INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS - IRISH GROUP

GROUNDWATER DEVELOPMENT IN LIMESTONE AQUIFERS

The Montague Hotel, Emo, Portlaoise. - 30th & 31st March, 1982.

TUESDAY 30TH MARCH

10.00 a.m.	Registration.
10.30	Irish Limestones - Dr. G. D. Sevastopulo, Trinity College Dublin.
11.15	Tea/Coffee.
11.45	Irish Limestone Aquifers - C. R. Aldwell, Geological Survey Of Ireland.
12.15 p.m.	Limestones as Aquifers - H. M. Townsend, U.S.A.
1.00	Lunch.
2.00	Cable-tool Drilling in Limestones - W. Jungmann, UOP Johnson Wellscreens (Ireland) Limited.
3.00	Film - Drilling Methods.
3.30	Tea/Coffee
4.00	Drilling Methods - Rotary and Down-the-Hole Hammer Systems - H. M. Townsend.
5.30	Discussion.

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WEDNESDAY 31ST MARCH

9.00 a.m.	Drilling problems: Circulation, Verticality, etc.; Well Development - H. M. Townsend.
10.30	Tea/Coffee
11.00	Borehole Logging - H. M. Townsend.
11.45	Borehole Logging Demonstration - E. P. Daly, Geological Survey Of Ireland.
12.30 p.m.	Lunch.
2.00	Sanitary Protection for Water Wells - H. M. Townsend.
3.00	Economic Considerations for Drilling Contractors - H. M. Townsend.
4.00	Discussion.

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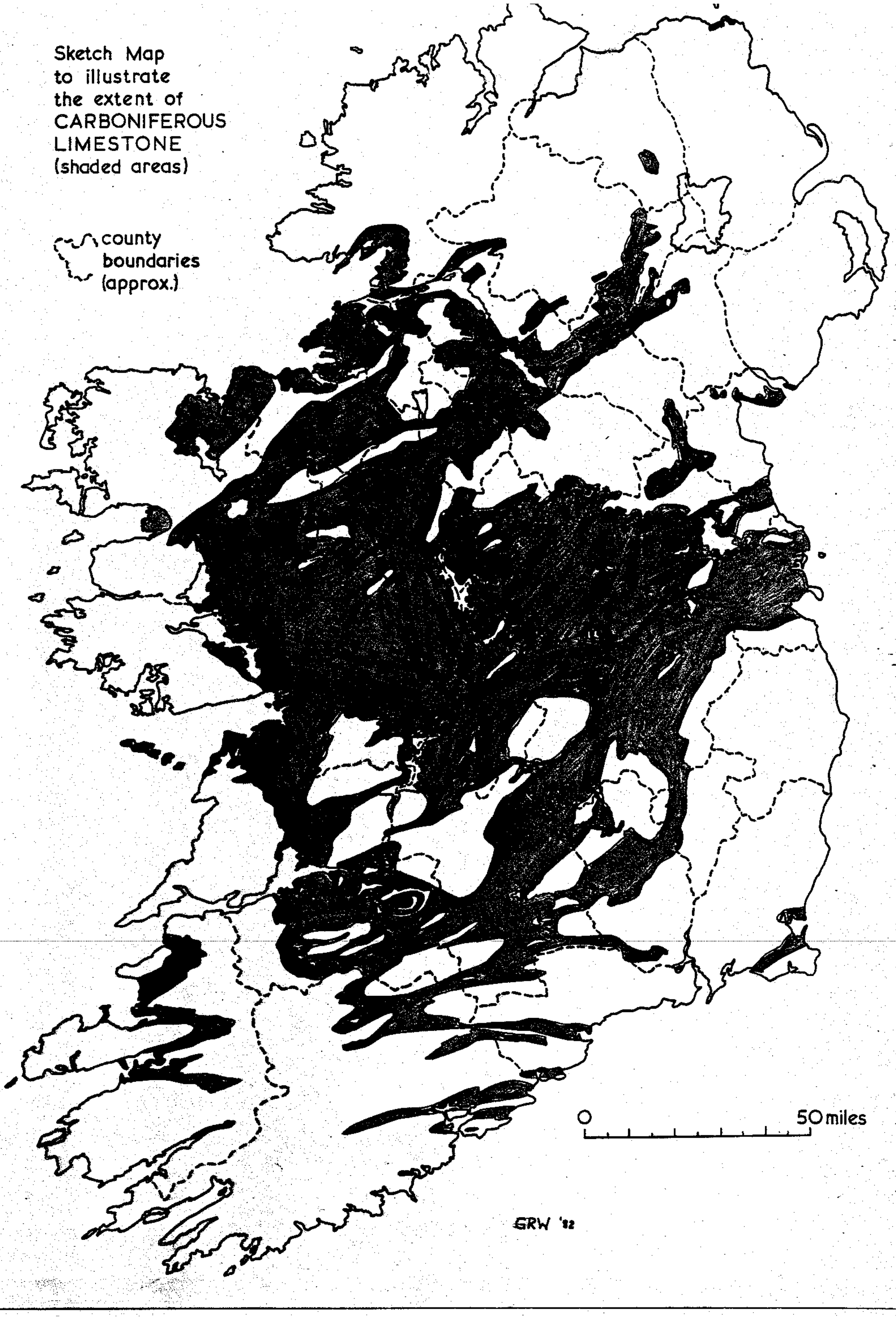
This Seminar has been organised by the Committee of the Irish Group of the International Association of Hydrogeologists: Dr. D. J. Burdon, President; G. R. Wright, Secretary; K. T. Cullen, Treasurer.

The organisers wish to thank all the speakers and their organisations for their presentations, and the management and staff of the Montague Hotel. Thanks are also due to:

Dr. C. Williams, Director, Geological Survey of Ireland for projectors and many other facilities;

Dunnes Welldrilling, Mallow, Co. Cork for their hospitality extended to Mr. & Mrs. Townsend during their visit to Ireland.


Sketch Map
to illustrate
the extent of
CARBONIFEROUS
LIMESTONE
(shaded areas)
county
boundaries
(approx.)
0
50 miles
GRW '82

The Limestone Aquifers of Ireland

Paper by C.R. Aldwell presented to

IAH Meeting on Limestone Aquifers

Emo, Co. Laois,

March, 30th 1982.

The Limestone Aquifers of Ireland

The type of limestone that was deposited determines whether it has the potential to become an aquifer. Pure limestone is dissolved by water. As a result water increases the size of the many natural fractures and cleavages such as bedding planes joints and faults. The extent to which a pure limestones potential as an aquifer comes to fruition depends on the amount of chemical solution that has taken place since it was laid down. Besides the natural weaknesses in the rock mass other important criteria which control the degree of chemical solution in limestone are climate, topography, the regional structure of the rocks, together with the nature of the adjoining and overlying strata. A distinction is sometimes made between those limestone aquifers in which groundwater is concentrated into a relatively small number of large conduits and those where water is spread more evenly in a large number of small fissures.

Thus limestones of the same type will vary greatly in their water bearing capacity from one locality to another depending on their post depositional history. By way of example, in the west of Ireland there is a large expanse of pure limestone of roughly the same type and age. Hydrogeologically however, it can be divided into three distinct and contrasting areas - the high Burren, the Gort lowlands and the Aran islands. The limestone of the Gort lowlands has been exposed to chemical solution for a very long time. It has many large underground conduit systems which because they are below the water table, are water filled. The limestone here is a large yielding if inconsistent aquifer.

The high Burren with remnants of its protective cover of shale still in place has been subject to active chemical solution for a relatively short time. As a result the cave systems extend only some 60m below surface. Since the Burren is a highland area the water does not, get down to the district water table but discharges laterally on meeting the unweathered zone of rock. The practical result is for an upper weathered zone of limestone with a little water at its base usually at less than 60m below surface, with the bulk of the recharge running off to the Gort lowlands or the sea. The Burren then is an area of recharge but does not contain significant groundwater.

The Aran islands give every surface impression of chemical solution. A study carried out by the Geological Survey a few years ago on Inish Maan however, showed that the weathered zone extends only about 15m below surface and that water discharges rapidly at a high level through a large number of small seepages. Again the Aran islands are an area without significant groundwater.

In the east of Ireland we see the same thing. Eugene Daly in his work in the Nore Catchment has found that groundwater in the limestone aquifers there concentrates in restricted zones close to present and past river systems.

I now propose to look at the limestone aquifers in Ireland - region by region. In doing so I have to generalise. Moreover, the geographical sub divisions I am making are arbitrary and subjective and some have greater justification than others.

In brief summary I regard the limestones in the northwest as low yielding in the north moderate to high yielding, in the west high yielding but inconsistent, in the midlands and east low yielding, in the south midlands and southeast variable and in the south high yielding.

<u>Region 1</u>. Northwest

(Donegal, North Leitrim, North Sligo, and north Mayo). The overview here if of yields of up to a few hundred gph. Much of the limestone is impure as around Ballina and west Sligo, dolomitised as near Ballyshannon and where pure often forming high ground as at Benbulben and Knocknarea. Locally there is evidence of more favourable conditions as at Crossmolina, Co. Mayo, Skreen, Lough Gill and the Rosses Point Peninsula, Co. Sligo and Laghey and Ballintra, Co. Donegal. H_2S is a problem in borings deeper than 30m in the dark limestones as at Enniscrone, Co. Sligo.

Region 2. North

(Armagh, Monaghan, Cavan, Fermanagh, Tyrone, south Leitrim, south Sligo, east Mayo and North Roscommon). This extensive region has limestone aquifers which yield 10,000 gph in favourable conditions and overall may be regarded as moderate to high yielding. Large springs and high yielding boreholes are present in the west of the region as in Ballymote, Tubbercurry, and Riverstown in Co. Sligo, Blacklion, Co. Cavan, and Marble Arch, Co. Fermanagh. In the east large yielding boreholes with yields up to 30,000 gph are present at Killeshandra Co. Cavan, Clones and Monaghan town and Clogher in Co. Tyrone. Problems include high sulphate levels due to solution of evaporites principally in Cos. Cavan, Monaghan and Tyrone and pollution risks in the large conduit systems of west Cavan, Fermanagh and south Sligo.

Region 3. West

(south Mayo, mid and south Galway, south Roscommon, north Clare). This region is most typically found within some twenty miles east of the big lakes with its exact eastern limit uncertain. It is an area of pure limestones with large springs, and with boreholes yielding up to 20,000 gph as at Tuam and Athenry. The chanelling of the groundwater into localised large conduits leads both to very variable results from one point to another and the fast movement of water often through swallow holes with its resulting pollution hazards particularly after heavy rain.

Region 4. Northeast

(South Monaghan, Louth, north Meath). The pure lowlying limestones in these counties yield around 10,000 gph in boreholes with larger yields likely to be available near Carrickmacross. Their occurrence is fragmented. The most important locations are Carrickmacross - Ardee, Drogheda- Duleek, Oldcastle and Carlingford. Problems include pollution risks due to large conduits at Carrickmacross where in the past there have also been drilling difficulties.

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Near Drogheda the limestones contain a yellow clay infill in the fissures which causes silt and grit problems in boreholes.

Region 5. Midlands and East.

(Longford, Westmeath, south Meath, Dublin, north Kildare, Offaly, southeast Galway and northeast Tipperary). Here are found mostly dark impure limestones interspersed with massive pale grey reefs. The overview is one of low yielding aquifers normally producing a few hundred gph. Good aquifers occur near Lanesboro, Co. Longford, and from Birr to Tullamore in Co. Offaly. H_2S is an endemic problem in the dark limestone areas.

Region 6. Southeast

(south Kildare, Laois, Kilkenny, Carlow). The limestones in this part of the country are quite variable water bearers but include two high yielding aquifers the Dolomite and the Upper Limestone. As already mentioned these limestones are good aquifers usually in restricted areas adjacent to the main river systems of the past and present. Yields of 15000 to 30,000 gph have been got from boreholes in the valley of the Barrow as at Athy, Carlow and Bagenalstown. In the Nore Valley there are large yielding bores as at Durrow and Fermoyle, Co. Laois while a spring with a yield of over 1 million gph exists near Paulstown, Co. Kilkenny.

Region 7. Midwest

(Limerick, Tipperary, south Clare). The limestones in this part of Ireland range from poor to moderate aquifers. They are variable in type with both dark impure limestones and pale grey reef. In Co. Limerick things are further complicated by the presence of many volcanic rocks interspersed with the limestones. Yields of up to 2500 gph are available in many districts except where the limestone is particularly impure as at Clarina Co. Limerick and Newport Co. Tipperary. Problems include the inconsistency of results from the reef limestone districts as around Askeaton, Co. Limerick and Rathcabbin, Co. Tipperary. Overburden of up to 60m is a drilling hazard in some areas between

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Newcastlewest and Dromcolliher.

Region 8. South

(Cork, Kerry, Waterford parts of south Limerick and south Tipperary, south Wexford). Limestones in this region are usually pure and form the floor of narrow synclines only a few km wide and surrounded by higher ground with older non-carbonate rocks. Yields in boreholes range from 10,000 gph up to 100,000 gph in exceptionally favourable conditions. It is thought that a major reason for the high yields is the strong folding of the limestones which produced many fractures which have subsequently been enlarged by solution.

Major wells are present south of Wexford Town, at Dungarvan, Mitchelstown, Cloyne-Aghada and the Dower spring near Castlemartyr, Co. Cork.

You will then see that the position of our limestone aquifers in Ireland is variable and complex. I hope however that I have succeeded to some extent in pulling together the various, hydrogeological data known to us and provided you with a general pattern within which we can discuss and access them further during our two days together.

DRILLING TECHNIQUES

Rotary Rig Selection

The first step in the planning of an individual water well job or multiple well ground water program is the collection and interpretation of technical field data. The success of any type of water well undertaking will depend on the accuracy and completeness of this information. There are four basic types of technical information required to plan a well design and select the proper drilling equipment.

These parameters are:

A. Subsurface geologic data.
B. Hydrological data.
C. Chemical water quality data.
D. General Project data.

A majority of this information is available from existing technical reports, project documents or well drilling logs. Project area data is collected during a field reconnaissance tour of the project area. Chemical water quality data can usually be obtained from agricultural personnel or public health/water supply personnel in the project area. In terms of selecting a well design, subsurface geological and hydrological information is most inportant.

In areas where previous ground water development has taken place, existing records may contain basic geological and hydrological data. If this is the case, a review of these records as well as a survey of existing wells and hydrological conditions in the project area will provide enough information to warrant a limited test drilling, mapping and test pumping program. If there has been limited ground water development activity in the proposed project area, however, a more thorough survey of existing subsurface geological and hydrological conditions is necessary.

In many cases, this type of limited test drilling, mapping and pump testing program can be an intergral part of the overall production well drilling program. The types of technical information required to design an efficient water well and select the proper drilling equipment covers a very broad scope and can be put to a variety of related uses. Specific data from each of the four main areas is needed to provide a basis for drill rig selection.

SELECTION OF WELL DESIGN AND DRILLING EQUIPMENT FROM FIELD INFORMATION

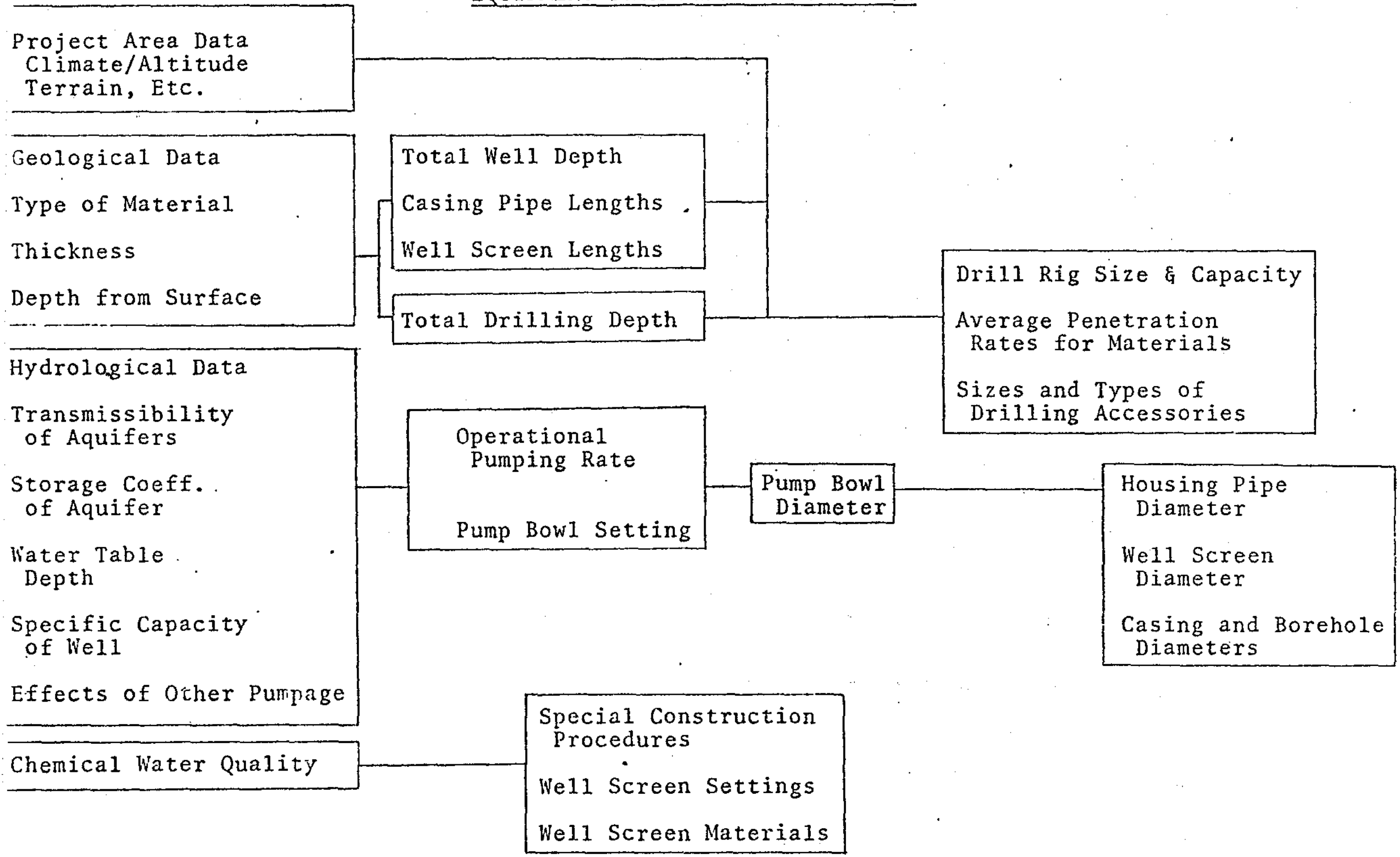


Figure 1

The selection of a drilling rig, for a specific project area, is a two step process. First, individual components and rig systems must be selected on the basis of technical information about the project and the project area. Second, all of the individual components must be considered as a total drilling system. Components must be matched to function effectively and efficiently.

Rig Size and Capacity

The overall size and capacity of a rotary rig is determined by the diameter and depth of the borehole to be drilled. Most rotary rigs are rated on the basis of hoist capacity or pulldown/pullback capacity. Under ideal drilling conditions, adequate circulation and drill string stability/strength, a rotary rig's depth capacity is roughly equal to the weight its hoisting system can lift. Often drilling depth will be limited by circulation requirements or borehole size rather than lifting capacity. To be safe the maximum depth capacity of a rotary rig should be calculated for an individual application and a given set of well design specifications.

Rotation and Pulldown Systems

A key factor in selecting a rotary rig is the capacity of the rotational system. When selecting the rotational system for a conventional rotary rig several factors should be considered. First and most important is the size and capacity of the rotary table. Many of today's conventional rotary rigs are available with hydraulically and mechanically driven rotary tables. It is important that the rotary table have adequate torque and rotational speeds to drill the specified boreholes under the subsuface geological conditions encountered in the project area. It is also important that the rotary table have a sufficient central opening or be retractable to allow the driller to set the specified size ranges of casing and drill pipe called for in the well design.

The second important factor when selecting a rotational system on a conventional rotary rig is the kelly. It is important that the kelly be of sufficient size and strength to transmit the full rotational torque of the rotary table to the drill string.

The tophead hydraulic drive rotary rig rotates the drill pipe from the top and moves up and down the mast with the drill pipe. When selecting a tophead drive rotary system, it is also important to consider the torque and rotational speed range required for a given application. The advantage of the hydraulic tophead drive system is that it allows the driller instant variable speed control with continuous maximum torque. The tophead drive rotational system also has the advantage of allowing the driller to maintain both rotation and circulation during a majority of the drill pipe handling process.

Rotation Speed and Penetration Rates

Rotary speed requirements for a rig are based primarily on the formations being drilled and the desired penetration rates. Rotational speeds in different formations are highly variable. In general harder rock formations are drilled at a slower rpm than soft formations. Therefore, the relationship between rotary speed and bit weight is an important consideration when selecting a rotary rig.

Bit requirements are based on formation hardness and desired penetration rates. Generally, speaking, bit rate is proportional to penetration rate from 3000 to 6000 pounds per inch of bit diameter.

Increasing bit weight will almost always increase penetration rates. However, a point is reached when the bit teeth are buried and/or bit bearing life is greatly shortened. This will negate the advantages of more rapid penetration rates by increasing the drilling cost. In general, more bit weight is required to drill at optimum penetration rates with larger bits and in harder formations. Larger bits, however, have stronger bearings and can withstand greater bit weights in hard formations than small bits. Therefore, in smaller hole size range (6" through 10") there is a rock hardness where optimum penetration will result in unacceptably short bit life.

In these cases, the use of the downhole drill should be considered. Experience shows that 6" through 10" holes in formations harder than medium limestone can be drilled more rapidly and less expensively with a downhole drill. The conventional rotary rig relies on the weight of the drill string to apply bit weight for tophole drilling. Optimum penetration rates can be reached only when the drill string is heavy enough to apply optimum bit weight for the formatiom being drilled. A tophead drive rotary rig with hydraulic pulldown system allows the driller to select the proper bit weight from the beginning of a hole without the use of drill collars, or relying solely on the weight of the drill string.

The advantage of this system is that the driller has an infinitely variable pulldown force available which allows him to control penetration rate and drill bit life through his bit weight and rotational speed control. The more advanced hydraulic tophead drive rigs have an automated feed system to allow the driller to fix a feed rate based on drilling conditions. If the drill encounters softer or harder conditions, the feed system will automatically adjust to maintain constant feed pressure.

AIR ROTARY DRILLING

The use of air as a drilling fluid is not new to the drilling industry. It has been in common use since the late 1800's. The greatest impetus to the use of air, as a circulating medium, was provided by the uranium boom in the United States during the 1950's. Prior to this time, most air uses were for operation of mining and construction percussion equipment, and the principle objective was to provide the percussive impact. It was during the 1950's that many innovative ideas were implemented in the use of air in exploratory drilling.

Selection of an adequate circulation system is a major factor in a rotary rig's suitability for a given project. The types and sizes of circulation systems used is primarily based on borehole depth, size, water heads encountered and formation characteristics. In many applications, more than one type of circulation system is needed.

Drilling with air has the advantage of simplicity as well as increased penetration rates and bit life compared to drilling with other circulation media. As a general rule, drilling with air rotary or the downhole drill should be considered only if subsurface conditions warrant it. Because of this many rotary rigs are dual purpose machines; primarly air medium, with the capability to use supplementary foam and/or mud circulation drilling if conditions require it.

In order to provide efficient drilling performance the following must be taken into account in the application of air rotary drilling equipment:

1. AIR PRESSURE - the major function of air pressure is to overcome water head in a borehole and to assure optimum performance of the drill.

Maximum air pressure is required to begin circulation from the bottom of the hole (called "unloading" the borehole). Once circulation has begun pressure requirements drop off. Under normal rotary drilling conditions, required air usually varies from 30 to 50 psig. Under extreme conditions, higher pressures, may be required.

When percussion tools are employed in connection with rotary drilling, air pressures vary according to the manufacturers' recommendations.

2. AIR VOLUME - the main function of air in rotary drilling is to cool and clean the drill bit, as well as to carry the drill cuttings from the borehole. The rock surface on the bottom of the borehole and the cutting surfaces on the rotary bit must be kept cool and clean for the bit to obtain optimum bit life and penetration rate. When cuttings have been cleared from the face of the bit, they must be carried up and out of the borehole. To perform this cooling and cleaning function, air volume is the primary consideration. For any size of cuttings, there is a critical velocity which will cause rock fragments to accelerate enough to overcome gravity and friction and rise up the borehole. In well drilling this velocity is called minimum bailing velocity and is a function of air volume and annular area. The velocity of the upward moving air is an important factor in the efficiency of air drilling. There are three factors which have an effect on this velocity namely, 1) hole diameter, 2) the O.D. of the drill stem, and 3) the volume output of the compressor. Hole diameter and drill stem O.D. effect the annular area.

The annular area is defined as the area of the hole less the area of the drill stem.

In order to assure good cuttings removal, the annular area must be kept full of the upward moving air. Therefore, it is logical that the smaller the annular area the less the air volume would be. However, if the hole diameter is increased while the air volume (cfm - cubic feet per minute) and drill pipe size remains constant, the bailing velocity will decrease. Under normal drilling conditions, the critical velocity will be approximately 3000 ft/min. This will vary with the size and density of the cuttings, however, a bailing velocity in excess of 3000 ft/min will provide sufficient cooling and cleaning.

There is also a practical maximum bailing velocity above which excessive drill pipe and tool wear will occur. Under average drilling conditions, bailing velocities over 5000 ft/min will cause a significant "sand blasting" effect. It is only logical that bailing velocities in excess of 5000 ft/min should be avoided. Therefore, an air compressor should be selected for a drilling rig that will provide enough air volume to maintain a bailing velocity of 3000 to 5000 ft/min. Table 1 shows the cfm required to maintain a 3000 ft/min bailing velocity for common borehole and drill pipe diameter.

Figure 1 - Air Velocity Determination Chart

To determine air velocity when pipe size, hole diameter and air volume are known, follow vertical Hole Diameter upward to its intersection with Pipe Size line, move horizontally to intersect Air Volume line. Read Air Velocity on diagonal Air Velocity line.

TABLE 1

MINIMUM CFM REQUIRED TO ATTAIN

3000 FPM OF BAILING VELOCITY

	ROD SIZES	
HOLE SIZE	4 1/2"	5 1/2"
5 7/8"	234	70
6"	258	94
6 1/4"	307	144
6 1/2"	360	196
7 1/2"	589	425
7 7/8"	684	520
8"	716	552
8 1/2"	851	687
8 3/4"	921	758
9 7/8"	1264	1101
10"	1305	1141
10 5/8"	1560	1396
12"	2025	1862
12 1/4"	2125	1961
15"	3315	3187
17"	4399	4255

NOTE:

Formula used to compute the required CFM:

$$BV = \frac{CFM \times 144}{\text{Area of Annulus}}$$ Where

BV = Bailing velocity
CFM = Cubic feet of free air per minute
Area of Annulus = Hole area minus O.D. Rod area in square inches

AIR VELOCITY DETERMINATION CHART

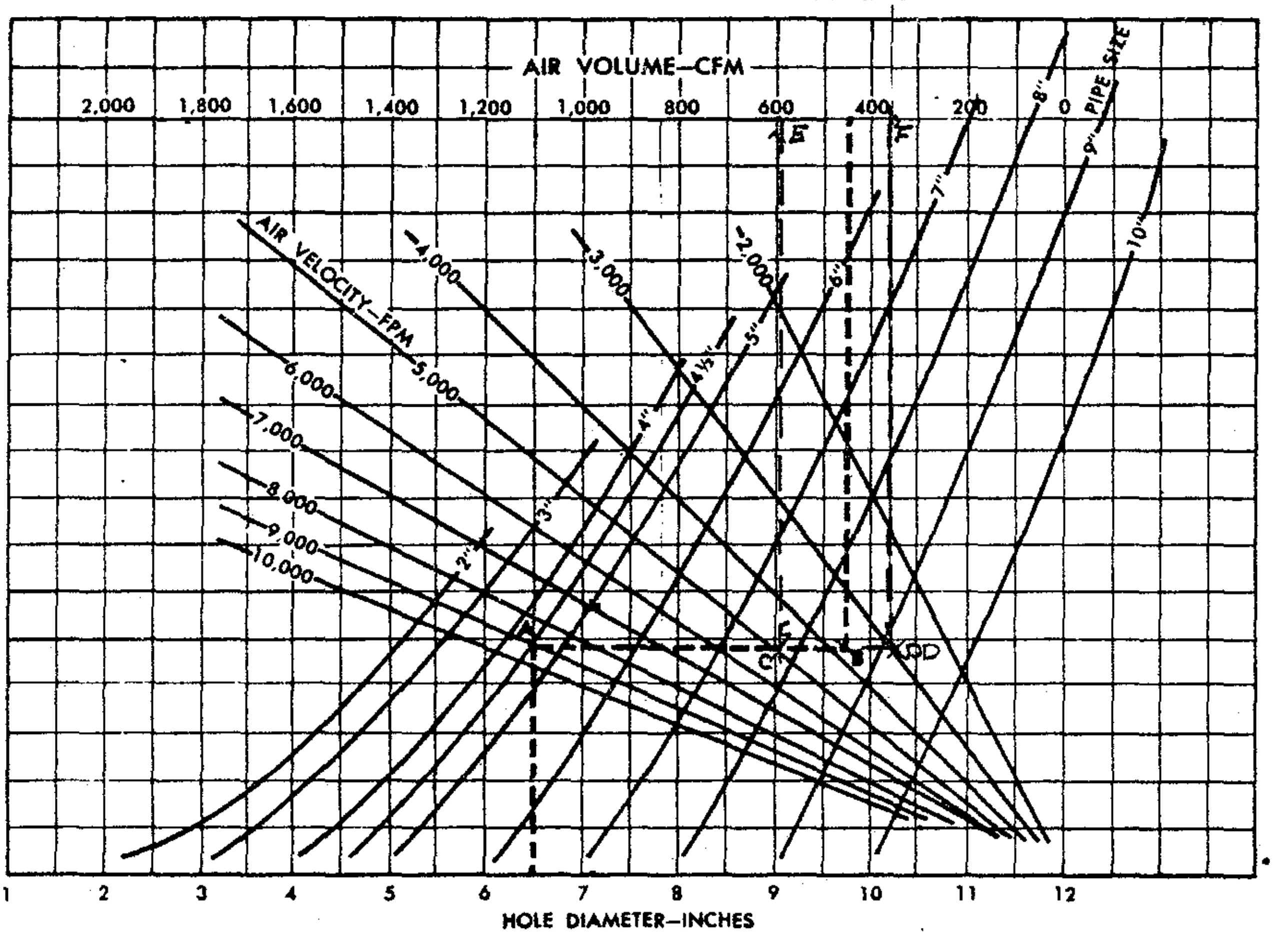
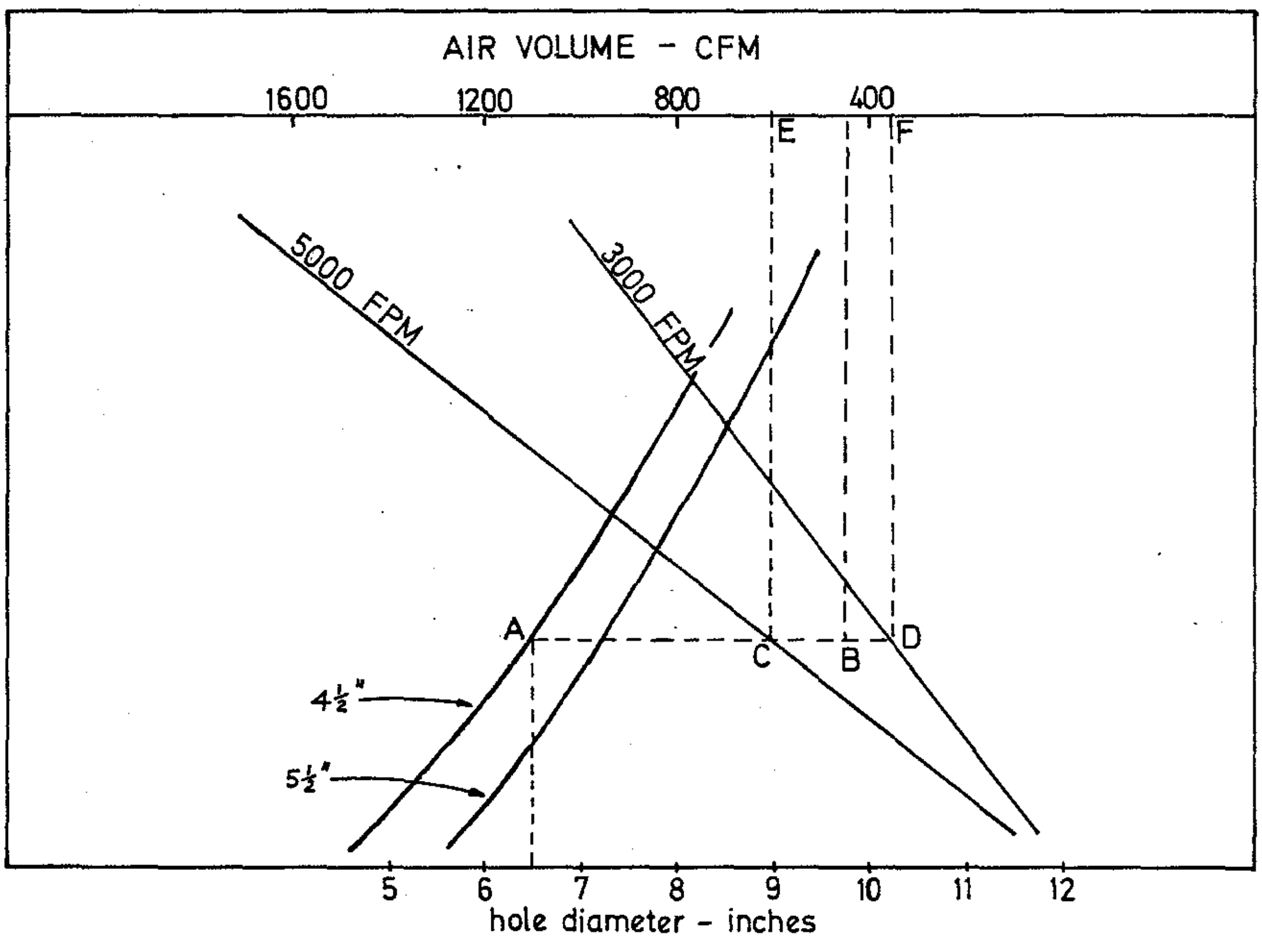
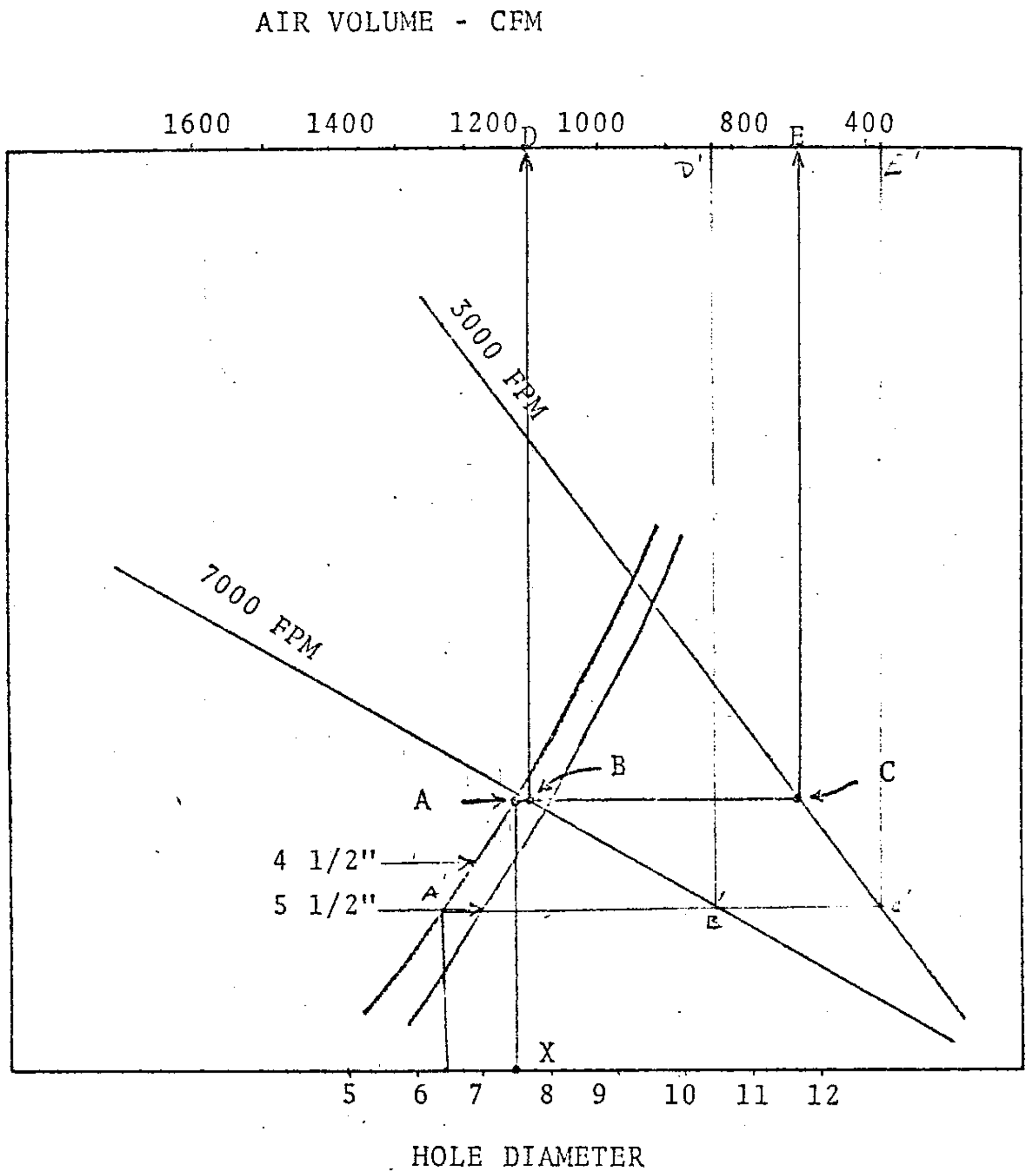


Figure 1
Source: Schramm, Inc.





AIR VOLUME - CFM
1600
1400
1200
1000
800
400
D
E
D'
E'
3000 FPM
7000 FPM
A
B
C
4 1/2"
5 1/2"
A'
B'
X
5
6
7
8
9
10
11
12
HOLE DIAMETER

Example: Drilling a 6½" hole using 4½" drill pipe and with 450 cfm air volume passing thru the annulus, follow the Hole Diameter line to Point A, its intersection with Pipe Size line. Move horizontally to Point B, to intersect air volume line. Read annulus Air Velocity at Point B (interpolating between 3000 and 4000 fpm) of 3700 fpm.

This chart can also be used to aid a driller in choosing a compressor model for a given well drilling application.

To determine a compressor that has a volume output, to maintain a 3000 to 5000 ft/min bailing velocity, when drill pipe size and hole diameter are known.

1. Make a point on the bottom line of the graph corresponding to the hole size (6½").

2. Draw a vertical line until the required drill pipe O.D. curve is intersected (4½") (A).

3. Draw a horizontal line to intersect 5000 fpm line (C).

4. Continue the horizontal line from A to C to the point of intersection with the 3000 fpm line (D).

5. Draw a vertical line from C and D until they intersect the top line of the chart at E and F.

6. Points E and F correspond to the cfm of air required to maintain a 5000 fpm and 3000 fpm bailing velocity respectfully.

A compressor with an air volume output within this range will provide adequate air to clean the borehole.

The selection of the proper type of drill stem is important in air drilling. Outside flush pipe should be used in order to minimize obstructions in the path of the upward flow of air. Tool joints, when used, cause the air to deflect outward against the hole wall and continually "sandblast" the wall, thus enlarging the hole.

The low pressure nozzle bits are more effective for air drilling in the majority of formations. The low pressure nozzle bit directs the air stream onto the cutters, whereas the jet-type nozzle bit directs the air stream between the cutters and directly upon the bottom of the hole.

Rotary speeds, for air drilling, are about the same as for conventional drilling.

AIR DRILLING ADDITIVES

For problem holes or large diameter holes, when the air volume requirements are exceptionally large, additives may be introduced into the air system.

The purpose of the additives is to increase the viscosity of the drilling medium (air). The additives that have been most successful are the bentonite foam mixture such as Quik-Foam (a Baroid product). Bariod has developed a new drilling additive called Gel-Foam. It is made from two of Baroid's regular products, Quik-Gel and Quik-Foam.

Drilling with Gel-Foam is a relatively new development that offers many interesting possibilities in air drilling. This concept offers the advantages of mud drilling with those of air drilling. It is a means by which rotary drilling can be used economically in areas where, up to now, there have been difficulties in the use of either air or mud drilling.

Additives to the air system increases the lifting capacity, reduces air requirements, prevents loss of air to the formation, increases drilling rate, prolongs bit life and improves geologic information obtained from the cuttings.

The economics of air drilling are variable and dependent upon many factors, however, it is claimed to be economical in over 75 per cent of all cases. The advantages of air drilling are many and include:

1) the elimination of fluid circulation equipment

2) the reduction of logistical problems

3) the rate of penetration is increased

4) the life of the bit is improved

Therefore, if fixed costs remained constant the increased penetration rate and bit life would reduce the overall drilling costs.

If subsurface conditions are not conducive to use of the Down Hole Drill or drilling with air and a rotary bit then we have to consider drilling with mud, as a circulating medium.

The composition of a drilling mud will depend upon the requirements of the particular drilling operations. Holes must be drilled through different type formations requiring different type drilling fluids. Economics, contamination, available make-up water, pressure, temperature and other factors are all significant in the choice of drilling fluid.

Water alone is sometimes an ideal drilling fluid and frequently used to drill areas where trouble free low pressure formations exist. When and where water is unable to perform the necessary functions of a drilling fluid, it becomes necessary to add other ingredients to make it perform better or, perhaps, even change the nature of the fluid itself.

In some areas, drilling can be started with water and the drilled solids incorporated into the water resulting in a reasonably good mud. In other areas, it may be necessary to add commercial clays to the water prior to starting drilling operations. The clays serve a dual purpose: First, to give body or viscosity to the drilling fluid and second, to seal the walls of the hole so the fluid being circulated will not be lost to the permeable formations being drilled.

The majority of drilling fluids may be classified as water base mud. The term water base mud refers to any drilling fluid having water as the liquid continuous phase and in which certain materials are held in suspension and other materials dissolved. There are numerous mud additives used to obtain special properties but basically, all water base muds have three components.

1. <u>Water Phase</u> - the continuous phase of the mud. Dependent on location and or available water, this may be fresh water, sea-water, hard water or soft water.

2. <u>Reactive Solids Phase</u> - composed of commerical clays and incorporated hydratable clays and shales from drilled formations and held in suspension in the fluid phase.

3. <u>Inert Solids</u> - refers to the three solids in suspension which are chemically inactive, these maybe inert drilled solids such as limestone, dolomite or sand,

The most important and most commonly used mud clay to obtain viscosity and fluid loss control is Wyoming bentonite or sodium montmorillonite. When the bentonite is mixed with fresh water, the layers absorb water and swell to the point where the forces holding them together become weakened and individual layers can be separated. Separating these packs into multiple layers is known as dispersion.

Mud performs a number of functions which are beneficial to the driller and also result in saleable holes. These functions are: (1) Cooling the bit; (2) Remove cuttings; (3) Lubrication of the bit bearings; (4) Prevents caving of the hole by hydrostatic head, consolidation of loose sediments, and it checks water intrusion; (5) Controls oil, gas, and water pressure; (6) Lubricates the drill pipe, wall of the hole, casing and slush pump; (7) Checks corrosion; (8) Holds solids in suspension; and (9) Cleans the hole and deposits the cutting in the mud pit.

Mud has certain properties which are basic to mud use in drilling wells. These properties are easily measured and controlled during the course of drilling. These properties are: 1. Weight (Density) measures the hydrostatic pressures in the borehole and solids content. It affects drilling rate, hole stability, aquifer damage, transportation and settling rate of cuttings. The desired weight is between 8.5 and 9.5 lb/gal. water weighs 8.34 lb/gal.

2. Viscosity (Thickness) measures the carrying capacity and gel development of the mud. It affects hole cleaning; drilling rate, hole stability, cuttings settling rate and drilling fluid circulating pressure. The desired limit is as thin as possible and still retain formation stability and cuttings lifting rate. Generally a 32 to 38 sec/qt. The viscosity of water is 26 sec/qt.

3. Filtration Properties (wall cake and filtrate) measures the ability of the circulating fluid to form a controlled filter cake on the wall of the hole. It effects hole stability, freedom of movement of the drill string, formation damage and development time. The desireable limits of a wall cake is 2/32 inches which is rapidly applied, slick, impermeable, soft and easily removed on back flow.

4. Sand Content measures the solid content of the mud of particle sizes of 200 mesh or over. A high sand content affects mud weight, equipment life, bit life, drilling rate, formation damage and drilling problems. The desireable limits of sand in suspension in a drilling mud is not over 2% by volume.

5. Calcium Indicator - measures the hardness of the make-up water due to dissolved calcium salt. A mixing water high in calcium salts (hardwater) affects mud mixing, filtration control, wall cake, supresses viscosity and gel development. It is recommended that the calcium content

should be less than 100 ppm. Water with a high calcium indicator can be corrected by pre-treating it with 1 lb. of soda ash per 100 gals.

6. pH measures the alkalinity or acidity of mixing water and drilling fluids. It affects mud mixing, hole stability and mud properties, corrosivity, viscosity, gel development and filtration control. The desireable limits is 8.5 to 9.5. It can be controlled by 1 to 2 lbs of soda ash per 100 gals of water.

If a mud program is planned with these properties in mind it will produce a good saleable hole with a minimum of trouble and downtime and the full potential of the aquifer will be achieved.

In most cases, mud circulation systems tend to reduce penetration rates and bit life compared to air circulation systems. Selecting a mud pump for a rotary drilling rig is much the same as selecting an air compressor. Both mud volume and pressure must be considered for a given set of drilling conditions. Mud volume requirements are a function of borehole diameter, bailing velocity and annular area. Bailing velocity can be calculated using the following equation:

$$B.V. = \frac{GPM \times .133}{\text{Annular area}}$$

where: B.V. = Bailing Velocity
GPM = Discharge of mud pump in gal./min.
Aa = Area of borehole annulus in ft^2
.133 = constant

The equation can be transposed to solve for required mud pump discharge.

$$GPM = \frac{BV \times Aa}{.133}$$

In mud drilling systems, there are two types of friction losses. Constant friction losses are the result of friction in the drill bit, drilling tools and surface connections. These losses are constant regardless of borehole death. Variable friction losses are the result of friction in the drill pipe and borehole annulus. These losses increase with depth. Total mud pressure for a given drilling program is the sum of the constant losses and variable losses at full borehole depth. The mud pump must be able to overcome these losses and provide the required mud circulating volume.

Crooked Holes

For several years after the advent of the rotary rig little regard was paid to the verticality of the drill hole, and as a result many wells were completed and produced for many years that were later found to deviated from vertical by large amounts. Cases are on record of wells found to deviated from vertical by more than 45°. In the Seminole Field in Oklahoma two wells drilled 660 feet apart at the surface ran together at a depth of 1000 feet.

Due to difficulties involved in completing wells with crooked holes as well as permanent difficulties encountered in producing such wells, studies were made to determine the causes of crooked holes and the possible means by which a well might be drilled with rotary tools and kept on an approximate vertical course. Deviation instruments were developed for checking the verticality of wells and correct drilling techniques were evolved for preventing appreciable deviation from the vertical.

There are two types of holes which deviate from the vertical; (1) A crooked hole is one in which the deviation from the vertical occurs within a relative short vertical interval and because of this, mechanical difficulties will arise. (2) A deflected hole is one in which the change in deviation is gradual enough that no appreciable mechanical difficulties will arise due to the deviation.

Experience has shown that the greatest single cause of crooked holes in rotary drilling is excessive weight on the bit. The weight on the bit becomes excessive when it is sufficiently great to cause the drill pipe to flex or buckle under compression. A reduction of the weight on the bit would remedy this condition. (Fig. 1) Another cause of crooked hole is a high rate of drilling mud circulation. An excessively high rate of mud circulation may, in certain types of formations, cause a cavity to be washed out ahead of the bit by the high pressure jets from the bit parts. As a result the bit deviates from a vertical course by following the line of least resistance. (Fig. 2) Here, again weight on the bit is an interrelated factor, since reduction in the weight on the bit would aid in the reducing the amount of deviation resulting from a jetting effect. However, reduction in pumping rate is the best remedy for this condition. Improper alignment of the drill string in starting a well, however, slight may result in increased deviation with depth. Therefore, it is important to be sure that the rig is level before starting the hole. Worn or out-of-gage bits are likely to deviate from the vertical because the driller will increase weight on the bit for a better penetration rate, which results in flexing of the drill string which in turn causes the bit to deviate from the vertical. Another cause of crooked holes is when the following subsurface situations are encountered. A relatively soft bed (A) underlain by a gentle dipping hard bed (B). The face of the bit tends to assume a position perpendicular to the hard bed and thus goes through at an angle inclined toward a perpendicular to the bedding planes. (Fig. 4) A bit may be deflected down dip in steeply dipping strata. A bit slides down dip when it encounters the hard bed (D) overlain by the relatively soft bed (C). The bit tends toward a direction parallel to the bedding planes. (Fig. 5) In order to avoid deviation from the vertical in such beds close control of the weight on the bit is necessary.

Because of the importance of maintaining a straight hole, a discussion of straight hole drilling and well surveying would not be complete without pointing out the many specific disadvantages that may accrue to the operator who does not keep a proper check on the course of a well bore during drilling.

An excessive number of twist offs in drill pipe may be directly attributable to this cause. The flexure of the drill pipe string during rotation in a crooked hole may cause early crystallization and failure. Rubbing of the drill pipe against the walls is more severe in a crooked hole and causes excessive wear of the pipe. If the hole is cased, the casing is also subjected to additional wear, and casing leaks may result. The additional frictional resistance to rotation of drill pipe in a crooked hole also causes a large increase in power requirements which adds to the drilling expense.

When the deviation begins to approach the maximum allowed amount, the method of bringing the hole back to a vertical course consists of reducing the weight on the bit to a sufficient degree that the bit will gradually assume a more nearly vertical course as drilling continues. If the deviation is found by test to exceed the allowable limit at any point the hole is plugged back to a shallow depth at which the deviation is within permissible limits and a new hole drilled. Considerable loss of time is experienced in straightening the hole in either case.

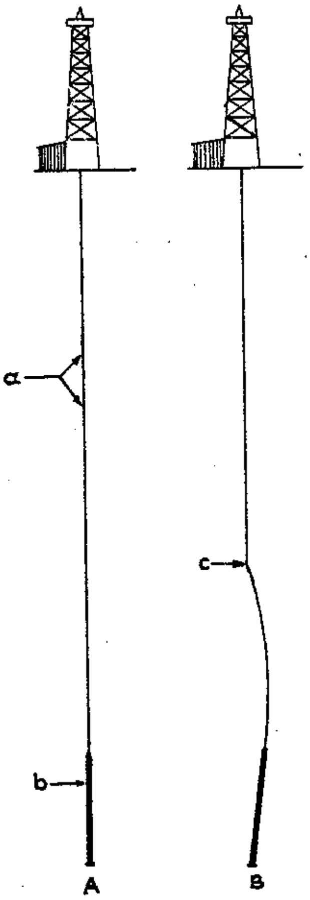


Fig. 1.

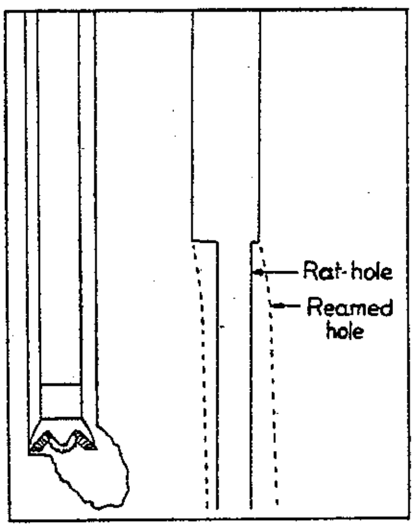


Fig. 2.   Fig. 3.

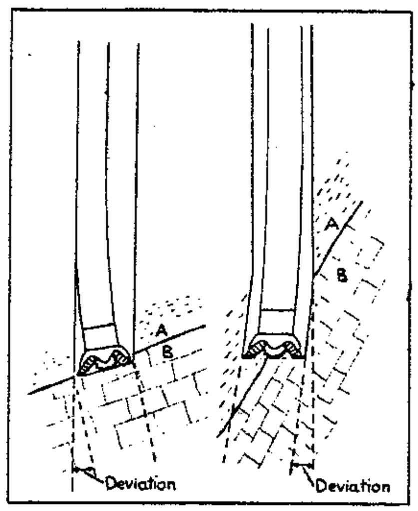


Fig. 4.   Fig. 5.

Lost Circulation

Lost circulation is one of the oldest and most common problems of rotary drilling. Although it constitues a major factor in most high drilling cost wells; and although much has been written on the subject, little systematic effort has been directed toward the solution or reduction of the problem. Lost circulation has been defined as the loss of whole mud in quantity to the formation. It may occur at any depth, anywhere that the total pressure against the formation exceeds the total pressure of the formation, and the openings in the formation are about three times as large as the largest particles occuring in quantity in the mud.

Causes of Lost Circulation

The formations in which lost circulation can occur can be listed under three types:

1. Coarsely Permeable Formations such as sands and pea gravel vary widely in their degree of permeability. Some of these formations take mud some do not. There is considerable variation as to what permeability is necessary to take mud. It has been demonstrated that mud cannot be forced into sand with a permeability of less than 14 Darcys. Whether or not a formation will take mud depends upon the rates between the pore openings and the particle sizes in the mud.

It is generally accepted that the formation openings which will permit mud to pass, must be about three times larger than the diameter of the maximum particle size found in quantity in the mud. Since this is the case, it may be concluded that mud loss only occurs to zones with relatively large openings.

2. Cavernous and Vugular Openings
Mud losses to cavernous and/or vugular formations and sometimes to reefs, gravel or other permeable zones are usually predictable in a given area because they occur in definite formations which are easily traceable. Vugs and caverns are generally found in limestone and dolomite. Losses to certain formations are so exact that they may form a pattern both in the area and in depth. Where the loss zones in wells have no pattern, mud loss to fissures may be assumed.

3. Fissures and/or Fractures

Mud loss may also occur in wells where no coarsely permeable zones or cavernous formations are known to exist. Such losses occur in fissures or fractures. These fissures or fractures may occur naturally or they may be created, enlarged or extended by mechanically imposed pressures. Once a fracture has been created or opened by an imposed pressure, mud lost to the fracture at a rapid rate will wash out and widen the fracture. Even though the pressure is later reduced, the opening may not close completely, and the loss of circulation will usually continue.

4. Mechanically Induced Fractures

The most outstanding cause of induced losses is mechanically imposed pressures. The effect of pressure surges developed by rapid running or spudding drill pipe will increase the effective mud density against the formations. If bit balling is present or if the annular area clearance is small, these pressures are further increased. Greater pressures are developed when pipe is spudded while circulation is in progress.

Methods and Devices for Locating Lost Circulation Zones

Several methods for locating the point of loss are available. Among these are: (1) The Spinner Survey, (2) The Temperature Survey, (3) The Radioactive Tracer Survey, (4) The Hot Wire Survey and (5) The Pressure Transducer Survey.

Preventive Measures

Preventing lost circulation before it starts is the most economical means of handling the problem. Basically, the problem is one of too much pressure on the formation. In rotary drilling the major pressure on the formation is the hydrostatic pressure of the mud column. In lost circulation areas, the mud weight should be controlled at the lowest value capable of controlling formation pressures.

Proper drilling practices should be followed such that no abnormal pressure surges are placed on the formations causing induced fractures. Often enlarged holes and insufficient pump capacities permit the accumulation of shales and cuttings in the mud thus adding to the hydrostatic head of the mud column.

When planning a drilling program, the possibility of lost circulation should be considered and all practical measures for preventing such losses should be taken. Every effort should be made to maintain optimum conditions of the mud coupled with good drilling practices.

Well Development

The combination of good drilling practices and the proper procedure of well development will result in achieving the full potential of the aquifer.

Drilling a well, under normal conditions, will result in some changes in the natural characteristics of the aquifer. If the well is drilled with a mud rotary rig a thin impermeable filter cake is deposited on the wall of the hole. If a percussion type rig is used; ie down-the-hole-drill or cable tool, vibrations set up by drilling or driving casing will pack the finer particles in the fractured zones. In both cases porosity and permeability is reduced, thereby reducing the yield of the well. This damage has to be corrected in-order-to achieve the maximum potential of the aquifer.

The purpose of well development is to remove the finer material from the aquifer to allow for the free flow of water into the screen area.

The object of well development is to cause water to flow both ways thru the screen. This rearranges the formation particles and also breaksdown any bridging effects by the particles.

The beneficial results of well development are:
1. It corrects any damage to or clogging of the water bearing formation which occurs as a side effect of drilling.
2. It increases the porosity and permeability of the natural formation in the vicinity of the well.
3. It stabilizes the sand formation around a screened well so that the well will yield water free of sand.

A screened well, designed to obtain water from a sand aquifer, may be completed in either of two ways. One method is by natural gravel packing. This method relies on the development process alone to generate, from the aquifer material, a highly permeable zone around the well sscreen. Completion by this method depends upon pulling out the finer particles from the water-bearing formation, bringing them into the well thru the screen openings, and bailing or pumping them out of the well. Removal of the finer particles leaves a naturally developed zone of uniformly graded sand or gravel of higher porosity and permeability surrounding the well screen. Another method is to artifically gravel pack the well. This method entails the placement of a highly permeable envelope of granular material around the well screen. Development work, in both methods, is continued until the formation is stabilized to prevent any further movement of sand. Completion by either one of these methods provides for the free flow of water into the well with negligible head loss which inturn results in reduced drawdown in the well.

There are a number of methods used to develop a well. They are as follows:

1. Mechanical Surging.
2. Surging With Air.
3. High Velocity Jetting.
4. Over Pumping.
5. Back Washing.

The addition of one of several polyphosphates, as a dispersing agent, facilitates the removal of mud. These polyphosphates disperse the clay particles in the drilling mud and break its gel properties. Breaking the gel makes the mud more easily removed by surging and back washing. The polyphosphates that work effectively in helping mud removal are: tetra sodium pyrophosphate, sodium tripolyphosphate, sodium hexameta phosphate and sodium septaphosphate. About 5 lb. of the chemical to each 100 gal. of water is sufficient to remove the mud.

Rock Wells

Drilling operations, in rock wells, also cause some plugging of fractures and crevices. The cuttings mixed with water form a slurry that can be picked up with a bailer. The pounding of the bit forces some of this slurry into the openings in the rock outside the borehole, thus effectively reducing the area of drainage. The full yield of the well can only be realized if all the openings in the rock are clean and can feed water into the well. Some of the development methods mentioned previously such as mechanical surging, overpumping, backwashing and surging with air are used to develop rock wells. In many cases explosives are used to shoot rock wells in-order-to enlarge a drainage system or to break into a more abundant fracture system. Charges of 30 to 500 lbs are generally used, the size varying with the hardness of the rock and the depth at which the charge is to be detonated. Hydrochloric acid can also be used to increase the drainage in limestone aquifers. The acid dissolves the limestone thereby enlarging the fractures, crevices and channels around the well bore.

Dissinfecting Wells and Piping

A necessary final step in well completion is the thorough disinfection of the well and its appurtenances

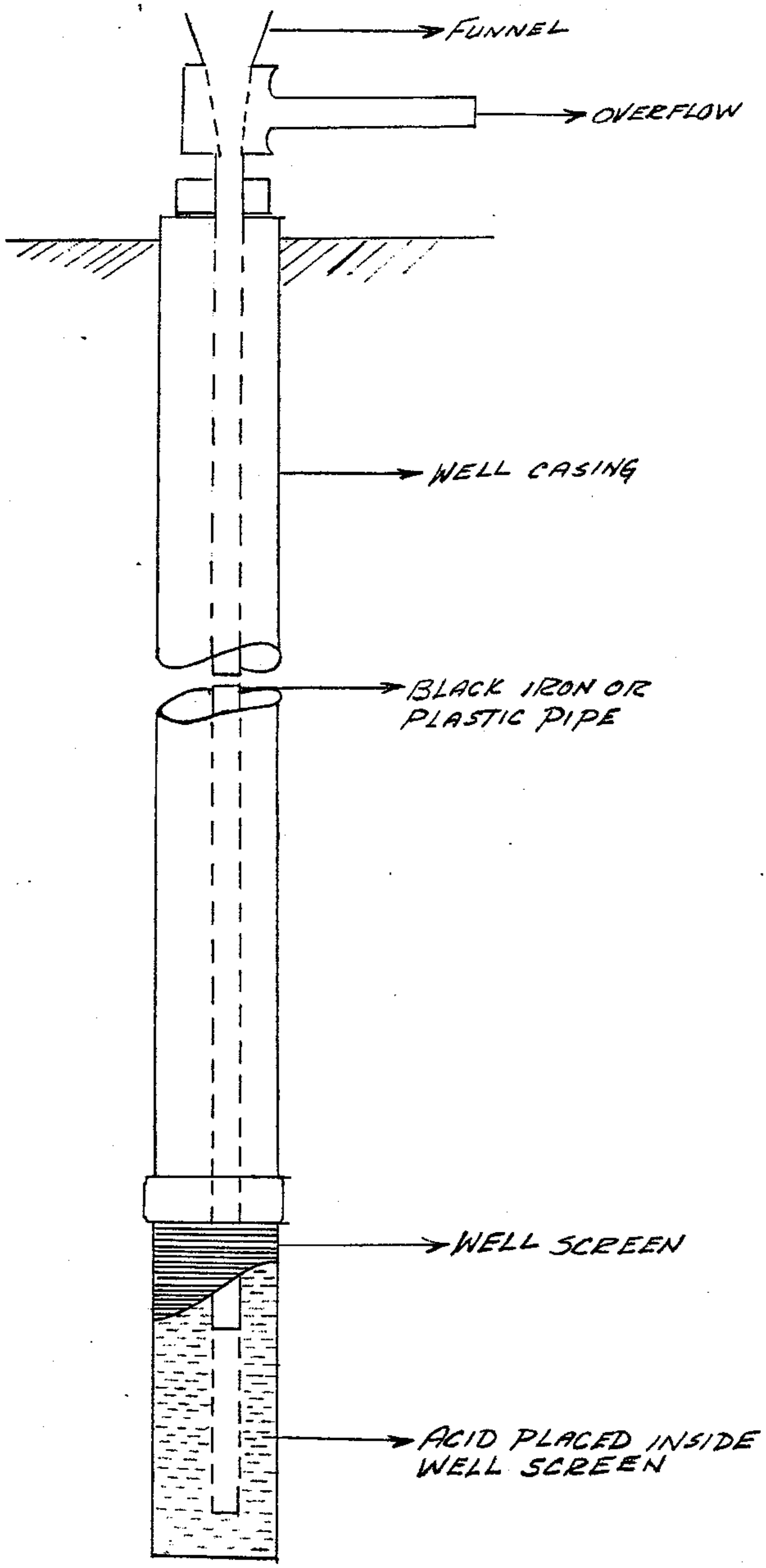


DIAGRAM TO SHOW HOW TO SPOT ACID IN WELL SCREEN.

to kill any bacteria that may be present.

The soil at the well site contains many types of bacteria. Most of these are harmless to man, however, one type known as coliform bacteria is an indicator of the presence of disease producing bacteria. An abnormal count of the coliform bacteria in the water is taken that the water is polluted by either animal or human waste.

A chlorine solution is the simplest and most effective agent for disinfecting a well, pump, storage tank or piping system. Highly chlorinated water for this purpose may be prepared by dissolving calcium hypochlorite, sodium hypochlorite or gaseous chloring in water.

Calcium hypochlorite is the easiest and safest product to use. It is a white granular material containing about 70% available chlorine by weight. It is marketed in tablet form under the trade name Pit-Tabs, HTH Tablets and Chlor-Tabs. Calcium Hypochlorite is the only product of the three that is in a granular form. It is, therefore, easily handled and stored. When stored under good conditions it will retain 90% of its chlorine content for 12 months. Sodium hypochlorite is only available in solution form. It is considerably less stable than calcium hypochlorite and does not retain its chlorine content for any length of time. Disinfecting solutions can also be prepared by bubbling chlorine gas through water. The chlorine dissolves in the water and forms a mixture of hypochlorous and hydrochloric acid. The pH of the water is reduced and this enhances the disinfecting action of the solution. Chlorine in the gaseous form is highly toxic and dangerous and is not recommended for disinfecting wells.

A solution of about 100 ppm available chlorine is recommended for disinfecting wells and piping systems. In order to assure this concentration a stronger solution should be initially introduced so that after mixing with the water in the well about 100 ppm chlorine will result.

CABLE-TOOL DRILLING

IN

LIMESTONES.

NOTES BY: W. L. JUNGMANN.

GENERAL RULES:

1) Swing all the iron you can.

2) Fill the hole as full as you can.

3) Keep it clean.

4) Don't lose anything in the hole.

5) Sometimes dry holes only seem so.

6) The driller takes the first drink.

REVIEW OF TOOLS:

1) Tool weights, shapes.

2) Tool dressing.

SEEING TO THE BOTTOM:

1) Drilling straight.

2) "Missing the vein".

3) Redrilling.

4) Tool guides.

DRILLING AIDS:

1) Mud.

2) Soap.

3) Revert.

4) Cement.

WHY AREN't ALL LIMESTONE WELLS DRY?

1) Cracks.

2) Fissures.

3) Tommy knockers.

4) The Limestone Connection.

5) "Hitting the Vein".

IF YOU WON'T DRINK IT, DON'T SELL IT:

1) Surface casing.

2) Casing joints.

3) Cementing.

4) Well Siting.

5) Pitless adaptors.

6) Softeners.

FISHING:

1) Prevention.

2) Why bother?

Geophysical Well Logging

E. Daly,
Geological Survey
of Ireland.

Geophysical Well Logging

Geophysical well logs have been run in many boreholes in the Carboniferous Limestone. The equipment used is a Gearhart-Owen Porta-Logger model PLA-PRG, number 101. The unit is mounted in a long-wheel base Land Rover. Six geophysical methods are normally used in investigations: spontaneous potential, single-point resistance, natural gamma, caliper, fluid velocity and fluid temperature. The uses of these methods and the conditions under which the logs can be run are summarised on Table A.

Spontaneous potential (s.p.) logs are continuous records of the natural electrical potentials developed between the borehole fluid and the surrounding rock materials. The measurements are made through two lead electrodes: one stationary in the ground at the surface, and the other moving in the borehole.

Single point resistance logs are continuous measurements of the resistance of the strata lying between a moving electrode in the hole, and a ground electrode. The same lead electrodes are used for both s.p. and resistance measurements.

The natural gamma log is a continuous record of the intensity of gamma radiation emitted by all naturally occuring radio isotopes in geological strata. The measurement is made by scintillation crystal (sodium iodide) used in conjunction with a photomultiplier tube.

The three methods described above mostly provide geological information. In the s.p. and natural gamma logs movement to the right generally indicates increasing clay or shale content whereas movement to the left indicates high sand content. With resistance logs the movement of the trace is opposite to the above.

/...

Caliper logs are made by running a caliper probe up the boreholes. The probe consists of three spring-loaded arms which follow the wall of the borehole and measure its diameter.

Fluid velocity logs are run with an impeller flowmeter which measures the rate of water movement in the borehole. These logs are run in both directions at constant velocity to determine the direction of water movement.

Fluid temperature logs, which provide a record of the thermal gradient of the fluid in the borehole, are made by running a probe with an exposed thermocouple down the borehole at a constant speed.

The three methods described above are primarily used to detect fissures and determine the flow regime in the borehole.

Examples of a number of well logs run in boreholes, in the Carboniferous Limestone, in the south eastern part of the country are shown in Figures 1-6.

TABLE A

USES, LIMITATIONS AND DETAILS OF GEOPHYSICAL LOGS USED IN THIS STUDY

PROBE	USES	BOREHOLE CONDITIONS	UNITS	LINE SPEED m/min	PROBE MOVING
Spontaneous Potential	Geological correlation, determination of bed thickness and detecting permeable zones.	Open hole fluid filled	Millivolts	5-6	Up the borehole
Single-Point Resistance	Geological correlation, determination of bed boundaries and changes in lithology and identifying fractures in resistive rocks.	Open hole fluid filled	Ohms	5-6	"
Natural Gamma	Identification of lithology and stratigraphic correlation.	Open or cased hole, dry or fluid filled	Counts per second	5-6	"
Caliper	Measuring hole or casing diameter. Locating fissures or wall collapse.	Open or cased hole, dry or fluid filled	inches	1	"
Fluid Velocity	Determining rate and direction of fluid movement up or down the hole. Locating points of water entry or loss.	Open or cased hole, fluid filled	Counts per second	3-12	Both directions
Fluid Temperature	Provides information on water movement and points of water entry.	Open or cased hole, fluid filled	Degrees centigrade	3	Down the borehole

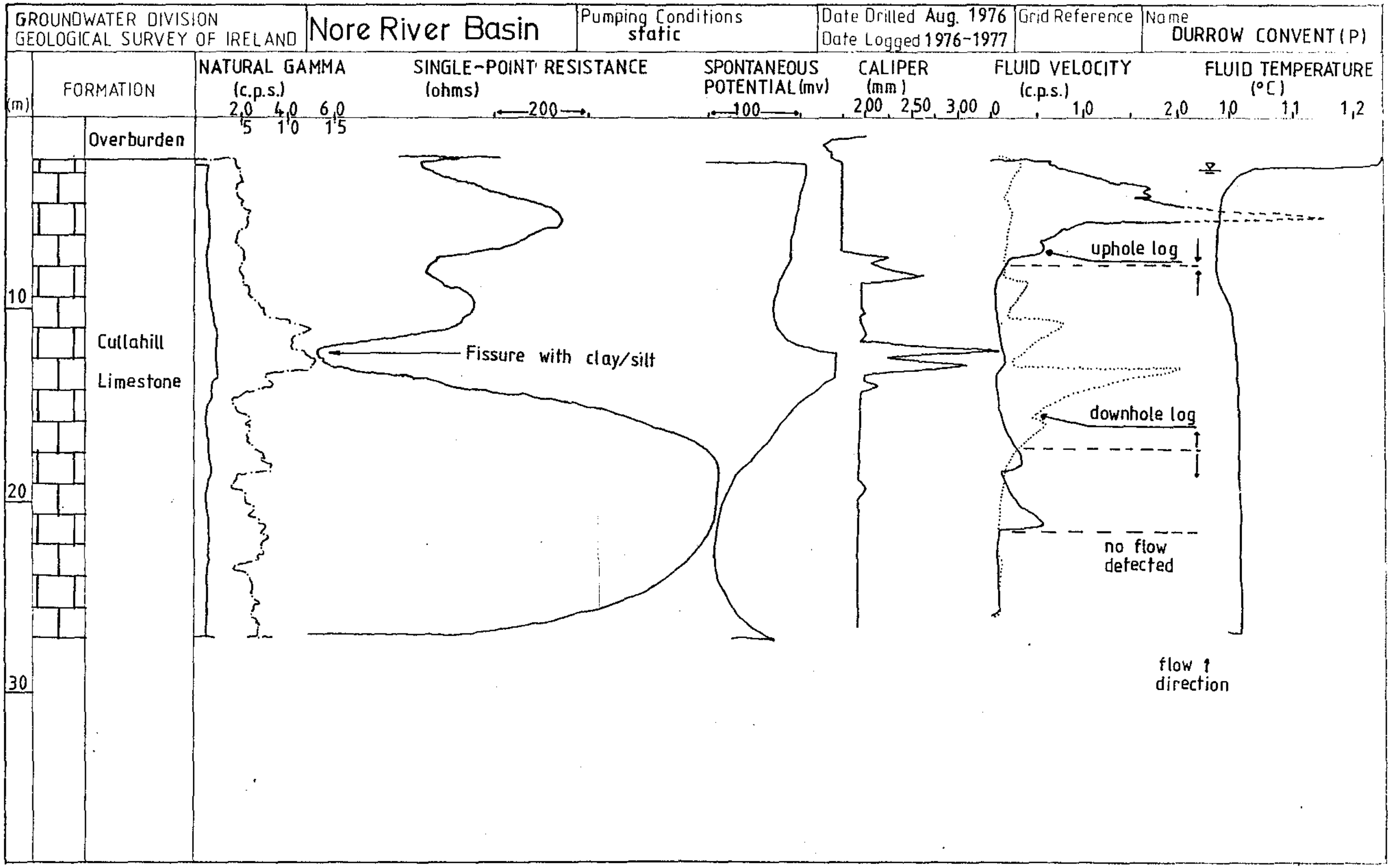


Figure 1 Geophysical Well Logs of borehole LS 29/3

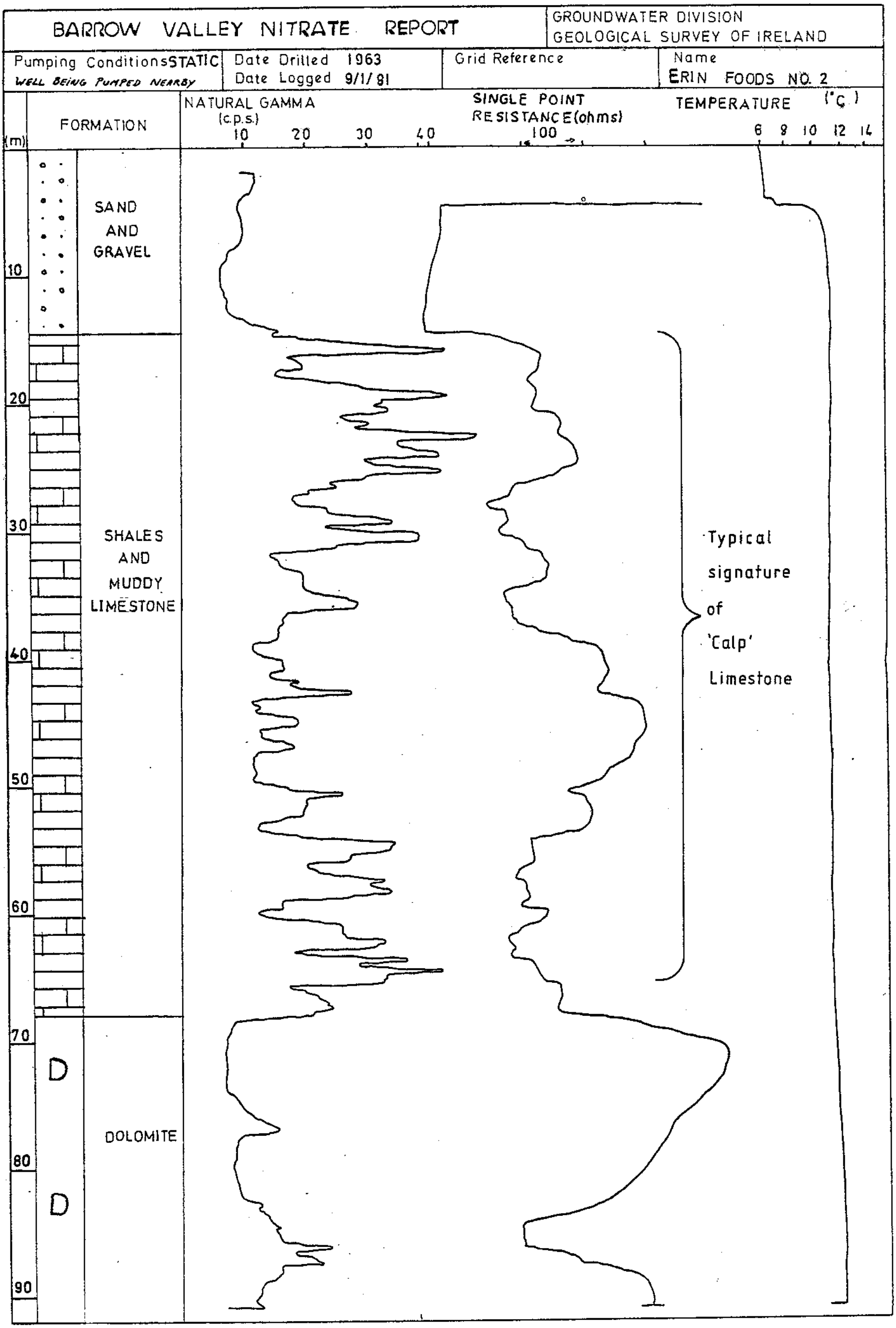


Figure 2 Geophysical Well Logs of Borehole CW 7/2

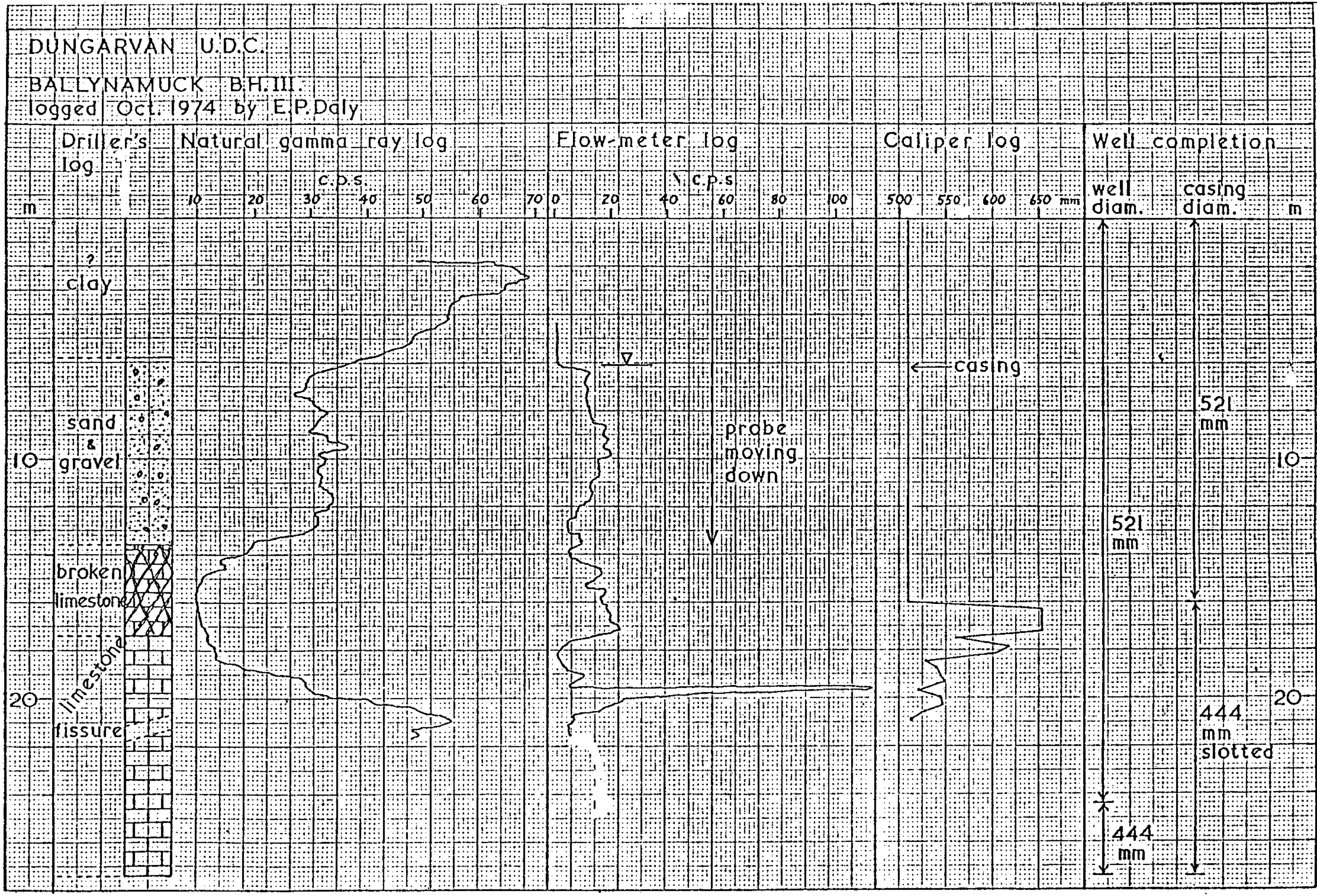

DUNGARVAN U.D.C.
BALLYNAMUCK B.H.III.
logged Oct. 1974 by E.P.Daly
Driller's log
Natural gamma ray log
Flow-meter log
Caliper log
Well completion
c.p.s.
c.p.s
m
10 20 30 40 50 60 70
0 20 40 60 80 100
500 550 600 650 mm
well diam.
casing diam.
clay
sand & gravel
broken limestone
limestone
fissure
casing
probe moving down
521 mm
521 mm
444 mm slotted
444 mm
10
20

Figure 3.

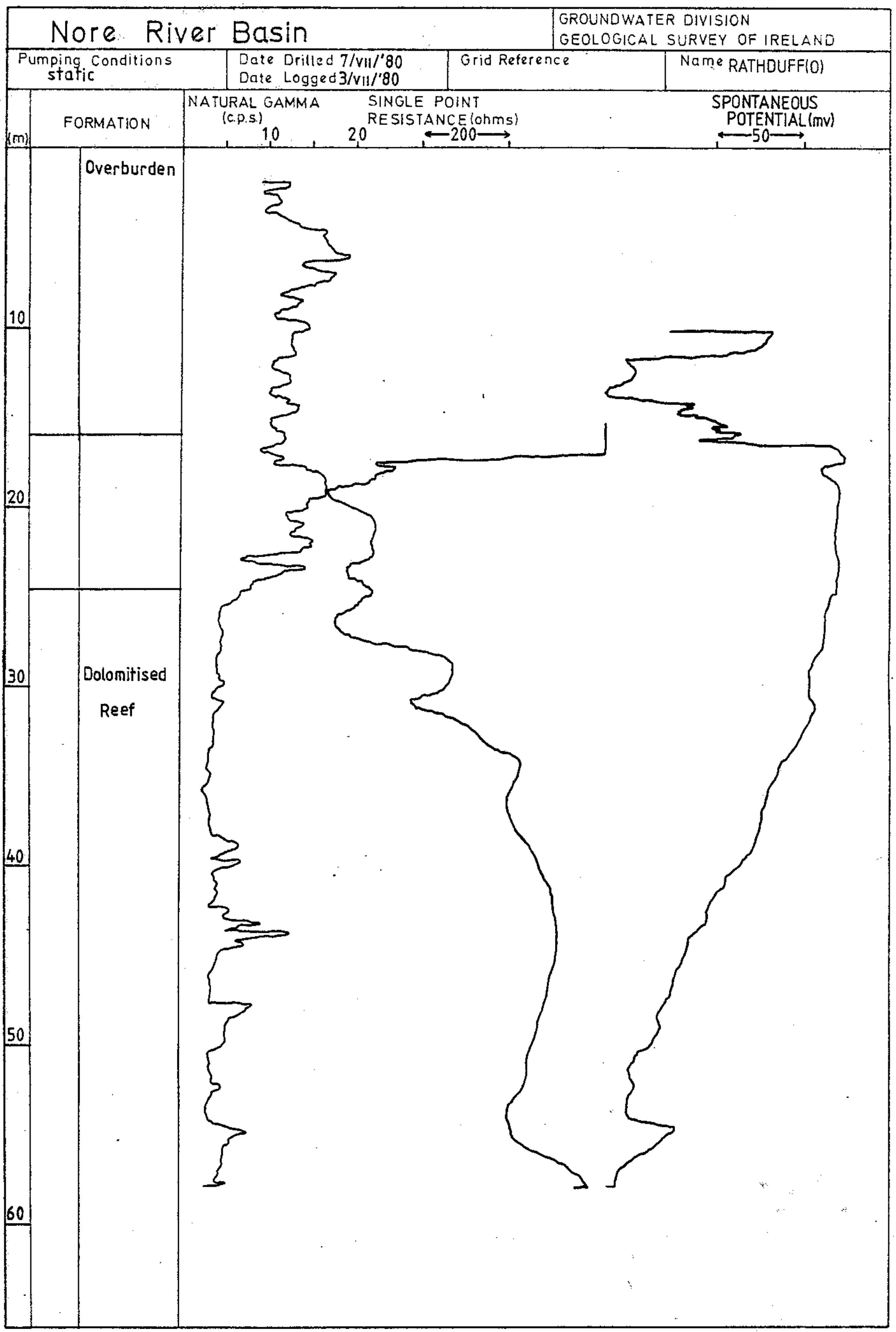


Figure 4 Geophysical Well Logs of borehole Kny 27/58

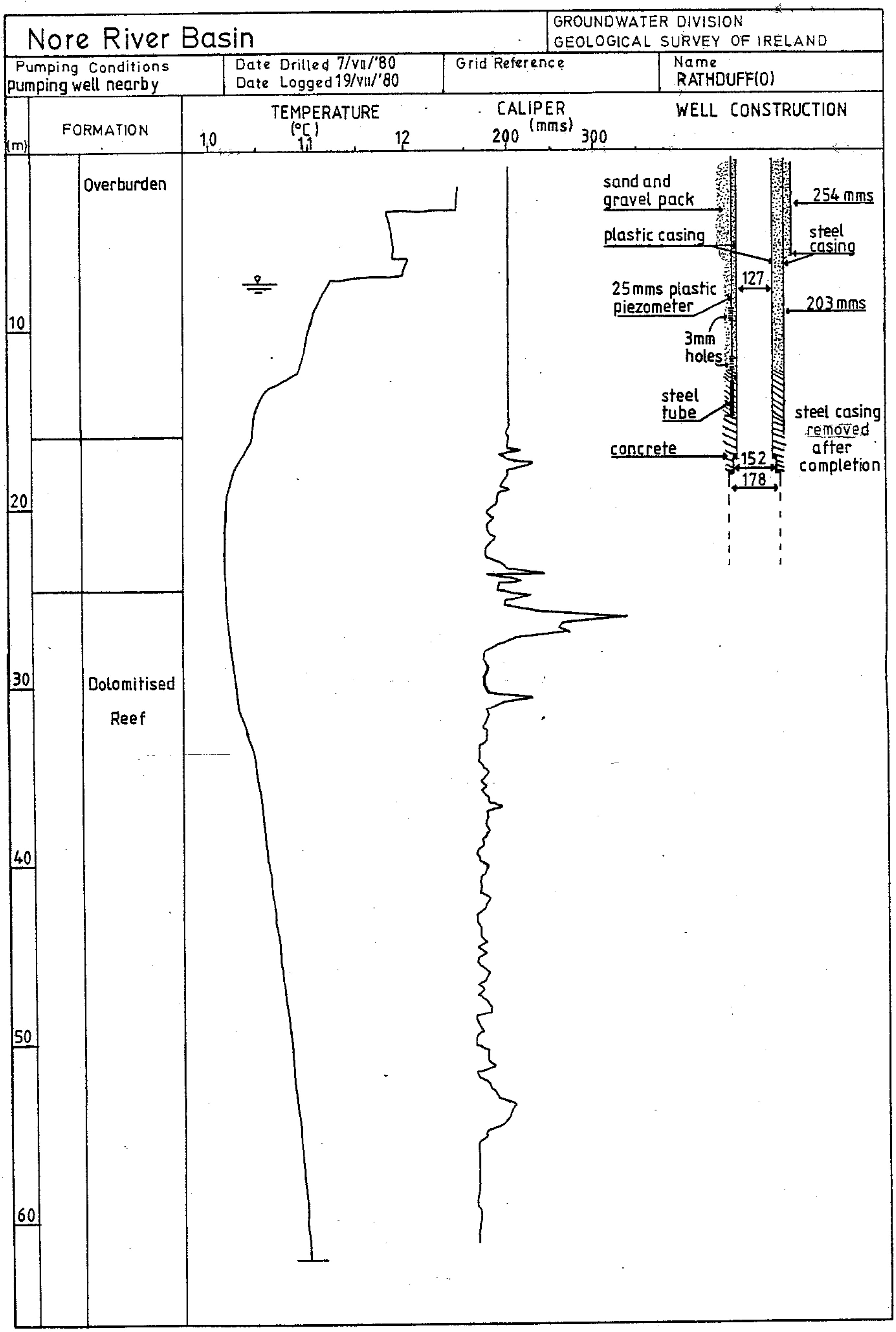


Figure 5 Geophysical Well Logs of borehole Kny 27/58

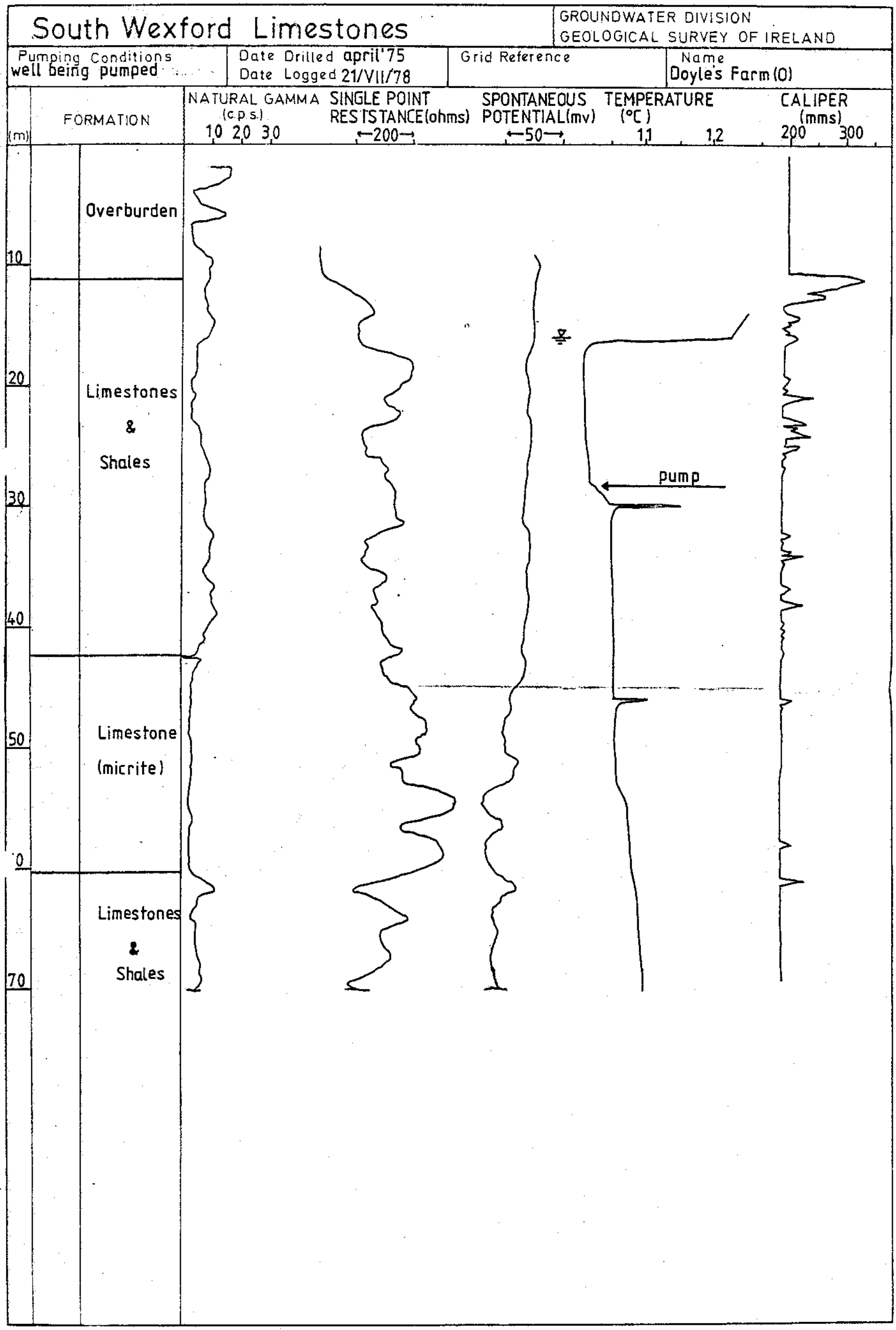


Figure 6. Geophysical well logs of borehole Wex 47/80