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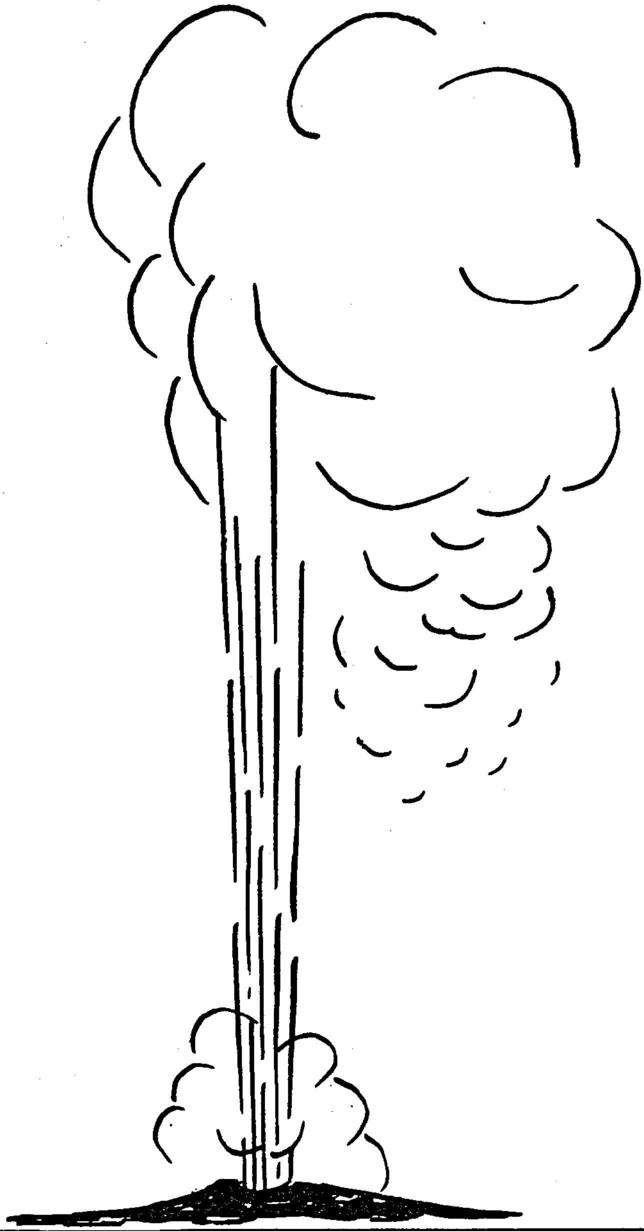

ECONOMIC INCENTIVES FOR IMPROVED GEOTHERMAL DRILLING MOTORS

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I ECONOMIC INCENTIVES FOR IMPROVED GEOTHERMAL DRILLING MOTORS

Improved drilling motors could produce significant cost reductions in geothermal drilling because of severe problems encountered in geothermal drilling including the following:

1. High rock strengths
2. High temperatures
3. Abnormally low formation pressures (hard rock areas)
4. Abnormally high formation pressures (geopressured areas)
5. Fractured formations
6. Lost circulation problems
7. Low drilling rates
8. Low bit footage
9. Severe drillstring corrosion.

Because of the hardness of the rocks and high temperature problems, the cost of drilling geothermal wells is 2 to 3 times higher than the cost of drilling comparable oil and gas wells. The cost of these geothermal wells must be significantly reduced before geothermal energy can be fully exploited. Faster drilling rates are needed to allow the development of geothermal resources with the rigs currently available. Essentially all available land drilling rigs in the United States are currently being used and few rigs are available for geothermal drilling. It will take 3 to 5 years to significantly increase the number of drilling rigs so it is important that methods be developed to allow available rigs to drill faster.

Reliable high temperature drilling motors could reduce geothermal drilling costs in the following ways:

1. Faster drilling
2. Increased bit footage
3. Improved dractured rock drilling
4. Improved directional drilling
5. Reduced hole deviation
6. Reduced blowouts
7. Reduced casing wear
8. Reduced keyseating
9. Reduced twistoffs
10. Improved milling operations
11. Improved sidetracking
12. Improved slim hole drilling
13. Reduced mud problems
14. Reduced lost circulation
15. Reduced drillstring corrosion
16. Reduced drillstring vibrations
17. Improved data telemetry
18. Reduced drillstring fatigure failures

Faster Drilling

Drilling rates are very low in most geothermal wells because of the hardness of the igneous and metamorphic rocks being drilled. Figure 1 shows that the drilling rates in granite are only 2 to 10 feet per hour compared to 50 to 100 in many sedimentary rocks.

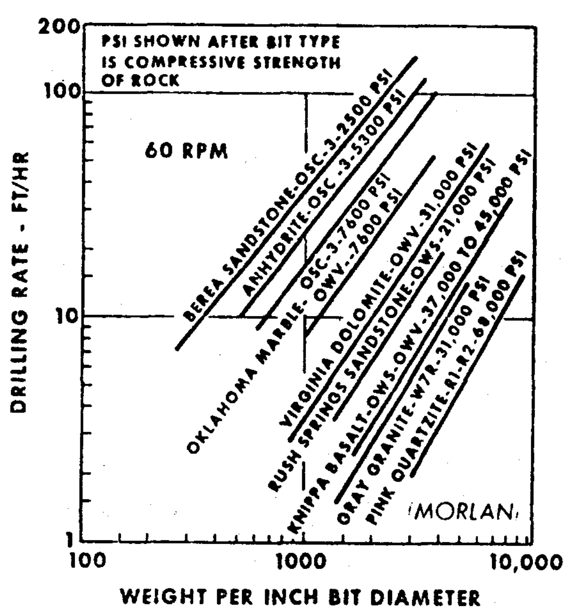

Figure 1 - Roller Bit Drilling Rates In Different Rocks.

If excessive bit weights are used, the bearings and inserts in the bits rapidly fail resulting in low bit footages and high drilling costs.

Drilling rates can be increased by using drilling motors to rotate the bits at higher speeds, as shown in Figure 2. In this case, a drilling rate of 20 feet per hour can be obtained at a bit weight of 15,000 pounds and a rotary speed of 50 rpm or at a bit weight of 10,000 pounds and a rotary speed of 200 rpm. The lower bit weight would result in longer bit life, especially with the new COMPAX bits being developed.

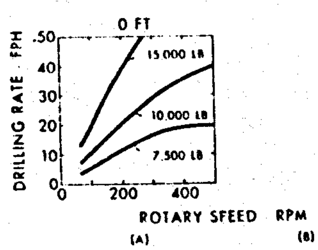

Figure 2 - Effect of Rotary Speed on Penetration Rate. (Maurer, 1962)

In hard rocks such as granite, the rotary speed is often limited to speeds of 50 to 75 rpm because of severe wearing of the drillpipe and because of the danger of twisting the drill-pipe in two if the reamers or bit stick in the hole. Under these conditions, the use of a downhole motor allows higher rotary speeds and higher drilling rates.

Increase Bit Footage

Sandia and many bit companies are developing COMPAX diamond bits as shown in Figure 3. These bits have potential for drilling much faster and much further than conventional diamond and roller bits. Tests to date indicate that these COMPAX bits operate most effectively at higher rotary speeds (200 to 400 rpm); therefore, downhole motors will be required for optimum operation of these bits.

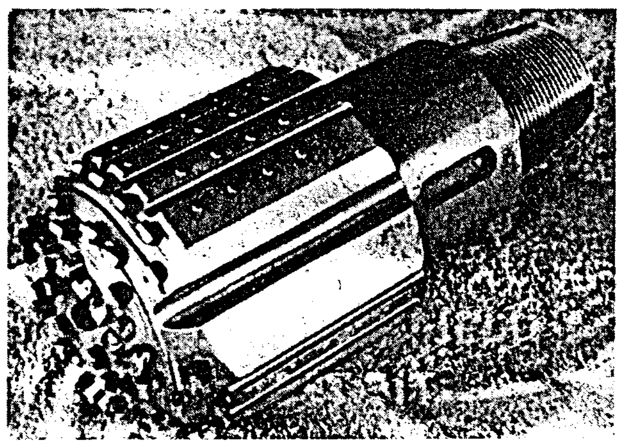

Figure 3 - G. E. COMPAX Bit. (Eaton, 1975)

Improve Drilling of Fractured Rock

Diamond bits cannot be used effectively in fractured rocks because of the deep diamond penetration required at low speeds (50 to 100 rpm). This results in excessive diamond breakage because of the high impact loads. Downhole motors will allow higher rotary speeds and thereby reduce the diamond penetration and diamond breakage as shown in Figure 4.

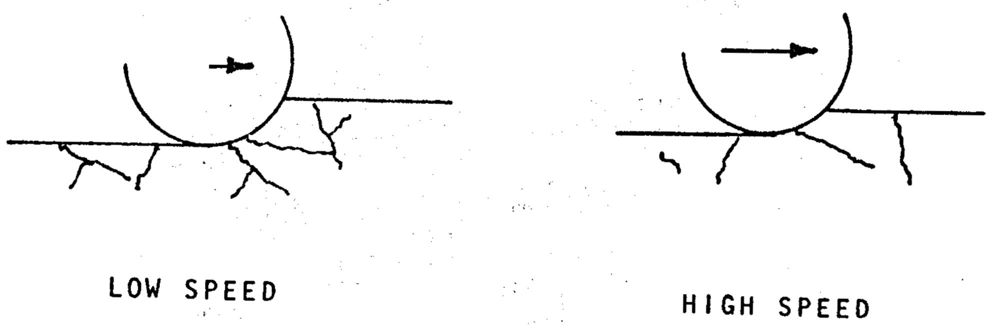

Figure 4 - Downhole Motors Allow Higher Speeds and Lower Diamond Penetration.

Improved Directional Drilling

Directional drilling is a key element in developing dry rock geothermal reservoirs. In this case, one of the holes is deviated to intersect the fracture pattern around the second hole so that cold water can be circulated down one well and up the second (Figure 5). No existing drilling motor can operate at temperatures above 200°C, so the development of these reservoirs will be very expensive unless improved motors are developed.

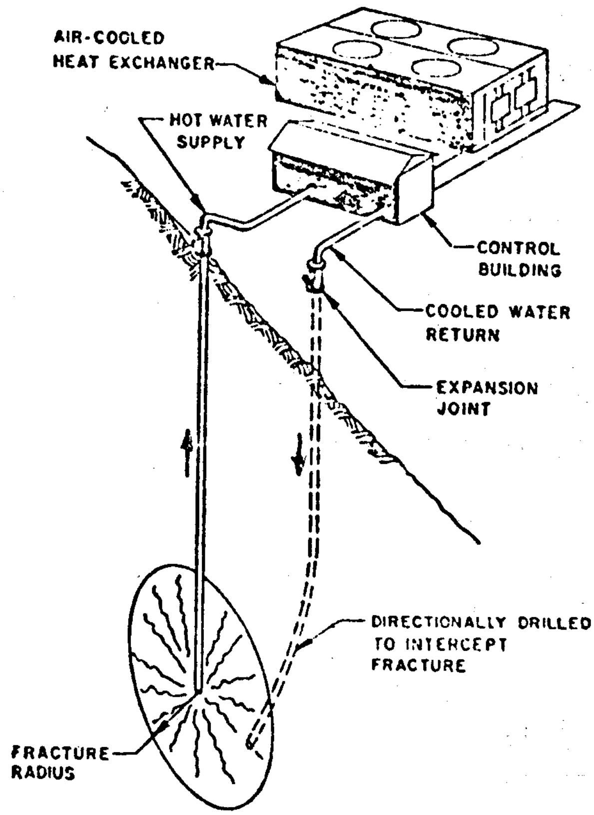

Figure 5 - Hot Dry Rock Geothermal System. (Blair, 1976)

In this case the hole is deviated by using a motor on a bent sub as shown in Figure 6.

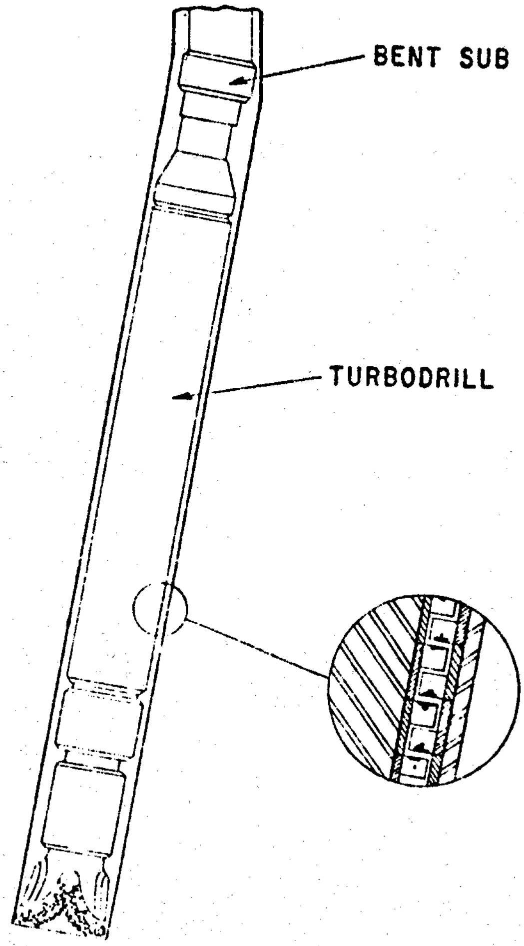

Figure 6 - Directional Control with Downhole Motor.

Reduced Hole Deviation

Hole deviation is a serious problem in many geothermal areas, especially in mountainous regions where the geology is complicated due to the high tectonic forces. Bits deviate more at high bit weights because of the deffection of the drill collars as shown in Figure 7. Consequently, it is often necessary to drill at reduced bit weights in these areas. The reduced bit weight reduces drilling rate and increases drilling costs.

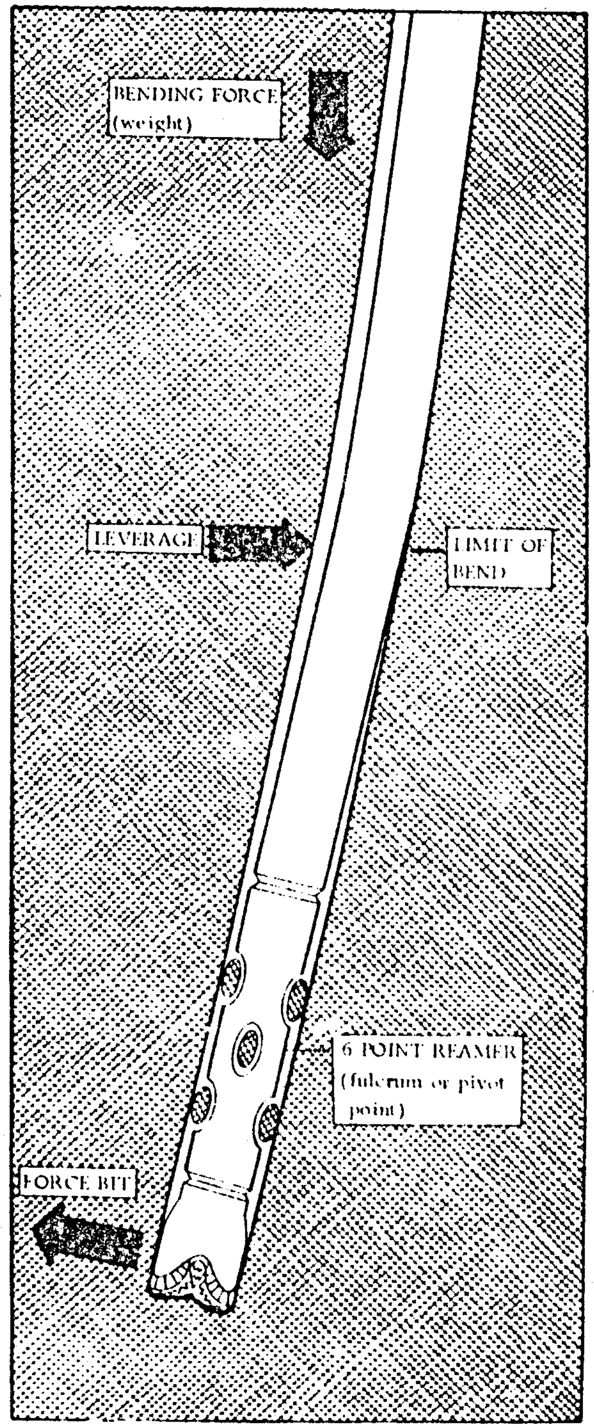

Figure 7 - Forces Tending To Deviate Bit.

Downhole drilling motors are useful in drilling in crooked hole country because they can drill at high rates with low bit weights because of their higher rotary speeds. This is illustrated in Figure 8 where drilling rate of 20 feet per hour is requiring a bit weight of 20,000 pounds at 50 rpm and 8,000 pounds at 200 rpm. A downhole motor could operate the bit at this higher speed and thereby reduce the hole deviation because of the lower bit weight.

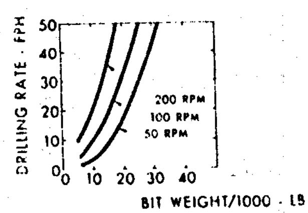

Figure 8 - Effect of Bit Weight on Drilling Rate. (Maurer, 1962)

Reduce Blowout

Blowouts occur when the pressure of the formation fluids exceeds the pressure of the column of fluid in the wellbore and the formation fluids flow into the wellbore in an uncontrolled manner. Figure 9 shows the normal situation where the hydrostatic pressure exerted by the drilling fluid exceeds the formation pressure. If the formation pressure increases and exceeds the mud pressure, an impending blowout condition will occur.

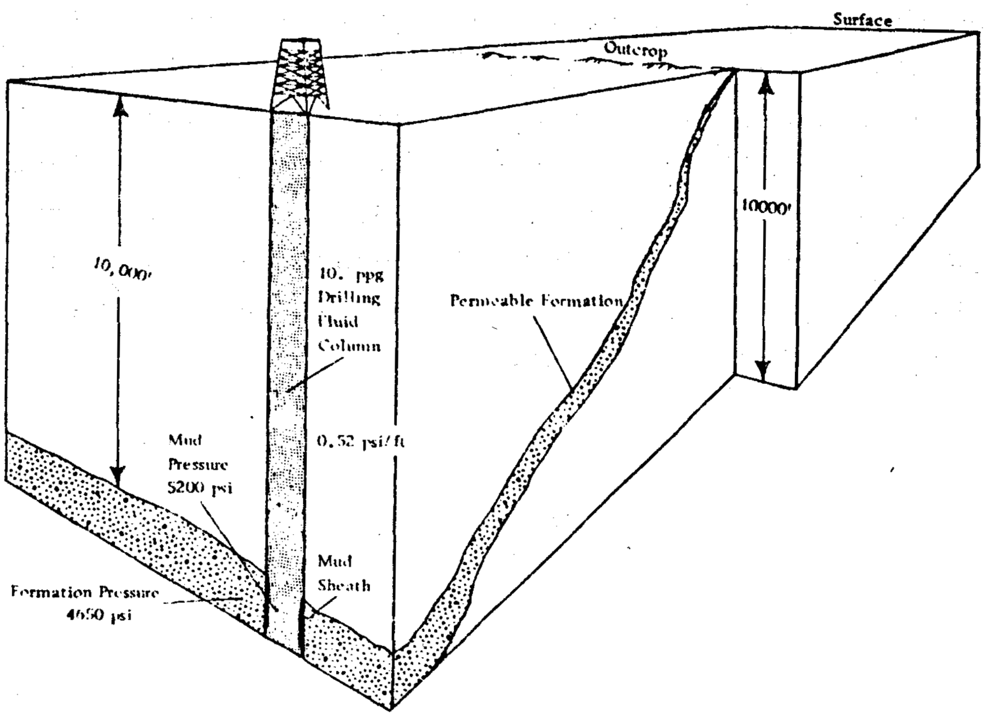

Figure 9 - Fluid Pressures During Normal Drilling Operations.

Blowouts are prevented by closing the blowout preventers at the surface and circulating heavier drilling fluid to control the formation fluids. This is often difficult in geothermal wells because of low water tables and because of lost circulation problems in fractured rocks.

The development of reliable drilling motors could allow increased use of downhole blowout preventers which will contain the formation fluids at the hole bottom while allowing circulation of heavier fluids (Figure 10). This could be an important improvement in geothermal drilling in many areas.

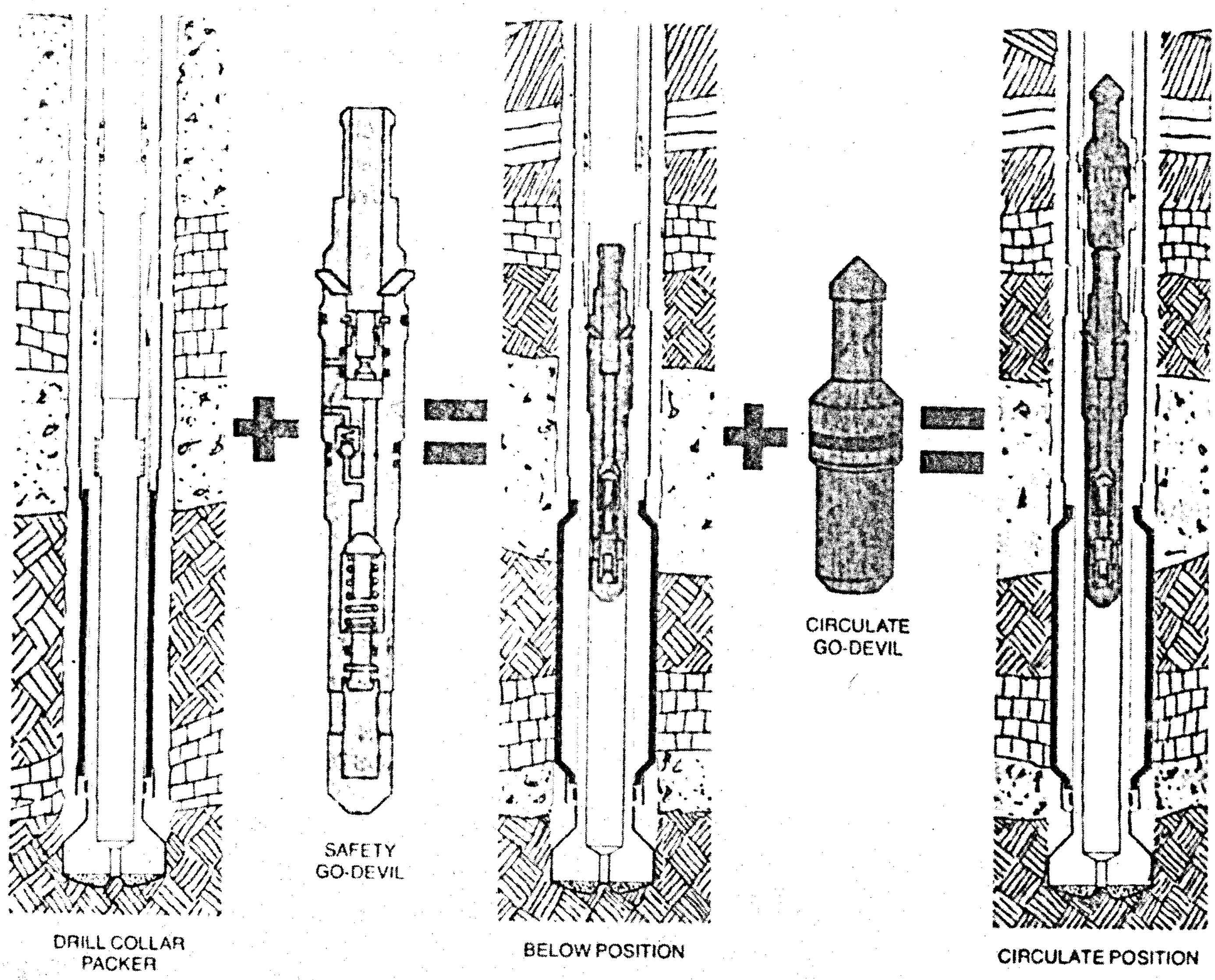

Figure 10 - Downhole Blowout Preventer.

Reduce Casing Wear

In highly deviated wells, the rotating drillstring often cuts through the casing and causes blowouts (Figure 11). This is a severe problem because the drillpipe tooljoints are often coated with tungsten carbide chips to reduce wear of these joints (Figure 12). These carbide chips act as cutting elements and rapidly cut through casing.

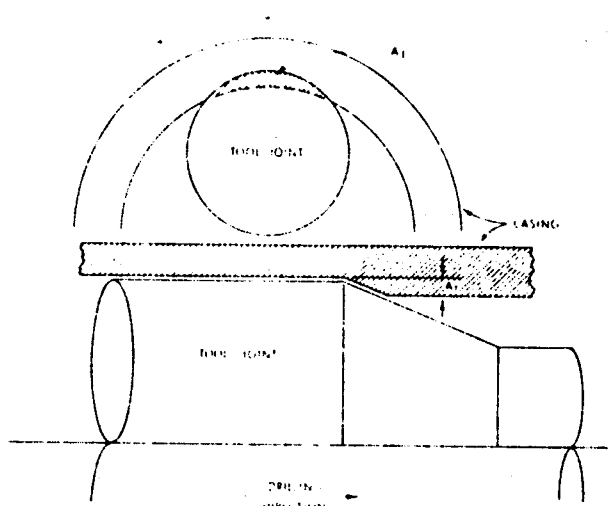

Figure 11 - Casing Wear In Highly Deviated Wells. (Bradley, 1975)

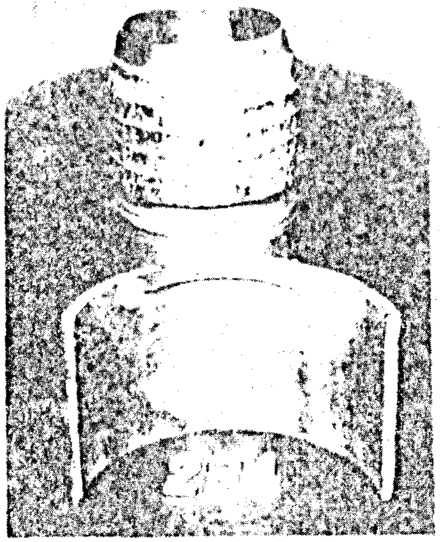

Figure 12 - Hardmetal On Tooljoints. (True, 1975)

Some of the major oil companies have banned the use of these hardmetal coatings on tooljoints because of this problem. This often results in excessive wear of the tooljoints and increased drilling costs. This would be especially true in geothermal wells because of the abrasive nature of most igneous and metamorphic rocks.

Reduced Keyseating

When high bit weights are used, doglegs often result due to the rapid changes in hole direction. As drilling progresses, the drillpipe wears a slot or "keyseat" in one side of the dogleg as shown in Figure 13. When the drillpipe is tripped out of the hole, the larger diameter tooljoints cannot be pulled through the keyseat and the pipe becomes stuck or it is pulled in two.

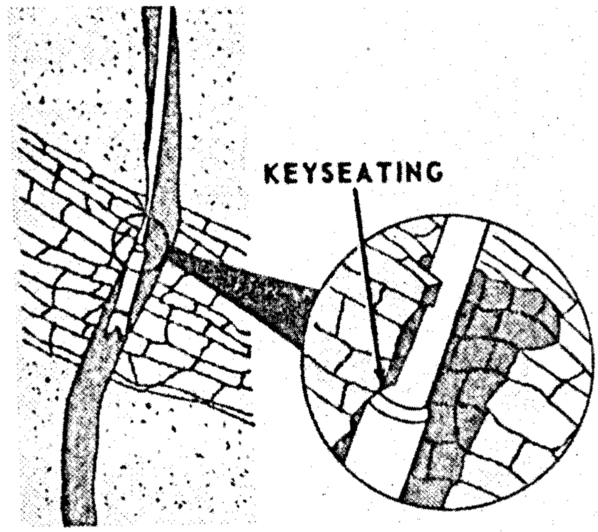

Figure 13 - Keyseating

Downhole motors allow fast drilling with high rotary speeds and low bit weights, thereby reducing the formation of doglegs. In addition, the motor eliminates the need for rotating the drillpipe and which eliminates the formation of the keyseats.

Reduced Twistoffs

Twistoffs are common in granite drilling because the stabilizers and reamers grab the hole walls with sufficient force to twist the drillpipe in two (Figure 14). Downhole motors eliminates the need for rotating the drillpipe and thereby eliminate these twistoffs. When motors are used, the drillpipe is rotated at low speed (15 to 20 rpm) to prevent differential pressure sticking of the drillpipe against the side of the hole. These low speeds greatly reduce the chance of twisting the drilling string in two.

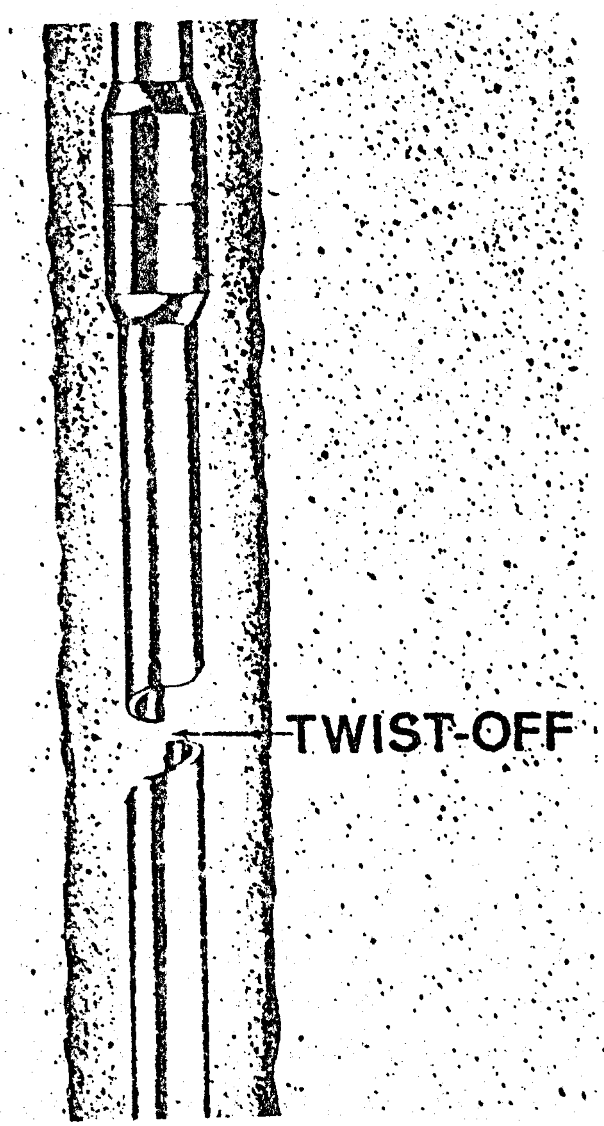

Figure 14 - Drillpipe Twistoff.

Improved Milling Operations

It is often necessary to grind up bit cones, drillpipe or other junk left in the hole using a junk mill as shown in Figure 15.

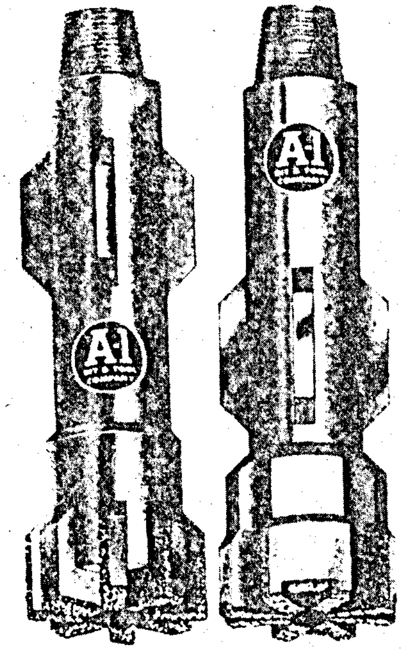

Figure 3
Regular Junk Mill

Figure 4
Heavy-Duty
Junk Mill

Figure 15 - Junk Mills.

This is often a time-consuming operation requiring weeks or even months if drill collars have to be milled. The milling rate is a direct function of the rotary speed of the milling tool. Experience has shown that milling rates using turbodrills or other downhole motors (400 to 1000 rpm) are often 5 to 10 times faster than conventional milling rates (50 to 100 rpm). The lack of motors could result in needless sidetracking or abandonment of many geothermal wells in the future.

Improved Sidetracking

When junk left in the hole connot be fished or milled, it is necessary to "sidetrack" the hole above the fish and to drill a new hole. If high temperature drilling motors are available, this will be a relatively easy job as shown in Figure 16.

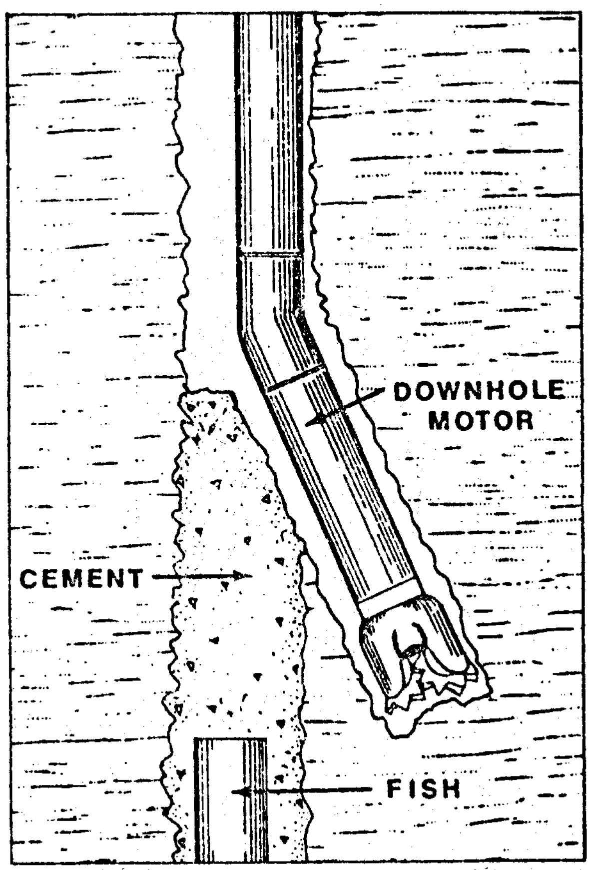

Figure 16 - Sidetracking with Downhole Motor.

If high temperature downhole motors are not available, it will be necessary to use a Whipstock as shown in Figure 17. Whipstocks are time consuming and difficult to use and they do not allow the drilling of a gage hole. Consequently, it is necessary to ream out the sidetracked hole before drilling can be resumed. Whipstocks are difficult to use in hard rocks such as granite and basalt and it is therefore likely that many geothermal wells will have to abandoned when fish are left in the hole unless reliable high temperature motors are developed.

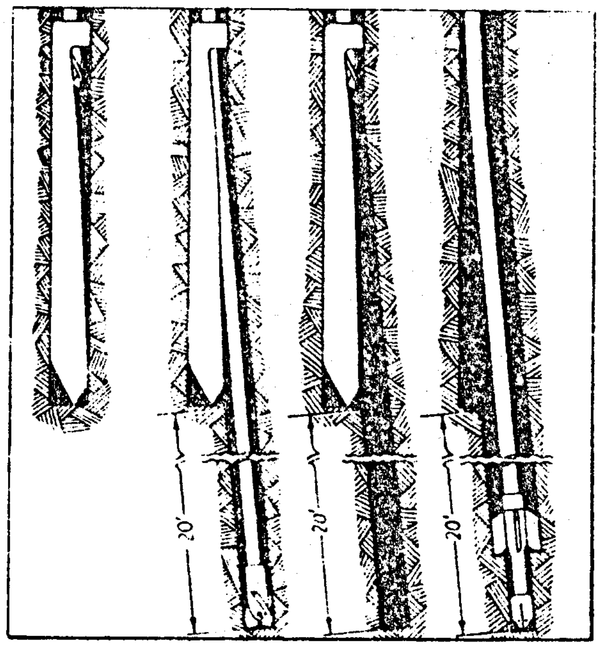

Figure 17 - Deviating A Hole with a Whipstock.

Oil and gas wells are sometimes sidetracked by use of a jet bit as shown in Figure 18. This technique cannot be used in geothermal wells because the rock is too hard to cut with the pump pressures available (2000 to 3000 psi).

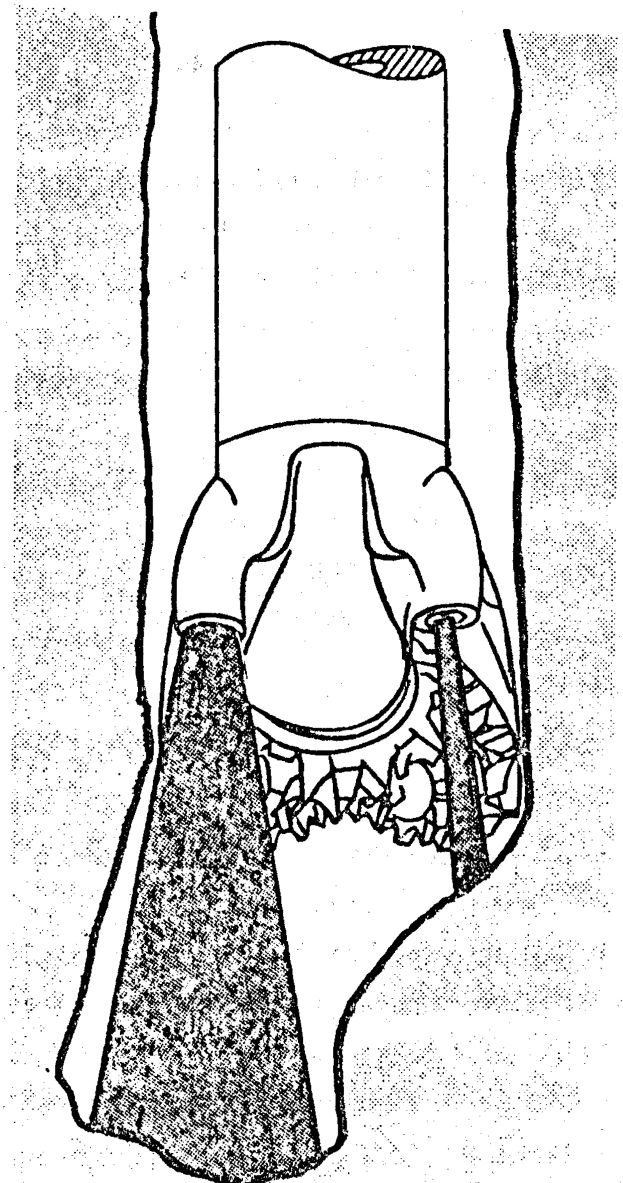

Figure 18 - Sidetracking Using Jet Bits.

Improved Slim Hole Drilling

The development of COMPAX bits will allow the use of slimhole exploratory drilling (less than 6 inch diameter) for oil and gas. It will be more difficult to drill slim geothermal exploration wells because of the reduced strength of slimhole drillpipe and the increased twistoffs due to the hardness of most geothermal drilling. Improved downhole motors would reduce this problem and allow the use of smaller diameter bits in geothermal wells. This could increase the number of exploratory wells that can be drilled and thereby allow the faster development of geothermal reservoirs.

These slimhole bits can also be used to deepen existing oil or geothermal wells to search for higher temperature zones at greater depths. This will be an inexpensive way to test these deeper zones.

Reduced Mud Problems

Most geothermal mud problems occur when trips are made and the mud heats up to the formation temperature. The mud is cooler during circulation because of cooling at the surface and because of the borehole acts as a large heat exchanger. During trips, the mud borehole is heated and problems arise due to increased gel strength, increased mud viscosity, increased filter loss and increased corrosivity. Figure 19 and 20 shows that the yield point and filter loss of geothermal muds is excessive at 500^{o}F.

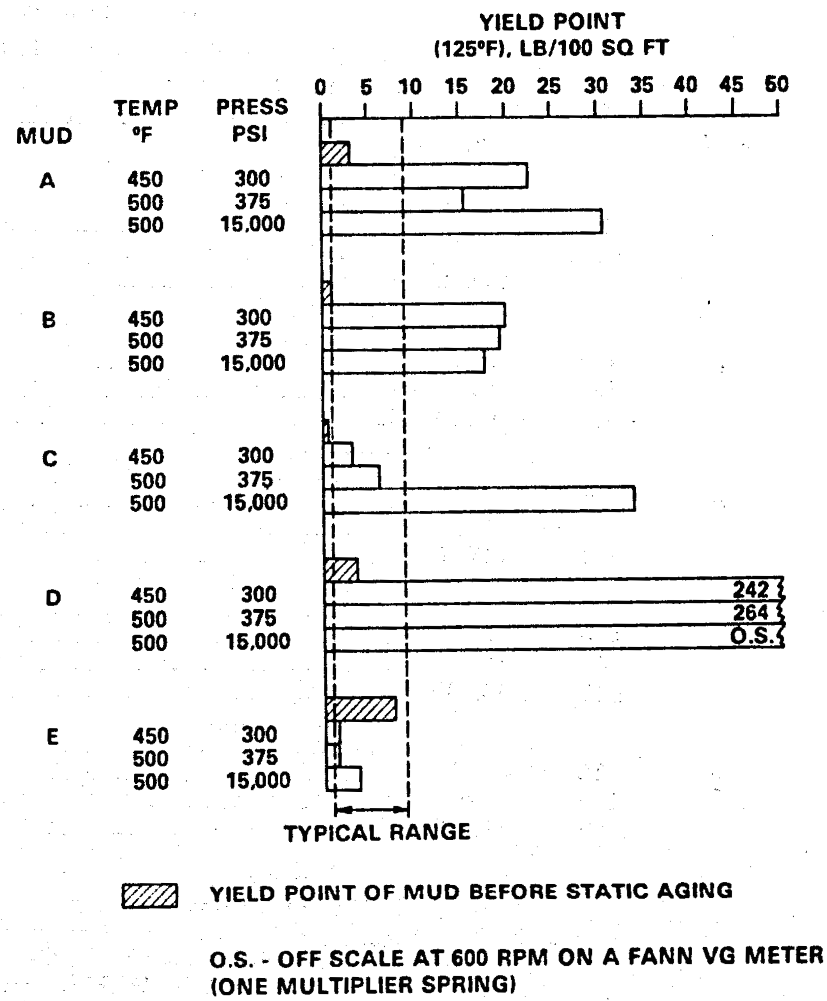

Figure 19 - Yield Point 9lb/gal Water Muds at 500°F (Remont, 1976)

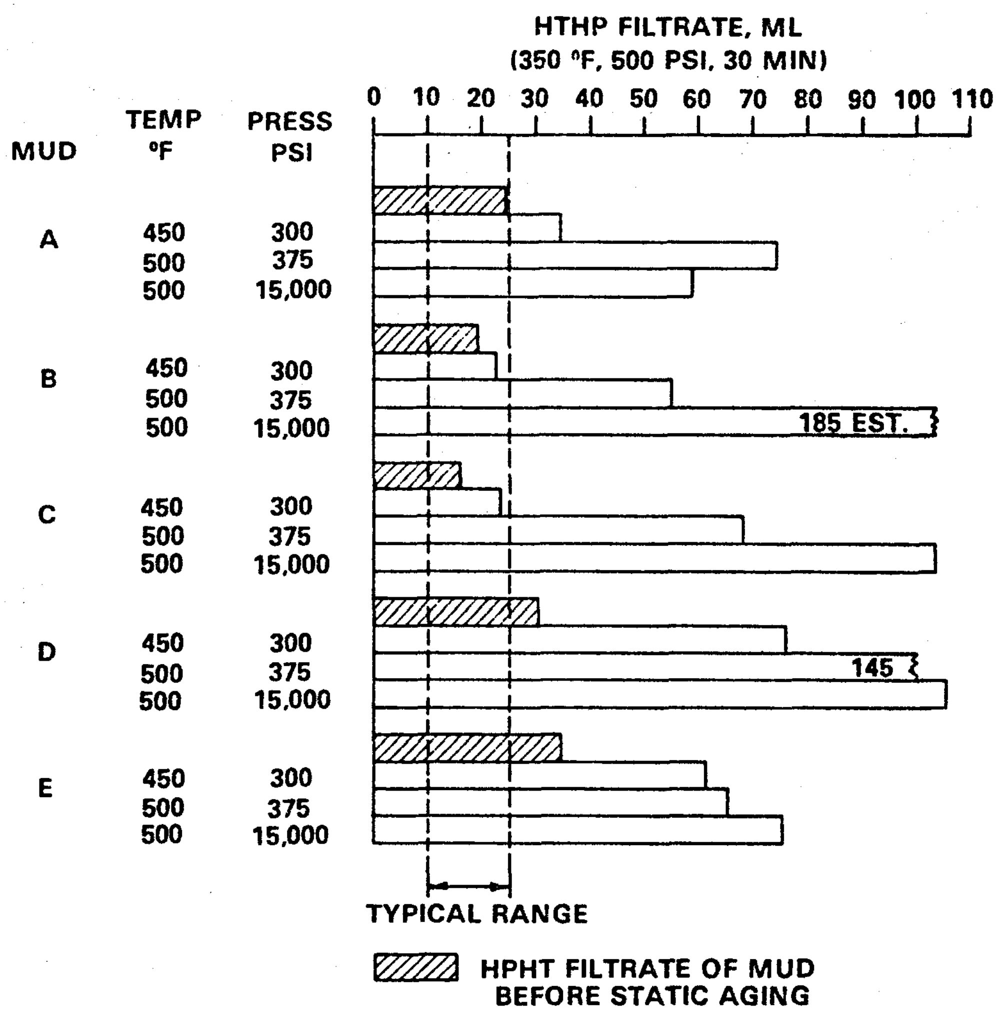

Figure 20 - Filter Loss of 9lb/gal Water Muds at 500°F (Remont, 1976)

The development of improved drilling motors and COMPAX bits should increase bit footage 2 to 3 fold and reduce the number of trips by 50 to 75 percent, thereby reducing the mud problems in these wells.

Reduced Lost Circulation

Lost circulation is a problem in many geothermal wells because of the low water tables in many mountainous areas and because of the fractured nature of most igneous and metamorphic rocks. Lost circulation can take place in naturally occurring fractures or in fractures induced by the high fluid pressures in the borehole (Figure 21).

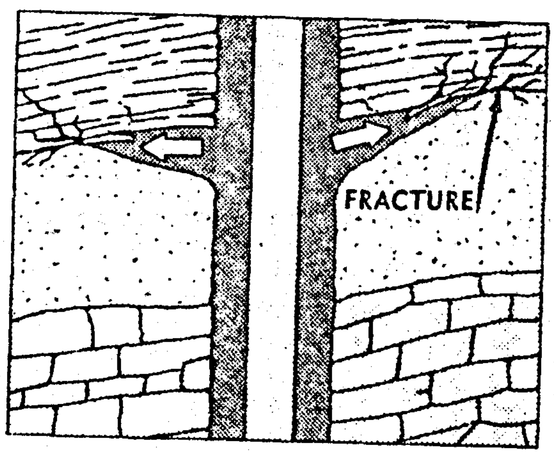

Figure 21 - Lost Circulation.

Severely fractured formations have been encountered in the hot dry holes being drilled by the Los Alamos Scientific Laboratories (Figure 22). These fractured formations coupled with low water tables have led to severe lost circulation problems.

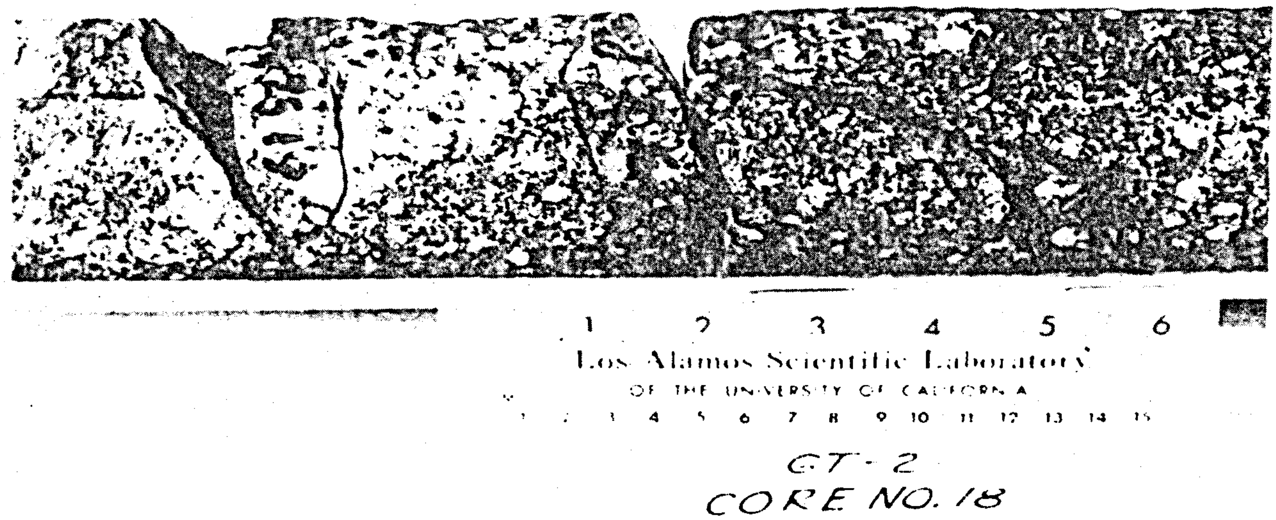

Figure 22 - Fractured Core From LASL Well. (Blair, 1976)

Lost circulation problems often occur during trips because of high pressure surges present ahead of the bit as the drillstring is being run into the hole (Figure 23). These pressure surges often fracture the formation or force the drilling fluid into existing fractures.

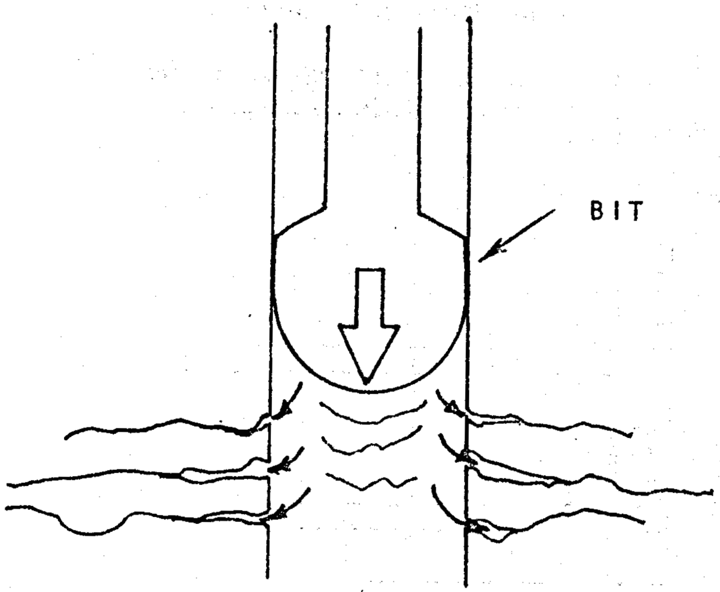

Figure 23 - Pressure Surges Ahead of Bit.

Imrpoved downhole motors used in conjunction with COMPAX bits would reduce the number of trips required during the drilling of a well and thereby reduce the lost circulation problem.

Reduced Drillstring Corrosion

Excessive corrosion of the drillstring and casing is a problem in most geothermal wells because of the presence of O_2, CO_2, and H_2s. The corrosion problem is accentuated by the increased corrosivity of drilling fluids at high temperature as shown in Figure 24. These tests were made on the best high temperature muds that could be supplied by the five major mud companies (Baroid, IMC, Magcobar, Milchem and Oilbase).

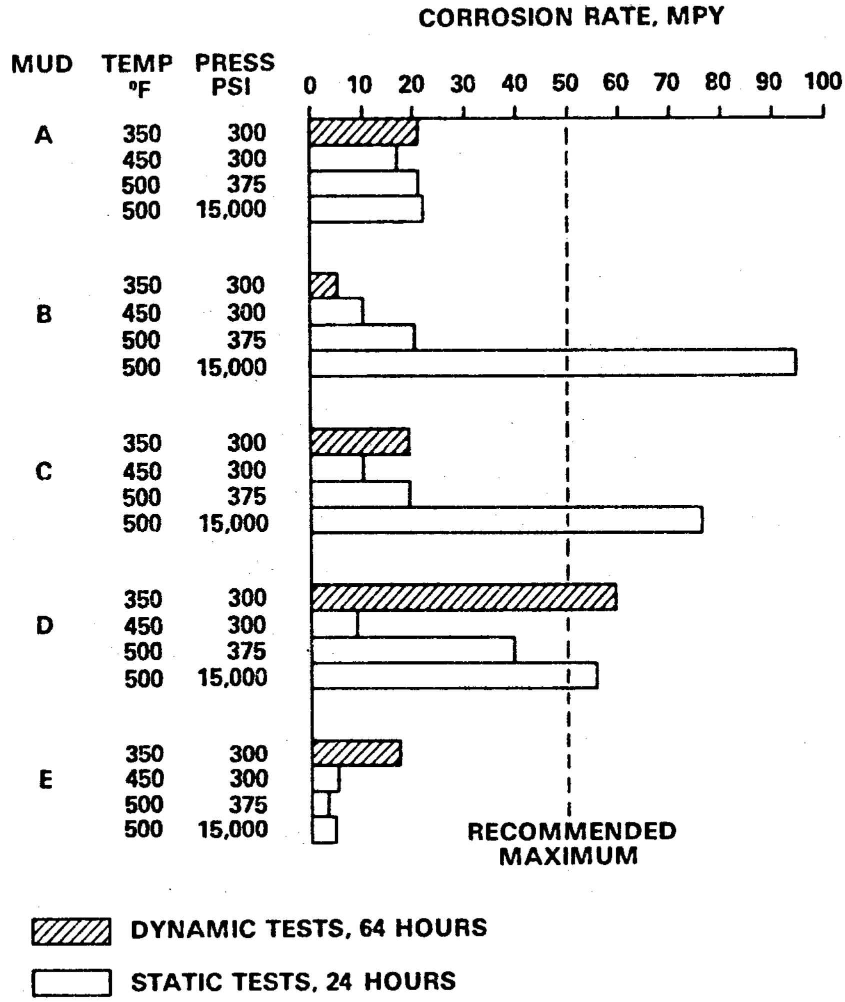

Figure 24 - Corrosivity of 9 lb/gal water muds at 500°F. (Remont, 1976)

The corrosivity of all of these muds were high at 500°F. This correlates with field geothermal drilling where the drillpipe has to be discarded after 3 to 4 wells (30,000 to 50,000 feet) whereas in oilwells the drillpipe is used for 200,000 to 300,000 feet before it is discarded.

<u>Reduced Drillstring Vibrations</u>

Drillstring vibrations are a problem in oilwell and geothermal drilling, especially in hard rock. In normal drilling, the bit weight oscillates ±30 percent from the applied weight whereas in rough drilling the bit bounces off bottom and produces high impact loads. Figure 25 shows an example of rough drilling where the bit is bouncing off bottom and producing bit loads in excess of 120,000 pounds. There high dynamic loads produce rapid failure of the bit bearings and bit inserts. In addition they cause fatigue failure and parting of the drillpipe.

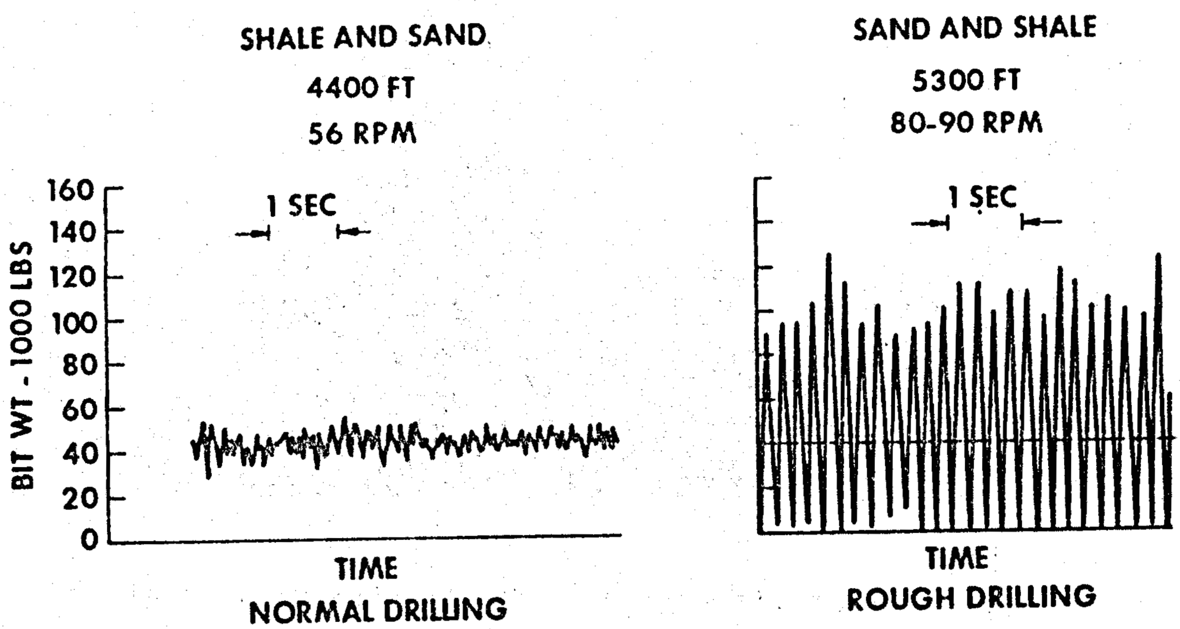

Figure 25 - High Dynamic Bit Loads. (Deily, 1968)

Figure 26 shows a roller bit used to drill granite in the LASL hot dry rock wells. A large number of the inserts are broken due to the high dynamic bit loads.

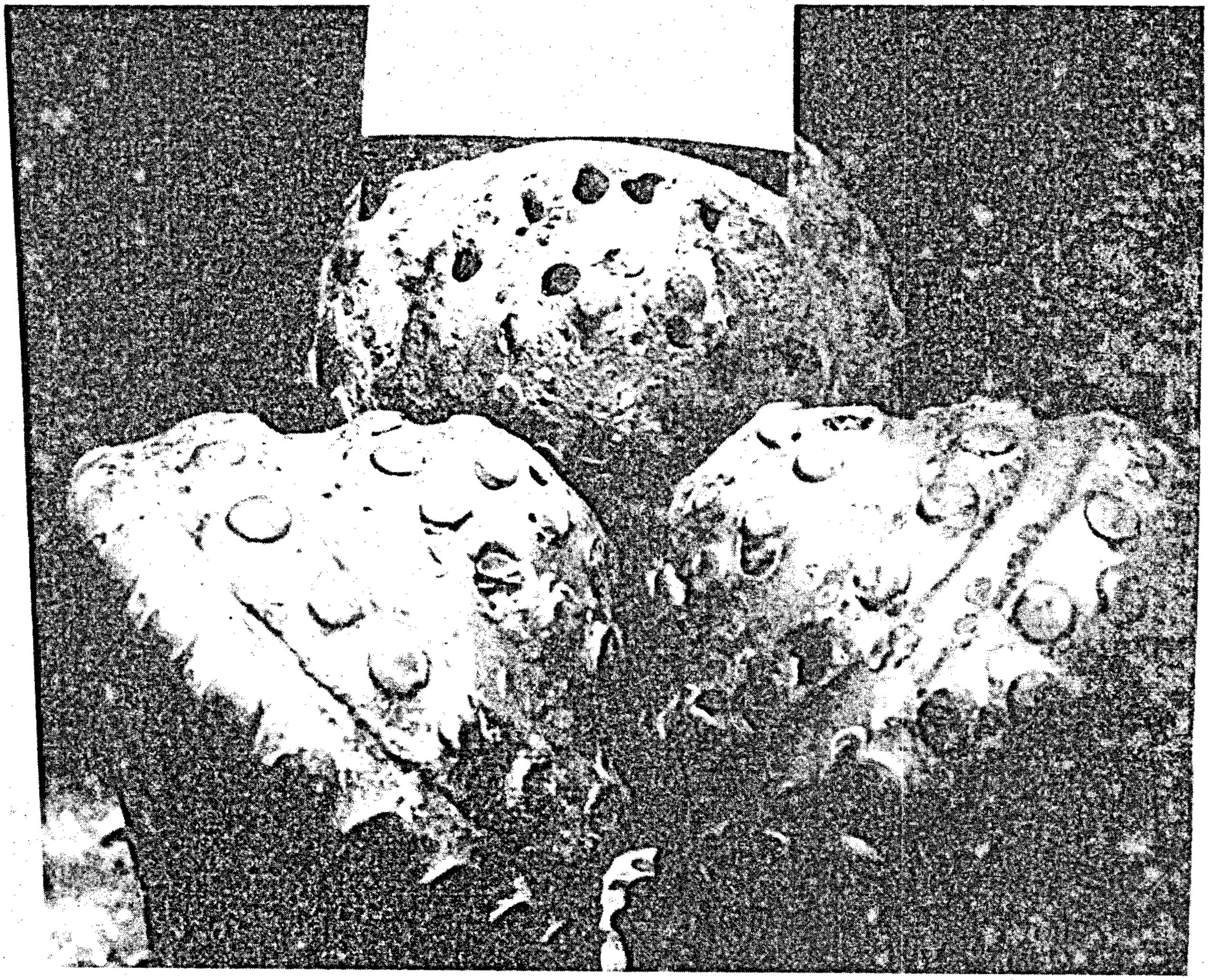

Figure 26 - Roller Bit Used In LASL Granite Well. (Blair, 1976)

The life of the bit bearings are severely reduced by high drillstring vibrations as shown in Figure 27.

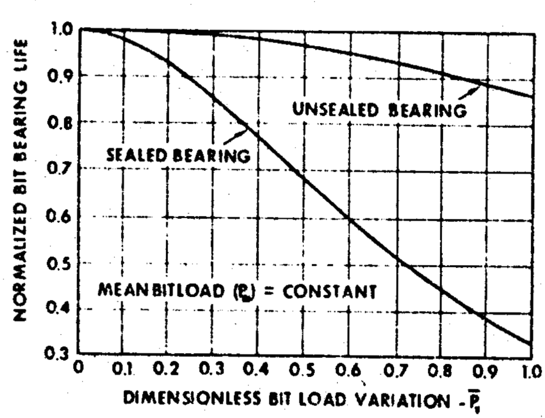

Figure 27 - Effect of Drillstring Vibrations on Bit Bearing Life. (Dorring, 1965)

When the amplitude of the vibration equals 50 percent of the bit weight ($\bar{P}_v$=0.5), the life of a sealed bearing is reduced by 33 percent whereas if it equals 100 percent of the bit weight ($\bar{P}_v$=1.0) the bearing life is reduced by 67 percent. This shows the importance of reducing drillstring vibrations in hard rock drilling.

These drillstring vibrations can be greatly reduced by using motors to rotate the bits at higher speeds and lower bit weights. The higher speeds prevent the drillstring from going into resonance and producing the high dynamic bit loads.

Improved Data Telemetry

ERDA is funding the development of the Teleco mud pulse telemetry system shown in Figure 28, which allows transmission of data to the surface while drilling. Coded pressure pulses are sent to the surface through the mud in the drillpipe while drilling.

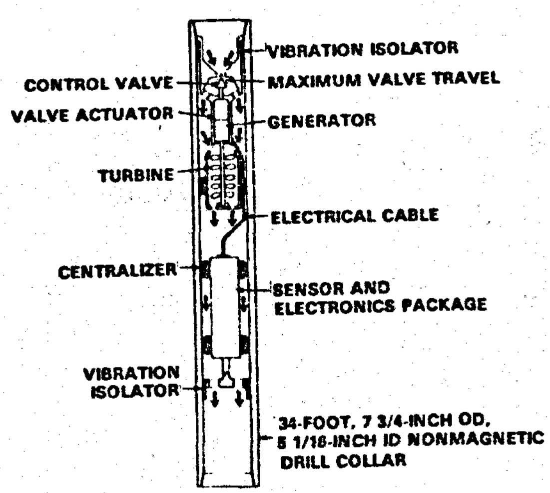

Figure 28 - Teleco Data Telemetry System. (Anon., 1975)

The primary use of these systems will be for directional surveying while drilling and real time control of the hole direction. This will require the use of drilling motors so that the direction of the bit can be continually charged to maintain the desired hole direction. This would be important in hot dry rock reservoirs where one hole must intersect the fracture pattern around the second hole. The motors will also reduce drillstring vibrations and noise problems associated with transmission of the signals. The reduced vibrations will increase the life of the electric instruments subjected to the severe downhole environment.

Reduced Drillstring Fatigue Failures

High cylic stresses are produced as drillpipe is rotated through dog-legs as shown in Figure 28. These cyclic stresses can produce rapid fatigue failure in sharp dog-legs. In some cases, an entire string of drillpipe can be ruined drilling through a dog-leg.

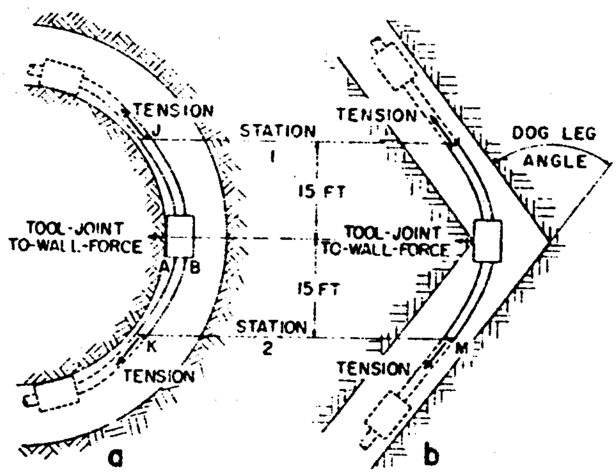

Figure 28 - High Drillpipe Stresses Produced by Dog-Legs.

Downhole motors allow the use of lower bit weights and thereby reduce the occurence of dog-legs. In addition, motors eliminate the need for rotating the drillpipe; thereby eliminating the cylic stresses and the fatigue problem.

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