PIT SLOPE MANUAL

supplement 2-3

GEOPHYSICS FOR OPEN PIT SITES

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THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

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SUMMARY

This supplement gives an overview of surface and borehole geophysical methods useful in evaluating the distribution of rock and soil types, and of rock fractures at open pit sites.

In regard to surface geophysics, emphasis is placed on do-it-yourself methods which operate with relatively inexpensive commercial equipment and are easy to use on simple geological structures.

Borehole geophysical methods, such as down-hole and intra-hole seismics, require a larger investment in logging equipment and a more complex analysis. Types of equipment are described and guidance is given in assessing possible benefits and costs of borehole logging for open pit sites.

For any short-term use it is probably most efficient to regard geophysical methods as specialist tools and to hire companies providing specialist services and interpretation.

ACKNOWLEDGEMENTS

G. Herget was responsible for producing the supplement; address enquiries to him at: 555 Booth St., Ottawa, K1A 0G1, Canada.

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INTRODUCTION

1. Geophysics can often fill important gaps in geological information by means of relatively quick surveys of the subsurface. For pit site investigation, those geophysical methods are most useful which can distinguish between fractured and solid rock, soft and hard materials, and water-bearing and dry strata. Favoured for such capability are seismic or sonic methods, electrical resistivity or radioactive methods, and fluid temperature measurements.

2. To familiarize the reader with available geophysical instruments and services, the following presentation is divided into three parts describing general principles of geophysical methods, surface geophysics and borehole geophysics. The section on surface geophysics concentrates on simple do-it-yourself methods, whereas the section on borehole geophysics dwells upon services provided by geophysical service companies and their charges.

PRINCIPLES OF APPLIED GEOPHYSICS

3. Geophysics deals with physical phenomena of the earth. This includes, in the widest sense, such diverse fields as geomagnetism, earthquake predictions, and composition of the earth. Applied geophysics is the application of fundamental physical principles to assist in the discovery of minerals and in the evaluation of engineering sites. Methods of applied geophysics can involve the measurement of properties associated with naturally occurring phenomena such as magnetism or radioactivity, or they can involve the reaction of a rock mass to induced physical effects such as seismic vibrations, electrical fields or radioactivity. In general, methods with induced physical effects provide more quantitative information.

4. Geophysical measurements are interpreted with the aid of a selected physical model. Therefore, knowledge of the local geology is a considerable asset. Field investigations provide more reliable answers if two complementary geophysical methods are employed, as for example seismic and resistivity surveys for gravel bed delineation. In general, horizontal boundaries between large dissimilar homogeneous bodies are more easily defined than vertical boundaries. Some of the more commonly employed geophysical principles are presented below.

SEISMIC METHODS

5. Seismic methods use a geophone at the reception point to measure the elapsed time between generation and reception of an elastic impulse. A distinction is made between reflection seismics, in which time is measured for an impulse to travel to and from a reflecting bed, and refraction seismics where travel times of first impulses are determined. The former is a more accurate method but is more involved and will not be discussed in this supplement. Analysis of refraction seismic measurements is carried out by time/distance plots.

6. The success of seismic methods depends on the degree of contrast in elastic properties of geologic bodies with respect to the surrounding rocks.

7. Oil exploration in sedimentary rocks has achieved good results in locating salt domes, basement rock contours, limestone horizons and faults.

8. Seismology is used in civil engineering to determine depth of bedrock (1), elastic properties of foundation sites, and damage to buildings from traffic and blasting vibrations.

9. Good correlation has been found between the propagation velocity of seismic waves and the fracture frequency in rocks by applying uphole and crosshole seismic methods where vibrations are measured or generated in drill holes (2, 3).

10. Unstable areas and sections of extensive fracturing in pit slopes have been delineated on the basis of low seismic velocities (4).

11. A correlation has been established between seismic measurements and blasting fractures for an open pit (5). Accuracies of ± 2 ft (± 0.6 m) were achieved, but difficulties can arise in detecting deep-seated, narrow structural features.

12. Sonic velocity measurements have been used in areas of discontinuous permafrost to delineate frozen ground by noting a marked increase in sonic velocity in such frozen zones.

13. Another application of seismic principles (6) is the borehole televiewer or seisviewer which measures the intensity of a high frequency sound reflected from a borehole wall (7,8). Fractures down to a width of 1/32 in. (0.8 mm) can be detected with the seisviewer; operation of this unit is possible in holes filled with dirty water or mud. With an orientation device, measurements of attitude of fractures in a borehole are possible.

ELECTRIC METHODS

14. Electric methods are of a wide variety and can distinguish between the measurement of ground potentials - eg, an orebody may act as a battery and furnish its own electrical field - the measurement of electromagnetic fields of ground currents, the resistivity or conductivity of rock, and the transmission and reception of electromagnetic waves through rock strata (6).

15. The resistivities of minerals, ores, rocks and formations vary over a much wider range than do densities which will vary only between 1.5 to 4 g/cm^3 or about three fold. The range of elastic wave speeds varies between 500 to 23,000 ft/s (150 - 7000 m/s); magnetic susceptibilities vary from 2 to 1×10^{-6}, whereas in ore prospecting the electrical resistivity can vary between 10^{-2} and 10^7 ohms, which corresponds to 10 powers.

16. The logging of electrical resistivity, spontaneous potential in boreholes (SP), and induction is quite common. The response of electric logs is strongly affected by the nature of water in pore spaces in the rock.

17. Electric methods provide information to locate sulphide ores, quartz veins and materials for highway, railroad and dam construction, and to determine depth of bedrock on tunnel and dam sites, permafrost zones, water bearing formations and buried metallic objects, such as pipes (3).

NATURAL AND INDUCED RADIOACTIVITY

18. All rocks contain radioactive elements in small amounts, with higher concentrations found in clays and shales. Broken zones of rock and faults allow the passage and accumulation of radioactive disintegration products. Gamma ray logging is used to detect this natural radioactivity and correlations are useful to determine lithologies - eg, shale and sand units - and the porosity of rock strata (6).

19. With the neutron log, radioactivity is induced by using a neutron source. This emits high-velocity neutrons which are slowed down by colliding with hydrogen atoms available in pore spaces. Other hydrogen atoms will capture the low-speed neutrons and emit gamma rays in the process. Depending on the amount of hydrogen atoms available, the intensity of the observed radioactivity will vary. This logging technique has been very successful in locating porous zones in oil wells.

20. The formation density log uses a source of gamma rays and a detector in a borehole. Both units are effectively sealed and protected from

each other, and the detector will receive only gamma rays scattered and deflected by electrons in the rocks close to the hole. The intensity of reflection increases with the electron content. As electron content increases with density, materials of different densities can be readily distinguished.

GRAVITY METHODS

21. Variations in the gravitational field can be measured by pendulum, gravimeter, or torsion balance. The analysis of the data will indicate the presence or absence of heavier or lighter bodies and is mainly of a qualitative nature. Very good results have been obtained in detecting the position of salt beds and salt anticlines. Cases have also been reported where gravity measurements are successfully used in delineating iron orebodies and dikes (6).

MAGNETIC METHODS

22. Magnetometer measurements of variations in the earth's magnetic field probably represent the simplest, least expensive and fastest geophysical method. The magnetite content of igneous and intrusive rocks creates magnetic anomalies which permit their detection in more weakly magnetic sedimentary strata. Additional important applications are surveys for iron ores, pyrrhotite, and placer deposits (6).

MISCELLANEOUS

23. A variety of methods could be cited at this point but only two common methods are given:

Temperature Probes

24. Temperature probes are used to measure the temperature of borehole fluid adjacent to formations of interest. Anomalous temperatures indicate groundwater flow into the borehole, eg, at fault intersections.

Caliper Probes

25. The caliper probe is used to measure borehole diameter with depth and can detect extreme roughness and caving of a borehole wall. The caliper log is required to correct changes in borehole diameter, to interpret borehole logs affected by changes in borehole diameter, and to provide indications of weak borehole sections.

SURFACE GEOPHYSICS

26. Only those methods are described in this section which require relatively little sophistication in terms of instrumentation and analysis. The equipment is portable and is available for about $2000 - $10,000.

HAMMER SEISMIC REFRACTION SURVEYS

27. A typical set-up is shown in Fig 1(a). Surveys of this nature allow subsurface exploration to a depth of about 50 ft (15 m), without using explosives for seismic wave generation (Fig 1(b)). Depth penetration can be improved by use of an enhancement seismograph which has a memory to superimpose repeated refractions while random signals or noise tend to cancel out. The method is well suited for locating flat-lying hard rock formations overlain by soil or by fractured rocks. Better depth penetration is achieved with larger hammers or weight drops, and by increasing the impact velocity (9). The velocity of the compression wave developed by ground shock correlates with the Rock Quality Designation (RQD) in rock as shown below (2, 3):

Velocity Index	RQD (%)
0.	0 - 25
0.20 - 0.40	25 - 50
0.40 - 0.60	50 - 75
0.60 - 0.80	75 - 90
0.80 - 1.00	90 -100

(a)

(b)

Fig 1 - Seismic refraction survey (a) shock generation by hammer impact (courtesy Soiltest, Inc.), (b) with the aid of explosives.

28. The Velocity Index is defined as the square of the ratio of compressional wave velocities in the rock mass and the rock material. The in situ data are normalized by using a laboratory value to eliminate the influence of lithology. Without normalizing, a closely-spaced jointed granite could show the same velocity as an unjointed friable sandstone. The velocity ratio will approach 1.0 as the number of joints decreases and as the rock improves in quality. The Velocity Index is equivalent to the ratio of in situ dynamic modulus to laboratory dynamic modulus.

29. All geophysical exploration techniques are interpreted in terms of a preconceived physical model. More confidence can be placed in the interpretation of results if an appreciation of the geological structure exists for the site, and if a complementary method is used to confirm the interpretation. For shallow seismic work, resistivity methods provide a suitable complement. Horizontal boundaries can be discovered much more easily than vertical ones but, even with the best methods, accuracies are rarely better than ± 1 ft (0.3 m). In general, at least one drill hole is required to prove the significance of geophysical findings.

Basic Equipment

30. Basic equipment consists of:

a. geophone,
b. electronic timing device,
c. cable,
d. hammer with shock switch,
e. oscilloscope for wave display,
f. steel plate.

Principles

31. This method is based on the travel of ground vibrations through rock or soil. The vibrations or shock waves are produced by hitting a steel plate on the ground with a suitable weight such as a 5-lb sledge hammer (Fig 1). The ground shock develops longitudinal waves, also called P-waves, which can penetrate any substance, followed by slower transverse waves or S-waves which cannot penetrate fluids, and the even slower transverse surface waves. Due to the short distances and correspondingly short travel times in

seismic exploration, transverse waves are rarely recognized and one works only with longitudinal waves which can be directly transmitted, refracted and reflected. The speed of the longitudinal waves increases for materials with higher elastic moduli, which in turn are related to the density and hardness of the material encountered. Examples are given in Table 1.

32. In seismic refraction surveys, the time of first arrival of the longitudinal wave between source and sensor (geophone) is measured. A geophone is a shock detector placed on the ground and includes a sensitive pendulum. It is connected to an oscilloscope so that a cathode ray image of the ground vibrations can be obtained. A longitudinal wave travelling along its wave path is the source of new waves at each point of its path. For short source-to-geophone distances, the longitudinal wave spreading along the surface will show first arrival. As the separation distance increases, longitudinal waves penetrating to a high-velocity layer, travelling along it and sending refracted longitudinal waves continuously back to the surface will show first arrival.

33. Arrival times are measured with an accuracy within ± 0.25 milliseconds. The timing device is activated by a shock switch built into the impact weight. The velocity can be calculated from the distance between the geophone and the striker plate, and the arrival time. This can be plotted and analyzed according to Fig 2.

Field Operation

34. The course in the field should be as straight as possible and in an area as level as possible. The geophone is placed on the ground with the timing device and oscilloscope nearby. At intervals of about 10 ft (3 m) stations are marked along the course. The operator observes the background noise, so that its wave pattern is not confused with the first arrival. The steel plate on the ground at the first station is hit and the operator records the time between shock generation and first arrival, the distance from steel plate to geophone, and the shape of the wave. This is repeated at each station. A survey course is normally about 150 to 200 ft (45 - 60 m) long. When a course has been completed in one direction, the steel plate is placed at the opposite end, and the procedure is repeated in the reverse direction. This allows necessary checks, and shows up any inclined structural features.

Table 1: Velocities of longitudinal waves (after compilation by Heiland) (6)

Formation	Locality	Longitudinal wave velocity m/sec	ft/sec
Air		330.8	1085
Water (fresh)		1435	4708
Water at 14°C at 20 m	Germany	1475	4840
Water (sea)		1480-1490	4856-4889
Weathered surface layer (Pleistocene)	E. Alberta, Canada	169-305	555-1000
Dry surface sands	California	330	1083
Weathered layer	E. Colorado	335-1690	1099-5545
Loess	Jena, Germany	375-400	1230-1312
Dry surface soil	California	600	1969
Weathered surface rocks	Oklahoma	610	2000
Loam (wet)	Australia	761	2497

Table 1: Velocities of longitudinal waves (after compilation by Heiland) (6) - cont.

Formation	Locality	Longitudinal wave velocity m/sec	ft/sec
Sands and clays			
Dune sand	Denmark	500	1640
Cemented sand	Australia	852-975	2795-3200
Sandy clay	Australia	975-1160	3200-3806
Pure sand	Gibraltar	1000	3281
Cemented sandy clay	Australia	1160-1280	3806-4200
Clayey sands	Gibraltar	1400	4593
Miocene sands and clays (wet)	N. Germany	1600-1700	5250-5578
Oligocene clays	Jüeterbog, Germany	1900	6234
Marls			
Eocene marls	N. Germany	1800	5906
Marl	Gibraltar	2000-2500	6562-8202
Marl	Spain	2000-3800	6562-12467
Eocene marls	Gibraltar	2400	7874
Calcareous marl	Spain	3000-4700	9843-15420
Sandstone			
Ribstone Creek sandstone (Upper Cretaceous)	E. Alberta	931-1130	3055-3708
Tertiary sands and shales	Los Angeles		
0-200 m	Basin	1000±	3281±
200-320 m		1900	6234
320-860 m		2100	6890
860-1650 m		2900	9515
1640-? m		3500	11483
Limestone and rock salt			
Cretaceous limestone	France	2140	7021
Carboniferous limestone	N. Germany	3000-3600	9843-11812
Rock salt domes	Texas, Spain	4720-7700	15486-25264
Crystalline rocks			
Igneous rock	Various	4000-6500	13124-21327
Gneiss and schists	Various	3100-7500	10170-24608

Calculation of Depth

35. The depth can be calculated for a series of flat-lying layers of material which are characterized by higher P-wave velocities with increasing depth. As the distance between geophone and striker plate increases, the transit path of the first arrival at the geophone will include increasingly deeper structural layers (Fig 2(a)). In plotting transit time vs distance, a segmented curve of the type shown in Fig 2(b) is produced. The slope of each section of the curve, in succession left to right, gives velocity of the first, second, third, etc. layers of the structure. The separation distances between the line segments are combined with the velocities of the layers to calculate burial distance to the interfaces. Figure 2(c) provides the equations required to calculate the first two interface depths.

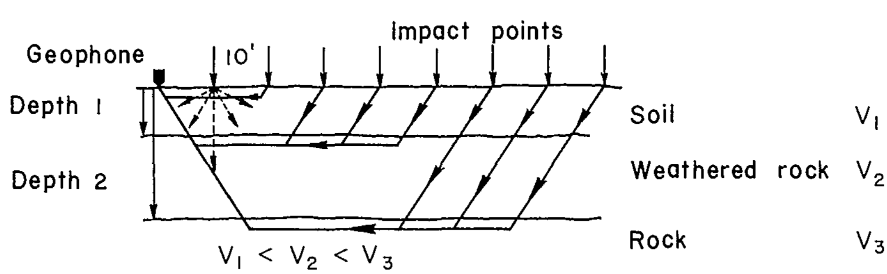
Rules for Interpretation

36. It is recommended to traverse the refraction line in both directions for the detection of structural features. Figure 3 provides an indication of the non-symmetry of opposed traverses when a single dipping structure is encountered.

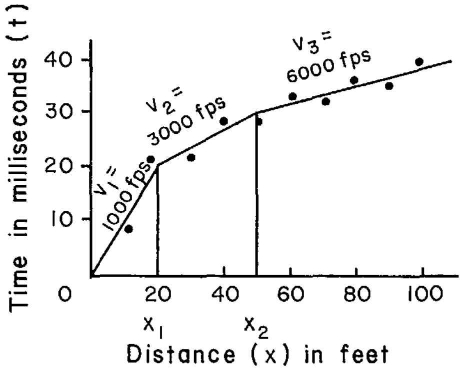
37. Other characteristic curves should be considered in making seismic refraction measurements, some of which are indicated in Fig 4.

38. There is often a gradual transition between zones, and the time transit curves reflect a gradual change between straight line sections. This can often be attributed to weathering and alterations. In the case of blast damage, it is probably an indication of the diminution of this damage with depth.

39. An error of 1 millisecond for transit time measurements in refraction seismic work at depths less than 50 ft (15 m) can result in a 1% error for the overburden depth of a material with a velocity of 10,000 ft/s (3048 m/s) at a base length of 100 ft (30 m). For work around open pit mines, equipment capable of measuring to 0.1 millisecond would be desirable. Commercial equipment in gen-



(a) Diagram of fastest path of longitudinal wave (refracted wave)



(b) Time - distance plot of first arrivals

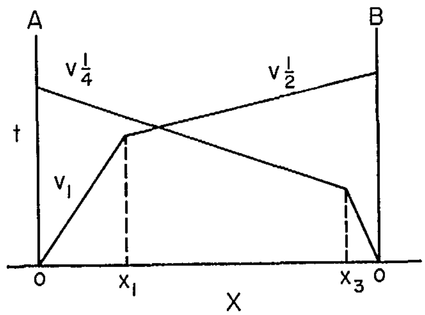
$$D_1 = \frac{X_1}{2}\left(\frac{V_2 - V_1}{V_2 + V_1}\right)^{1/2}$$

$$D_2 = 0.80\, D_1 + \frac{X_2}{2}\left(\frac{V_3 - V_2}{V_s + V_2}\right)^{1/2}$$

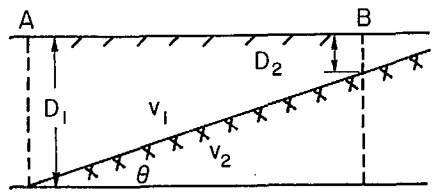
for given example (figure b) the depths are D_1 = 7 feet, D_2 = 20 feet

(c) Depth calculations

Fig 2 - Refraction seismic measurements.



(a)



(b)

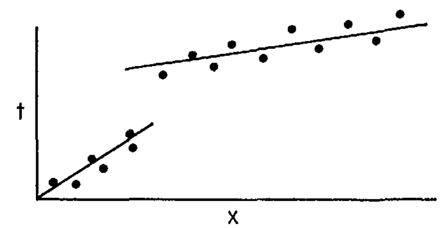
$$V_2 = 2 \cdot \frac{V_{\frac{1}{4}} \; V_{\frac{1}{2}}}{V_{\frac{1}{4}} + V_{\frac{1}{2}}}$$

$$D_1 = \frac{x_1}{2}\left(\frac{V_{\frac{1}{2}} - V_1}{V_{\frac{1}{2}} + V_1}\right)^{1/2}$$

$$D_2 = \frac{x_3}{2}\left(\frac{V_{\frac{1}{4}} - V_1}{V_{\frac{1}{4}} + V_1}\right)^{1/2}$$

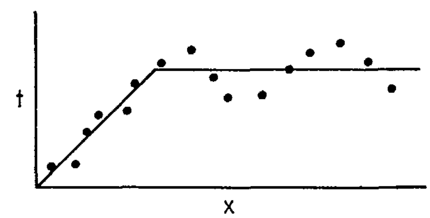
(c)

Fig 3 - Refraction seismic measurements, illustrating non-symmetry of opposed traverses.



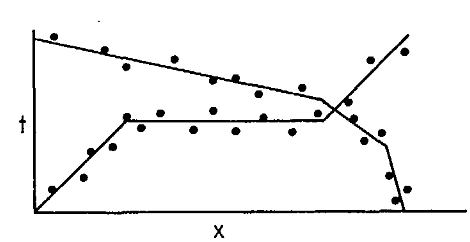
A low velocity zone (i.e. sand lens) sandwiched between two higher velocity zones.

(a)



An irregular interface between two media.

(b)



A fault or discontinuity such as a rock ledge.

(c)

Fig 4 - Interpretation of seismic refraction measurements.

eral measures to about 0.25 milliseconds.

40. In conducting seismic refraction measurements, the increment in the separation distances between seismometer and striker plate need not be constant. With close proximity between seismometer and the striker plate, proportionally larger times are required for the disturbance to be transmitted between plate and geophone, because the low-velocity overburden material is the transfer material. It is recommended that an increment of 5 ft (1.5 m) be used within the first 30 ft (10 m) of the geophone, after which the increment

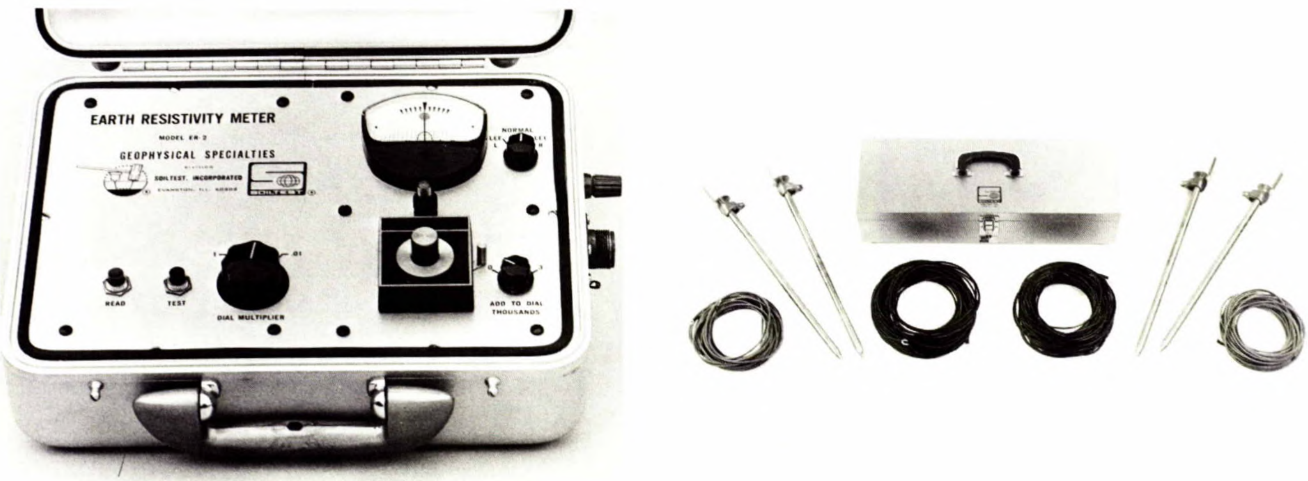


Fig 5 - Electrical resistivity meter and accessories.

should be increased to 10 ft (3 m) up to a distance of 100 ft (30 m). Beyond 100 ft (30 m), an increment of 20 ft (6 m) seems reasonable. Time-distance curves should be plotted in the field as the measurements are made. This permits detection of anomalous readings and verification that the equipment is working properly.

41. It is worth remembering that water-saturated formations can be erroneously interpreted as rock strata with velocities of 5000 - 6000 ft/s (1524 -1828 m/s), and that a shock wave travelling through air can be interpreted as a surface layer with a velocity of 1115 ft/s (340 m/s).

ELECTRICAL RESISTIVITY SURVEYS

42. Electrical resistivity surveying is used in rock and overburden evaluation. Depending on the conditions and equipment used, depths from 100 to 500 ft (30-150 m) can be probed. The basic equipment is shown in Fig 5. This method complements seismic refraction surveys in determining the depth of soil cover, and in locating water table and gravel beds. The method has been used successfully in detecting faults in bedrock covered by overburden. Analysis becomes difficult if more than three or four layers are involved.

Basic Equipment

43. Basic equipment consists of:

a. resistivity meter and batteries,
b. electrodes (metal stakes),
c. cable.

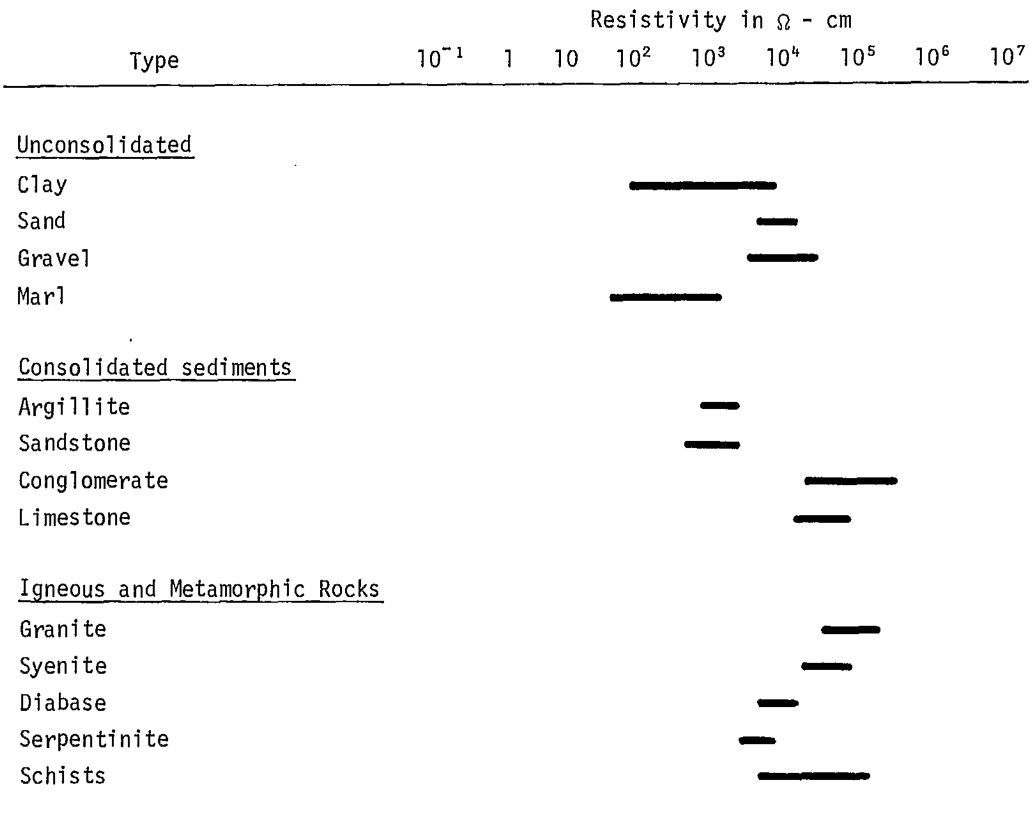
Principles

44. Electrical resistance of rock and soil varies widely (Table 2). Conductivity or resistivity of rock can be determined with the aid of an electric field set up between electrodes placed in the ground.

Field Operation

45. The most common electrode layout is the Wenner configuration (Fig 6). Four equally-spaced electrodes are used with direct or alternating current applied at the two outer electrodes. A voltmeter measures potential between the two inner electrodes.

Table 2: In situ resistivities of rocks and soils (compiled after Heiland) (6)



46. Four stainless steel stakes are usually adequate for soil overburden. If the soil is dry, a small amount of water can be used to provide a good contact. The ground potential caused by natural earth currents can be obtained by measuring the voltage with the current source switched off. This voltage has to be subtracted from subsequent readings. Alternatively, a small voltage can be used in the voltmeter circuit to balance this ground potential. To overcome the effect of electrolytic polarization, the direction of the current should be reversed periodically. If an AC source is used, this problem does not exist. Figure 6 indicates the positions of the instruments and the symbols of the variables.

Depth Calculation

47. Having obtained the values of the current, I, between the outer electrodes, the voltage, V, between the inner electrodes and the spacing, A, the apparent resistivity of the material below the electrodes is calculated from the following equation (7):

$$\rho = 2\pi A \frac{V}{I} \qquad \text{eq 1}$$

48. The resistivity calculated with this formula establishes the depth of the affected strata as approximately A. Thus, various depths can be sounded by varying the spacing. Figure 7 illustrates the type of resistivity curve obtained with a dry sand overlying a more conductive decomposed diabase.

Rules for Interpretation

49. Where two- or three-layer structures are involved and considerable traverses are available, the following rules assist in the interpretation:

a. The depth probed is equal to the probe separation distance.
b. As each horizontal layer with sufficient resistivity contrast is intersected, there will be a

change in the slope of the curve.

50. The accuracy of detection of an interface depth between two zones depends on the resistivity ratio, ρ_1/ρ_2. It is assumed there is no lateral change of resistivity in the area being surveyed.

51. The interpretation of more complex curves related to complex structures requires considerable experience, and the reader is referred to the excellent treatise "Interpretation of Resistivity Data" by R. G. van Nostrand and K.L. Cook (10).

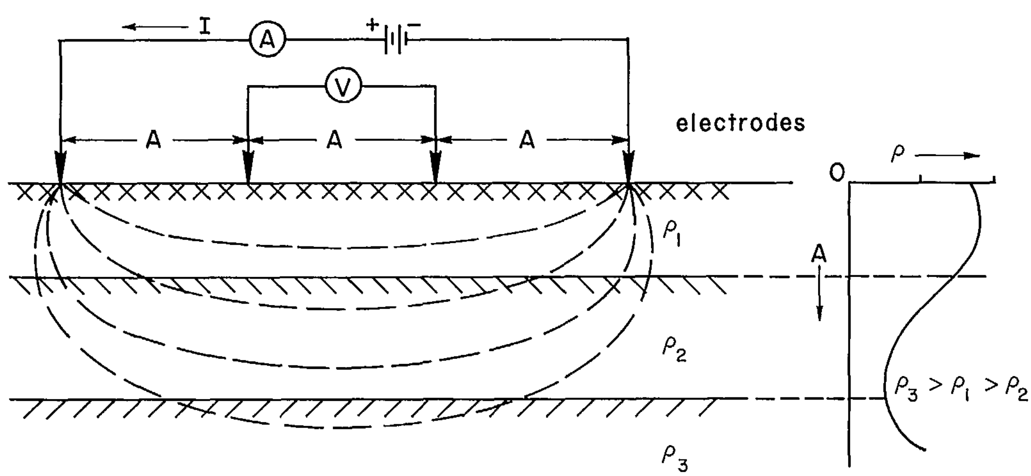
Schlumberger Layout

52. Another configuration often used is the Schlumberger layout (Fig 8). In it the two potential electrodes are closely spaced at the centre of the array with a separation distance, A.

53. If X > 20A, then the following equation can be used to calculate the apparent resistivity in the vicinity of the potential electrodes:

$$\rho = \frac{\pi}{A} \cdot \frac{X^2}{I} \cdot \frac{V}{I} \qquad \text{eq 2}$$

With this configuration, apparent resistivity is plotted against X using logarithmic paper. This allows a very sharp definition of vertical boundaries between materials of different resistance. An example is given in Fig 9. Horizontal layering can also be determined and standard curves have been published for analysis (10).



(ρ = resistivity, A = amperemeter, V = voltmeter, A = spacing)

Fig 6 - Wenner configuration.

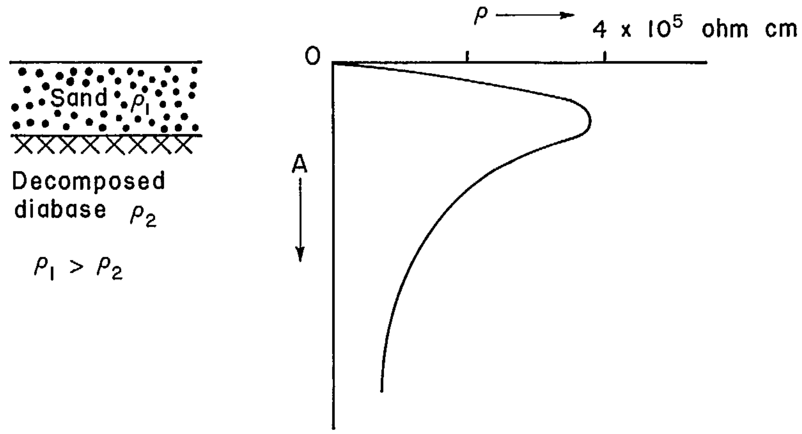


Fig 7 - Apparent resistivity curve.

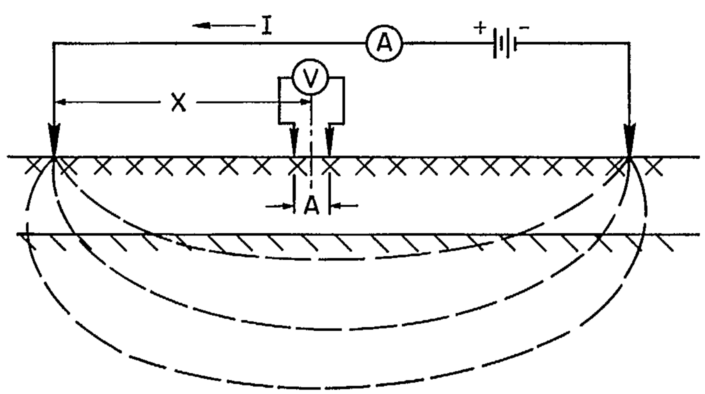


Fig 8 - Schlumberger layout.

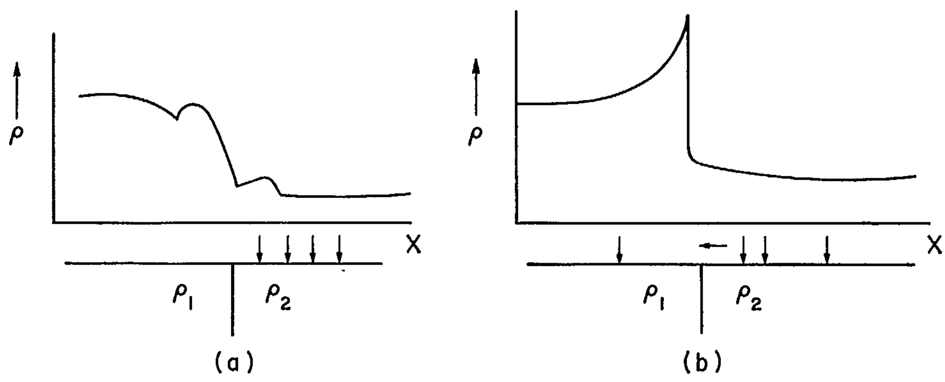


Fig 9 - Lateral traverses and crossing of a resistivity discontinuity.

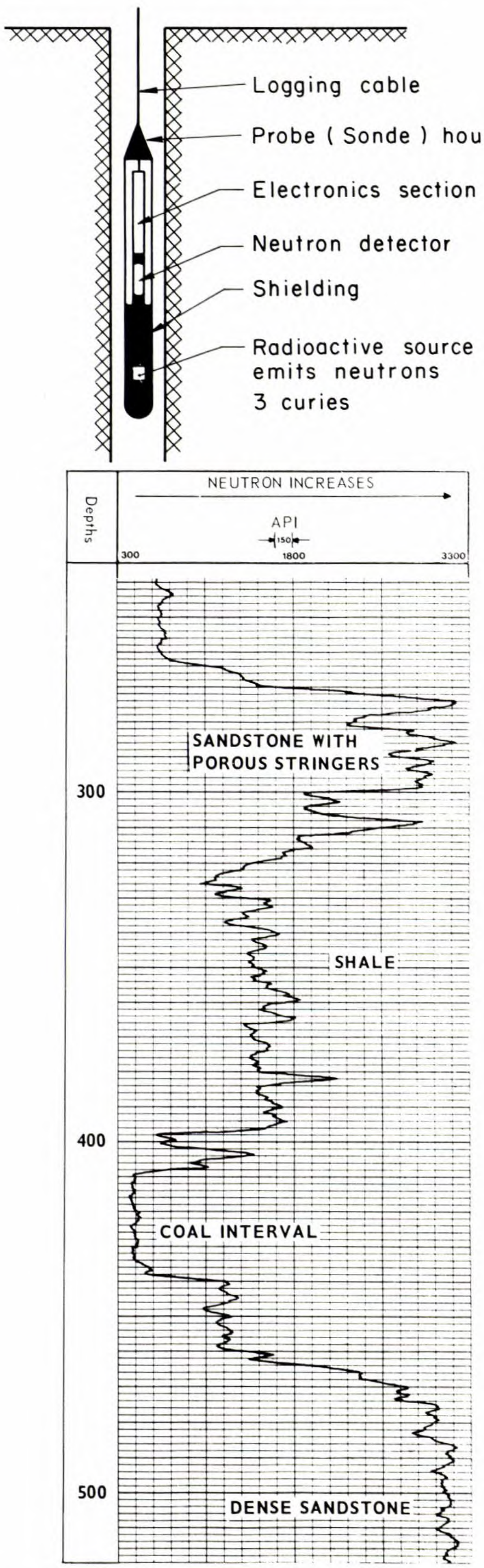


Fig 11 - Correlation of neutron log with lithology.

60. To prepare a borehole for logging, it is necessary to have it filled with a fluid, usually drilling mud or water. The kind of borehole fluid is of particular importance in electric logging, in which case it is advisable to use water, or water-based drilling mud of fairly low salinity.

61. Boreholes are usually logged by raising the probe to the borehole collar. The speed at which the borehole is logged will depend on the measurements being made, and ranges from approximately 10 ft/min (3 m/min) for radiation and caliper logging to 100 ft/min (30 m/min) for electric and sonic logging.

62. It should be noted that, when the services of contractors are used, the customer normally accepts financial responsibility for recovering or replacing probes lost due to caving of the borehole, or to other misfortune. The loss of neutron or density probes represents a serious hazard.

SERVICES AND COSTS

63. Services available from geophysical borehole-logging organizations can be separated into the following three groups:

Group I:

64. Shallow-depth, to 1000 ft or 300 m, hand-operated, portable logging systems capable of measuring and recording single-point resistance, spontaneous potential, and in some cases natural gamma radiation as a function of depth. The probes used are approximately 1 5/8 in. (41 mm) in diameter. Typically, such a unit would weigh 170 lb (77 kg) and cost from $9,000 to $14,000, depending on the gamma ray probe option.

Group II:

65. Medium-depth, to 3000 ft or 1000 m, motor-operated, portable borehole logging systems capable of recording the following geophysical logs as a function of depth:

a. electrical resistivity, spontaneous-potential log (SP) and single-point resistance; probe diameter 1 1/2 in. (38 mm) or 2 in. (51 mm),
b. Gamma ray and neutron; probe diameter 1 11/16 in. (43 mm),
c. density (borehole compensated); probe diameter

Fig 12 - Truck mounted winch and mast for lowering and raising of probes.

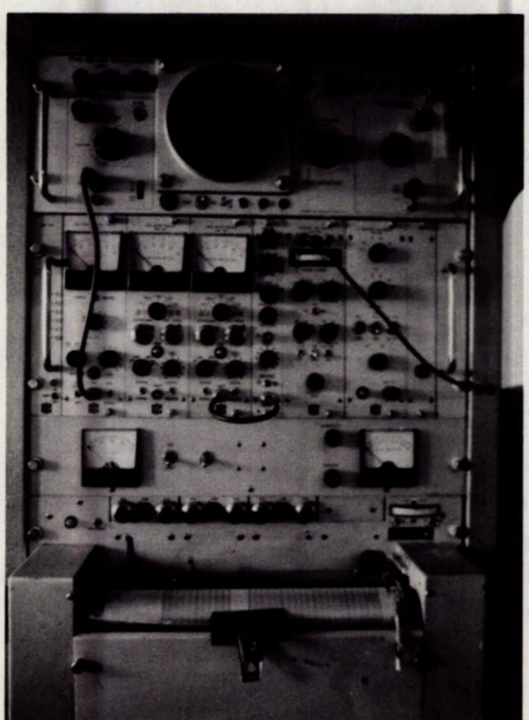


Fig 13 - Electronic system for recording signals from the probe.

Fig 14 - Helicopter transport of borehole logging equipment.

1 11/16 in. (43 mm),

d. sonic (borehole uncompensated); probe diameter 2 1/8 in. (54 mm),

e. caliper; probe diameter 1 1/4 in. (32 mm), and

f. temperature, probe diameter 1 7/16 in. (37 mm).

Typically, such a unit would weigh 450 lb (204 kg) skid- mounted and cost from $21,000 to $50,000, depending on the range of probes chosen. The hazards associated with most radiation logging equipment preclude their use by other than licensed personnel.

66. Representative service rates for specialist borehole logging organizations are given in Table 3. An incomplete list of typical companies supplying these services follows:

B.P.B. Instruments (Canada) Ltd., ph.279-8014
5915C - 36th Street, S.E., Calgary Alberta.

Roke Oil Enterprises Ltd., ph.273-5553
516 Moraine Road, N.E., Calgary, Alberta.

Group III:

67. Group III consists of full size, mobile truck- or skid-mounted, borehole logging systems offering a complete range of logging services for deep boreholes. Since these systems were originally developed for use in the oil industry, the probe sizes are generally larger than those used at medium-depth (ie, greater than 4 in. or 102 mm in diameter). The following small-diameter probes have been developed, however, for use with these systems:

Table 3: Typical service rates for geophysical borehole logging (1974)

Cost item	Group II		Group III	
	Western Canada	Eastern Canada	Western Canada	Eastern Canada
		Trip Basis[1]		
Per foot[2]	$0.30 - $0.85	$0.35 - $1.00	$0.40	$0.50
Minimum per probe	$120.00	$120.00	$700.00	$800.00
Basic charge			$350.00	$600.00
Per mile (roundtrip from base)	$0.50	$0.60	$2.00	$2.00
		Monthly contract basis[1]		
Skid unit and engineer	$8,000	$10,000	$8,000	$8,000
Per foot[2]	$0.30 - $0.85	$0.35 - $1.00	$0.40	$0.50
Minimum per probe	$1,000	$1,200		
Probe rental each (average)			$1,000	$1,000
Per mile (roundtrip from base)			$2.50	$3.00

Notes: (1) Board and lodging at customer's expense
(2) Includes prints of borehole logs

Table 4: Typical service rates for dipmeter and borehole televiewer logging (1974)

Cost item	Dipmeter		Borehole televiewer	
	Western Canada	Eastern Canada	Western Canada	Eastern Canada
		Trip basis (1)		
Per foot (2)	\$0.75	\$0.85	\$2.00	\$2.00
Minimum per probe	\$750.00	\$850.00		
Basic charge (roundtrip from base)	\$1,200.00	\$1,500.00	\$1,200.00/day	\$1,200.00/day
Per mile (roundtrip from base)	\$2.00	\$2.00	\$1.00	\$1.00

Notes: (1) Assumes other probes will also be run
(2) Includes processing of records

a. electrical resistivity and SP - probe diameter 1 1/2 in. (38 mm),
b. induction, electrical resistivity and SP - probe diameter 2 3/16 in. (56 mm),
c. Gamma ray and neutron - probe diameter 1 11/16 in. (43 mm),
d. sonic (borehole uncompensated) - probe diameter 1 11/16 in. (43 mm). Sonic (borehole compensated) - probe diameter 2 in. (51 mm),
e. caliper - probe diameter 1 3/4 in. (45 mm),
f. temperature - probe diameter 1 11/16 in. (43 mm).

68. Group III services are provided by a small group of specialist borehole logging companies. The equations used by these companies to calculate the cost of the logging services are complicated, but approximate rates are indicated in Table 3. As an example, a few companies are quoted which offer full geophysical logging services, including assistance with interpretation of the boreholes logs. This short list is by no means complete:

Birdwell Division of Seismograph Service Corporation,
P.O. Box 1590, Tulsa, Oklahoma 74102.

Dresser Atlas Division of Dresser Industries Inc., ph. 233-5000
1200-505 3rd Street, S.W., Calgary, Alberta.

Schlumberger of Canada Ltd., ph. 269-7331
350-717 7th Ave., S.W., Calgary, Alberta.

69. In addition to the logs described above, the Group III logging companies offer two probes which measure the dip and dip direction of discontinuities intersecting the borehole. These are the dipmeter, or diplog, and the borehole televiewer, or seisviewer.

70. The smallest dipmeter offered by the specialist logging companies has a diameter of 4 in. (102 mm) and can operate in boreholes of 4 1/2 in. (114 mm) diameter or larger. Boreholes of 5 1/2 in. (140 mm) diameter or larger, however, are usually required for dipmeter surveys. The dipmeters generally incorporate a borehole directional survey. The smallest borehole televiewer is 3 3/8 in. (86 mm) in diameter and can operate in boreholes of 4 in. (102 mm) diameter or larger. Usually probes require boreholes of at least 4 3/4 in. (121 mm) diameter.

71. Rates for dipmeter and borehole televiewer services are indicated in Table 4. It should be noted that these rates include computer processing of the dipmeter records and photographic records of the borehole televiewer record.

72. In addition, some of the major logging companies provide a mechanical property log which is based on sonic, density and caliper logs. A sample of the cost for this special service is given in table 5 below.

Table 5: Footage rates for mechanical properties log (1974)

Sonic, density and caliper logs	$3.00/ft
Borehole televiewer or seisviewer	$2.00/ft
Basic crew charge (roundtrip from base)	$1,200.00/day
Mileage charge (roundtrip from base)	$1.00/mile

Costs include charges for computer processing of records to obtain the mechanical properties as a function of depth.

INTERPRETATION AND REPORT SPECIFICATIONS

73. A clear distinction should be made between the geophysical measurements themselves, those physical or mechanical properties derived indirectly using theoretical formulae, and those properties derived indirectly on the basis of an established correlation between the measured and the required property. Equations should be applied only after careful examination of their validity for the case in question; empirical correlations are generally preferred.

74. The first step in the interpretation is to make any necessary corrections to the probe readings for borehole diameter and for borehole fluid characteristics. The various geophysical observations in each of several boreholes may then be compared and correlated to determine the subsurface geometry of structural features intersected by the boreholes. If dipmeter or borehole televiewer surveys have also been made in the boreholes, the interpretation is made considerably easier, and complicated structural features may then be identified.

75. Reports should include the following data:

a. the drillhole location, surface datum and depth, inclination and direction, the characteristics and location of any casing set in the borehole, the characteristics of the drilling fluid and the fluid level in the borehole at the time of logging;
b. the geophysical borehole logs at an appropriate scale, fully annotated with details of instrument settings and logging speeds, together with core- and drill-cuttings logs, where available;
c. derived results, together with details of formulae or correlation data used in their derivation, and any assumptions incorporated in the calculations.

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