SOCIETY OF PETROLEUM ENGINEERS OF AIME
6200 North Central Expressway
Dallas, Texas 75206

161

PAPER NUMBER SPE 5182

A Resume of the Drilling Fluids Used on the World's Deepest Well

By

Wayne McFarland and Robert Meyer, Members SPE-AIME, IMCO Services

This paper was prepared for the Deep Drilling and Production Symposium of the Society of Petroleum Engineers of AIME, to be held in Amarillo, Texas, Sept. 8-10, 1974. Permission to copy is restricted to an abstract of not more than 300 words. Illustrations may not be copied. The abstract should contain conspicuous acknowledgment of where and by whom the paper is presented. Publication elsewhere after publication in the JOURNAL OF PETROLEUM TECHNOLOGY or the SOCIETY OF PETROLEUM ENGINEERS JOURNAL is usually granted upon request to the Editor of the appropriate journal provided agreement to give proper credit is made.

Discussion of this paper is invited. Three copies of any discussion should be sent to the Society of Petroleum Engineers office. Such discussion may be presented at the above meeting and, with the paper, my be considered for publication in one of the two SPE magazines.

INTRODUCTION

Lone Star Producing Company, Dallas, has set a new depth record, 31,441 feet, on their Bertha Rogers #1, near Burns Flat, Oklahoma. The old record, also held by Lone Star, is 30,050 feet, set on their #1 E. D. Baden in the same general area of Oklahoma.

Since these wells are the first ever to exceed 30,000 feet, they are the trend setters as the industry is forced to probe deeper for hydrocarbon deposits and/or geothermal energy. The knowledge and experience gained on these wells should prove invaluable in the planning of future deep tests.

This paper deals with one facit of the latest well, the drilling fluids. Included is a brief description of the geological characteristics that were expected in this well, a summary of the mud types and problems encountered while drilling, and some discussion of the auxiliary equipment and testing programs that are necessary for maintaining an optimum fluid at all times. It is hoped that from all this, the reader will gain some insight into the details concerned in handling a job of this magnitude, and possibly use this information as an aid for improvement in the future.

EXPECTED GEOLOGY

As is the case for most wells, the expected geological characteristics for the Rogers were determined from seismic data and offset well information in the same general area. Because of the depth, however, the bottom portion of the well could be classified as a rank wildcat, with the characteristics highly speculative.

The Burns Flat area of Oklahoma overlies part of the Southern flank of the Anadarko Basin. This flank is a steep, block faulted limb, paralleling the Amarillo-Wichita uplift (Fig. 1). The "Anticipated Geological Section" (Fig. 2) gives a better idea of the formations to be penetrated.

The primary target for this well was the Devonian dolomite (Hunton), which was non-commercial in the Baden test.

The sediments of the Anadarko basin are mainly carbonates with mixed layers of sand and shale. However, because of the intense folding, faulting, and uplifting that has taken place along the southern flank of this basin, massive sections of shale and some sand are predominant from about 12,500 feet to in excess of 23,000 feet.

Formation pressure is usually normal or subnormal and can be controlled with a less than 10 ppg fluid; however, the Pennsylvania age Atoka and Springer, are generally gas bearing and may contain excessive pressures. Mud weights exceeding 16 ppg are necessary to control sloughing shales and high pressure gas sands in these intervals.

The Mississippian Goddard can also be pressured if porosity and permeability is present. If this is the case, 13 ppg mud is usually sufficient to hold back the pressure.

As stated previously, the bottom part of the hole was highly speculative. It was anticipated, however, that the formations would be normally pressured, with formation temperatures in the range of 450 to 500°F.

DRILLING FLUIDS SUMMARY

Because of the variety of fluids used to drill the Rogers #1, the summary on drilling fluids will be divided according to pipe setting intervals (i.e. surface casing, intermediate casing, liner, and total depth).

Surface Casing Interval (0-4608')

Since the projected Total Depth of this well necessitated the use of 20 inch surface casing, the surface interval was drilled in two stages. A 17½ inch hole was drilled and logged, then opened to 26 inches to allow the 20 inch casing to be set and cemented to surface.

Upper parts of the Ponototoc (Brown Dolomite equivalent) are porous and are potential lost circulation zones. To eliminate trouble from these zones, in the event mud weight has to be raised, the setting depth for the surface pipe was about 100 feet below these zones, at 4,608 feet.

No mud problems were encountered in drilling this part of the hole. The basic drilling fluid was brine water weighing 8.8 to 9.6 ppg. The large hole diameter and low annular velocities required the addition of attapulgite and presheared asbestos fibers for improved carrying capacity. A funnel viscosity of approximately 35 sec/qt. was maintained. Two to five percent diesel oil was emulsified in the system for improved mud lubricity and hole conditions. Fluid loss was not controlled and lost circulation material was added only as needed. The pH of the system was maintained above 10.5 for corrosion protection, with oxygen scavengers added for further protection.

Intermediate Casing Interval (4,608'-14,205')

A 17½ inch hole was drilled below the 20 inch surface casing and 14 inch intermediate casing was set at 14,205 feet. A fractured, unconsolidated shale lies in the top of the Atoka. This shale is unable to withstand the possible 17 ppg mud weight which was anticipated for drilling the Springer. Therefore, the intermediate casing had to be set far enough into the Atoka to isolate this potentially severe lost circulation zone.

Since mud weights in the range of 12 ppg are sometimes required to drill into the top of the Atoka, it was recommended that the brine water system used to drill the surface interval be changed to a non-dispersed, extended bentonite-type fluid, prior to drilling out. It was felt that a fluid of this type would allow optimum penetration rates while drilling this interval, along with ease of weight up if necessary. Formation pressures were expected to be normal to the Atoka, with anticipated problems being lost circulation and some sloughing shale near the bottom of this interval.

Drilling was relatively uneventful down to 9600 feet. Mud weights were kept below 9.0 ppg and the funnel viscosity was maintained at 35 sec/qt. At 9600 feet, minor lost circulation was encountered and mica additions were begun on a daily basis. Traces of H_2S were picked up by the logging unit at around 10,400 feet. This necessitated the addition of H_2S scavengers. Zinc compounds were used. Diesel oil and emulsifier additions were initiated at 10,600 feet for lubricity. The oil content was maintained at approximately 3%. At around 12,100 feet, the mud weight was raised to 10.5 ppg prior to drilling into the Atoka. This resulted in 40 bbl/hr. mud seepage and the mud weight was cut back to 10.2 ppg. The concentration of mica in the mud was increased to 3 ppb, and the mud weight raised to 10.6 ppg with no problems. By 12,600 feet, the weight had been increased to 11.1 ppg, which resulted in severe mud seepage of 70 bbl/hr. The problem was corrected by cutting the weight back to 10.9 ppg, and increasing the mica content to 4 ppb.

Offset well information indicated that the mud weight would have to be in the range of 11.5 ppg as drilling progressed into the Atoka so the weight was gradually increased. At 12,900 feet, mud weight of 11.4 ppg resulted in complete lost circulation. In order to gain 100% returns, a pill containing large concentrations of lost circulation material was spotted on bottom and the mud weight was cut back to 10.7 ppg. It was now decided that no further increase in mud weight would be attempted unless hole conditions required it.

At 13,500 feet, lost circulation again occurred and the mud weight was further reduced to 10.3 ppg. Following this final reduction, no further problems were encountered and the 14 inch intermediate casing was set with 10.2 ppg mud. The anticipated pressures in the top of the Atoka were not encountered as evidenced by the absence of problems with sloughing shale or excessive gas in the mud. The API fluid loss of the mud used to drill this interval was maintained between 10 and 15 cc/30 min. with sodium polyacrylate. As in the surface interval, corrosion was closely monitored. Corrosion rings were run at all times, with a corrosion rate of 25 mils/year set as maximum. A minimum pH of 10.5 was maintained for corrosion protection, and the use of oxygen scavengers was continued.

In general, this interval was drilled with minimum mud problems, with the exception of lost circulation. Viscosity fluctuations became somewhat of a problem with the addition of zinc compounds for H_2S protection. The fluctuations were minimized by the addition of water and a reduction in the rate at which the material was added to the system.

Liner (14,205'-23,550')

A 12¼ inch hole was drilled below the 14 inch intermediate casing using the same non-dispersed mud as above. The mud weight was maintained at 10.2 ppg to drill the first 1500 feet under intermediate casing. Asphaltic material was added to the oil phase of the mud for sloughing shale. The oil content remained at 2 to 3%.

At around 15,600 feet, the background gas in the mud began to increase and the mud weight was increased to 10.6 ppg. Continual increases in background gas resulted in a mud weight of 12.5 ppg by 16,447 feet. At 16,700 feet, the hole fell in, shutting off circulation and sticking the pipe. The pipe was worked free and circulation established. At this point, the mud had to be circulated through the mud-gas separator to remove the large amount of entrained gas. The mud weight was raised to 13.8 ppg to control severe shale sloughing and gas influx into the well bore.

A small kick (60 bbls.) was taken at 17,100 feet. The well had to be put on the choke, requiring 15 ppg mud to kill it. Because of the large amount of gas in the mud, the weight was raised to 16.2 ppg and the mud was circulated continuously through the mud-gas separator while drilling. By 17,300 feet, the mud weight was up to 16.6 ppg and the 10 min. gel strength of the mud was becoming excessive. Small additions of lignosulfonate were initiated to remedy this situation.

A continuing increase in the amount of gas in the mud necessitated the use of a rotating head. Since the gas was high pressure-low volume, the rotating head allowed the well to be drilled under balanced, with the mud being circulated through the mud-gas separator. Trip gas had to be circulated out through the choke. Formation pressures, as shown by "dc" exponent and "E-logs" were equivalent to 16.8 to 17.0 ppg.

By 17,600 feet, the mud weight was 16.9 ppg which reduced the gas in the mud to a level where it was no longer necessary to circulate through the separator. Minor lost circulation (180 bbls.) was encountered at 17,650 feet. A reduction in mud weight to 16.7 ppg and mica additions corrected the problem.

Drag on connections began increasing. It was decided to lower the high temperature fluid loss below 20 cc/30 mins. to improve hole stability without raising mud weight. Because of this, the non-dispersed system was discontinued and additions of lignite, lignosulfonate, and bentonite were initiated at around 17,900 feet. Mud weight was maintained at 16.7 ppg and it was still necessary to circulate out trip gas through the choke.

Prior to drilling into the Springer (19,100 feet), the formations were tested to an equivalent mud weight of 17.2 ppg. No problems were encountered and the mud weight was increased to 16.9 ppg. By 19,300 feet, the mud weight was up to 17.1 ppg, resulting in complete lost circulation (2744 bbls.). A 15 ppg pill containing a large concentration of mica, ground walnut shells, and fiber material was spotted on bottom and the mud weight reduced to 16.9 ppg. Returns were established and drilling continued.

Drag on connections continued to be a problem and a large amount of cavings were observed coming across the shaker. Fill on bottom after trips became excessive. For this reason, the mud weight was once again increased. By 19,800 feet, the mud weight reached 17.3 ppg and complete returns were lost again (1905 bbls.). A 16.8 ppg pill, similar to the one tried previously, was spotted on bottom and the mud weight reduced to 16.5 ppg. Full returns were established. At this time, it was decided to raise the oil content of the mud to between 8 and 10% in an effort to minimize the drag on connections. Background gas remained low but excessive drag on connections continued.

By 20,100 feet, the mud weight was back to 17.0 ppg with no problems. At around 21,600 feet, it became necessary to use the centrifuge on the active system to control the fine solids in the mud. No further problems were encountered to liner setting depth. The top of the Mississippian Goddard came in at approximately 23,000 feet and the 9 5/8 inch liner was set some 500 feet into the top of the Goddard at 23,550 feet with 17.0 ppg mud.

Open Hole Interval (23,550'-31,441')

After hanging the 9 5/8 inch liner to 23,550 feet and testing the liner top, excess cement was drilled from inside casing, with the 17.0 ppg lignosulfonate mud which had been cut back to 16.2 ppg. It was determined that the Goddard was normally pressured and the weighted lignosulfonate mud was stage displaced from the hole with field NaCl brinewater weighing 10.0-10.2 ppg. Stage displacement was necessary to compensate for the 7000+ psi pressure differential at total depth between the two fluids. Displacement was accomplished using the rig slush pumps.

After displacing with brinewater, a 7 7/8 inch hole was drilled from the casing shoe to total depth of 31,441 feet. Presheared asbestos fibers were added while drilling ahead to give additional lifting capacity to the mud. Problems with drag and hole fill indicated that funnel viscosity was not a significant guideline for hole cleaning ability. Instead, emphasis was placed on keeping a sufficiently high yield point to overcome cuttings slip velocity inside the 14 inch intermediate casing. This seemed to be an accurate procedure due to the occurrence of hole fill on connections and trips wherever yield points below the calculated critical valve were used to drill segments of the open hole interval.

Drilling continued with no appreciable problems through the Mississippian using the NaCl brine/asbestos fiber drilling fluid. Solids control procedures were stressed through this interval to aid in maintaining a low solids drilling fluid. Mud solids (excluding solids contributed by brinewater) ranged from 2-4% by volume. Penetration rates achieved through usage of this fluid were exceptionally good. The major mud problem experienced resulted from precipitation of insoluble salts from the field brine due to carrying pH above 11.5 for protection against drill string corrosion. These precipitated salts caused an increase in the amount of fines in the mud, resulting in excessive viscosities. This was partially solved by utilizing a settling pit for pretreatment of brinewater with Caustic Soda.

Prior to drilling the Devonian (Hunton) it was decided to start adding a polyanionic cellulosic polymer to the mud to give filtration control in the range of 15-20 ml/30 min. In conjunction with the polymer, a dispersant was added to improve the mud's resistance to thermal degradation.

Consistometer testing of the drilling fluid became increasingly important after addition of the above products to the base fluid. Daily mud treatments were based on the need to maintain at all times a fluid capable of cleaning the hole, yet stable under the extreme down hole conditions of temperature and pressure being experienced.

On the Baden #1, drilled by Lone Star, temperature gelation of the drilling fluid resulted in a fishing job. To prevent this from occurring on the Rogers #1, it was decided that consistometer testing of the drilling mud would be done on a daily basis. Tests were run at temperatures and pressures ranging from ambient to 500°F and 20,000 psi. As a result, the mud was treated to remain stable at maximum conditions on the consistometer. Consequently, no evidence of extreme thermal degradation was reflected in the mud although bottom hole static temperature reached an estimated 450°F.

The Hunton and subsequent formations were drilled to total depth with the base fluid described above. Asphaltic oil was added to the mud to maintain an oil content of 4-6% by volume to impart mud lubricity. H_2S scavengers were added prior to topping the Ellenburger (Arbuckle). Continued emphasis was placed on keeping a thermally stable fluid capable of effectively cleaning the hole. Additional testing was done periodically to test thermal stability of the base mud weighted with barite to mud weights above 14.0 ppg.

Penetration rate and general hole conditions remained excellent throughout the drilling of this interval while utilizing this fluid. The mud remained static in the hole for long periods of time due to logging operations and one fishing job caused by drill pipe failure. Bottoms-up mud after these operations was quite fluid, showing little effect of temperature and pressure.

CONCLUSION

Basically, the drilling fluids used to drill this well would have to be classified as conventional. The large volume in the active system (4300 bbls. average) created some problem, which necessitated careful planning as to the uses of special equipment and testing procedures to economically handle the system.

Because of the age and hardness of the formation, the penetration rates were usually low, making solids control easy. The rig was equipped with tandum high angle shakers with 40 and 80 mesh screens, an eight cone desander and a 12 cone desilter. This combination proved very efficient, until near the bottom of the liner interval. After the mud had been dispersed, it was necessary to use a centrifuge to control the amount of fine solids in the mud.

The presence of pressured shales in the Atoka and Springer made a degasser and mud-gas separator necessary. Since these shales are usually high pressure-low volume, they could be drilled under balanced, using a rotating head and circulating the mud through the mud-gas separator to remove the large amount of entrained gas. This allowed less mud weight to be used, resulting in a savings in a barite and an increase in penetration rate.

An additional savings in barite was obtained by using an automatic mud mixer. This particular equipment monitors the flowline and suction pit mud weights and automatically adds barite when necessary to maintain a preset mud weight. This has the advantage of adding barite evenly throughout the system, thus suppressing high and low spots common to manual additions.

Because of this, minimum problems were encountered in maintaining mud weight or in raising the mud weight when it became necessary for holding back pressure.

A detailed testing program was extremely important for maintaining an optimum fluid. The program centered around the daily checks done by the service representative, but was supplemented by the addition of a mud testing trailer on location. The trailer included complete pilot testing facilities, along with an oven for aging bombs and a Fann consistometer. The primary function of the trailer was to monitor the effect of temperature and pressure on the mud and to run pilot tests to see what materials would be necessary to maintain or improve the stability of the mud system. The object was to stay several hundred feet ahead of the mud at all times. This information proved extremely valuable in the bottom part of the hole, where the bottom hole temperature approached 450°F. By maintaining a stable mud in the consistometer, the mud remained stable in the hole. Additional samples were sent to research facilities on a periodic basis, for even further testing.

Corrosion was of prime concern and was closely monitored. Oxygen and H_2S scavengers were maintained in the mud in the upper intervals and again while drilling below the liner. Some problems with cracked pins and boxes were encountered in the upper intervals but were eliminated by addition of sulfide scavengers.

Corrosion rings were run in the drill pipe and an oxygen meter was used. As long as the pH of the mud was maintained above 10.5, corrosion rates were minimized and no other corrosion inhibitors were necessary.

The experience gained on this well takes some of the mystery out of drilling super deep wells. The technology and fluids of today have advanced to the point where a 35,000 foot well is attainable.

REFERENCES

1. Russell, William L.: "Structural Geology for Petroleum Geologists," McGraw-Hill Book Co., Inc. (1955) Page 282-283.

2. "Principles of Drilling Fluid Control," Petroleum Extension Service, University of Texas at Austin, Twelfth Edition, Pages 136-137.

3. Kennedy, John L.: "Lone Star's Deep Hunton Test Headed for 29,000 feet," Oil and Gas Journal, May 28, 1973.

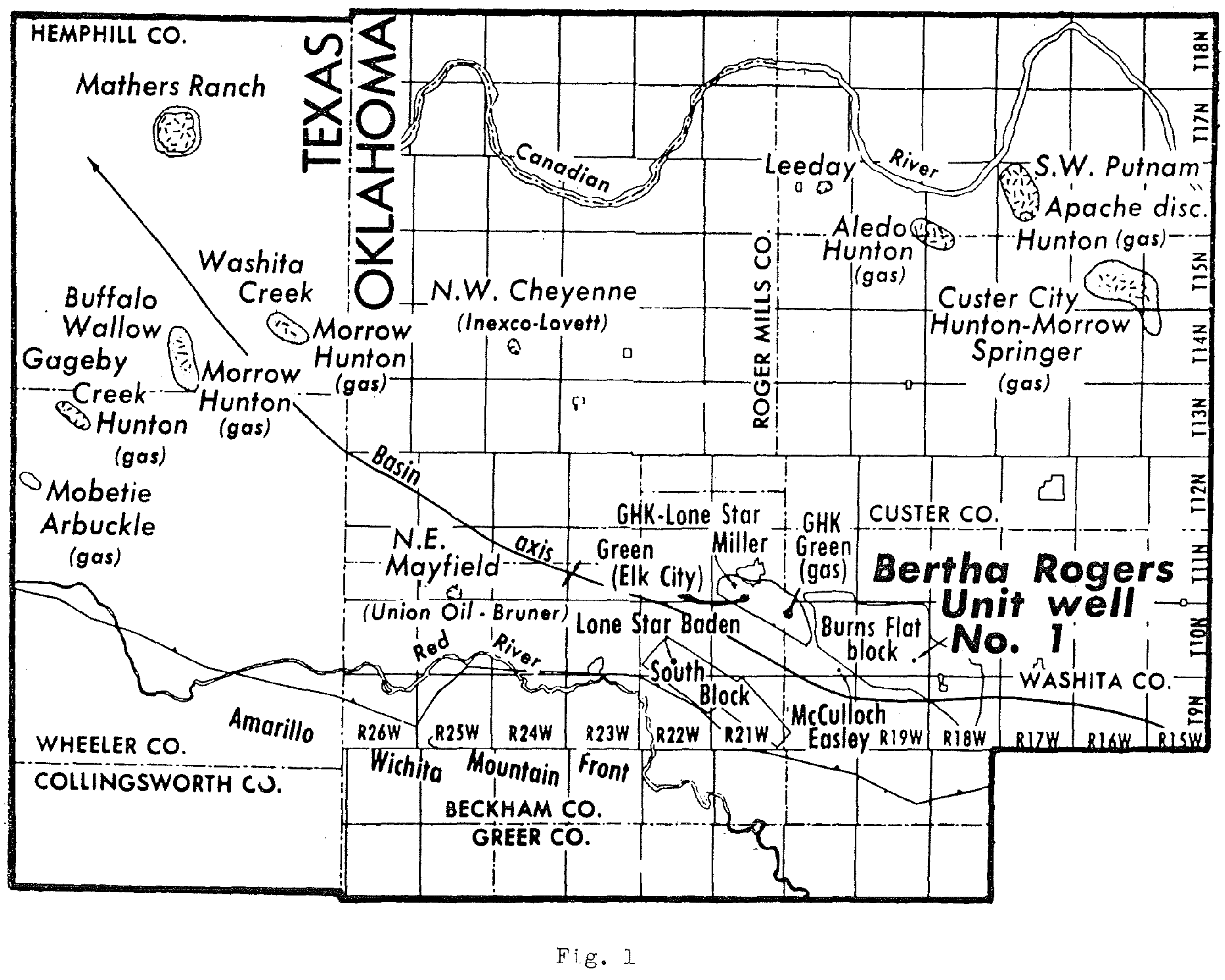

Fig. 1

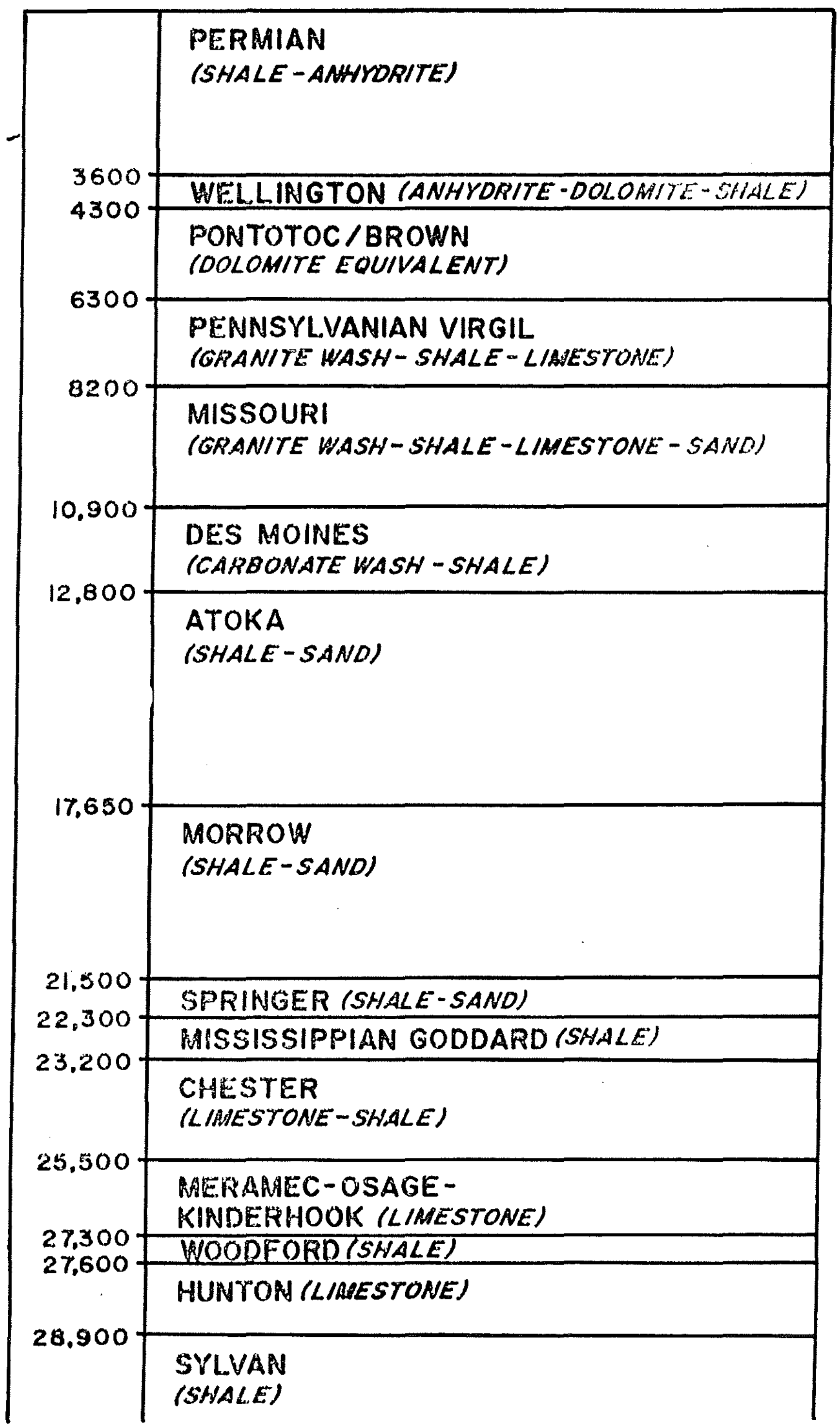

Fig. 2 - Geological section.

168

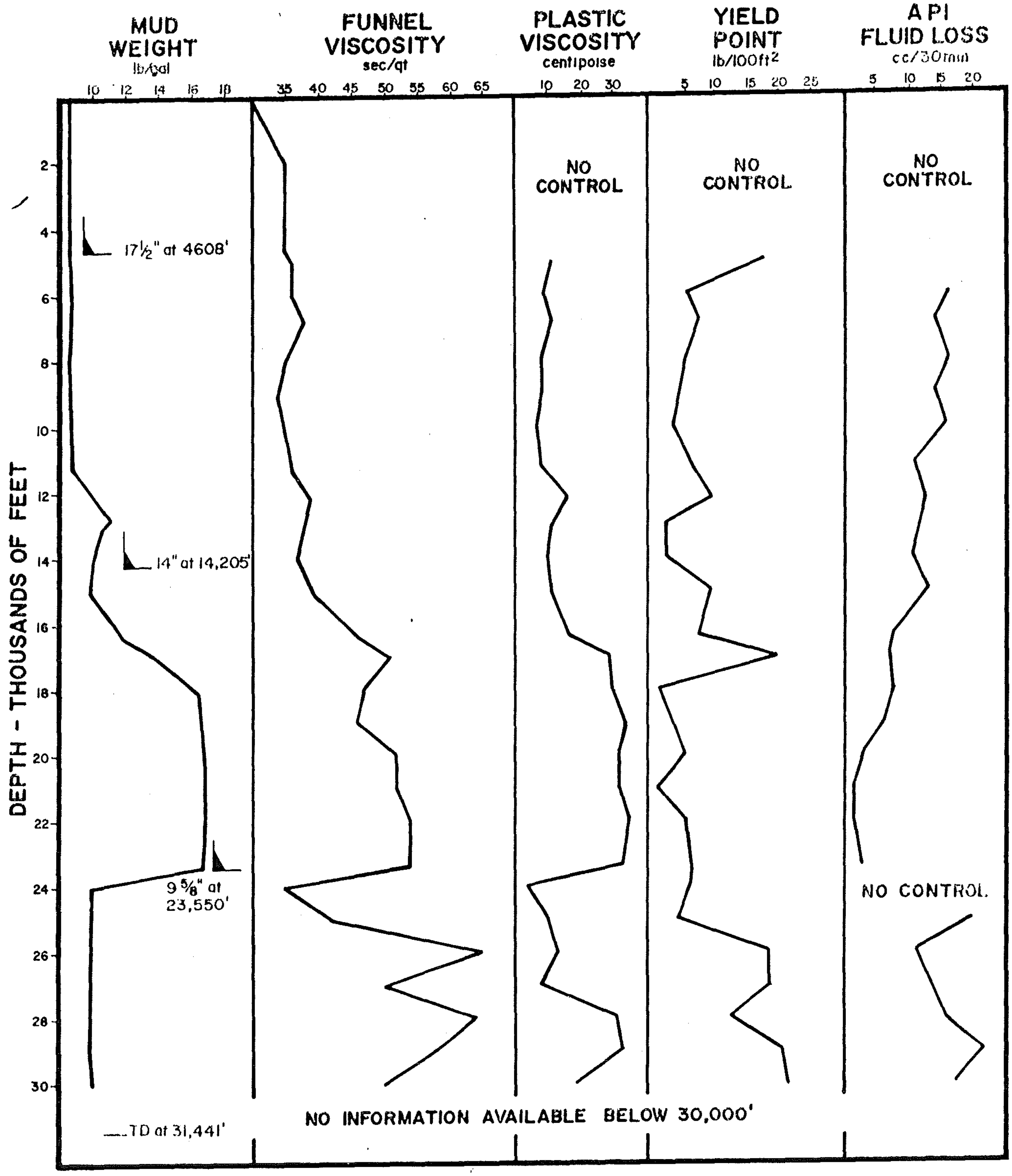

Fig. 3 - Average mud properties.