FIELD RESULTS USING MEASUREMENT-WHILE-DRILLING (MWD) DIRECTIONAL SYSTEMS IN LONG BEACH, CALIFORNIA

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ABSTRACT

One of the more extensive uses of directional drilling anywhere in the world has been in the development of the East Wilmington Oil Field in Long Beach, California. The average well achieves a deviation from vertical in excess of 50° and wells with a build-up in the 70° to 80° range are not uncommon before they are dropped off to 50° or less when penetrating the completion interval. Over 780 wells have been drilled in this field to date, requiring the highest degree of control and accuracy in order to avoid intersection of other wells and to obtain proper bottom hole spacing. The Measurement-While-Drilling (MWD) directional system has been tested on several wells and proven to provide the required accuracy along with many advantages over past methods used in the field development.

Accurate transmission by MWD of bottom hole measurements to the surface is provided by mud pressure pulses generated in the drill pipe downhole and detected by a pressure transducer mounted on the standpipe. Surface equipment includes the means for detecting, recording and processing these pressure pulses, to translate the information from the pressure pulses to rig floor displays useable by the drilling crew.

FIELD DESCRIPTION

The Long Beach Unit of the East Wilmington Oil Field covers 6,500 acres onshore and offshore in the beach area of the city (Fig. 1). All wells are drilled from four manmade islands (Fig. 2) and from sites in the Port of Long Beach. The islands are landscaped to blend with the local scenery (Fig. 3). Development of the field was started in 1965 and currently consists of 550 producing wells and 232 water injectors (Fig. 4). Output is in excess of 66,000 barrels of oil and 424,000 barrels of water per day, while 498,000 barrels of water per day are injected.

Seven separate oil bearing formations have been developed and the main producing interval is the Ranger zone (Fig. 5). This zone comprises a series of inter-bedded sands and shales containing approximately 220 ft. of net sand. Vertical depth may be from 2500 ft. to 4500 ft. depending on the location over the faulted anticline (Fig. 6). Wellheads at the surface are located in cellars and are spaced on 6 ft. centers.

Development of the field is by THUMS Long Beach Company, field contractor for the City of Long Beach, who is the unit operator. THUMS is a consortium representing Texaco, Exxon (formerly Humble Company), Union, Mobil and Shell.

SYSTEM ACCURACY OF MWD DIRECTIONAL DATA

To control the bit in both the vertical (inclination) and horizontal (azimuth or direction) planes with sufficient accuracy to meet the needs for successful development of this field requires the highest degree of accuracy in measurements. A recent paper by 'Wolff and DeWardt (1980) discusses the lateral position uncertainties of deviated wells as a function of their average inclination for various kinds of surveys. It reports that the weakest point in directional surveying undoubtedly lies in the compasses used. It further suggests that running two different types of surveys in a well, for instance magnetic and gyro multi-shots, will reveal possible gross errors in either survey and thus increase the reliability of the eventual result.' This procedure was followed in the testing phase of the MWD directional tool. In the first three wells comparison of the MWD measurements showed less variation than single and multi-shot surveys and fell between the two on well A-133 as shown (Fig. 7).

The accuracy of the MWD directional system is dependent on both the accuracy of the sensor device and on the capability of the transmission system to transmit accurately the data measured by the sensor. Basic sensory accuracy for the particular type sensor used is dependent on proper calibration. For the measurement of bearing a sensor of a type known as a fluxgate magnetometer combined with either bi-axial or tri-axial inclinometers is employed. The magnetometer measures the magnetic vector of the earth's magnetic field in three axes. The inclinometer is rigidly coupled mechanically to the magnetometer so that its gravity axis is aligned with the z-axis of the magnetometer. Errors in this mechanical alignment may create offsets due to departures from orthogonality. It was determined that an error correcting system was necessary even after elaborate attempts to perfectly align these axes by use of shims and fine set screw adjustments. One concern was that the mounting be permanent and not subject to change after being in the drilling environment a few hundred hrs. Therefore, a non-adjustable fixed mechanical mounting method was selected and the offset or mis-alignment errors were corrected for in each sensor unit by a calibration system that is included in the computer processing of the data. By properly identifying and correcting these offsets, it is possible to achieve a measurement accuracy of azimuth to 7/10 of a degree or better. Without proper calibration the combined magnetometer/inclinometer rotational error may typically be as much as $\pm 2^{o}$ for a total spread of 4^{o}. Another way of correcting or eliminating this error would be to always rotate the sensor to stop in its previous position. To maintain simplicity of the downhole tool, this was not thought to be a practical solution. Since an onboard computer is a part of the system for detecting the pulse coded signal in the drilling mud stream, it is possible to program the computer to automatically provide this correction. This is the solution provided in the present system.

Digital Code Transmission and Signal Detection

High fidelity in transmission of the measured signal is provided by using a pseudo digital code. This digital code using 12 bit resolution provides an accuracy of 1 part in 4096 or 1/20 of a degree in azimuth accuracy. The data transmission requires an average of 30 sec. per sample. Seven words are transmitted using three pulses per word for a total of twenty-one pulses to send the required information to let the computer calculate the hole angle and direction. This translates to an average time of 210 sec. or 3-1/2 min. to transmit the required data. Since this information is sent while drilling, it does not use up valuable rig time. The rig time used is the storage time required when taking the data. This occurs when the pumps are shut down to make a connection. The desired storage time is 2 min. For assurance of transmission reliability, the downhole information is sent up twice. By repeating transmission of the stored data a second time assurance is provided of transmission accuracy. Figure 8 shows processed and unprocessed pressure data as recorded from a pressure transducer located in the standpipe. The pump strokes are plainly visible and tend to mask the data carrying signal before processing by the computer. A subtraction type filter in the computer removes repetitive information such as the cyclical pump strokes and makes the signal easy to see with the naked eye.

The computer is programmed to do further signal detection without the aid of the operator and converts each pulse to the digital value represented by the time slot in which it appears.

Computation Methods

These values are then stored in the computer memory and printed out by a printer. After a few seconds of computation the computer calculates hole angle and azimuth which is then printed out on the same sheet. This information appears as shown in Figure 9.

As a back-up in case of computer failure, the operator can use a scaled transparent overlay to convert each signal to the digital value represented by the time slot in which it appears. These values may be then manually entered into a programmable calculator and computed again in seconds but slightly longer than when processed by the larger computer. A print-out device is also available for the hand held computer and lists the complete information as shown in Figure 10.

Use of Mud Motors

When using mud motors with a "bent sub" for purposes of changing hole angle and direction, there may be a considerable amount of mud pressure variation due to the variable load imposed on the drill. As weight on the bit is increased the motor loads up increasing the pressure and as the weight is drilled off the pressure decreases. These variations or dramatic excursions are shown in Fig. 11. In such cases, it is most difficult to distinguish the signal from the noise without the aid of the computer. Since the key information desired in this drilling mode is the face of the bent sub or the tool face rather than angle and azimuth of the hole, a "dynamic" mode is used. This dynamic mode is automatically sequenced after sending all the data required for the hole angle and direction computation. It uses this same stored data but replaces two of the magnetic vectors with updated values that are measured while the tool is drilling. Since the hole does not change immediately from the angle and direction just measured, the stored values are still close to true values and reducing the variables to be measured to only two, means that the tool face information can be updated every 60 sec. The variation of this information may be considerable. It is often necessary to raise the drill string approximately 1 ft. for 1 min. to update the tool face. Experience has shown the dynamic mode of the system provides reliable data for establishing new hole angles and directions that saves valuable rig time. The complete surface instrumentation is shown by Fig. 12. A rig floor display that is controlled and automatically updated by the computer is shown in Fig. 13. The operating principle of the bent sub is illustrated in Fig. 14.

Description of Pulser Device

The method of producing pulses in the time slots required, according to a measured signal, is by a pulser sub that controls a bypass valve to the annulus of the drill string. Usual open time for the valve is 1/2 sec. This pulser sub is located a short distance above the bit and connects to the downhole sensors. It is presently available in 7-in. and 8-in. diameters. It adds less than 2 meters to the length of the drill string. The measuring devices that connect to the pulser sub extend into the internal bore of the drill string and in the case of the directional device, is located 18 ft. below the pulser sub. Since it is necessary to locate the magnetometer in a non-magnetic collar, this special collar is normally provided as part of the entire MWD system. The only special feature is a slightly larger bore than normal in order to provide circulation clearance. The magnetometer sensor is packaged in a 2-in. O.D. housing and the non-magnetic collar is normally bored to 3-1/4 in. This provides sufficient clearance between the sensor housing O.D. and the drill collar I.D. to keep pressure losses in this section to a minimum. Development work to reduce the diameter of the magnetometer housing to a size that would permit its placement in standard sizes of bored collars is now progressing at a very rapid rate.

Power Supply

The entire downhole system is powered by batteries. Present types of battery packs used have a temperature rating of 300°F and an expected life of 250 hrs. for transmitting directional information. As other sensors are added and the frequency of pulses transmitted increases, it will reduce the battery life. Due to simplicity and reliability of a battery pack, it reduces the overall cost of a downhole system as compared with systems using a mud powered downhole turbine generator for power. For high temperature wells exceeding 300°F, a special high temperature battery pack rated to 375°F is available. Since circulating mud normally keeps temperatures in the tool string somewhere between surface temperature and bottom hole temperature, it is expected that the very high temperature batteries will be required only in unusual cases. Due to their shorter life and higher cost, high temperature batteries are not expected to become standard. Since the bypass valve requires very little power to operate, it permits the practical use of batteries for a downhole power supply.

System Limitation

The shortcoming of this MWD system is that in order for the bypass valve to create a pressure pulse when operated, there must be a pressure differential between the inside of the drill pipe and annulus. In modern jet bit drilling this is nearly always the case. And in fact, the higher the differential the greater the size of the pulse obtained when the valve is operated. It is obvious that one advantage of the system is that it utilizes power furnished by the pumps at the surface to create the pulse. There may be drilling conditions on occasion, however, where it is desireable to use regular circulation type bits or large nozzles in the jet bits to reduce pressure losses and obtain larger circulation volumes. Under such conditions where maximum gallons per minute are desired and pressure loss across the bit is kept to a minimum, it is difficult to produce good pulses with the bypass valve technique. In such unusual cases a special throttle sub is introduced between the pulser unit and the mud motor.

Field Examples

Prior to the use of MWD directional surveying, the conventional surveying methods required an average of 20% of the rig time per well drilled. By elimination of the conventional surveying time, the rig continues drilling during this former lost time and thus benefits even more than the indicated 20%. Under the most favorable conditions, there have been single 8 hr. tours make as much footage as normally made in a 24 hr. day. Due to the time required for running pipe, cementing, and logging, the overall time savings indicated appears to effectively be about 25%. This cuts the time from 25 or 26 days formerly required to drill a typical well to 20 or 21 days.

In addition to the savings in survey time, MWD provides the information for guidance of mud motor runs, simularly to the methods using wireline conductor line type steering tools. One additional advantage here is that the mud motor may be used for longer trips without the hazard of damaging the wireline cable during the drilling process and for several joints with no loss of rig time.

Further benefits have previously been cited by other authors and were referred to as "The Second-Tier Benefits" (Newton et al., 1980).

CONCLUSIONS

The reliability of the pulse identification and coding system for accurate transmission of hole angle and direction has proven to be at least as good as conventional surveying methods. It has met the needs for continued development drilling in the Long Beach Field. The use of MWD directional surveying methods results in a considerable savings of rig time and an improvement in drilling efficiency.

REFERENCES

NEWTON, R., KITE, R.L., & STONE, F.A. - "Telemetry - MWD - The Second-Tier Benefits". TRANSACTIONS - 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, Sept. 21-24, 1980. SPE: 9224.

WOLFF, C.J.M. & DE WARDT, J.P. - "Borehole Position Uncertainty. Analysis of Measuring Methods and Derivation of Systematic Error Model". TRANSACTIONS - 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, Sept. 21-24, 1980. SPE: 9223.

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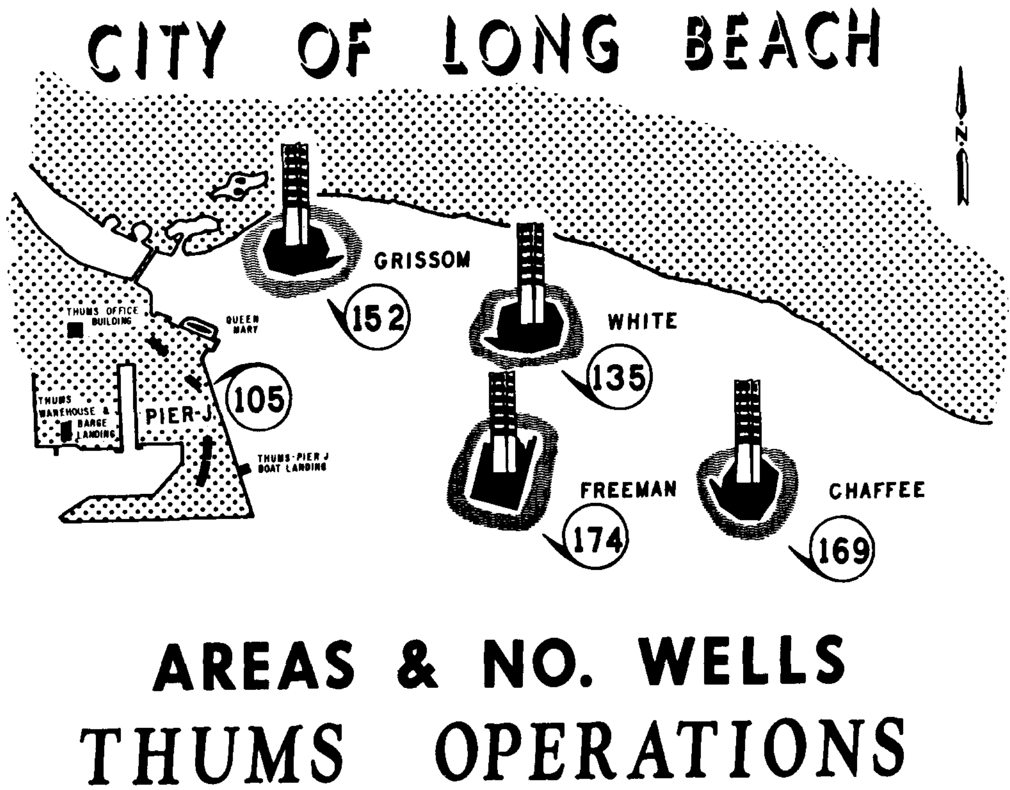

FIGURE 1—THUMS OPERATIONS - CITY OF LONG BEACH

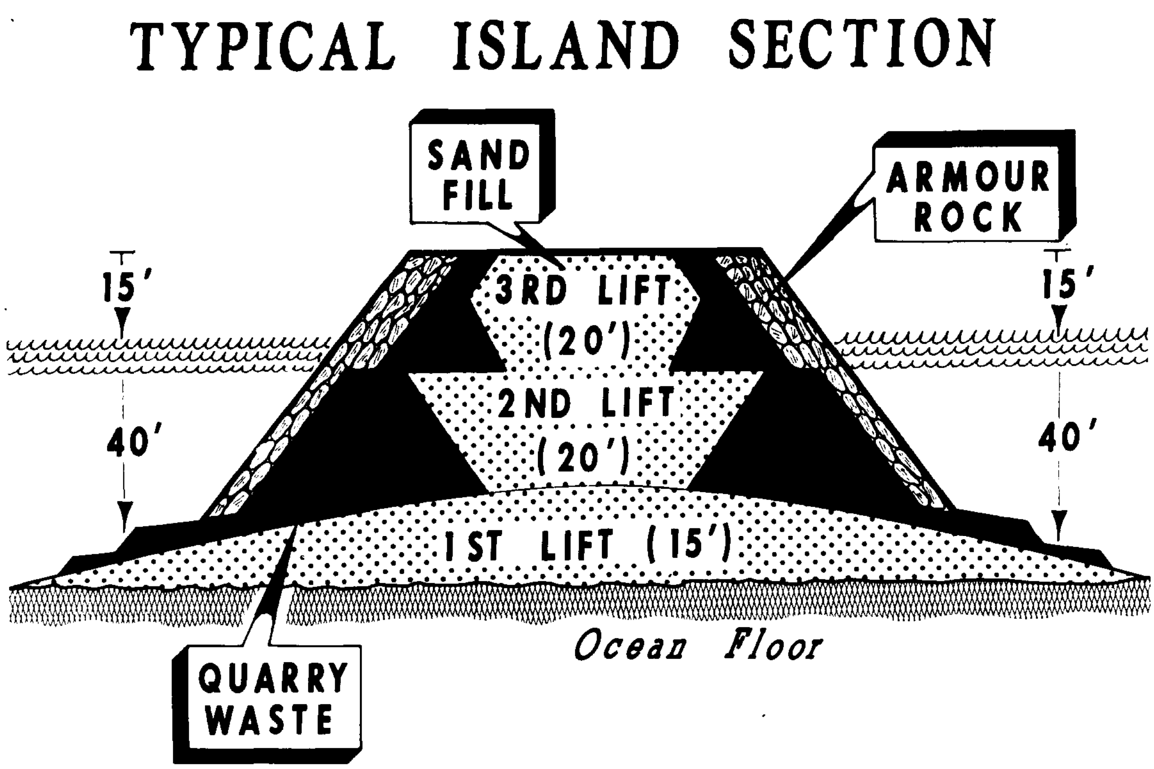

FIGURE 2—TYPICAL ISLAND SECTION

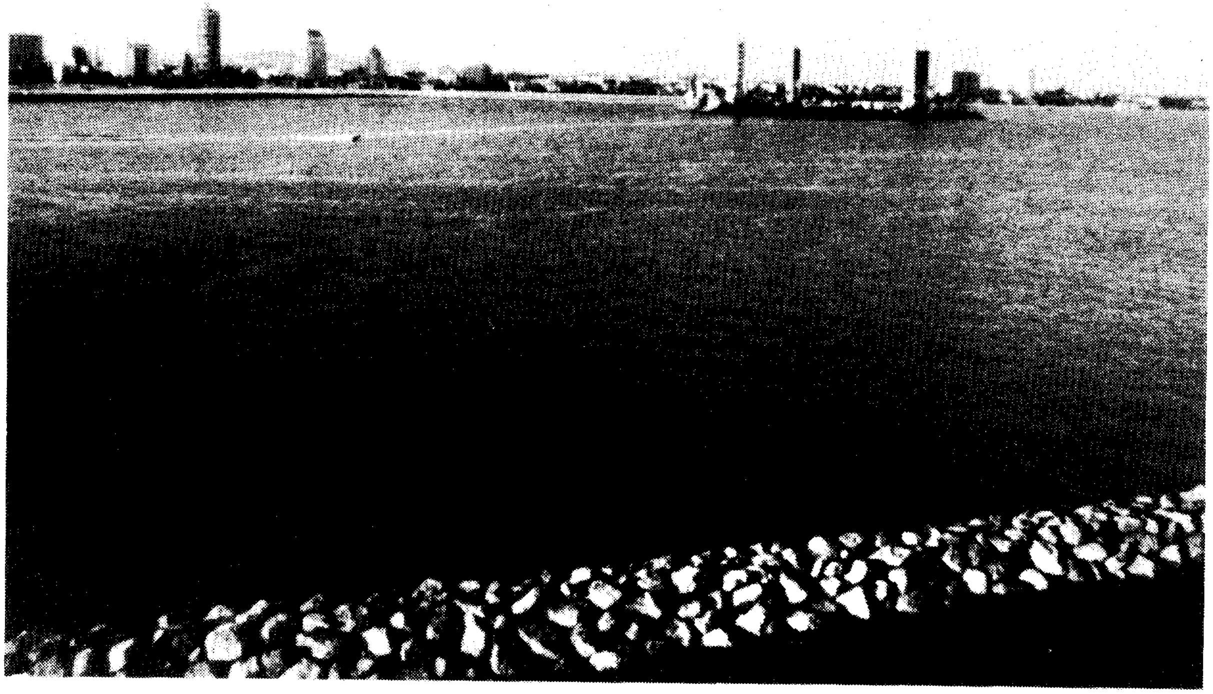

FIGURE 3—ISLAND LANDSCAPING

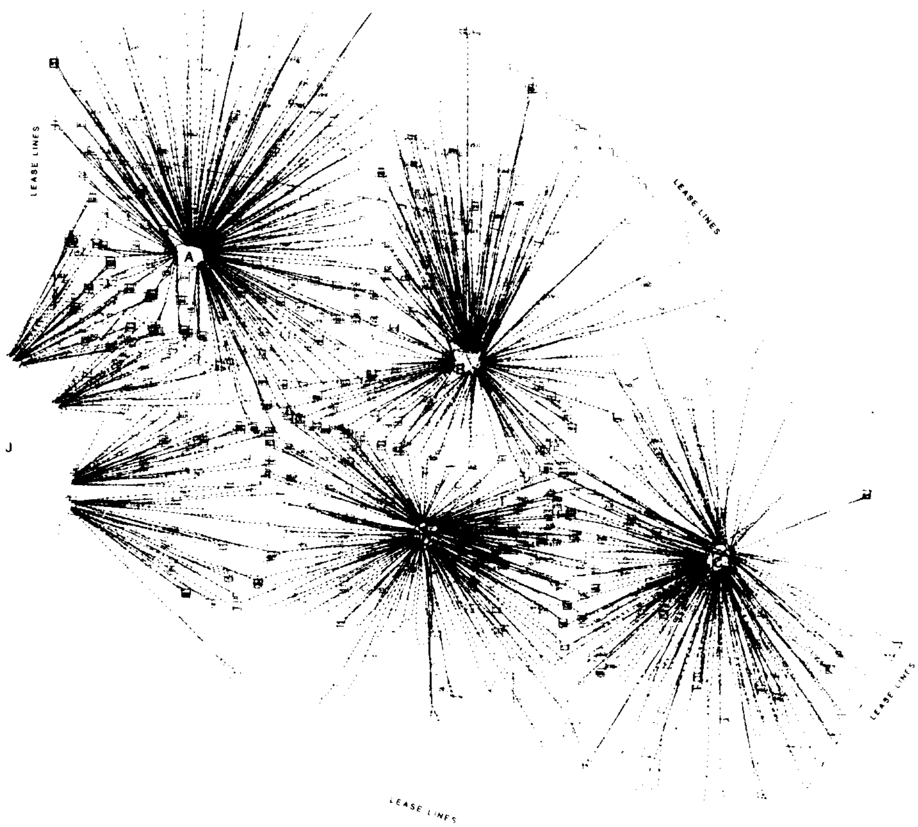

FIGURE 4—WELLS DRILLED TO DATE

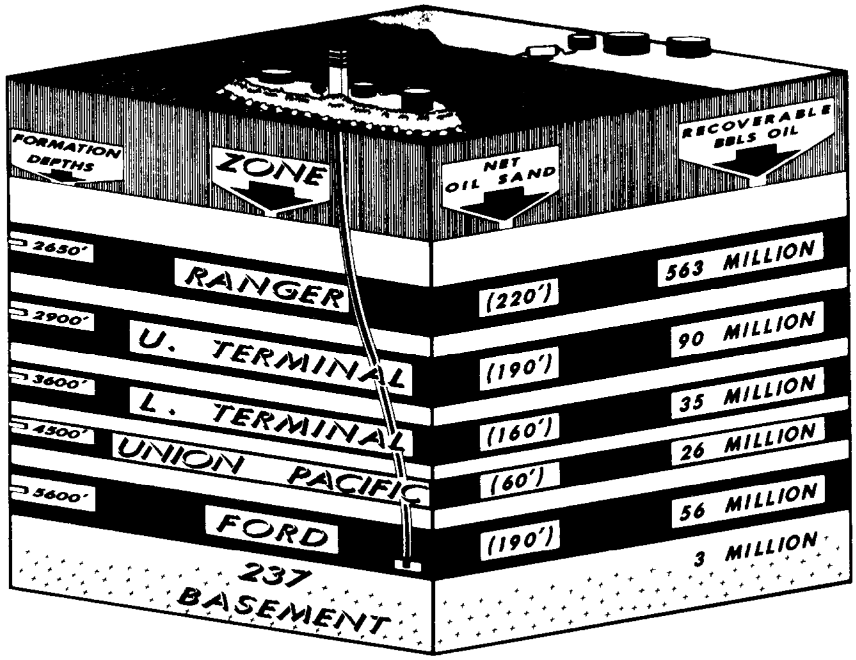

FIGURE 5—RANGER ZONE BLOCK DIAGRAM

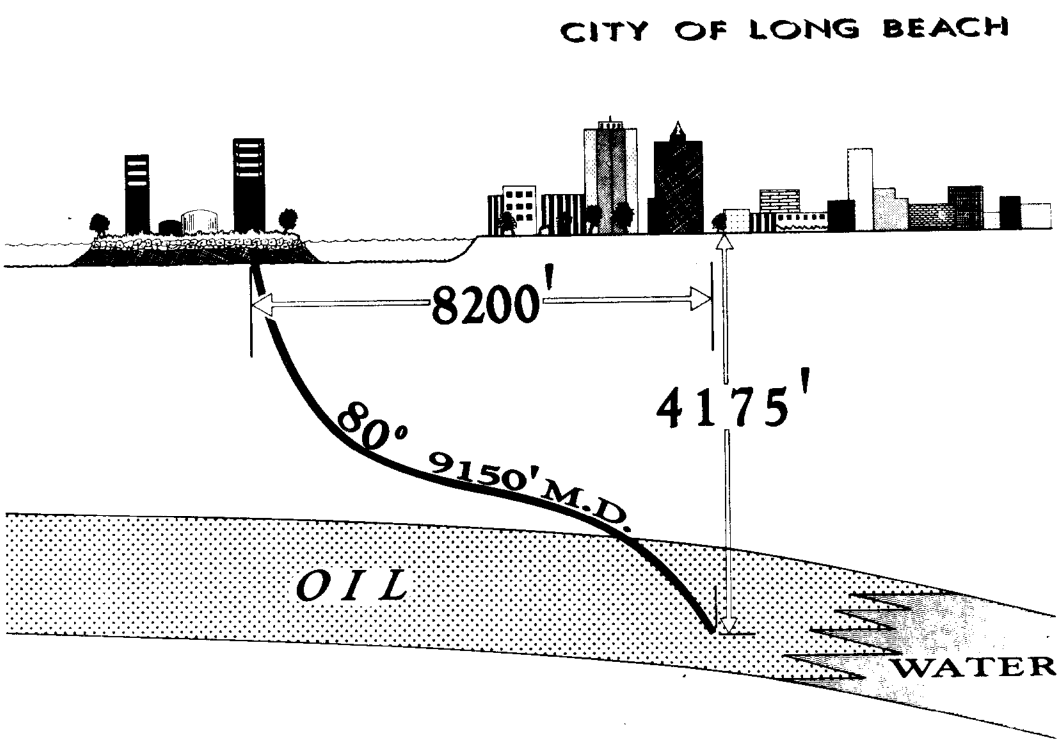

FIGURE 6—VERTICAL DEPTH VERSUS MEASURED DEPTH

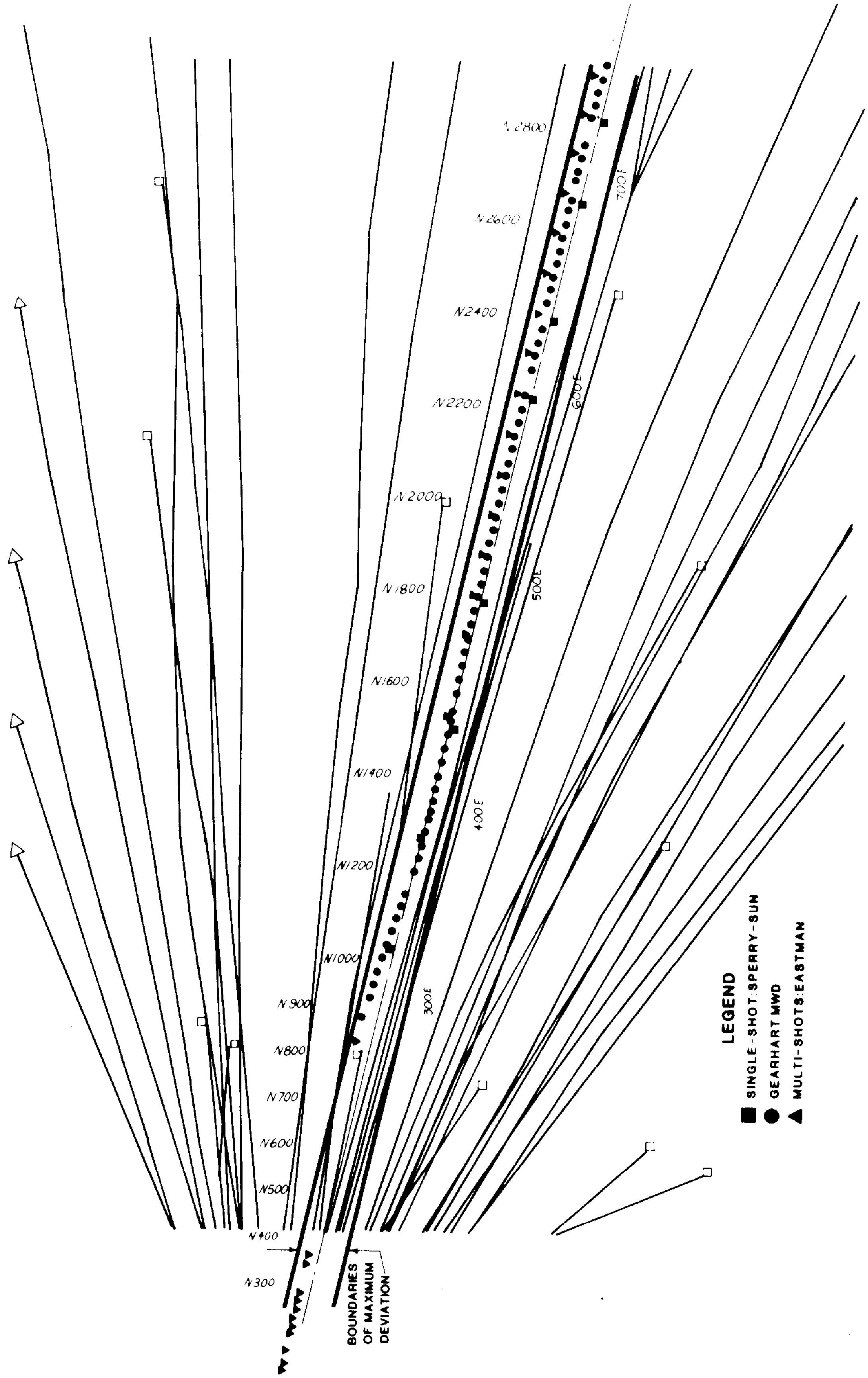

FIGURE 7—PLOT OF VARIOUS SURVEY RESULTS

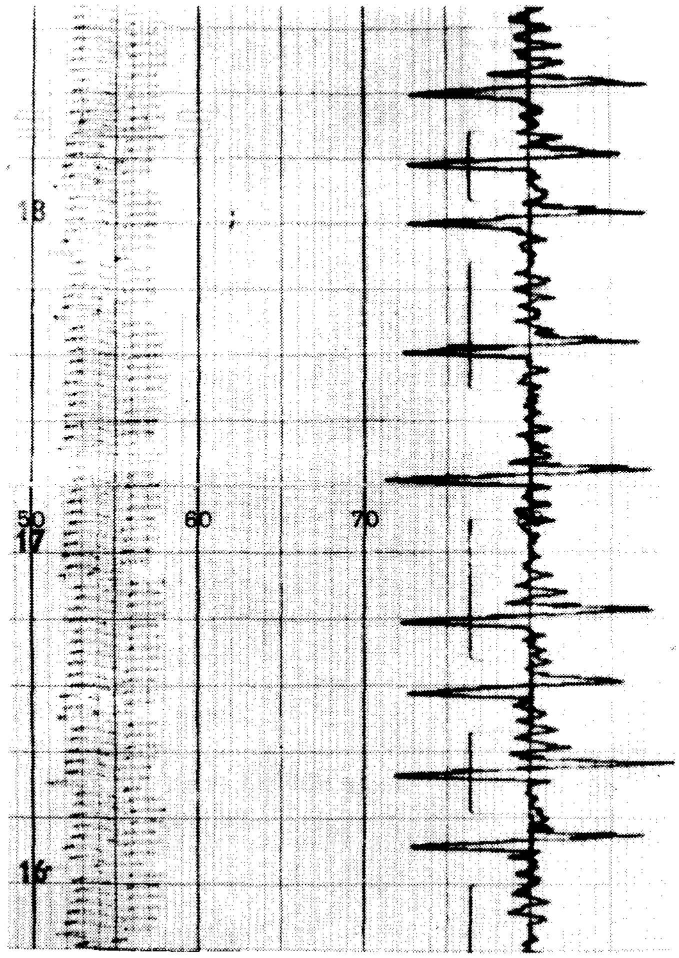

FIGURE 8—ANALOG RECORDING OF STANDPIPE PRESSURE

```
COMMAND ? DEP                                                        Run 6
   *** DEPTH:      3054 ***                                      Survey 42

COMMAND ?         PRT
  DEPTH   =          3054    PRESSURE =          186
     REF     =         .00          130.00        186
   TEMP     =       836.00          836.00        186
       X     =     1828.00         3304.00        186
       Y     =     1784.00         3288.00        186
       Z     =     3808.00         3814.00        186
       A     =     3134.00         1036.00        186
       B     =     2176.00         1000.00        186

COMMAND ?   COM,2
16:30.30  09-01-80
   DEPTH     AZI     INC     ROT     TEMP     PSI        EA      EB    EX    EY    EZ
    3054     12.3    70.9    222.5    26       186      -.639   .696  .433  .426  .731

COMMAND ? DEP
   *** DEPTH:     2054 ***
```

FIGURE 9—MINI-COMPUTER PRINT-OUT

MWD SURVEY

ELEC 3
MAG 42

X 5. 15. 2.
Y 3. 2. 8.
Z 7. 7. 1.
A 2. 14. 9.
B 8. 10. 15.
T 1. 10. 0.

TEMP 26.23
INC 71.07
AZI 12.66
ROT 329.65

R23= 0.7384
R24= -1.4211
R25= 1.9044
R26= -2.0928
R27= 3.7313

R17= 0.2815
R18= -0.5381
R19= 0.7310
R20= -0.4779
R21= -0.8163

FIGURE 10—HAND HELD COMPUTER PRINT-OUT

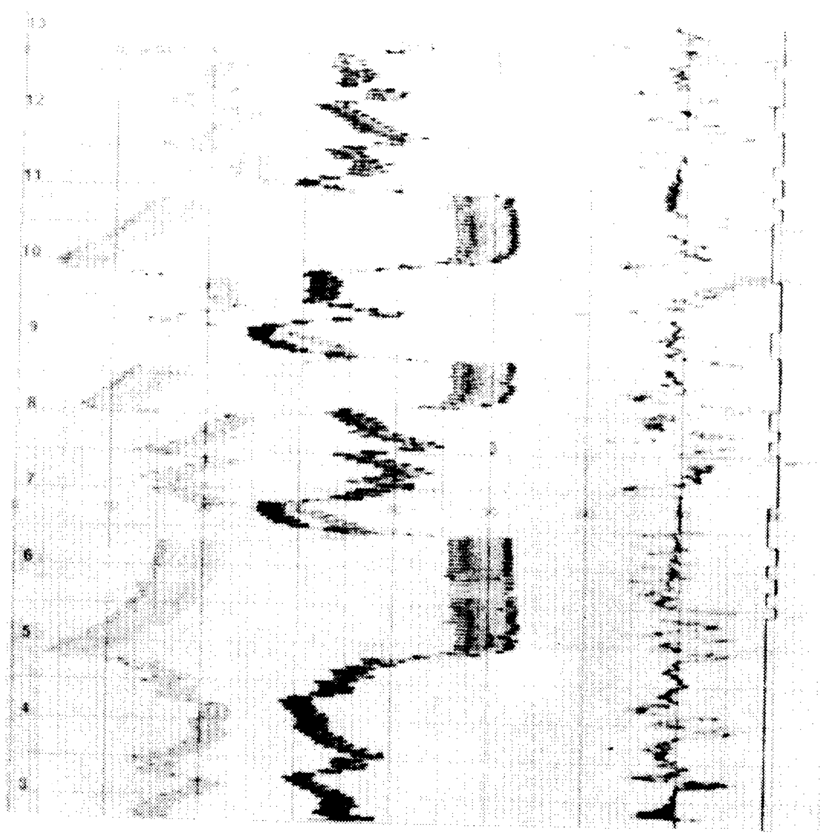

FIGURE 11—STANDPIPE PRESSURE RECORDING WITH DYNA DRILL

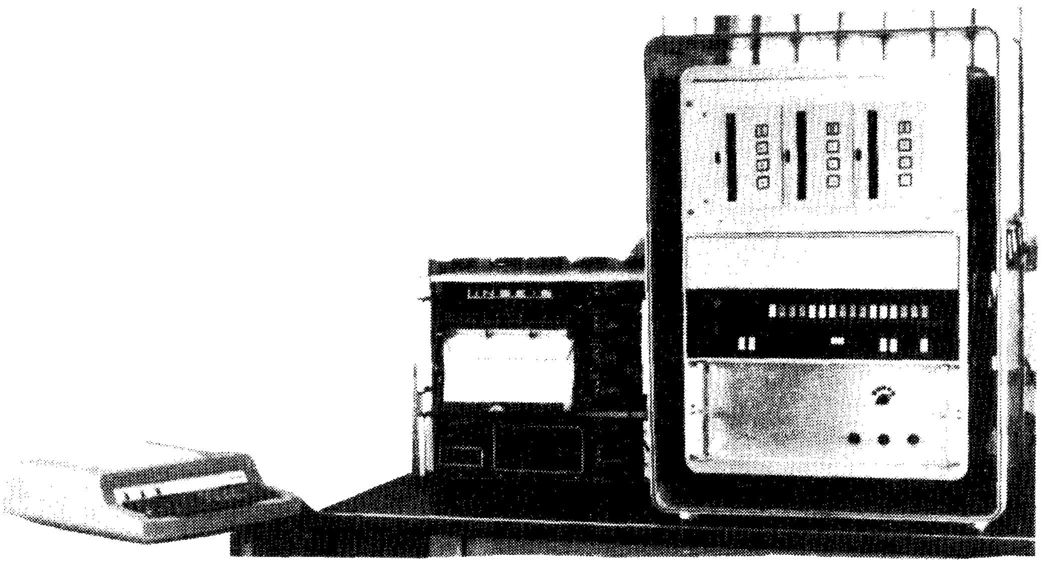

FIGURE 12—SURFACE INSTRUMENTATION

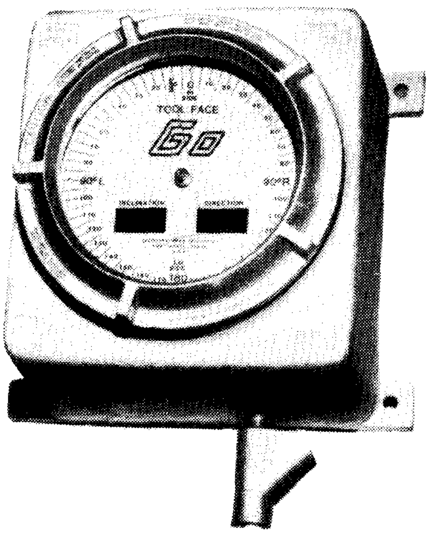

FIGURE 13—RIG FLOOR DISPLAY

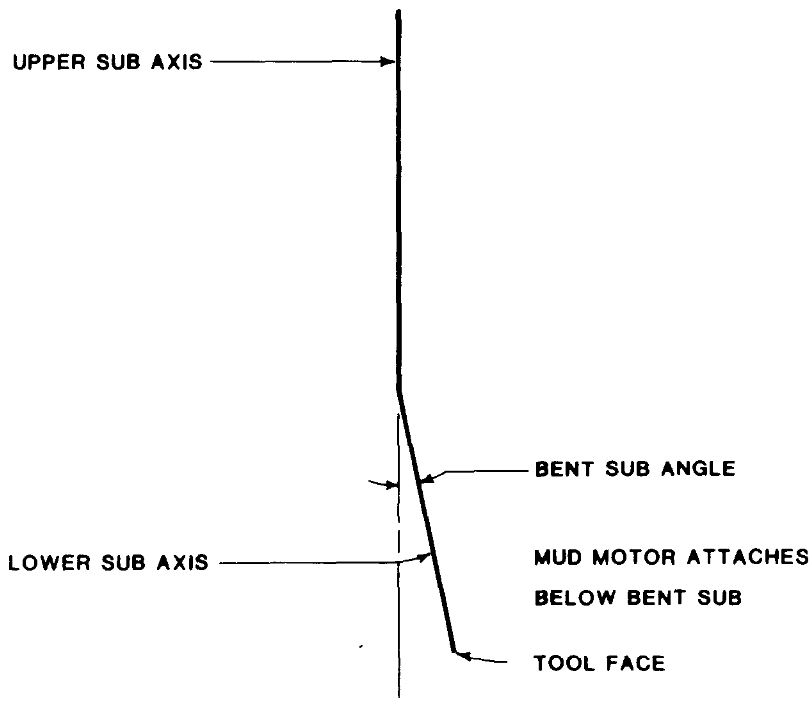

FIGURE 14—BENT SUB OPERATING PRINCIPLE