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A MONITOR SYSTEM APPROACH TO
INFORMATION SYSTEMS RELATED
TO PETROLEUM EXPLORATION
AND PRODUCTION

By

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CHAPTER I

INTRODUCTION AND SCOPE

In recent years, there has been an increasing awareness throughout the world concerning the limited number of hydrocarbon reserves available. The task of the explorationist is becoming increasingly difficult, as the "easy" oil has been found. Yet the demand for oil and gas energy is increasing, and new pools and oil fields must be uncovered.

Through extensive research efforts, geological and geophysical methods have been found to be the most satisfactory for locating oil, but these are indirect methods. They indicate only the structural and stratigraphic locations where oil might be found. They give no evidence whatsoever as to whether there might be a significant accumulation at a depth of one, two, three, or even four miles below the surface of the earth. The only method that is available for answering this critical question is the exploratory well.

In view of the high costs and complicated methods used in oil exploration and production, it is essential that a computer-based, integrated information system be developed so that the decisions for locating the oil, drilling the well, and developing the reservoir can be properly and promptly made.

Scope of Thesis

In this dissertation, the author will generally review and discuss the existing exploration and production data processing systems and also develop a monitor system which is intended to organize and combine all related computer programs in such a way that the data processing procedures can be accessed and monitored through the monitor system.

The outlines and the sequence of discussion are described as follows:

System Hardware Configuration

Hardware covers the basic considerations in the selection of a computer-based information system, the differences between a commercial computer and a scientific computer system, and the special peripheral equipment required by the exploration and production data processing system.

Today, the industry witnesses two simultaneous trends; one is to use massive systems for massive operations, and the other is use the mini computer specially configured to handle special purpose operations.

Exploration Data Processing System

Exploration data, in general, will be used to locate the oil and gas reservoir. It can be subdivided as follows:

Geophysical Information System. That system provides a quantitative analysis about the subsurface structure by means of gravity, magnetic and seismic survey.

Geological Information System. That system provides detailed qualitative information about subsurface structure such as formation, lithology, fault and isopach.

Automatic Mapping System. That system displays the location of the reservoir by either two-dimensional contour mapping or three-dimensional perspective plot. The object of exploration efforts is to find out the geological structure under the earth's surface. A very efficient way to display the structural information is by the contour mapping which will tell exploration engineers and scientists where the reservoir is and how much the reservoir contains. Basically, contour mapping is a set of mathematical techniques to perform analysis and display of three-dimensional surfaces. The techniques are designed for the class of problems for which the surface is defined by a sampling of points on the surface.

Production Data Processing System

Petroleum production deals primarily with drilling the producing wells and developing oil and gas reservoirs.

Optimal Drilling System. This is a real time computer controlled system which is so designed that the cost of drilling will be reduced by maximizing the efficiency of operation.

Petroleum Production Evaluation System. This evaluation system represents a series of computer programs designed to analyze the flow of oil, gas and water in a reservoir.

The computer program calculates individual well pressures and individual well production characteristics and compares these calculations with the observed field data gathered over the life of the reservoir. When an adequate comparison is obtained, the reservoir model is now capable of predicting future performance. Many alternatives can be evaluated such as increased production rates, infill drilling, and secondary recovery techniques when predicting future performance.

Reservoir Simulation System. This system is designed to simulate mathematically the complex interaction of natural forces and physical properties under actual field conditions.

Computerized Investment Planning System. This system provides a means for reservoir engineers and management to combine data and assumptions within an analytical planning system which quickly and effectively integrates these data in developing an optimal solution and operating guide lines.

Automatic Reservoir Calculation System. The reservoir parameters such as pay zone (oil production zone) thickness, porosity, permeability, and hydrocarbon saturation calculated from the well logging system will be automatically fed into this system. The output is the total hydrocarbon volume in the reservoir and the total volume of oil which can be produced (movable oil).

Monitoring System

Since the information system for petroleum exploration and production involves tremendous amounts of computer hardware, software, and highly complicated technology, it might take the industry several years' effort to develop and accomplish an integrated information system.

One way to solve the problem, at least to a certain extent, is to develop an information monitoring system which has the capability to retrieve all kinds of data-based files and also has the capability to access each of the exploration and production subsystems. After the data have been processed, the results will be reported or displayed through a computer output unit.

An efficient way to monitor the whole system is to use an interactive computer language through a cathode ray tube graphic terminal which permits the users to select the functional programs and edit on-line the operational procedures. Through this computer graphic terminal, an exploration scientist or a production engineer can continuously test his data with various models until the optimal solution or answer is found. Then, he can push a button on the terminal and a photostatic copy is made from a hard copy device.

In this dissertation, the author intends not only to review the existing automatic data processing system, primarily the computer software and application theory for petroleum exploration and production, but also to envision the trends and demand for automation in the future.

The monitor system developed by the author is primarily intended to present an idea, a "TOTAL SYSTEMS" approach concept (Eldin, 1968), to illustrate how an information system can be organized and integrated in such a way that the overall efficiency of the system can be improved. However, in the real world implementation, the scope of application in the design of an integrated information system has to be modified or rectified, depending very much on the computer hardware capability, software availability and complexity of the application involved.

In a more practical sense, particularly, in view of the complexity of petroleum exploration and production involved, there are difficulties in the development of a unique data-based file system and retrieval procedure to cover all the exploration and production data files. Thus, it is more practical and feasible to integrate an information system regarding petroleum exploration and production to a lower subsystem level. In other words, to develop systems for geological, seismic, gravity and magnetic and production application respectively. Nevertheless, the trend to develop an integrated information system in the petroleum industry is unique and obvious.

Furthermore, the author realizes that an effective integrated information system should be designed by the user of the system. However, creative system analysts have a considerable contribution to achieve this goal. The efforts presented in this research are

directed toward the data processing aspect of the information system and does not in any way claim to be presenting solutions to problems that the petroleum industry has spent millions of dollars to explore during the last decade.

CHAPTER II

SYSTEM HARDWARE CONFIGURATION

The petroleum industry is one of the most advanced industries in implementing the automatic data processing system. The selection of a data processing system, however, can still be a harrowing experience for all concerned. Even today, after the first decade of digital processing of their data, the exploration scientists and production engineers are still not thoroughly familiar with digital computing systems. On the other hand, specialists in digital computing and related equipment often do not have the depth of knowledge and experience which would allow them to design the ideal system for oil exploration and production.

It is evident that the combination of the computer technology and exploration and production experience will bridge the gap. As a result, an ideal information system can be derived. Lindseth (1971) has made an extensive study on the Digital Equipment for Exploration Data Processing. Some of the ideas are presented below.

The Selection of a Computer-based Information System

In spite of recent advances in design technology, there are still two basic types of computers. One type is designed for commercial and business type processing; the other type is designed for scientific and engineering calculations. The two applications are not compatible and it can be stated that with few exceptions a scientific processing system will not be efficient on commercial applications. As machines increase in size the difference diminishes. Recent improvements in design technology tend to diminish the differences as they apply to the central processor.

Commercial machines are basically designed to handle a large number of relatively small transactions.

Some geological applications fit this system very well. Geologic data files in which well tops are retrieved from a digital tape file, subsea, or perhaps isopach, calculations made, and the output listed, is in many ways similar to a commercial application and a commercial machine may be well suited for this work.

A scientific machine concentrates on numerical calculations. Numerous complex numerical calculations are often repeated millions of times and require very high-speed processors, with the ability to handle large numbers, and often with specially designed mathematical units to perform certain mathematical functions. Perhaps the most typical application of this type in the exploration industry is

seismic data processing. Enormous blocks of numerical data are input to the machine and subject to extremely lengthy and complex calculations at very high speed in order to perform digital filtering and related mathematical processes.

Until recently, small machines which would perform these operations for seismic data did not exist; only medium to large size systems were capable of handling the huge volumes of data and the extremely lengthy calculations at reasonable cost. The total capacity of any of these machines was nearly always very large, and the basic operating costs high. Therefore, they could not normally be justified economically unless a large volume of input data on a continuing basis was available to them.

For some time, the tendency of many centers has been toward ever larger computer systems in which all possible work is consolidated for operations on a single large system. However, many people have found to their sorrow that increasing the size of a single system to handle combined loads of different processing requirements resulted in a drop in productivity and an increase in expense. Many of the new so-called mini-computers actually have the speed and power of the medium to large size systems of five to ten years ago.

Today, the industry witnesses two simultaneous trends: one to massive systems for massive operations, and the other to a proliferation of small systems specially configured to handle special operations. In many cases, other desirable conditions are also

considered, such as the effort to better apply the computer to one use to which it is well adapted, as an extension to the human mind, performing very high-speed routine tasks of sorting, classifying and calculating, to provide the analyst and interpreter with data in a form readily usable for decision making.

Special Hardware Configuration

Any system used for processing exploration and production data of any kind will require a number of additional special purpose devices which will not commonly be found on standard equipment configurations. Some of these are very expensive, but in some cases are necessary to perform the processing operation successfully. Some of the special-purpose output devices may be operated as a separate off-line operation, rather than connected directly to the computer; generally, output on high-speed magnetic tape which in turn is read by a separate lower speed tape drive attached to the off-line output device.

A current design trend is to connect off-line devices to a very low cost mini-computer. The unit will often have fairly extensive programming capabilities so that the special purpose device is essentially a small auxiliary computer system. The flexibility of a programmable computer offers many advantages over the more traditional hard-wired control units for special purpose gear and is today for many applications actually cheaper. This was not the case a relatively short time ago. One of the greatest arguments against

multi-use computer systems is that one or more expensive pieces of peripheral gear may be idel except for the time when a specific type of data is being processed. A complete, smaller, special configuration may be no more expensive in total than the special peripheral gear attached to the large system, and provide much more convenience and greater capabilities for the user.

The special configurations consist of one or more of the following special peripheral devices.

Fast Computation Units

The most elementary of these devices is a simple hardware multiply instruction. All computers have the ability to add numbers, but many, particularly the small and the commercial models, perform the multiplication operation by a software program. A standard hardware option for practically all of these is a hardware device to allow direct multiplication to be performed. Any scientific system would include one of these as a necessary item.

The hardware multiply and, to a lesser degree, the hardware floating point are frequently standard options for many computer systems. A slightly more complex instruction which is strictly special-purpose is the multiply/add instruction developed by some manufacturers. This allows a multiplication to be performed and the result summed to a previously stored value as a single operation, simplifying programming and increasing the speed for this commonly used operation.

Thus far, the special additions are all modification to the basic central processing unit and provide limited increases in performance. They may be insufficient for many geophysical data processing applications, particularly so-called filtering operations, such as time domain convolution and cross-correlation procedures, so a number of special purpose arithmetic boxes have been designed to perform special operation in conjunction with or parallel to the central processor. The first of these devices introduced was the convolution unit designed for most of the computers used for seismic data processing. This high speed unit attached to the system performs the convolution operation in an arithmetic unit separate from the central processing unit.

It soon became apparent that a special arithmetic unit to perform the Fast Fourier Transform algorithm would provide an even greater increase in throughput, so a number of these were designed and are available for many makes of computers. The apparatus is similar to the convolution box but performs the Fast Fourier Transform instead of the convolution function.

The next step was to combine these two functions into a single box and, in some cases, add certain other capabilities which make the unit especially well adapted to signal processing. The result of the combination is a device which is usually termed an array processor or array transform processor. These range in size from the small minicomputer attachment worth some \$20,000 to huge systems

costing several hundreds of thousands of dollars. Essentially, they all perform similar operations, the only difference being in capacity and speed.

Graphic Display Units

The extremely large volumes of data which are handled by all exploration personnel require some quick and readily comprehensible form of data output. Maps, charts, graphs and so forth have long been used as means of effective and rapid data presentation, and many devices have been developed which are capable of producing computer output directly in this form.

The seismic plotter has always been a substantial part of the seismic data processing system. In relation to the new powerful mini-computer system, no completely acceptable alternative to the high quality film output section at a reasonable price has been introduced to this date. However, a very acceptable substitute is provided by the high-speed electrostatic printer device.

The electrostatic printer develops the output image in much the same form as the faster developed on a television screen. A sequence of closely spaced lines is developed, each made up of a series of dots in a form which then plotted will form an image. The operation is extremely fast, equivalent to approximately 5,000 printer lines per minute, or a few seconds per seismic record.

Plotters are extremely versatile under control of proper computer software. They may produce practically any graphic output, maps, charts, sections, and other displays that are used by geologists. Unfortunately, even the fastest is a relatively slow device compared to most computer operations. Hence, standard procedure is very often to operate the graphic plotters as off-line units. The desired information to be plotted is recorded on a digital magnetic tape. A slow speed tape reading unit is attached to the plotter through a control unit, reads the tape and feeds it to the plotter at an acceptable rate. As mentioned earlier, newer plotting systems now almost invariably use a mini-computer and the control unit. The low cost of the mini-computer and increased sophistication in software permits, in many cases, the full geologic processing operation to be done on the mini-computer, again permitting direct control over the system by the exploration scientists and reservoir engineers.

Interactive Graphics Terminal

The use of interactive computer graphics enables the engineers and scientists to communicate with the computer directly. They can access and retrieve the huge data immediately. After examining the display on the screen, they can edit and modify the data immediately, then may apply a variety of numerical models and display the results in the form of contour map or report chart. If the result is satisfactory, by pushing a button, a photostatic copy is made from a hardcopy device.

One of the interactive display terminals has been developed and manufactured by Tektronix, Inc. The hardware of this display terminal consists of five components: (1) CRT (Cathode Ray Tube) Display Unit, (2) Programmed Function Key Board, (3) Joystick, (4) Alphanumeric Keyboard, and (5) Graphic Tablet.

The terminal is a direct-view, storage-type cathode ray tube display terminal. It is capable of printing characters, symbols, lines, and vectors. It also has an alphanumeric keyboard for transmitting to the computer. The terminal can generate graphics data on the display unit and send graphics data to the computer by use of a "Joystick" and the "Graphic Tablet". The Program Function Keyboard is used to interact with the computer operating system and with the user's graphical interactive application program.

CRT Display Unit. The display unit, as shown in the upper half of Figure 1, contains a direct-view storage CRT. The surface of the display unit acts as the CRT terminal's memory, and serves the double purpose of image storage and viewing screen. Once data is written on the surface of the display unit, it remains visible for more than 15 minutes without noticeable degradation. To clear the viewing surface for fresh data, the screen of the display unit erases in one-half second. The display can also present a "non-storing" cursor, which can be moved about on the screen. The cursor is useful for locating beam position and for graphic input.

The Tektronix display screen is approximately 8-1/4 inches wide by 6-1/8 inches high. It contains 1023 by 760 addressable points, normally referred to as raster units. The origin or (0.0) point on the display surface is at the lower left corner of the screen.

Joystick. This device allows the user to conveniently converse with the computer system and his program in a graphic dialogue. Pictures can be drawn on the screen by the user and the data transmitted to the computer as it is being drawn. Also, screen locations can be identified to the program.

Alphanumeric Keyboard. The Tektronix keyboard as shown in the lower half of Figure 1 contains 72 keys. As each key is struck, data representing the associated character is transmitted to the computer. The characters transmitted are also displayed on the CRT screen under normal circumstances.

Graphic Tablet. The graphic tablet is a graphic input device. It is used to input locational data from the 11-1/4" x 11-1/4" tablet surface. The tablet surface represents 1024 x 1024 raster units with (0.0) being at the lower left hand corner. The locational data is defined by the use of an electronic stylus pen, and the input must be initiated and terminated by using the PFK keys, with subsequent entries made by pressing the stylus pen point to the tablet surface.

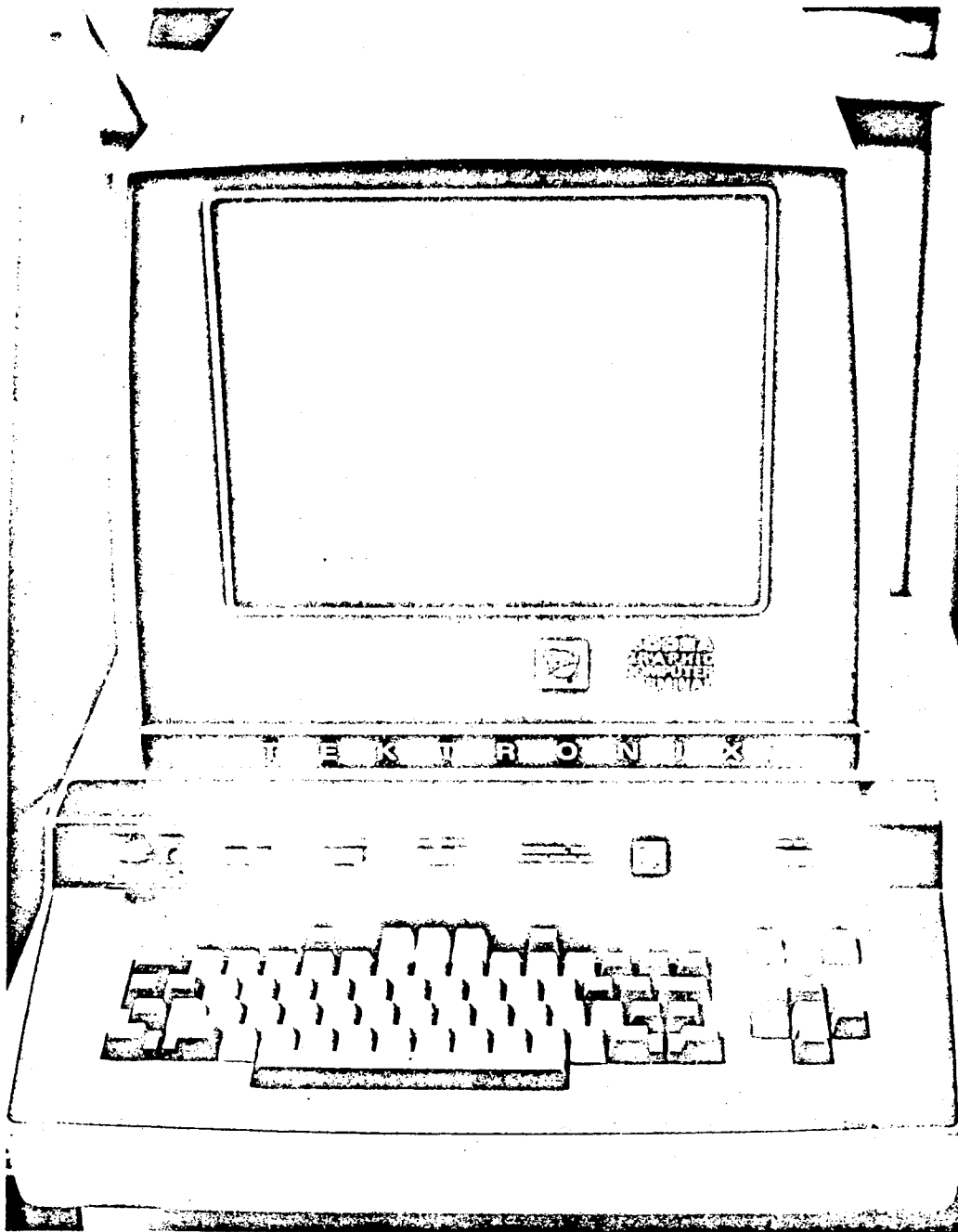


FIGURE 1

CRT DISPLAY UNIT

Virtual Storage Computer

In the petroleum industry, there are a great number of application-oriented programs designed to solve one of the exploration and production problems. Each of those programs may occupy several hundred thousand storage units (bytes). An integrated information system such as this paper intends to develop will combine all the exploration and production programs into a unique system. This system will occupy, once being brought into the computer, such a great amount of memory storage that no existing system can provide enough storage space unless extensive programming efforts are made to overlay each of these subsystems. Another way to solve the problem is to use the virtual storage computer system such as the 370/VS developed by IBM (1972).

Virtual storage -- an image created by system control programming -- is the functional equivalent of a computer's main (real) storage. Virtual storage techniques can create an apparent address space far in excess of the real storage capacity of the computer.

The contents of virtual storage are physically located in real storage and in auxiliary disk storage. Real storage is used in conjunction with the auxiliary storage in such a way that the virtual storage address space, rather than the limited space of real storage, is available for program instructions and data. Hence, in many cases, the programmer is relieved of many of the constraints

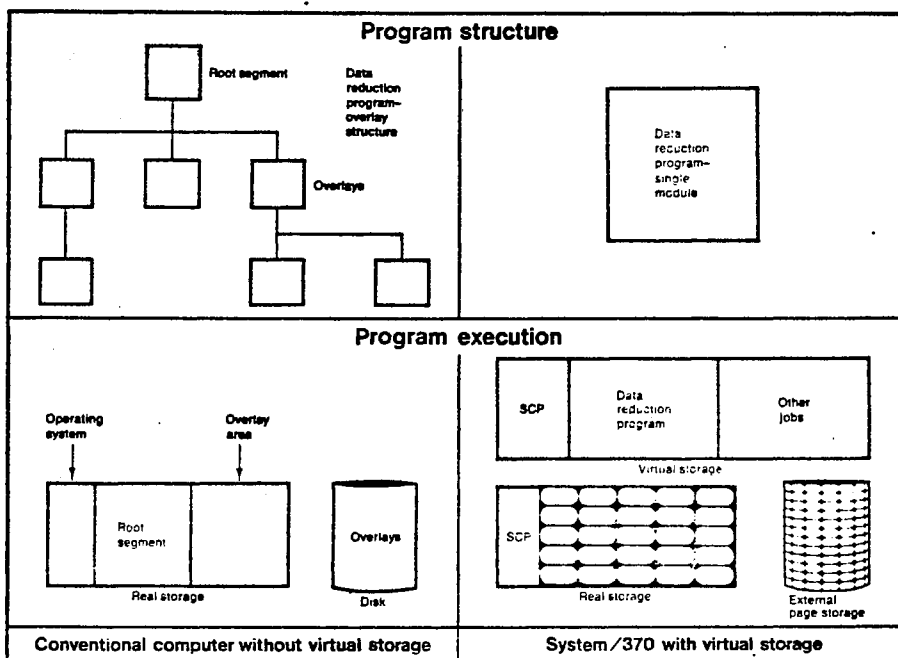
imposed on him by the size of real storage, and his productivity may be enhanced.

With virtual storage, users may experience much greater flexibility in the designing and programming of applications. Less time can be spent maintaining current programs, and jobs can be scheduled and run with greater freedom. In general, the more ambitious the application, the more the user should benefit from virtual storage, especially in terms of integrated data bases, communications systems for tying together a company's operations, terminal services for programmers, and on-line data entry.

A basic requirement for implementing virtual storage is a mechanism for dynamic address translation -- that is for converting an address in virtual storage to an address in real storage. Dynamic address translation (DAT) involves a table look-up process for finding the appropriate real address when a page in real storage is referenced, and for signalling when a page must be brought into real storage.

Figure 2 illustrates the concept of virtual storage in comparison with the conventional computer.

With virtual storage, new applications can be easier and less costly to install, and they are available to a wider range of data processing installations. Analysts and programmers can concentrate on the problems of the application itself, rather than on those created by limited main storage.



A LARGE DATA REDUCTION PROGRAM RUNS ON A CONVENTIONAL COMPUTER AS SHOWN AT LEFT: BECAUSE REAL STORAGE IS LIMITED, THE PROGRAM IS DIVIDED INTO A ROOT SEGMENT AND SEVERAL OVERLAYS. THE ROOT SEGMENT RESIDES IN REAL (MAIN) STORAGE AND THE OVERLAYS IN DISK STORAGE, FROM WHICH THEY ARE BROUGHT INTO REAL STORAGE AS NEEDED. WITH VIRTUAL

STORAGE, ILLUSTRATED AT RIGHT, THE PROGRAM CAN BE WRITTEN AS A SINGLE MODULE WITHOUT OVERLAYS. IT RESIDES, AS PAGES, PARTLY IN REAL STORAGE AND PARTLY IN DISK (EXTERNAL PAGE) STORAGE. PAGES ARE BROUGHT INTO REAL STORAGE AS NEEDED. MEANWHILE, VIRTUAL STORAGE IS LARGE ENOUGH SO THAT OTHER JOBS CAN BE PROCESSED AT THE SAME TIME.

FIGURE 2
 VIRTUAL STORAGE COMPUTER IN
 COMPARISON WITH CONVENTIONAL COMPUTER

Considerations in System Design

For practically any seismic application, the central processing unit should have a cycle speed of approximately one microsecond. The upper limitation for practical processing is probably somewhere around 4 to 8 microseconds, with the range from 1 to 2 being the most common. Addition and multiplication speeds also have a substantial bearing on seismic throughput. Hopefully the add time will not be much greater than 2 basic cycle times and a multiply time not more than 8 to 10 times. In most of these applications, hardware multiply will be required to obtain adequate speeds.

A minimum of 2 magnetic tape drives will be required for any geological or geophysical system, and an additional one is preferable. The possible exception is a minimum geological system in which the output is directly placed on a plotter or printer. This is rather an unusual case.

Most recently, with the advent of very high performance, low cost mini systems, much of the exotic and mystical nature is being removed from computer installations and they are becoming more of a working tool.

The trend toward ever larger systems continues, as it should be, for uniform loads which expand through natural growth.

CHAPTER III

GEOLOGICAL INFORMATION SYSTEM

For any given project, the geologist is faced with the tasks of gathering, sorting, classifying, filing, retrieving, reducing, displaying, and interpreting data. As more and more information becomes available, more time is required for gathering, sorting and filing, etc., and often too little time is devoted to interpretation. At this point, the geologist is not being used effectively, and the feasibility of a data information system coupled with an efficient and flexible retrieval program becomes quite apparent. Thus, the concept of a data information system is one of the most obvious applications of the computer in geology.

With many of the more arduous tasks of data filing, sorting, and retrieving now done by the computer, the geologist is given more time for data reduction, display and interpretation. It will be seen that data reduction and display can also be done with considerable effect by a computer. Once data has been retrieved from the information system, maps can be contoured, cross sections plotted, and other types of geologic modeling can be done. The displaying of retrieved data is another major application of the computer in geology.

The GEOLOGICAL INFORMATION SYSTEM consists of a series of computer programs and files such as general well data files, well data retrieval program, cross section program, grid generation program, trend surface analysis program, contour mapping and perspective display program. (CDP,1971)

Harbaugh and Merriam (1968) in "Computer Applications in Stratigraphic Analysis" discussed the theory and methodology of a geological information system fairly extensively. One of the most comprehensive geological information systems which offers service to the petroleum industry was developed by Computer Data Processors in Calgary, Canada. The author together with Hessing, Pierce and Powers (1972) presented algorithms and procedures used for automatic contour mapping and surface interpolation which honor every input data point. This chapter is based primarily on these publications and other articles. Figure 3 illustrates how these various programs are linked, one to the other, to form the system.

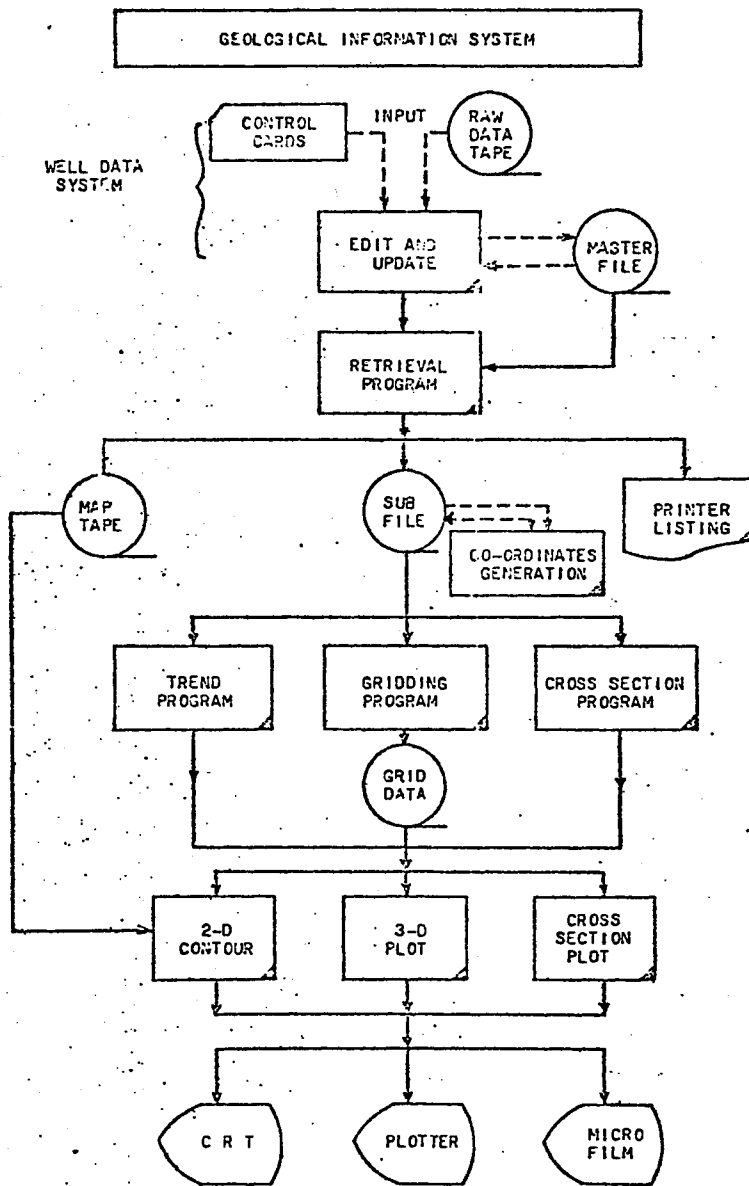


FIGURE 3
 GEOLOGICAL INFORMATION SYSTEM

Well Data Information System

Practically all information relating to any given well drilled for petroleum, whether a dry hole or a producer, has potential value. Some of the information will be of interest to the geologist, some to the geophysicist, and some to the petroleum engineer. Many of the potential uses will overlap, with the same data being used for different purposes. Such pooling of well information into a single file is commonly referred to as an Information System or Data Bank. Most explorationists will refer to it as a General Well Data File.

Petroleum Information, in cooperation with the petroleum industry, has developed data files containing information on approximately 600,000 wells drilled in the United States. These files provide the most valuable information for future oil exploration.

The generation and maintenance of the file system and the contents of the file are discussed as follows (CDP, 1971).

A retrieval program has been written to selectively retrieve items of information from the File, according to each User's requirements and these, in conjunction with the other programs (Contour, etc.) can save the geologist a lot of time on a routine basis.

Data Collection

In designing the initial data gathering procedure, every effort is made to use directly all existing items of information. If some of the data is in digital form, a suite of conversion programs will

be used to read the existing data from the old file and reformat it to be compatible with the new file.

However, the largest portion of data that will normally enter into the file will consist of old hard copy reports. The system is therefore designed to effectively gather, transcribe and keypunch this data to be merged into the master file. The data flow must continue for the gathering of information for all new wells (See Figure 4).

Edit Update Program - Geofile

In order to maintain a CURRENT FILE of data which is essentially error free, the program GEOFILE performs an edit on each feasible item of information before entering data on the file. Only those items of information which successfully pass the various edit and logic checks are entered onto the CURRENT FILE.

1. To be accepted by the various edit routines, and subsequently be entered on the File, every well must contain: valid unique identifier, valid initialization date, valid reference elevation, and valid total depth.
2. All subsequent dates to be entered on the FILE must chronologically fall between the initialization date of the well and the date of the UPDATE run.
3. All subsequent depths to be entered on the FILE must fall between 0 and the entered total depth of the well.

4. Certain items of information such as depths, dates, elevations, pressures, coordinates, etc., must fall within certain prespecified limits.
5. All fields of information are edited for illegal characters.
6. Certain groups of information together must pass specific logic checks.

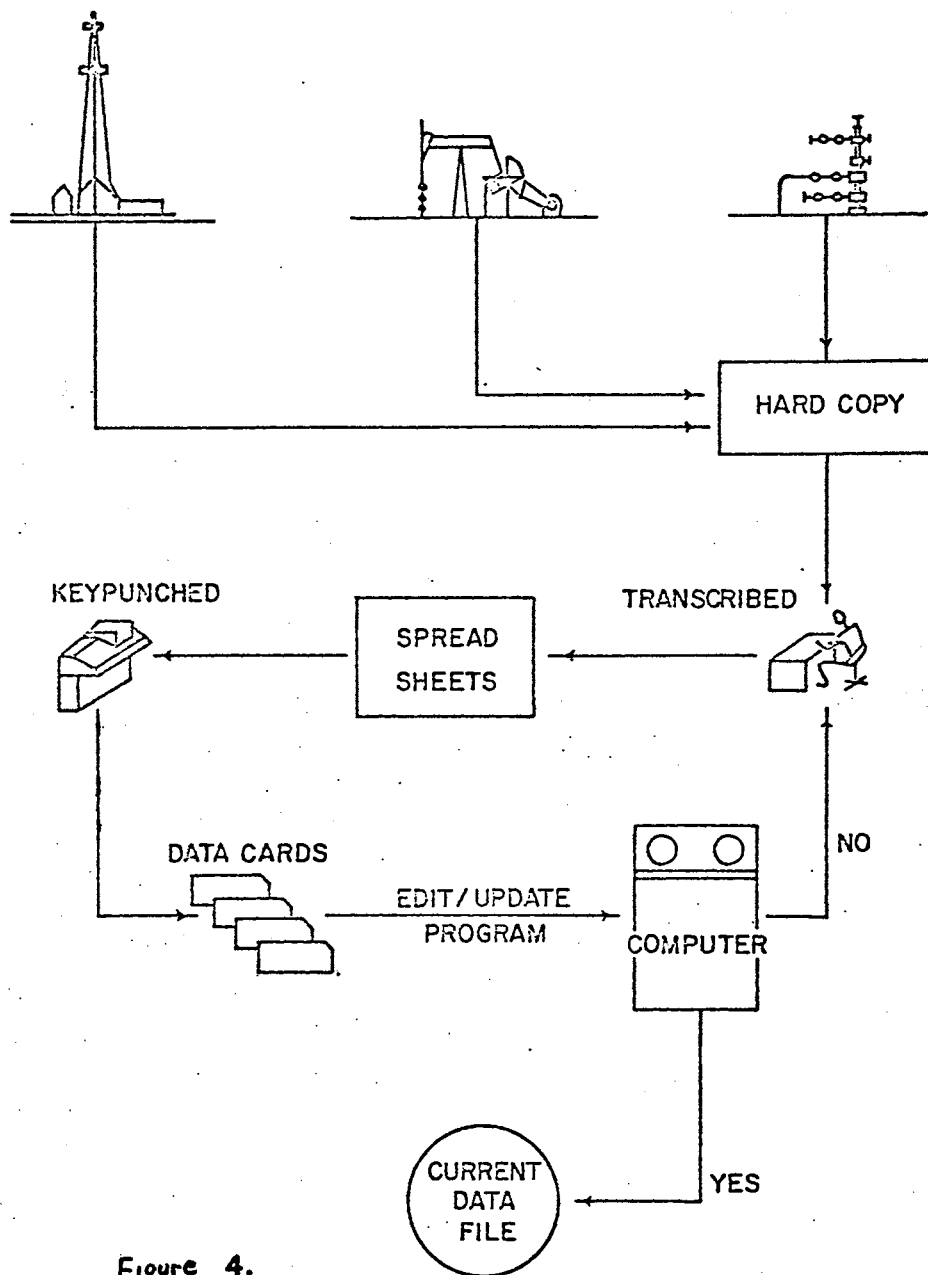


Figure 4.

DATA COLLECTION , CODING AND TRANSCRIPTION
TO CREATE GENERAL WELL DATA FILE.

From CDP(1971)

File Contents

The GENERAL WELL DATA FILE consists of several items of information most often required by the exploration geologist. Those items of information for each well on the FILE are shown in Figure 5.

SUMMARY CODES AND GENERAL INFORMATION																
STATE CODE	COUNTY CODE	UNIQUE WELL NUMBER	SIDELOCK	WELL CODE	OPER. SEQ.	ZONES	PERMIT NO.	WELL ID	PRIV. CODE	FIELD CODE	OPERATOR CODE	WELL STATE	FORMATION & ZONE CODE AT TOTAL DEPTH	FORMATION & ZONE CODE OF PRODUCING FORMATION	TOTAL DEPTH	DATE COMPLETED
10010																
LOCATION AND CLASSIFICATION																
STATE CODE	COUNTY CODE	UNIQUE WELL NUMBER	SIDELOCK	WELL CODE	OPER. SEQ.	ZONES	STATE	COUNTY	LOCATION/FOOTAGE			SPOT	WELL CLASS			
101													UNIT	FINAL		
OPERATOR WELL NUMBER, AND LEASE NAME																
STATE CODE	COUNTY CODE	UNIQUE WELL NUMBER	SIDELOCK	WELL CODE	OPER. SEQ.	ZONES	OPERATOR NAME			WELL NUMBER	LEASE NAME					
101																
OPERATOR ELEVATIONS - AREA NAME																
STATE CODE	COUNTY CODE	UNIQUE WELL NUMBER	SIDELOCK	WELL CODE	OPER. SEQ.	ZONES	OPERATOR ELEVATIONS		DISTRICT	SURVEY OR DISTRICT NAME		FIELD/FOOT/AREA WILDCAT				
101																
GEOLOGIC FORMATION AND DRILLED TOTAL DEPTH																
STATE CODE	COUNTY CODE	UNIQUE WELL NUMBER	SIDELOCK	WELL CODE	OPER. SEQ.	ZONES	DRILLERS TOTAL DEPTH	LOG TOTAL DEPTH	PLUG BACK TOTAL DEPTH	OLD TOTAL DEPTH	FORMATION & ZONE CODE AT TOTAL DEPTH					
101																




 NUMERICAL ACCESSION NUMBER
 NUMERIC SEQUENCE WITH IN WELL
 FIELDS CHECKED BY COMPUTER LOGIC AND EDIT

Figure 5. - General information and well identification. From Forgotson and Strout (1969)

The Retrieval Process

Of all the tasks required of a geologist, data retrieval must be the most tedious. Before evaluation can begin, and a final data interpretation made, the required information must first be obtained from the various files. The retrieval of the required data could thus take several days or even weeks.

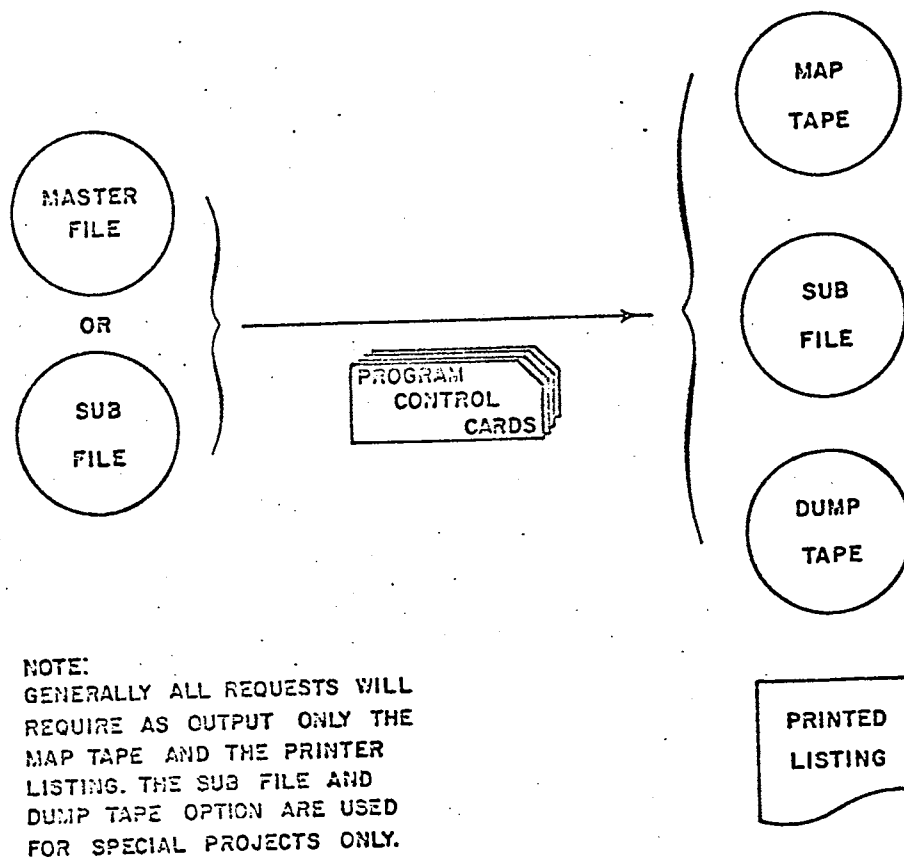
With the aid of the computer, the task of retrieving required information has become very much simplified. The retrieval program is used to select or extract various necessary data from the CURRENT WELL FILE, according to the specifications of the USER. Any data contained in the FILE can be retrieved. Various data contained in the FILE can be retrieved. Various data types contained in the FILE can act as logical operators (to be discussed in this section). But first, a brief look at the operation of the Retrieval Program is in order.

Retrieval Operation

Once the parameters that control the volume and types of data to be retrieved have been determined, PROGRAM CONTROL CARDS are punched, and along with an Input tape, are submitted to the computer center, where the retrieval is initialized (Figure 6).

Input to the Retrieval Program is either the CURRENT WELL FILE TAPE, a SUB FILE tape created during a previous retrieval, or a tape of data in precisely the same format as the CURRENT FILE.

Data output, of course, is governed by the parameters set by the USER for that particular retrieval. Standard output consists of the general well information for each well (location, dates classification, total depth, etc.) and those items of information specified by the USER (Figure 7).



NOTE:
 GENERALLY ALL REQUESTS WILL
 REQUIRE AS OUTPUT ONLY THE
 MAP TAPE AND THE PRINTER
 LISTING. THE SUB FILE AND
 DUMP TAPE OPTION ARE USED
 FOR SPECIAL PROJECTS ONLY.

Figure 6.

RETRIEVAL OPERATION

From CDP (1971)

There are, however, four different output units which may be utilized during a data retrieval:

Line Printer. In all but a few cases, the data to be retrieved will be output to the line printer. The output format, though dependent upon the number of different types of data retrieved is FIXED, and data is sorted by the UNIQUE WELL IDENTIFIER. The printer listing provides the USER with hard copy data for his study area. In some cases, the project ends at this stage.

Further, a summary of statistics (Figure 8) is listed for each data retrieval, indicating the number of wells retrieved, the number of geologic units retrieved and their respective range of values, etc. This statistical summary is a valuable tool in evaluating a data retrieval, setting contour intervals for further processing, etc.

Map Tape. In most cases where further processing is required, a MAP TAPE is generated. Residing on it are the locations of the various wells retrieved (by UNIQUE IDENTIFIER) and the various requested z values. These z values generally include a reference evaluation, structural subsea values, computed isopach values, etc. Most often, the MAP TAPE is then used as input for further processing such as coordinate generation, data gridding, etc.

Sub File. Where very large volumes of data are to be processed, and several subsequent data retrievals are required, it is often advantageous to create a SUB FILE. The SUB FILE is a tape of data

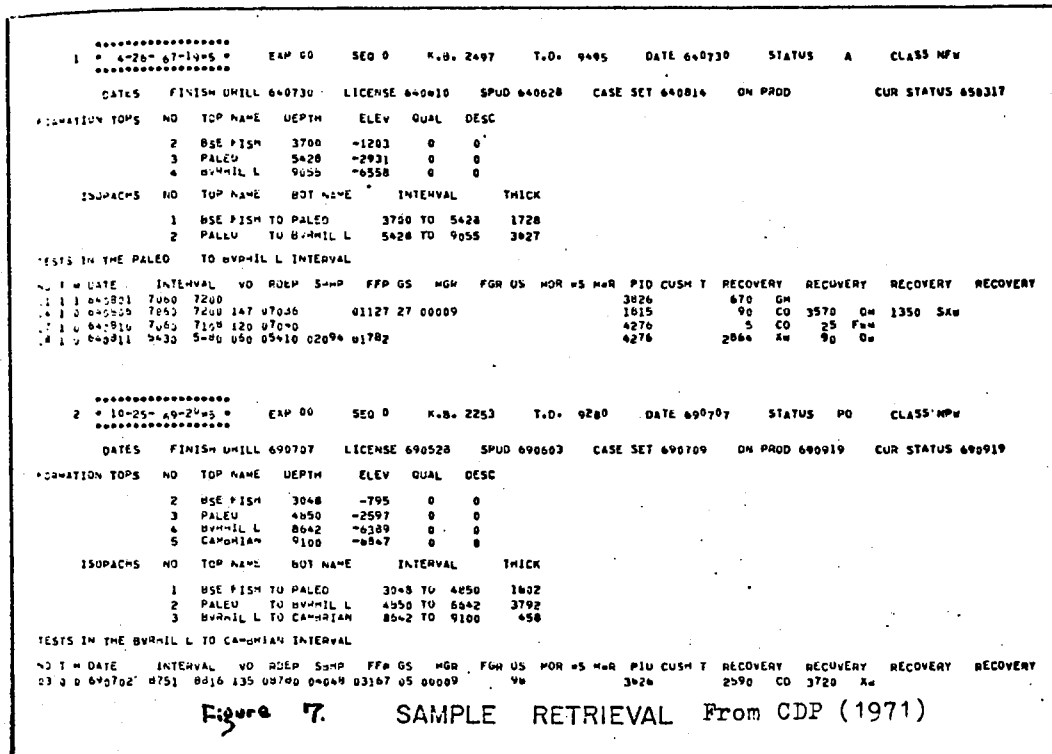


Figure 7. SAMPLE RETRIEVAL From CDP (1971)

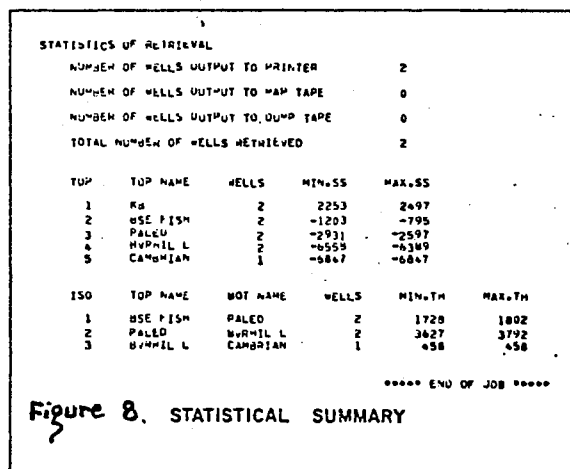


Figure 8. STATISTICAL SUMMARY

containing ALL the information available on the CURRENT FILE for the various wells requested during a retrieval. It is in precisely the same format as the CURRENT FILE, and can therefore be used as input to the retrieval program. The use of this option can save much computer time when multiple types of retrievals are to be made from a smaller area, as each subsequent retrieval has less input data to scan. Such is the case when well information for fairly active areas is required by many explorationists.

Dump Tape. This feature allows the USER to output the retrieved information to a tape in "card image" format. This option is used to accommodate those requests which are not standard to the Retrieval Program. The DUMP TAPE is then used as input for other types of processing such as data manipulation, sorting, and re-formatting, etc. Data sorting on this portion of the FILE will require less computer time than sorting the entire CURRENT FILE, and for this reason, the option is often utilized. For most retrievals though, only the line printer and map tape units are employed. The creation of the SUB FILE and DUMP TAPE is for special projects which do not constitute a standard data retrieval.

Retrieval Logic

As each data retrieval is tailored to the specific needs and requirements of the individual USER, it is important that various items of information in the FILE be used as "retrieval keys" or

operators. The various retrieval operations to be discussed need not be utilized for all projects, but most data retrievals will make use of at least one. These logical operators can be broadly classified as: Include/exclude restrictions and AND/OR/NOT restrictions. A brief explanation of these logical or BOOLEAN operators follows.

Include/Exclude Restrictions

Include or Logical Equal To. This operator means that, in order to be accepted by the retrieval program, the data in question must be equal to the User specified codes or limits. Otherwise, that well will be rejected; e.g., a geologist may be interested in only those wells that were drilled in administrative region OKLA. OKLA, then, is the INCLUDE OPERATOR, and only those wells in OKLA will be retrieved.

Exclude or Logical Not Equal To. This operator simply works in the reverse way to the INCLUDE OPERATOR; e.g., a geologist may be interested in all wells except those that were classified as WILDCAT wells. The WILDCAT classification is the EXCLUDE operator, and all wells other than WILDCATS will be retrieved.

And/Or/Not Restrictions

Often it is desirable to retrieve wells from the File on the basis of some specific data type being present or absent, or on the basis of at least one of several related data types being present. The logical AND/OR/NOT operators are used for these types of retrievals.

"And" Operator. All types of data (either Equal to or Not Equal to) that are AND controlled must be present or the well will be rejected; e.g., a USER may be interested in wells that were classified as WILDCATS, AND produced oil, AND were drilled since 1965. If only one or two of the above three restrictions are satisfied, the well in question will be rejected. All three conditions must be fulfilled.

"Or" Operator. At least ONE of the OR controlled data types must be present, or the well will be rejected; e.g., a geologist may be interested in only those wells that were tested in FORMATION X, OR had a hydrocarbon show in FORMATION X, OR had a core cut in FORMATION X. If any ONE of the above conditions is met, the well will be retrieved.

"Not" Operator. The presence of any NOT controlled data types in a well, will cause the entire well to be rejected; e.g., a geologist may choose to do a retrieval (for trend analysis) of all the wells in an area that do not have a specific carbonate unit present.

Retrieval Program Options

Outlined below are the various program options available to the USER with the different types of logical operators that can be applied to each data type.

Well Location or Areal Definition

For most retrievals, information required will be for specific wells, or for a group of wells that fall within some areally or geographically defined limits. The various wells contained in the FILE can be defined areally by any one or all of three different methods, namely:

By UNIQUE WELL IDENTIFIER

By some rectangular area defined by minimum and maximum degrees of latitude and longitude.

By some irregularly shaped political, geological or graphically defined area, e.g., state.

An example which defines the area to be retrieved is shown in Figure 9.

Gross Well Information

There are, however, other well variables upon which a retrieval can be keyed. Like the methods for defining well location, generally only one or two of these options are implemented. The various well parameters referred to in this category are:

Well classification

Well status

Well depth (total)

Well dates (initial and/or final)

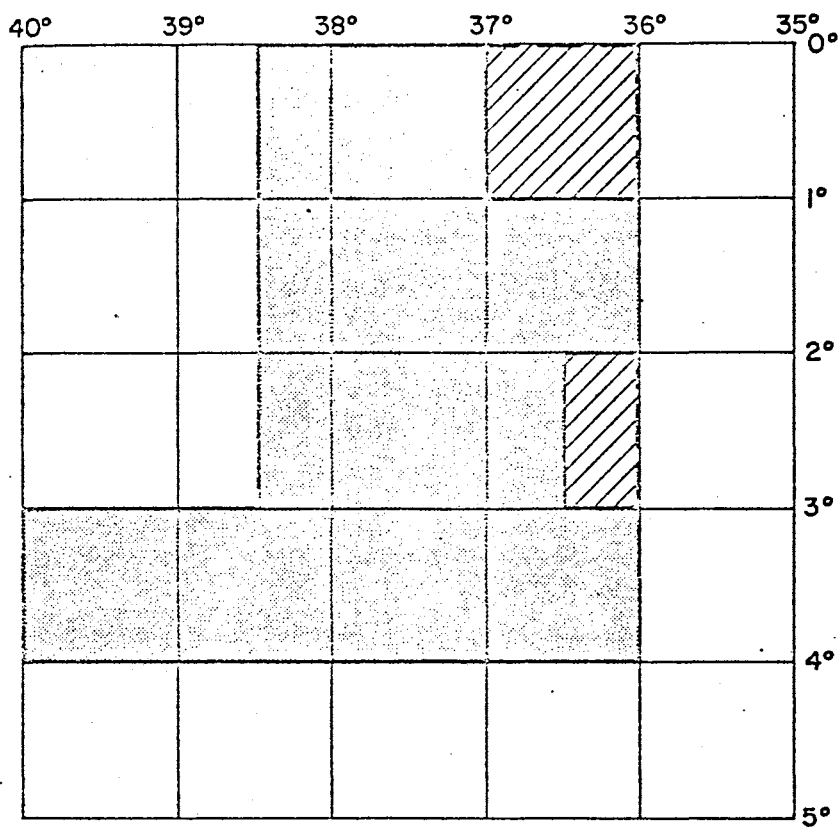

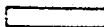
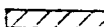
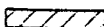


Figure 9.

RETRIEVAL AREAS

	1	FROM	0° - 3° S	AND	36° - 38°30' W
	2	FROM	3° - 4° S	AND	36° - 40° W
	3	EXCLUDE	0° - 1° S	AND	36° - 37° W
	4	EXCLUDE	2° - 3° S	AND	36° - 36°30' W

ILLUSTRATING A RETRIEVAL BY RECTANGULAR AREAS
 DEFINED BY GEOGRAPHICAL CO-ORDINATES. SHADED
 AREA IS AREA FROM WHICH DATA WILL BE RETRIEVED.
 ALL OTHER AREAS ARE IGNORED. From CDF (1971)

Interval Analysis

Certain items of data are retrieved from the FILE by reference to a specific isopach interval. By necessity, this "REFERENCING INTERVAL" must have been previously defined, or the data cannot be retrieved. Data that must be retrieved in this manner include:

Well Log Information

Cored Intervals

Intervals of Hydrocarbon Shows

Producing Zones

Formation Test Results

Cross Section

During the evaluation of a set of data, the geologist often requires the use of a structural or stratigraphic cross section. The CROSS SECTION program is used to retrieve information from the FILE, reduce it according to the parameters chosen by the geologist, and display it accordingly.

Input to the program must be either the CURRENT FILE or a tape of data in the same format, such as a SUBFILE created during a data retrieval, whereas output from the program consists of a printer listing of the requested information (Figure 10) and a magnetic tape which is subsequently used to drive the plotter. Information output to the printer includes the location (by its UNIQUE IDENTIFIER) of each retrieved well; the name and code and type of each retrieved well; the name and code and type of each of the geologic units to be plotted, along with the quality of the pick; the drill depth and computed subsea values for both the top and base; the unit descriptive code (faulted, disconformable, etc.) and where applicable, the percent of sand, shale, for each of the geologic units retrieved. Intervals of hydrocarbon shows, if requested, are also output to the printer.

A summary of statistics appears at the back of the listing to aid the USER in evaluating the quality of the retrieval. Included are the length of the section in actual meters, the minimum and maximum elevations of each of the retrieved units, and the size of the section to be plotted in inches.

RETRIEVAL OF WELL (10) LOCN SR23P14NE90P44A

WELL PREFIX (6MIRA005 GB) LATITUDE 6.37106 LONGITUDE 44.62390 REF ELEV 18.4
TOTAL DEPTH 3600.0

LIST OF RETRIEVED TOPS

	NAME	CODE	TYP	QLY	SRC	DEPTH	ELEV D	DEPTH	ELEV D	SS	SH	NC	T
(1)	600666	600666	0	B	1	300.0	-281.6	0.0	0.0				
(2)	700777	700777	0	B	1	1800.0	-1781.6	0.0	0.0				
(3)	800888	800888	0	B	1	3100.0	-3081.6	0.0	0.0				

LIST OF RETRIEVED HYDROCARBON SHOWS

	TYP	QLY	SRC	DEPTH	ELEV	DEPTH	ELEV
(1)	0	B	P	2600.0	-2581.6	2806.0	-2781.6

LENGTH OF SECTION 41067.73

MAXIMUM ELEVATION 0.0

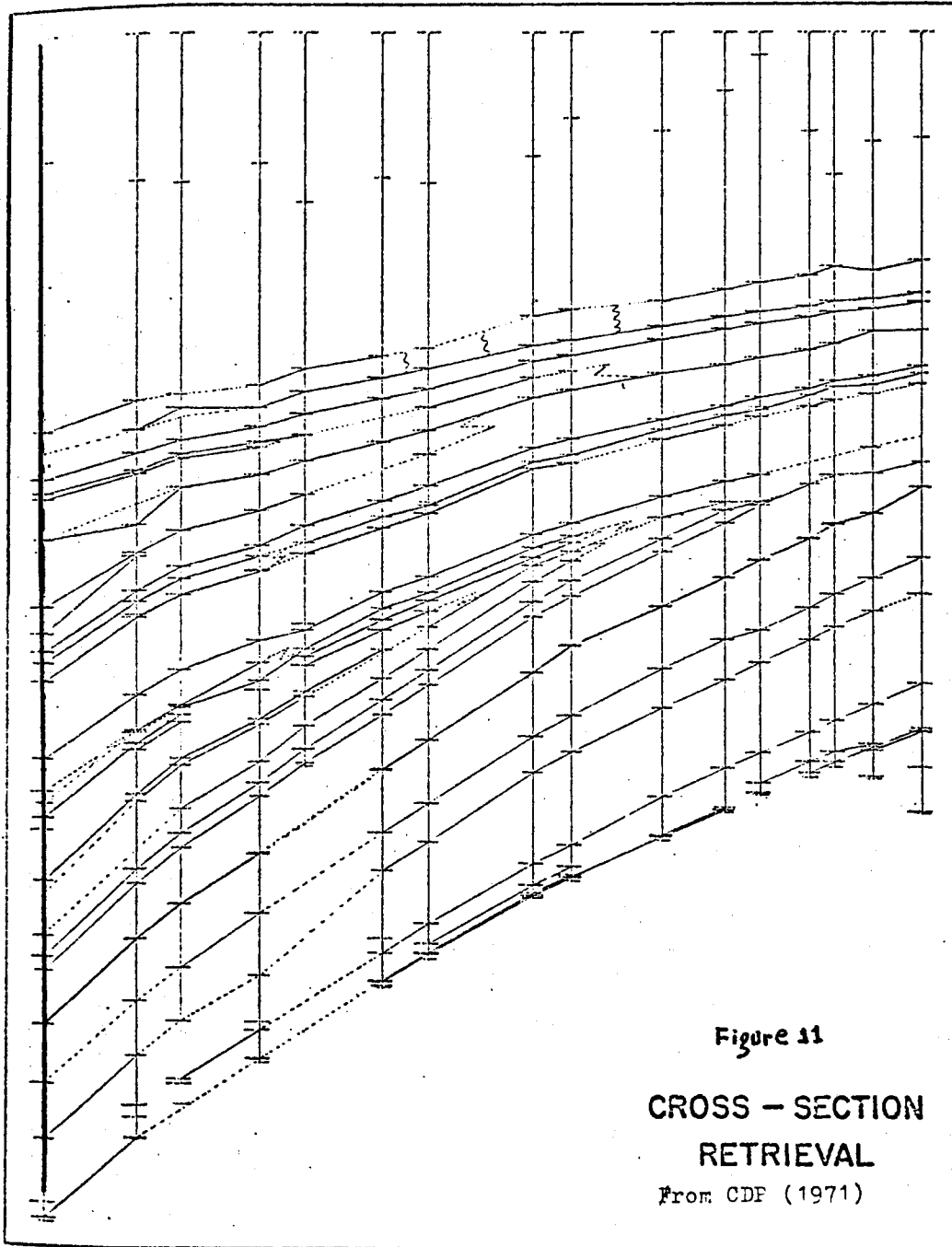
MINIMUM ELEVATION -3900.00

SIZE OF PLOT X = 27.4 INCHES, Y = 13.0 INCHES

Figure 10:

AUDIT OUTPUT OF 'GEOSEC'
PRIOR TO PLOTTING CROSS
SECTION

A reduced version of a hypothetical cross section prepared by this program appears as Figure 11. It can be seen that with sufficient care taken in the choice of the various parameters, the cross section program can become a very valuable display tool to the explorationist (GDP, 1971).



Ojakangas (1967) had developed a method by which geologic section may be drafted automatically to show the geology at present as well as at any specified time in the past.

A stratigraphic cross section prepared by a computer-controlled plotter showing the geology of Wind River Basin is shown in Figure 12.

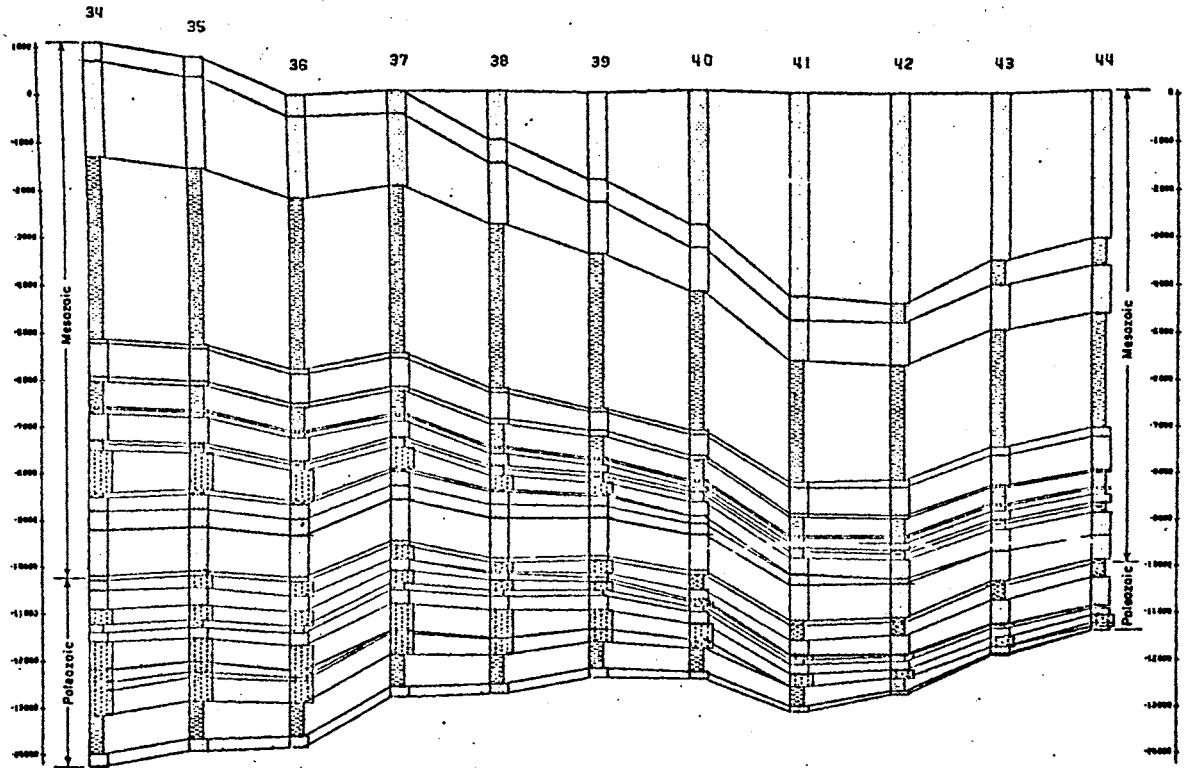


Figure 12. Cross section Showing Geology of Wind River Basin
From Harbaugh and Merriam(1968)

Gridding Process

Gridding is a surface fitting process by numerical approximation technique. The program GRID is used to interpolate a uniform grid of z values from a set of randomly distributed data points in x , y , and z where x and y represent the Cartesian coordinates, and z is the associated value of the field at each coordinate pair.

Crain (1969) reviewed the various surface interpolation schemes. He concluded that the most commonly used mathematical surface interpolation employs polynomials and other simple functions.

The Interpolating Polynomial

The function of the simplest mathematical form is the "interpolating polynomial", namely:

$$f(x,y) = a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + \dots \quad (1)$$

The coefficients are determined by solving the set of equations:

$$f(x_i, y_i) = z_i, \quad u = 1, 2, \dots, N \quad (2)$$

This is a direct extension of the interpolating polynomial.

To fit a geological surface, a lower order (usually not higher than three) is adequate.

Orthogonal Polynomials

The advantages of orthogonal polynomials can be used to allow computation to much higher orders. This advantage is somewhat offset by the complexity of generating orthogonal polynomials to fit non-equispaced data.

The author has developed a gridding program which uses the contour surface developed by Hessing, Lee, Pierce and Powers (1972) (see (15)). This involves constructing a net of quadrilaterals (see Figure 13). The vertices of each quadrilateral are either an original data point or a calculated point using a weighted least squares fit. Then, a bicubic surface is constructed and fitted over each of the quadrilaterals. The bicubic parameterizations are described as follows (Ferguson, 1964):

$$X(u,v) = \sum_{p=0}^3 \sum_{q=0}^3 a_{p,q} u^p v^q$$

$$Y(u,v) = \sum_{p=0}^3 \sum_{q=0}^3 b_{p,q} u^p v^q$$

$$Z(u,v) = \sum_{p=0}^3 \sum_{q=0}^3 c_{p,q} u^p v^q, \quad 0 \leq u, v \leq 1,$$

The desired grid $(x_{i,j}, y_{i,j})$ of points is generated in the region. Once a quadrilateral is found which contains a point $(x_{i,j}, y_{i,j})$, the corresponding equations

$$x(u,v) = x_{i,j}$$

$$y(u,v) = y_{i,j}$$

are solved for u, v by the Newton-Raphson method (Scharborough, 1950). The desired z -value is calculated by $z_{i,j} = z(u,v)$. Thus the points generated in this way lie on the same surfaces used in the contouring program.

The algorithms used to solve non-linear simultaneous equations (Searborough, 1950) is described in Appendix C. The computer generated grids, interpolated from a set of randomly distributed data, together with superimposed contour maps are shown in Figures 14 and 15. Figure 14 represents a contour map for randomly spaced data. Figure 15 represents a contour map for gridded data. The surfaces shown in Figure 14 and Figure 15 are matched very well.

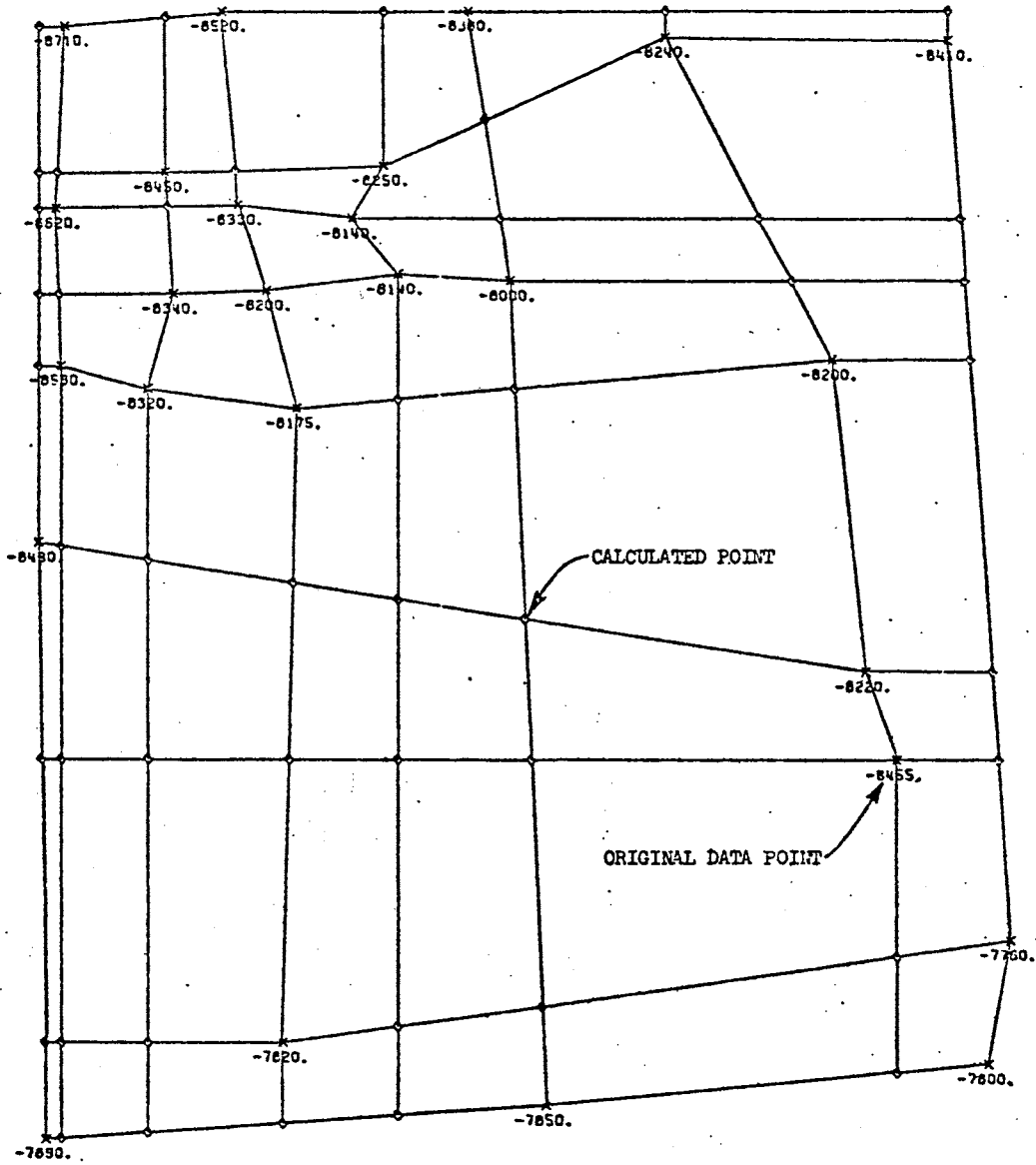


Figure 13. Planar "grid" of sample data case.

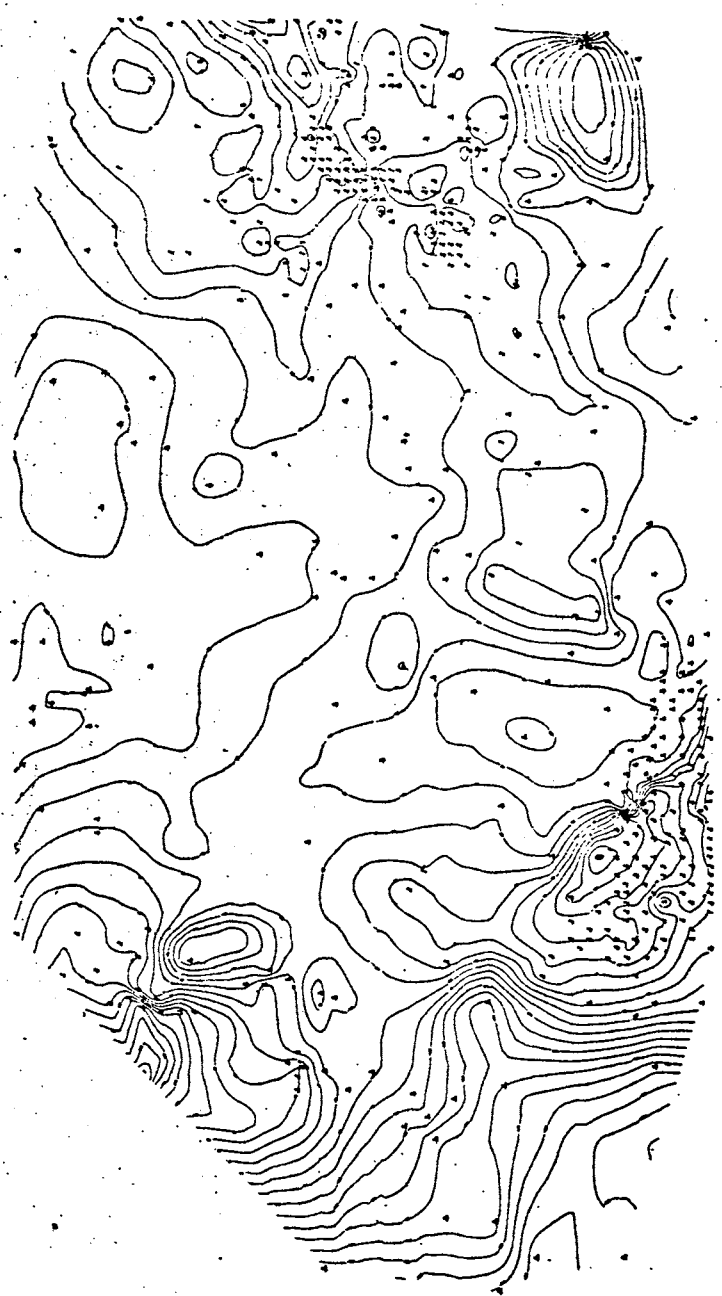


Figure 14. Contour Map for Randomly Spaced Data

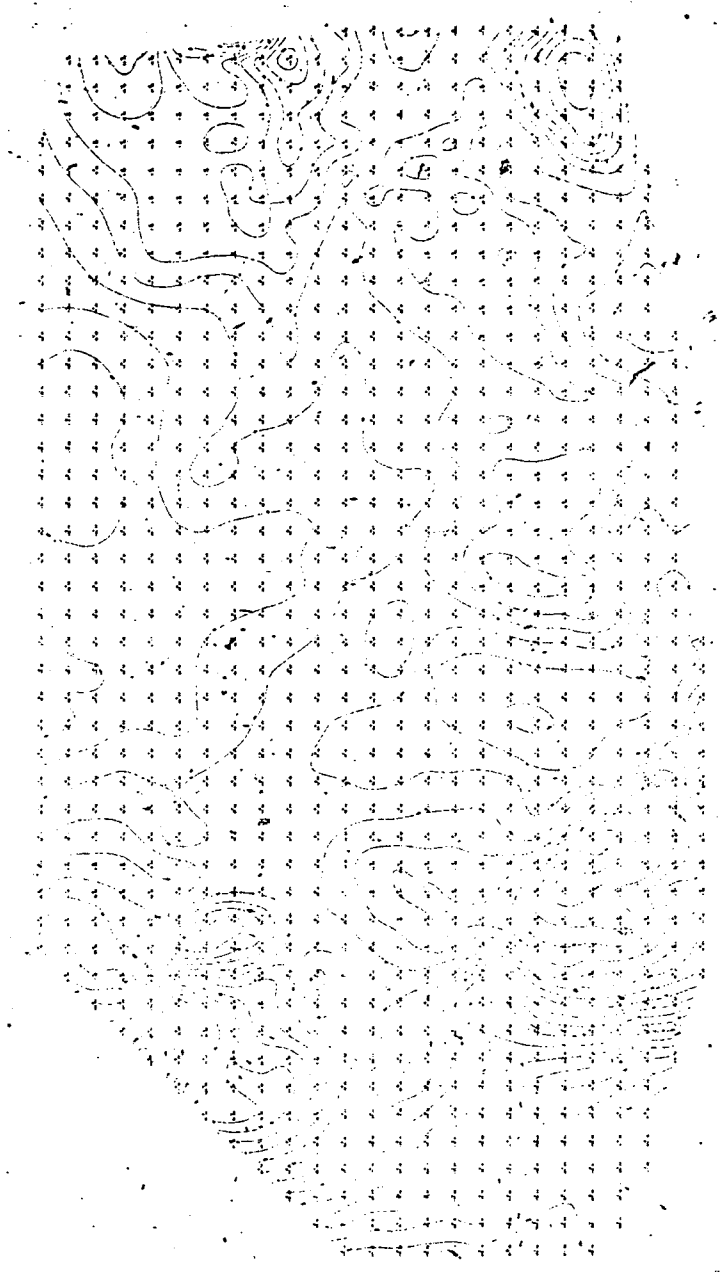


Figure 15. Contour Map for Gridded Data

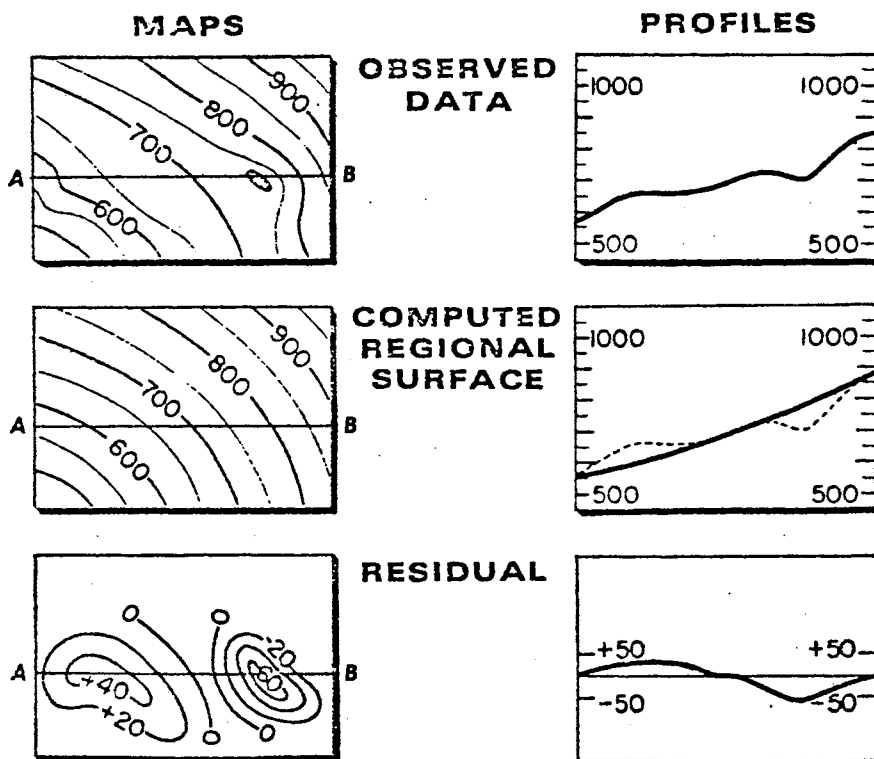
Trend Surface Analysis

Trend analysis deals with the recognition, isolation, and measurement of trends that can be represented by lines, surfaces, or four-dimensional "hypersurfaces". Trend analysis in geology seeks to separate broadscale variations, or trends from local variations. This is accomplished by fitting a trend function to a set of data values. Most trend analysis in geology has dealt with trend surfaces consisting of a plane or gently curving surfaces defined by a lower order polynomial.

Trend-surface analysis, as practiced in geology, has invariably involved the fitting of trend surfaces to satisfy the least-squares criterion. This results in the trend surface passing through, above, or below each actual data point. The difference between the computed value of the trend surface at a point and the value of the observed actual surface at that point is termed the residual value (or deviation value). In satisfying the least-squares criterion, the sum of the squared residuals is minimized. If the trend surface is thought of as the regional or large-scale component, then the residual value can be emphasizing local component: represented by residual values. (Harbaugh and Merriam, 1968)

Figure 16 from Forgotson and Iglehart (1967) illustrates the methodology. The upper left diagram is a contour map of observed data, below which is a map showing the second-order computed regional surface. Below that is a residual map showing a positive and negative anomaly. These residual features are derived by subtracting the regional surface from the observed data.

TREND ANALYSIS



The upper diagrams show a contour map and profile of observed data. The middle diagrams show the second-order computed regional trend surface and its corresponding profile. The lower diagrams show the residual map and its profile obtained by subtracting the regional surface from the observed data.

From Forgotson and Iglehart (1967)

Figure 16

The examples of four-dimensional surfaces to illustrate trend surfaces are shown in Figure 17.

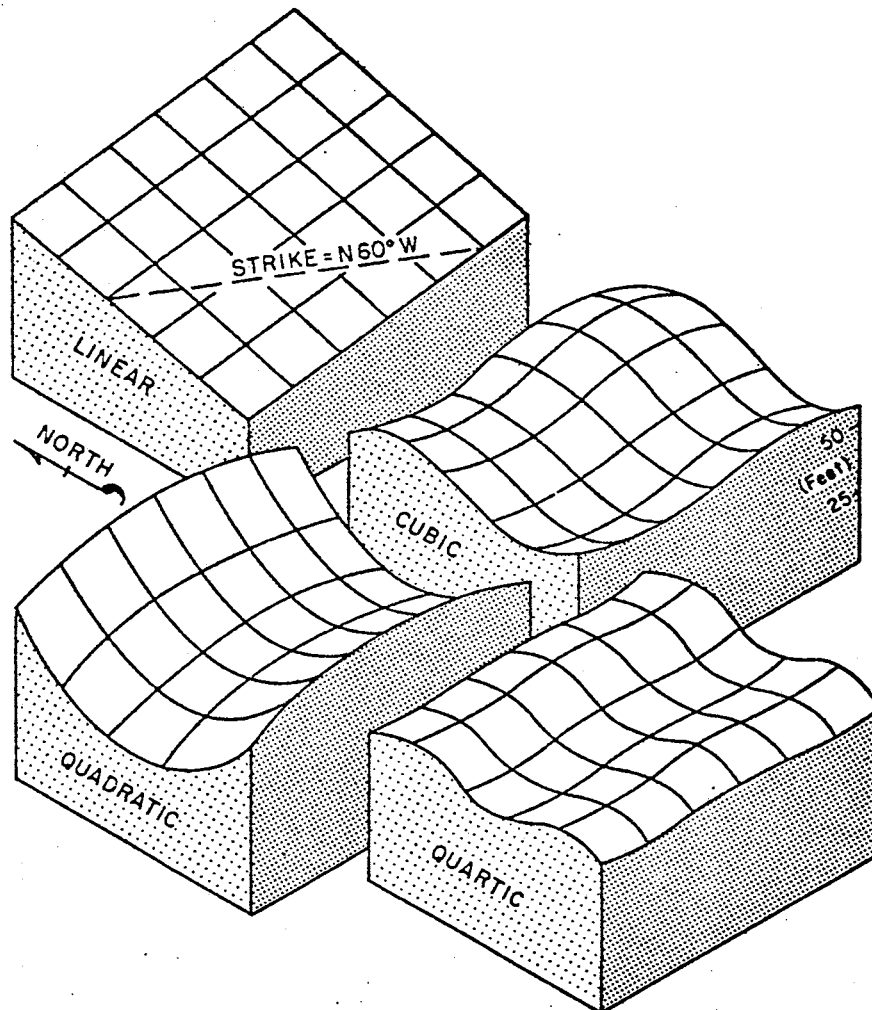


Figure 17. Examples of linear through quartic regional trend surfaces (after Krumbain, 1957).

Least Squares Criterion

The least-squares criterion is readily illustrated by the problem of fitting a straight line to observed values of two variables that have been plotted as points on a two-dimensional diagram. The least squares criterion for best fit can be expressed as follows.

$$(x_{\text{obs}} - x_{\text{trend}})^2 = \text{minimum},$$

where x_{obs} = observed data value, and

x_{trend} = calculated trend surface value at data point.

A least squares fit for a plane through the data points is illustrated in Figure 18.

As practiced by geologists, trend analysis has invariably involved the fitting of a line (in two dimensions) to satisfy the least squares criterion (see Figure 19).

In trend surface analysis, this plane is expressed as a first order polynomial equation:

$$z = A_x + B_y + C$$

Each of the variables in x and y has been raised to the power of one; hence the name first order polynomial. Where the x and y variables raised to the power of two, we would be dealing with a second order polynomial or a parabola.

$$z = A_x^2 + B_{xy} + C_y^2 + D_x + F_y + G$$

Thus, any surface, regardless of its complexity, can be expressed as a polynomial equation simply by raising the order of the polynomial to the necessary powers of x and y . A fairly simple structural surface requires a lower order polynomial equation to define it uniquely.

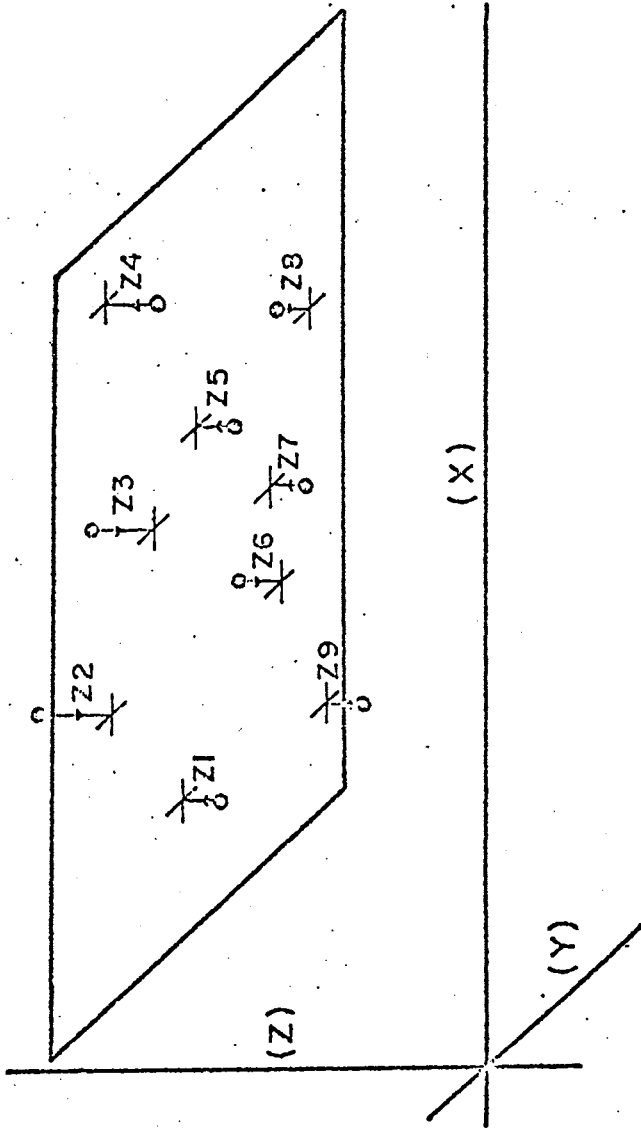


Figure 10.

LEAST SQUARES FIT OF A PLANE TO DATA POINTS

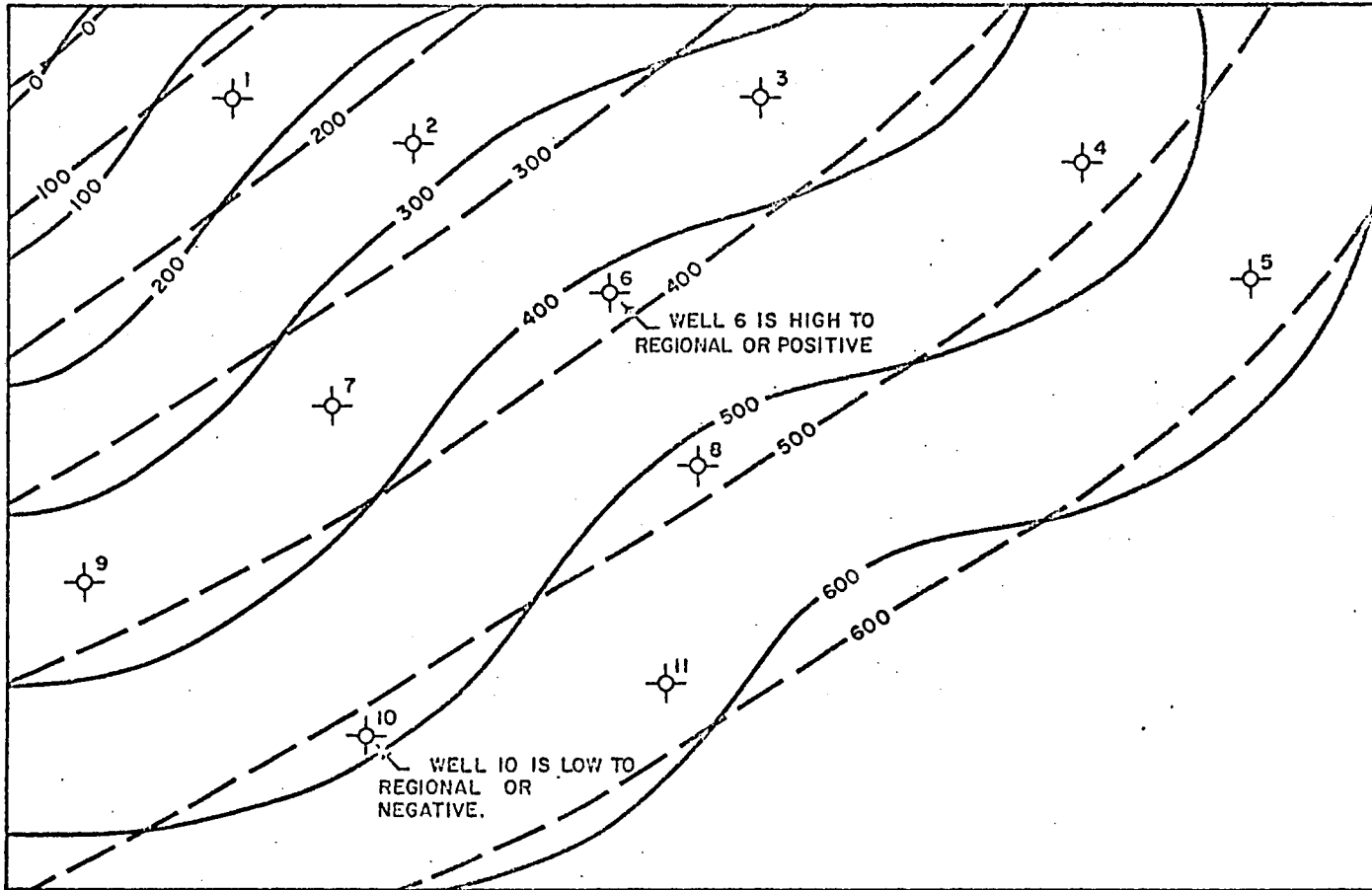


Figure 19

ILLUSTRATING A TYPE OF TREND ANALYSIS OFTEN PRACTISED BY GEOLOGISTS.
 SOLID LINE — GEOLOGIC STRUCTURE.
 BROKEN LINE — GEOLOGISTS INTERPRETATION OF THE TREND OF THAT STRUCTURE.

However, very little can be gained in exploration by determining the order of polynomial required to define a specific surface. As outlined above, the purpose of trend surface analysis is rather to separate the larger scale regional variations or trends from the smaller, more localized features. In most cases, the lower order polynomials (first through fifth), are all that are required for defining a suitable trend for a particular set of data.

The Trend Operation

The trend surface program developed by Computer Data Processors, Ltd., is described as follows: The operation of the program consists of forcing through the input x-y-z data various orders of polynomial equations, in order to arrive at a best or closest fit, according to the least squares criterion, for each polynomially defined surface selected. Coefficients for up to a ninth order polynomial equation can be established, and any five surfaces can be determined at one pass through the data.

Output from the TREND SURFACE program will consist of: the location of each input point by UNIQUE IDENTIFIER, and/or its x-y coordinates, the actual input z value, and the corresponding trend and residual values for each input point for each order of polynomial chosen.

Figure 20 is an illustration of printed output from the Trend Surface Program.

Figure 21 is a statistical report for the Trend Surface Program which is used to evaluate the output of the program and aid the user to choose the orders of trend and/or residual values to be used for mapping.

X COORD	Y COORD	INPUT VALUE	DEG. TREND	ONE RESID	DEG. TREND	TWO RESID	DEG. TREND	THREE RESID	DEG. TREND	FOUR RESID
38.	19.	-10	-128.	118.	352.	-362.	202.	-212.	-140.	130.
75.	79.	-10	-66.	75.	293.	-303.	225.	-235.	18.	-28.
38.	180.	578	-26.	684.	338.	247.	339.	239.	215.	363.
37.	275.	610	34.	576.	352.	259.	384.	226.	387.	223.
60.	317.	545	63.	452.	331.	214.	374.	171.	428.	117.
37.	397.	550	111.	439.	389.	161.	419.	131.	551.	-1.
24.	588.	538	231.	357.	515.	73.	478.	112.	689.	-101.
14.	648.	544	267.	277.	576.	-32.	530.	30.	704.	-160.
32.	889.	543	422.	118.	301.	-261.	670.	-139.	564.	-24.
86.	923.	395	449.	-54.	777.	-382.	672.	-277.	544.	-149.
92.	1037.	430	503.	-73.	865.	-455.	882.	-372.	519.	-89.
197.	27.	50	-105.	155.	157.	-107.	57.	-7.	-14.	64.
192.	113.	-10	-51.	41.	152.	-162.	140.	-150.	79.	-89.
171.	172.	-10	-16.	6.	174.	-184.	199.	-209.	154.	-164.
125.	176.	-10	-19.	9.	225.	-235.	245.	-255.	180.	-190.
199.	231.	-10	24.	-34.	150.	-160.	204.	-214.	198.	-208.
155.	307.	-10	67.	-77.	214.	-224.	275.	-285.	315.	-325.
131.	358.	635	103.	582.	281.	424.	316.	369.	402.	283.
156.	422.	574	148.	434.	253.	321.	304.	279.	418.	164.
108.	469.	573	155.	405.	334.	236.	363.	207.	514.	56.
152.	524.	577	294.	373.	316.	261.	335.	242.	478.	99.
133.	623.	545	255.	280.	428.	137.	386.	159.	541.	4.
180.	921.	497	453.	39.	672.	-175.	604.	-107.	542.	-45.
268.	52.	-10	-81.	71.	81.	-91.	22.	-32.	21.	-31.
284.	111.	-10	-42.	32.	61.	-71.	59.	-69.	54.	-64.
280.	184.	-10	3.	-13.	66.	-76.	109.	-119.	100.	-110.
252.	288.	-10	66.	-76.	109.	-119.	179.	-189.	194.	-204.
212.	342.	-10	96.	-106.	164.	-174.	232.	-242.	279.	-289.
298.	393.	-10	138.	-148.	194.	-204.	173.	-183.	200.	-210.
217.	432.	-10	134.	-144.	182.	-192.	244.	-254.	314.	-324.
223.	456.	620	105.	432.	219.	401.	261.	359.	393.	267.
257.	569.	490	244.	246.	242.	248.	259.	231.	342.	148.
201.	603.	527	268.	267.	320.	287.	319.	208.	437.	90.
284.	903.	679	458.	151.	554.	55.	514.	95.	525.	104.
217.	957.	538	483.	53.	684.	-146.	637.	-99.	569.	-22.
217.	1037.	578	536.	42.	799.	-221.	789.	-211.	629.	-51.
274.	1243.	568	546.	22.	759.	-191.	774.	-230.	679.	-111.
353.	19.	-10	-95.	83.	14.	-24.	-75.	65.	13.	-23.
398.	233.	-10	47.	-57.	-19.	9.	45.	-55.	31.	-41.
342.	271.	-10	65.	-75.	23.	-33.	102.	-112.	93.	-103.
343.	354.	-10	118.	-128.	53.	-63.	127.	-137.	127.	-137.
348.	448.	-10	177.	-187.	97.	-107.	156.	-166.	171.	-181.
326.	504.	-10	211.	-221.	140.	-150.	183.	-193.	215.	-225.
357.	578.	10	261.	-251.	169.	-159.	188.	-178.	209.	-199.
326.	609.	702	277.	425.	215.	487.	224.	478.	265.	437.
351.	696.	973	335.	638.	273.	709.	257.	716.	285.	688.
369.	791.	632	327.	235.	359.	274.	327.	303.	344.	288.
353.	937.	575	488.	87.	548.	27.	531.	44.	531.	44.
436.	48.	-10	-65.	55.	-48.	38.	-99.	89.	6.	-16.
407.	114.	-10	-27.	17.	-34.	24.	-28.	18.	9.	-19.

Figure 20.

ILLUSTRATING PRINTER OUTPUT FROM
TREND SURFACE ANALYSIS.

VARIABLE 3
MAX DEG 6

POINTS USED 200

REJECTED

AREA 0
NULL 0
ERROR 0
BLANK 0
RANGE 0

XMIN, XMAX	.1400000000E 02	.1568000000E 04	
YMIN, YMAX	.3000000000E 01	.1043200000E 04	
ZMIN, ZMAX	-.1000000000E 02	.1102000000E 04	
XYZ SCALE	.7770000000E 03	.5200000000E 03	.5500000000E 03
XYZ BIAS	.7969199999E 03	.4962949999E 03	.2578549999E 03

XC
XC

200 POINTS PROCESSED

DEGREE 1	GOODNESS OF FIT 32.01 ,	PERCENT IMPROVEMENT .00
DEGREE 2	GOODNESS OF FIT 58.19 ,	PERCENT IMPROVEMENT 81.77
DEGREE 3	GOODNESS OF FIT 60.12 ,	PERCENT IMPROVEMENT 3.33
DEGREE 4	GOODNESS OF FIT 67.69 ,	PERCENT IMPROVEMENT 12.58

EXAMPLE OF STATISTICAL OUTPUT FOR TREND SURFACES
NOTE RATHER POOR FIT IN THIS EXAMPLE

Figure 21.

Automatic Contour Mapping

The representation of three-dimensional surfaces in the two-dimensional plane by means of contour lines is in widespread use in most fields of the physical and natural sciences. In particular, it is one of the most common ways of displaying numerical data used in geology. Structure, thickness, lithofacies, and geochemical data are commonly portrayed with contour maps.

In contouring, computers have several principal advantages: reduced cost by comparison with manual methods; strict adherence to a consistent contouring method, that is, objectivity and repeatability; and ease in updating and revision due to added information.

In more rigorous terminology, the object of contouring is to draw lines of constant value of a dependent variable (z), projected into the plane of two independent variables (x, y). Normally the raw data will consist either of a finite number of values of the dependent variable (z_i) at a set of locations (x_i, y_i), or a mathematical expression relating z to x and y .

Automation of contour mapping procedures has been accomplished successfully by a variety of methods. In general, these contain two distinct stages: first to interpolate a mesh of grid points from the raw data locations and, secondly, the contouring of the grid data. (Crain, 1969). This, contouring by this scheme works fairly well if the data are uniformly spaced. For irregularly spaced data, the grid

approach may be unable to honor every data point and the contour lines will fail to represent a surface which contains the original data points.

One method of honoring every data point by constructing a smooth surface through the original data was developed by Hessing, Lee, Pierce and Powers (1972) and published in GEOPHYSICS. This method divides the region to be contoured into quadrilaterals whose vertices include the data points. After supplying values at each of the remaining vertices by using a surface-fitting technique, bicubic functions are constructed on each quadrilateral to form a smooth surface through the data points. Points on a contour line are obtained from these surfaces by solving the resulting cubic equations. The algorithm and the details of the procedure are described in Appendix B, and the example contour map from this procedure is shown in Figure 22.

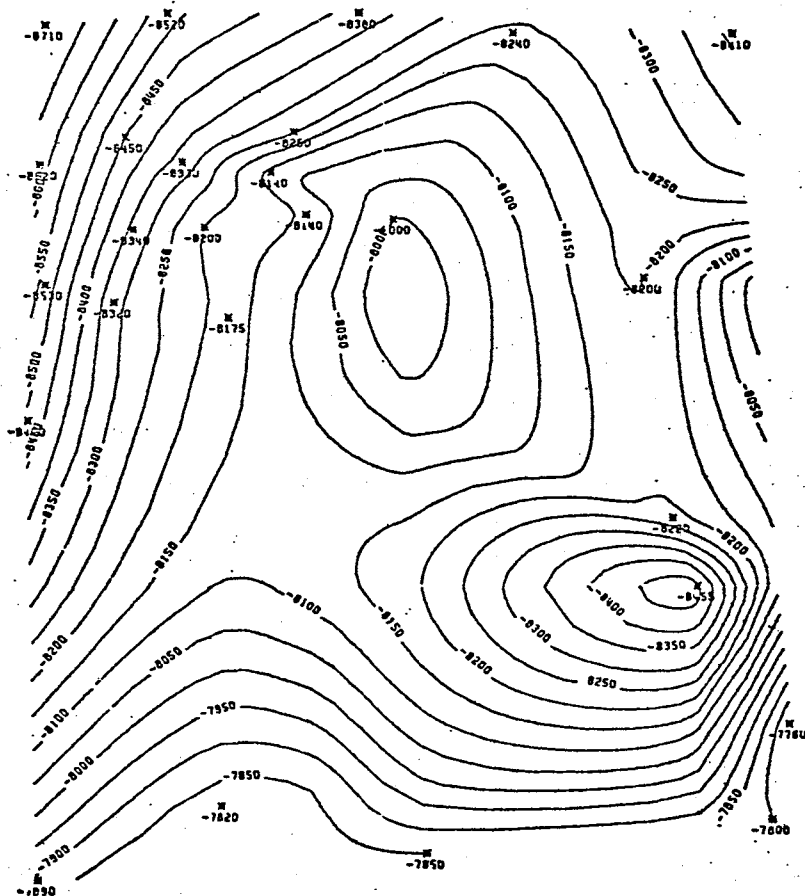


Figure 22. Contour map of sample data case.

Three Dimensional Perspective Display

During the evaluation of a set of well information, the interpreter often finds it to his advantage to reduce that data and display it in some fashion. Traditionally, the exploration geologist has made effective use of structural and stratigraphic cross sections, posted show maps, contoured maps of structure and isopach, etc. To the skilled and experienced interpreter, a contoured map represents a type of three-dimensional picture, the length and width of the map representing the x and y components of his data, and the various contour levels of his z component. From this display of information, a professional interpretation is made.

Often, however, even to the most experienced explorationist, some of the more subtle features of a contoured map which may be highly significant are masked. This is particularly true when attempting to envision the trend or regional component of the data. In effect, the true perspective of the data is sometimes lost.

The purpose then, of the PERSPECTIVE program is to create a plot of some variable in three dimensions. Often this variable is the top or base of some geologic unit, a polynomially defined trend or residual, the top of a pay zone, etc. The effect is similar to that obtained by viewing an areal photograph of some consistent geological features (such as sand dunes) through a stereoscope. The third dimension is actually represented in perspective to the plane of the page.

Input to the PERSPECTIVE must be a set of those gridded data, whereas output is a simple listing of those parameters chosen by the USER but, more important, a plot tape.

Figure 23 illustrates the scheme of the perspective display.

Figure 24 is an example of a perspective plot together with the corresponding contour map.

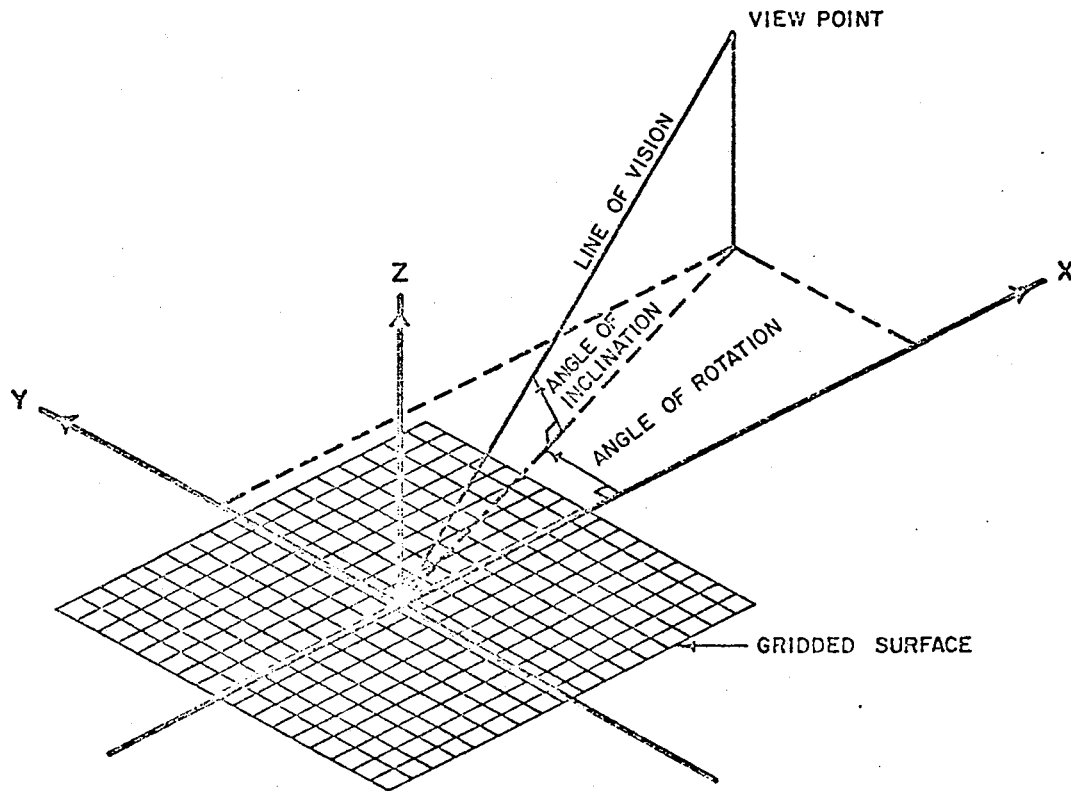


Figure 23.

ILLUSTRATING GRID PERSPECTIVE PARAMETERS

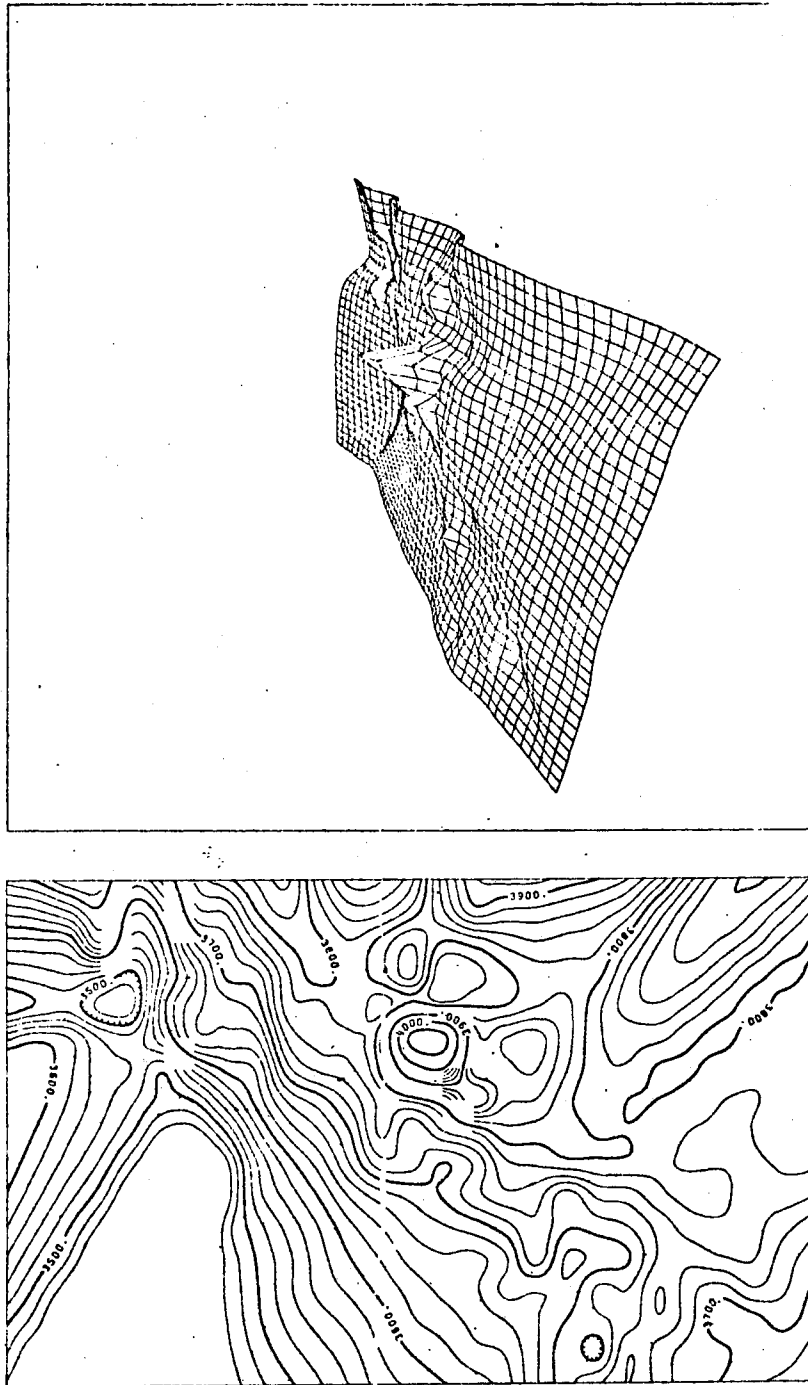


Figure 24. Contour Map and 3-D Perspective Plot
From CALCOMP (1968)

CHAPTER IV

GEOPHYSICAL INFORMATION SYSTEM

Exploration geophysics is one of the most recent and remarkable weapons in the oilman's exploratory arsenal. Developed within the past 45 years, it has become an important ally aiding our efforts to find fuels and raw materials in the earth.

Today, geophysics is closely interrelated with the development and use of advanced technology in such areas as communications engineering, telemetry and information retrieval--sciences which also have become integral parts of the nation's space programs.

The primary concern of petroleum geophysicists has been one of obtaining more reliable information with which to localize areas where accumulations of oil and gas might occur. To this end, they have consistently sought improved technology to measure gravity and magnetism and to propagate and record elastic and electromagnetic waves in the earth.

The acceleration in development of geophysical technology has been particularly apparent since the middle 1950's. At that time, two major innovations were introduced: (1) magnetic tape seismic signal recording and (2) sophisticated reproduction techniques.

The seismograph provides the only direct way of acquiring subsurface structural information without drilling wells, and it has been successful in supplying this information.

Seismic waves generated at or near the surface penetrate the earth's crust and reflect from subsurface rock layers back to the surface. There the reflected signals can be recorded, just as is done with radar. The geophysicist receives a printed record or seismogram from which he can measure the depth to various strata.

When a series of seismic shots are made over a considerable distance, the resulting succession of seismograms show a cross section of the subsurface structures.

In the early days, dynamite was used almost exclusively for generating seismic waves, but today mechanical sources of wave energy--such as earth vibrators--are also used. In one widely used vibratory technique (shaking rather than shooting), a truck-(or boat-) mounted unit creates seismic waves by means of a vibrator pad which is lowered to the earth, or into the water when it is used offshore.

In marshes and offshore areas, the industry relies primarily on the air gun, a compressed air device which is highly efficient and compatible with the ecology. Vibratory techniques are also used; dynamite has almost disappeared from the scene in such areas.

In contrast to the ruggedness of the source of seismic reflections are extremely sensitive instruments.

Each geophone picks up the signals bouncing off many layers of strata and produces its own seismic "trace," which is recorded both on sensitized paper and on magnetic tape. The amount of time (milliseconds) it takes for a seismic wave to bounce back from the various strata gives the geophysicist a clue to the depth of each rock layer.

The digital recorder has vastly improved the industry's ability to record and play back seismic recordings. In earlier days, reproductions of the field-produced original sustained a noticeable fall-off in quality. By contrast, reproductions of recordings taken from the digital recorder have shown no quality loss, while the digital recorder itself is capable of picking up a greater range of seismic signals.

Computers and electronic equipment used to play back seismic recordings have overcome many of the noise and interpretational problems which formerly limited the seismic explorer. Computerized display equipment also makes it possible to compress wide areas of seismic exploration into desk-size sections that may be analyzed more easily than older style displays.

In addition to the seismograph, there are other tools which are also widely used by geophysicists to measure various characteristics of the earth. Of these, the best known are the magnetometer and the gravimeter.

The magnetometer is an instrument which measures variations in the earth's magnetic field caused by changes in magnetic properties of subsurface rocks. Resembling a large camera, the magnetometer is used both on the ground and in the air to accurately measure magnetic intensity. Airborne, it is a particularly effective means of mapping the broad structural characteristics of large areas.

The earth's magnetic properties have always intrigued scientists, beginning with the discovery that a lodestone will align itself in an approximately north-south direction. Later it was ascertained that

each of the earth's three major classes of rocks--sedimentary, igneous and metamorphic--have different magnetic properties according to their content of iron. Sedimentary rocks--those associated with oil and gas--generally have low magnetic properties compared to the others, particularly igneous rocks, which are much denser and contain more iron.

As a widely used reconnaissance tool, the magnetometer has been responsible for identifying and mapping some of the world's best oil hunting areas.

The gravimeter, on the other hand, literally weighs the earth. It can detect variations in the gravitational pull of rocks which lie as much as several miles below the earth's surface. Because large masses of dense rock increase the pull of gravity, gravimeter readings at a number of surface points provide a key to underlying structural conditions. Anticlines, for example, can often be located because the apex of the arch places denser layers of rock closer to the earth's surface, thus increasing the "pull" in the immediate area. Salt domes, too, have been identified with the gravimeter because the salt is considerably less dense than surrounding rocks.

Our ultimate goal in using geophysics in exploration is to find oil and gas. Since there is no direct means of detection from the surface, we must use indirect means to look for conditions where they are likely to exist.

Gravity and Magnetic Data Processing System

The petroleum industry usually uses an airborne magnetic survey as a preliminary step for exploitation, since it can cover a very large area with a relatively cheaper cost. If the result shows some promising features, a gravity and seismic survey might follow in order to locate the so called "oil trap" structure.

One of the gravity and magnetic data processing systems was developed by Geometric in Palo Alto, California, which offers computerized data presentation and interpretation services using advanced techniques for the compilation, reduction, machine-contour-plotting, and analysis of a variety of mappable data.

The system structure and flow diagram are illustrated in Figure 25. The detail descriptions are given as follows:

Input Data

The system can process data of various types and formats. Acceptable data include magnetic tape (digital and FM), punched cards, punched paper tape, analog strip charts, maps and lists of posted values.

Data Reduction and Interpolation

The data from each survey are first examined to detect gross errors in data acquisition and compilation. Systematic errors are removed according to techniques appropriate to the data.

Survey data are usually randomly distributed and often must be interpolated to a grid in order to plot contour.

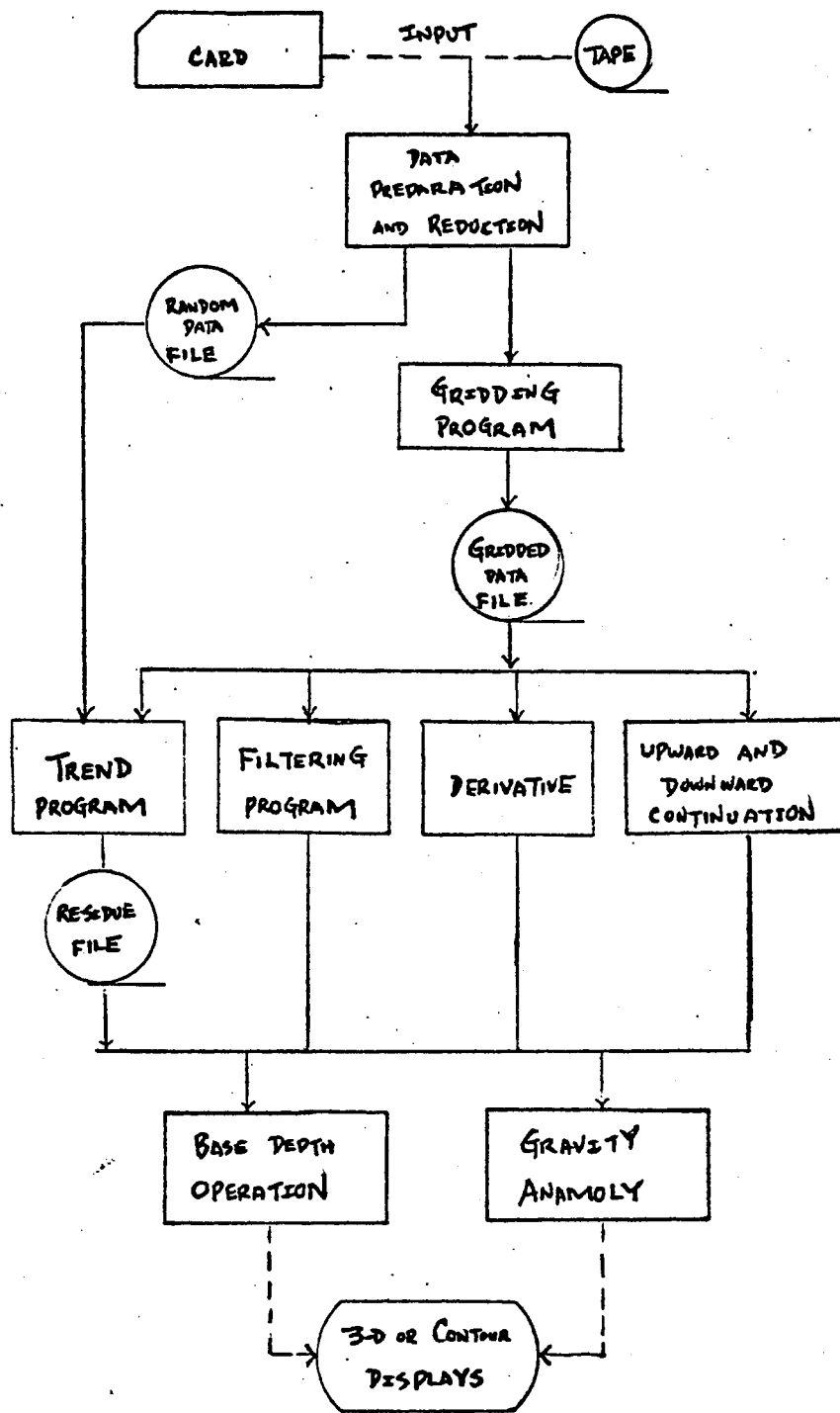


Figure 25.

GRAVITY AND MAGNETIC DATA PROCESSING SYSTEM

Filtering or Trend Surface Analysis

Filtering is used to accentuate anomalies of a given dimension by reducing the amplitude of other anomalies present. In potential field data, the effect is to isolate shallow sources from deep or distant sources. Such separation of anomalies is accomplished by the use of a trend surface prior to the initial interpolation process described above, or by a separate filtering process on the interpolated grid. Filtering is performed using a fast Fourier transform algorithm in two-dimensional frequency space to observe large, small or intermediate sources corresponding to high-pass, low-pass or bandpass criteria. Practically any type of data can be filtered in such a fashion to enhance its use in interpreting trends and subtle features.

Derivatives

First and second vertical derivatives are computed using a fast Fourier transform algorithm. The frequency response of the desired derivative is first computed and multiplied by the data spectra in the frequency domain. Inverse transformation of the derivative operator and the data spectra yields the derivative, which is then contoured for presentation. The second vertical derivative is used to delineate the plan-view boundaries of magnetic intra-basement anomaly sources. The first derivative is, in many cases, more useful for interpretation and magnetic depth-to-basement calculations and is also used, together with horizontal derivatives, in several newer methods involving vector gradients, Euler's theorem and the total gradient.

Upward and Downward Continuation

It is possible to compute potential fields, e.g., gravity and magnetic, at levels other than that at which the data were originally acquired. These upward and downward continuation maps are computed by exponentially filtering the data in the vertical direction, the result of which is to reduce or accentuate the effects of near-surface bodies. Such maps can also provide additional estimations of the depths to anomalous sources.

Depth-to-Basement Computation

Depth-to-basement calculations are performed on filtered or detrended maps and profiles. The calculations utilize either the well known methods outlined by Vacquier, et al, or a newer method developed by GeoMetrics for automated depth-to-basement computations. The latter uses the phase and amplitude Fourier spectra (not power spectra) of the surface magnetic fields. The spectra of the magnetic fields from a generalized sedimentary/basement model are composed of the magnetization spectra of the basement, an exponential depth factor, and a magnetic latitude effect. The spectra are first corrected for asymmetries due to magnetic declination and inclination, i.e., the data are reduced-to-the-pole. Using either two-dimensional spectra in map form, or the one-dimensional spectra of profiles, the spectrum of the magnetically anomalous bodies. Non-linear regression is then applied to the demodulated spectrum to determine source parameters,

such as the depth to intra-basement, infra-basement, and sedimentary anomalies for petroleum exploration, and depth, width, inclination and type of body for mineral exploration.

Figure 26 is a machine drawn contour map for total magnetic intensity by aeromagnetic survey.

Figure 27 is a perspective or 3-D map presentation of total magnetic intensity data of Figure 26 as viewed from the lower left and lower right corners of the contour map of Figure 26. This presentation, together with the contour map, can be used as a visual aid for discerning trends, for presentation of complex data to higher management, or for presentation in slides and publications.

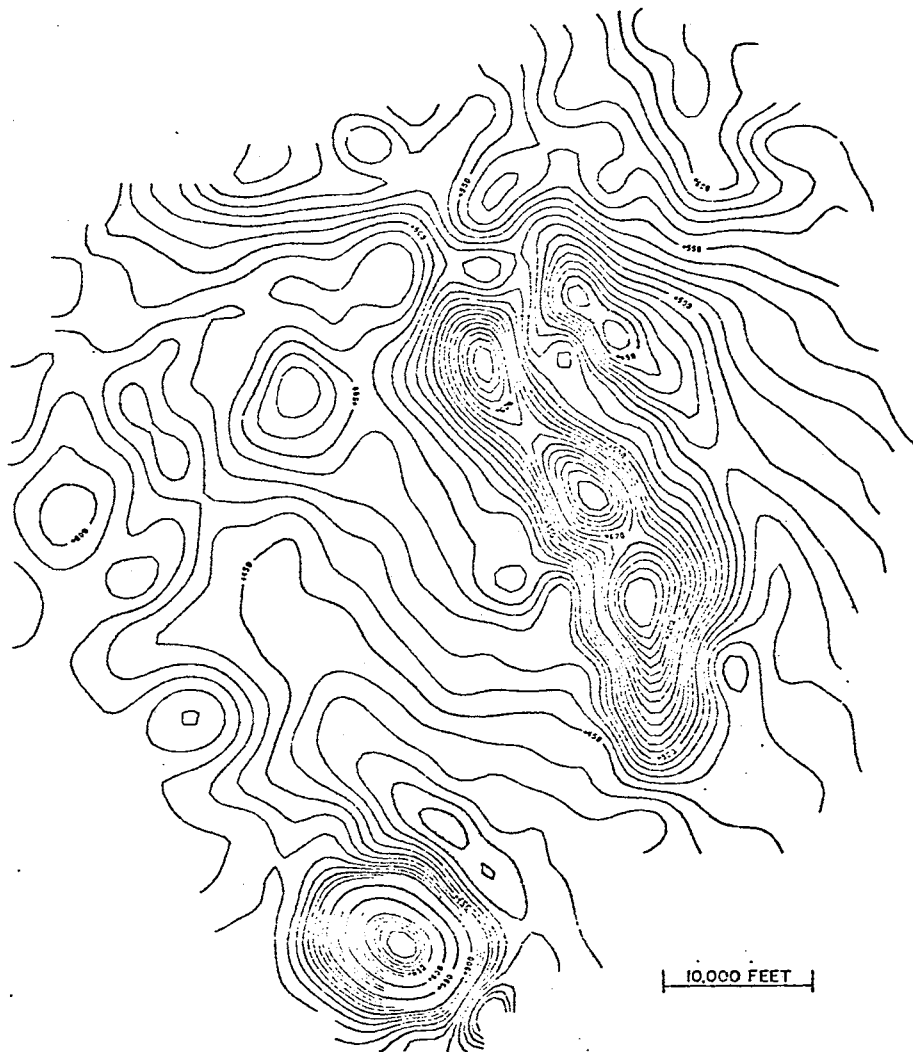


Fig. 26 Observed total magnetic intensity contour map, machine drawn by a digital incremental plotter. The aeromagnetic survey data were processed by the compilation, interpolation, splining, and contouring methods outlined herein. From *Geometrics* (1970)

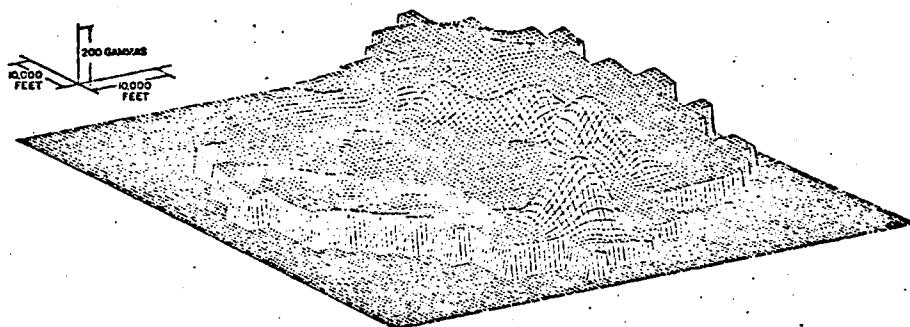
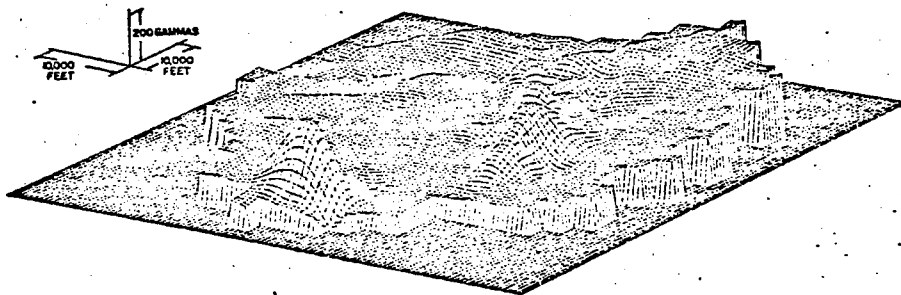


Fig. 27. Perspective or 3D map presentation of total magnetic intensity data of Fig. 26 as viewed from the lower left and lower right corners of the contour map of Fig. 25. This presentation, together with the contour map, can be used as a visual aid for discerning trends, for presentation of complex data to higher management, or for presentation in slides and publications. From *GeoMetrics* (1970)



Seismic Data Processing System

As mentioned before, the seismic data provides the only direct way of acquiring subsurface structural information without drilling wells, and it has played an important role in oil exploration. One of the seismic data processing systems was developed by the Seismograph Service Company in Tulsa, Oklahoma. The Seismic Data Processing System features an integrated software design which includes the acquisition, processing and interpretation of seismic data.

Basic System Design

Data Reduction. Depending upon the seismic source, field data is initially reduced with a variety of programs such as cross-correlation, grain recovery, spherical divergence, etc., but it is basically re-formatted to a floating point work tape in this portion of the system.

Preprocessor. The preprocessor concept allows the majority of data parameters to be entered independent of the actual data. Tables are generated, filters designed, and other parameters are interpreted and verified. Numerous logic checks on input parameters are incorporated to insure quality control. The preprocessor function can be run in an edit mode to permit a final check for errors that would abort the routines during the actual processing of seismic data.

Processing Routines. Processing routines encompass some 40 application programs. All of these programs are applied in the floating point mode to floating point data. There is no scaling

associated with any processing routine other than output. These application programs are the basis for one of the most comprehensive floating point systems in existence today.

The data flow and system configuration are illustrated in Figure 28. The software subroutines are grouped by the functional characteristics and are described as follows.

General Programs

FLOIN. Data can be accepted in floating point formats from practically any type of 7- or 9- track field recorders. Facilities are also available to process any type of analog input. Special features include binary gain recovery, automatic rejection of invalid records, bias removal, time break detection, resampling (up or down), true amplitude recovery, and scanning.

FLOCOR. Special VIBROSEIS correlation techniques are used with options to use the recorded sweep, validity checks, variable channel input, and correlation in the floating point mode.

FLOGAIN. Gain application is accomplished in the floating point mode, and such types of gain curves as program, exponential, true spherical divergence (multi-channel, if desired) and time to the Nth are used.

FLOEQUL. Trace-to-trace or record-to-record equalization is accomplished prior to output and may be time variant (up to 3 windows) or time invariant. Transition problems are eliminated with variable

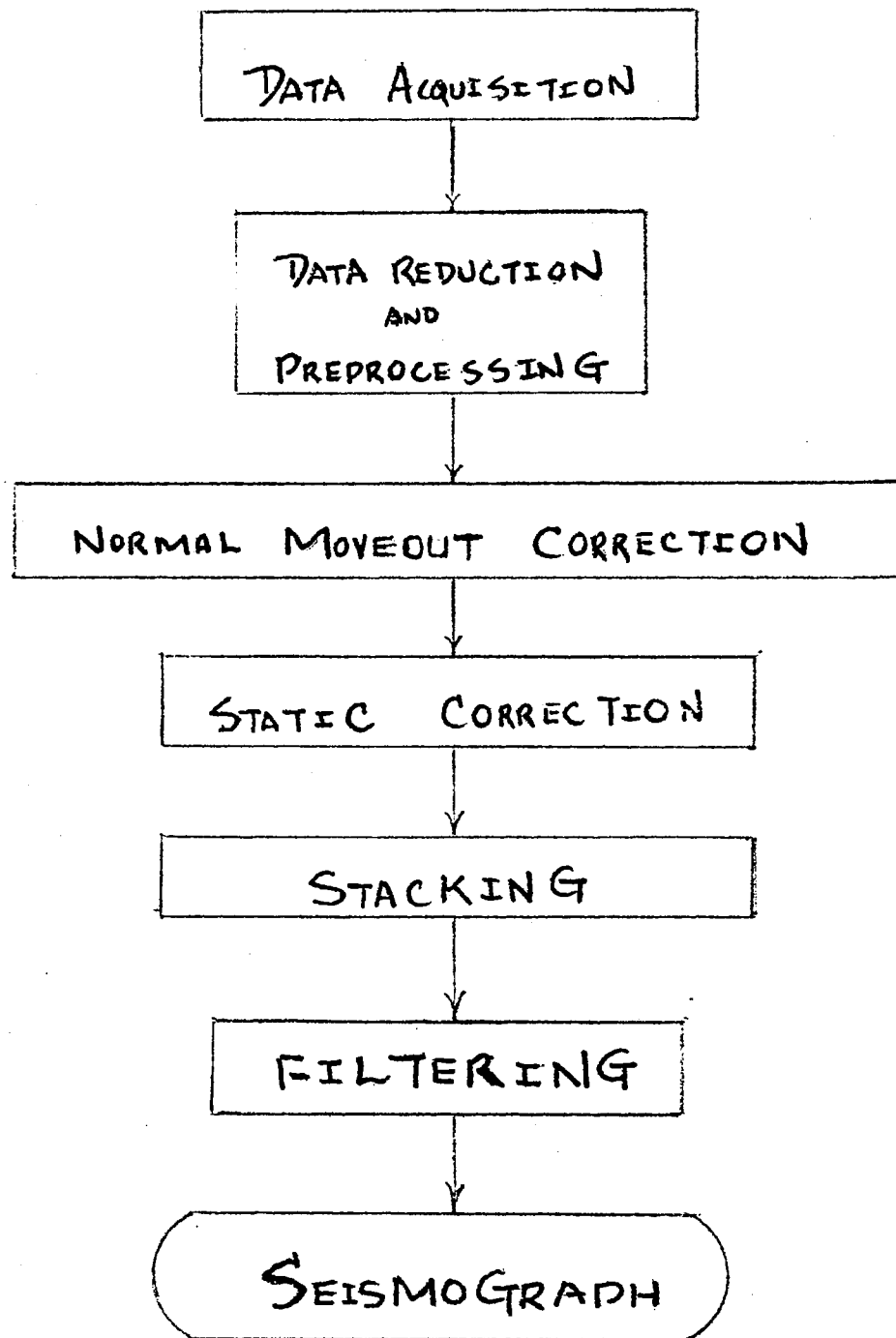


FIGURE 28.

SEISMIC DATA PROCESSING SYSTEM

zones. Types of solutions include Absolute Value Mean, Root Mean Square, Absolute Descale and Constant Descale. The use of certain types of equalization in conjunction with complete floating point processing allows for the measurement of meaningful amplitude relationships that might not be possible in a fixed point processing system.

Velocity Programs

VELCON. Automatic velocity is determined using the sum of all possible cross-correlation techniques. A 24-trace 'gather' is defined and a sliding 24-millisecond window sweeping from starting average velocity to ending average velocity with incremental velocity scans is used to determine the maximum correlation value. Floating point accuracy allows an RMS average velocity curve to be drawn through points of true maxima, based on certain criteria.

VELTAN. Concentrated velocity modeling is done using the VELCON method of computation. All CDP points are used for determination of the model. Output to the Cal-Comp plotter includes a display of each CDP analysis. Adjacent interval velocity, average velocity, and power plots are displayed in cross sectional form.

FLOVELF. Normal moveout computation is made using straight raypath calculations. Types of input include RMS Average Velocity, Delta-T, Exponential, Time vs Depth, Velocity Power Series, and Interval Velocity. As many as 40 charts with up to 102 different velocity layers are available on one line.

FLOSNO. Normal moveout application is always made to at least 1 millisecond accuracy, regardless of the sampling rate used in processing. Application is made on an interpolative basis, that is, functions are derived and interpolative corrections are made between functions from one common depth point to the next.

Static Programs

FLOCOST. Based on correlation methods, the deviations within a CDP group are measured. These deviations are then checked for coherence over a series of windows. Threshold requirements are entered and deletion or partial deletion of traces within a group is made based upon these threshold requirements.

FLOSTIM. Automatic static corrections are made using a CDP group taking the average correlation maxima over as many as three windows with decreasing priority.

Filtering Programs

FLOFILT. Digital filters are designed in floating point. They are true zero-phase filters and are applied in the time domain. The filters are optionally time variant (up to five zones) so transitional problems are eliminated. The operators are self-designing in regard to length and can be displayed on the line printer in both the time and frequency domains. Types of filters include Low Pass, High Pass, Band Pass, Band Reject, Notch and Spike. Since the filter weights are floating point, and the data is floating point, there is no need for scaling after filtering.

Analysis Programs

FILTEST. FILTEST is a routine to aid in designing the optimum band limits and time zones for digital filtering.

FLOANYL. This program is used to analyze the quality of the field data as well as the data after processing. Such things as the mean, maximum and minimum values are listed. This program can be used to determine the types of gain correction curves which would best fit the data.

CHAPTER V

PRODUCTION INFORMATION SYSTEM

Petroleum production deals primarily with drilling the producing wells and developing oil and gas reservoirs.

After a thorough geological and geophysical survey has been made, the subsurface structure has been mapped, and a possible oil reservoir has been located, then the production stage begins. The first step is to drill a well according to the geological study. This involves some optimal drilling technique which could be controlled by a real time computer.

To predict and control the reservoir production, the Petroleum Production Evaluation System calculates individual well pressures and production characteristics so that the flow of oil, gas and water in a reservoir can be analyzed.

Another sub-system included in the production information system is the Reservoir Simulation System which is designed to simulate mathematically the complex interaction of the natural forces and physical properties under actual field conditions.

In order to make the best investment and return, a Computerized Investment Planning System is developed which provides reservoir engineers and management an optimal solution and operating guidelines.

Real Time Drilling Optimization
and Monitoring System

Drilling for petroleum is one of the most costly industrial activities in America. To drill a well is a tremendous undertaking requiring great quantities of equipment and high costs. The cost of a single exploratory well - known as a "wildcat" - may range from about \$100,000 to about \$3 million, depending largely on where the well is drilled and how deep it must go.

The risks involved in finding a new oil or gas field still remain high, despite the technological advances made by the industry in recent years. Only about one out of every nine exploratory wells is a field discovery and only one in 50 stands a chance of finding significant new reserves.

Once a field has been found, the costs and the risks usually decline. "Development" wells may range in cost from about \$50,000 to over \$1 million. In remote areas, like Alaska's North Slope or in the ocean regions, the costs remain high for each development well drilled.

In recent years, the industry has concentrated its efforts on developing new equipment and new techniques to improve drilling efficiency and lessen costs. One of these is optimized drilling, in which wells are drilled using computer-analyzed data taken from wells already drilled in the same fields or those nearby. The computer, after analyzing and comparing the data, prescribes such drilling variables as the weight on the bit, rotary speed, rate of mud circulation, type of drill bit and dozens of other factors.

Real Time Drilling Monitor

The RTDM (Real Time Drilling Monitor) is a real time operated drilling optimization and monitoring system that utilizes on-site drilling data to give discrete time optimal controls over a drilling task. The data is recorded continuously during the drilling, but sampled only at a fixed time interval (e.g., every 10 minutes) of a bit run. The resulting information is then fed back to a computer (or a computer terminal) as a performance measurement of the drilling operation. After a real time evaluation and correction, a new control decision is made by which a new interval of a bit run is to be drilled. These interval control decisions are continuously revised throughout the process of a drilling job.

Deterrent Factors in Conventional Optimum Drilling

In the last decade, optimum drilling has played an important role in the drilling industry as a means of reducing costs by improved efficiency of operation. Various bit manufacturers and oil company research departments have made impressive efforts in the advancement of this technique. Nevertheless, the practical value of optimum drilling is still limited. This is largely because of some obstacles encountered in drilling optimization. Experience indicates that the following are the major deterrent factors that affect the operation.

Data. The quality of optimum drilling depends to a large extent upon the accuracy of drilling data. Conventional drilling data is collected from offset wells in the forms of geolograph, well logs, and

bit records. It gives a detailed history of an offset well. However, it provides little information about a proposed well. The utilization of these data requires interpretation, such as data evaluation, assembly, and extrapolation. This procedure can induce a variety of errors, mainly human and inherent, which may then be in part or both cumulative to the final decision.

To appreciate this, one might start to visualize the necessity of an on-site data acquisition device such as the one used in the monitor system. Use of this on-site data retrieval provides a direct data contact between the drilling object and the drilling machine. It enables the system to detect infinitesimal changes in the bottom hole conditions and provide immediate control response to the drilling operation.

Bit Run Strategy. In conventional optimum drilling, drilling controls are given as a guideline in terms of a specific set of optimum operating values such as bit weights, rotary speeds, etc., in order to achieve a preset sequence of footages for a proposed well. These bit run footage goals are estimated by the analysis of the offset bit run records. They are rigid and often inadequate. As a result, bit run optimum strategies may not result in a workable drilling program for a proposed well. This is particularly true when two wells do not correlate in their characteristics. A succession of increasing cost would occur as a consequence of these strategies.

A substantial savings can be realized if the optimum drilling strategy is based upon a flexible, rather than restrictive, interval decision such as RTDM provides.

Formation. In conventional optimum drilling, in order to provide a realistic drilling program for a proposed well, a complex and cumbersome formation assignment is conducted. It is to estimate a variety of formation characteristics that a proposed drilling trajectory would encounter (a drilling trajectory is a path to be followed by drilling bits from a prescribed surface location to a predetermined subsurface objective). This forecast includes: the subsea depths of formation tops, regional dip, porosity, lithology, drillability, abrasiveness, etc. It is apparent that it is difficult to obtain an accurate and reliable forecast on such a heterogeneous matter as formation. However, in conventional optimum drilling, determination of an optimum drilling program for a proposed well is primarily based upon this information. Once the actual drilling is started, sizable control discrepancies can occur. It would be necessary to reschedule the optimum drilling program in order to achieve the expected results.

In RTDM, instead of being forced to make compromises of a rigid drilling program, the system is able to evaluate the formation in real time. With the use of feed-back data, the formation parameters are computed, with which the system optimization is performed. The resulting real time decision is then possible for the most realistic optimum for the transient formation conditions that the bit may encounter.

Monitor System Description

The RTDM is a drilling monitoring control system that is based upon a continuous evaluation of real time drilling data and provides

optimum control decisions for drilling. It is presently designed for use with a computer time-sharing terminal and incorporated with an on-site data acquisition device. The system physically consists of two components; 1) system hardware, and 2) system software (the computer programs that monitor and control the hardware).

System Hardware

A. Equipment

The equipment of the system includes;

(1) A Drilling Data Acquisition Analog

A Honeywell Voltmeter, Model 620-II.

(2) A Drilling Real Time Computer

A G.E. Time-Sharing Computer Terminal

Interrelations of these hardware units are shown in Figure 29, System Hardware Elements.

In Figure 29, a real time data feedback and drilling control cycle is illustrated by the path indicated. The dashed marked "rectangle" encloses the units which could be housed in a drilling cabin or a mobile trailer. A time-sharing computer, G.E. 635 connected by data lines, is assumed.

B. Communication and Response

The response times of the monitor system I/O are subject to the hardware efficiency and specifications. In the present system, data feedback output rate (as well as the terminal data input rate) is 0.8 data items/sec. The drilling control response with respect to each

interval is presently less than 30 seconds. This speed can be greatly enhanced if an independent real time computing facility (e.g., a mini-computer) is available at the drilling site.

System Software. The software of the system consists of 14720 characters, including five dynamic data files, six subroutines, and twelve function-subroutines. The software is written in FORTRAN language for use in any G.E. time-sharing system.

Data files - Data files are an essential part of the real time monitor system. They insure that the system performs its multi-interval decisions throughout the process without losing its integrity.

Subroutines - Functions of the software's subroutines are:

<u>Subroutine Name</u>	<u>Main Function</u>
<u>.DFA</u>	Data file updating and accessing
<u>.TMG</u>	Time synchronization and control
<u>.CVT</u>	Feedback analog data conversion
<u>.FDX</u>	Formation sensing and classification
<u>.TAU</u>	Dullness evaluation
<u>.RTW</u>	Control variables calculation

Function - Subprograms - There are twelve lower-level system routines, performing special mathematical computations.

All of the above routines are under the control of a supervisory main program, which interfaces I/O, assigns data channels, executes interrupts, and enables the user to communicate with the system.

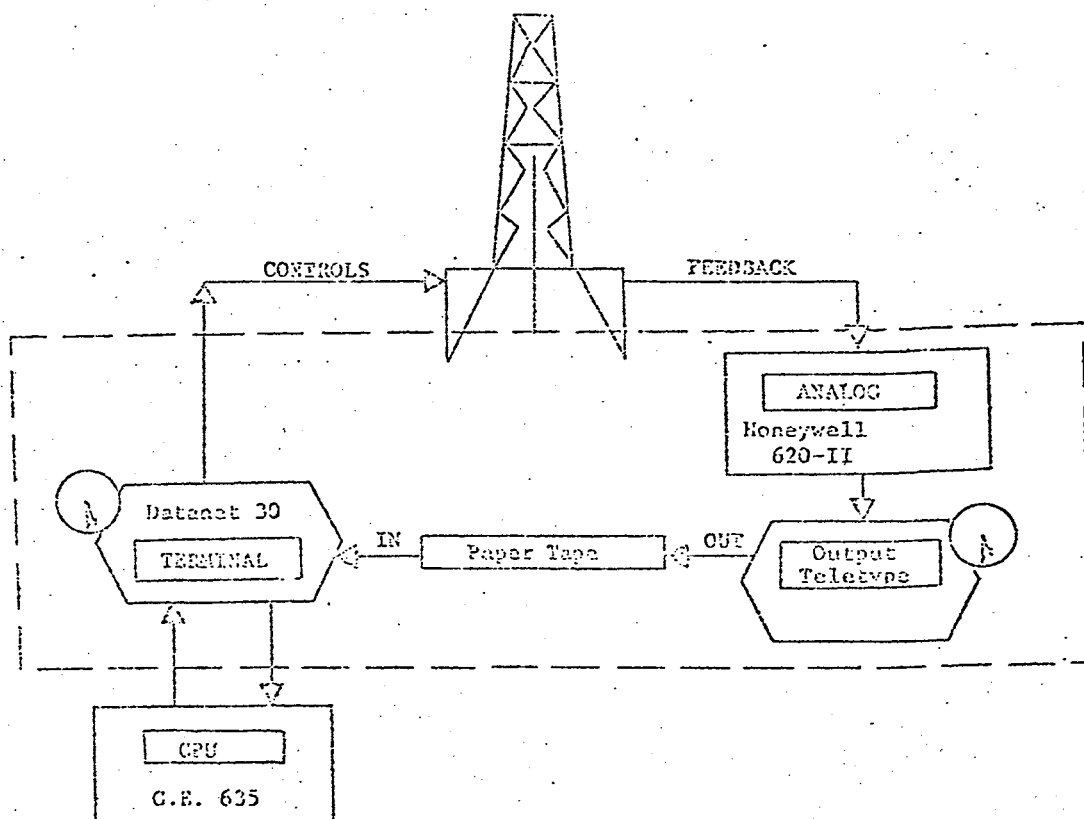


FIGURE 29.

REAL TIME DRILLING MONITOR SYSTEM

Petroleum Production Evaluation System

One of the most comprehensive petroleum production evaluation systems, designed to analyze past field performance and predict future behavior of all reservoirs, was developed by International Computer Applications Ltd. This evaluation system represents a series of programs designed to analyze the flow of oil, gas and water in porous media. This suite of programs is designed to analyze past field performance and predict future behavior of all oil and condensate reservoirs. Past field performance is evaluated through a technique called "history matching". The computer program calculates individual well pressures and individual well production characteristics and compares them with the observed field data gathered over the life of the reservoir. When an adequate comparison is obtained, the reservoir model is now capable of predicting future performance. Many alternatives can be evaluated such as increased production rates, infill drilling, and secondary recovery techniques when predicting future performance.

This system is divided into three subcomponents. The Compositional Model, the Compressible Flow Model, and Incompressible Flow Model. The Compositional Model differs from Compressible Models in that it accurately accounts for mass transfer between phases. The Compressible Model is designed to treat a black oil reservoir where the three phases are water, gas and oil. The incompressible system is similar to the compressible system with the exception that a constant pressure gradient distribution exists in the reservoir at all times.

Three-Dimensional Compositional Model

This program is designed to simulate historical and future performance of volatile oil and gas condensate reservoirs produced under any of a variety of schemes. These producing schemes include natural depletion, dry or enriched gas injection, water injection, and full or partial cycling. The program simulates one-, two-, or full three-dimensional flow of water and two hydrocarbon phases in a heterogeneous reservoir. Mass transfer between hydrocarbon liquid and gaseous phases is handled using K-values (permeability) dependent upon pressure, temperature, and fluid composition.

The K-values used are functions of pressure obtained by matching laboratory data from a depletion experiment on a reservoir fluid sample. The fluid properties of density, viscosity and compressibility are computed from published correlations (again, modified as necessary to match available laboratory data) as functions of pressure and composition at reservoir temperature. Flash calculations are performed at specified separator pressure and temperature conditions to yield compositions and amounts of surface liquid and gas recoveries.

The novel and rigorous method of solution employed differs appreciably from the several approaches reported in the literature for compositional simulation. The program numerically solves the set of simultaneous finite difference equations corresponding to:

- (1) the set of N partial differential equations expressing conservation of mass of each of the N components

- (2) the N relationships $Y_i = K_i X_i$ expressing phase equilibrium within each grid block
- (3) the constraints $\sum X_i = 1, \quad \sum Y_i = 1$

Solution of these equations is implemented in such a manner that the calculation is implicitly built into the flow equations. Thus solution is in effect simultaneously performed for composition as well as pressure and fluid saturations.

Program Features

- (1) evaluate feasibilities and economics of full and partial cycling of gas condensate reservoirs,
- (2) estimate sweep efficiency of cycling operations for alternate well spacings or configurations,
- (3) estimate recoveries and economics of gas and/or water injection as opposed to natural depletion of volatile oil reservoirs,
- (4) determine the need for compositional as opposed to simpler--two or three "component"--models for prediction of performance of a specific volatile oil or gas condensate reservoir.

Input Data Requirements

The input data requirements consist of:

- (1) the permeability and porosity distributions over the reservoir,

- (2) the location of reservoir boundaries including the subsea depth to the top and bottom of the sand(s) as a function of areal position,
- (3) depths of any initial gas-liquid and liquid-water contacts,
- (4) composition of oil and/or gas initially present,
- (5) tabular or polynomial representations of pressure-dependent K-values as determined from laboratory data,
- (6) correction factors determined from any available laboratory data to be applied in correlations used to calculate viscosity, density and compressibility as functions of pressure and composition,
- (7) water compressibility, density and viscosity and rock compressibility,
- (8) relative permeability and capillary pressure data,
- (9) well locations and perforation intervals; surface condition rates of gas, oil and water production and surface separator operating conditions. Alternatively, producing pressures may be given along with well PI indices as known or determined by history matching,
- (10) operating data such as workovers, limiting gas and/or water production rates or limiting gas-oil and/or water-oil ratios.

As in many reservoir simulations much of the above required input data is uncertain or even unavailable. This, however, is not a serious drawback if reservoir performance data is available. The performance

data is used in what is called the history matching phase. This is where the uncertain or unknown data is adjusted until the model simulates the actual reservoir performance. A very accurate reservoir description can often be obtained by history matching.

Compressible Flow Model

This model comprises three different programs. The Three-Dimensional, Three-Phase Program accounts for three compressible phases (oil, water and gas--including dissolved gas) flowing in three spatial directions. This is used for any reservoir where performance is affected by three-dimensional flow and compressible analysis is needed.

3-D, 3-Phase Compressible Flow Model. This program represents a powerful tool for use by reservoir engineers in analyzing observed field performance and predicting future behavior. The reservoir model consists of a numerical solution of the partial differential equations describing three-phase flow in three space dimensions. The program also contains the logic necessary to efficiently solve the flow equations in less than the full three-dimensional mode and therefore can be economically used to solve one, two or full three-dimensional problems at the user's option.

Reservoir heterogeneity is accounted for through the variable permeability, porosity, and field geometry arrays which are read as input data. Fluid property variations with pressure and saturation

are read in tabular form. The variable reservoir description and accurate fluid property treatments combined with the solution to the unsteady state flow problem, results in a model that can give an accurate prediction of reservoir performance under any given operating conditions.

Two-Dimensional, Three-Phase Compressible Flow Model. This program is just a two-dimensional version of the Three-Dimensional, Three-Phase Compressible Flow Model. It has all of the features of the three-dimensional model except that flow is accounted for in only two space dimensions. The two-dimensional version can be used for areal and cross-sectional as well as one-dimensional studies. This program coupled with INTERCOMP's Vertical Equilibrium Program provides an economical package which will accurately simulate any three-dimensional reservoir problems.

One-Dimensional, Three Phase Compressible Flow Model. This program is just a one-dimensional version of the Three Dimensional, Three-Phase Compressible Flow Model. It has all of the features of the three-dimensional model except that flow is accounted for in only one space dimension. The one-dimensional model is a very useful tool for studying reef type reservoirs where flow in the vertical direction dominates and gravity drainage is important. This program has a gas percolation routine built in to handle upward migration of gas without resorting to small time steps.

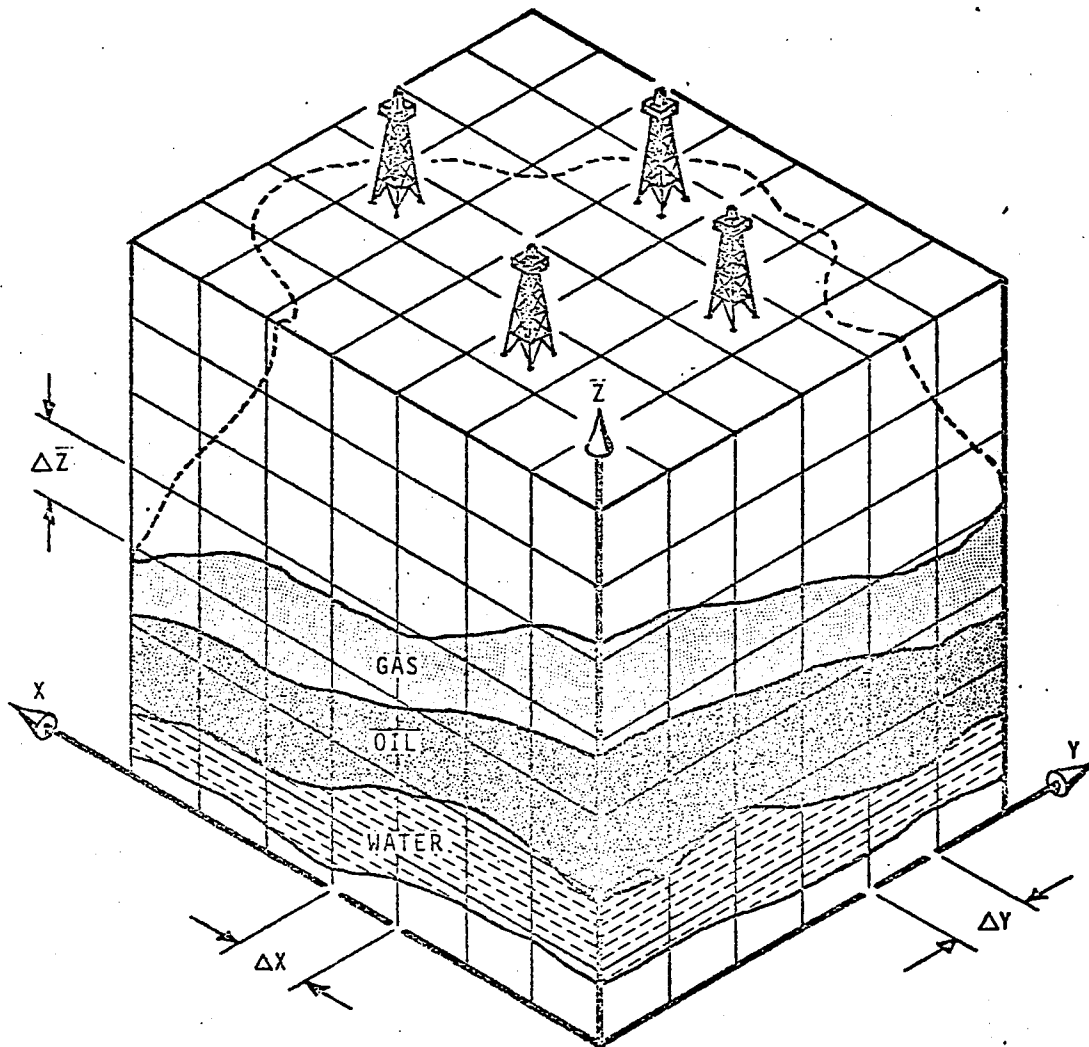


FIGURE 30. THREE DIMENSIONAL FLOW MODEL
From International Computer Applications
(1971)

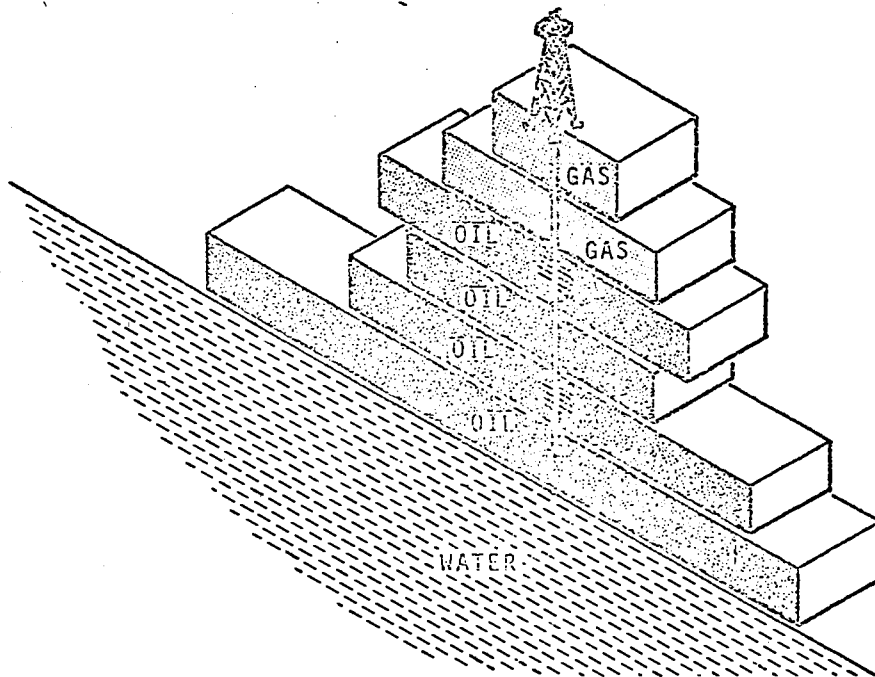
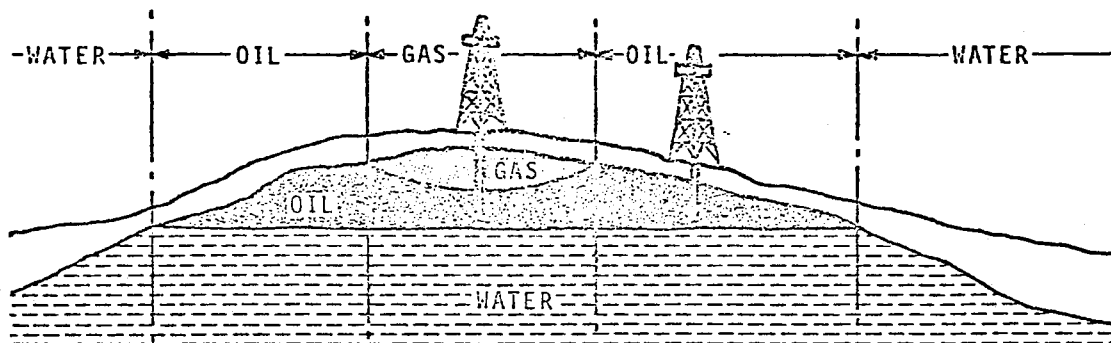


FIGURE 31.

TWO DIMENSIONAL FLOW MODEL
From International Computer Applications (1971)

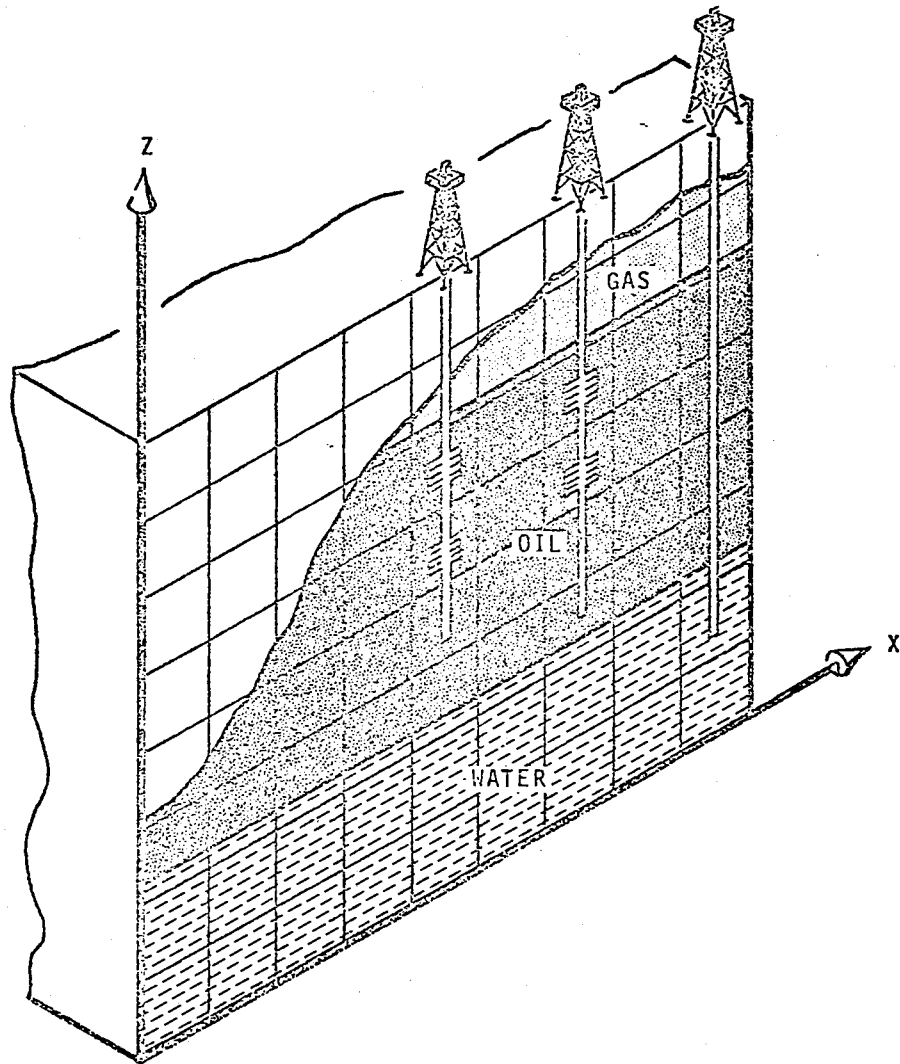


FIGURE 32.

ONE DIMENSIONAL FLOW MODEL
From International Computer Applications (1971)

Three-Dimensional, Two-Phase Incompressible Flow Model

This program simulates the transient flow of two incompressible fluids flowing in a three-dimensional porous media. The calculations include the effect of viscous, gravity, and capillary forces. Reservoir heterogeneity is accounted for through variable permeability, porosity and reservoir geometry arrays which are read in as input data. The combination of variable reservoir description with rock and fluid property data such as relative permeability and capillary pressure data, results in a model which can be used to accurately simulate the performance of many production operations.

The program numerically solves the partial differential equations describing two-phase, incompressible, unsteady-state flow in a porous media. These equations are solved in three dimensions. However, the program logic is such that the model will accurately and economically simulate flow in one, two, or three space dimensions.

There are two limitations to be considered: First the model accounts only for two-phase flow. Second, since the fluids are assumed to be incompressible, the program must be run in a pressure maintenance mode. The program is therefore useful mainly for pressure maintenance operations with water and oil as the two phases present. Gas-oil simulations may be done if gas compressibility is not important. This is sometimes the case where small pressure gradients are the rule.

Recognizing these limitations, this program can be used to predict reservoir behavior in an accurate and very economical manner. The assumption of incompressible fluids does minimize the amount of calculations necessary to perform the simulation and will therefore give answers at the lowest possible cost.

The program may be used to predict fluid movement in one, two, or three space dimensions so that areal and cross sectional studies as well as full three-dimensional studies can be done using the same model. Internal logic in the program prevents unnecessary calculations when run in less than full three-dimensional mode, so computing time is minimized.

Basic Equations. The flow equations used in this model are well known and result from a combination of the continuity equation plus Darcy's Law for each phase. The system of equations for incompressible flow used in this model are:

$$\nabla \cdot \frac{KK_{rn}}{\mu_n} \nabla \phi_n - Q_{nv} = \phi \frac{\partial S_n}{\partial t} \quad (1)$$

$$\nabla \cdot \frac{KK_{rw}}{\mu_w} \nabla \phi_w - Q_{wv} = \phi \frac{\partial S_n}{\partial t} \quad (2)$$

$$P_n = P_w + P_c \quad (3)$$

$$S_w + S_n = 1.0 \quad (4)$$

where n and w refer to the nonwetting and wetting phases respectively. Equations (1) and (2) are approximated by an implicit finite difference equation at each grid block and the resulting difference equation at each grid block and the resulting difference equations are solved using the Douglas-Rachford iterative alternating direction method.

Nomenclature. Variables:

g = acceleration of gravity

k = absolute permeability

k_r = relative permeability

p = pressure

p_c = capillary pressure

q = injection or production rate, per unit bulk volume of
reservoir

s = saturation

t = time

u = viscosity

ϕ = porosity

Φ = potential

ρ = density

Subscripts:

n = nonwetting phase

w = wetting phase

Required Input Data

(1) The reservoir description information consists of permeability, porosity, elevation, outline of reservoir and the location of the initial wetting-nonwetting phase contact.

(2) The fluid property data consists of densities, viscosities, relative permeability and capillary pressure data.

(3) The operating information consists of well locations, rates, and producing strategies such as workovers, limiting water-oil ratios, etc.

In many cases, most of the above input data, required by the model, is uncertain or even unavailable. A very accurate reservoir description can often be obtained by history matching.

Typical performance data which are useful for history matching purposes include individual well pressure as a function of time and production and producing gas-oil or water-oil ratios.

Reservoir Simulation System

D. R. McCord and Associates, Inc., a subsidiary of University Computing Company, has recently announced the completion of the Reservoir Simulation System. The Reservoir Simulation System (RSSYSTEM) is a group of eight computer programs designed to simulate mathematically

the complex interaction of natural forces and physical properties under actual field conditions. Because of the ability of computers to solve the space variables in numerical analysis, established engineering techniques may be extended to the more complex systems of multi-phase, multi-dimensional conditions. Each of the models in the RSSYSTEM has its own capability and application; horizontal, vertical, multi-layered or three-dimensional configurations may be considered. In any of the linear flow models, radial flow into a given wellbore can be taken into account. Within the vertical configuration, either linear or radial flow within the matrix may be considered. The effects of formation dip, gravity and capillary pressure are incorporated mathematically. Although reservoir engineering problems vary almost inexhaustibly, the models of the RSSYSTEM have been found to be comprehensive enough to account for virtually all naturally occurring variations in rock and hydrocarbon properties.

Once a problem has been defined, or the purpose of the study established, the appropriate model is selected. Through judicious application of known geological and engineering field data, which is coded into specially designed formats, computer runs may be designed to simulate past production behavior or field history, when this information is available. A match of individual well pressure and production history is achieved by careful adjustments to various rock and fluid parameters. This method also checks the validity and quality

of the existing data. One of the principal functions of the RSSYSTEM is to predict or forecast performance. The model is used with the revised data to predict the production and pressure of each well operating under normal field control. The reservoir engineer may test his ideas in considerable detail, and if the production of the field is simulated with enough variations, a reliable near-optimum situation can be determined. A plan of development selected from the choices offered by this kind of reservoir study is always more advantageous and economical than a scheme undertaken through a random approach.

The flow diagram of the system structure and input stream are illustrated in Figure 33.

The simplified full field study, using the computer mathematical model, is shown in Figure 34.

ENGINEERING AND DATA GATHERING ACTIVITIES AND THEIR RELATION TO THE RESERVOIR SIMULATION SYSTEM PROGRAMS

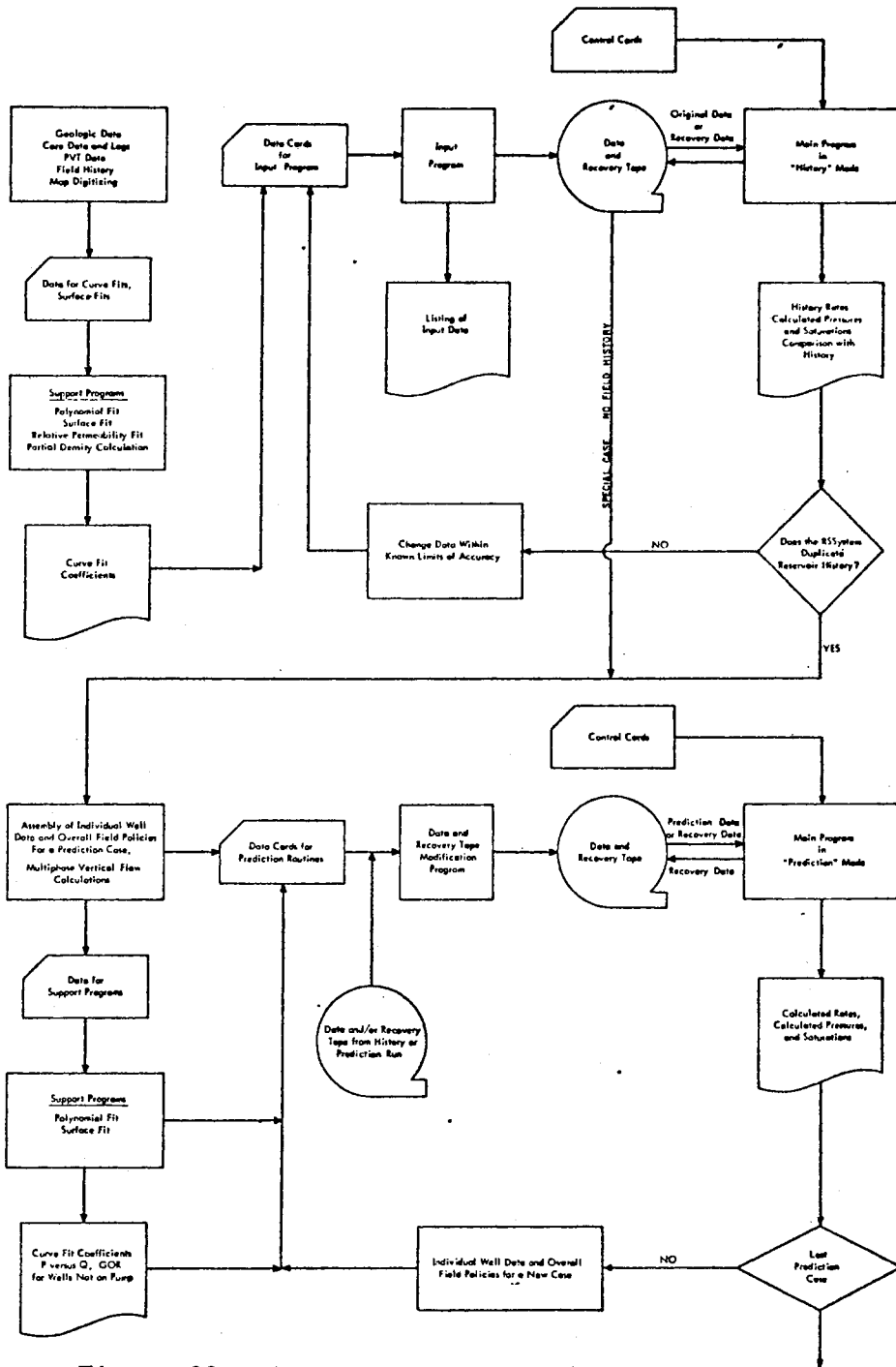


Figure 33. System structure and Input STREAM for the reservoir simulation SYSTEM

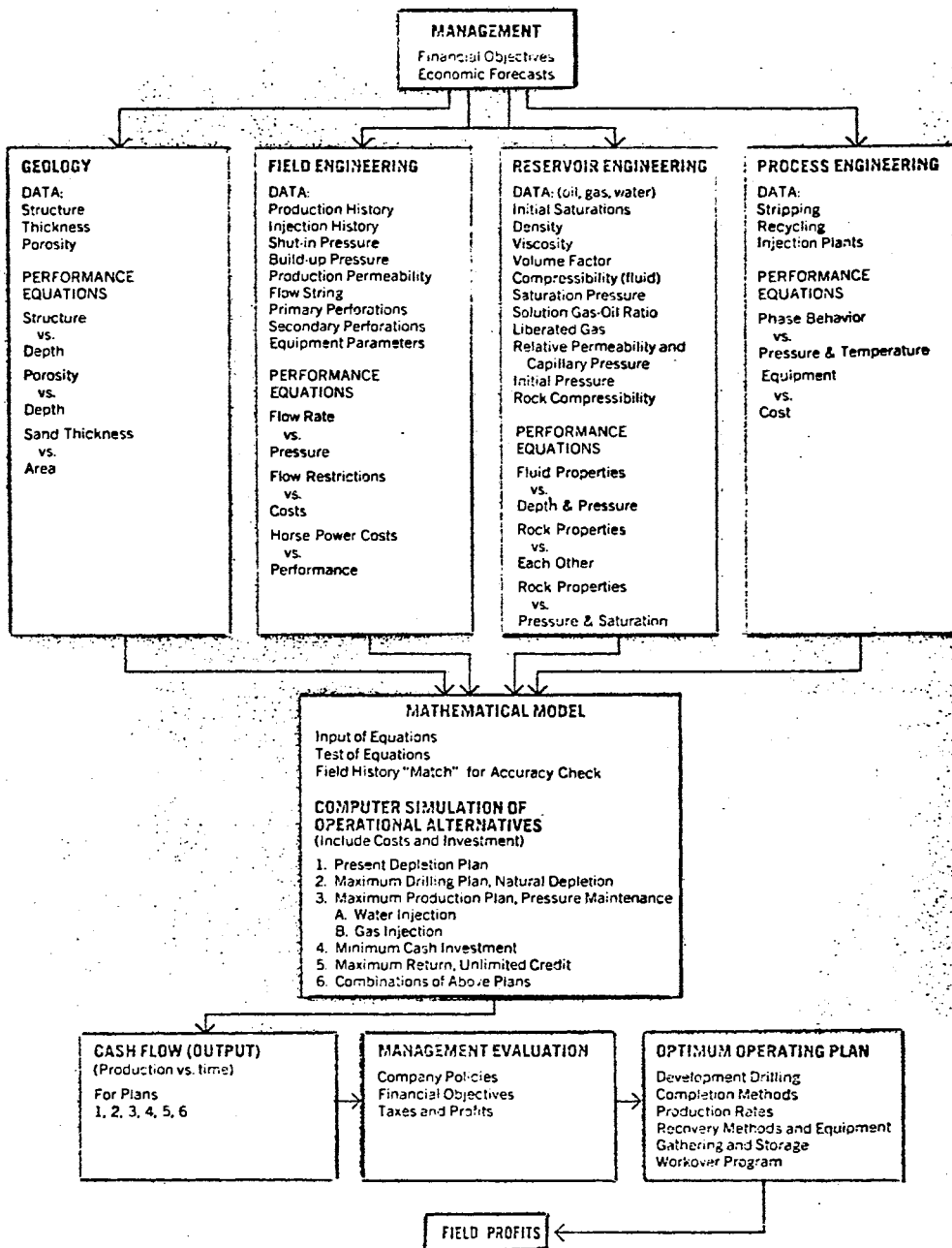


FIGURE 34.
FIELD STUDY USING COMPUTER MATHEMATICAL MODEL.

Computerized Investment Planning System

In all business enterprises, some form of planning takes place, although the quantity and quality may vary widely depending upon the nature of the business and the attitude and level of sophistication of the management. Since the petroleum industry has long been involved in applying the latest technology to improve operations, it is no surprise that petroleum companies have been among the first to begin applying modern computer-based management methods to their critical planning problems.

The greatest advantage to be gained from applying the computer in a planning situation is to provide a mechanism by which data and assumptions can be easily and quickly converted into meaningful planning guidelines. With an efficient and flexible system, it is possible to feed in new data as soon as it becomes available to keep planning current.

From a technical standpoint, the oil business gives rise to some of the most difficult analytical planning problems encountered in business. As a result, progress toward development of improved computerized planning systems for the petroleum industry has come slowly. However, recent mathematical developments combined with the ability of modern day computers to process enormous quantities of data at fantastic speeds now makes it possible to consider all significant interactions in a complex oil system in generating the kind of information required by enlightened petroleum managements to make better decisions.

Scientific Software Corporation, a consulting company in Englewood, Colorado, has developed a Computerized Investment Planning System which probably is the most comprehensive and flexible computer system in solving such a program. The Investment Planning System provides a means for reservoir engineers, pipeline engineers, and company management to combine data and assumptions within an analytical planning system which quickly and efficiently integrates these data in developing optimal expansion and operating guidelines. IPS is applicable to planning development of an oil or gas reservoir system, be it a single reservoir, a single reservoir with multiple horizons, or a set of reservoirs which do or do not interact through a common pipeline. Extension of IPS downstream to include refining and marketing considerations is feasible. In this way, optimal investment balances between functional areas in an integrated petroleum company could be established.

System Description

The investment system is shown schematically in Figure 35. The large box represents the financing entity which pumps investment capital into the system. This capital initially goes into geology and geophysics, land acquisition, exploratory drilling and development drilling, and producing facilities. The geological and geophysical box and the land acquisition box convert capital into exploratory projects which determine the inner workings of the exploratory drilling

box. Drilling boxes act as converters which transform investment capital into wells and facilities. The production box converts input of wells and facilities into crude. Crude, in turn, is converted into money in the crude sales box. What is left of this money after paying royalties is gross (working interest) income from which are deducted operating costs, income tax and mineral and property taxes. The remainder represents cash earnings after tax and is returned to the financing entity. The difference between what is returned to and what is left to the financing entity is profit. Ordinarily, the objective is to make this difference as large as possible.

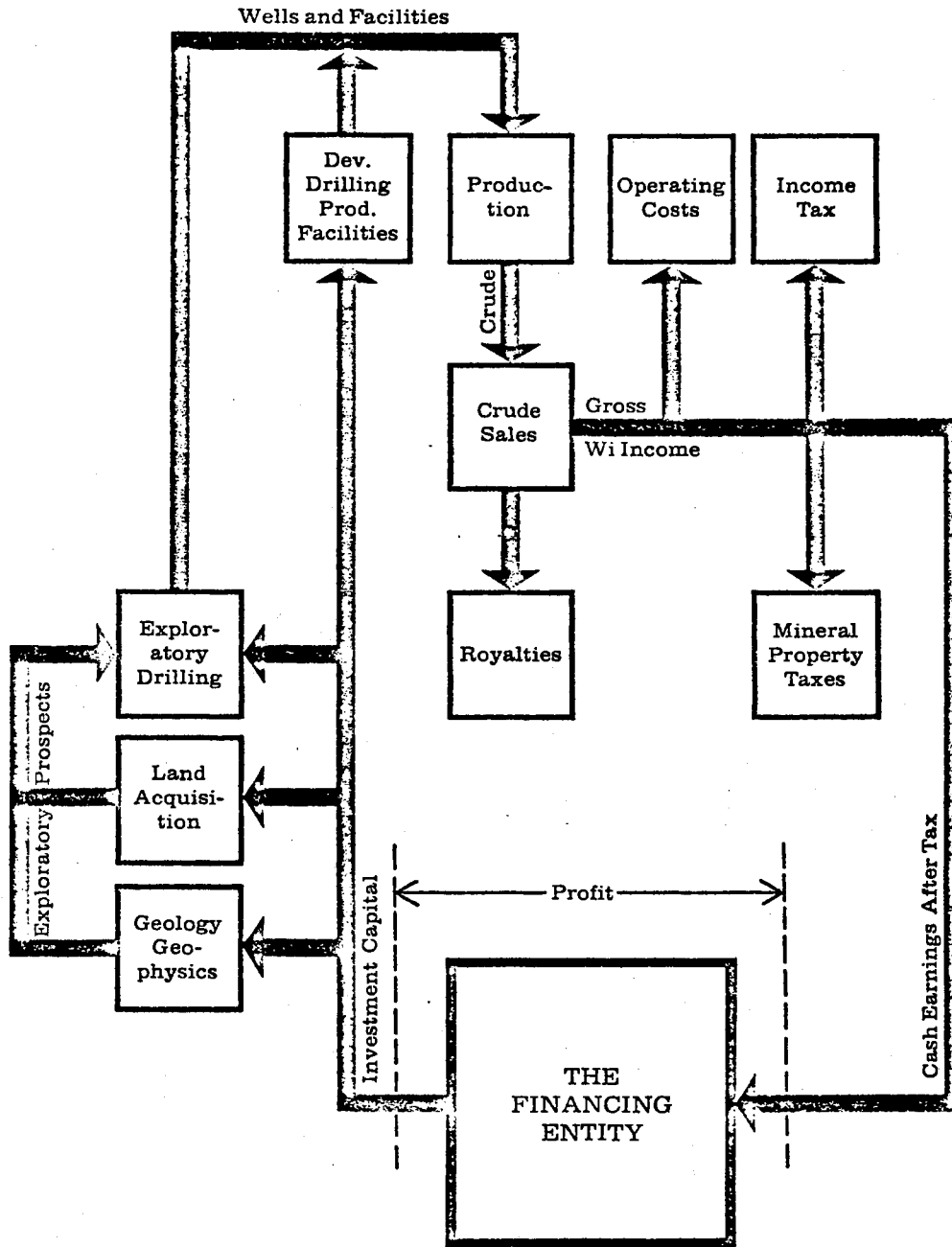


FIGURE 35. THE INVESTMENT SYSTEM FOR PETROLEUM INDUSTRY
From Scientific Software Corporation

In order to use a mathematical model in a computer to assist in planning performance of this system, the flows and the objective of the operations must be translated into mathematical equations. This translation involves: (1) Defining the relationship between inputs and outputs to each of the boxes. (2) Tying together output of boxes with inputs to succeeding boxes. (3) Expressing in mathematical form the economic yardstick by which performance of the system is to be measured.

The resulting equations contain variables (the unknown inputs and outputs of the boxes) which are functions of time. For example, amount of drilling which occurs, volume of production obtained and amount of income tax paid are all functions of time. In addition, variables are interrelated through time because they depend on the investment plan. Output from drilling boxes depends upon outputs from geology and land acquisition up to that time. Output from the production box at any time depends on output of drilling boxes up to that time. Similarly, income tax and royalties paid at any time depend upon all past outputs from drilling boxes.

The inner workings of each box are readily determined by the basic data appropriated to the system. Conversion of capital to exploratory projects and exploratory wells is determined by the petroliferous nature of the area or areas of operation. Conversion of capital to wells and facilities depends upon cost of pipelines, etc; as well as

depth and geographic location of productive horizons. Limited availability of drilling rigs and manpower for supervision affect development drilling and producing facilities. Production is governed by productivity and recovery from individual wells or reservoirs, by production mechanism in each field, as well as by capacity and type of surface facilities. Finally, money flow in crude sales, royalties, and income tax is determined by contractual and government rules which apply. The desired economic yardstick is dynamic rather than static--input and output of each box are unknown functions of time--a planning horizon must be considered which is broken up into time intervals or periods. Number of periods and number of years in each period are specified by the planner. Often a period of one year is satisfactory for early stages of the planning horizon with longer periods thereafter.

Thus, a planning horizon of 15 years might realistically be divided into seven to ten periods. Activity within each period is represented as a system of the type depicted above. All of these systems are interconnected and are considered simultaneously in determining an investment plan which is best for a 15-year planning horizon.

Organization of the System

There are four distinct segments which perform the four main functions of investment planning; (1) Data input. (2) Economic modeling and simulation. (3) Report generation. (4) Alternative

plan comparison. These segments are designed to operate efficiently as one integrated system but ordinarily calculations would be stopped after each segment.

The unique features of the Input Segment are flexibility and ease of inputting data, degree to which input data are checked for errors, and printing of useful and easily readable summary reports of all input data for a given case. Providing input summary reports along with output reports in reporting study results allows management to readily relate assumptions to results and provides careful documentation of the basis for an investment planning study.

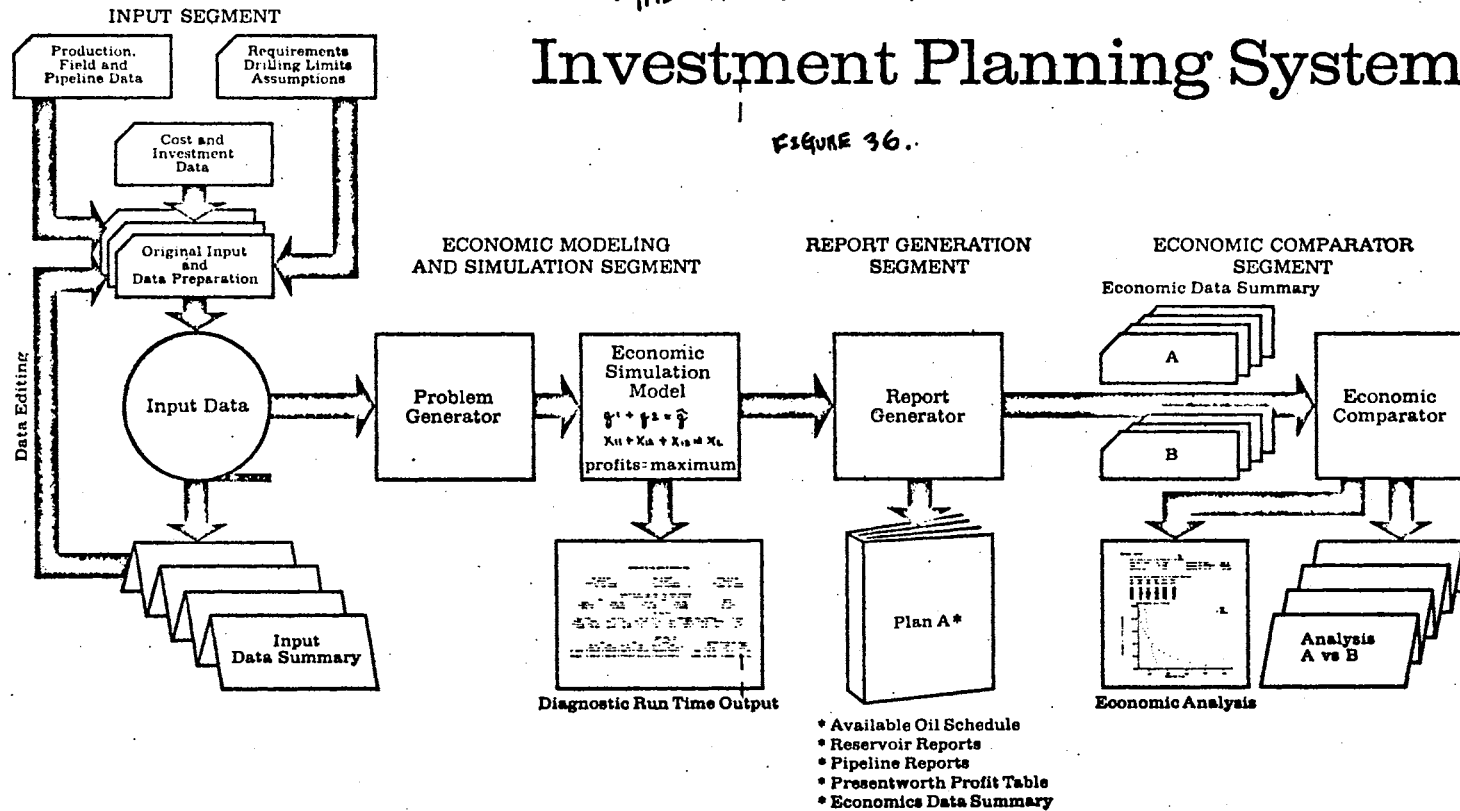
The front end of the Economic Modeling and Simulation Segment is a problem generator. The problem generator performs two major functions: (1) It generates all mathematical equations required to model the system. (2) It calculates numerical values for all coefficients in these equations. Because the problem generator is very efficient, the analyst can make changes in his data and/or his assumptions and let the computer do the work of reflecting those changes both in the equations and in the numerical coefficients. The back end of the Economic Modeling and Simulation Segment is the economic simulation model generated by the problem generator. This model describes flow of money and hydrocarbons over time--it simulates the behavior of the system and comes up with optimal planning guidelines. (Both linear and non-linear optimization techniques are utilized in simulating performance to generate optimal guidelines.)

The Report Generation Segment produces study results in a form readily understandable and usable by analysts and management. This segment also punches into cards a complete tabulation of aggregate dollar and crude flows in every year of the planning horizon.

The final segment accepts as input these cards for two different case studies and passes them in parallel through a conventional economic evaluation program which computes incremental yardsticks by which the two alternative cases can be compared.

THE PROGRAM ORGANIZATION OF THE Investment Planning System

FIGURE 36.



CHAPTER VI

MONITOR SYSTEM

An information system is a tool to improve the decision-making ability. The most effective approach is the "TOTAL SYSTEMS" which organizes and integrates all subsystems into a single information system.

In this paper, the author intends to develop an information system which combines and organizes the existing subsystems pertaining to petroleum exploration and production into a unique monitor system. By having all information (data files, processing programs and procedures) stored on random access equipment, in one central processing location, through man-machine communication facilities (CRT terminal, tele-processing equipment), the exploration scientist and production engineer can immediately retrieve the data file, access the processing modules, test various numerical models and display the result. The process can be continuously carried on until an optimal answer or result is achieved.

The monitor system developed herein, however, is primarily intended to present the "TOTAL SYSTEMS" concept rather than an application procedure. In any event, the scope of application, as mentioned in the introduction, has to be modified or rectified, depending largely on the computer availability and complexity of the applications. In view of the complication of the petroleum exploration and production involved,

there are difficulties in the development of a unique data-based file system and retrieval procedure to cover all the files pertaining to exploration and production. It is, therefore, more practical and feasible to integrate the system to a lower subsystem level. In other words, to develop integrated systems for geological, seismic, gravity and magnetic and production application respectively.

The proposed monitor system utilizes an interactive graphic terminal which is connected to a host computer. The Graphic Computer Terminal is manufactured by TEKTRONIX INC. (model 4002A) which is shown in Figure 36-1. The hardware components identified by the encircled numbers are described below.

Cathode Ray Tube

The direct view storage CRT 1 is approximately 8-1/4" wide by 6-1/2" high and is capable of displaying characters, symbols and lines.

Alphanumeric Keyboard

The alphanumeric keyboard 2 allows alphanumeric data to be transmitted to the computer.

Joystick

The joystick 3 device allows the user to select a location on the CRT display. Moving the joystick causes a cross hair "cursor" to move about on the screen. When a desired position is located on the screen by the "cursor", the location is sent to the computer by pressing PROGRAM FUNCTION KEY Number 30 which is labeled POINT DETECT.

Program Function Keyboard (PFK)

The program Function Keyboard 4 is used to select options at various times during operation.

Copier

The Copier 5 may be used to obtain hard copy of the CRT displays.

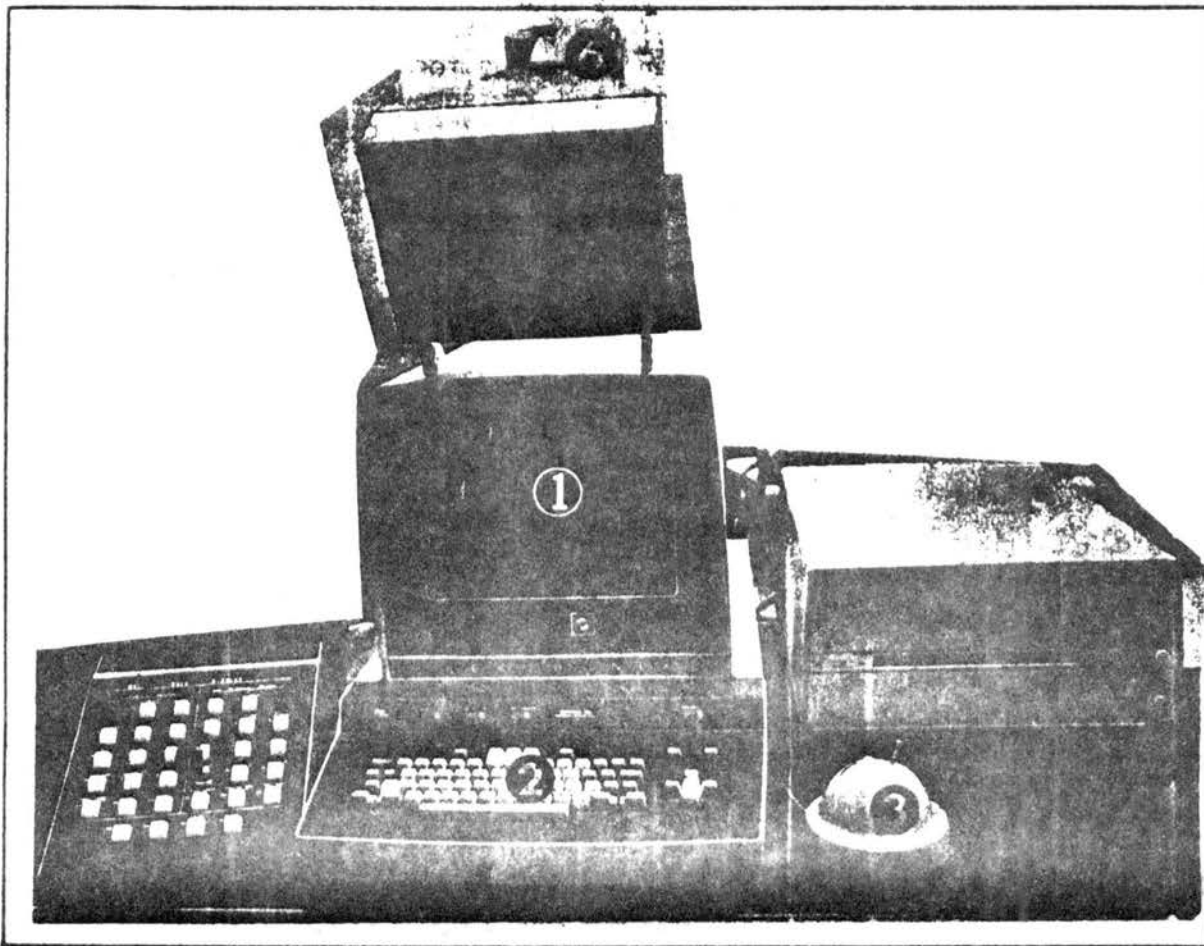


Figure 36-1. TEKTRONIX 4002A Terminal

System Organization Chart and Flow Diagram

The Monitoring System consists of a number of computer programs and computational procedures which can be best illustrated by the organization chart and flow diagrams.

Figure 37 is an organization chart of the Integrated Information System which shows the overall structure of the Exploration and Production System.

Figure 38, the flow diagram of the Integrated Information System, illustrates the logic flow and relationship among these subsystems: Figure 38-1, the Geological Information System, Figure 38-2, the Geophysical Information System, Figure 38-3, the Production Information System. All are flow diagrams for managing the applications for exploration and production. The detailed descriptions are discussed in Chapters III, IV, and V respectively.

The subsystem marked by ▲ indicates this particular subsystem is available in the petroleum industry in the form of a computer program or procedure.

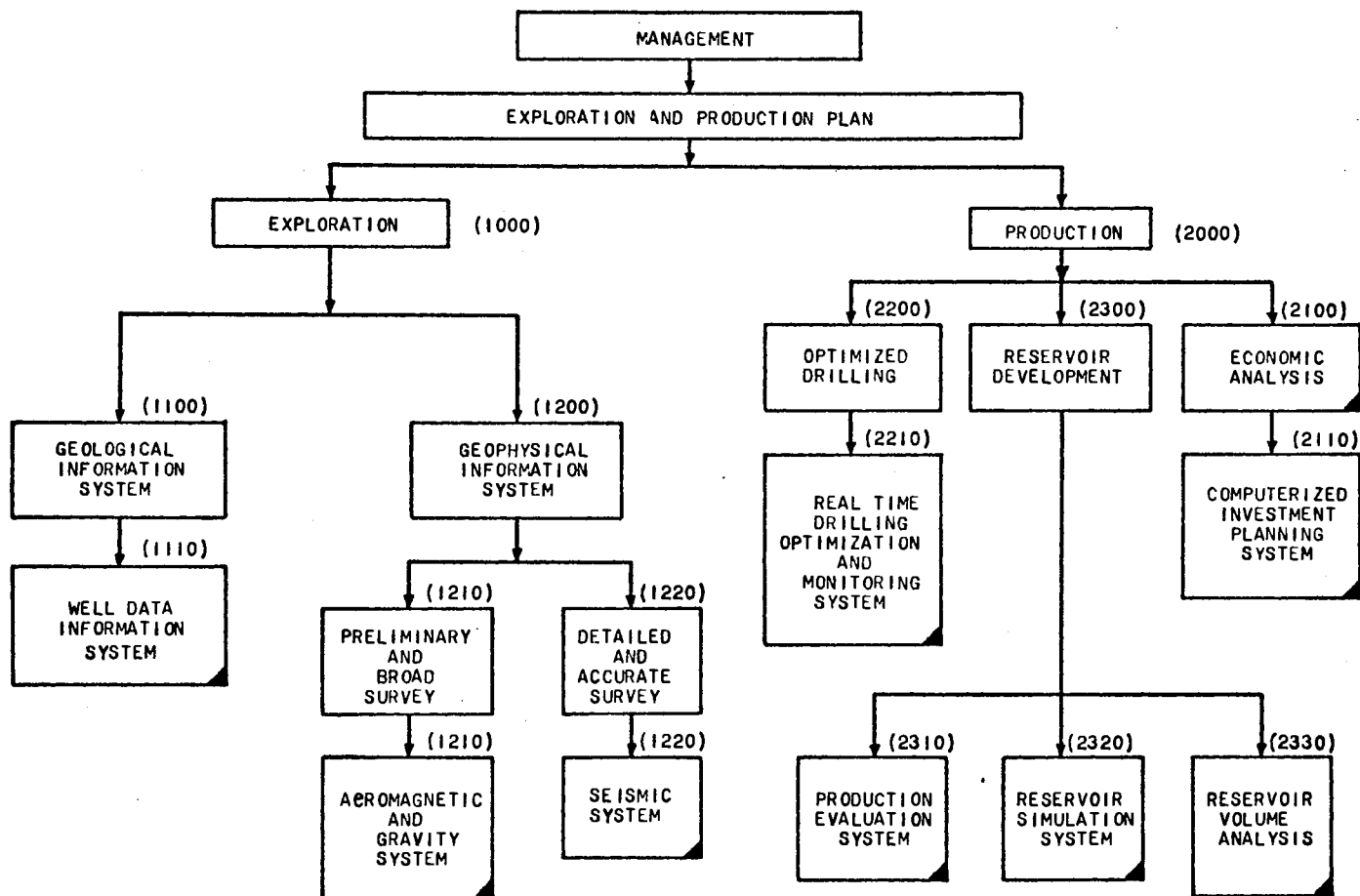


FIGURE 37

ORGANIZATION CHART OF THE INTEGRATED EXPLORATION AND PRODUCTION INFORMATION SYSTEM
 NOTE: ◻ INDICATES THAT COMPUTER PROGRAM IS AVAILABLE IN THE PETROLEUM INDUSTRY

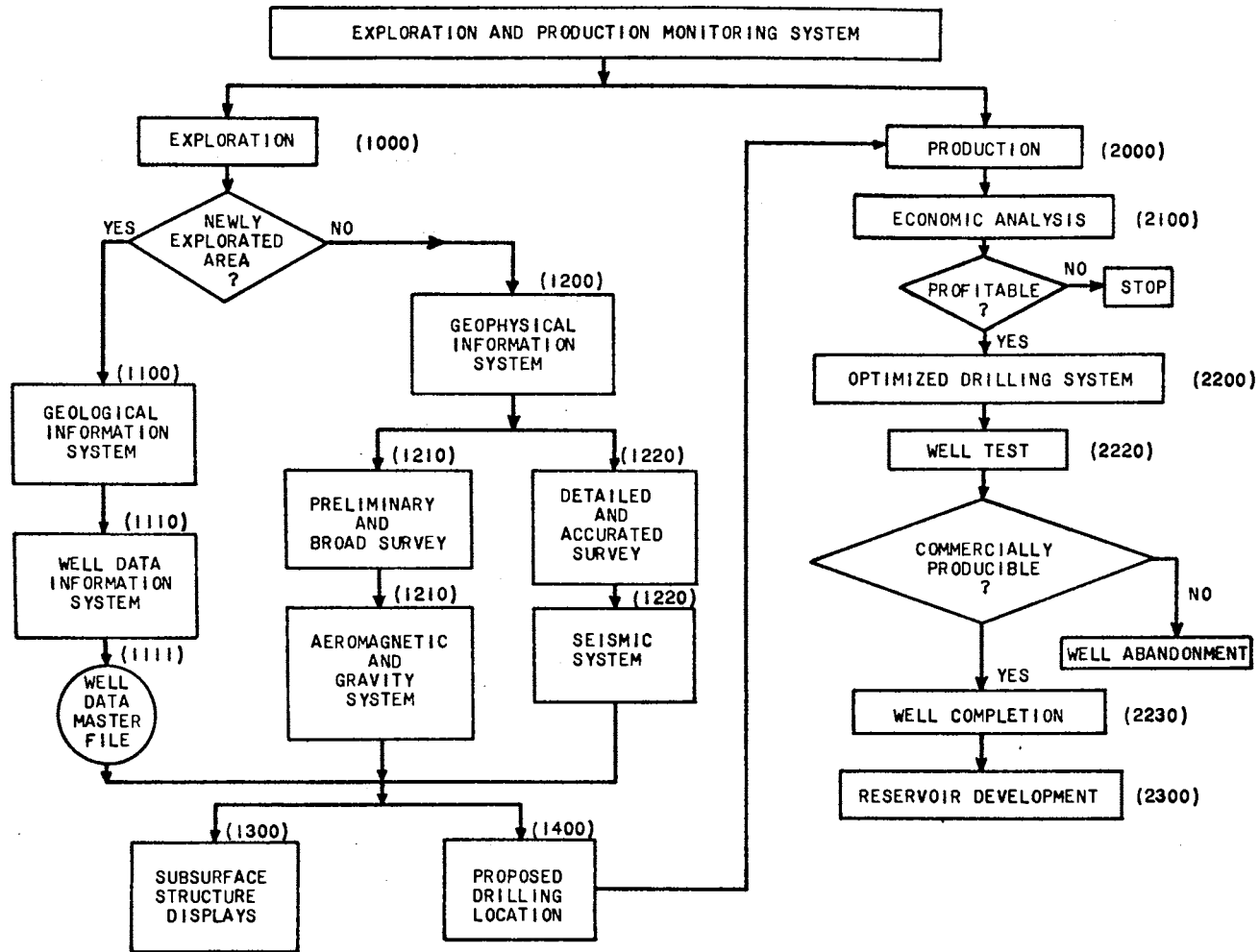


FIGURE 38

FLOW DIAGRAM OF THE INTEGRATED EXPLORATION AND PRODUCTION INFORMATION SYSTEM

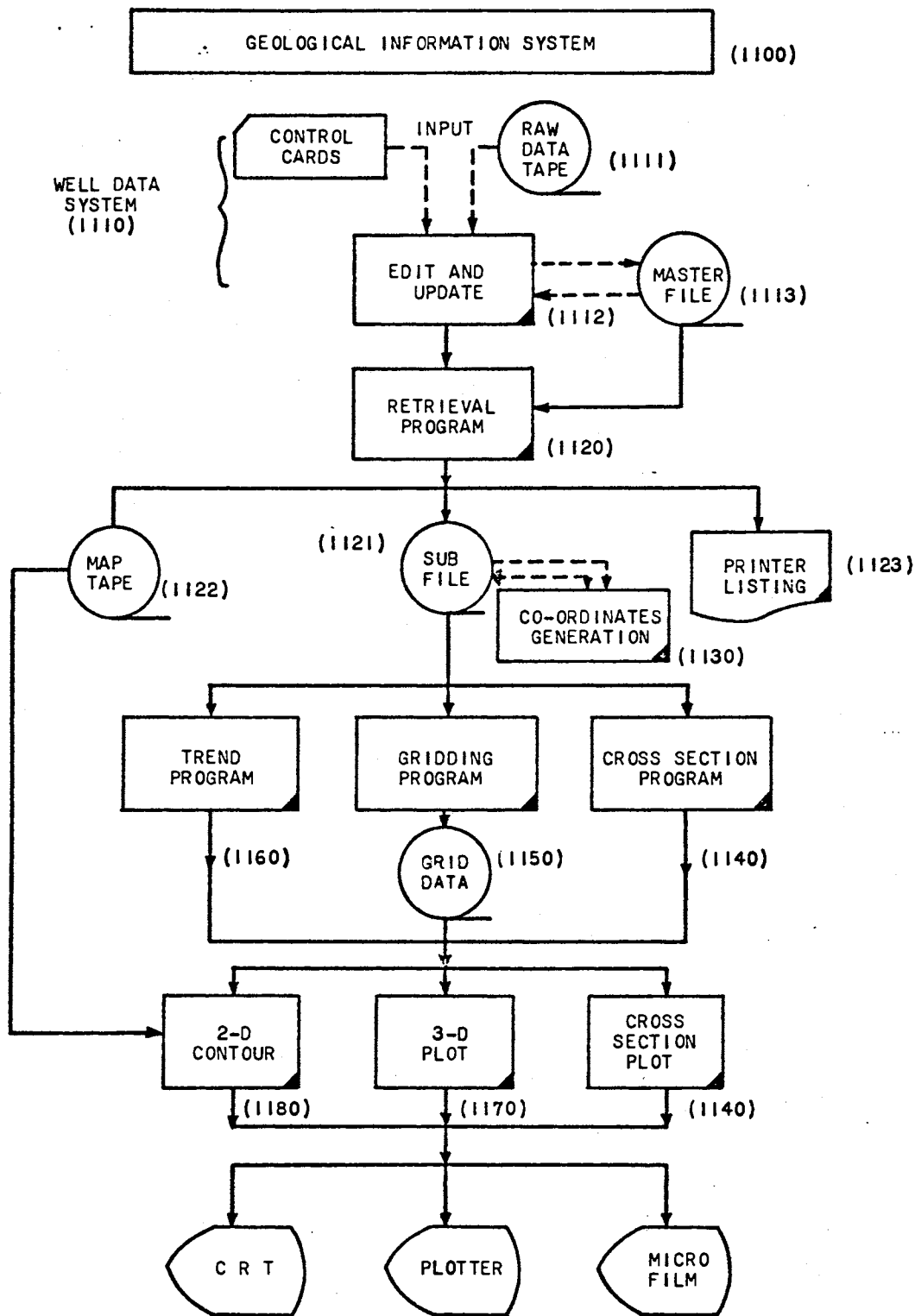


FIGURE 38-1
GEOLOGICAL INFORMATION SYSTEM

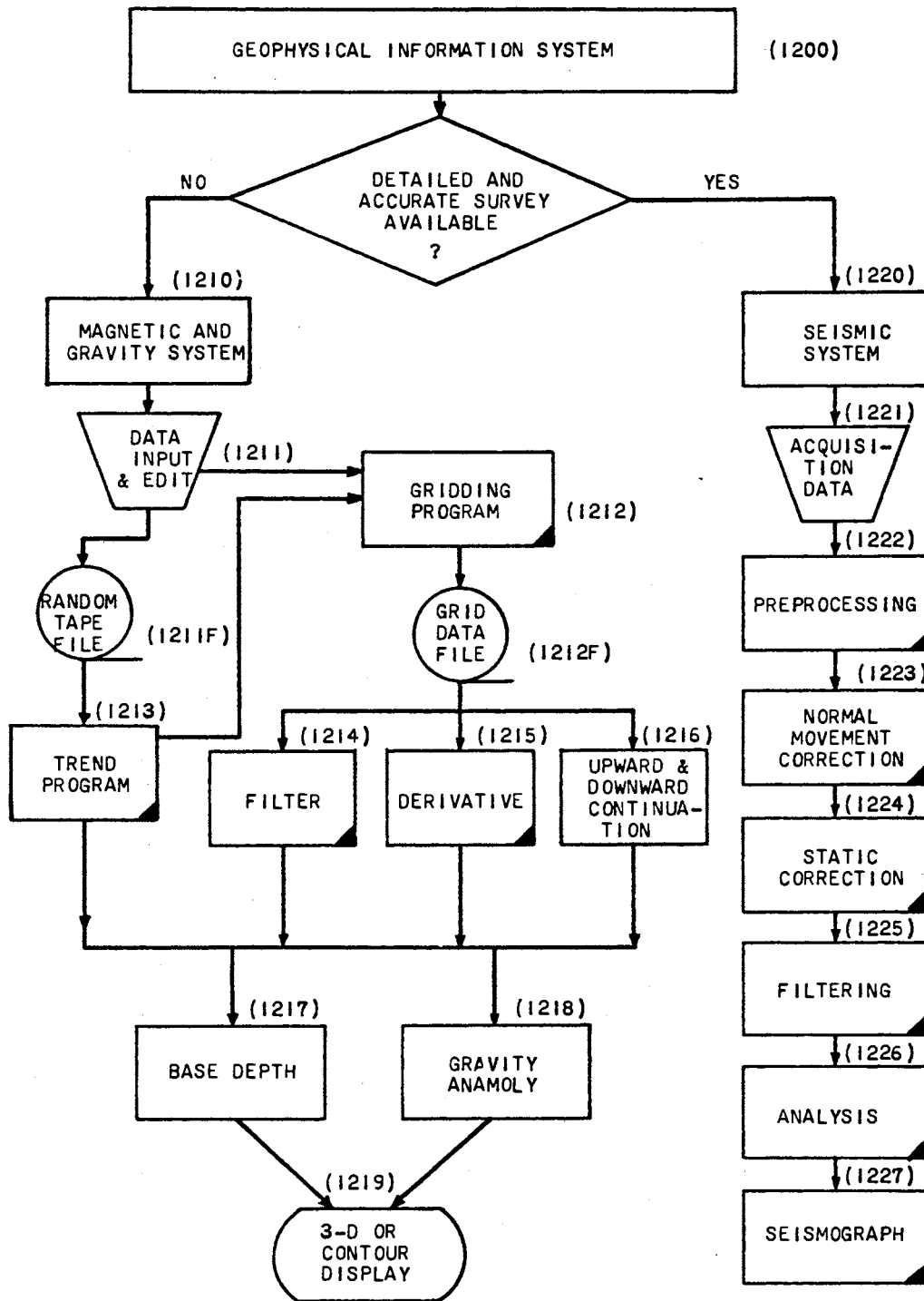


FIGURE 38-2
 GEOPHYSICAL INFORMATION SYSTEM

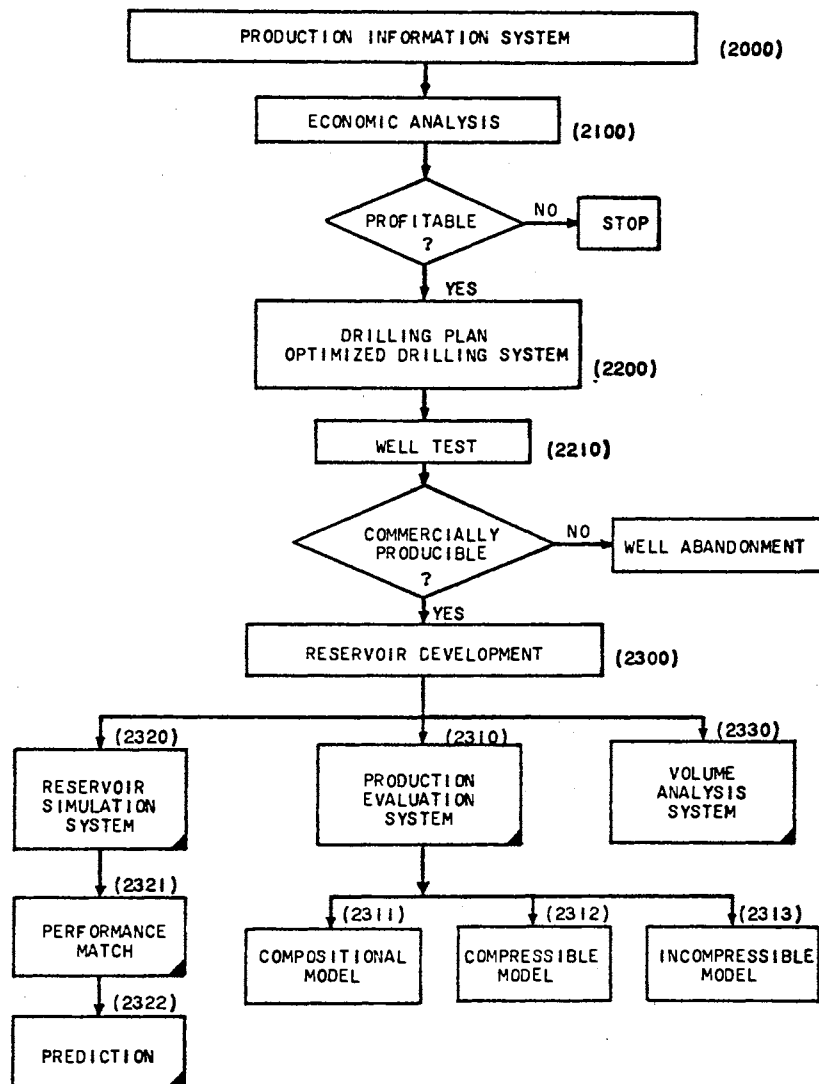


FIGURE 38-3
PRODUCTION INFORMATION SYSTEM

Index Code for Each Subsystem

For convenience of cross reference, an index code system is developed for each of the subsystems and programs. Each index code contains four (4) digits. The first digit indicates the first level identification, the second digit indicates the second level identification, and so forth. For example, 1111,

The first "1" indicates "The Exploration System".

The second "1" indicates "The Geological Information System".

The third "1" indicates "The Well Data Information System".

The fourth "1" indicates "The Random Data File".

The whole subsystem and index codes are described below.

Index Code for each Subsystem and Program

		<u>PAGE</u>
1000	Exploration Information System	124
1100	Geological Information System	23
1110	Well Data Information System	26
1111	Raw Data Tape	25
1112	EDIT and Update	27
1113	Master File	25
1120	Retrieval Program	31
1121	Sub-File	32
1122	Map File	32
1123	Printer Listing	34
1130	Coordinates Generation (Geologist)	25
1140	Cross Section Program	41
1150	Gridding Program	46
1160	Trend Program	52
1170	3-D Plot	64
1180	2-D Contour	61

		<u>PAGE</u>
1200	Geophysical Information System	68
1210	Magnetic and Gravity System	72
1211	Data Acquisition and Editing	73
1212	Gridding Program	73
1213	Trend Program	74
1214	Filter Program	74
1215	Derivative Program	74
1216	Upward and Downward Continuation	75
1217	Base Depth	75
1218	Gravity Anomaly	73
1219	3-D or Contour Display	77
1220	Seismic System	79
1221	Acquisition Data	79
1222	Preprocessing	79
1223	Normal Moveout Correction	81
1224	Static Correction	83
1225	Filtering Program	83
1226	Analysis	81
1227	Seismograph	81

		<u>PAGE</u>
2000	Production Information System	85
2100	Economic Analysis	118
2200	Real Time Drilling Optimization and Monitoring System	86
2201	Hardware	90
2202	Software	91
2210	Well Test	127
2300	Reservoir Development	127
2310	Production Evaluation System	93
2311	Compositional Model	94
2312	Compressible Model	97
2313	Incompressible Model	102
2320	Reservoir Simulation Model	105
2321	Performance Match	127
2322	Prediction	127
2330	Volume Analysis System	127

Computer Interactive Output and Operation Examples

Upon the user's request, through the alphanumeric keyboard and joystick, the interactive terminal will display a list of options (subsystems) available on the screen of the CRT, the user can make a selection by detecting the block desired. The operational instruction is self-defined and displayed on each of the subsystems.

Figure 39 displays the Exploration and Production Monitoring System. Figures 40 through 45 describe the Exploration, Geological, Geophysical, Aeromagnetic, Seismic and Production Information Systems respectively.

The following examples are used to illustrate the function and operational procedure of the Mointoring System.

Example -- To Retrieve Well Data and Generate Contour Map

An exploration geologist tries to study the geological structure for finding a possible oil reservoir. First of all, he has to select the Geological Exploration System. After detecting the block (system) desired, the Geological Exploration System is shown on the screen with all optional subsystems posted (Figure 41).

Since this is a study of subsurface structure, the Well Data Display option is chosen and it also is shown in Figure 46, which contains a menu of initial options. By choosing the REGIONAL MAP OPTION, (using the joystick, position the cross hair on the line indicating the REGIONAL MAP OPTION, then press the DETECT KEY), a map of the United States is shown. (Figure 47).

To select the area of interest, again use the joystick and detect key, the data in the area of interest is shown in Figure 48.

To contour the data of interest, simply press the CONTOUR KEY which is KEY 16 in the Program Function Keyboard, the map is shown in Figure 49.

Q...EXIT...

EXPLORATION AND PRODUCTION
MONITORING SYSTEM

- EXPLORATION INFORMATION SYSTEM
 - 1. GEOLOGICAL EXPLORATION
 - 2. GEOPHYSICAL EXPLORATION

- PRODUCTION INFORMATION SYSTEM
 - 1. ECONOMIC ANALYSIS
 - 2. OPTIMIZED DRILLING
 - 3. RESERVOIR DEVELOPMENT

FIGURE 39.

(SELECT AN OPTION BY DETECTING A BOX, AND DEPRESS KEY 30)

EXPLORATION INFORMATION SYSTEM

- GEOLOGICAL EXPLORATION
- GEOPHYSICAL EXPLORATION

(IF THE AREA INTERESTED HAS NO WELL DATA AVAILABLE,
OR THE AREA HAS NEVER BEEN EXPLORED BEFORE,
USE GEOPHYSICAL EXPLORATION)

EXIT TO

FIGURE 40.

- MONITORING SYSTEM
- PRODUCTION SYSTEM

GEOLOGICAL EXPLORATION SYSTEM

- 1. DATA RETRIEVAL
- 2. WELL DATA DISPLAY
- 3. TREND ANALYSIS
- 4. CONTOUR
- 5. THREE DIMENSIONAL DISPLAY
- 6. PROPOSED DRILLING LOCATION

EXIT TO

- GEOPHYSICAL SYSTEM
- EXPLORATION SYSTEM
- PRODUCTION SYSTEM

FIGURE 41.

GEOPHYSICAL EXPLORATION SYSTEM

- AEROMAGNETIC AND GRAVITY DATA PROCESSING SYSTEM
(FOR PRELIMINARY AND BROAD AREA EXPLORATION)

- SEISMIC DATA PROCESSING SYSTEM
(FOR DETAILED AND ACCURATE SURVEY)

EXIT TO

- GEOLOGICAL SYSTEM
- EXPLORATION SYSTEM
- PRODUCTION SYSTEM

FIGURE 42.

AEROMAGNET AND GRAVITY DATA
PROCESSING SYSTEM

- DATA RETRIEVAL
- FILTER PROCESS
- DERIVATIVE PROGRAM
- UPWARD AND DOWNWARD CONTINUATION
- GRAVITY ANOMOLY
- BASE DEPTH
- DISPLAY

FIGURE 43

- GEOPHYSICAL SYSTEM EXPLORATION SYSTEM
- SEISMIC EXPLORATION PRODUCTION SYSTEM
- QUIT

SEISMIC DATA PROCESSING SYSTEM

- DATA ACQUISITION
- DATA REDUCTION AND PREPROCESSING
- NORMAL MOVEMENT CORRECTION
- STATIC CORRECTION
- FILTERING
- SEISMOGRAPHY

- QUIT
- GEOPHYSICAL SYSTEM
- EXPLORATION SYSTEM
- PRODUCTION SYSTEM

FIGURE 44

PRODUCTION INFORMATION SYSTEM

- ECONOMIC ANALYSIS
- OPTIMIZED DRILLING
- RESERVOIR DEVELOPMENT
 1. RESERVOIR SIMULATION
 2. PRODUCTION EVALUATION
 3. VOLUME ANALYSIS

- EXPLORATION SYSTEM
- MONITORING SYSTEM
- QUIT

FIGURE 45.

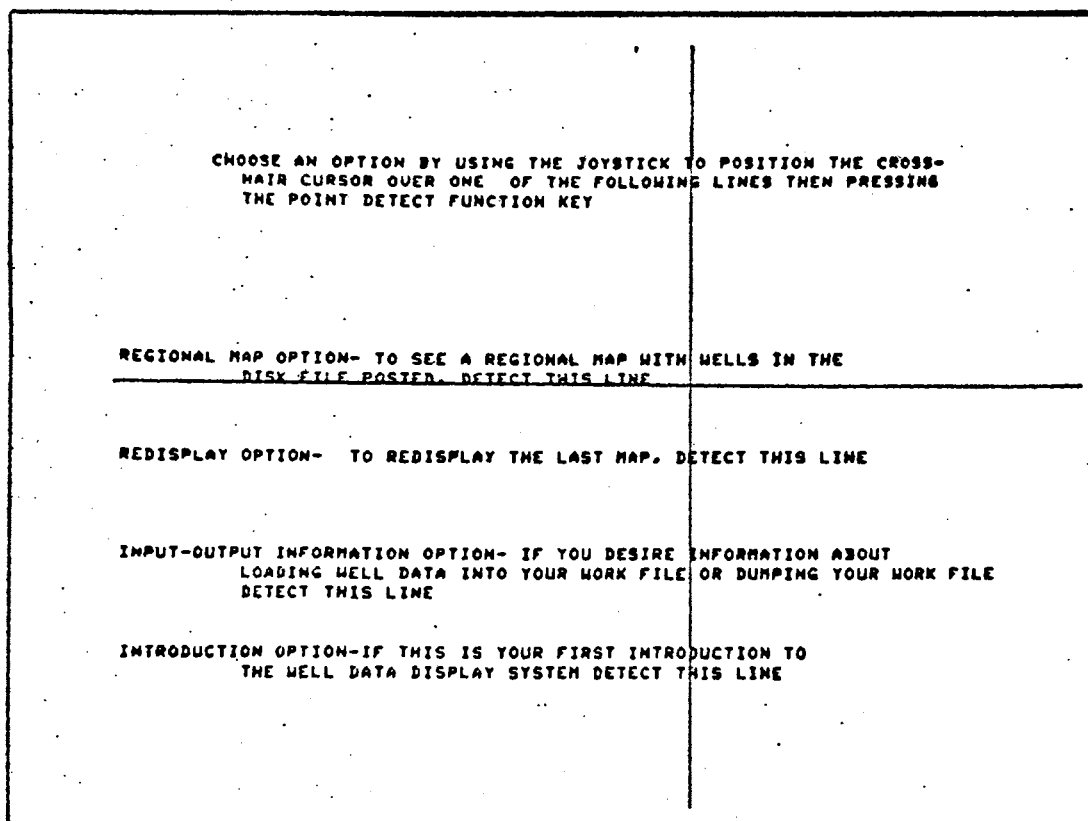


Figure 46. The first display of the program is a menu of initial options. Using the joystick, position the cross hair on the line indicating the REGIONAL MAP OPTION. Then press the POINT DETECT key.

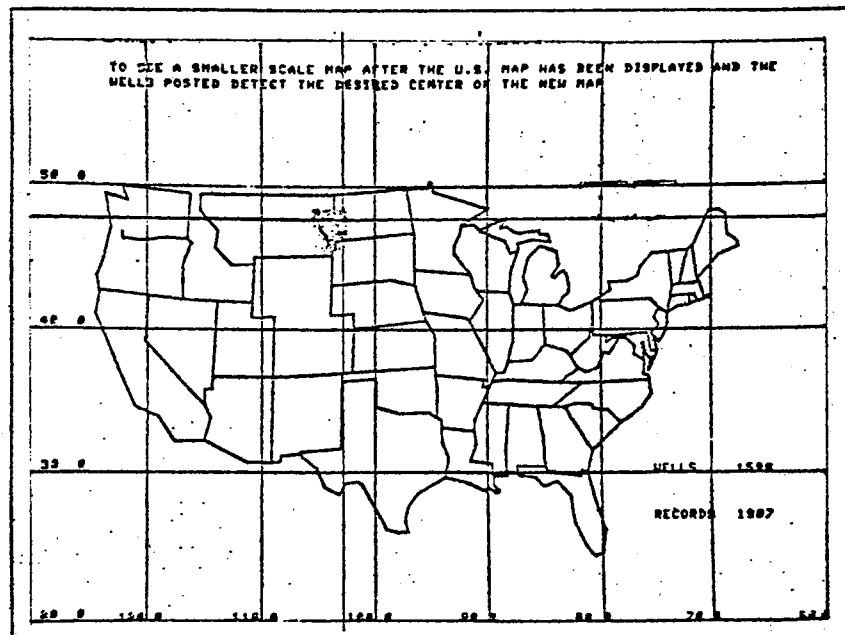


Figure 47. The REGIONAL MAP OPTION spots the wells from the work file onto a map of the United States. Center the cross hair on a particular area of interest and press the POINT DETECT key

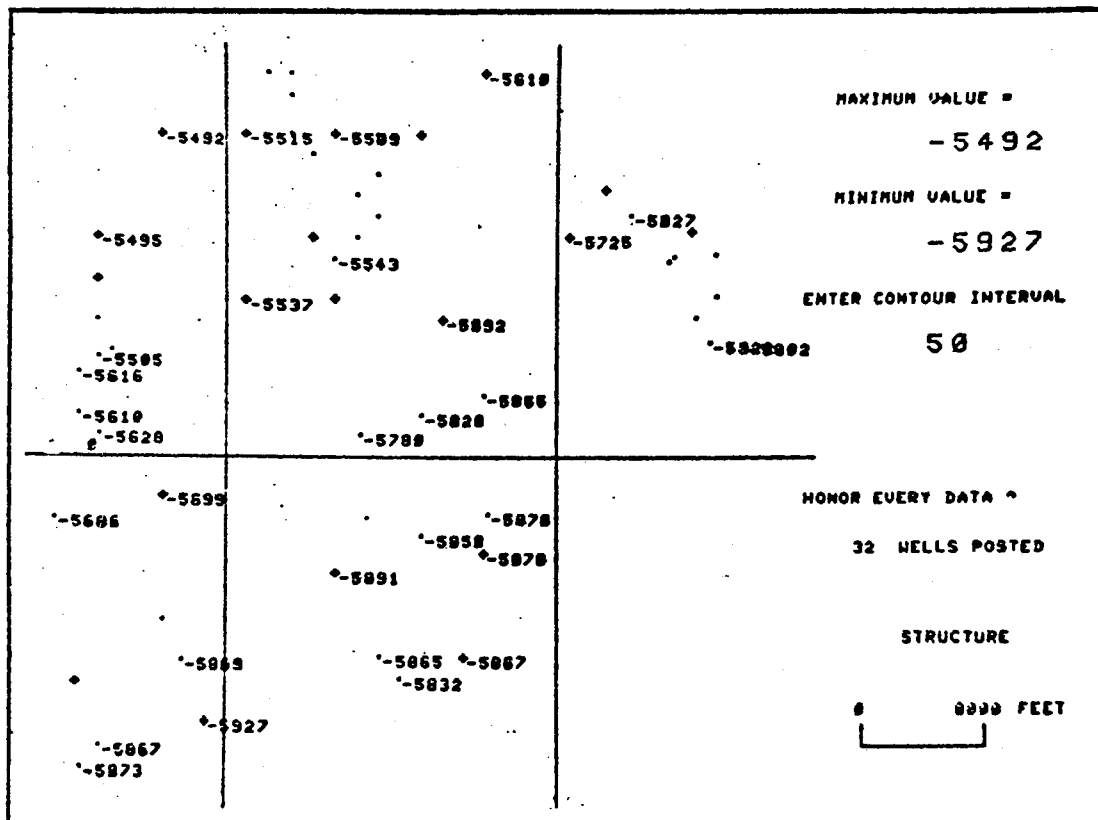


Figure 4B. DATA OF INTEREST

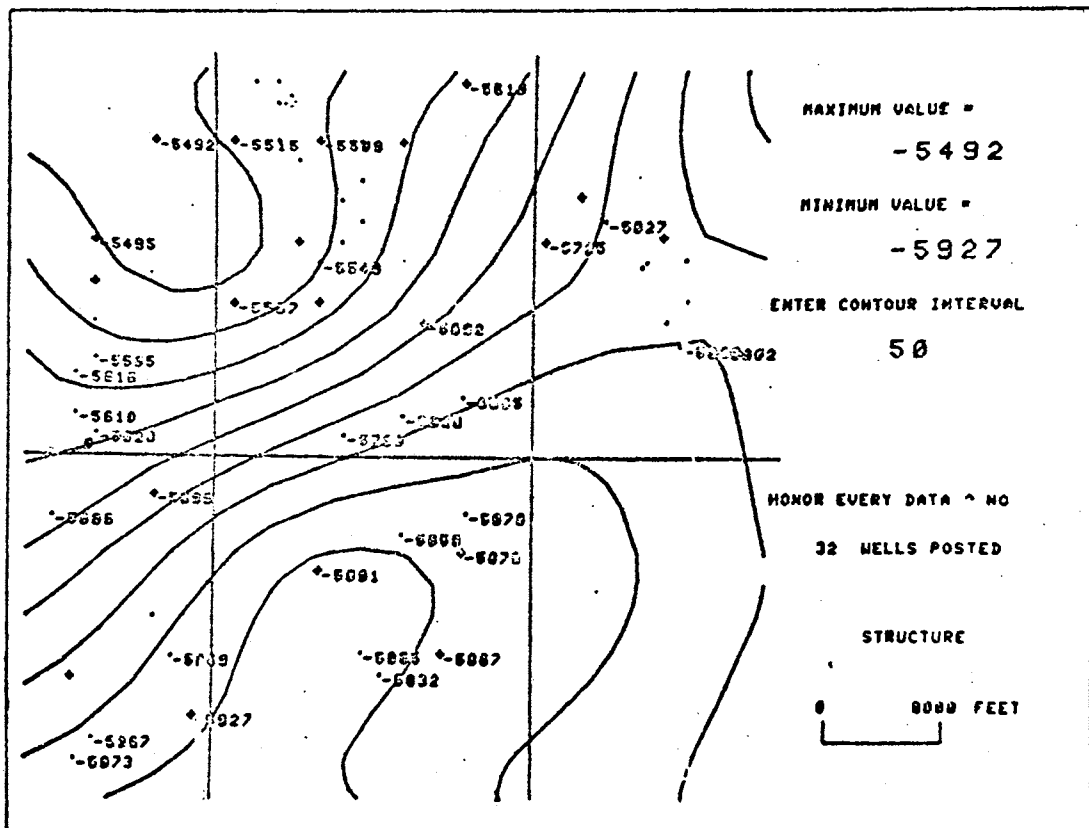


Figure 49. CONTOUR MAP for the DATA of INTEREST

CHAPTER VII

SUMMARY AND CONCLUSIONS

In the study presented herein, the author intends not only to review the existing automatic data processing system, primarily the computer software and application theory for petroleum exploration and production, but also to envision the trend and demand for automation in the future.

The computer applications in the petroleum industry are increasing at a faster pace than ever. The computer-oriented information system has been proven to be not only desirable but necessary. The most effective way to utilize a computer-oriented system is the "TOTAL SYSTEM" approach which organizes and integrates all subsystems into a single information system.

An integrated information system can be materialized, at least to a certain extent, by using an interactive computer terminal, together with a CRT display unit and generalized data-based files. By having all information (data files, application programs and processing procedures) stored on direct access equipment, in one central processing location, through man-machine communication facilities (CRT terminal, alphanumeric and programming functional keyboard, etc), the exploration scientist or production engineer can converse directly with the computer to retrieve and edit his data, access the processing modules, test various models and hypotheses and display the result. This process can be continuously

carried on, from one area to another, until an optimal solution or a final answer is achieved. The ultimate goal of this information system is to enable the scientist and engineer to use the computer as an extension of his own mind.

Nevertheless, the monitor system developed herein is primarily intended to present the "TOTAL SYSTEMS" approach concept rather than an application procedure. In view of the complexity of the petroleum exploration and production involved, it is more feasible to integrate the information system to a lower subsystem level.

Furthermore, the author realizes that an effective integrated information system should be designed by the user of the system. However, creative system analysts have a considerable contribution to achieve this goal. The efforts presented in this research are directed toward the data processing aspect of the information system and does not in any way claim to be presenting solutions to problems that the petroleum industry has spent millions of dollars to explore during the last decade.

Recommendations for Further Study

The research presented herein represents only the beginning in the development of an integrated information system. A great deal remains to be accomplished by the petroleum industry.

The sequence in which the items for further study are listed in no way indicates the order of importance or preference.

1. To develop a comprehensive file management system which contains all exploration and production data with standardized file format and up-date procedure. With a direct data entry terminal operating as part of a time-sharing system, it permits data to be edited on line by computer programs using complex logic to detect and signal errors in format, invalid codes, and to check logical content of the files.

2. To develop a generalized retrieval program which can easily access, update and process all data-based files and create a project (working) file used by the monitoring system.

3. Each subsystem or individual application program should be so programmed that it becomes a unique module which can be easily incorporated into the "TOTAL SYSTEM".

4. To develop a problem (exploration and production) oriented language so that the user can converse with the computer more readily.

5. To develop a language interface program (or super translator) which can incorporate a set of programs written in different languages, i.e., if the Monitoring system, for example, is written in FORTRAN

language which cannot directly call (link) a program or a subroutine written in the COBOL, PL-1 language or other high level language. With this interface program, the capacity and flexibility of the Monitoring System are largely increased.

SELECTED BIBLIOGRAPHY

- (1) Buller, J. M. "A Computer-Oriented System for the Storage and Retrieve of Well Information," Canadian Petroleum Geology Bull., 1964.
- (2) CAMCOMP, "Three-D, A Perspective Drawing Software System," California Computer Products, Inc., 1968.
- (3) Crain, I. K. "Computer Interpolation and Contouring of Two Dimensional Data: A Review," Geoexploration, Vol. 8, No. 2, 1970, pp. 71-86.
- (4) CDP, "Digital Geological File Processing Technique," Calgary: CDP Computer Data Processors Ltd., ed., W. G. Carr, 1971.
- (5) "Computerized Investment Planning System," Englewood, Colorado: Scientific Software Corporation, 1971.
- (6) GeoMetrics, "Data Service for Geophysics and Remote Sensing," Palo Alto, California: 1970.
- (7) Deikert, E. W. "Developments at the Man-Machines Interface," An International Symposium on Computer Applications in the Earth Sciences, New York: Plenum Press, 1969.
- (8) Dobrin, Milton B. "Computer Processing of Seismic Reflections in Petroleum Exploration," An International Symposium on Computer Applications in the Earth Sciences, New York: Plenum Press, 1969.
- (9) Eldin, H. K. "The Cubic Concept Approach to Management Information System," Proceedings of the Oklahoma Academy of Science, 1968.
- (10) Ferguson, J. "Multivariable Curve Interploation," J. ACM, Vol. 11, 1964, pp. 221-228.
- (11) Forgotson, J. M. Jr. and C. F. Inglehart, "Current Users of Computers by Exploration Geologists," Am. Assoc. Petroleum Geologists Bull., Vol. 51, 1967, pp. 1202-1224.
- (12) Forgotson, J. M., Jr. and John L. Strout, "Future of Well-Data Information Systems," An International Symposium on Computer Applications in the Earth Sciences, New York: Plenum Press, 1969.

- (13) Harbaugh, John W. and Daniel F. Merriam, Computer Applications in Stratigraphic Analysis, New York: John Wiley & Sons, Inc., 1968.
- (14) IBM, "New Dimensions for the Problem Solver: System 370 with Virtual Storage," Computing Report, Vol. 8, No. 2, 1972, pp. 2-7.
- (15) Hessing, R. C., Henry K. Lee, Alan Pierce, and Eldon N. Powers, "Automatic Contouring Using Bicubic Functions," Geophysics, Vol. 37, No. 4, 1972, pp. 669-674.
- (16) Johns, Park J. Petroleum Production, New York: Reinhold, 1946.
- (17) Krumbein, W. C. "Regional and Local Components in Facies Map," Am. Asso. Petroleum Geologists Bull., Vol. 40, 1956, pp. 2163-94.
- (18) Lindseth, R. O. Recent Advances in Digital Processing of Geophysical Data, Calgary: Society of Exploration Geophysics, 1968.
- (19) Lindseth, R. O. "Digital Equipment for Exploration Data Processing," Calgary: Canadian Society of Exploration Geophysicists, Digital Lecture Series, 1971.
- (20) Lovering, T. G., and D. F. Davison, "Storage and Retrieval of Analytical Data on Geological Materials," Colorado Sch. Mines Quart., Vol. 59, No. 4, pp. 247-258.
- (21) Lynch, Edward J. Formation Evaluation, New York: Harper and Row, 1962.
- (22) McIntyre, D. B. "Program for Computation of Trend Surfaces and Residuals of Degree 1 through 8," Dept. Geology, Seaver Lab., Pomona College, 1963.
- (23) McIntyre, D. B., David D. Pollard, and Roger Smith, "Computer Programs for Automatic Contouring," Computer Contribution 23, Lawrence: Geol. Survey, University of Kansas, 1968.
- (24) Merriam, D. F. "Computer Aids Exploration Geologists," Oil and Gas Jour., Vol. 65, No. 4, 1967, pp. 118-121.
- (25) Merriam, D. F. Symposium on Computer Applications in Petroleum Exploration, Lawrence: University of Kansas, 1969.

- (26) Miller, D. F. "Trend Surface: Their Application to Analysis and Description of Environments of Sedimentation," Jour. Geology, Vol. 64, No. 5, pp. 425-446.
- (27) Ojakangas, D. R. "Mathematical Simulation of Oil-Trap Development: (Unpubl. doctoral dissertation, Stanford Univ., 150 p.)
- (28) Pirson, Sylvain J. Elements of Oil Reservoir Engineering, New York: McGraw-Hill, 1950.
- (29) "Reservoir Simulation Program Description," Houston: International Computer Applications Ltd., 1971.
- (30) "Reservoir Simulator," Englewood, Scientific Software Corporation, 1970.
- (31) Scarborough, J. B. Numerical Mathematical Analysis, The Johns Hopkins Press, 1950.
- (32) "Seisystem 70," Tulsa: Seismographic Service Corporation, 1970.
- (33) "The Reservoir Simulation System," Dallas: D. R. McCord and Associates, Inc, 1970.
- (34) Weber, J. N. "Impact of Digital Computer on the Geological Sciences," Jour. Geol. Educ., Vol. 12, No. 2, pp. 41-48.
- (35) Weber, J. N. and Deines, P., "General Information Retrieval Program for Geological, Geophysical and Geochemical Data," Pennsylvania State Univ. Mineral Industries Experiment Station Bull. 81, 1964.
- (36) Wilks, S. S. "Statistical Inference in Geology, in Earth Science," Problem and Progress in Current Research, Univ. Chicago Press, 1963, pp. 105-136.

APPENDIX
PROGRAM LISTING FOR THE
MONITORING SYSTEM

```

CC
C  EPMS -- EXPLORATION AND PRODUCTION MONITORING SYSTEM
C
C  THIS PROGRAM USES IBM 1800 MPX SYSTEM AND TEXTRONIC 4010 CRT DISPLAYS UNIT
C  MONITORING THE EXPLORATION AND PRODUCTION INFORMATION SYSTEM BY AN INTERACTIVE
C  GRAPHIC TERMINAL
C
C      WRITTEN BY HENRY K. LEE
CC
C      DIMENSION MESS(40)
C      DIMENSION IXBI(3),IYBI(3)
C
C  FILE 7 IS A DISK FILE STORED ALL MESSAGES DISPLAYED ON CRT SCREEN
C
C      DEFINE FILE 7(200,40,U,K7)
C  CLEAR SCREEN
C  10 CALL BLNK3
C      IX=12
C  DISPLAY
C      EXPLORATION AND PRODUCTION MONITORING SYSTEM                                01
C
C      READ(7'1) MESS
C      IY=540
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'2) MESS
C      IY=600
C      CALL CHAR3(IX,IY,MESS,76,1)
C  DISPLAY
C      EXPLORATION INFORMATION SYSTEM                                03
C      1. GEOLOGICAL EXPLORATION                                    04
C      2. GEOPHYSICAL EXPLORATION                                  05
C
C      READ(7'3) MESS
C      IY=520
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'4) MESS
C      IY=460
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'5) MESS
C      IY=430
C      CALL CHAR3(IX,IY,MESS,76,1)
C
C      PRODUCTION INFORMATION SYSTEM                                06
C
C      1. ECONOMIC ANALYSIS                                        07
C      2. OPTIMIZED DRILLING                                       08
C      3. RESERVOIR DEVELOPMENT                                     09
C
C      READ(7'6) MESS
C      IY=380
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'7) MESS
C      IY=320
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'8) MESS
C      IY=290
C      CALL CHAR3(IX,IY,MESS,76,1)
C      READ(7'9) MESS

```

```

      IY=260
      CALL CHAR3(IX,IY,MESS,76,1)
C   DISPLAY
C   (SELECT AN OPTION BY DETECTING A BOX, AND DEPRESS KEY 30)
C   EXIT
C
      READ(7*10) MESS
      IY=100
      CALL CHAR3(IX,IY,MESS,76,1)
      READ(7*82) MESS
      CALL CHAR3 (IX+60, 740, MESS,76,1)
CC
C   DRAW BOXES
CC
      IXB1(1)=10*12 + 6
      IXB1(2)=IXB1(1)
      IXB1(3)=893
      IYB1(1)=530
      IYB1(2)=390
      IYB1(3)=745
      CALL DASH5(864,760,864,735)
      CALL DASH5(864,735,1020,735)
      CALL LBOXD(IXB1,IYB1,3,10,IXD,IYD,0,IGUM)
C
      CALL LCDT2(IXD,IYD,1,NB)
      CALL LBOXD(IXB1,IYB1,3,10,IXD,IYD,40,IGDT)
      GO TO (101,201,999),IGDT
101 CALL LFXPL
      GO TO 10
201 CALL LPRDD
      GO TO 10
999 CALL QUIT
      CALL EXIT
      END

VARIABLE ALLOCATIONS
MESS(I )=002F-0008   IXB1(I )=0032-0030   IYB1(I )=0035-0033   K7(I )=0036
IXD(I )=0039        IYD(I )=003A        IGUM(I )=003B        NB(I )=003C

STATEMENT ALLOCATIONS
10  =0065  101 =0188  201 =018F  999 =0193

FEATURES SUPPORTED
ONE WORD INTEGERS
INCS

CALLED SUBPROGRAMS
BLNK3  CHAR3  DASH5  LBOXD  LCDT2  LFXPL  LPRDD  QUIT  COMGO  ISTOX

INTEGER CONSTANTS
12=0042      7=0043      1=0044      640=0045      76=0046      2=0047      600=
460=004C      5=004D      430=004E      6=004F      380=0050      320=0051      8=
10=0056      100=0057      82=0058      60=0059      740=005A      893=005B      530=
760=0060      735=0061      1020=0062      0=0063      40=0064

CORE REQUIREMENTS FOR LEPMS

```

// JOB 14 JAN 73 PLEEO1R1 006 FF 06040201 HENRY LEE 1819 225 00.350
 // FOR 14 JAN 73 00.360 HRS

*LIST ALL
 SUBROUTINE LAERO

CC
 C LAERO--AEROMAGNETIC AND GRAVITY
 CC

DIMENSION MFSS(40),JX(12),JY(12)

DATA JX/7*137,3*246,2*540/
 IX=12

10 CALL BLNK3
 DISPLAY

AEROMAGNETIC AND GRAVITY DATA	51
PROCESSING SYSTEM	52

DATA RETRIEVAL	53
----------------	----

FILTER PROCESS	54
----------------	----

DERIVATIVE PROGRAM	55
--------------------	----

UPWARD AND DOWNWARD CONTINUATION	56
----------------------------------	----

GRAVITY ANOMALY	57
-----------------	----

BASED DEPTH	58
-------------	----

DISPLAY	59
---------	----

READ(7*51)MESS

IY=660

CALL CHAR3(IX,IY,MESS,76,1)

READ(7*52)MESS

CALL CHAR3(IX,IY-30,MESS,76,1)

IY=560

NREC=53

DO 30 K=1,7

CALL LWTHG(7,NREC,IX,IY,MESS,76,1)

NREC=NREC+1

30 IY=IY-30

GEOPHYSICAL SYSTEM	EXPLORATION SYSTEM	61
--------------------	--------------------	----

SEISMIC EXPLORATION	PRODUCTION SYSTEM	62
---------------------	-------------------	----

QUIT **{FILE NEEDED}	63
----------------------	----

IY=200

NREC=61

DO 40 K=1,3

CALL LWTHG(7,NREC,IX,IY,MESS,76,1)

IY=IY-30

40 NREC=NREC+1

JY(1)=569

DO 50 I=2,7

50 JY(I)=JY(I-1)-30

JY(8)=209

JY(9)=179

JY(10)=149

JY(11)=209

JY(12)=179

CALL LBQXD(JX,JY,12,10,IXD,IYD,0,INDUM)

60 CALL LCDT2(IXD,IYD,1,NR)

CALL LBQXD(JX,JY,12,10,IXD,IYD,20,IDET)

14 JAN 73
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GO TO (60,60,60,60,60,60,60,60,71,72,73,74,75), IDFT

```

C
72 CALL LSEIS
73 CALL QUIT
74 CALL LEXPL
75 CALL LPROD
71 RETURN
END

```

VARIABLE ALLOCATIONS

```

MESS(I)=0029-0002      JX(I)=0035-002A      JY(I)=0041-0036      IX(I)=0042
K(I)=0045              I(I)=0046              IXD(I)=0047         IYD(I)=0048
IDFT(I)=004B

```

UNREFERENCED STATEMENTS

10

STATEMENT ALLOCATIONS

```

10 =006C 30 =00AF 40 =00D9 50 =00F2 60 =0135 72 =0155 73 =01

```

FEATURES SUPPORTED
ONE WORD INTEGERS

CALLED SUBPROGRAMS

```

BLNK3  CHAR3  LWTMG  LBOXD  LCOT2  LSEIS  QUIT  LEXPL  LPROD  COMGO

```

INTEGER CONSTANTS

```

17=0052      7=0053      51=0054      660=0055      76=0056      1=0057      52=00
200=005C     61=005D      3=005F      569=005F     2=0060      209=0061     179=00
20=0066

```

CORE REQUIREMENTS FOR LAFRO

```

COMMON      0  INSKEL COMMON      0
VARIABLES   R2  PROGRAM      270

```

END OF COMPILATION

```

LGEDP
DMP FUNCTION COMPLETED
Y/ FOR 11 JAN 73 16.793 HRS
*LIST ALL
SUBROUTINE LEXPL
CC
C SUBROUTINE TO CONTROL EXPLORATION INFORMATION SYSTEM
CC
C DIMENSION MFSS(40),JXR(4),JYB(4)
C
C EXPLORATION INFORMATION SYSTEM 11
C
C GEOLOGICAL EXPLORATION 12
C GEOPHYSICAL EXPLORATION 13
C
10 CALL BLNK3
IX=12
READ(7*11)MESS
IY=640
CALL CHAP3(IX,IY,MFSS,76,1)
READ(7*12)MESS
IY=520
CALL CHAR3(IX,IY,MESS,76,1)
READ(7*13)MESS
IY=460
CALL CHAR3(IX,IY,MESS,76,1)
C DISPLAY
C (IF THE AREA INTERESTED HAS NO WELL DATA AVAILABLE, 14
C OR THE AREA HAS NEVER EXPLORATED BEFORE, 15
C USE GEOPHYSICAL EXPLORATION) 16
C
C EXIT TO 17
C
C MONITORING SYSTEM PRODUCTION SYSTEM 18
C
READ(7*14)MESS
IY=280
CALL CHAP3(IX,IY,MFSS,76,1)
READ(7*15)MESS
IY=254
CALL CHAR3(IX,IY,MESS,76,1)
READ(7*16)MFSS
IY=228
CALL CHAR3(IX,IY,MESS,72,1)
C
READ(7*17)MESS
IY=120
CALL CHAR3(IX,IY,MESS,72,1)
READ(7*18)MESS
IY=74
CALL CHAR3(IX,IY,MESS,72,1)
C DRAW BOXES
JXB(1)=125
JXB(2)=JXR(1)
JXB(3)=14*12+5
JXB(4)=40*12+5
JYB(1)=530
JYB(2)=470
JYB(3)=84
JYB(4)=84

```


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```

C
CALL LBOXD(JXB, JYB, 4, 10, IXD, IYD, 0, IDUM)
CALL PFKL2(30, 1)
CALL LCOT2(IXD, IYD, -1, NB)
CALL LBOXD(JXB, JYB, 4, 10, IXD, IYD, 20, IDET)

```

```

C
GO TO(100, 200, 300, 900), IDET
100 CALL LGEOL
GO TO 900
200 CALL LGEMP
GO TO 900
300 CALL LPROD
900 RETURN
END

```

VARIABLE ALLOCATIONS

```

MESS(I) = 0029-0002    JXB(I) = 002D-002A    JYB(I) = 0031-002E    IX(I) = 0032
IYD(I) = 0035          IDUM(I) = 0036          NB(I) = 0037          IDET(I) = 0038

```

UNREFERENCED STATEMENTS

10

STATEMENT ALLOCATIONS

```

10 =005E 100 =015B 200 =015F 300 =0163 900 =0165

```

FEATURES SUPPORTED

ONE WORD INTEGERS

CALLED SUBPROGRAMS

```

BLNK3  CHAR3  LBOXD  PFKL2  LCOT2  LGEOL  LGEMP  LPROD  COMGO  ISTOX

```

INTEGER CONSTANTS

```

12=003E    7=003F    11=0040    640=0041    76=0042    1=0043    520=00
290=0048    15=0049    254=004A    16=0048    228=004C    72=004D    17=00
125=0052    5=0053    40=0054    530=0055    470=0056    84=0057    4=00
20=005C

```

CORE REQUIREMENTS FOR LEXPL

```

COMMON      0  INSKEL COMMON      0
VARIABLES   62  PROGRAM      298

```

END OF COMPILATION

// JOB 15 JAN 77 PLEEO1P1 006 FF 06040201 HENRY LEE 1810 225 1
 // FOR 15 JAN 77 17.374 HRS

*LIST ALL
 SUBROUTINE LGEO

CC
 C GEOL--GEOLOGICAL EXPLORATION SYSTEM
 CC

DIMENSION MESS(40)
 DIMENSION JX(9),JY(9)

C
 IO CALL BLNK3
 IX=12

C DISPLAY
 C
 C GEOLOGICAL EXPLORATION SYSTEM

C DATA RETRIEVAL (WELL)
 C TREAD ANALYSIS (WELL)
 C CROSS SECTION (PLAN)
 C CONTOUR (MSSB)
 C 3-D DISPLAY
 C PROPOSED DRILLING LOCATION
 C

READ(7*21)MESS
 IY=680
 CALL CHAR3(IX,IY,MESS,72,1)
 READ(7*22)MESS
 IY=580
 CALL CHAR3(IX,IY,MESS,72,1)
 READ(7*23)MESS
 IY=550
 CALL CHAR3(IX,IY,MESS,72,1)
 READ(7*24) MESS
 IY=520
 CALL CHAR3(IX,IY,MESS,72,1)

READ(7*25)MESS
 IY=490
 CALL CHAR3(IX,IY,MESS,72,1)

READ(7*26)MESS
 IY=460
 CALL CHAR3(IX,IY,MESS,72,1)

READ(7*27)MESS
 IY=430
 CALL CHAR3(IX,IY,MESS,72,1)

C DISPLAY
 C
 C EXIT TO

C
 C GEPHYSICAL SYSTEM
 C EXPLORATION SYSTEM
 C PRODUCTION SYSTEM
 C

READ(7*28)MESS
 IY=260
 CALL CHAR3(IX,IY,MESS,72,1)

READ(7*29)MESS
 IY=200
 CALL CHAR3(IX,IY,MESS,72,1)

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```

READ(7*30)MESS
IY=170
CALL CHAR3(IX,IY,MESS,72,1)
READ(7*31)MESS
IY=140
CALL CHAR3(IX,IY,MESS,72,1)
JX(1)=13*12+6
JX(2)=JX(1)
JX(3)=JX(1)
JX(4)=JX(1)
JX(5)=JX(1)
JX(6)=JX(1)
JX(7)=246
JX(8)=246
JX(9)=246
C
JY(1)=590
JY(2)=560
JY(3)=530
JY(4)=500
JY(5)=470
JY(6)=440
JY(7)=210
JY(8)=180
JY(9)=150
C
CALL LBOXD(JX,JY,9,10,IXD,IYD,0,INDM)
100 CALL LCDT2(IXD,IYD,1,NR)
CALL LBOXD(JX,JY,9,10,IXD,IYD,20,IDET)
C
GD TO(110,120,130,140,150,160,170,180,190),IDET
CC
C WELL DATA RETRIEVAL AND DISPLAY
CC
110 CALL LINK(WELLD)
C
120 CALL LINK(WELLD)
130 CALL LINK(INLAN)
CC
C CONTOUR
CC
140 CALL LINK(TMAS8)
CC
C 3-D DISPLAY
CC
150 CALL LINK(GRPER)
C
160 GO TO 100
C GEOPHYSICAL SYSTEM
170 CALL LGFOP
C EXPLORATION SYSTEM
180 CALL LEXPL
190 CALL LPROP
RETURN
END

```

77 FOR 14 JAN 73 00.378 HRS

*LIST ALL

SUBROUTINE LGEXP

CC

C GEOP--GEOPHYSICAL EXPLORATION SYSTEM

CC

DIMENSION MESS(40),JX(5),JY(5)

10 CALL BLNK3

C

DISPLAY

C

GEOPHYSICAL EXPLORATION SYSTEM 41

C

AEROMAGNETIC AND GRAVITY DATA PROCESSING SYSTEM 42

C

(FOR PRELIMINARY AND BROAD AREA EXPLORATION) 43

C

SEISMIC DATA PROCESSING SYSTEM 44

C

(FOR DETAILED AND ACCURATE SURVEY) 45

C

C

IX=12

READ(7,41)MESS

CALL CHAR3(IX,640,MESS,76,1)

C

IY=560

NREC=42

DO 20 I=1,4

CALL LWTMG(7,NREC,IX,IY,MESS,76,1)

NREC=NREC+1

IF(I-2)12,14,12

12 IY=IY-30

GO TO 20

14 IY=IY-70

20 CONTINUE

C

EXIT TO 46

C

GEOLOGICAL SYSTEM 47

C

EXPLORATION SYSTEM 48

C

PRODUCTION SYSTEM 49

C

IY=220

NREC=46

DO 50 I=1,4

CALL LWTMG(7,NREC,IX,IY,MESS,76,1)

NREC=NREC+1

IF(I-1)42,44,42

42 IY=IY-30

GO TO 50

44 IY=IY-60

50 CONTINUE

C

JX(1)=13*12+6

JX(2)=JX(1)

JX(3)=246

JX(4)=246

JX(5)=246

JY(1)=568

JY(2)=468

JY(3)=168

JY(4)=138

JY(5)=108

C

CALL LBOXD(JX,JY,5,10,IXD,IYD,0,IDUM)

CALL LCDT2(IXD,IYD,L,NB)

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CALL LBOXD(IJX, JY, 5, 10, IXD, IYD, 20, IDET)

C

GO TO(110, 120, 130, 140, 150), IDET

C

110 CALL LAERO

GO TO 10

120 CALL LSEIS

GO TO 10

130 CALL LGEOL

150 CALL LPROD

140 RETURN

END

VARIABLE ALLOCATIONS

MESS(I) = 0027-0000

JX(I) = 002C-0028

JY(I) = 0031-002D

IX(I) = 0037

I(I) = 0035

IXD(I) = 0036

IYD(I) = 0037

IDUM(I) = 0038

STATEMENT ALLOCATIONS

10 =005C 12 =0091 14 =0099 20 =009F 42 =00C9 44 =00D1 50 =00

150 =0150 140 =0152

FEATURES SUPPORTED

ONE WORD INTEGERS

CALLED SUBPROGRAMS

BLNK? CHAR3 LWTMG LBOXD LCO? LAERO LSEIS LGEOL LPROD COMGN

INTEGER CONSTANTS

12=0040

7=0041

41=0042

640=0043

76=0044

1=0045

560=00

30=004A

70=004B

220=004C

46=004D

60=004E

13=004F

6=00

168=0054

138=0055

108=0056

5=0057

10=0058

0=0059

20=00

COPE REQUIREMENTS FOR LGEOP

COMMON 0 INSKEL COMMON 0

VARIABLES 64 PROGRAM 276

END OF COMPILATION

// JOB 15 JAN 77 PLFF01.R1 006 FF 06040201 HENRY LEF 1819 225 20.291

// FOP 15 JAN 77 20.292 HRS

*LIST ALL
SUBROUTINE LPROD

CC
C PROD--PRODUCTION INFORMATION SYSTEM

CC DIMENSION MESS(40),JX(6),JY(6);

C DATA JX/ 3*130, 3*246/

C IX=12

C 10 CALL BLNK3

C DISPLAY

C PRODUCTION INFORMATION SYSTEM 90

C ECONOMIC ANALYSIS 91

C OPTIMIZED DRILLING 92

C RESERVOIR DEVELOPMENT 93

C 1. RESERVOIR SIMULATION 94

C 2. PRODUCTION EVALUATION 95

C 3. VOLUME ANALYSIS 96

C READ(7,90)MESS

C CALL CHAR3(IX,690,MESS,76,1)

C IY=560

C NR=91

C DO 20 K=1,6

C CALL LWTMG(7,NR,IX,IY,MESS,76,1)

C NR=NR+1

C IF(K-4)12,14,16

C 12 IY=IY-40

C GO TO 20

C 14 IY=IY-30

C 20 CONTINUE

C EXPLORATION SYSTEM 98

C MONITORING 99

C QUIT 100

C IY=160

C NR=98

C DO 28 I=1,3

C CALL LWTMG(7,NR,IX,IY,MESS,76,1)

C IY=IY-30

C 28 NR=NR+1

C JY(1)=570

C JY(2)=530

C JY(3)=490

C JY(4)=170

C JY(5)=140

C JY(6)=110

C CALL LROXD(JX,JY,6,10,IXD,IYD,0,TDUM)

C 30 CALL LCDT2(IXD,IYD,1,NB)

C CALL LROXD(JX,JY,6,10,IXD,IYD,20,INDET)

C GO TO(30,30,30,41,43,42),INDET

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41 CALL LEXPL
42 CALL QUIT
43 RETURN
END

VARIABLE ALLOCATIONS

MESS(I) = 0027-0090	JX(I) = 002D-0028	JY(I) = 0033-002E	IX(I) = 0034
K(I) = 0037	II(I) = 0038	IXD(I) = 0039	IYD(I) = 003A
IDET(I) = 003D			

UNREFERENCED STATEMENTS

10

STATEMENT ALLOCATIONS

10	=0061	12	=0092	14	=009A	20	=00A0	28	=00C4	30	=0101	41	=01
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FEATURES SUPPORTED
ONE WORD INTEGERS

CALLED SUBPROGRAMS

BLNK3	CHAR3	LWTMG	LROXD	LCDT2	LEXPL	QUIT	COMGO	ISTOX	MDFRD
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INTEGER CONSTANTS

12=0044	7=0045	90=0046	680=0047	76=0048	1=0049	560=00
40=004E	30=004F	160=0050	98=0051	3=0052	570=0053	530=00
110=0058	10=0059	0=005A	20=005R			

CORE REQUIREMENTS FOR LPRD

COMMON	0	INSKEL COMMON	0
VARIABLES	68	PROGRAM	222

END OF COMPILATION

// JOB 12 JAN 73 PLEEO1R1 004 FF 06040201 HENRY LEE 1819 225 12.336
 // FOP 12 JAN 73 12.338 HRS

*LIST ALL

SUBROUTINE LSEIS

CC

C SEIS-- SEISMIC DATA PROCESSING SYSTEM

CC

DIMENSION MESS(40), JX(10), JY(10)

C

DATA JX/6*130, 4*246/

10 CALL BLNK3

DISPLAY

C

C

C

C

C

C

C

C

C

<u>SEISMIC DATA PROCESSING SYSTEM</u>	71
DATA ACQUISITION	72
DATA REDUCTION AND PREPROCESSING	73
NORMAL MOVEMENT CORRECTION	74
STATIC CORRECTION	75
FILTERING	76
SEISMOGRAPHY	77

IX=12

READ(7*71)MESS

CALL CHAR3(IX,640,MESS,76,1)

C

IY=540

NR=72

DD 20 K=1,6

CALL LWTMG(7, NR, IX, IY, MESS, 76, 1)

IY=IY-30

20 NP=NR+1

C

C

C

C

DISPLAY	QUIT	78
DISPLAT	GEOPHYSICAL SYSTEM	79
DISPLAT	EXPLORATION SYSTEM	80
DISPLAT	PRODUCTION SYSTEM	81

IY=200

NP=78

DD 30 K=1,4

CALL LWTMG(7, NR, IX, IY, MESS, 76, 1)

NR=NR+1

30 IY=IY-30

C

JY(1)=540

DD 50 I=2,5

50 JY(I)=JY(I-1)-30

JY(7)=200

DD 60 I=8,10

60 JY(I)=JY(I-1)-30

C

CALL LBQXD(JX, JY, 10, 10, IXD, IYD, 0, IDUM)

70 CALL LCPT2(IXD, IYD, 1, NR)

CALL LBQXD(JX, JY, 10, 10, IXD, IYD, 20, IDFT)

C

GO TO (70, 70, 70, 70, 70, 70, 70, 81, 82, 83, 84), IDFT

C

81 CALL QUIT

83 CALL LEXPL

84 CALL LPROD

82 RETURN

END

VITA

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