PLANNING FOR TROUBLE-FREE DRILLING

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INTRODUCTION

The World War II Allied assault on the beaches of Normandy is described by Corneluis Ryan in The Longest Day, a book in which the author provides a detailed record of one day in history. It would be a mistake, however, to think that the story of the Normandy Invasion is completely told by relating only events of that single day. Planning for June 6, 1944 began years before, and nothing that happened on that day was more important than the efforts spent in planning the operation.

Not only a military operation, but any major undertaking demands a detailed, well thought-out plan to achieve success, especially when the undertaking involves safety of personnel, considerable financial investment, and coordinated efforts of many people.

Drilling a well is just such an undertaking, and a plan for drilling the well provides the drilling manager, the person with ultimate responsibility at the well-site, exactly what a battle plan gives an army general -- a orderly and detailed program for successful completion of his mission. This paper will discuss in detail each of the components of a drill plan.

In the case of a drilling project, success is measured by reaching total depth without exposing personnel to unnecessary hazards, while reducing total drilling days, keeping non-drilling days at a minimum and controlling overall costs. Simply stated the benefits of effective planning are fourfold:

* Safety
* Economy
* Evaluation
* Formation Protection

Safety

Decisions at the drill site always give first consideration to the safety of personnel and equipment. Although safety is of prime importance precautions that do not reflect realistic hazards add unnecessary cost to drilling a well. The drilling plan provides the drilling manager with an important tool for assessing the hazards of a decision. Because of this, the act of preparing the plan itself becomes an important safety precaution.

Economy

Anything that safely controls the time and materials needed to drill a well to total depth improves the economy of the project. Among these are maintaining a maximum rate of penetration, prolonging bit life, and reducing trip time and frequency. The drilling program provides a basis for choosing fluids, bits, and rig equipment that save money by ensuring maximum penetration rate, extended bit life and reduced trip time and frequency.

A second important factor in drilling economy is the mud program, particularly the removal of drilled solids, the mud-type and density, and the control of other mud properties.

Evaluation

An ongoing record and analysis of a drilling activity is secondary in importance only to production as the purpose behind drilling a well. Constant evaluation gives up-to-the-minute data for drilling decisions which enhances safety and economy. It also provides a historical record of such data as lithology, hydrocarbon shows, bit and drilling fluid performance and problems encountered. This record is invaluable in planning future wells.

Formation Protection

The drilling fluid program and the hydraulics program are of primary importance in formation protection. Drilling fluids, because of their chemical composition and circulating pressures, and the process of drilling itself alter formations from their virgin state. The drilling plan, particularly with respect to fluids and hydraulics, strives for minimum damage of anticipated formations.

Of particular importance with respect to formation protection, is drilling a guage hole with minimum formation damage so that good electric logging will be possible. Electric logging is the primary tool for evaluating production potential of the well.

Formation damage must be avoided for reasons other than good evaluation. Particular types of formations, such as shale, must be protected to ensure hole stability thus preventing problems that would impede drilling performance.

A third, and particularly critical reason for protecting formation integrity is to safeguard future production of the completed well. Severe damage to the producing zones during drilling can render a well incapable of economic operation.

THE DRILLING PLAN

Responsibility for a successful drilling operation rests on the drilling manager at the drill site, but he does depend on others for expert advice and for help in accumulating background data. Moreover, success of a drilling plan depends heavily on the attitude of those who will be involved in its execution. To achieve a high level of cooperation, all those involved should have an input to the planning and decision making process. Ultimately, however, the final analysis of data and crucial day-to-day decisions are the responsibility of the drilling manager.

Assembling the Drilling Plan

Each part of the drilling plan is dependent on each of the other sections (i.e., casing, bits, hydraulics), and a systematic, step-by-step procedure is the surest way to bring together technical know-how and raw data into a well-designed drilling program. A good final plan will achieve optimum drilling performance not by setting up rigid directives for equipment and operating procedures, but by providing flexible guidelines for anticipating and solving problems.

Collecting Information

Background information provides the raw material from which a drilling plan is put together. The first piece of data needed is the exact location of the proposed well. Knowing the exact location will allow the new well to be compared to offset wells in proper perspective. For this reason it is important to know the legal description of the drilling site and the coordinates for plotting it on a map.

The surface location of the well should be far enough from lease boundaries to allow for some deviation from true vertical at total depth. Maintaining a perfectly straight hole (just as straightening a crooked hole) greatly increases drilling cost because of reduced penetration rate (Fig. 1).

Reference Wells

Once the prospective well has been plotted on the map, other wells in the immediate area should also be located and plotted (Fig. 1). Wells drilled to at least the depth of the proposed well will be primary reference wells. Wells drilled to lesser depths are of secondary interest unless they are very near the proposed location, or they penetrate to depths of specific interest. If no wells of the geologic depth projected for the new well have been drilled nearby, then wells further away may provide useful clues to subsurface features.

Pressure Profiles

A pressure and fracture gradient profile for each prospective reference well should be calculated at this point before any further planning is attempted. Pore pressure is calculated from electric logs, and fracture gradients are determined from the pore pressures. A pressure profile is generated from the bit record of each well by developing a "dsc" curve from drilling data. If pore pressure was calculated as the reference well was drilled, and is available, it can be used to verify fracture gradients derived from electric log calculations. Figure 2 illustrates a formation pressure profile calculated from electric logging records and a calculated fracture gradient profile.

Geology-Lithology

Geologic (or formation) tops must be identified accurately for the reference wells, along with detailed descriptions of the formations drilled through. This is done by using mud logs, electric logs, and geologists' sample interpretations. A geologic column showing lithology at all depths should be drawn for each well.

Geologic Faults

Primary reference wells should not be separated from the proposed well by geologic faults because calculated pressure profiles from different wells cannot be translated across faults with any assurance of accuracy. It is possible for a deep well to be only a few hundred feet from the location of the proposed well but be useful only as a secondary reference because of an intervening fault. This is true because pressures on opposite sides of the fault may not correspond. A well further away, but in the same fault block could be a more valuable tool for determining dipping trends and depths of interest. Fault maps should be consulted if available, because they are very important in selecting suitable reference wells.

Poor reference-well selection will result in unsatisfactory casing design and faulty mud programming. In addition it will not help prevent serious drilling problems, such as well kicks, lost circulation, stuck pipe and sloughing shale.

Gathering Reference Data

Data from reference wells should be gathered into a central location to facilitate cross referencing during well planning. These data include electric logs, bit records, daily drilling reports, mud reports, mud-log reports, and, if available, reports from data monitoring units. Detailed written recaps of wells are especially valuable in describing problems encountered in the reference wells. Reference-well data will be used in several different phases of program planning.

PROJECTING GEOLOGY OF THE PROPOSED WELL

Geologic Cross Section

Using reference-well data as a guide a geologic cross section can be drawn of the area where the well is to be drilled. Figure 3 illustrates a typical cross section of four reference wells and a proposed well. The purpose of the cross section is to establish geological depths in the proposed well. This is done by plotting the reference wells on the cross section at their positions relative to the proposed well and noting the dipping trends. This allows reference-well formation tops to be projected to the proposed well. If seismic data is available it can be used to confirm the extrapolated dipping trends.

Problem Zones

Close examination of reference-well data will reveal the problems encountered in drilling these wells. If no major faults intervene, similar problems could occur in the proposed well at the same geologic depths with the same drilling conditions. One purpose of a plan for the proposed well is to neutralize problems encountered in reference wells by determining the causes and formulating solutions to them. A good drilling plan will anticipate and solve problems through applied engineering techniques.

Specific conditions should be checked for in reference wells. The problems these conditions may cause and conventional solutions to them are:

Surnormal pressures. High pressure zones can result in kicks and are handled by the mud program and the casing program.

Subnormal pressures. Pressure regressions sometimes cause lost circulation and/or differential sticking of the drill string. The mud and casing programs deal with these.

Sloughing shales. These shales may have micro fractures and be water sensitive, or they may have major fracturing and cause a rubble or boulders. Shale formations with a high degree of inclination tend to slough. The mud, casing, bit and hydraulics programs each deal with this type problem.

Mud contaminates. Salt, anhydrite, limestone, saltwater, gumbo shales, and sour gases (H_2S and CO_2) contaminate mud and are handled primarily in the mud program, but are also considered in the bit, hydraulics, casing, cementing and logging programs.

THE PROGRAMS

Mud Program

The mud program is designed to provide accurate geological interpretation. It also ensures:

*A safe operation by:

(1) Controlling downhole pressures
(2) Controlling sour-gas intrusions

*A trouble-free operation by:

(1) Controlling drilled solids
(2) Preventing lost circulation
(3) Providing optimum hole cleaning without overloading the annulus with drilled cuttings
(4) Preventing tubular corrosion
(5) Preventing or controlling contamination
(6) Stabilizing the borehole
(7) Controlling formation damage
(8) Eliminating temperature problems
(9) Contributing to bit performance

The drilling plan contains a detailed mud program that will realize the objectives given above. For each depth interval the program discusses potential problems and the recommendations for chemical treatment and mechanical equipment needed for each interval. Required mud densities are determined from pore pressure calculations. Safety factors for these densities are determined by annular pressure losses, and these safety factors offset the hazards associated with tripping the drill string. The mud program should not incorporate excessive safety factors since this will reduce drilling rates and increase the chances of lost circulation and differential sticking of the drill string.

A mud type for each formation is selected that will allow maximum drilling performance, protect formations, be temperature-stable, and prevent or control anticipated contamination. The plan gives general chemical mud treatment for each drilling interval. Specific treatment must be determined by the mud engineer as the well progresses. The mud program should be a flexible guideline that facilitates problem solving and making adjustments to achieve optimum drilling performance.

Rheological properties (i.e. plastic viscosity, yield point and gel strengths), which give optimum hole cleaning may be recommended in the plan. Careful attention must also be given to fluid-loss recommendatons. An ultra-low fluid loss can add to mud cost unnecessarily. High fluid-loss can be a cause of differential sticking and formation damage. Special additives, such as lubricants, may be recommended in the program but should be used at the discretion of the wellsite personnel.

The mud program should include contingency plans for lost circulation, pressure control, differential sticking, and sour gas intrusion. A step-by-step procedure for handling each of these problems should be recommended.

The mud program contributes to the overall success of the drilling operation because it directly affects drilling rates, well logging, casing, pressure control, hole stability, formation protection and well evaluation. For this reason, the mud program must be planned carefully with the overall operation in mind.

Casing Program

The drilling plan assumes the project will result in a producing well, therefore the casing selected must be the right size to accommodate tools for completion and production. This consideration will determine hole size in all sections of the hole, including the lower section.

The casing seats of each string are determined by using the recommended mud densities and the fracture gradient curve for the proposed well, beginning with the production string and moving toward the surface (Fig. 2). The fracture gradient at each casing seat should be great enough to withstand the hydrostatic pressure of the maximum mud weight used below the casing seat, plus the equivalent circulating density of the system while drilling or tripping. Figure 2 illustrates a safety margin of .3 lb/gal in the large hole and .5 lb/gal in the small hole to give adequate protection to prevent exceeding fracture pressure. Estimated circulating density for each size hole is generally used.

The casing should be designed with adequate safety factors to prevent bursting and collapse. Drift diameters of recommended casing must allow for running desired bit sizes in the lower intervals.

Cementing Program

A good casing design is worthless unless the casing string is properly cemented in place in the wellbore. A properly cemented casing string serves the following purposes that contribute to a successful drilling operation.

* Eliminates communications between formations behind the casing and the active wellbore, thus sealing off lost circulation zones, high pressures zones, and contaminant zones (e.g. salt, etc.)

* Bonds casing to formation
* Protects fresh water zones from contamination
* Protects possible production zones in the upper hole
* Provides higher exposed fracture gradient , which allows higher mud weight to be used in the lower hole

Cement slurry is usually designed in consultation with the cement service-company personnel. The slurry design is based on three primary criteria: (1) hole temperature, (2) density required and (3) pumping time (i.e. thickening time). Information about these criteria must be accurate to allow proper selection of additives.

Theoretical cement volume is based on a caliper measurement of the open hole prior to running casing. In practice, however, the actual volume of cement required will be more than the amount calculated for a guage hole. The amount of additonal cement varies with different areas and different depths by a factor perculiar to area and depth. A cement engineer experienced in the area of the well is invaluable in estimating the excess factor and he should, of course, be involved in the planning process.

Float equipment and other related tools should be specified in the cement program. Equipment will include centralizers, scratchers, etc., if recommended.

The initial cement program should be reviewed several days prior to running each casing string, and adjustments made if necessary, based on experience with previous strings.

Bit Program

Bit records and lithology columns prepared earlier from the primary reference wells are needed to prepare the bit program. Bit performance is also dependent on well-designed hydraulics and mud programs. These should be considered as well in interpreting reference-well data.

The bit program should recommend: (1) bits designed to penetrate specific intervals, (2) the weight on the bit, and (3) the RPM that will give the maximum rate of penetration without excessive bit damage.

The bit records show which runs were good and which were bad. A cost analysis will reveal whether or not each bit used in the reference well was the most cost effective. This analysis involves comparing the bit records and the lithology to see if the optimum bit was used in each formation. The bit should have penetrated the formation with minimum wear to teeth and bearings, and with relatively good rates of penetration. Bits that performed best in the reference wells should be suitable for the proposed well. An engineer from the bit company, who is experienced in the area where the well is located, should be consulted to confirm proper bit selection.

Drill String - Bottom Hole Assembly

Drill pipe recommendations must take into account maximum anticipated loads and torque. If the proposed hole is large and/or highly deviated, a relatively large-size drill pipe may be needed to resist higher than normal torque.

The bottom hole assembly is designed to:

* Provide the weight to be applied to bit, plus the additional weight needed to ensure that the drill string neutral point is always in the bottom hole assembly while drilling. The latter is very important because maintaining the neutral point in the bottom hole assembly prevents drill pipe fatigue and potential twist-offs. This will also facilitate controlling hole deviation. To accomplish this in smaller holes, it may be necessary to use some Hevi-Wate drill pipe on top of the drill collars. Hevi-Wate is a trademark of Drilco Division of Smith International, Inc.
* Control hole deviation by proper placement of stabilizers.
* Prevent drill string vibration by means of a shock absorbing device. This device will also: (1) ensure that the bit is continuously on bottom, (2) improve penetration rate, and (3) decrease bit damage.
* Provide for freeing stuck pipe by using a jarring device.

Rig Selection

At this point in the planning process enough data on the proposed well has been developed to permit selecting the proper drilling rig. The rig must be sturdy enough to perform all anticipated hoisting, drilling, and mud handling, plus have some additional capacity for a safety factor. In selecting a rig, particular attention should be focused on the mast, substructure, rotary, blocks, swivel, drawworks, compound, engines and mud pumps.

<u>Selection of mast, substructure and rotary</u>. To make the proper selection, consult the data already compiled on maximum casing load, maximum drilling depth, bottom hole assembly, drill pipe size, wireline size and mud weight to be used at various depths. These data are necessary to calculate maximum static hookloads, maximum set-back loads, and maximum rotary-table loads.

<u>Selection of block and swivel</u>. The required block size is governed by maximum loads and wireline size. These data are used to determine the number of lines to be strung on the block. The normal wireline hookload safety factor of casing load is 2 to 1. The normal safety factor for the working load is 3 to 1.

<u>Power required for hoisting</u>. The hook horsepower required to handle the pipe is calculated using the hook load and the speed at which the pipe is moving.

$$\text{Hook horsepower} = \frac{\text{hook load (\#) X velocity (ft/min)}}{33{,}000}$$

About 30% of input horsepower is lost in the transmission system, drawworks drive system and the blocks with about 70% actually transmitted to the hook. Useful horsepower available to the hook is calculated as follows:

$$\text{Hook horsepower} = \text{Drawworks Input HP} \ \ X \ .70$$

<u>Mud pumps</u>. The rig should have two mud pumps, each capable of supplying the needed hydraulic horsepower independently of the other. Having two primary pumps will eliminate losing drilling time during repairs. Hydraulic horsepower requirements

will be determined in the hydraulics program (see below). Mechanical and volume efficiencies of the pumps must be considered to determine the true horsepower available for useful work.

Mud handling facilities. Efficient mud handling and processing is significant in maintaining low mud-treating costs. Two high-volume centrifical mud-mixing pumps, steel tanks, agitators (fluid or mechanical), shale shakers, and mud storage are needed to facilitate mud treatment and to prevent waste.

Personnel

Credentials for personnel on the rig should be considered carefully. Experienced and well-trained tool pushers and drillers are key factors in successfully drilling a well. Training in emergency procedures, such as pressure control should not be overlooked.

Hydraulics Program

After the drilling rig for the prospective well has been selected, the hydraulics program can be prepared knowing the actual pump data, surface equipment, drill-pipe size, and drill-collar size. The goal of the hydraulics program is to ensure maximum bit performance and bottom-hole cleaning by achieving the best balance between circulating rate, system pressure losses and the hydraulic horsepower expended at the bit. For any given rig and hole situation, there are certain considerations that govern rig hydraulics.

(1) Available hydraulic horsepower
(2) Annular velocity required to lift cuttings and to maintain laminar flow of the drilling fluid
(3) Nozzle velocity required to provide adequate bit and bottom-hole cleaning.
(4) Pressure rating of the surface equipment.
(5) Mud density and flow characteristics (PV, YP).
(6) Formation protection.

The hydraulics program can be prepared by computer or manually from the various tables and slide rules available. The computer program is much faster and will produce fewer errors.

The hydraulics program is designed to be a guide and should be flexible. Hole conditions and actual drilling conditions can cause the program to be changed in order to maintain optimum drilling performance and to solve specific problems as drilling progresses.

Electric Logging

The Electric Logging section of the program is designed by the geological and/or the production personnel but should be included in the total drilling program. A suite of logs for each logging interval and an estimated time of running should be shown in the program. It may be necessary with extended logging times to recondition the hole prior to completion of the logging run. The drilling engineer may want to recommend a specific log to assist in determining lost-circulation zones or pressure zones.

Monitoring and Reporting

Two of the primary goals in drilling a well are geological evaluation and optimum engineering performance. For this reason, a capable monitoring unit should be selected based on experience in the area to be drilled, and on expected problems. The selection of the monitoring unit is usually done jointly by the drilling engineers and the geologists since the capabilities of the unit will benefit both.

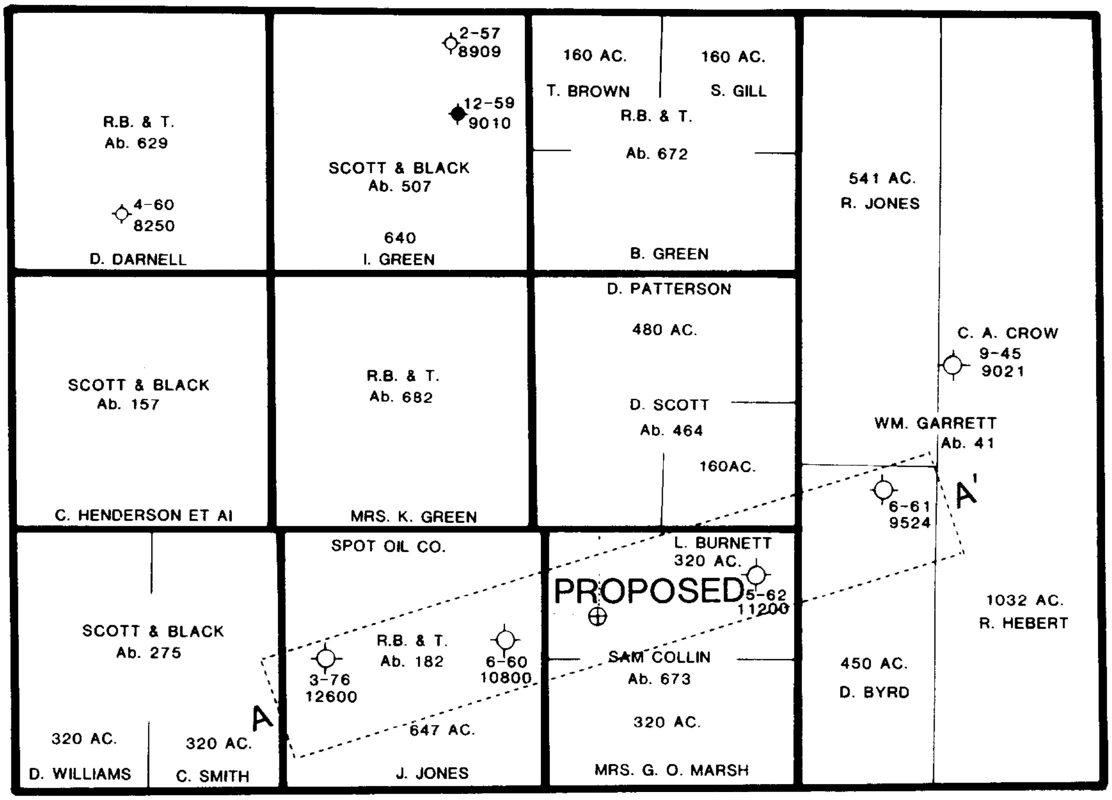
The drilling manager at the wellsite uses the engineering data compiled by the monitoring team to improve drilling performance through decisions about bit selection, optimum weight on bit and bit RPM, correct mud densities, casing seat selection, prevention of twist-off due to drill string washouts or increased torque and drag, and the prevention of tripping kicks due to improper hole fillup.

The geologist uses the lithology and hydrocarbon data to establish geological zones and interpret possible production zones.

The drilling plan also outlines monitoring unit reporting instructions. Drilling data must be recorded and reported through proper channels in order to permit sound judgement in operative decisions. Management personnel not at the wellsite must have credible data in order to give proper support to the drilling operation. Memories grow dim once a well is complete, therefore, reports must be detailed and accurate. The data will be needed at a later time in analyzing the well.

CONCLUSION

The drilling plan provides for safe and efficient use of equipment, tools, and personnel. It is a guide and a tool to assist in drilling a well with minimum problems. Some problems will undoubledly still occur because it is impossible to predict exactly what will be encountered as a well is drilled. Hopefully the problems will be minor. A good drilling program helps eliminate most major problems and provides contingency plans for those problems that do occur.



WELL SITE LOCATION - REFERENCE WELLS

FIGURE 1

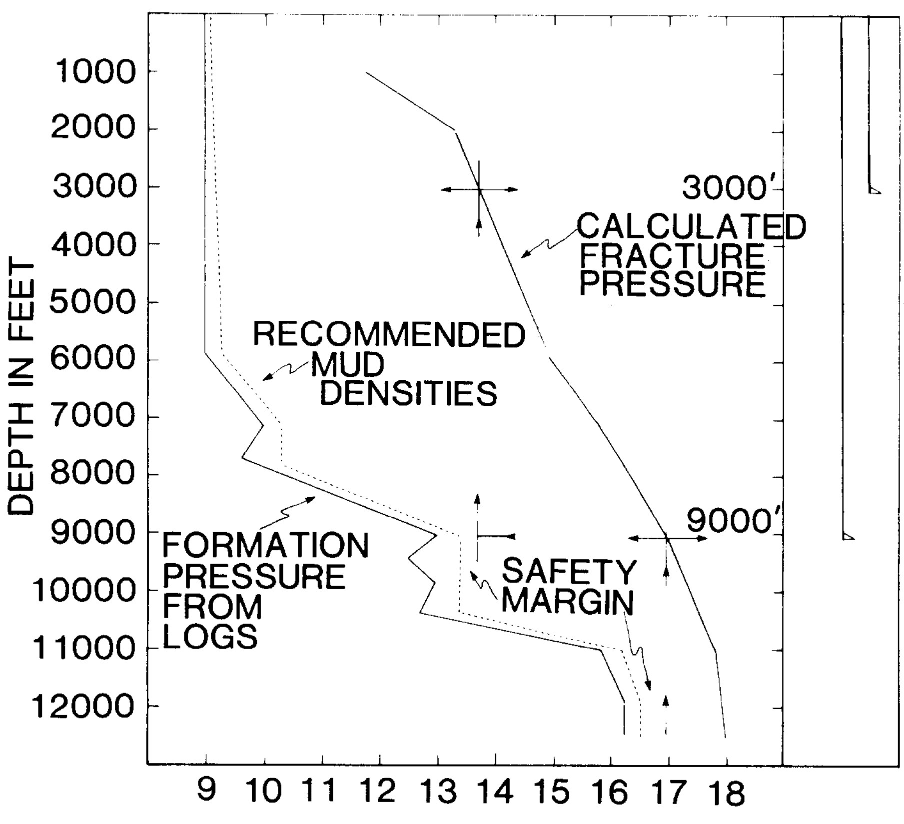
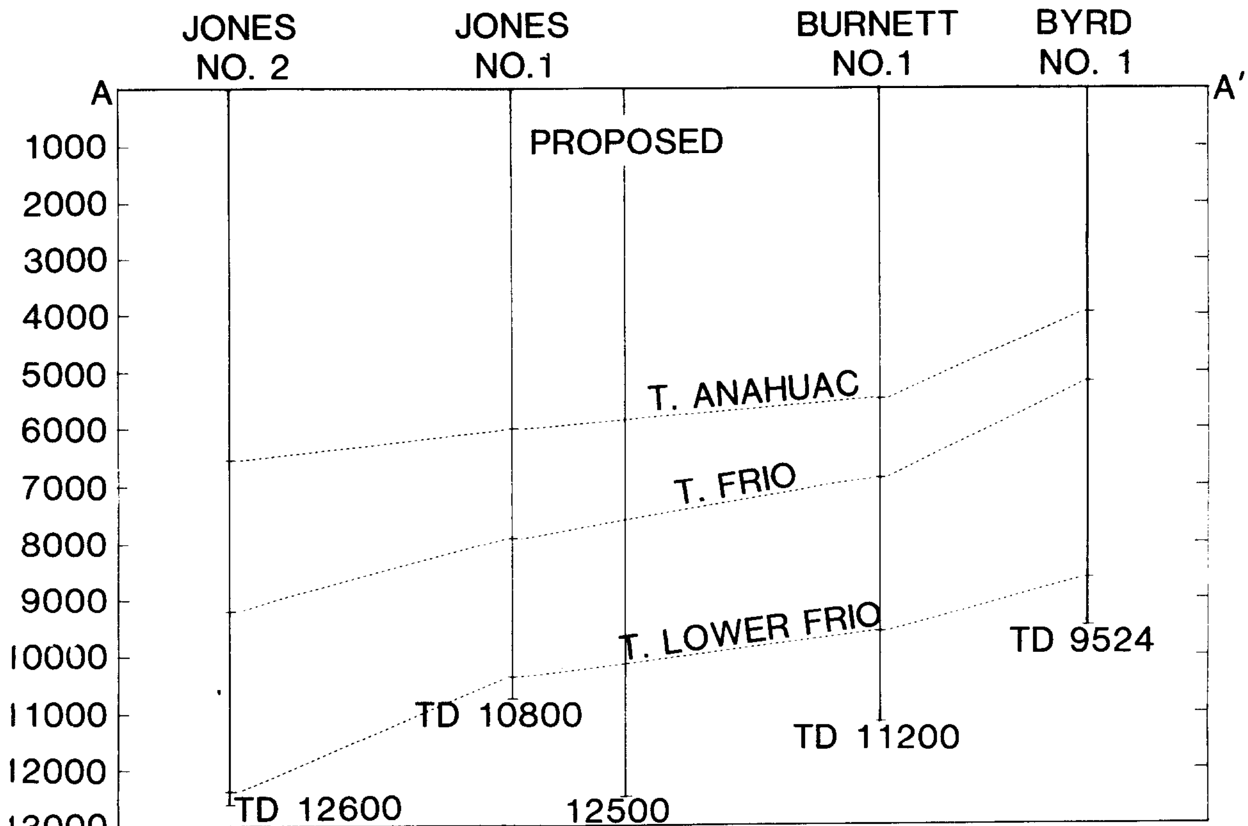


FIGURE 2



CROSS SECTION OF REFERENCE WELLS AND PROPOSED WELL
FIGURE 3