COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT No. 93

Geophysical Exploration For Underground Water

BY

W. A. WIEBENGA and E. E. JESSON

Issued under the Authority of the Hon. David Fairbairn
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MINISTER: THE HON. DAVID FAIRBAIRN, D.F.C., M.P.

SECRETARY: R. W. BOSWELL

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ILLUSTRATIONS

SUMMARY

The rock characteristics that enable geophysical methods to be used in the search for underground water are electrical resistivity, elastic properties, magnetisation, and density. Large scale structures, such as artesian basins or sub-basins, may be mapped by a combination of seismic, gravity, and magnetic methods; gravity surveys are useful for tracing deep leads or buried valleys; seismic and resistivity surveys are generally most useful in shallow basins for measuring depth to bedrock, locating the water table, and perhaps giving some information on rock characteristics or salinity of water. Bore-logging methods can be used for structural correlation and for measurements of porosity, permeability, and salinity.

The costs of the various geophysical methods are compared, and practical applications of the methods are illustrated by examples.

1. INTRODUCTION

Fundamentally, hydrological problems do not differ from problems met with in the search for mineral deposits. It may even be said that water is Australia's most sought-after mineral. Hence the tools used for solving problems in conventional mineral search may be equally well applied to water problems. Climate may influence the practical execution of a survey to some extent, but it does not change the choice of the methods. It is the purpose of this paper to discuss some rock characteristics associated with ground-water problems, and some of the tools used in solving the problems.

The contents of this Report was presented to the Arid Zones Conference at Warburton, Victoria, in November 1960.

2. ROCK CHARACTERISTICS

Resistivity

Electrical resistivity is the rock characteristic used in electrical surveys and bore logging (or well logging). In the following, some formulae and concepts are explained.

$$r = FR_W = P^{-m} R_W \quad \ldots\ldots (1)$$

in which

r is rock resistivity in ohm-metres,

P is porosity as a fraction,

R_W is resistivity of pore solution in ohm-metres,

m is a cementation constant, and

F is a formation factor equal to P^{-m}

R_W approximately equals 5000/C ohm-metres, in which C represents the salinity in p.p.m. For a temperature of about 20°C, and only small temperature variations, a temperature correction is not needed.

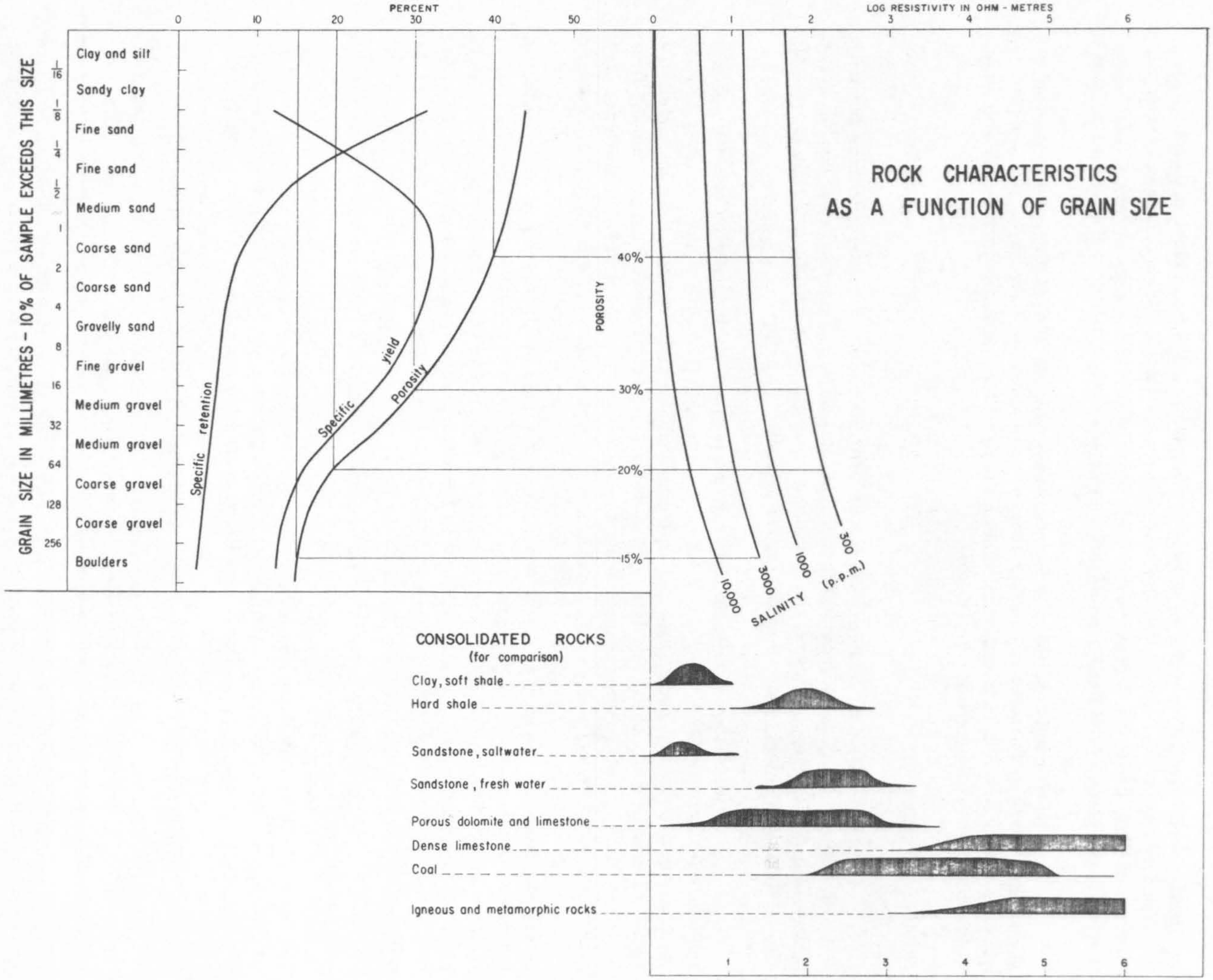
The cementation constant m ranges between 1.25 and 2.2 or higher. In unconsolidated deposits near the surface, m equals about 1.25; in moderately cemented rocks m is about 1.8 and in highly cemented rocks it may be 2.2 or higher.

Equation (1) is generally used in the linear log form:

$$\log r = -m \log P + \log R_W \quad \ldots\ldots (1a)$$

Plate 1 shows how the porosity, specific yield, and specific retention of unconsolidated sediments vary with grain size (Todd, 1959), and shows how their resistivities vary with porosity and salinity. For comparison, the resistivity ranges of some consolidated rock types are shown as well.

ROCK CHARACTERISTICS AS A FUNCTION OF GRAIN SIZE



From Plate 1 it may be observed that:

(a) Unconsolidated deposits containing salt water have a much lower resistivity than those containing fresh water.

(b) The older cemented igneous and metamorphic rocks have a much higher resistivity (by a factor of 10 or more) than unconsolidated surface rocks; hence, it should not be difficult for resistivity methods to disclose subsurface valleys filled with unconsolidated deposits, and it may even be possible to delineate the salt water zones.

In bore logging, the differences in porosity between gravel, sand, and clay are clearly recorded, and with suitable equipment and sufficiently thick layers, accurate estimates of porosity may be given. In hydrological studies the resistivity of rocks may be classed as one of the most important rock characteristics.

Seismic velocities

The seismic velocities in rocks are controlled principally by rock porosity, although several other minor factors play their part as well: e.g. cementation or consolidation, hydrostatic and unilateral stress, the degree of saturation with liquids or water, grain size, and sorting all play their part as modifying influences.

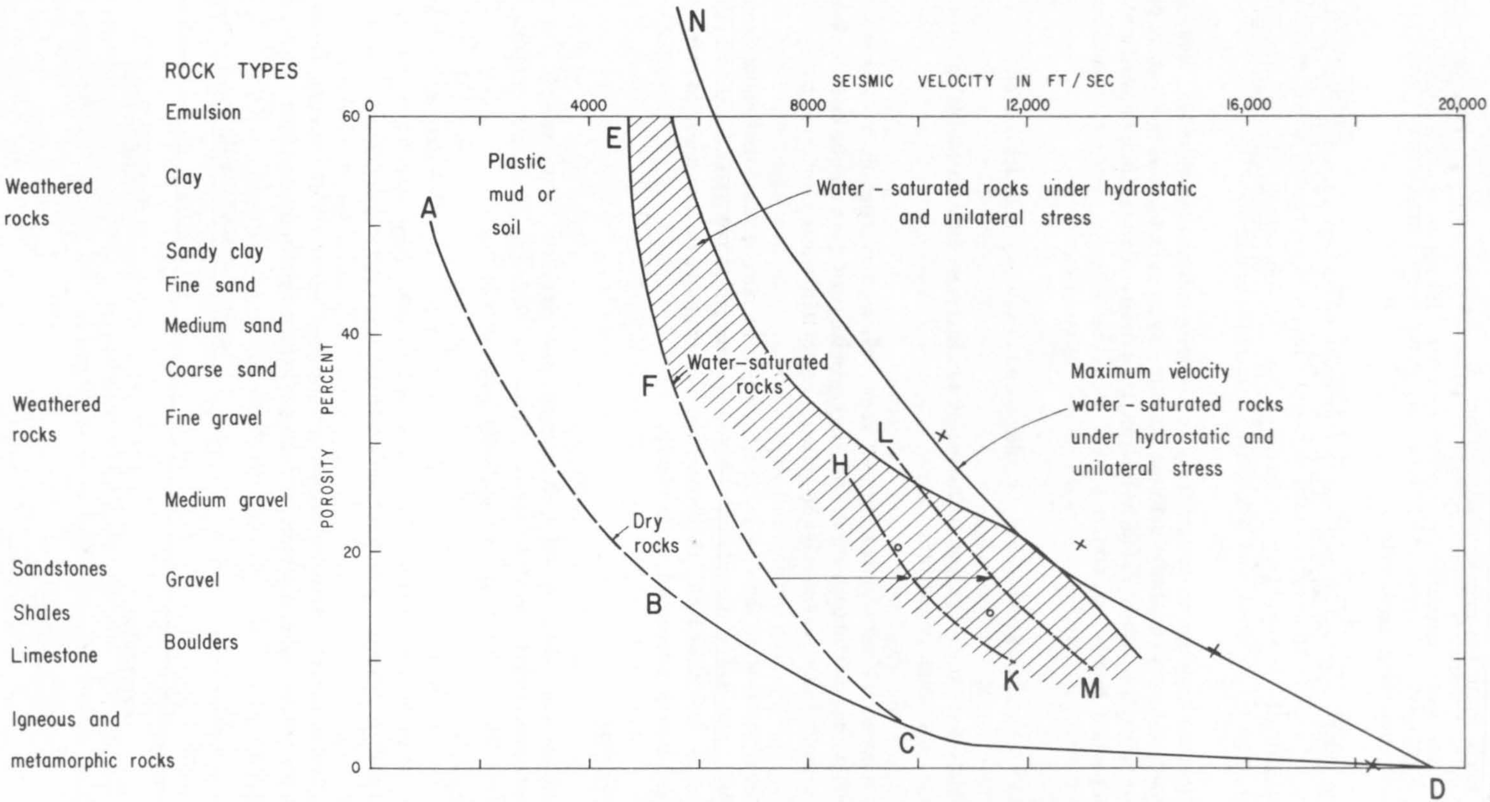
Plate 2 shows a diagram illustrating quantitatively the relation between porosity and seismic velocity for a variety of rock types. Curve ABCD shows approximately how the seismic velocity in dry rock under negligible hydrostatic and directional stress varies with rocks of different porosity and type. This is derived from practical experience and from Wuerker (1956). This curve is applicable to dry rocks above the water-table. Curve EFC gives the seismic velocity in water-satured, unconsolidated rocks under negligible hydrostatic and directional stress (Hamilton, 1956; Wyllie, Gregory & Gardner, 1958). Under certain circumstances, namely in gravelly or sandy unconsolidated sediments, the velocity is that of the water wave transmitted through the rock pores; a second wave, slower than the pore wave, is transmitted through the solid rock particles or rock frame but is rarely recorded in field work because its arrival is usually masked by the earlier pore wave. The first arrival of the pore wave in unconsolidated rocks can be used in field work to determine the depth to the water-table.

Partially water-saturated or moist unconsolidated rocks, referred to as plastic mud or soil, are represented in the diagram between A and E.

Curve ND gives the maximum velocity ('terminal velocity') under hydrostatic and unilateral stress for rocks saturated with brine; the data were measured on rock samples (Wyllie et al., loc. cit.). These conditions represent the maximum velocity likely to be encountered. For rocks saturated with low-salinity water, the velocity will be slightly lower but not sufficiently lower to allow differentiation between fresh and saline water.

The effect of hydrostatic stress is diagrammatically indicated by a shift of curve FC to position HK; the effect of unilateral stress is indicated by a further shift to LM. In its extreme position LM coincides with ND.

The hatched area on the diagram represents a zone of water-saturated rocks whose porosities and seismic velocities were measured on rock cores. The data were taken from Nafe and Drake (1957, p. 450).



RELATION BETWEEN ROCK TYPES, POROSITIES, AND SEISMIC VELOCITIES

PLATE 2

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 369-2

The crosses (x) on the diagram represent rocks whose average porosities and seismic velocities were measured in situ in boreholes. It may be observed that the crosses are close to curve ND.

The small circles (o) represent measurements on cores of consolidated, water-saturated sandstone under zero hydrostatic and zero unilateral stress (Wyllie et al., loc. cit.)

The following conclusions may be derived in relation to practical hydrological work:

(a) In general, the lower the porosity, the higher the seismic velocity. However, the width of the hatched zone indicates that rocks with a considerable range of porosity may have the same seismic velocity. Thus deep-water sediments (well sorted and therefore highly porous) may have the same seismic velocity as shallow-water sediments (poorly sorted and therefore less porous).

(b) Water-saturated rocks have a higher seismic velocity than dry rocks.

(c) Hydrostatic pressure and unilateral stress increase the velocity but only towards a limit ('terminal velocity').

(d) In unconsolidated water-saturated rocks the wave through the rock pores may be faster than that through the solids, and hence the pore wave can be used to determine the depth to the water-table in seismic refraction work.

(e) Rock types with their associated porosities and grain sizes under favourable conditions can be correlated with yield (Plate 1). Hence seismic velocities, which can be associated with rock types and porosities, can also under favourable conditions give a measure of the yield.

Magnetic properties

Magnetite, owing to its high magnetic susceptibility and to its wide distribution in rock, is the most important of the ferromagnetic minerals, and is largely responsible for the induced and remanent (or residual) magnetisation of rocks.

The intensity of induced magnetisation (I) is defined as the induced pole strength per unit area along an area normal to the inducing field (H). These quantities are related by the formula $I = kH$, in which k is a factor known as the magnetic susceptibility.

The following data from Birch, Schairer and Spicer (1950) indicate the magnetic susceptibilities (in e.m. c.g.s. units) of ferromagnetic minerals in fields of 0.5 to 1.0 oersted.

Mineral	Magnetic susceptibility (c.g.s. units/cm^3)
Magnetite	0.3 to 0.8
Pyrrhotite	0.01 to 0.03
Ilmenite	0.03 to 0.04
Specularite	0.003

The wide distribution of rocks with high magnetic susceptibility is shown by the following figures which give the percentage of rocks, within each rock type, that have magnetic susceptibility greater than 0.001 c.g.s. units/cm^3.

Rock Type	Percentage
Basalt	66
Basic plutonics	49
Granite	17
Metamorphic rocks	7
Sedimentary rocks	8

Remanent (or residual) magnetisation is defined as the existing pole strength per unit area (or magnetic moment per unit volume) when the inducing field is reduced to zero. The remanent magnetisation of igneous rocks was acquired when the rocks cooled from the Curie temperature in the then prevailing Earth's field. The ratio of remanent magnetisation (I_r) to induced magnetisation (I_s) varies considerably for different rocks. Below are some figures quoted by Birch _et al._ (_op. cit._ p.297). I_s was induced in a field of 0.5 oersted.

Rock	I_r / I_s
Basalt	0.5 to 9.3
Gabbro	1.4 to 28.0
Granite and granite porphyry	0.3 to 6.4

These values illustrate the importance of remanent magnetisation.

The induced and remanent magnetisations have a combined effect in the vertical magnetic intensity as measured along a traverse. During weathering, the ferromagnetic minerals partly or completely lose their magnetic properties. If the remanent magnetisation vector is negligible, or in the same general direction as the Earth's field vector, weathered shear zones ('demagnetised' rock zones) are indicated by lower vertical magnetic anomalies (minima or 'lows') in the magnetic profile. This characteristic has been successfully used, in combination with other methods, to delineate weathered shear zones or subsurface valleys in granite or other basement rocks containing magnetite. If the remanent magnetisation vector is in a direction approximately opposite to the present Earth's field, and exceeds the induced magnetisation, shear zones or subsurface valleys would be indicated by magnetic 'highs', but up to date no evidence has been found that this type of anomaly occurs.

In areas with subsurface valleys filled with alluvial material, sharp magnetic anomalies with steep gradients, but covering small areas, indicate the presence of shallow alluvial magnetite deposits, usually sand or gravel (aquifers) containing magnetite.

The above paragraphs show how magnetic methods could be used in combination with other methods to assist in the selection of drilling targets for water in shallow deposits.

Density

If the density contrast between basement and overlying strata is known, the depth to the basement can be estimated accurately from gravity measurements. Therefore, subsurface valleys and deep leads can be delineated by gravity surveys.

Other rock characteristics such as permeability, electrical self-potential (S-P), and radioactivity will be discussed under logging methods.

3. TYPES OF PROBLEM

Broadly, hydrological problems that can be solved by geophysical tools may be arranged into three groups:

Large-scale structures, e.g. artesian basins

The methods used for water investigation here are the same as those used in oil exploration: gravity, seismic refraction, and seismic reflection methods. Usually no detailed information about the rock types is obtained, but drilling targets are chosen according to structure (synclines, faults, rock contacts).

Shallow basins, subsurface valleys or deep leads

The requirements for a suitable ground-water supply include:

(1) Suitable thickness of sediments.

(2) Reasonable porosity of these sediments.

(3) Suitable permeability of sediments.

(4) Low salinity of the pore solutions.

(5) Sufficient replenishment of water.

To answer some of the questions associated with the above requirements it is necessary to make a bedrock contour plan; from this it can be seen whether the basin is partly or completely closed, and where regular flushing out by surface water takes place.

Further, it is desirable to know the distribution of fresh and salt water, to obtain some indication of the rock types, and if possible to locate the water table. Most of this information can be obtained by using a combination of resistivity (traversing and depth probing), seismic refraction, and magnetic surveys. The gravity method can often be used, but if not necessary should be avoided because of the large amount of topographical surveying and computing it requires.

Problems that can be solved by bore logging

Logging of bores gives the following information:

(1) Qualitative evidence of the rock types.

(2) Inter-correlation of boreholes.

(3) Quantitative estimates of the porosity and permeability of the rocks and of the salinity of the pore solutions (with suitable equipment). In drilling for water, logging should always be used to determine which strata should be cemented off to avoid contamination, and which strata should be used for water production.

4. METHODS

Seismic

The seismic refraction method is the one most used, and the principal objective is to determine the depth to the discontinuity between sediments and the basement. The method depends upon the contrast in the elastic properties of different strata. The physical laws involved resemble those of optical phenomena in that energy propagated through the ground undergoes reflection and refraction at discontinuities.

An explosive charge detonated near the ground surface at the 'shot-point' produces a train of seismic waves, which are reflected and refracted at discontinuities. A ray meeting a discontinuity at the critical angle is reflected along the discontinuity, giving rise to rays which travel upwards to the surface, where they are detected by 'geophones'. The travel times of the rays from the shot-point to the geophones via the discontinuities are recorded.

A series of equally-spaced geophones is set up in line and the first-arrival times (and later-arrival times if possible) are plotted against the horizontal distance from the shot-point. Such a plot is called a 'time/distance' curve.

The slopes of successive sections of the time/distance curve indicate the velocities of the seismic waves in successive formations, and from these data it is possible to compute the depth to the formations. The computation techniques are extensively discussed in the literature and hence will not be described in this paper.

Although the principal objective of the seismic method is the determination of the depth to elastic discontinuities, the seismic velocity is an important indication of the physical character of the material.

It is possible, and even probable, that the physical characteristics (such as seismic velocities) of sediments and underlying weathered bedrock overlap. Under such conditions the seismic method cannot locate the contact between sediments and weathered bedrock. Even if there is sufficient seismic velocity contrast between three formations, the intermediate formation must have at least a certain minimum thickness before its presence can be detected from first-arrival times of seismic events. Thin alternating layers or lenses of sand, clay, and gravel cannot be identified individually by seismic methods. Usually, the layers are recorded as larger groups or units with velocity equal to the average velocity of the members of the group.

Seismic reflection methods, commonly used in surveys to disclose deeper and larger structures, are not discussed here because they are already extensively described in the literature.

Resistivity

Of the several electrical methods in use in geophysical exploration, the resistivity method is thought to be the most suitable for the problems encountered in seeking shallow water deposits.

In the resistivity method, electric current is supplied to the ground at two points and the potential is measured between two other points. The ratio of potential to current, multiplied by a spacing factor, gives what is known as apparent resistivity. It is generally accepted that the depth of current penetration is about the same as the electrode spacing.

The resistivity methods of exploration may be classified as follows:

(a) Depth probing or 'electrical drilling', in which there is a variable electrode spacing, and therefore a variable depth penetration. This makes it possible to determine the depth to basement or bedrock, to water level, or to beds of stratigraphic importance in general, provided that the formation boundaries are marked by sufficiently large resistivity discontinuities.

In 'electrical drilling' the normal Wenner configuration is usually used: the four electrodes are equally spaced in line, the two inner electrodes being potential electrodes. For convenient interpretation of the electrical drilling, the log resistivities are plotted against the logs of the electrode separations and compared with pre-computed two-, three-, and four-layer theoretical curves.

(b) Traversing, in which the electrode spacing (and therefore the depth penetration) is kept constant and the arrangement is moved as a whole. Hence horizontal variations in character or variations in depth of a given formation may be determined.

Depth estimates are never very accurate, and their inaccuracy increases with the number of layers in the geological cross-section. However, the resistivity method is very valuable as an easy and cheap reconnaissance tool.

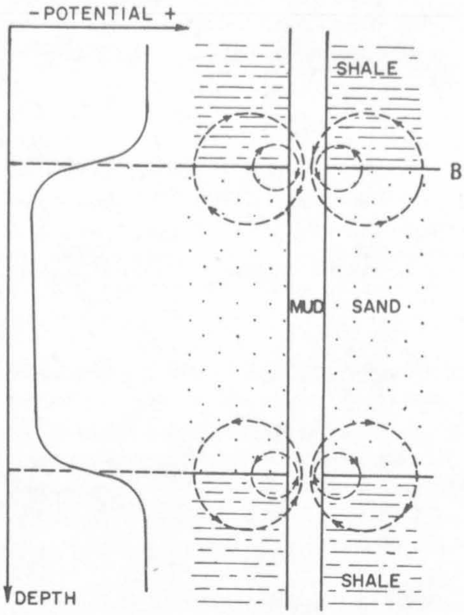
Magnetic

The magnetic method depends on the susceptibility contrast between formations, and should therefore provide a means of determining the discontinuity between basement and the overlying strata if the basement contains magnetite. Magnetic anomalies indicate undulations in the basement (especially shallow basement), and the sharpness of the anomalies is a good indication of depth. Field operation with a magnetometer measuring vertical magnetic force is fast and cheap. Used alone, the magnetic method is rarely adequate, but in combination with other geophysical methods it will often render valuable additional information.

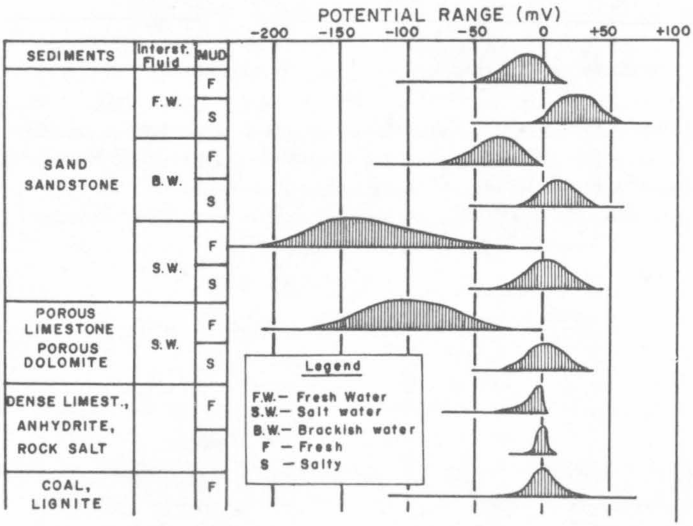
Gravity

The gravity method depends on the detection of variations, in the Earth's gravitational field, due to the uneven distribution of subsurface rocks of different densities. Because several features, such as density variations in bedrock and in sediments, may give the same anomaly, the interpretation is usually qualitative. A gravity survey will indicate anomalous zones for further testing by other methods.

PLATE 3



Typical potential graph for sand in shale formation



Potential range of common sediments

SELF - POTENTIAL LOGGING

G 369-23

If the gravity method is used in rough country, corrections for topography have to be applied. These may be greater than the anomalies being sought. They also require extensive topographical surveying.

Unless other geophysical methods fail, the gravity method is not recommended, because of the high accuracy requirements of the topographical survey as compared with resistivity or magnetic traversing. It is less expensive than seismic work, but in general gives less-precise information.

Gravity surveys are useful in tracing deep buried valleys.

Bore logging

Single-point resistance logging. In single-point resistance logging, recordings are made of variations in electrical resistance between the logging electrode at some point down the hole, and the ground electrode situated at the surface. Practically the whole of the resistance in the circuit is in the immediate neighbourhood of the electrodes. As the ground electrode is stationary its resistance is assumed to be constant during the measurements, and the recorded changes of resistance are therefore due to the logging electrode passing through beds with different resistivities.

The amplitude and width of the variation is controlled by the nature and thickness of the beds opposite the logging electrode, the borehole diameter, and the resistivity of the mud. However, the recorded variations are not linearly related to the differences of resistivity of the beds; variations in the higher ranges of rock resistivity have a smaller effect on the log than similar variations in the lower ranges. Therefore in the higher ranges it is impossible to estimate with any accuracy the true resistivity from the single-point resistance log.

The resistivity of a rock is inversely proportional to the product of its porosity and the salinity of the pore solutions. Assuming that the salinity of the pore solutions remains about the same over large rock sections, variations in the resistance log will indicate variations in porosity, and with certain limitations these can be translated into geological terms. For instance clay and shale, being very porous, are indicated by a low resistance; and unsorted materials of low porosity, such as gravel and unsorted sand, are indicated by a high resistance. Well-sorted sand (commonly fine-grained) is indicated by a medium resistance on the log.

By using more-complex multi-electrode equipment, it may be possible to make accurate estimates of rock resistivities. Resistivity logging can be done only in uncased holes filled with water or drilling mud. This applies also to self-potential logging, described in the following paragraphs.

Self-potential (S-P) logging (Plate 3). The potential graph is obtained by measuring the potential difference between the logging electrode and the ground electrode. As the ground electrode is at constant potential, the record shows the way the potential varies along the hole.

The potentials measured in logging are set up when the fluid column is introduced during the drilling, and are considered to be mainly of electro-chemical origin. Laboratory experiments have shown that a flow of current takes place around the common point of contact of shale, sandstone containing saltwater, and a fresh water drilling fluid; the direction of current flow is from shale to drilling fluid to sandstone and back to shale. As a consequence of this circuit, the current flowing in the mud column will produce a potential drop opposite the shale/sandstone boundary within the drilling-fluid column. The potential of the fluid column within the sandstone will be negative with respect to the potential of the fluid within the shale. Should the drilling fluid be more saline than the pore solution in the sandstone, the current of the electro-chemical circuit will be reversed, and the sandstone will be positive with respect to the shale.

Laboratory experiments have shown that the total electromotive force (E) generated by the electro-chemical phenomenon can be represented by the empirical formula:

$$E = k \log_{10} (Rm/Rw)$$

where Rm is the resistivity of the drilling fluid

Rw is the resistivity of the pore solution

k is the constant depending on the nature of the bed.

For clean sand and a pore solution of sodium chloride, with E in millivolts, k is about 70. For sand containing a minor amount of clay, k is somewhat lower.

The shape and amplitude of the S-P anomaly due to a bed may be influenced by the following factors:

(1) Total electromotive force (static S-P) involved.

(2) Thickness of the bed.

(3) Resistivity of the surrounding formation and the drilling fluid.

(4) Diameter of the borehole.

(5) The degree of infiltration of drilling fluid into the bed.

(6) Permeability of the bed.

Because the S-P log usually indicates the permeability of formations, it is sometimes called the 'permeability log'. In practice the S-P log through shale and clay is used as zero reference line, and permeable sand and gravel may be indicated by negative anomalies as great as 100 mV.

In the weathered zone near the surface, the S-P log often shows irregularities, or a drift, caused by electro-chemical reactions associated with weathering.

Radioactive (gamma-ray) logging. Radioactive logs show the natural radioactivity of the formations penetrated by the drill. The following is a list of sedimentary rocks in decreasing order of relative radioactive intensity:

(1) Organic clay and shale

(2) Clay and shale

(3) Shaley sandstone

(4) Shaley limestone

(5) Sandstone

(6) Limestone

(7) Dolomite

(8) Salt

(9) Coal.

As clay and shale are generally more radioactive than sand or limestone, the radioactive log variations generally correspond to lithological changes in a manner similar to the variations in the S-P log. In other words, in many places there is a very good correlation between radioactive variations and S-P variations. For this reason radioactive logs may replace S-P logs where it is difficult or impossible to take S-P logs; for instance, in cased holes, in holes with a saline or oil-based drilling mud, or in empty holes. Radioactive logging may also be used for correlation of old holes either cased or uncased. The response of the radioactive probe does not depend only on the radioactivity of the formations. It also depends on the diameter of the hole, the density of the drilling fluid, and the casing thickness. These conditions have to be taken into account in interpretation, and corrections have to be applied for quantitative interpretation.

The radioactive probe used in the Bureau's Widco logger is calibrated against a known cobalt source, and the results are expressed in millirontgen per hour per inch (mr/h/in). With this unit a combination of radiation energy and flux is measured.

Costs

A comparison of the costs of geophysical methods when applied to ground-water problems is shown in Table 1. It is of interest to compare these costs with those for test drilling. Assuming 50,000 ft of traverse, with test holes 100 ft deep spaced at 200-ft intervals, the cost of drilling at £1 per foot is £25,000.

Examples

Some examples of the use of geophysical methods are given in Plates 4 to 9.

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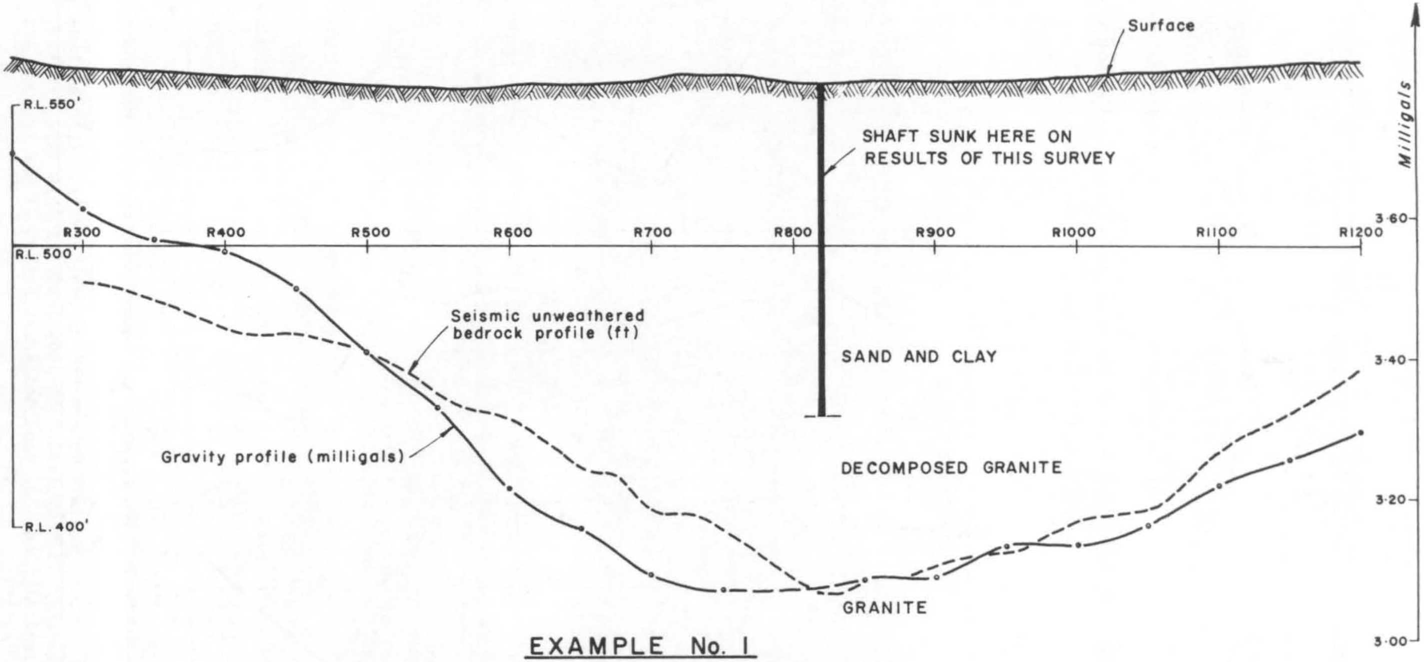


EXAMPLE No. 1

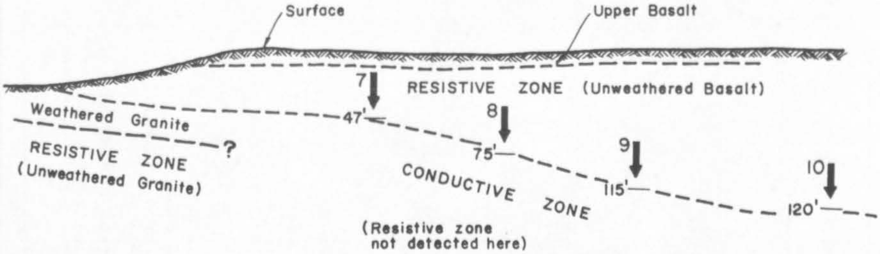
This shows seismic and gravity profiles across a buried alluvial valley. A shaft, sunk where shown, penetrated the ancient stream channel, 40 ft wide, near its centre. Streams such as this can provide useful water.

The lack of contrast in physical characteristics between the alluvium and decomposed bedrock makes it necessary to trace the unweathered bedrock. Nevertheless the general shape of the valley is believed to be substantially correct.

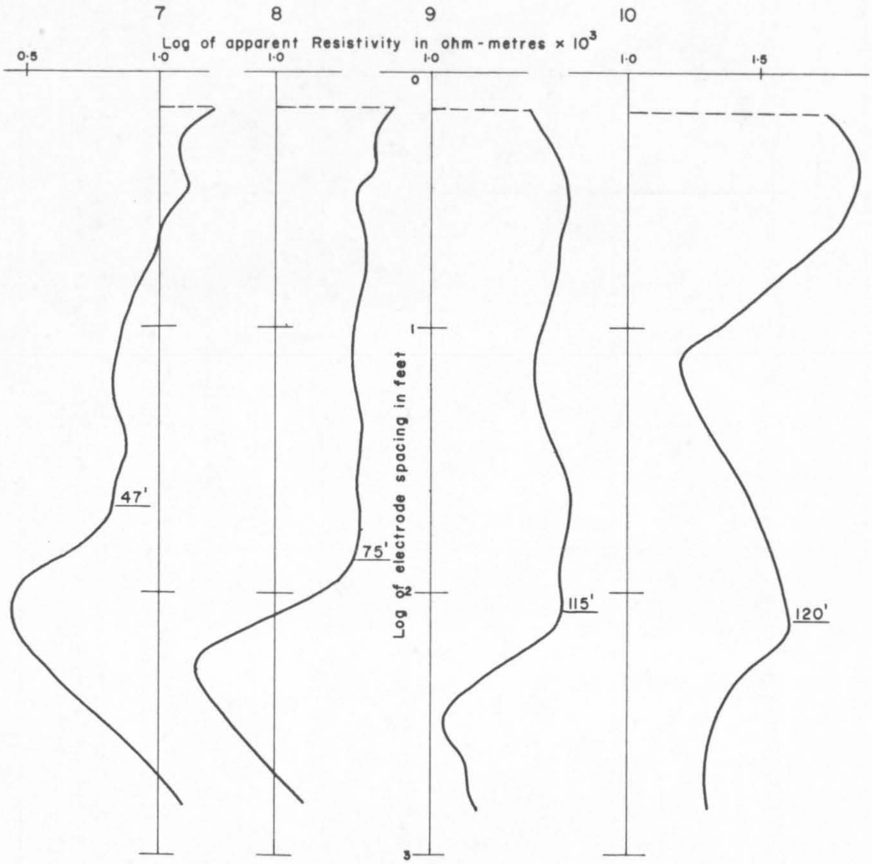
G 369-17

PLATE 4

PLATE 5



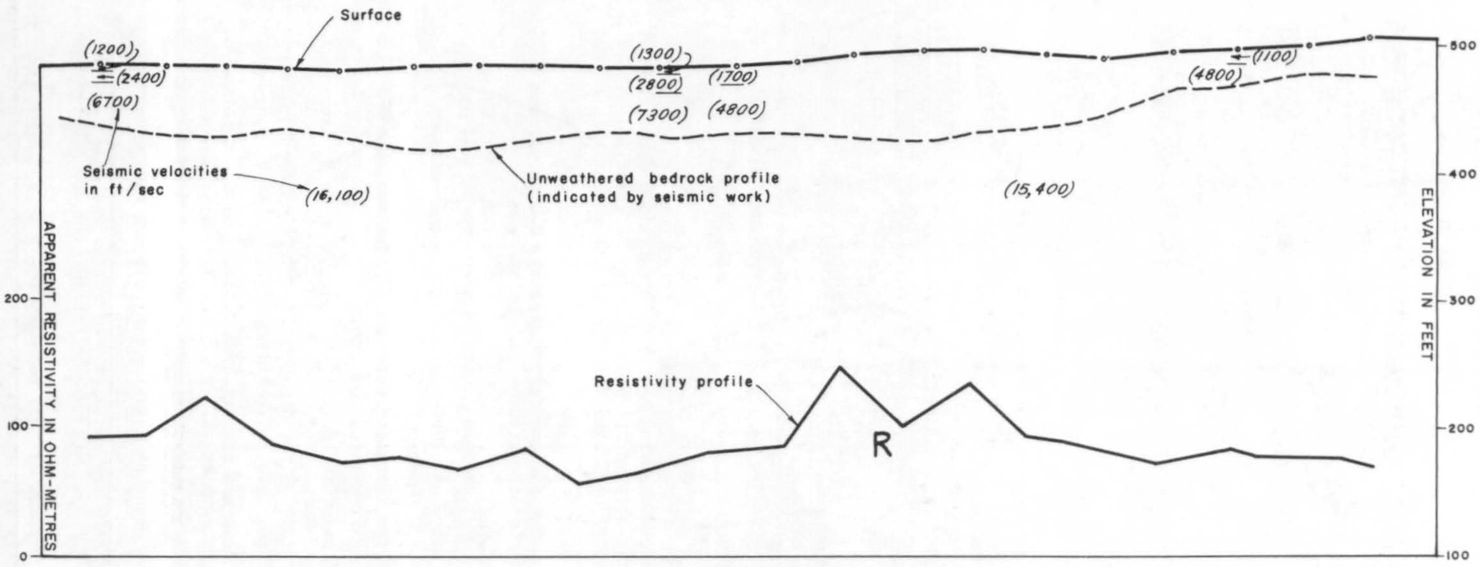
CROSS-SECTION DERIVED FROM RESISTIVITY DEPTH PROBES SHOWN BELOW



EXAMPLE No. 2

This shows a cross-section determined by resistivity 'depth probing' which was used to trace a deep lead. In deep leads of this type, if the conductive zone contains beds of sand and gravel, then it may represent a useful source of water.

G 369-20



EXAMPLE No. 3

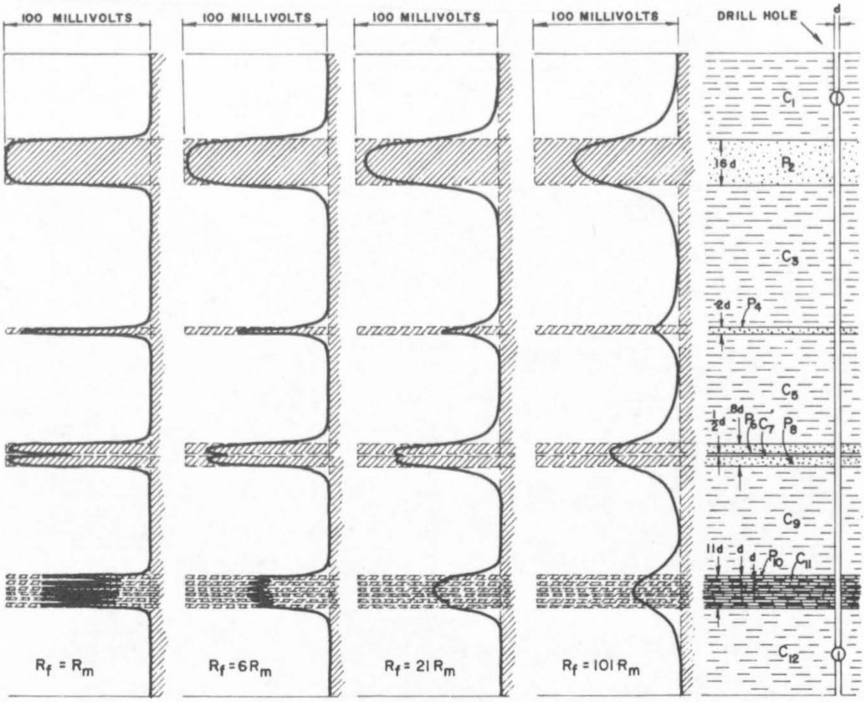
These are seismic and resistivity profiles in a valley filled with alluvium, water from which provides a regular supply to a nearby town.

The seismic velocity of 4800 ft/sec, characteristic of water-saturated sand and gravel, is shown on the right hand side. The resistivity anomaly (R) indicates either a low-porosity material or low-salinity water. Because the water table has been detected here, it is concluded that the anomaly (R) is due to fresh water. This should be a good source of water.

On the left, the velocity of about 7000 ft/sec together with the low.resistivity indicates a partially consolidated clay. This would have a high porosity, a low permeability, and probably a saline water.

PLATE 6

PLATE 7



PERMEABLE STRATA, P — IMPERVIOUS STRATA, C

STATIC S-P DIAGRAM — S-P LOG

EXAMPLE No. 4

This is a hypothetical case showing how an S-P log varies for different bed thicknesses (expressed in terms of the hole diameter 'd') and the resistivity of the formations 'R_f' (expressed as a function of the resistivity of the drilling mud, 'R_m').

Summarising these and other factors influencing the S-P curve, and assuming, in each case, that the other factors remain the same:

1. S-P decreases as the bed thickness decreases below about 16d.
2. S-P decreases as R_f increases. This factor also rounds-off and broadens the negative S-P peaks.
3. As the resistivity of the formation water (R_w) increases, the S-P increases in the positive sense:

   $R_w < R_m$, S-P is a negative deflection, increasing as R_w decreases.

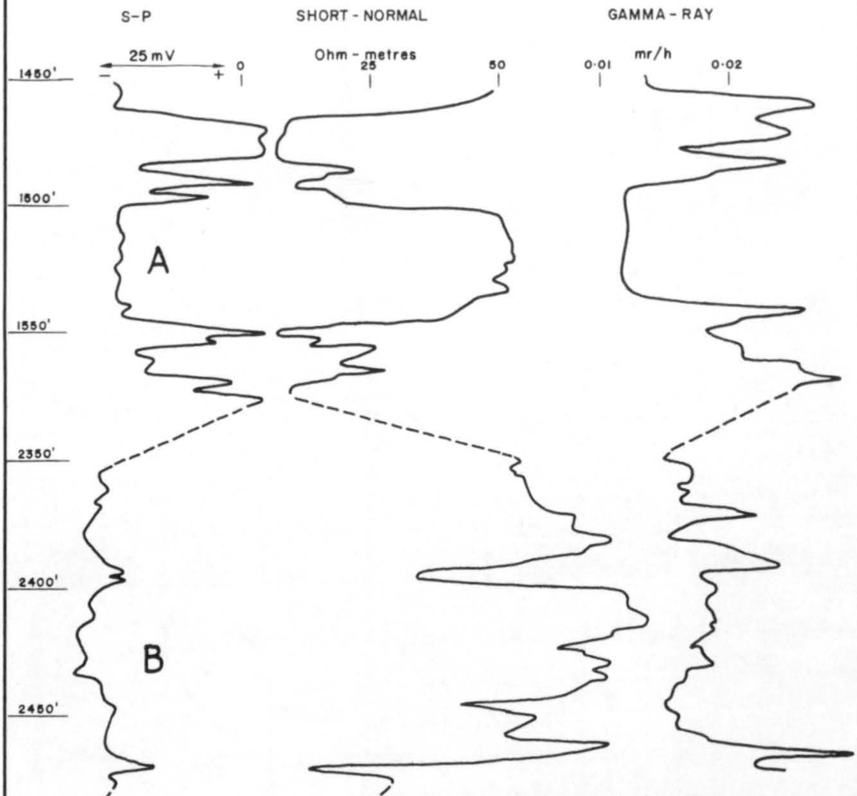
   $R_w = R_m$, S-P deflection = 0, i.e. same as the shale value.

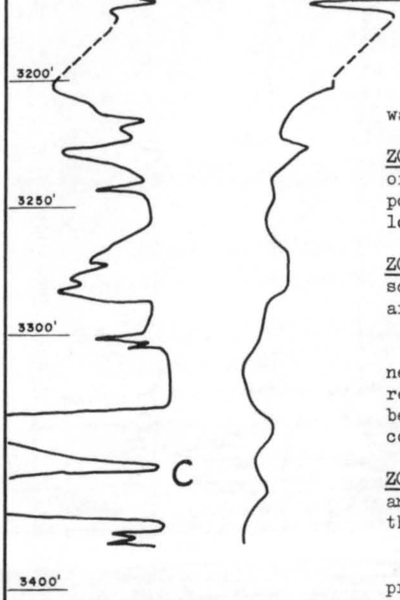
   $R_w > R_m$, S-P is a positive deflection, increasing as R_w increases.
4. Generally, permeable beds are invaded by a filtrate of the drilling mud; this effectively increases d. i.e., the S-P peaks are wider and, for thin beds, the amplitude of the S-P peaks is reduced.

   It should be noted that the actual potentials are independent of the permeability, down to very low values of permeability, and the effects mentioned here are due to the effective increase in hole size.

   The drawing above is reproduced from Document No. 2 of Schlumberger Well Surveying Corp.

PLATE 8





EXAMPLE No. 5

This illustrates the use of water-bore logs to locate the best aquifers.

ZONE A clearly shows the characteristics of a sandstone bed: a negative self-potential, a high resistivity, and a low radioactivity.

ZONE B is similar to Zone A but is not so obvious on the S-P log because there are no shale S-P values for comparison.

Zone B, having a larger negative S-P value, and higher resistivity than Zone A, should be a better aquifer, being cleaner and containing water with a lower salinity.

ZONE C; the larger negative S-P values and low resistivity values indicate that the zone contains brackish water.

This bore eventually produced water with a salinity of about 400 p.p.m. from zones similar to Zone B.

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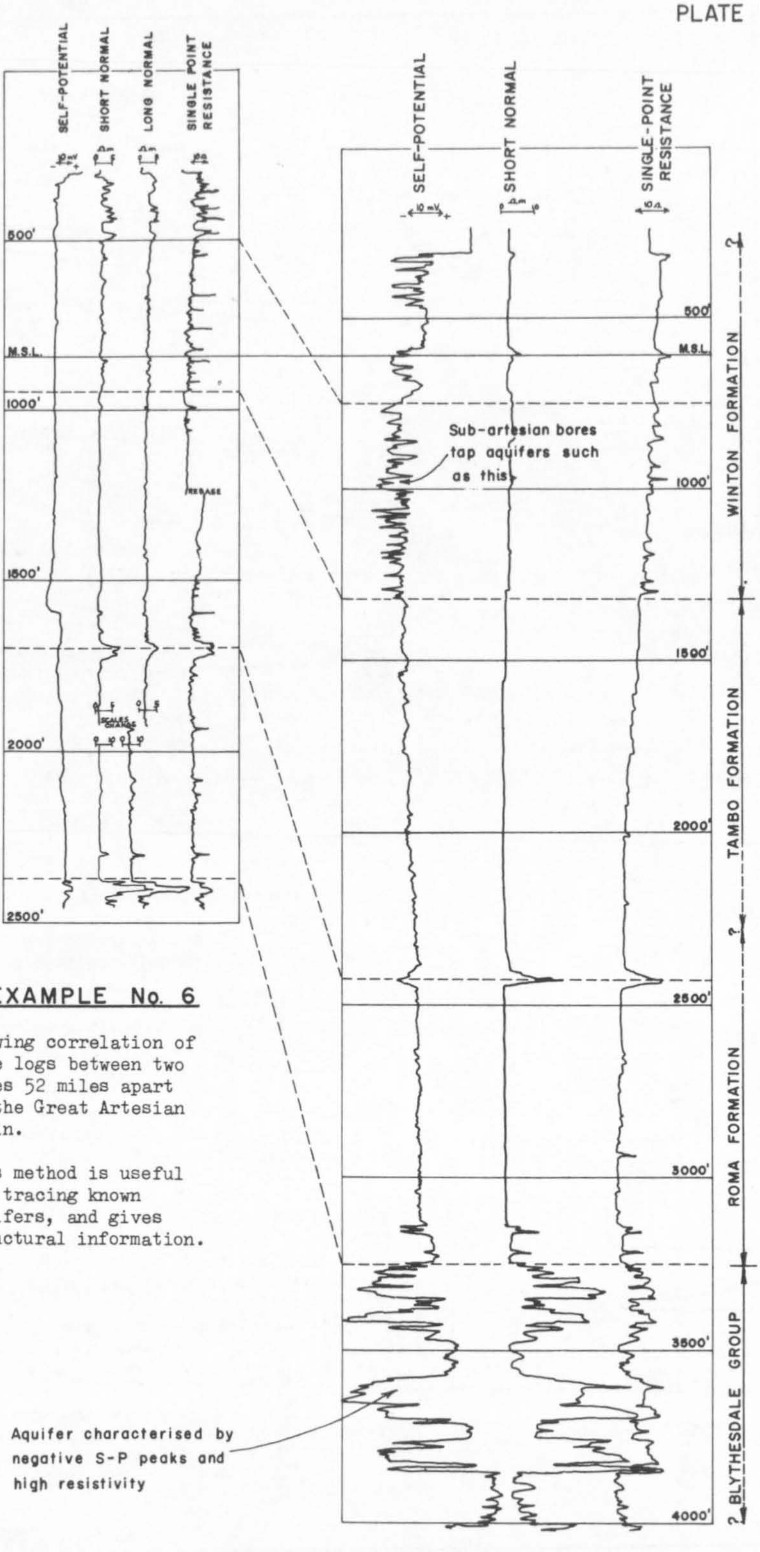

EXAMPLE No. 6

Showing correlation of bore logs between two bores 52 miles apart in the Great Artesian Basin.

This method is useful for tracing known aquifers, and gives structural information.

THESE DATA SHOULD BE CONSIDERED IN CONJUNCTION WITH THE QUALITY AND RELIABILITY OF THE RESULTS OBTAINED.

TABLE 1

COST COMPARISON OF GEOPHYSICAL METHODS APPLIED TO GROUND-WATER PROBLEMS

		SEISMIC	£ /week	RESISTIVITY	£ /week	MAGNETIC	£ /week	GRAVITY	£ /week
PERSONNEL	Party Leader, salary & overtime at £45/week	mainly reductions	45	mainly reductions	45	observing and computing	45	mainly reductions	45
	Geophysicist, " " 40 "	" "	40	Grade 1 or Asst. Geo. to read meter	30		-	Grade 1 or Asst. Geo. to read meter	30
	Technician " " 30 "	operator	30		-		-		-
	Powder Monkey " " 20 "	2	40		-		-		-
	Field Hands " " 20 "	2	40	4	80		-		-
	Surveyor " " 40 "		40		40		40	3	120
	Chainman " " 20 "		20		20		20	3	60
VEHICLES	1/6d per mile	3; 200 miles each	45	1; 400 miles	30	1; 400 miles	30	3· 200 miles each	45
EQUIPMENT	depreciation, spares, maintenance etc.	life equip. 5 yr	40	life equip. 5 yr (N = negligible)	N	life equip. 10 yr (N = negligible)	N	life equip. 10 yr	10
	Consumable items	gelignite, recording paper and chemicals	100						
ACCOMMODATION	£3/day/man. If camping this includes depreciation of camping equipment, camping allowance, extra vehicle.		190		140		60		160
INTERPRETATION	Party Leader additional time to that available in field.	1 week	35		-		-	1 week	35
OVERHEADS	(Drafting, editorial work, checking etc.) (difficult to evaluate).		50		20		20		50
WEEKLY COVERAGE AND TOTAL COST	5 day field work/week	Three 500-ft spreads + one weathering spread per day: 7500 ft	715	50-ft intervals 5000 ft/day + Occasional depth probes: 25,000 ft	405	50-ft intervals 10 min/stn 12,000 ft	215	50-ft intervals 70 stns/day 17,500 ft	555
COST COMPARISON FOR 50,000 ft of traverse		6.7 weeks	4750	2 weeks	810	4.2 weeks	905	2.9 weeks	1610