present value.

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

The economic Model of an open pit mine described in this thesis can be summarily illustrated with the following diagram:

```
     MINE PLANNING--
                   |
                   |- +TIME FACTOR=OPEN PIT PLANNING SYSTEM
                   |
FINANCIAL PLANNING--
```

The Model can, in fact, be considered as a "total systems"
planning tool for the evaluation of open pit mining ventu-
res. It can be adapted to the study of any proposal and any
deposit by tailoring its computer programmes. These computer
programmes then simulate:

1) the physical and geologic conditions of the user's deposit,

2) the particular pit production method, and

3) the venture's cost structure.

Previous contributions to the field employed in this Model are:

1) the estimation of mineral grades by Weaver (11),

2) the design of an optimum pit surface by Lerchs and Grossman (5), and

3) the economic planning decisions derived by Lane (4).

This thesis introduces simulation techniques for pit produc-
tion, physical features and costing. Most importantly, it
also introduces the time factor into planning and evalua-
tion. The incorporation and synthesis of these innovations,
as well as the preceding contributions make this Model an

improvement over previous open pit planning systems. It does, in fact, represent a significant development in the field.

This development assures that there is no loss of accuracy as a result of the Model being a general planning tool. This is because its computer programmes are tailored to simulate the physio-economic differences between deposits. Additionally, equivalent cut-off grades are compared with the total mineral content of all recoverable minerals at each point in the deposit instead of comparing the traditional predetermined cut-off grades with the primary mineral only. The interpolation method used in the Model to estimate mineral grades is more adaptable than the other methods used for massive deposits. This is due to the search parameters which are redefined for each deposit.

In conclusion, certain recommendations for the further development and understanding of the Model can be made. These would be:

A) An anlysis of the Model to measure the sensitivity of its variables. A sensitivity analysis also would reveal any pathological situations not encountered in the testing of the computer programmes.

B) A study of the Model to establish whether its lengthy execution time can be cut down. For example, the Grade Prediction Programme could be made more efficient by eliminating some of the repetitious computations. The computations for the T-S net cash value distribution can be improved by eliminating its outermost DO loop which cycles with time. The time factor could be obtained solely from the indicator array 'YR' instead of from both the array and the DO loop parameter. This would eliminate the need to search through all grid -blocks for each particular year.

C) Finally, the Model could be further developed to include all costing situations. Then, rather than tailoring the programmes, the user would merely select those situations peculiar to his needs.

CHAPTER 10 REFERENCES

1) Hartman, R.J., Varma, C.G., A Three Dimensional Optimum Pit Program and a Basis for a Mining Engineering System, Proc. Symposium and Short Course on Computers and Operations Research in Mineral Industries, The Pennsylvania State University, University Park, Pa., V.3, April 1966.

2) International Business Machine Corp., IBM System/360 Operating System FORTRAN Language, IBM Corp., Poughkee-psie, N.Y., 1967.

3) International Business Machine Corp., IBM System/360 Operating System Job Control Language, IBM Corp., Poughkeepsie, N.Y., 1967.

4) Lane, K.F., Choosing the Optimum Cut-Off Grade, Quar-terly of the Colorado School of Mines, Golden, Colo., V.59, no.4, p.811, Oct. 1964.

5) Lerchs, H., Grossman, I.F., Optimum Design of Open Pit Mines, Transactions of the Canadian Institute of Mi-ning, V.118, p.17, 1965.

6) Ore, O., Graphs and their Uses, Random House, New York, N.Y., 1963.

7) Pana, M.T., ET AL, a Description of Computer Techniques Used in Mine Planning at the Utah Mine of Kennecott Copper Corporation, Proc. Symposium and Short Course on Computers and Operations Research in Mineral Indust-ries, The Pennsylvania State University, University Park, Pa., V.2, April 1966.

8) Pana, M.T., The Simulation Approach to Open Pit Design, Transactions of the Short Course and Symposium on Computers and Computer Applications in Mining and Exploration, University of Arizona, Tuscon, Ariz., March 1965.

9) Pfleider, E.P. (editor), Surface Mining, Seely W. Mudd Series of The American Institute of Mining, Metallurgical and Petroleum Engineers, New York, N.Y., 1968.

10) Spiegel, M.R., Theory and Problems of Statistics, Schaum Publishing Co., New York, N.Y., 1961.

11) Weaver, R.C., Relative Merits of Interpolation and Approximating Functions in the Grade Prediction Problem, Stanford University Publications in the Geological Sciences, Stanford, Calif., V.9, no.1, 1964.