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GEOLOGICAL SURVEY

International Geological Correlation Program

PROJECT 98 - COGEODATA WORKSHOP ON COMPUTER APPLICATIONS IN MINERAL RESOURCE PROBLEMS

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Table of Contents

List of figures

List of figures (continued)

Preface

The purpose of the workshop is to provide an overview of the methodology for creating geologic data bases and the subsequent utilization of the data via interactive computation and computer graphics for resolving specific resource problems. To meet this overall objective, the workshop has been organized to follow from the creation of a mineral resource inventory file through specific resource applications. The workshop is made up of examples which illustrate the nature of this activity. The examples are:

I. Data-Base-Construction. - A step-by-step explanation of the development of a computer-based mineral deposit inventory beginning with the conversion of a "needle-sort" card file to GRASP using CONVERT. Emphasis is placed on the principles of data base construction and the general applicability of interactive files.

II. Utilization of a Mineral Deposit Data Base. - Demonstration of interactive data retrievals using GRASP. The example illustrates the relationships between the data retrieved, its use, and subsequent display. An application of computer graphics is included.

III. Decision Modeling. - Demonstration of decision modeling applied to mineral deposits in Central Norway. Included are syntheses of remote sensing, geologic, structural and geophysical data for the purpose of identifying favorable areas of search for future exploration.

IV. Toromocho Porphyry Copper Model. - A detailed analysis of the application of computer graphics to a geologic data base for the Toromocho porphyry copper deposit in Peru. Primary emphasis is placed on the use of computer graphics in resolving specific economic, policy and engineering problems.

V. Computer Applications Software for the National Coal Resources Data System. - An example of a large "custom-tailored" data retrieval system and the subsequent treatment processes presently used for the coal resources program of the United States Geological Survey. In this system, the data attributes and the user community are prime considerations. Computer graphics are utilized to meet specific requirements in coal resource estimates.

EXAMPLE I

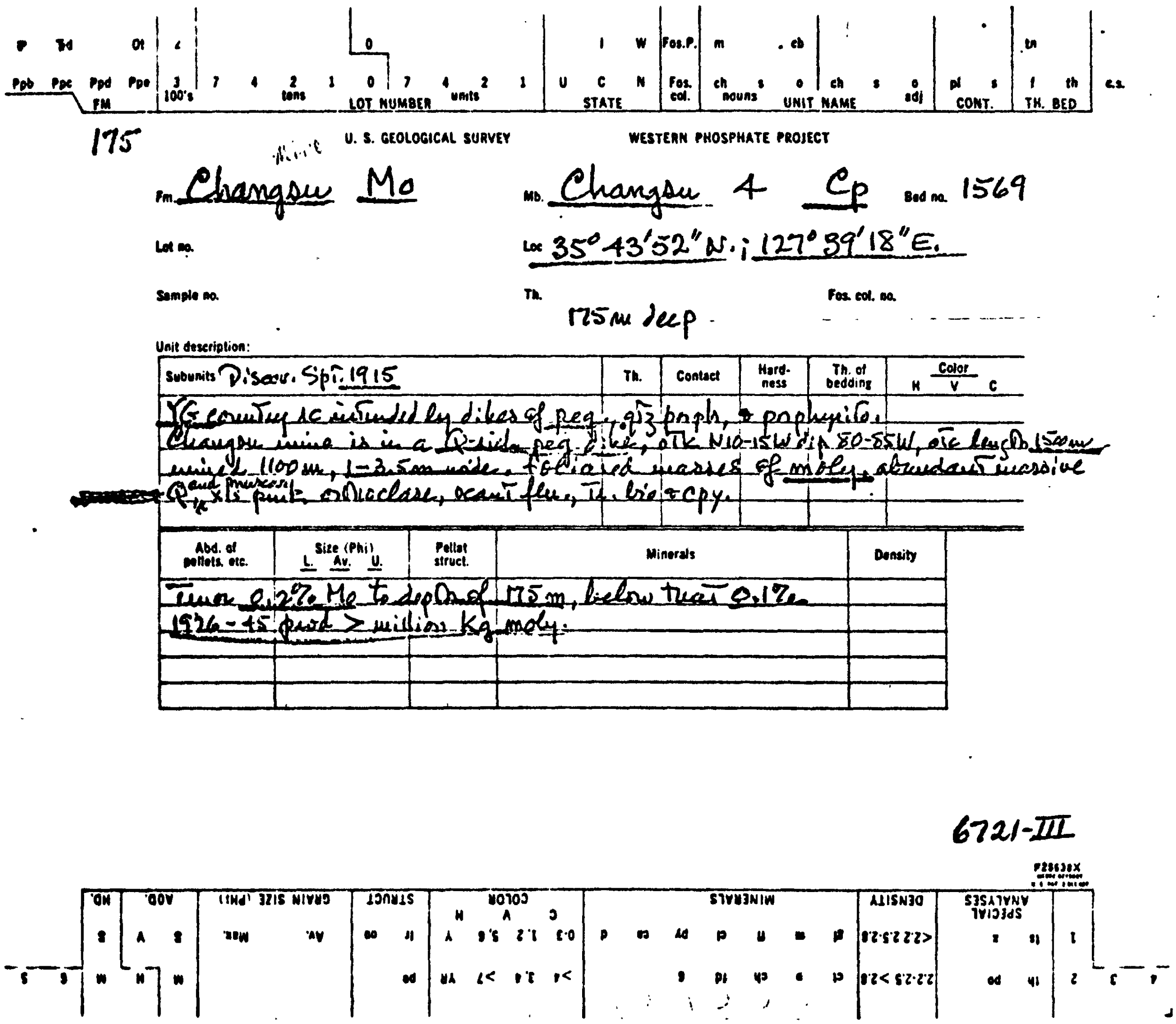
Data Base Construction

Existing worldwide mineral deposits data far surpass the resources of any organization to properly handle on a day-to-day basis. The increasing demand for data on short notice in varying formats literally demands that the data be stored in a computer processible form. For data stored on cards, sheets of paper or other forms which require manual retrieval, the need to convert to a computerized form is obvious. The following illustrations provide a step-by-step explanation of a conversion of a "needle-sort" card file on mineral deposits in Korea into a fully processible computer-based data file. The steps outlined in the following five figures provide a general guideline as to how data bases can be constructed.

FIGURE 1

Sample of original Korean mineral deposit data document

The original data document in figure 1 is not unlike much of the original data which exist on mineral deposits in current files worldwide. There is no doubt that this kind of information is valuable; in its present form, however, any use of information of this type either for reporting purposes or for analysis is all but impossible. Clearly, here is a situation where a computerized system for storage and retrieval of data is justified. With such a system, data could be retrieved, manipulated, and displayed in any desired format. Furthermore, the existing data could be updated without serious difficulty. Let us consider, therefore, constructing a mineral deposit data file using GRASP (Bowen, R.W. and J.M. Botbol, 1975). The data for the example are based on Korean mineral deposit records on file at the U.S. Geological Survey.


175

U. S. GEOLOGICAL SURVEY

WESTERN PHOSPHATE PROJECT

Fm. Changsu Mine Mo

Mb. Changsu 4 Cp

Bed no. 1569

Lot no.

Loc 35°43'52"N.; 127°39'18"E.

Sample no.

Th. 175m deep

Fos. col. no.

Unit description:

Subunits Discov. Spt. 1915	Th.	Contact	Hard-ness	Th. of bedding	Color H V C
YG country is intruded by dikes of peg., qtz porph, & porphyrite. Changsu mine is in a Q-rich peg dike, strike N10-15W dip 80-85W, strike length 1500m, mined 1100m, 1-3.5m wide. foliated masses of moly, abundant massive Q and muscov. xls pink orthoclase, scant flu, tr. bio & cpy.					

Abd. of pellets, etc.	Size (Phi) L. Av. U.	Pellet struct.	Minerals	Density
Tenor 0.2% Mo to depth of 175m, below that 0.1%. 1926-45 prod > million Kg moly.				

6721-III

FIGURE 1

Sample of original Korean mineral deposit data document

FIGURE 2

Unit records of raw data

For the Korean mineral deposit data, the type of structure most suited for storage and retrieval is a relational data structure. For relational structure, the concept is that of a group or table of RELATIONS. The columns represent the attributes and the rows the entities. For the Korean example, the entity is the mineral deposit and the attributes are the descriptive elements of the deposit. A unit record consists of a set of descriptions for a mineral deposit. The file is the set of unit records.

The coded form of figure 1 is shown as unit record 0001 in figure 2. Note there are different data type entries; for example, "changsu mine" (name) = variable length character string, "1915" (year of discovery) = integer, and "0.1" (Mo%) = floating point. Under GRASP, there are six different data types allowed.

RAW DATA

```
 0001changsu mine   changsu       cp 3543521273918vein type    moly                qz,or,ti,cpy   1915   15002.25


\c  0.1             1000   1926-1945
yg country rx is intruded by peg dikes,qzt porph,porphyrites. str n10-15w dip 80-85w.belowth
 0002unsu mine      korying       ksp3548031281754vein type     gold,silver         py                   4  380 0.20


                                   0.004131941
veins are in fault fissures in granite. strike n dip 70w. nativeform of gold. sulfide minerals are rare.
 0003tukchae mine   suncheon      cn 3458121271606fissure fillinggold,silver        py,aspy              100 0.5 12
   1   1
\c5


                                16.8  28    1959                 42           1959
metasediments(sch,hornfels,qzt) intruded by granite. str n dip 65e
 0004haman mine     haman         ksn3511231282324vein type     cpy                 aspy,py,pyrr                   0.45
      1


1                               0.2
oldest mine. consists of 6 workings. str n dip 70w. yeonnok prod 5 tons co
 0005ilgwang mine   tongnae       ksn3518131291331breccia pipe  cu,gold,silver      aspy,pyrr,py  1931


0.81             371800 1938-19450.12                           0.06
ountry rx is  granodiorite stockwork of veinlets of q associated ore minerals. alteration is characteristic.    large re
serves of
\c low grade.
```

FIGURE 2

Unit records of raw data

FIGURE 3

Reformatted unit records

To provide ready access for GRASP, the unit records in figure 2 are reformatted for use in the CONVERT program (Bowen, R.W., 1977) which is used to generate the files expected by GRASP. In this instance, a fixed record length of 80 characters per line is specified. The columns are divided into fields and within each field is a number, a character string or a blank which represents the value of the respective attribute.

REFORMATTED DATA FILE

```
Rec.No.  Name               Location              Latitude-Longitude  type          commodity
0001changsu mine    changsu         cp 3543521273918vein type       moly
     qz,or,ti,cpy    1915   15002.25
     Assoc.Minerals  Disc.Date


                                          Production  Production Date
Comments           0.1                     1000    1926-1945
yg country rx is intruded by peg dikes,qzt porph,porphyrites. str n10-15w dip 80
-85w.belowth

0002unsu mine       korying         ksp3548031281754vein type       gold,silver
     py                    4  380 0.20



 0.004131941

veins are in fault fissures in granite. strike n dip 70w. nativeform of gold. su
lfide minerals are rare.

0003tukchae mine    suncheon        cn 3458121271606fissure fillinggold,silver
     py,aspy                100 0.5 12      1   15


                                                                            16.8
 28      1959                  42             1959

metasediments(sch,hornfels,qzt) intruded by granite. str n dip 65e
```

FIGURE 3

Reformatted unit records

FIGURE 4

Ancillary files for CONVERT to GRASP

In addition to the raw data file in figure 3, the CONVERT program requires files which contain information on the structure of the raw data file. The data definition (DD) file contains the name of each variable, the data type and the position of the field in the input records of the raw data file. The first record of the DD file contains the total number of fields, the total number of characters in each record of the raw data file, and the number of lines (that is, 80-character groups) to skip before processing begins. The mask file contains the name of each variable and the data type. The definitions file contains this same information together with the complete description of each variable.

Once these files and two others have been generated, the CONVERT program is executed. It is at this stage that the data are compressed and stored for later retrievals by GRASP.

DATA DEFINITION FILE

```
 87  794    0
recno    1    1    4
name     6    5   19
county   6   20   34
state    6   35   37
latdg    1   38   39
latmn    1   40   41
latsc    1   42   43
longdg   1   44   46
longmn   1   47   48
longsc   1   49   50
deptyp   6   51   65
oremin   6   66   85
assmin   6   86  100
yrdisc   1  101  104
novns    1  105  107
avln     2  108  111
avwi     2  112  115
avthk    2  116  119
maxln    2  120  123
maxwi    2  124  127
maxth    2  128  131
bi%      2  132  137
biapr    2  138  144
biyrpr   1  145  148
bicp     2  149  155
bicpyr   1  156  164
co%      2  165  170
coapr    2  171  177
coyrpr   1  178  181
cocp     2  182  188
cocpyr   1  189  197
ni%      2  198  203
niapr    2  204  210
niyrpr   1  211  214
nicp     2  215  221
nicpyr   1  222  230
fe%      2  231  236
feapr    2  237  243
feyrpr   1  244  247
fecp     2  248  254
fecpyr   1  255  263
as%      2  264  269
asapr    2  270  276
asyrpr   1  277  280
ascp     2  281  287
ascpyr   1  288  296
pb%      2  297  302
pbapr    2  303  309
pbyrpr   1  310  313
pbcp     2  314  320
pbcpyr   1  321  329
zn%      2  330  335
znapr    2  336  342
znyrpr   1  343  346
zncp     2  347  353
zncpyr   1  354  362
cu%      2  363  368
cuapr    2  369  375
cuyrpr   1  376  379
```


MASK FILE

```
87
recno    1
name     6
county   6
state    6
latdg    1
latmn    1
latsc    1
longdg   1
longmn   1
longsc   1
deptyp   6
oremin   6
assmin   6
yrdisc   1
novns    1
avln     2
avwi     2
avthk    2
maxln    2
maxwi    2
maxth    2
bi%      2
biapr    2
biyrpr   1
bicp     2
bicpyr   1
co%      2
coapr    2
coyrpr   1
cocp     2
cocpyr   1
ni%      2
niapr    2
niyrpr   1
nicp     2
nicpyr   1
fe%      2
feapr    2
feyrpr   1
fecp     2
fecpyr   1
as%      2
asapr    2
asyrpr   1
ascp     2
ascpyr   1
pb%      2
pbapr    2
pbyrpr   1
pbcp     2
pbcpyr   1
zn%      2
znapr    2
znyrpr   1
zncp     2
zncpyr   1
cu%      2
cuapr    2
cuyrpr   1
```

DEFINITIONS FILE

```
  1
entire record
   1  87  87   1
recno    1  record number
name     6  name of mine
county   6  county
state    6  state
latdg    1  latitude, degrees
latmn    1  latitude, minutes
latsc    1  latitude, seconds
longdg   1  longitude, degrees
longmn   1  longitude, minutes
longsc   1  longitude, seconds
deptyp   6  type of deposit
oremin   6  ore mineral
assmin   6  associated mineral
yrdisc   1  year of discovery
novns    1  number of veins
avln     2  average vein length
avwi     2  average vein width
avthk    2  average vein thickness
maxln    2  maximun vein length
maxwi    2  maximum vein width
maxth    2  maximum vein thickness
bi%      2  bismuth assay in %
biapr    2  bismuth annual production
biyrpr   1  year of bi annual production
bicp     2  bismuth cumulative production
bicpyr   1  year of bismuth cum. prod.
co%      2  cobalt assay, %
coapr    2  cobalt annual production
coyrpr   1  year of co annual prod.
cocp     2  cobalt cumulative production
cocpyr   1  year of cobalt cum.prod.
ni%      2  nickel assay, %
niapr    2  nickel annual production
niyrpr   1  year of nickel annual prod.
nicp     2  nickel cumulative production.
nicpyr   1  year of nickel cumulative product
fe%      2  iron assay, %.
feapr    2  iron annual production
feyrpr   1  year of iron annual prod.
fecp     2  iron cumulative production
fecpyr   1  year of iron cumulative production
as%      2  arsenic assay, %
asapr    2  arsenic annual production
asyrpr   1  year of as annual prod.
ascp     2  arsenic cumulative production
ascpyr   1  year of as cumulative prod.
pb%      2  lead assay, %
pbapr    2  lead annual production
pbyrpr   1  year of lead annual production
pbcp     2  lead cumulative production
pbcpyr   1  year of lead cumulative productio
zn%      2  zinc assay, %
znapr    2  zinc annual production
znyrpr   1  year of zinc annual prod.
zncp     2  zinc cumulative production
zncpyr   1  year of zinc cumulative productio
cu%      2  copper assay, %
```

FIGURE 4

Ancillary files for
CONVERT to GRASP

FIGURE 5

Dump of records from GRASP

Using GRASP, the entire contents of each unit record can be displayed. In this instance, the contents of the first two records of the Korean mineral deposit data base are shown in figure 5. The first record can be compared with the original data document in figure 1. In the next example, a variety of GRASP retrievals are presented.

References

Bowen, R.W. and Botbol, J.M., 1975, The geologic retrieval and synopsis program (GRASP). U.S. Geol. Sur. Prof. Paper 966, 84 p.

Bowen, R.W., 1977, >udd>GRASP>grasp.info., U.S. Geol. Sur. Honeywell Reston Multics System, 4 p.

```
ENTER NUMBER OF LINES/PAGE: 80

CATEGORY: entire record
 recno         1
 name     changsu mine
 county   changsu
 state    cp
 latdg          35
 latmn          43
 latsc          52
 longdg        127
 longmn         39
 longsc         18
 deptyp   vein type
 oremin   moly
 assmin   qz,or,ti,cpy
 yrdisc       1915
 avln      1500.
 avwi      2.250
 mo%       .1000
 mocp      1000.
 mocpyr   -19261945
 commnt   yg country rx is intruded by peg dikes,qzt porph,porphyrites
          . str n10-15w dip 80-85w.belowtk
XXXXXXXXXXXXXXXXXXXXXXXX
CATEGORY: entire record
 recno         2
 name     unsu mine
 county   korying
 state    ksp
 latdg          35
 latmn          48
 latsc           3
 longdg        128
 longmn         17
 longsc         54
 deptyp   vein type
 oremin   gold,silver
 assmin   py
 movns           4
 avln      380.0
 avwi      .2000
 auapr    0.4130e-02
 auyrpr       1941
 commnt   veins are in fault fissures in granite. strike n dip 70w. na
          tiveform of gold. sulfide minerals are rare.
XXXXXXXXXXXXXXXXXXXXXXXX

ENTER COMMAND:
```

FIGURE 5

Dump of records from GRASP

EXAMPLE II

Utilization of a Mineral Deposit Data Base

In the previous example, it was demonstrated step-by-step how a mineral deposit data base can be constructed. In this example, it is shown how such data are retrieved, manipulated and displayed. The retrievals are made through GRASP.

The following four figures illustrate some of the many possible GRASP retrievals.

FIGURE 6

GRASP commands

GRASP is a program to provide retrieval and manipulative capabilities for two-dimensional relational data bases. Intended for use in a time-share computing environment, GRASP communicates with the user through a series of commands which are listed in figure 6. Once the user masters these 15 commands, the user commands GRASP. In figure 6, the help command has been executed. A GRASP session consists of a series of such commands.

```
ENTER COMMAND: help                          ENTER COMMAND:

THE COMMANDS WHICH MAY BE ISSUED (AND THEIR MEANING) ARE LISTED BELOW:

cond- INITIATES THE REQUEST FOR RETRIEVAL CRITERIA TO BE ENTERED IN
      THE FORM: NAME REL VALUE
logi- INITIATES THE REQUEST FOR A LOGICAL EXPRESSION TO BE ENTERED
      USING LOGICAL OPERATORS.
sear- INITIATES THE SEARCH OF A FILE BASED UPON PREVIOUSLY ENTERED
      CONDITIONS AND LOGIC.
list- ALLOWS THE USER TO LIST SELECTED VALUES (VARIABLE NAMES WILL
      BE ASKED FOR) IN A FILE.
file- ALLOWS THE USER TO SELECT OR CHANGE THE DATA BASE TO BE USED.

quit- TERMINATES THE SYSTEM.

name- USED TO PRINT ITEM NAMES, THEIR TYPES AND DEFINITIONS IN A
      SELECTED SET OF GROUPS.
help- USED TO OBTAIN THE ABOVE COMMAND DEFINITIONS.

revi- LISTS THE FILES WHICH HAVE BEEN USED AS WELL AS THE CONDITIONS
      AND LOGIC ENTERED.
dump- PRINTS ALL ITEMS PRESENT FOR EACH RECORD IN A SELECTED FILE.
      WAITS AFTER EACH N LINES
func- PROVIDES FOR THE COMPUTATION OF FUNCTIONS ON ITEMS IN A DATA
      SET (OR FILE).
defi- USED TO DEFINE NEW VARIABLE NAMES IN TERMS OF ORIGINAL ITEM
      NAMES (NAME=EXPRESSION)
appe- USED TO APPEND ONE GRASP FILE TO ANOTHER. THE TWO FILES MUST
      HAVE IDENTICAL STRUCTURE
conv- EXECUTES THE CONVERT PROGRAM.

mult- PERMITS EXECUTION OF MULTICS COMMANDS.
```

FIGURE 6

GRASP commands

FIGURE 7

Examples of GRASP retrievals

A broad spectrum of retrieval and data manipulative capabilities are possible using GRASP. In figure 7, a few of the possibilities are shown. The function command provides for the computation of functions for items in the data base. In the example, the mean statistics are requested for the annual Cu, Zn and Pb production, respectively. Only a few records contained information on production; however, the results are reported even if the information is available only for a single record. The conditions command initiates the request for retrieval criteria. In the example, the conditions are that the annual production for Cu, Pb, Au and Zn be greater than zero. The logic command initiates the request for a logic operation. In the example, the conditions are combined by a logical .OR. relation. The search command initiates a search of the data base based on the previously defined logic. The user can create a file of the output of a search. In this case, the output file is given the name "sample" and contains the 11 records which satisfied the request. The list command allows the user to list selected values in a file. In the example, the type of deposit, name of mine and the ore mineral of the 11 records in "sample" are requested. The items can be listed by column or by row as shown in figure 7 and continuing in figure 8.

```
ENTER COMMAND: function

ENTER NAME OF FILE:
FUNCTIONS AVAILABLE AT THIS TIME ARE:
    mean    fit
ENTER FUNCTION NAMES AND CORRESPONDING ARGUMENTS.

1. mean cuapr,znapr,pbapr

2.

MEAN STATISTICS FOR cuapr   WITH     3 ITEM(S).
 MIN= 9.59600       MAX= 51.5030       MEAN= 31.0653
 SUM= 93.1960       VARIANCE= 439.789       STD DEVIATION= 20.9712

NO VALUES PRESENT FOR znapr

MEAN STATISTICS FOR pbapr   WITH     1 ITEM(S).
 MIN= 421.020       MAX= 421.000       MEAN= 421.000
 SUM= 421.000       VARIANCE=0.000000       STD DEVIATION=0.000000


ENTER COMMAND: conditions

A. cuapr gt 0

B. pbapr gt 0

C. auapr gt 0

D. znapr gt 0

E.


ENTER COMMAND: logic

ENTER LOGIC: a.or.b.or.c.or.d


ENTER COMMAND: sear

ENTER INPUT FILE NAME:  kormf

ENTER OUTPUT FILE NAME: sample
ALL    69 RECORDS OF kormf    SEARCHED.
       11 RECORDS FOUND WHICH SATISFY THE REQUEST.
THEY HAVE BEEN STORED IN sample
```

```
ENTER COMMAND: list

ENTER NAME OF FILE: sample

ENTER NUMBER OF LINES/PAGE:
AT EACH PAUSE PRESS CR KEY TO CONTINUE. TO ABORT ENTER A.
3 TYPES OF LISTING ARE POSSIBLE:
  C - COLUMN TYPE (DEFAULT FORMAT)
  U - COLUMN TYPE (USER FORMAT)
  R - ROW TYPE

SELECT C, U, OR R: c

WOULD YOU LIKE OUTPUT TO BE TO DISK? (y OR n): n

WOULD YOU LIKE THE OUTPUT SORTED? (y OR n): n
ENTER THE LIST OF ITEM NAMES.

1.  deptyp

2.  name

3.  oremin

4.


  deptyp     name       oremin
vein typ   unsu min   gold,sil
fissure    tukchae    gold,sil
vein typ   seogyo m   gold,sil
vein typ   kumjae m   gold sil
vein typ   hungsin    cpy
vein typ   chilgok    cpy,gln,
vein typ   okkye mi   cpy, sph
vein typ   youngjun   gold
vein typ   samwang    gold
vein typ   cholma     cpy
vein typ   tokum mi   gold sil


ENTER.COMMAND: list

ENTER NAME OF FILE: sample

ENTER NUMBER OF LINES/PAGE:
AT EACH PAUSE PRESS CR KEY TO CONTINUE. TO ABORT ENTER A.
3 TYPES OF LISTING ARE POSSIBLE:
  C - COLUMN TYPE (DEFAULT FORMAT)
  U - COLUMN TYPE (USER FORMAT)
  R - ROW TYPE

SELECT C, U, OR R: r
```

FIGURE 7

Examples of GRASP retrievals

FIGURE 8

More examples of GRASP retrievals

The define command is used to define new variable names in terms of the original variables. In the example, the variables longdec and latdec are defined and represent longitude and latitude expressed decimally, respectively. The purpose is to generate a graphic display of selected mineral deposits. In order to determine the area to be displayed, the mean statistics of the latitude and longitude of the deposits to be plotted are calculated using the function command. The multics command permits execution of multics commands, that is, commands outside GRASP. In the example, the multics command map is executed and the appropriate input data provided. Not shown in the example was the creation of the file named "koreax" which contains the values of longdec and latdec for the deposits to be plotted.

```
DO YOU WISH TO ENTER A NEW LIST OF NAMES? (y OR n)! n


deptyp   =vein type
name     =unsu mine
oremin   =gold,silver
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =fissure filling
name     =tukchae mine
oremin   =gold,silver
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =secgyo mine
oremin   =gold,silver
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =kumjse mine
oremin   =gold silver
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =hungsin
oremin   =cpy
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =chilgok
oremin   =cpy,gln,sph,au,ag
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =okkye mine
oremin   =cpy, sph, gln
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =youngjung mine
oremin   =gold
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =samwang mine
oremin   =gold
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =cholma
oremin   =cpy
$$$$$$$$$$$$$$$$$$$$$$$$$
deptyp   =vein type
name     =tokum mine
oremin   =gold silver
$$$$$$$$$$$$$$$$$$$$$$$$$


ENTER COMMAND: define
```



```
ENTER LIST OF NEW VARIABLE DEFINITIONS (OR help FOR MORE INFORMATION)

 1. longdec=longdg+longmn/60+longsc/3600

 2. latdec=latdg+latmn/60+latsc/3600

 3.


ENTER COMMAND: function

ENTER NAME OF FILE: sample
FUNCTIONS AVAILABLE AT THIS TIME ARE:
    mean    fit
ENTER FUNCTION NAMES AND CORRESPONDING ARGUMENTS.

1. mean latse
latse   IS AN INVALID NAME. RE-ENTER LINE.

1. mean latdec,lond$gdec

2.

MEAN STATISTICS FOR latdec  WITH    11 ITEM(S).
 MIN= 34.5500       MAX= 37.9750      MEAN= 35.8622
 SUM= 394.484       VARIANCE= 1.32038      STD DEVIATION= 1.14908

MEAN STATISTICS FOR longdec WITH    11 ITEM(S).
 MIN= 126.595       MAX= 129.157      MEAN= 127.875
 SUM= 1406.62       VARIANCE= .660435      STD DEVIATION= .812671


ENTER COMMAND: multics
YOU MAY EXECUTE ANY MULTICS COMMAND,
SO BE CAREFUL. ENTER grasp TO RETURN TO THE GRASP SYSTEM.

ENTER MULTICS COMMAND: map


Enter desired projection:lambert

Enter appropriate title and end with a $:koreax$

Enter longitude min, max, and step size:125.,130.,1.

Enter latitude min, max, and step size:33.,39.,1.

Enter coastline file desired:coastlines

Enter political file desired:pasia

Enter name of file with grasp-list coordinates:koreax
```

FIGURE 8

More examples of GRASP retrievals

FIGURE 9

Map display of selected Korean mineral deposits

From the information provided to the entry requests of the multics map command such as the desired projection, title, map area, boundaries and so forth, the map in figure 9 was produced. The data shown plotted on the map are the 11 mineral deposits having coordinate references in the data base. In a matter of minutes, therefore, a special purpose map was produced which could have been used to satisfy an immediate request, to explore some newly discovered relationship in the data base or else to provide a quick-look before proceeding with a finished product. In every case, the user is in touch with a system with dynamic flexibility and ease of operation, two very important human requirements in computing.

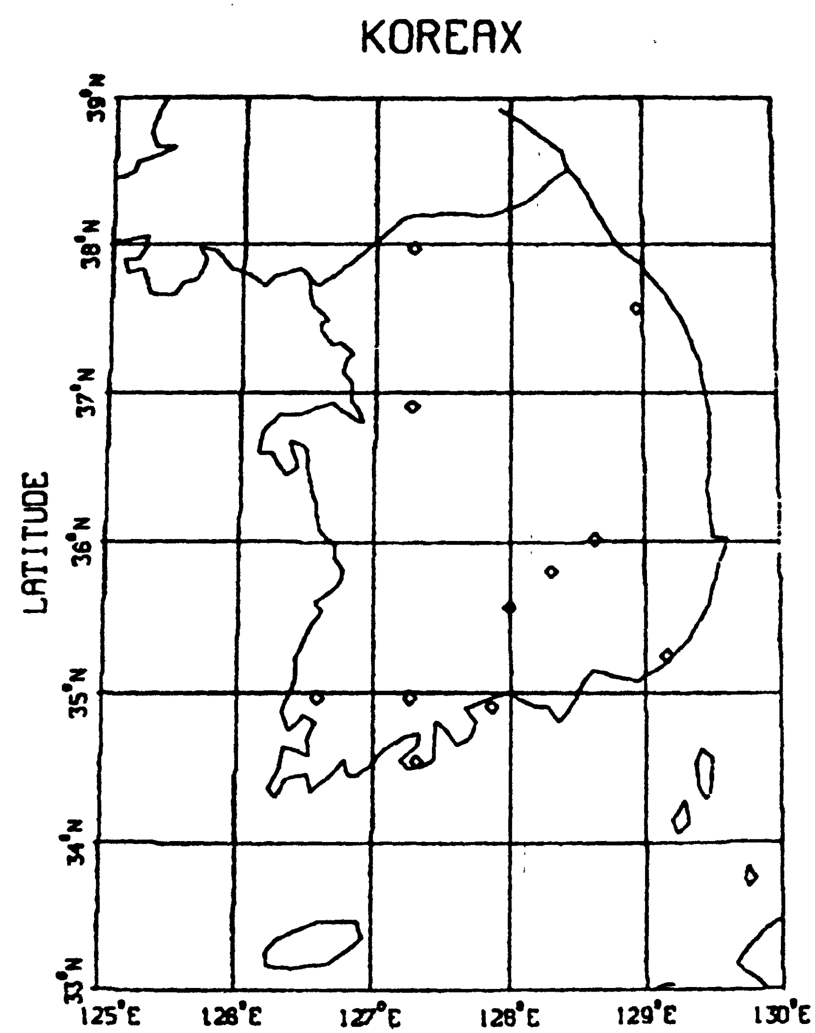


FIGURE 9

Map display of selected Korean mineral deposits

EXAMPLE III

Decision Modeling

Rarely does the geologist have sufficient data to guarantee success in exploration. In part, this is due to lack of sufficient areal coverage. Considering the size of most exploration targets in relation to the area of search, it is not surprising that insufficient data are usually collected. In greater part, however, it is the limited understanding of the significance of observations relative to a particular deposit model which gives rise to the greatest uncertainty in exploration. As a partial remedy, decision modeling has been developed to assist the exploration geologist in reducing this uncertainty. Decision modeling is a computer-based method which allows the exploration geologist to create, test and apply deposit models based on multivariate data. Using decision modeling, the favorability of a region with respect to a wide variety of models is readily evaluated. Decision modeling is performed in a time share computing environment. As a result, modeling and regional evaluations are performed dynamically allowing full flexibility in model formulation and characterization of regions. A full account of the method in this workshop is inappropriate. However, the method can be demonstrated by taking an example using mineral deposit data from the Grong area of central Norway. In central Norway, massive sulphide deposits occur in rock types and geologic structures which have been mapped extensively. Remote sensing data are available also.

FIGURE 10

Known mineralized area in central Norway

Using the program, a display of the known mineralized locations in central Norway is shown. The plus (+) sign indicates that at least one ore deposit occurs within the respective cell. Each cell measures 1.25 km on a side. The zeroes (0) indicate areas in which deposits could occur based on the geology. The blank cells are considered outside the area of interest. The cells with enclosed squares represent the chosen model. The model represents an area characterized by massive sulfide deposits in a particular geologic setting. By an appropriate choice of variables, it will be demonstrated how areas of similar geologic setting outside the model area can be identified.

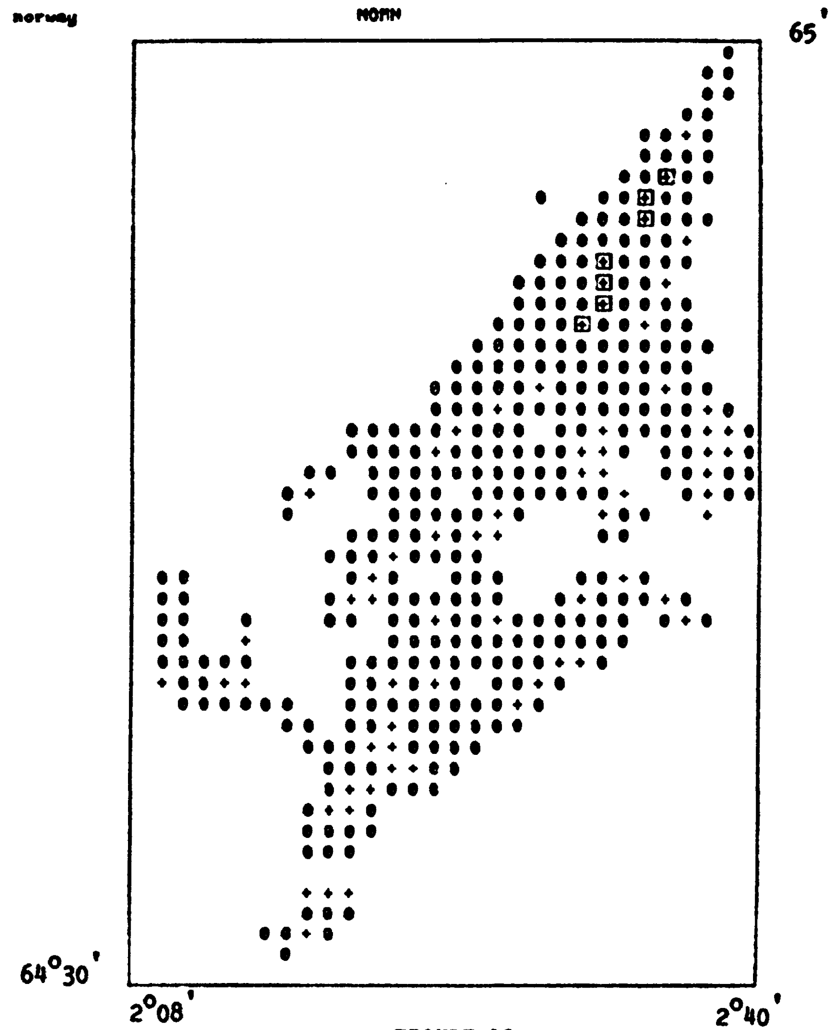


FIGURE 10

Known mineralized area in central Norway

FIGURE 11

Variable selection

The selection of variables in decision modeling is accomplished by inspecting the observed associations among all variables. In figure 11, the 24 variables to be considered are listed. Variables 1 through 13 were derived from remote sensing data and represent density slices and the averages for bands 4 and 7. Variable 14 shown in figure 10 represents the presence or absence of mines within a given cell. Variables 15 through 19 represent the percentage within each cell of different rock types. The latter information was obtained from geologic maps prepared at a scale of 1:100,000. Variables 20 and 21 refer to distances from prominent structural features in the area. Variables 22 and 23 refer to computed values based on aeromagnetic data collected for the region. Variable 24 is a discriminant index constructed from control data outside the map area. Thus, the variables to be considered represent information from remote sensing, geologic, structural and geophysical data. For each variable, a plus (+) sign for a cell indicates a value which is anomalously greater than the values in neighboring cells. A minus (-) sign indicates a value which is anomalously lower than the values in neighboring cells. A zero (0) indicates that the value is neither higher or lower than the values in neighboring cells and a blank indicates missing data. For non-missing data, therefore, the possible values of each variable form a ternary array expressed as (1, 0, - 1).

```
-------------------------------------------------
'ncharan' operation 3. Selection/Deletion of variables.

Next move??



The following are all available variables:
   B408  1   B410  2   B411  3   B412  4   B413  5   B499  6   B708  7,
   B712  8   B716  9   B720 10   B799 11   B4AU 12   B7AU 13   NOMN 14,
   SURF 15   GABB 16   ACID 17   GNST 18   OKSU 19   DINU 20   DISE 21,
   MGVL 22   MGMP 23   DISC 24

Next move??



You are about to begin...
Step 2.  Addition/Deletion of variables to the list of selected ones.



Enter:
     1 to ADD variables,
     2 to DELETE variables,
     CR to return to the variable selction stream.

 1

Enter r to read vars. from a file, d for direct entry, CR for local stream. d

Enter the variable numbers. 1-24,x

Next move?? 5



You are about to begin...
Step 5.  Return to 'ncharan'.
CONGRATULATIONS!!! You have a consistent model.

???
```

FIGURE 11

Variable selection

FIGURE 12

Associations of variables .I.

For the 7 cells selected as the model, the associations among all 24 variables are shown in figures 12 and 13. In figure 12, the product matrix is displayed. The product matrix is defined as the product of the transpose of the 7x24 data matrix times the data matrix. The diagonal elements represent the difference for each variable pair between the number of positive-positive or negative-negative matches and the number of positive-negative or negative-positive matches. The highest possible value along the diagonal is 7 which happens for variable 14. Associations of the other variables with variable 14 can be seen by inspection.

```
---------------------------------------------
'ncharan' operation 5. Computation of weights.
weight calculation steps are as follows:
  step   function
    1      read user-supplied weights from a file or the keyboard
    2      compute product, tally, and probability matrices
    3      print the matrices
    4      select a method and compute weights
    5      print the weights
    6      save the weights in a file
    7      return to charan
Enter CR to execute step 2

Next move??
Probability calculation:
Enter CR to bypass, 1 to use sampling-without-replacement model
  or 2 to use sampling-with-replacement model

 1
Enter CR to execute step 3

Next move??

Do you wish to print the product matrix?? yes
product matrix
```

variable	name																								
1	B408	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	B410	0	3	1	-2	1	1	1	2	-3	0	1	0	0	-3	0	0	0	-2	0	-1	3	-1	0	-2
3	B411	0	1	4	1	-1	0	1	0	-1	1	1	0	1	0	0	0	0	-2	0	-2	1	0	1	-2
4	B412	0	-2	1	3	-2	-2	0	-2	2	1	0	0	1	3	0	0	0	1	0	-1	-2	2	1	1
5	B413	0	1	-1	-2	5	0	-1	2	-1	0	-1	-1	0	1	0	0	0	2	0	0	0	0	0	0
6	B499	0	1	0	-2	0	3	0	2	-1	-2	0	1	-2	-3	0	0	0	-2	0	2	1	-3	-1	0
7	B708	0	1	1	0	-1	0	2	0	0	-1	2	0	-1	-2	0	0	0	-2	0	-1	2	0	0	-1
8	B712	0	2	0	-2	2	2	0	4	-2	-2	0	1	-2	-2	0	0	0	-1	0	1	1	-2	0	1
9	B716	0	-3	-1	2	-1	-1	0	-2	4	-1	0	0	-1	2	0	0	0	1	0	1	-2	1	0	2
10	B720	0	0	1	1	0	-2	-1	-2	-1	4	-1	-1	4	2	0	0	0	1	0	-2	0	2	1	-2
11	B799	0	1	1	0	-1	0	2	0	0	-1	2	0	-1	-2	0	0	0	-2	0	-1	2	0	0	-1
12	B4AU	0	0	0	0	-1	1	0	1	0	-1	0	1	-1	-1	0	0	0	-1	0	1	0	-1	0	1
13	B7AU	0	0	1	1	0	-2	-1	-2	-1	4	-1	-1	4	2	0	0	0	1	0	-2	0	2	1	-2
14	NOMN	0	-3	0	3	1	-3	-2	-2	2	2	-2	-1	2	7	0	0	0	5	0	-1	-5	3	1	2
15	SURF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	GABB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	ACID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	GNST	0	-2	-2	1	2	-2	-2	-1	1	1	-2	-1	1	5	0	0	0	5	0	0	-4	2	0	2
19	OKSV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	DINW	0	-1	-2	-1	0	2	-1	1	1	-2	-1	1	-2	-1	0	0	0	0	0	3	-1	-2	-1	2
21	DISE	0	3	1	-2	0	1	2	1	-2	0	2	0	0	-5	0	0	0	-4	0	-1	5	-1	0	-3
22	MGUL	0	-1	0	2	0	-3	0	-2	1	2	0	-1	2	3	0	0	0	2	0	-2	-1	3	1	0
23	MGHP	0	0	1	1	0	-1	0	0	0	1	0	0	1	1	0	0	0	0	0	-1	0	1	1	0
24	DISC	0	-2	-2	1	0	0	-1	1	2	-2	-1	1	-2	2	0	0	0	2	0	2	-3	0	0	4

```
Do you wish to print the tally matrix?? yes
```

FIGURE 12

Associations of variables .I.

FIGURE 13

Associations of variables .II.

In figure 13, the tally matrix and the probability matrix for the 24 variables are displayed. The upper right triangular portion of the tally matrix contains the number of positive-positive matches and the lower left triangular portion contains the number of negative-negative matches for each variable pair. The diagonal element of the tally match contains the number of +1's for each variable. The upper right triangular portion of the probability matrix contains the number of positive-positive or negative-negative matches for each variable pair and the lower left triangular portion contains the probability expressed as a percentage that this number is <u>not</u> due to chance.

By studying the associations revealed in the product, tally and probability matrices, it is possible to select an appropriate subset of variables. In the example, it is seen that variables 5, 9, 18 and 24 are anomalous in over half the 7 cells in the model and are mutually related. Thus, these 4 variables are selected as the components of the model.

tally matrix
variable name

1	B408	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	B410	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	B411	0	2	2	2	0	0	0	0	1	1	0	0	1	2	0	0	0	0	0	0	0	1	1	0
4	B412	0	0	0	3	0	0	0	0	2	1	0	0	1	3	0	0	0	1	0	0	0	2	1	1
5	B413	0	2	1	0	3	0	0	1	1	1	0	0	1	3	0	0	0	3	0	1	0	1	0	2
6	B499	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	B708	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	B712	0	2	1	0	2	2	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
9	B716	0	0	0	0	0	0	1	0	3	0	0	0	0	3	0	0	0	2	0	1	0	1	0	2
10	B720	0	0	0	0	0	0	0	0	0	3	0	0	3	3	0	0	0	2	0	0	0	2	1	0
11	B799	0	1	1	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	B4AV	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	B7AV	0	0	0	0	0	0	0	0	0	1	0	0	3	3	0	0	0	2	0	0	0	2	1	0
14	NOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	5	0	1	0	3	1	3
15	SURF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	GABB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	ACID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	GNST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0	2	0	3
19	QKSV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	DINW	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1
21	DISE	0	3	2	0	2	1	2	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
22	MGVL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1
23	MGHP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
24	DISC	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	3

Do you wish to print the probability matrix?? yes
probability matrix
variable name

1	B408	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	B410	0	100	2	0	2	1	1	2	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0
3	B411	0	86	100	2	1	1	1	1	1	1	1	0	1	2	0	0	0	0	0	0	2	1	1	0
4	B412	0	0	88	100	0	0	0	0	2	1	0	0	1	3	0	0	0	1	0	0	0	2	1	1
5	B413	0	86	18	0	100	1	0	3	1	1	0	0	1	3	0	0	0	3	0	1	2	.1	0	2
6	B499	0	12	29	0	29	100	0	2	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	1
7	B708	0	29	49	0	0	0	100	0	1	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0
8	B712	0	63	23	0	91	63	0	100	0	0	0	1	0	1	0	0	0	1	0	1	2	0	0	2
9	B716	0	0	23	63	10	0	71	0	100	0	1	0	0	3	0	0	0	2	0	1	1	1	0	2
10	B720	0	0	23	11	10	0	0	0	0	100	0	0	4	3	0	0	0	2	0	0	1	2	1	0
11	B799	0	29	49	0	0	0	98	0	73	0	100	0	0	0	0	0	0	0	0	0	2	0	0	0
12	B4AV	0	0	0	0	0	59	0	59	0	0	0	100	0	0	0	0	0	0	0	1	0	0	0	1
13	B7AV	0	0	23	11	10	0	0	0	0	99	0	0	100	3	0	0	0	2	0	0	1	2	1	0
14	NOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	5	0	1	0	3	1	3
15	SURF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0
16	GABB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0
17	ACID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0
18	GNST	0	0	0	0	73	0	0	29	15	15	0	0	15	0	0	0	0	100	0	1	0	2	0	3
19	QKSV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0
20	DINW	0	0	0	0	30	86	0	26	43	0	0	71	0	0	0	0	0	29	0	100	0	0	0	2
21	DISE	0	73	54	0	54	0	54	15	29	29	54	0	29	0	0	0	0	0	0	0	100	0	0	0
22	MGVL	0	0	29	65	12	0	0	0	12	65	0	0	65	0	0	0	0	15	0	0	0	100	1	1
23	MGHP	0	0	73	59	0	0	0	0	0	59	0	0	59	0	0	0	0	0	0	0	0	59	100	0
24	DISC	0	0	0	11	50	57	0	79	56	0	0	86	0	0	0	0	0	71	0	86	0	11	0	100

Enter CR to execute step 4

Next move??

FIGURE 13

Associations of variables .II.

FIGURE 14

Selection of subsets of variables

Returning to the variable selection step in the decision modeling program, the subset of variables selected for the model is now specified. The selection of variables numbered 5, 9, 18, and 24 is shown in figure 14.

```
------------------------------------------------
'ncharan' operation 3. Selection/Deletion of variables.

Next move??



The following are all available variables:
   B408  1   B410  2   B411  3   B412  4   B413  5   B499  6   B708  7,
   B712  8   B716  9   B720 10   B799 11   B4AV 12   B7AV 13   NOMN 14,
   SURF 15   GABB 16   ACID 17   GNST 18   QKSU 19   DINU 20   DISE 21,
   MGVL 22   MGMP 23   DISC 24

Next move??



You are about to begin...
Step 2.  Addition/Deletion of variables to the list of selected ones.



Enter:
     1 to ADD variables,
     2 to DELETE variables,
     CR to return to the variable selction stream.

 1

Enter r to read vars. from a file, d for direct entry, CR for local stream. d

Enter the variable numbers. 5,9,18,24,*

Next move?? 4



You are about to begin...
Step 4.  Print a list of current selected variables.
The following are the SELECTED variables:
   B413  5   B716  9   GNST 18   DISC 24

Next move??



You are about to begin...
Step 5.  Return to 'ncharan'.
CONGRATULATIONS!!! You have a consistent model.

??? 5
```

FIGURE 14

Selection of subsets of variables

FIGURE 15

Weight calculation

For the four variables selected for the model consisting of seven cells, the product, tally and probability matrices clearly show the associations among the four variables. The variable weights are calculated as the first principal component of the product matrix. The weights are expressed in terms of a unit vector. In the example, variable 18 which represents the rock type greenstone has the highest weight and is considered the most important attribute of the model. Of second importance is variable 24 which represents the discriminant index. Of third, and of equal importance, are variables 5 and 9 which represent different fractiles of spectral bands 4 and 7. Using the weights obtained for these four variables, it is possible to evaluate all cells in the area relative to the model.

```
------------------------------------------------
'charan' operation 5. Computation of weights.
weight calculation steps are as follows:
  step   function
     1     read user-supplied weights from a file or the keyboard
     2     compute product, tally, and probability matrices
     3     print the matrices
     4     select a method and compute weights
     5     print the weights
     6     save the weights in a file
     7     return to charan
Enter CR to execute step 2

Next move??
Probability calculation:
Enter CR to bypass, 1 to use sampling-without-replacement model
  or 2 to use sampling-with-replacement model

 1
Enter CR to execute step 3

Next move??

Do you wish to print the product matrix?? yes
product matrix
variable name
    5     B413   5  -1   2   0
    9     B716  -1   4   1   2
   18     GNST   2   1   5   2
   24     DISC   0   2   2   4

Do you wish to print the tally matrix?? yes
tally matrix
variable name
    5     B413   3   1   3   2
    9     B716   0   3   2   2
   18     GNST   0   0   5   3
   24     DISC   0   0   0   3

Do you wish to print the probability matrix?? yes
probability matrix
variable name
    5     B413 100   1   3   2
    9     B716  10 100   2   2
   18     GNST  61  12 100   3
   24     DISC  50  56  71 100
Enter CR to execute step 4

Next move??
select a method of weight calculation
    1 : Primitive method
    2 : 1st principal component of product matrix
    3 : 1st principal component of probability matrix
or CR to bypass weight calculation

Enter 1, 2, 3, or CR to bypass 2
Enter CR to execute step 5

Next move??

Do you wish to print the weights?? yes

variable name weight
    5    B413  0.348
    9    B716  0.348
   18    GNST  0.696
   24    DISC  0.522
Enter CR to execute step 6

Next move??

Enter CR or the filename on which weights are to be saved
Enter CR to execute step 7

Next move??

???
```

FIGURE 15

Weight calculation

FIGURE 16

Degrees of association

As a prelude to mapping the similarity of cells to the model, a histogram of the computed values of similarity for the model cells and non-model cells is generated and shown in figure 16. The frequency and percent frequency are tabulated by class interval. In the example, there are seven non-model cells associated with the two model cells with the highest similarity values and it is these seven cells which are of most interest. By selecting a cutoff value of 0.72, it is possible to divide the distribution into two classes in which one class of cells is considered as being similar and one class of cells dissimilar to the model.

```
------------------------------------------------
"ncharan" operation 6. Computation of degrees of association.

frequency distribution
            class interval          model   cells       non-model  cells
                                    freq     pct        freq      pct
------------------------------------------------------------------------------
  1      -0.64       -0.57           0      0.00         4       1.54
  2      -0.57       -0.50           0      0.00         0       0.00
  3      -0.50       -0.43           0      0.00         8       3.08
  4      -0.43       -0.36           0      0.00         1       0.38
  5      -0.36       -0.30           0      0.00         0       0.00
  6      -0.30       -0.23           0      0.00        15       5.77
  7      -0.23       -0.16           0      0.00         7       2.69
  8      -0.16       -0.09           0      0.00        11       4.23
  9      -0.09       -0.02           0      0.00         6       2.31
 10      -0.02        0.05           2     28.57       108      41.54
 11       0.05        0.11           0      0.00         8       3.08
 12       0.11        0.18           1     14.29         4       1.54
 13       0.18        0.25           0      0.00        13       5.00
 14       0.25        0.32           1     14.29        26      10.00
 15       0.32        0.39           0      0.00        22       8.46
 16       0.39        0.45           0      0.00         1       0.38
 17       0.45        0.52           0      0.00         8       3.08
 18       0.52        0.59           0      0.00         3       1.15
 19       0.59        0.66           1     14.29         6       2.31
 20       0.66        0.73           0      0.00         0       0.00
 21       0.73        0.80           0      0.00         2       0.77
 22       0.80        0.86           1     14.29         6       2.31
 23       0.86        0.93           0      0.00         0       0.00
 24       0.93        1.00           1     14.29         1       0.38
------------------------------------------------------------------------------
     totals                          7                 260

???

------------------------------------------------
"ncharan" operation 7. Display of computed values and/or raw data.

Next move?? 2
You are about to plot the degrees of association.
Enter:
    CR to proceed with a plot of the degrees of association, or
    the number of the step to which you wish to branch.


Enter CR to plot current data, or, enter name of file to be plotted.

Do you wish to plot the grid(y or n)? y

Do you wish to plot training cell outlines (y or n)? y

Enter the desired map type. 1
Enter the boundaries in ascending order, separated by commas, and all on one line.
 Exclude the upmost and lowest boundaries. .72
```

FIGURE 16

Degrees of association

FIGURE 17

Similarity map

Based on a cutoff value of 0.72 for the histogram data in figure 16, a map showing the distribution of the two classes of similarity is presented in figure 17. Cells with the number 1 are judged as being dissimilar. Cells with the number 2 are judged to be similar to the model. Blank cells indicate missing data. By comparing figure 17 with figure 10, it can be determined that two of the seven cells judged similar (circled in figure 17) contain known deposits. Of the 260 non-model cells for which data are available, 34 contain known deposits. Thus, even if no new deposits are discovered in the five non-model cells judged similar to the model, the number of cells with deposits "discovered" by the model is twice the number expected by chance. Such a result clearly demonstrates the value of decision modeling for exploration. Moreover, the non-model cells judged similar to the model and which do not contain known deposits are considered favorable for purposes of resource appraisal.

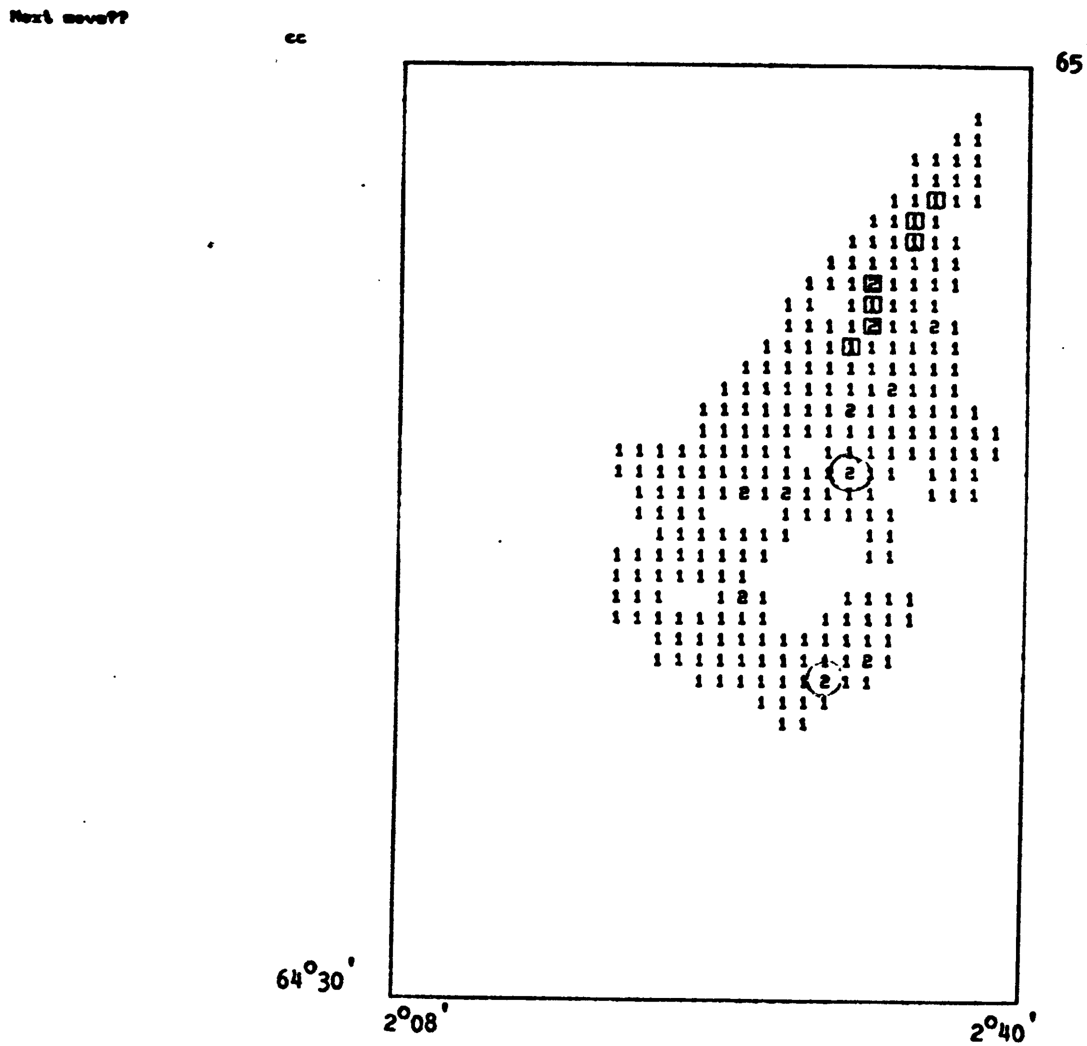


FIGURE 17

Similarity map

EXAMPLE IV.

Toromocho Porphyry Copper Deposit, Peru

In the case of the Toromocho porphyry copper deposit, the original data consisted of comprehensive conventional engineering maps, geologic maps, and assay data for 12 elements. Surface samples, samples for underground workings, and 2000 samples from approximately 150 drill holes were assayed. All data were computerized and recorded on magnetic tape.

On the basis of the area of influence of the known data, the deposit was divided into 26,000 blocks 45 m wide x 45 m long x 15 m thick. The original data set included assays for 12 elements; total copper, copper oxide, lead, zinc, silver, gold, molybdenum, bismuth, tungsten, arsenic, and antimony. It was determined that the most significant elements were total copper, lead, zinc, silver, and molybdenum. These elements were used as the basis for an "interpolated" (or "predicted") model of the mine. Using the method of Kriging, a mine model of assay values was constructed from the blocks of known metal content. This model was transformed into GRASP form for subsequent computer processing.

The following figures present a GRASP scenario which encompasses the retrieval analysis and display of the Toromocho mine model data. The scenario was executed on a Tektronix 4014 CRT (cathode ray tube) computer terminal. Due to the fact that the terminal is of the "storage tube" type display, image scrolling was not possible, and the scenario was interrupted each time the screen was filled. During each interruption, a hard copy was made off the screen image, the screen was cleared, and the scenario resumed. Thus, the eight figures that follow present a single scenario. In the figures, the user's response is underscored. Where the response is a carriage return, <u>(CR)</u> is indicated.

FIGURE 18

Initiation of "GRASP" scenario, selection of data base,

and display of stored variables

Following the login to the computer, GRASP is initiated by typing grasp. This places the user in GRASP. The data bases available on the user's account are first displayed. In this case, there are six, and amigo is the data base selected. Amigo contains the Toromocho mine model data. The names command invokes a display of the variables that comprise amigo.

For the Toromocho model, the unit record contains the data for each mine block which has six variables; index number, total copper, lead, zinc, silver, and molybdenum. The index number is a 6-digit integer (type code = 1) in which the first two digits represent the block number in an E-W direction, the second two digits represent the block number in a N-S direction, and the third two digits represent the block number in a vertical direction. The other five variables are real numbers (type code = 2) and represent the assay values for copper, silver, lead, zinc, and molybdenum, respectively.

```
grasp
WELCOME TO THE USGS GRASP RETRIEVAL SYSTEM.
AT THE CURRENT TIME THE FOLLOWING DATA BASES ARE AVAILABLE:

amigo   - kriged metal values for toromocha

corridas- toromocha runs for all holes

rassfl  - an initial RASS file moved from IBM

michop  - Michigan Oil & Gas pools

cribni  - Nickel records from the CRIB file on IBM

Uganda  - Edited Uganda data from the BGR

BEFORE ANY OF THESE DATA BASES MAY BE ACCESSED,
A DATA BASE FROM THE ABOVE LIST MUST BE SELECTED.


ENTER DATABASE NAME: amigo



ENTER COMMAND: names

WOULD YOU LIKE TO SEE MEANING OF TYPE CODES? no
CATEGORY: entire record
 NAME TYPE  DESCRIPTION
 ---- ----  -----------
index   1
cugd    2
aggd    2
pbgd    2
zngd    2
mogd    2
```

FIGURE 18

Initiation of "GRASP" scenario, selection of data base, and display of stored variables

FIGURE 19

Definition of new variables, selection of retrieval conditions, and establishment of logical relations between variables

By using the define command, the original six variables are transformed to a set of 11 new variables for use during the computer retrieval session. These 11 temporary variables are shown in figure 19.

Note that the first user entry in the define list is "read joe". This is a message to GRASP that says "a new definition list has already been created and is in a file called 'joe'; please read that file and load the definitions into the appropriate part of GRASP". Inasmuch as "read joe" is not a definition, GRASP does not begin numbering until the first definition entry of the file is actually read.

The new variable level is the height (in meters) of a block above sea level. It is calculated using the rightmost two digits of index. The mod function is used to decode index. In the context of the GRASP define command, mod is the remainder of a number divided by 10. Consider the following example:

<u>given:</u> index = 147925
bench height = 15 m
elevation of base of mine = 4200 m
<u>find:</u> elevation of the block
<u>solution:</u> a = mod (index) = 5
b = mod (index/10)*10 = 2*10 = 20
level = (a+b-1)*bench height = 4200 =
(5+20-1)*15 + 4200 = <u>4560</u> m

Similar calculations are performed in the conversion of index into a northing and an easting.

The formulas for converting assays to $/ton of rock are stored in a file called "dolval". To compute $/ton of rock from an assay value, the following formula is used:

$/ton = (volume) x (specific gravity) x (price/ton) x assay value
where
volume = 15 m x 45 m x 45 m
and
specific gravity = 2.7

Once the 11 new variables are defined, the next step is to specify the criteria for retrieval. In the example, the conditions specified are: (A) mine level = 4545 m., and (B) copper assay greater than 0.5%. The .and. relation between conditions (A) and (B) is specified by executing the logic command. This is invoked at the bottom of figure 19, and completed in figure 20. Thus, every mine block at the 4545 m level in which the copper content is greater 0.5% is to be retrieved.

```
ENTER COMMAND: define
ENTER LIST OF NEW VARIABLE DEFINITIONS (OR help FOR MORE INFORMATION)

 1. read joe
 1. level=((mod(index)+mod(index/10)*10)-1)*15+4200.
 2. y=mod(index/100)+mod(index/1000)*10
 3. x=mod(index/10000)+mod(index/100000)*10
 4. north=(y-1)*45+3328.91
 5. east=(x-1)*45+1776.91

 6. read dolval
 6. $zn=zngd*7.44*1.1023
 7. $pb=pbgd*3.1972*1.1023
 8. $mo=mogd*40.*1.1023
 9. $cu=cugd*10.28*1.1023
10. $ag=aggd*4.49*1.1023
11. $tot=$zn+$pb+$cu+$ag+$mo

12.


ENTER COMMAND: conditions

A. level eq 4545

B. cugd gt 0.5

C.


ENTER COMMAND: logic
```

FIGURE 19

Definition of new variables, selection of retrieval conditions, and establishment of logical relations between variables

FIGURE 20

Data base search, retrieval and output list specifications

After the conditions and logic commands are executed, the search of data is begun. GRASP does not require the name of the input master file to be specified, so a CR defaults the input file name to the name of the master file (that is, amigo). The name of the file into which the retrieved data are put is xxx.

GRASP indicates that it searched 25,578 records and found 259 blocks at level 4545 which had copper assay values above 0.5%.

To process the data further, a program called PLOTEM is used. The input to PLOTEM is a character file which is the output from GRASP written in columnar form. The list command is executed on the file xxx and the disk output option selected.

```
ENTER LOGIC: a.and.b


ENTER COMMAND: search

ENTER INPUT FILE NAME:

ENTER OUTPUT FILE NAME: xxx
ALL 25578 RECORDS OF amigo    SEARCHED.
      259 RECORDS FOUND WHICH SATISFY THE REQUEST.
THEY HAVE BEEN STORED IN xxx


ENTER COMMAND: list

ENTER NAME OF FILE: xxx

ENTER NUMBER OF LINES/PAGE:
AT EACH PAUSE PRESS CR KEY TO CONTINUE. TO ABORT ENTER A.
3 TYPES OF LISTING ARE POSSIBLE:
  C - COLUMN TYPE (DEFAULT FORMAT)
  U - COLUMN TYPE (USER FORMAT)
  R - ROW TYPE

SELECT C, U, OR R: c

WOULD YOU LIKE OUTPUT TO BE TO DISK? (y OR n): yes
```

FIGURE 20

Data base search, retrieval and output list specifications

FIGURE 21

GRASP exit to multics and PLOTEM initiation

When xxx is output to disk as a character file, it requires a name so that it can be identified later by PLOTEM. The assigned name in figure 4 is 14545. The variables to be written onto disk for the example are the easting, northing, copper assay, and "$ value of copper/ton of rock".

Once the data set 14545 is created, a multics command can be executed because GRASP permits access to any programs at the systems level. In this case PLOTEM is selected.

When initiating interactive graphics, it is necessary to specify the CRT terminal transmission rate. In this instance, the terminal is operating at a speed of 960 characters/sec (9600 baud).

```
ENTER NAME OF DISK DATA SET TO BE CREATED: 14545
ENTER THE LIST OF ITEM NAMES.

1.  east

2.  north

3.  cugd

4.  $cu

5.


ENTER COMMAND: multics
YOU MAY EXECUTE ANY MULTICS COMMAND,
SO BE CAREFUL. ENTER grasp TO RETURN TO THE GRASP SYSTEM.

ENTER MULTICS COMMAND: plotem
enter transmission rate in characters/second

960
```

FIGURE 21

GRASP exit to multics and PLOTEM initiation

FIGURE 22

Selection of file to be processed, variables to be evaluated and type of map to be generated by PLOTEM

PLOTEM asks for the name of the file to be processed (in this case, 14545), the number of variables and the positions in the record of the variables that correspond to the x and y directions of the map. A plan map is selected as the type of map to be plotted, and variable 3 (copper assay) is selected as the variable to be mapped.

For the variable, PLOTEM determines the range of the copper assay values, and prompts the user on whether or not to generate also a grade/tonnage curve. In this case, a grade/tonnage curve is desired and PLOTEM waits for the user to copy the screen and enter a CR to proceed.

```
please enter the name of the file to be plotted.
14545
enter the number of  variables, and the
field nos. of the x and y coords of the plot desired
4,1,2
please enter 1 if you want a plan map
             2 if you want an e-w cross section looking n
             3 if you want a n-s cross section looking e.
1
enter the variable number that you wish to plot.
3
data values range from      1.172 to     0.500.


enter 1 for grade/tonnage curve,
      2 to bypass.
1



enter  cr  to continue
```

FIGURE 22

Selection of file to be processed, variables to be evaluated and type of map to be generated by PLOTEM

FIGURE 23

Grade/tonnage curve

PLOTEM clears the screen and draws the grade/tonnage curve shown in figure 23. It should be noted these are the data that were retrieved originally and stored in xxx and then transformed to 14545. Thus, the grade tonnage curve reflects only those data. The ordinate is scaled to million metric tons of rock because each 45 m x 45 m x 15 m block contains approximately 82,000 tonnes.

Once the curve is drawn, PLOTEM waits for a <u>CR</u> to continue.

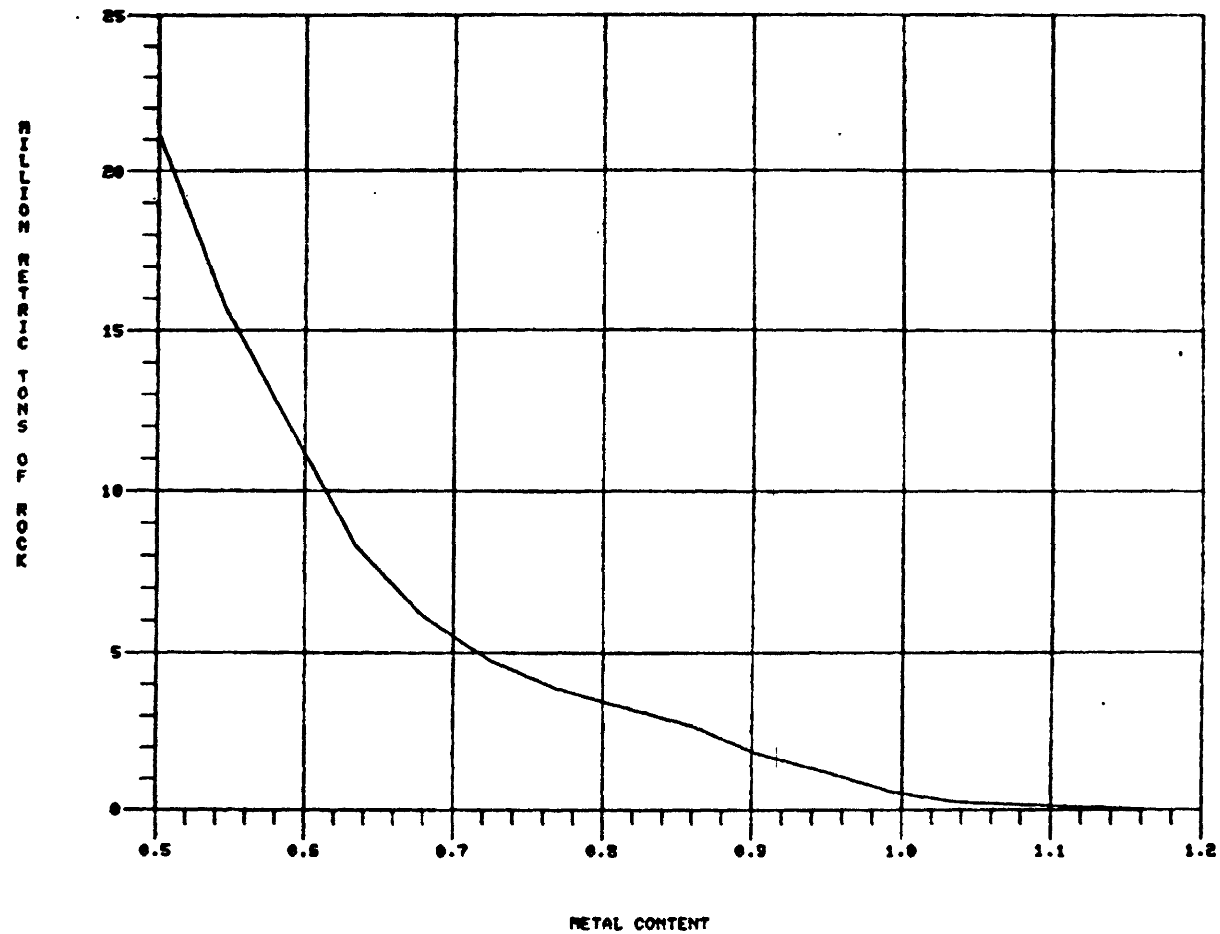


FIGURE 23

Grade/tonnage curve

FIGURE 24

Selection of contour intervals and frequency distribution generation

PLOTEM asks for the number of intervals into which the data will be divided, in this instance, four. Next, the five boundaries of the four intervals are specified, and the frequency distribution print-out option is selected.

PLOTEM prints the computer system clock time and this is followed by the frequency distribution. The time serves as a unique screen image identifier that can be used to sort the distributions (and their associated maps) generated during an active session.

PLOTEM asks for a title of the map to be plotted, pauses to allow for copying, and expects a CR to continue.

```
enter the number of contour levels in the freq. dist.
4
enter in ascending order, level boundaries.
.6,.7,.9,1.,1.2
enter 1 if you want a frequency distribution,
      2 if you wish to bypass printout.
1


08/11/78  0816.2 edt Fri


frequency distribution
  class          no. of    % of            million metric tons
interval         blocks   total            of rock
-------------------------------------------------
  0.60    0.70       73   51.77             5.987
  0.70    0.90       44   31.21             3.609
  0.90    1.00       16   11.35             1.312
  1.00    1.20        8    5.67             0.656


enter title
Toromocho, copper, .6,.7,.9,1.,1.2


enter  cr  to continue
```

FIGURE 24

Selection of contour intervals and frequency distribution generation

FIGURE 25

Plan map of data values

The final PLOTEM product is a plot of the values tabulated in the frequency distribution in figure 24. The numbers refer to the class in the frequency distribution. For example, "1" indicates that a block contains between 0.6 and 0.7% copper, "2" that a block contains between 0.7 and 0.9% copper, and so forth. "0" indicates that a block contains less than 0.6% copper which is the specified lower boundary for this particular run. The system clock time is printed also.

Plan maps such as the one shown in figure 25 are valuable aids in mine planning and for economic evaluation of mineral depostis. The dynamic flexibility, ease of calculation and subsequent graphic display afforded by GRASP coupled with PLOTEM offer a new dimension for the mining engineer or geologist. It is anticipated this approach will become commonplace within a few years.

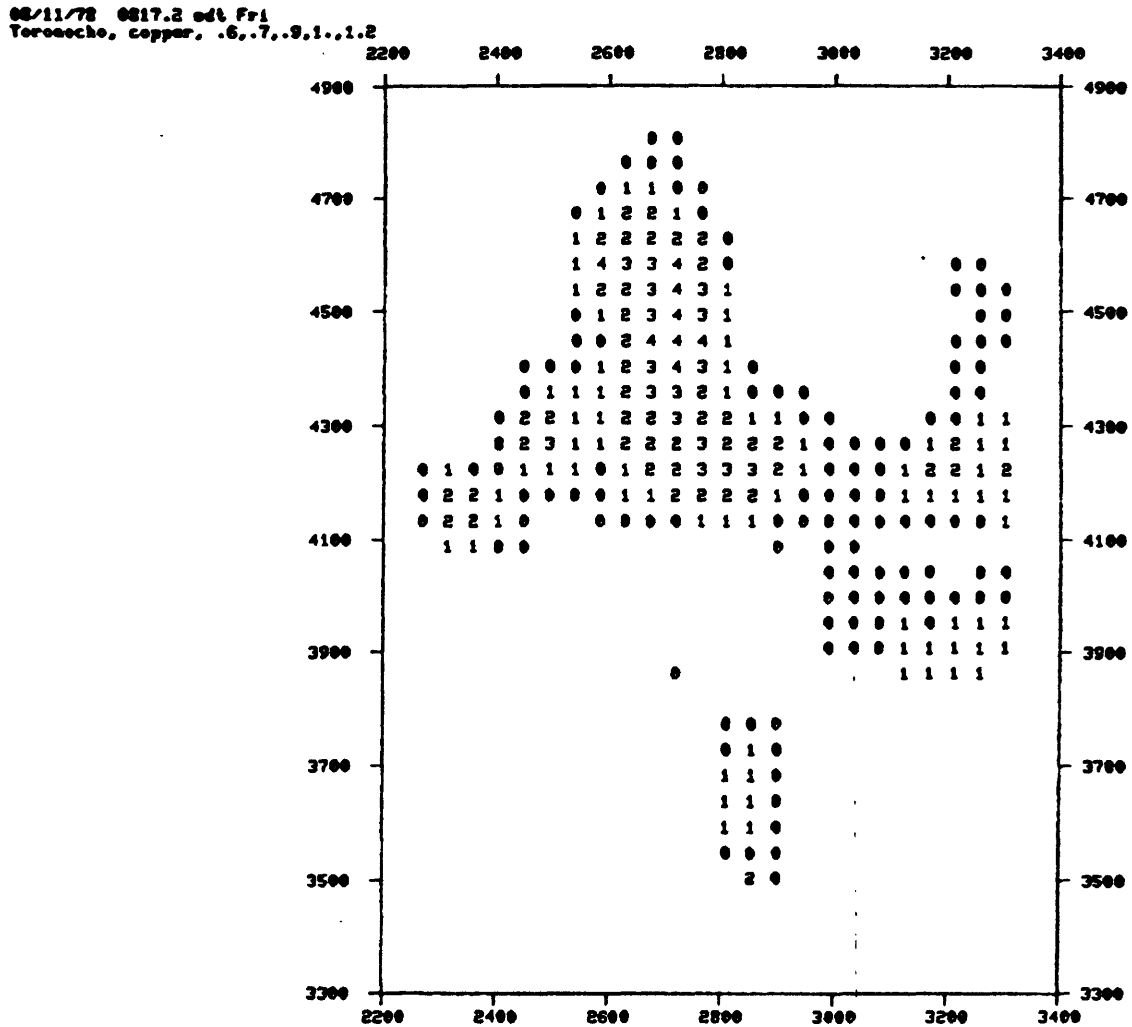


FIGURE 25

Plan map of data values

EXAMPLE V
Computer Applications Software for the National Coal Resources Data System

Software for the National Coal Resources Data System has been developed in two phases. Phase I software provides interactive retrieval and editing capability for access to, and modification of, the National Coal Resources Data Base. Results of retrievals can be summarized and tabulated in formats compatible with published coal resource documents. This part of the system has been operational for two years.

The Phase II software called GARNET is a set of interactive programs developed to aid the commodity geologist in analyzing and evaluating resources when dealing with irregularly-spaced, point-located field data. With this system of programs, the geologist can generate an interpolated grid surface based on measured values at each of a set of observation points. From these interpolated surfaces, the geologist can produce structure maps, coal thickness maps, maps showing the ratio of thickness of overburden to bed thickness maps, and resource maps.

Outcrop and political boundaries can be added to the data set by means of a digitizer. Thickness, overburden, or chemical concentration boundaries can also be added. The program allows for a variety of different combinations for computation. The resource maps produced are based on the standard reliability category distances from the point of field observation. Volume and tonnage values are computed for each reliability category and for each set of boundary constraints.

The calculations and subsequent map displays can be accomplished during a single session at an interactive graphics terminal. An option is provided, however, for creating a plot tape to produce maps off-line on a plotter if it is desired.

GARNET was designed to meet the growing need for more accurate and more rapid computation of coal resource inventories. It automates, in effect, those time-comsuming tasks that heretofore the geologist performed manually.

The following eight figures illustrate the applications for which GARNET was designed. A simplified set of data are used for the purpose of this workshop.

FIGURE 26

Contour plot of a topographic surface

Figure 26 is an illustrative example of a contour plot of a topographic surface. In the future, gridded data for actual surfaces will be provided by the Topographic Division in the U.S. Geological Survey and will be compatible with published $7\frac{1}{2}$ minute quadrangle topographic maps.

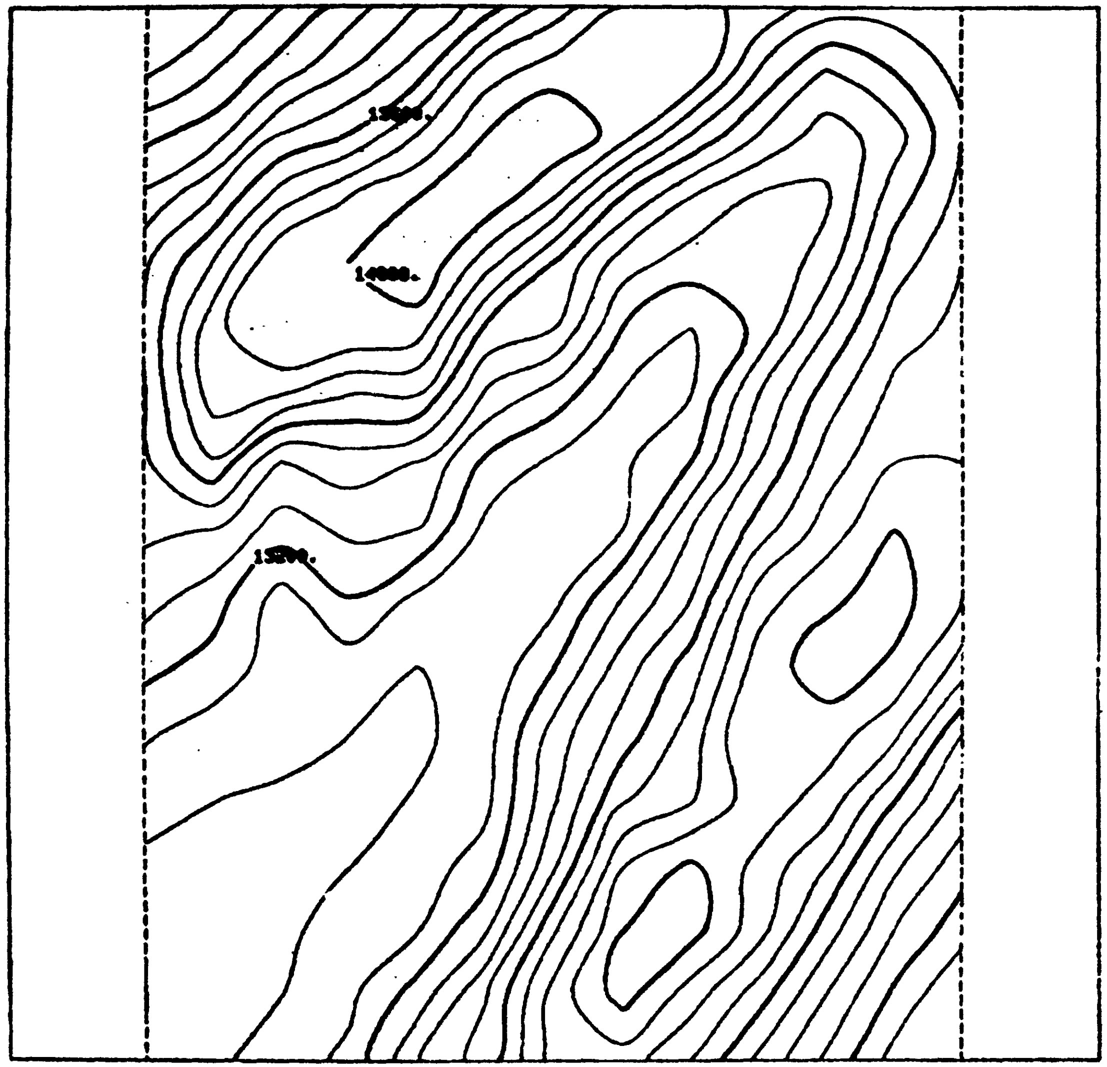


FIGURE 26

Contour plot of a topographic surface

FIGURE 27

Structural contour map of a coal bed

Figure 27 demonstrates the ability of GARNET to generate a contour map given a set of irregularly-spaced data points with the corresponding structural elevations of a coal bed. The irregularly-spaced points are processed by GARNET to produce a gridded data set. The gridded data are then used by GARNET to produce the contour map shown in the figure.

ELEVATION MAP OF COAL

STRUCTURE SURFACE

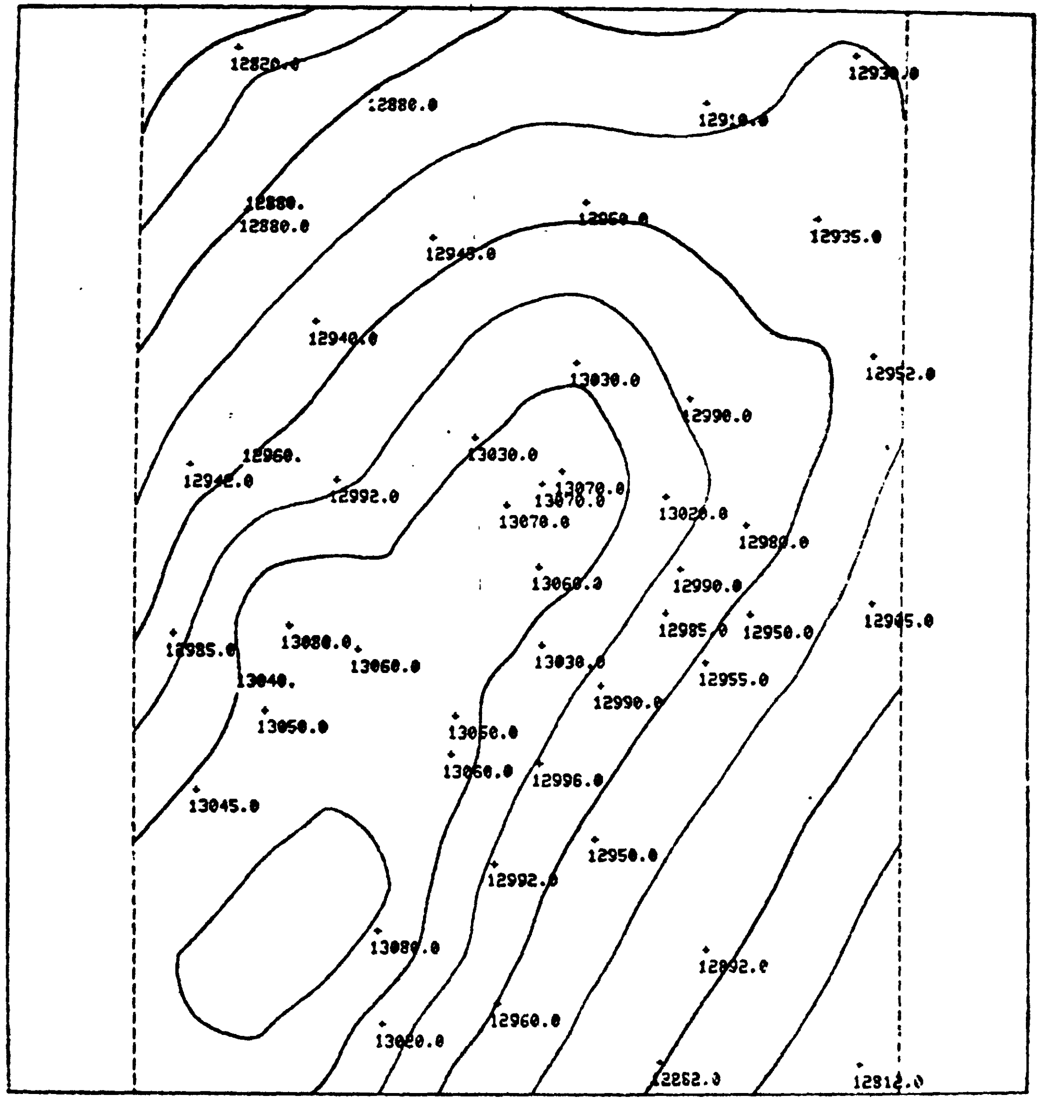


FIGURE 27
Structural contour map of a coal bed

FIGURE 28

Coal isopach map

Similarly, a contour map of coal thickness can be generated from the irregularly-spaced thickness measurements.

BED THICKNESS MAP

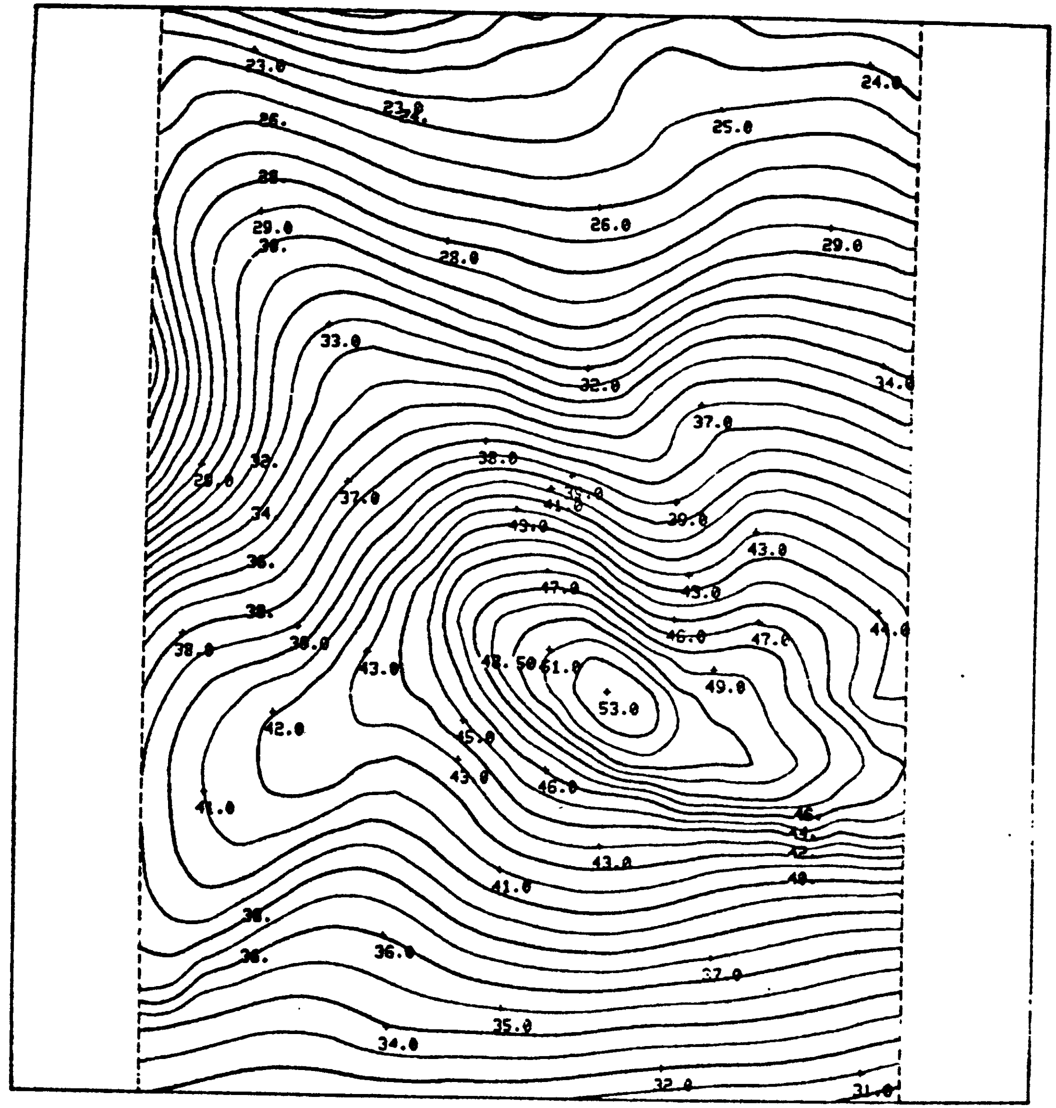


FIGURE 28
Coal isopach map

FIGURE 29

Thickness of overburden map

Figure 29 demonstrates the capability of GARNET to produce a contour map of the thickness of overburden obtained by subtracting the grid values of the structural elevation of a bed from the corresponding grid values of the topographic surface.

MAP OF OVERBURDEN DEPTH.

(TOPOGRAPHIC ELEVATIONS MINUS

THE STRUCTURE ELEVATIONS)

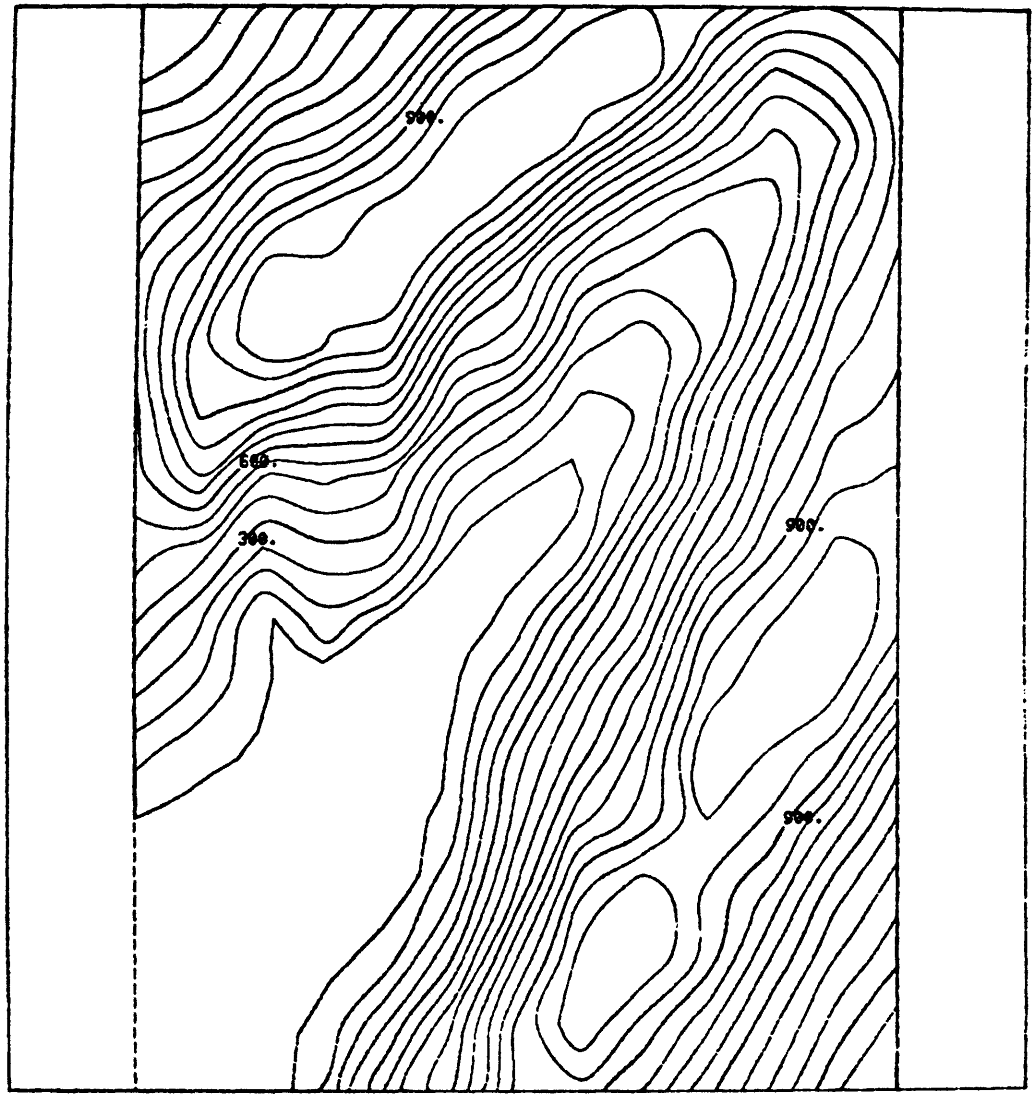


FIGURE 29

Thickness of overburden map

FIGURE 30

Ratio of thickness of overburden to coal thickness map

Figure 30 is a contour map of the ratio of the thickness of overburden to coal thickness, obtained by dividing the grid values from the previously obtained thickness of overburden map by the corresponding grid values for the coal thickness map.

OVERBURDEN-TO-THICKNESS RATIO MAP

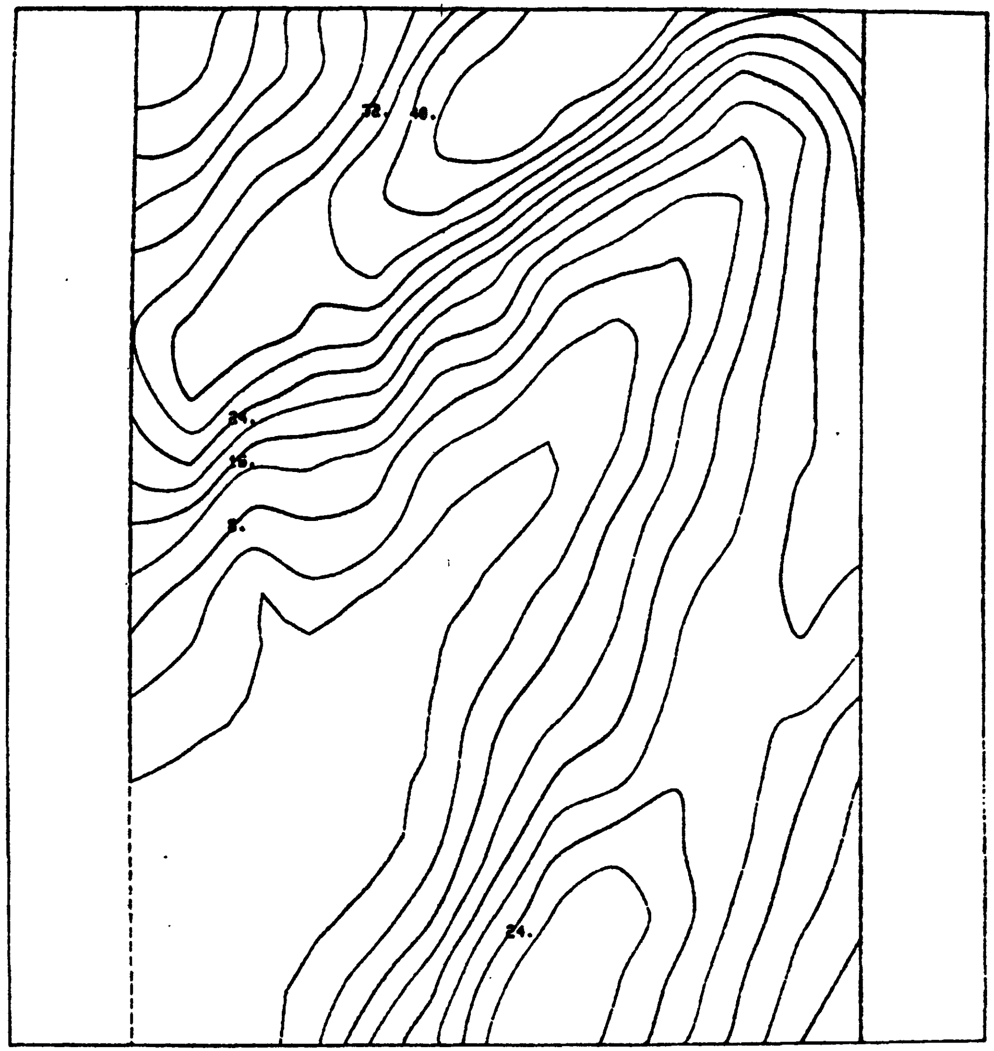


FIGURE 30

Ratio of thickness of overburden to coal thickness map

FIGURE 31

Example of coal resource map with eroded region excluded

Figure 31 is an example of a coal resource map consisting of an overlay of the coal thickness contours together with the observation points. A digitized boundary of the coal outcrop is used to exclude resource calculations for the eroded region (shown with the dashed contours). Resource volumes (and, hence, tonnages) computed for a radius of one quarter mile from the observation point (note smaller circles) define the measured resource category. Resource volumes computed from a radius of one quarter mile to a radius of 3/4 miles (note larger circles) from the observation point define the indicated resource category.

RESOURCE MAP WITH ERODED

REGION EXCLUDED

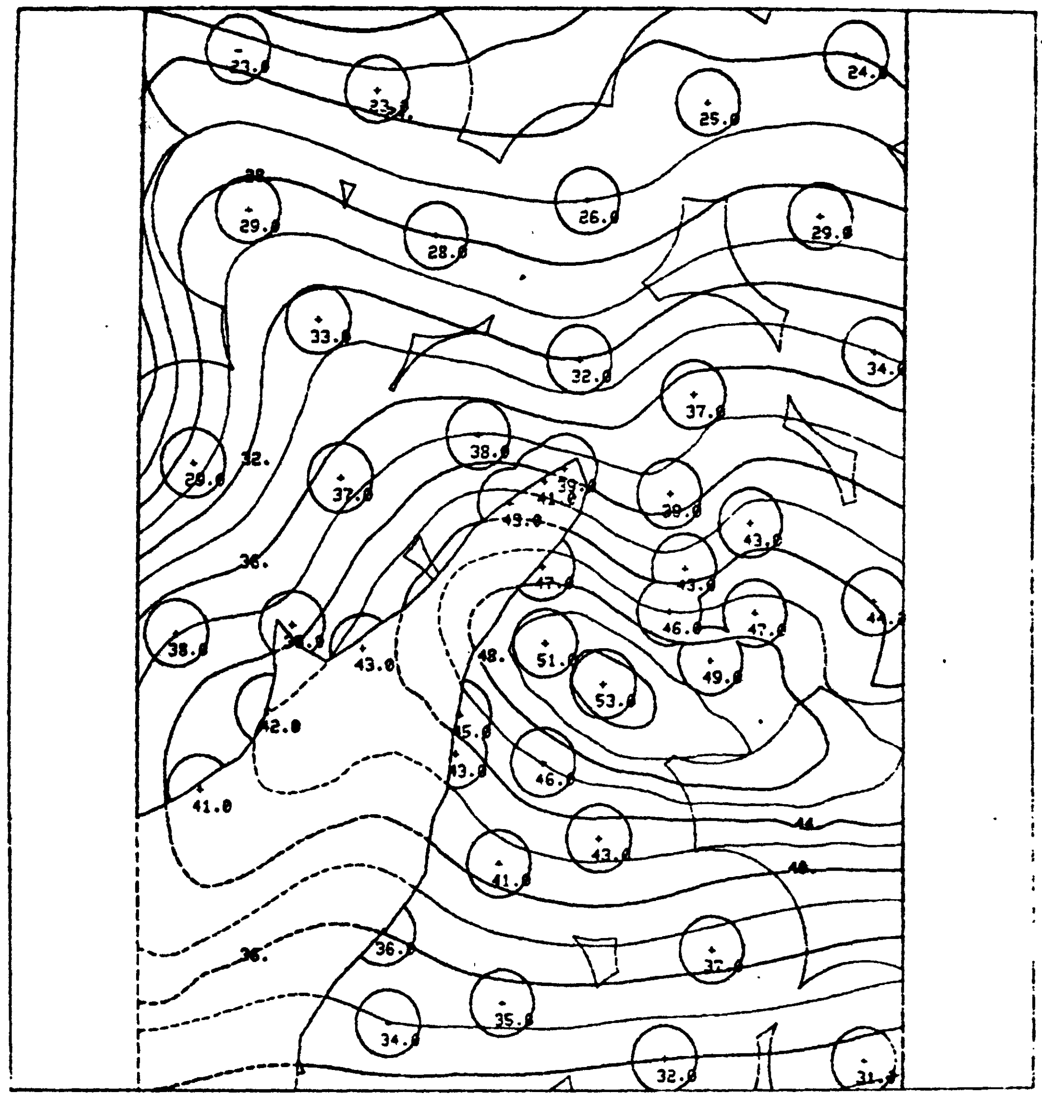


FIGURE 31

Example of coal resource map with eroded region excluded

FIGURE 32

Coal resource map which satisfies specified conditions

With GARNET it is possible to delimit regions satisfying specified conditions. For example, it is possible to delimit regions for which coal thickness is greater than 28 feet. If another region is delimited by a different condition, that is, a thickness of overburden to coal thickness ratio greater than 30, it is possible to combine these two regions into one which satisfies both criteria. An example of a resource map satisfying both of these conditions is shown in figure 7.

RESOURCES MAPPED FOR THICKNESS

GREATER THAN 28 FEET AND

OVERBURDEN-TO-THICKNESS RATIO

GREATER THAN 30.

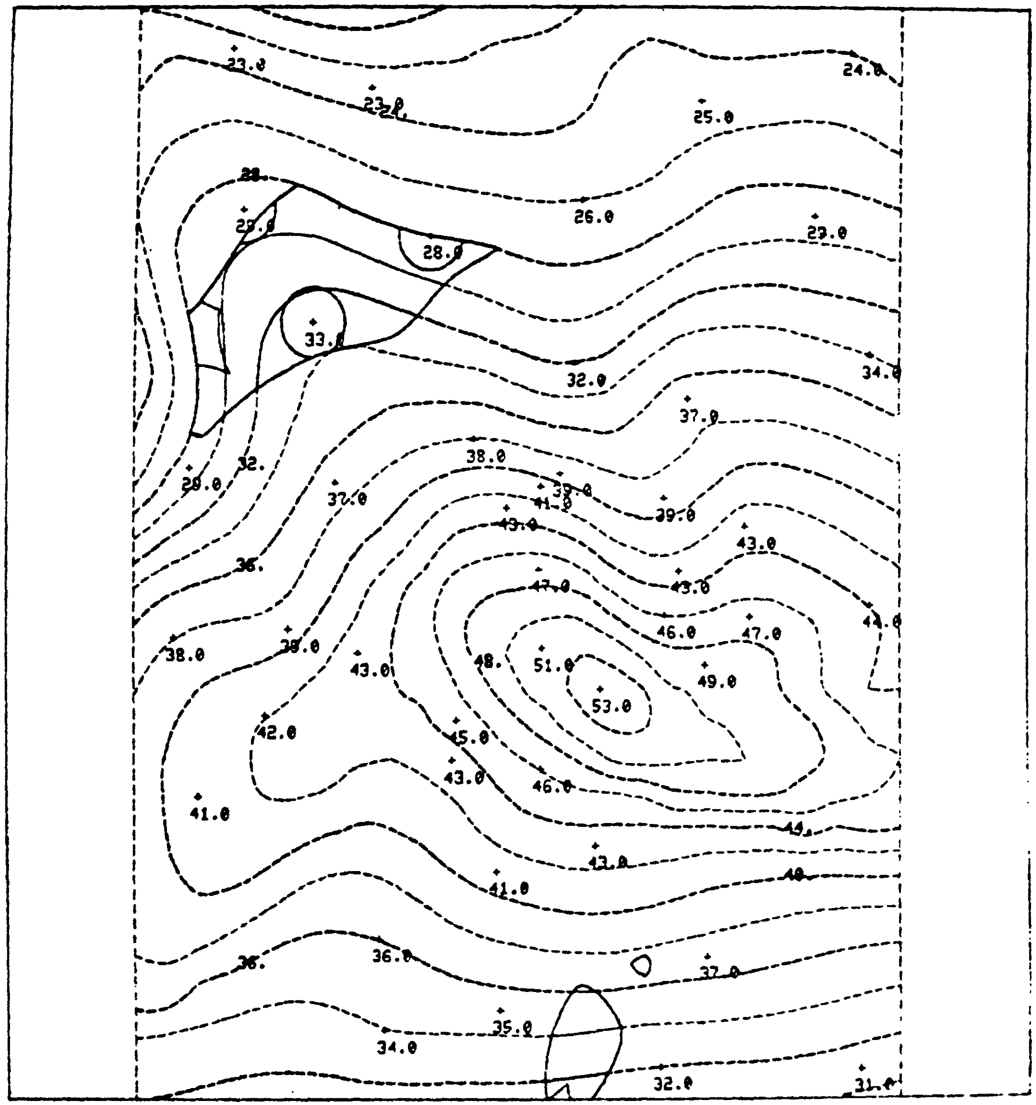


FIGURE 32

Coal resource map which satisfies specified conditions

FIGURE 33

Topographic contour map of USGS $7\frac{1}{2}$ minute quadrangle

Figure 33 shows a topographic contour plot computed from gridded elevation data supplied by the Topographic Division of the USGS for the Jewell Ridge Quadrangle. This file contains 62,272 gridded data points with a corresponding ground separation of 164 feet between grid points.

TOPOGRAPHIC PLOT OF THE JEWELL

RIDGE 7½ MINUTE QUADRANGLE

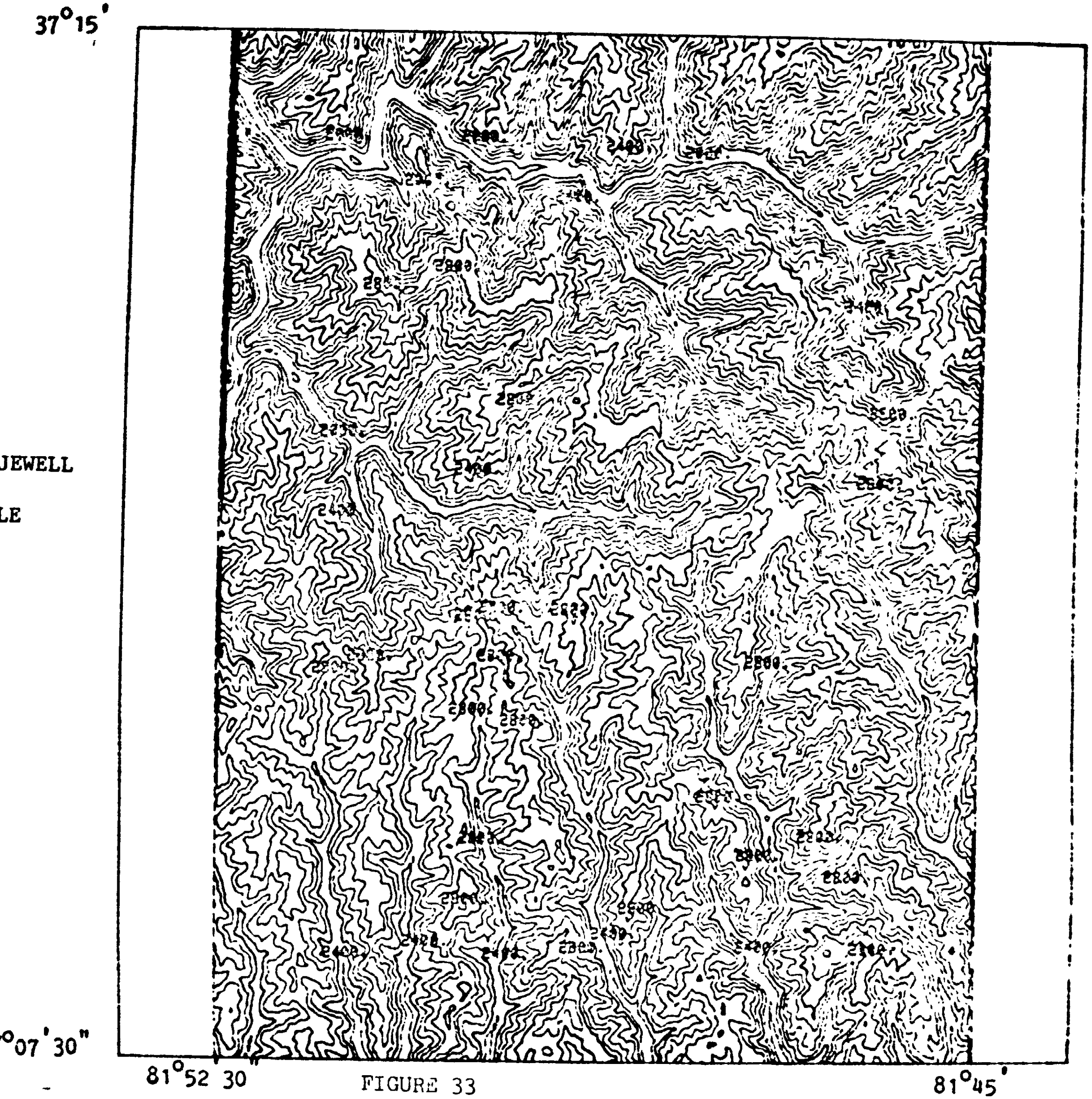


FIGURE 33

Topographic contour map of USGS 7½ minute quadrangle