Engineering & Groundwater Geophysics:

Essentials

By

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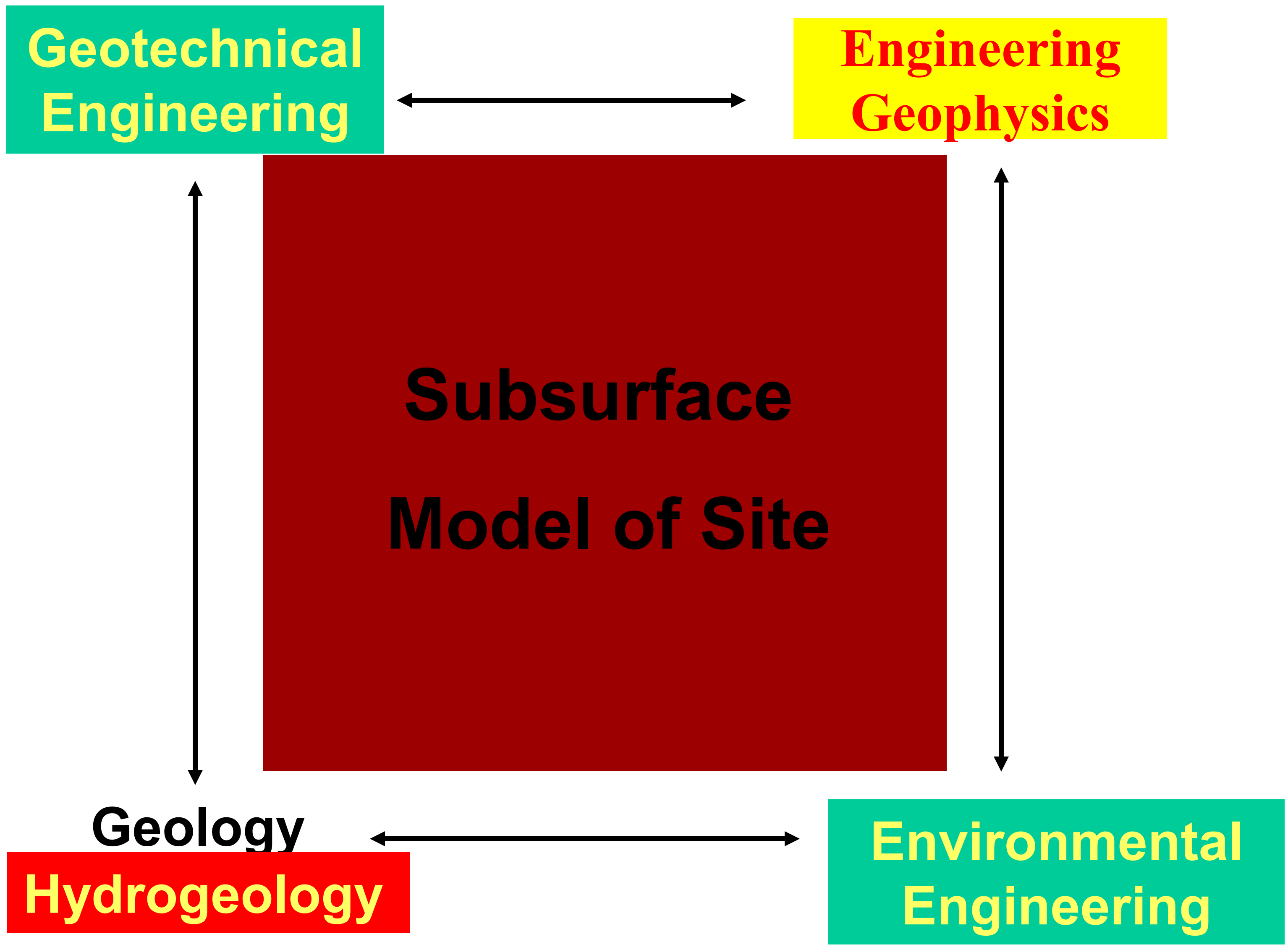
Roads & Highways

Groundwater

Project Stages

- Pre-feasibility
- Feasibility & design
- Detailed design
- Construction & monitoring
- Rehabilitation/remediation

Geotechnics:Supporting Technical Disciplines

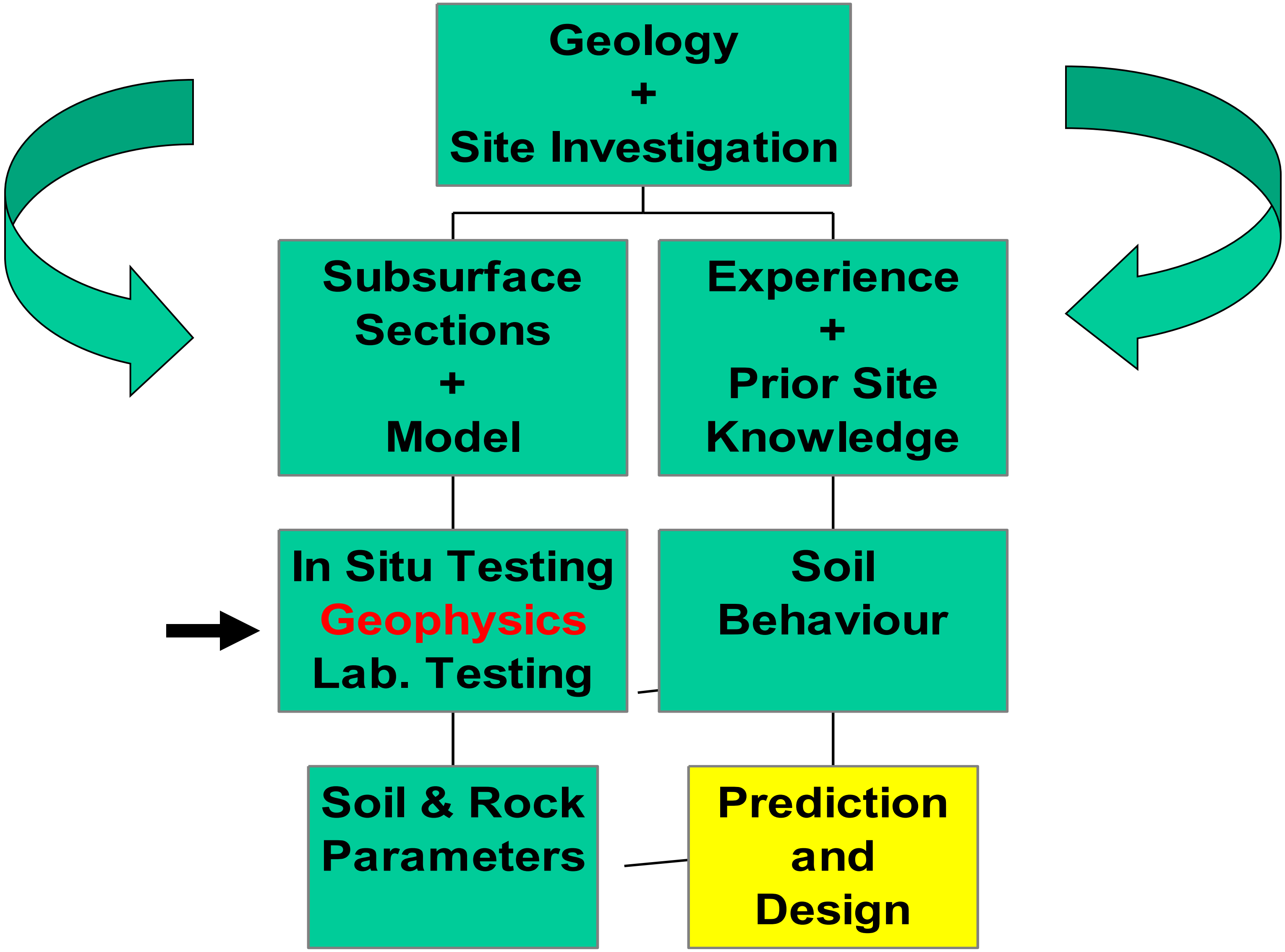


Geotechnics & Geoscience are characterised by:

- Uncertainty- how much?
- Idealization – how much?
- Approximation (± 25% is good but not good enough)

➢ RISK !

Prediction & Design



Geophysics is a form of non-destructive in situ testing (NDT) whose objective is to provide enhanced subsurface information in a more cost-effective manner than by invasive methods such as drilling.

Site Investigation Objectives & Scope

Site characterisation for a defined purpose:

For example

- **determine nature, thickness, dip & variability of strata**
- **determine relevant physical/chemical properties of strata**
- **determine groundwater level & variations**
- **Establish a geological, hydrogeological & geotechnical model for the site**

Obtain this information in the most technically accurate and economic manner

Scope must accord with purpose not SI budgets!!!!

Site Investigation Components

- ***Site Exploration (or testing) –search for buried features/objects/hazards***

- ***Parameter Specification -depth/size/geophysical property/geotechnical property***

Site Investigation Phases

- Preliminary
  - assess general site suitability & plan subsequent investigations
  - Methods: geological survey, site inspection, existing logs
- General exploration
  - identify most suitable areas & general site characterisation
  - Methods: simple exploration, sampling and testing
- Detailed
  - Characterise properties of specific subsurface features
  - Methods: carefully selected exploration techniques, sampling and testing

Site Exploration Methods:

- Test Pits
- Boreholes
- Probes (in-situ tests)
- Geophysics (surface & borehole)

Methods applied depend on,

- sampling requirements
- extent of investigation
- site conditions
- budgets

traditional methods of investigation by drilling

"Geophysics supplements rather than displaces traditional methods"

c. 1959

Traditional Drilling Methods – *not much change*

c. 2009

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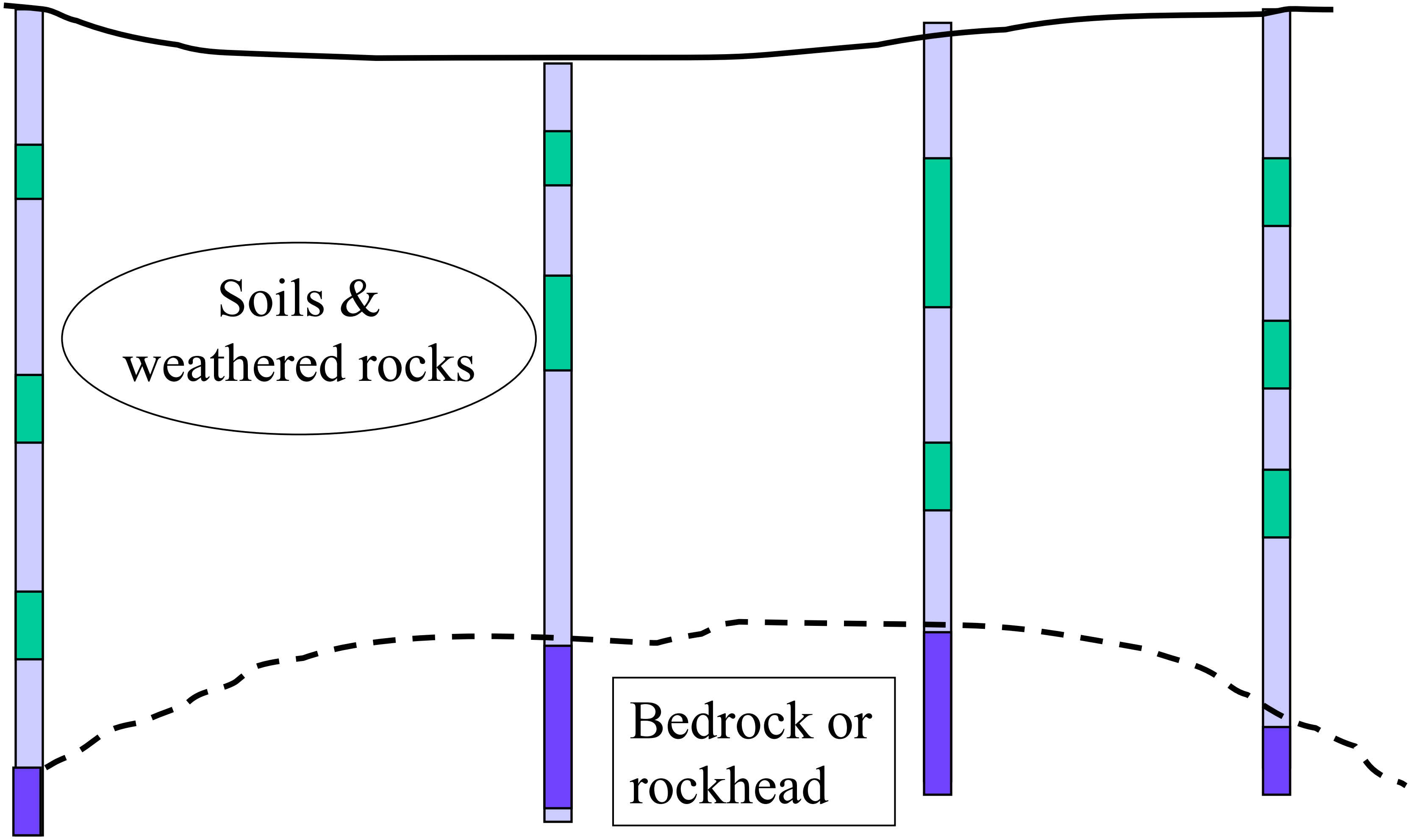
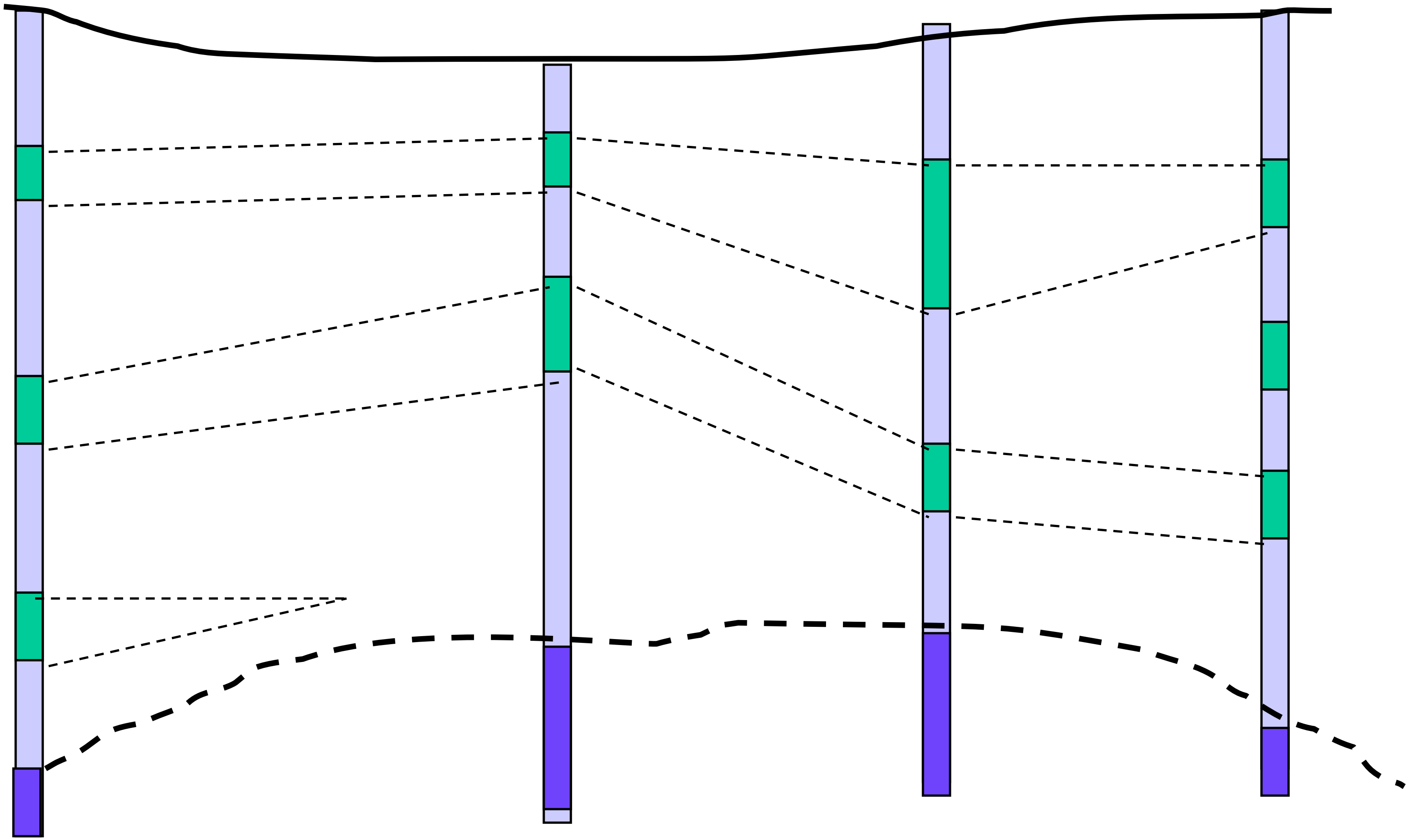
Geological Model:Traditional Approaches

We can still get it very wrong!!!

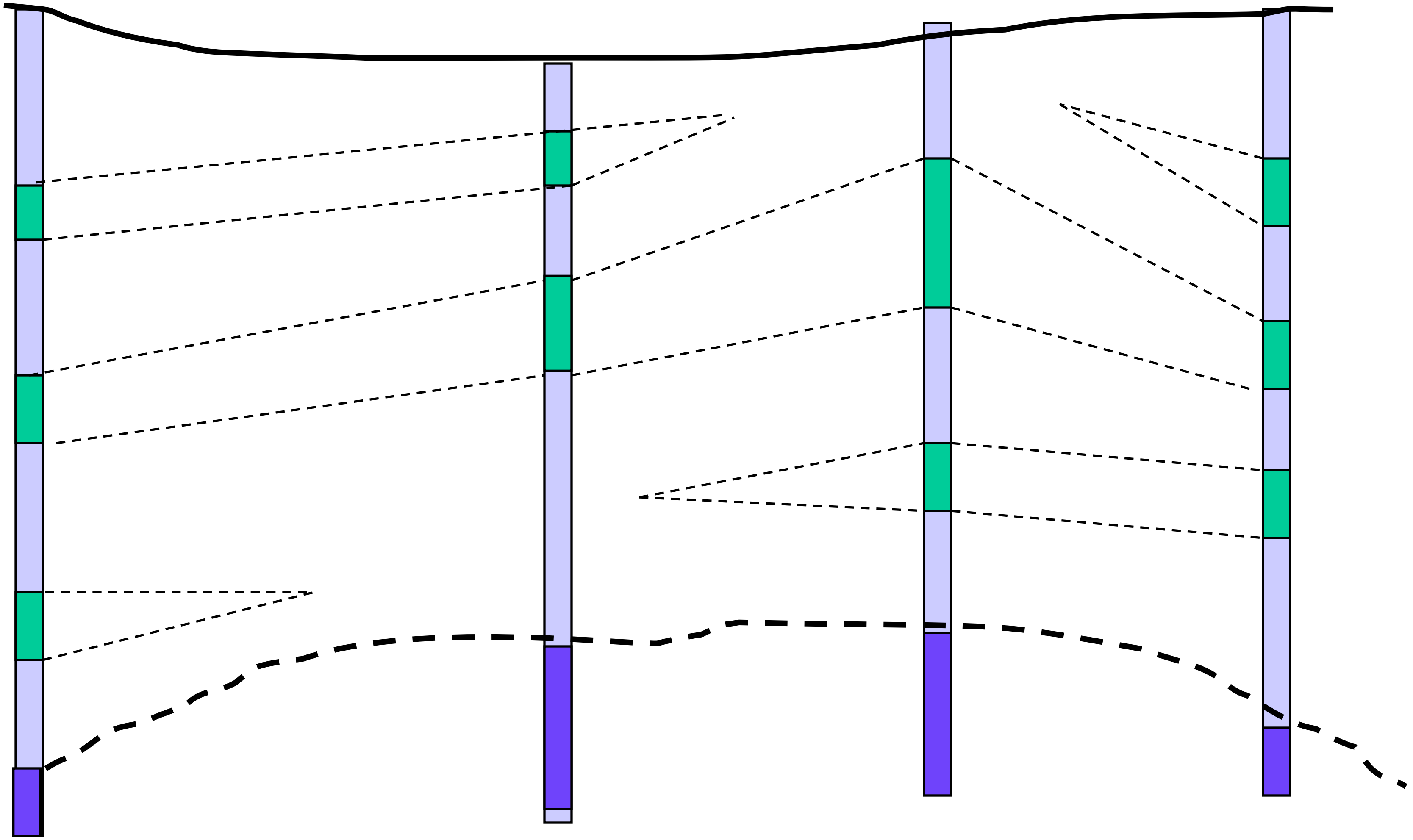
Traditional Site Investigation



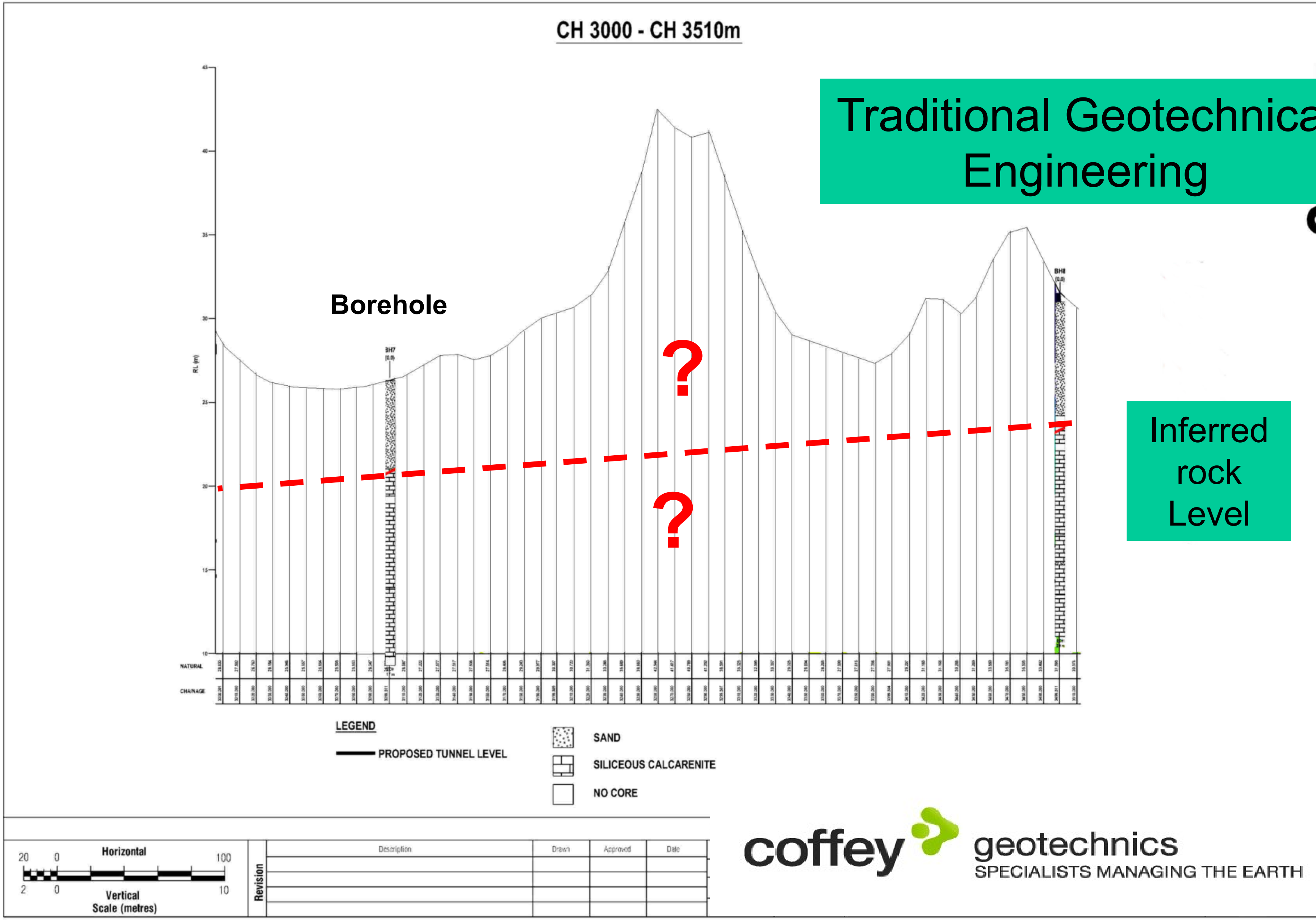
GEOLOGICAL MODEL – you can get it very wrong if you start interpolation from the top



GEOLOGICAL MODEL – better if you start from the bottom but you still no guarantees !!!



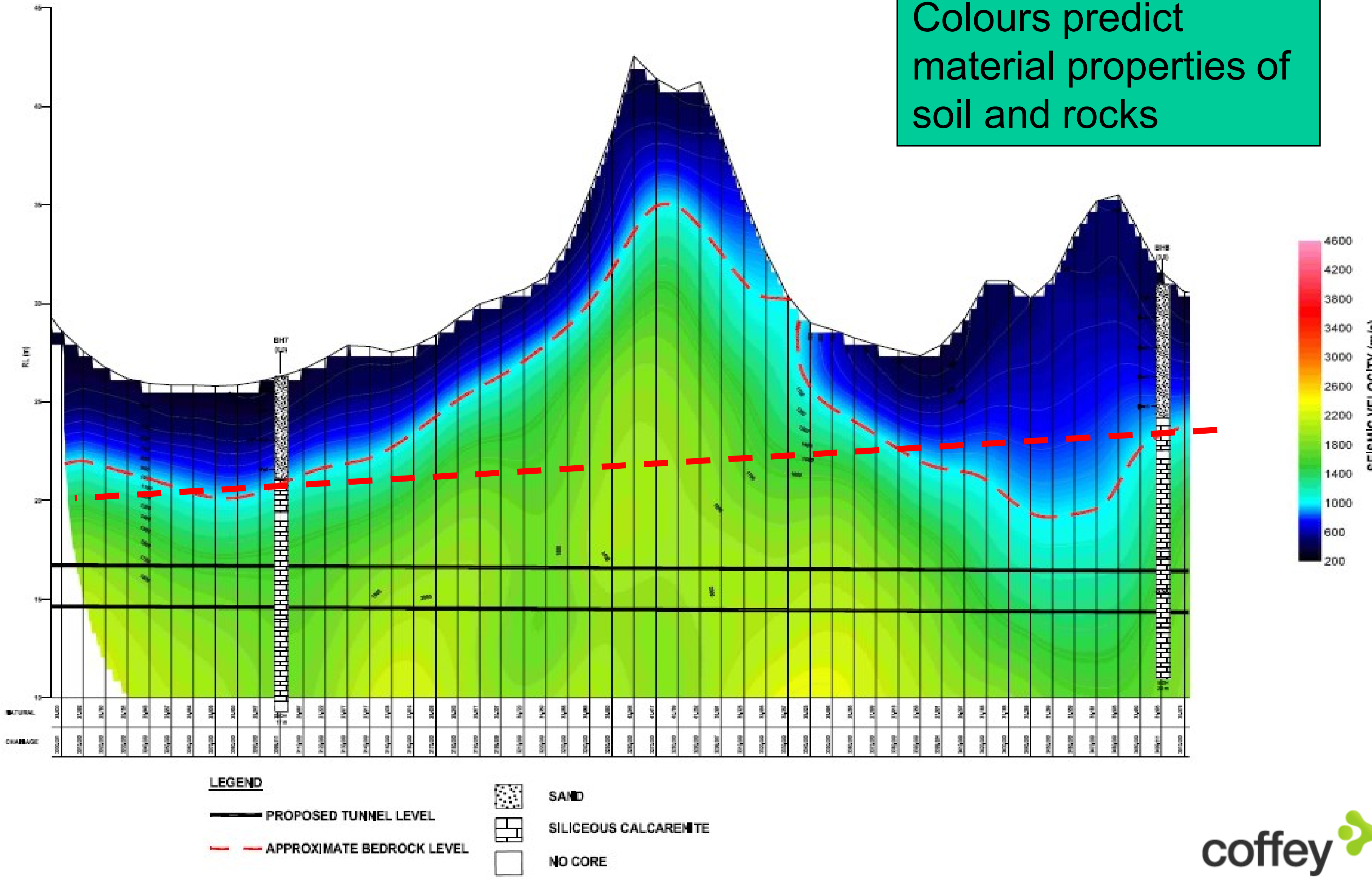
Traditional Geotechnical Engineering



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

With Geophysics – actual soil thicknesses

Colours predict material properties of soil and rocks



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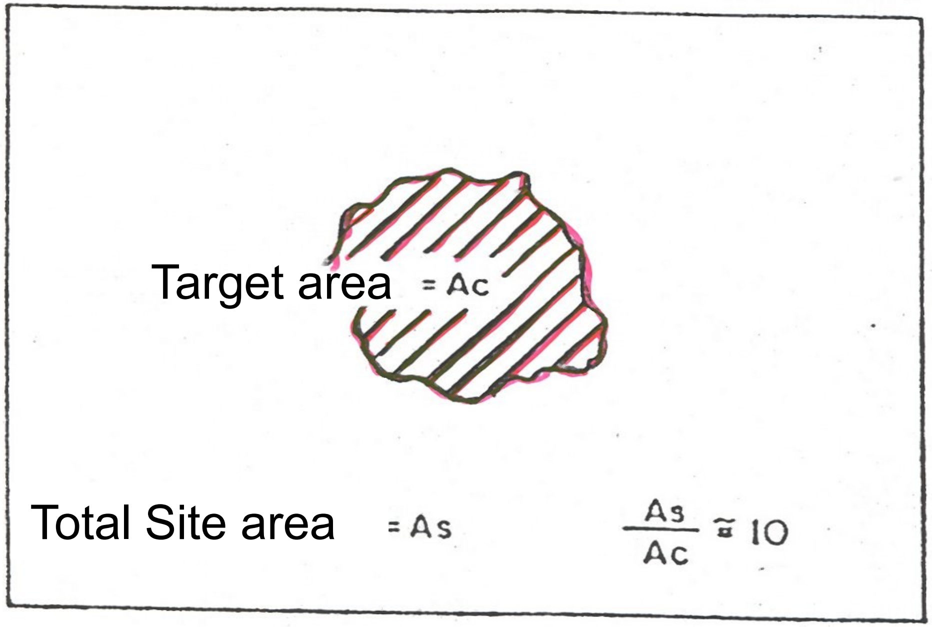
c. 1959

Traditional Drilling Methods – *not much change*

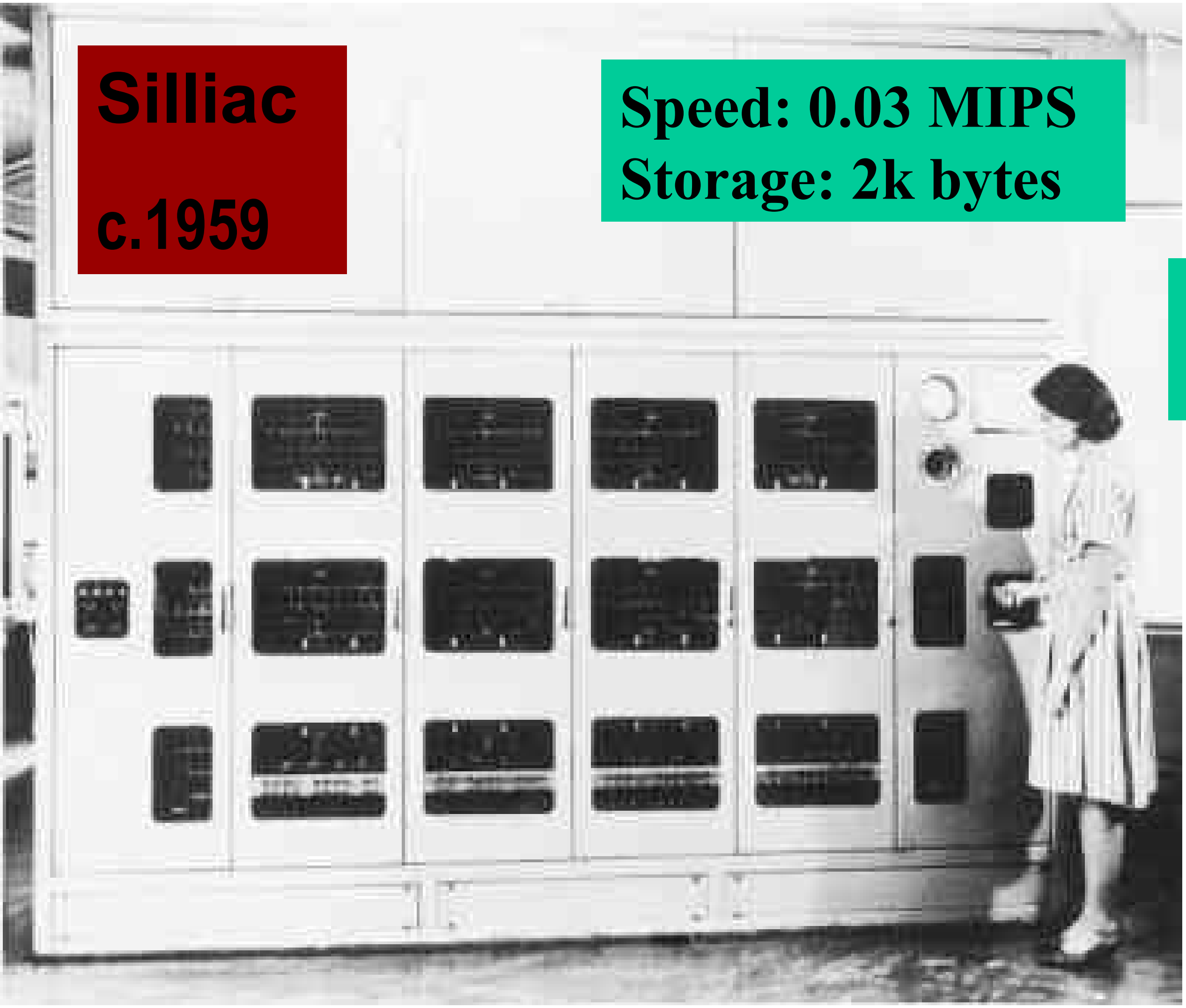
c. 2009

Traditional Grid Drilling or Sampling



Probability of Detection	As/Ac = 10	As/Ac = 100	As/Ac = 1000
100	16	160	1600
98	13	130	1300
90	10	100	1000
75	8	80	800
50	5	50	500
40	4	40	400
30	3	30	300

Advances in Computer Technology



Silliac

c.1959

Speed: 0.03 MIPS
Storage: 2k bytes

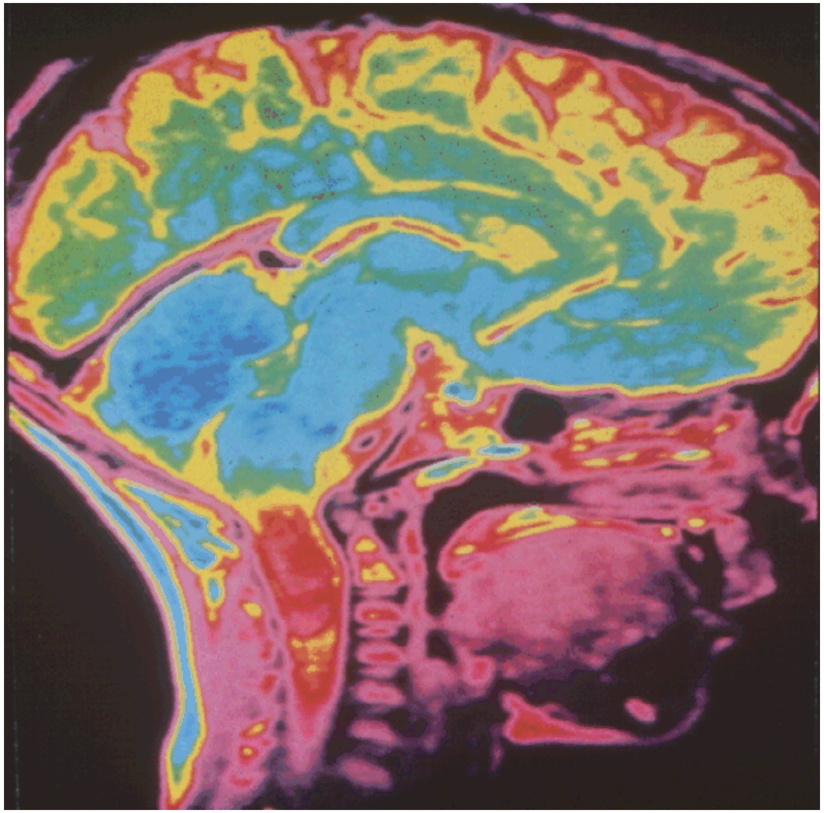
Speed: 10,000 MIPS
Storage: 100 Gigabytes

Notebook

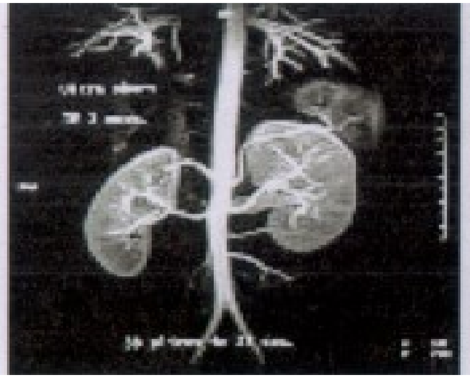
c. 2009

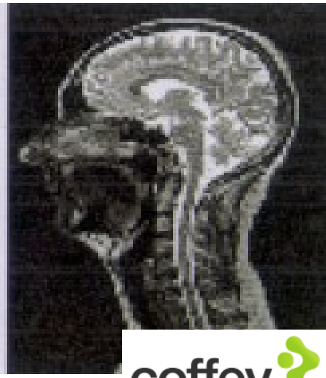
TRADITIONAL ?

NEW ?



Advances in geophysical imaging parallel advances in medical imaging





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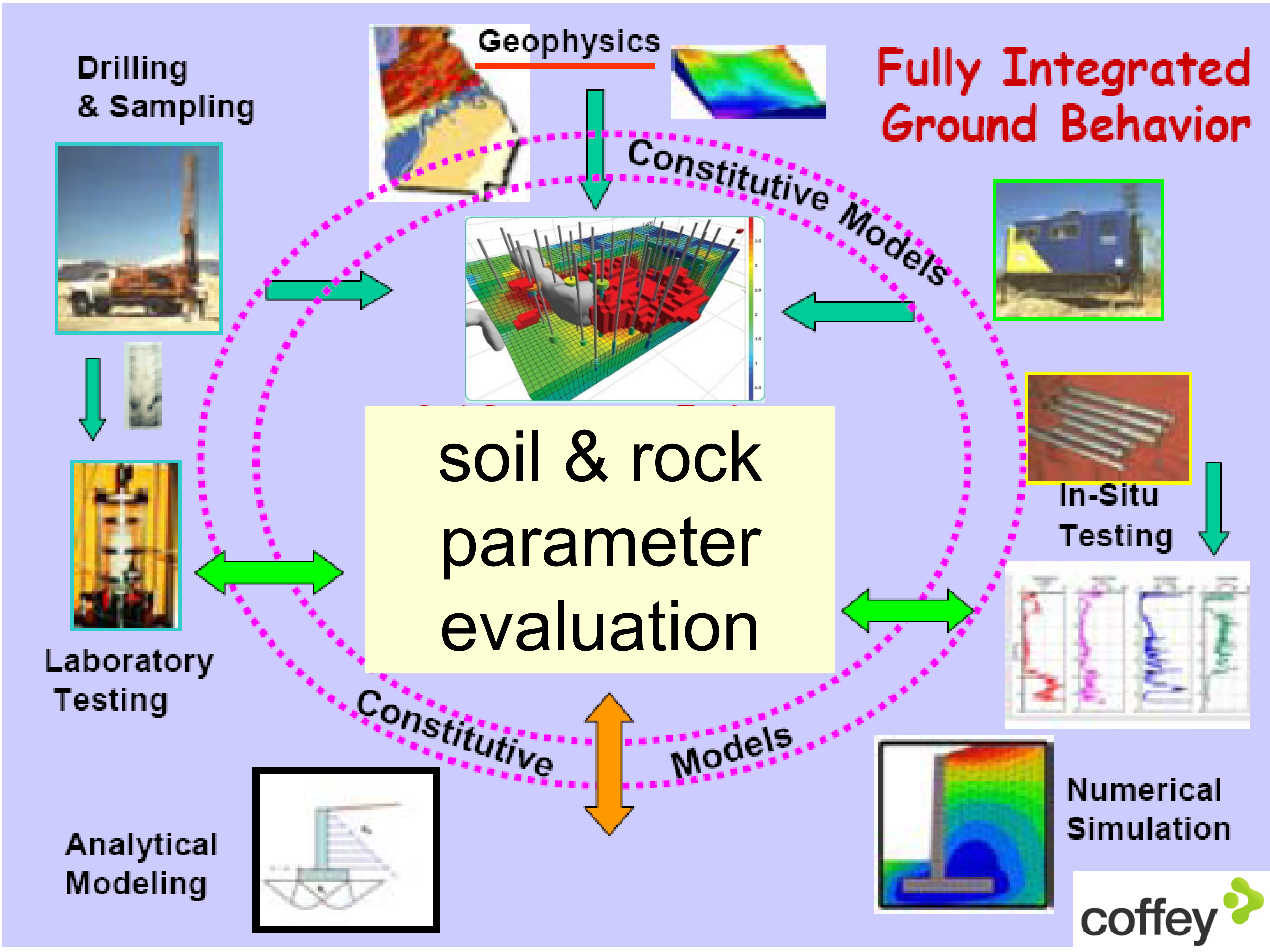
Investigation Method	***Scale of Sample***	***Sample size/ Site size***
Traditional drill & sample	**mm to m**	**1: 1,000,000**
+ geophysics	**m**	**1 : 10,000**

"Geophysics enhances ground knowledge"



Fully Integrated Ground Behavior
Drilling & Sampling
Geophysics
Constitutive Models
In-Situ Testing
Laboratory Testing
soil & rock parameter evaluation
Constitutive Models
Analytical Modeling
Numerical Simulation
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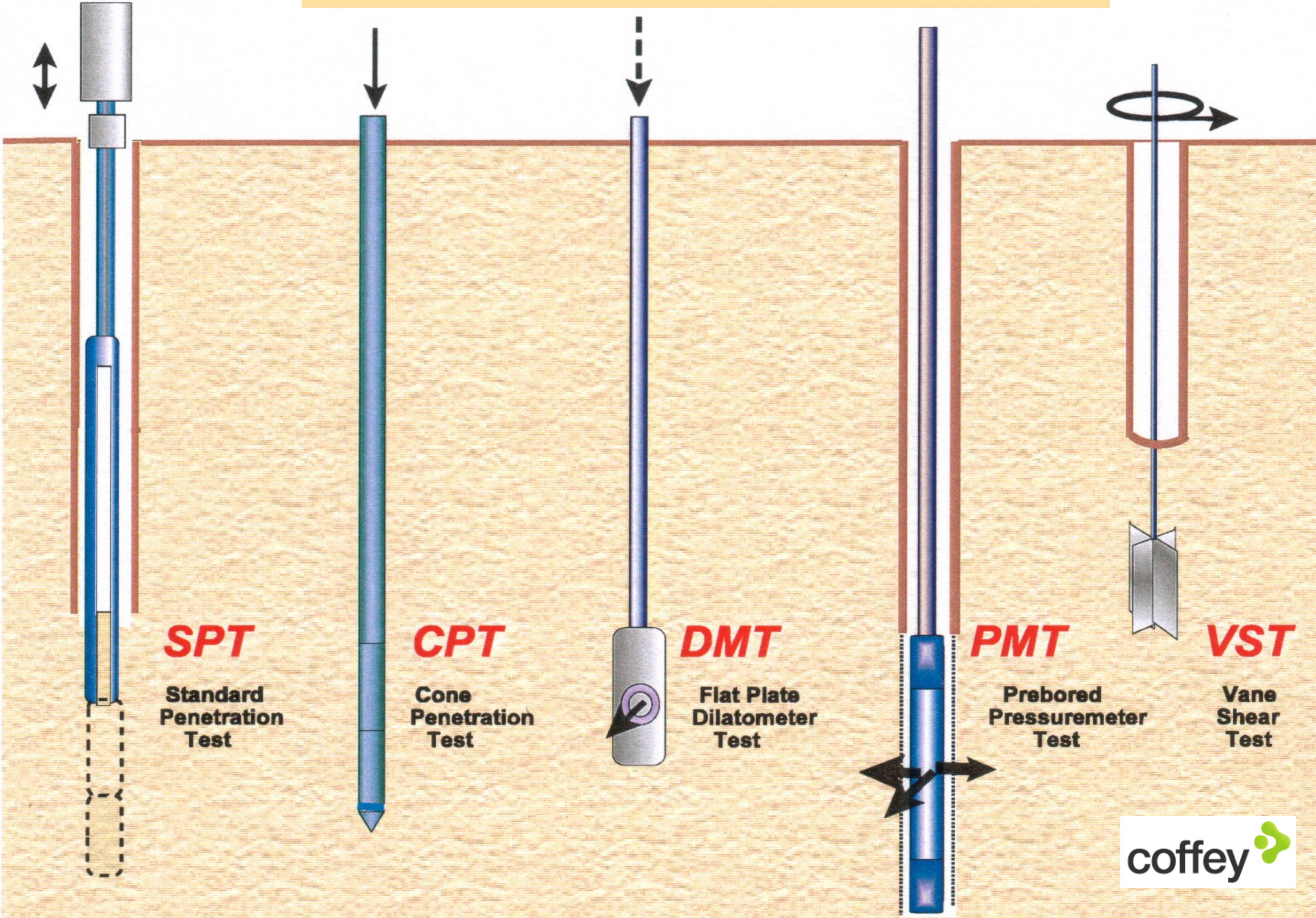
In Situ soil testing methods



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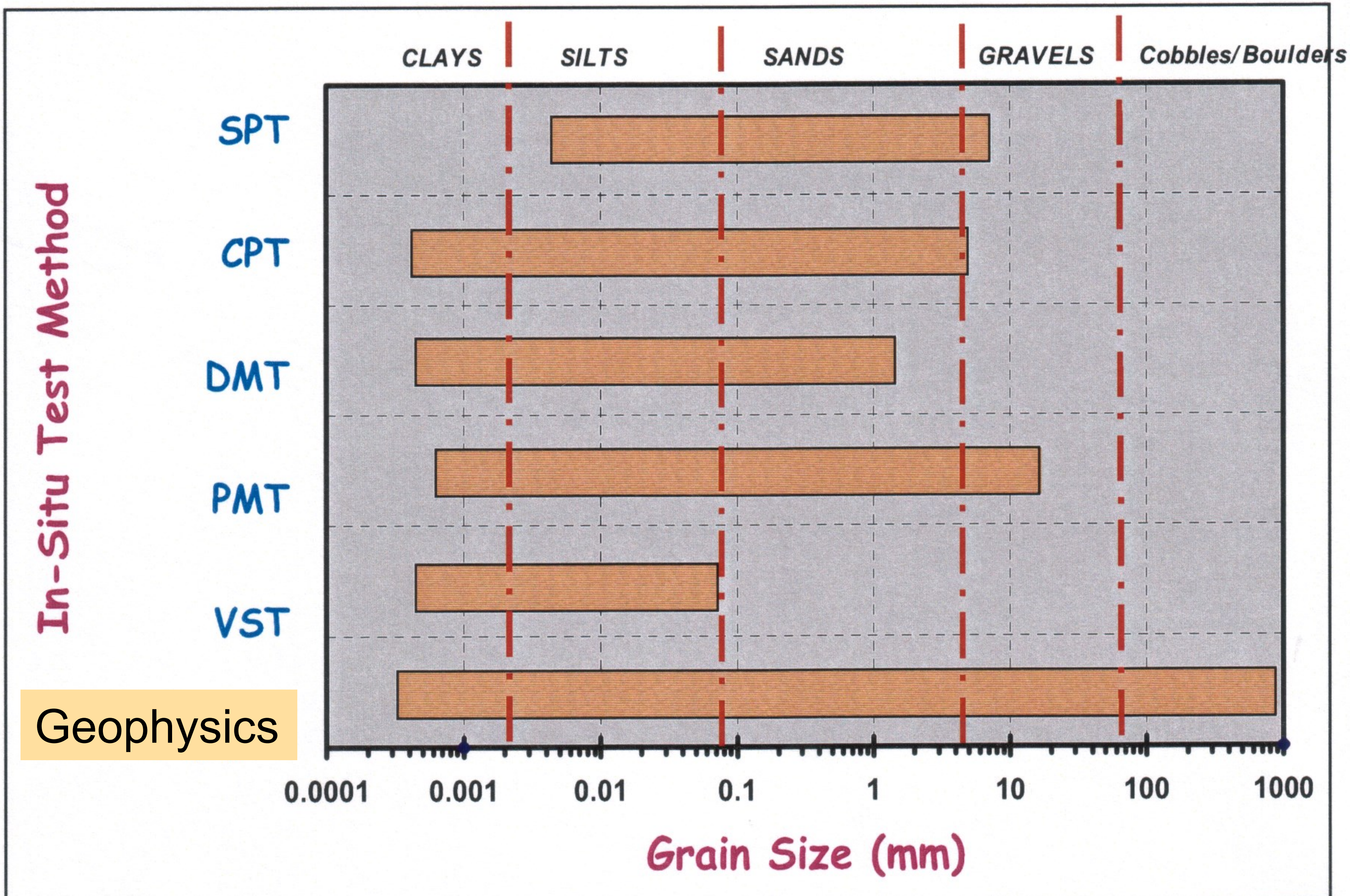
RELEVANCE OF IN-SITU TESTS TO DIFFERENT SOIL TYPES

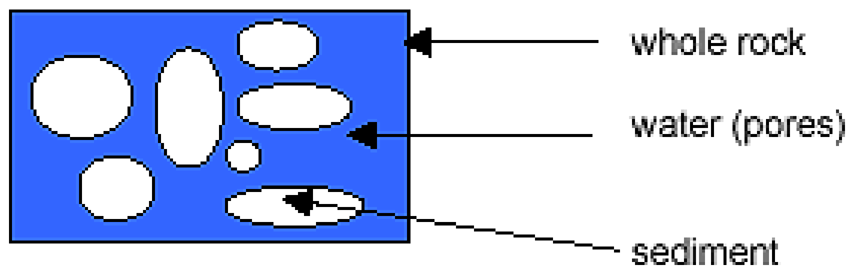


What about groundwater?

DEFINITION OF POROSITY AND PERMEABILITY

POROSITY:

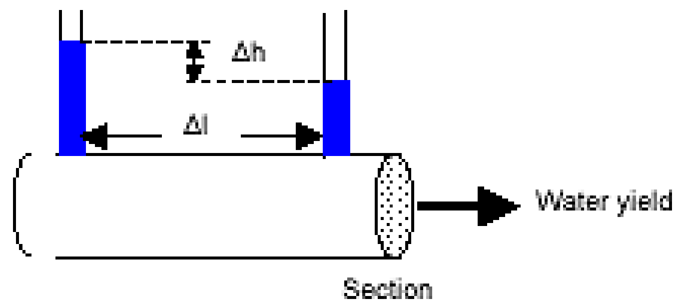
$$\text{Porosity} = \frac{\text{volume of pores}}{\text{volume of rock}}$$



PERMEABILITY:

$$\text{Permeability} = \frac{\text{water yield}}{\text{sample section}} \;/\; \text{hydraulic gradient}$$

with hydraulic gradient = $\Delta h / \Delta l$



POROSITY AND PERMEABILITY OF ROCKS

DEFINITIONS

- **POROSITY:** (unit: %) — *quantity of water*, existing in rocks = volume of water / volume of rocks
- **PERMEABILITY:** (unit : m/s) — *speed of the water*, when pushed by pressure = yield per unit of hydraulic pressure gradient

NUMERIC VALUES FOR VARIOUS TYPES OF ROCKS

TYPE OF ROCKS		POROSITY (%)	PERMEABILITY (m/s)
UNCONSOLIDATED (Soft sediments)	gravel	30	10^{-2}
	sand	25	10^{-4}
	clay	50	10^{-12}
CONSOLIDATED sandstone limestone granite , basalt	massive	1	10^{-10}
	fissured / fractured	5	10^{-8}
	weathered	15	10^{-6}

NB: These values are only indicative and largely depend on local conditions

Groundwater impacts can be sudden & dramatic

House collapse over brick sewer

Geotechnical factors must be included in construction risk management systems

Risk = Hazard x Probability of Occurrence

(Vulnerability)

Risk cannot be ignored but can be,

managed

minimised

shared

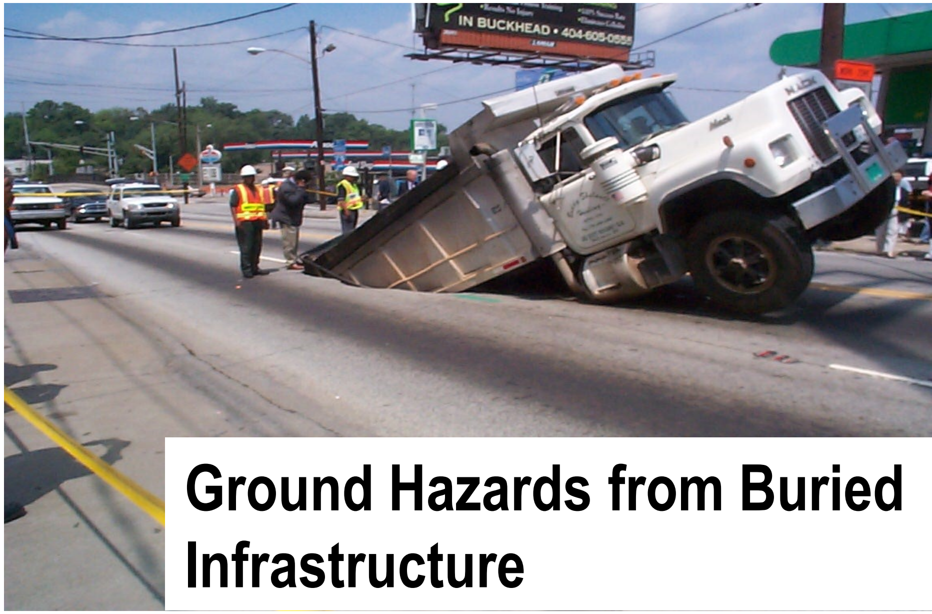
transferred

accepted

Ground Hazards to Construction

"Geophysics is a component of a ***RISK*** *management system"*

risk = hazard x probability of occurrence



Ground Hazards from Buried Infrastructure

Geophysical Response = physical property contrast

x

active volume

x

1/distance ^{n} (or depth ^{n})

x

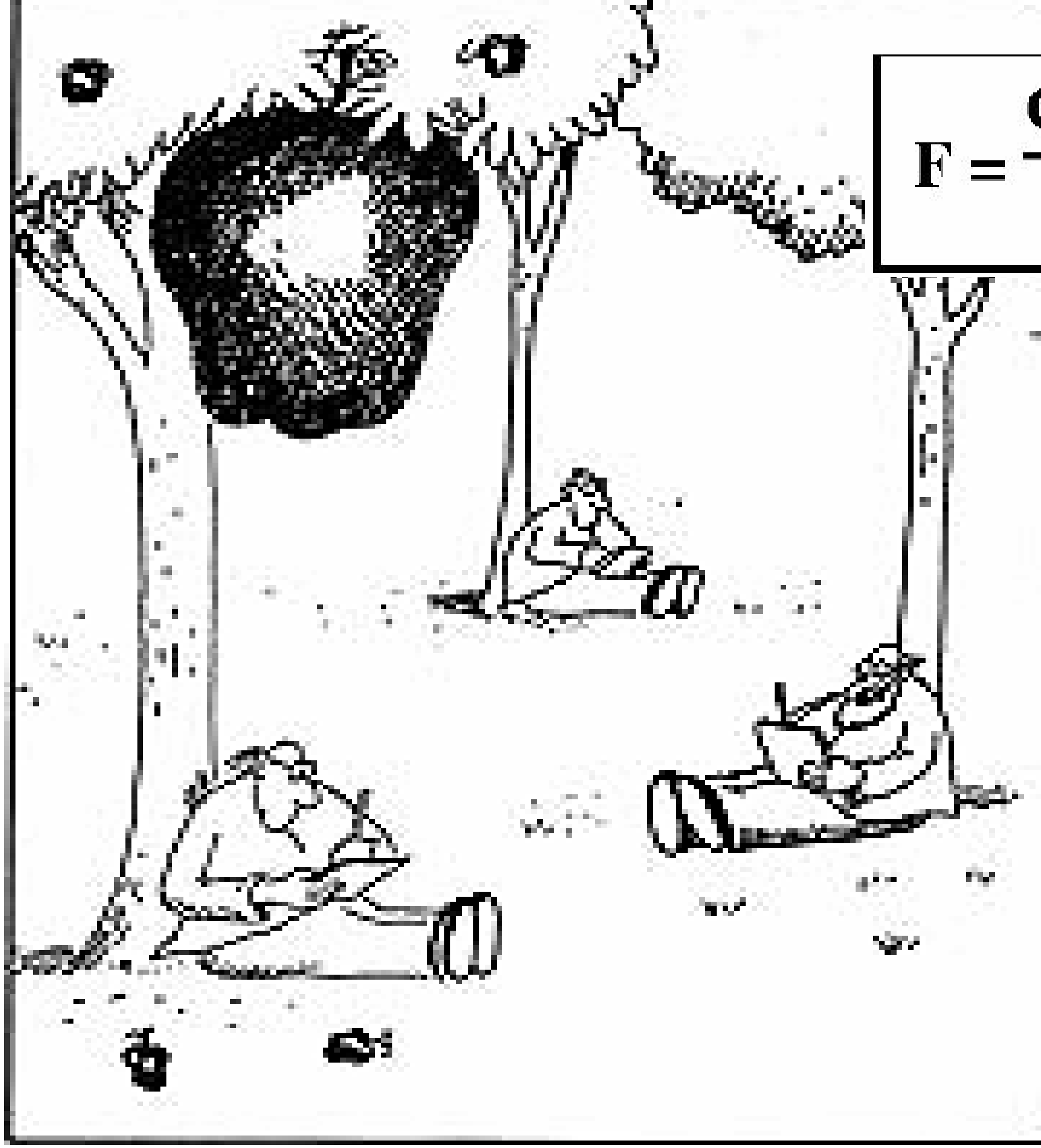
primary field

n = 2 to 5

Geophysical Method	Derived Parameter	General Relationships with other properties
Gravity	Density	Density
Magnetics	Magnetisation	Magnetic iron content, rock type
Electromagnetics	Electrical Conductivity	Salinity, saturation,clay content, porosity
Radar	Dielectric constant	Water content, voids
Resistivity	Electrical Resistivity (1/conductivity)	Salinity, saturation,clay content, porosity
Seismic	Seismic velocity, density	Saturation, strength, density, stiffness

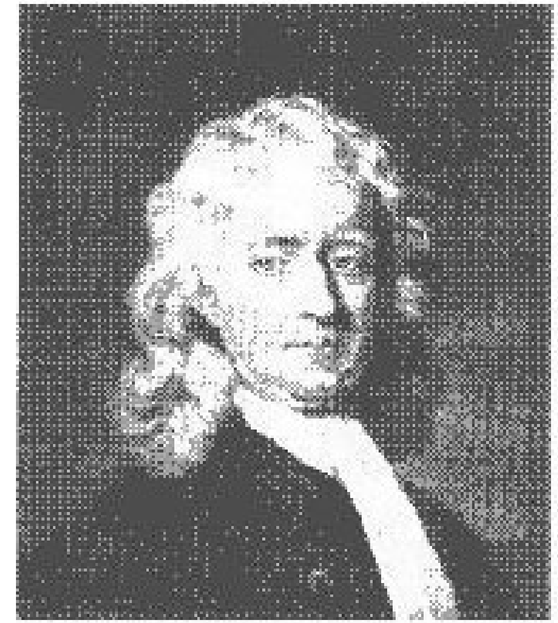
Type	Material Property	Order of Magnitude Variation
Geotechnical	Stiffness/strength	6
	Permeability	13
	Density	<1
Geophysical	Electrical conductivity	6
	Seismic velocity	1
	Seismic wave attenuation	4
Structural	Made to specification (e.g. steel)	<<1

Geophysical Method	Examples of Geotechnical Application	Examples of Groundwater Application
Gravity	Paleochannels, voids	Volume of saturated sediments
Magnetics	Dykes and sills	Faults & shears
Electromagnetics	Soil classification	Groundwater contamination, salinity mapping, clays
Radar	Pavement condition assessment	Water filled voids
Resistivity	Unstable mass	Groundwater contamination, salinity mapping, clays
Seismic	Bedrock mapping, rippability	Aquifer mapping
Geophysical Logging	Joints, fracture location	Aquifer location, setting well casing



$$F = \frac{G m_1 m_2}{r^2}$$

"Nothing yet. ...How about you, Newton?"



$$g = \frac{G m_1}{r^2}$$

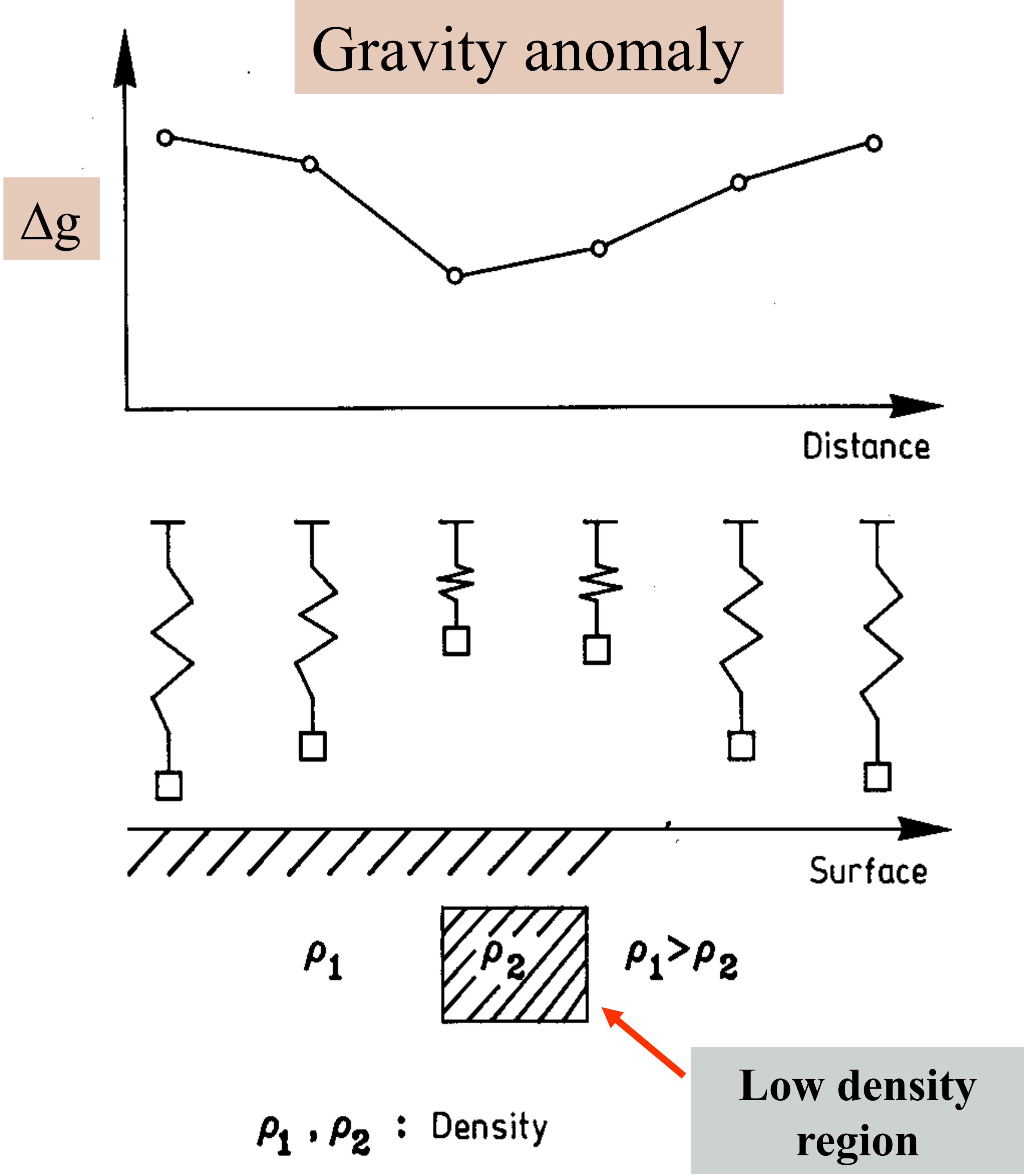
Gravity

Density of Natural Materials

Material	Density (gm/cm^3)
Air	~0
Water	1
Sediments	1.7-2.3
Sandstone	2.0-2.6
Shale	2.0-2.7
Limestone	2.5-2.8
Granite	2.5-2.8
Basalts	2.7-3.1
Metamorphic Rocks	2.6-3.0

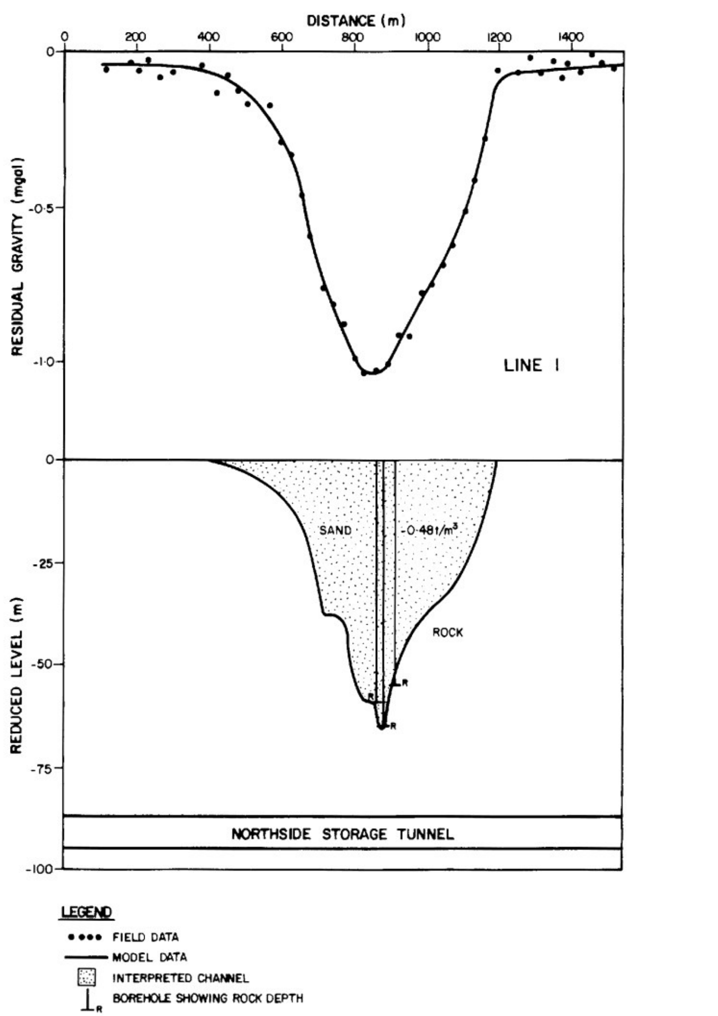
GRAVITY

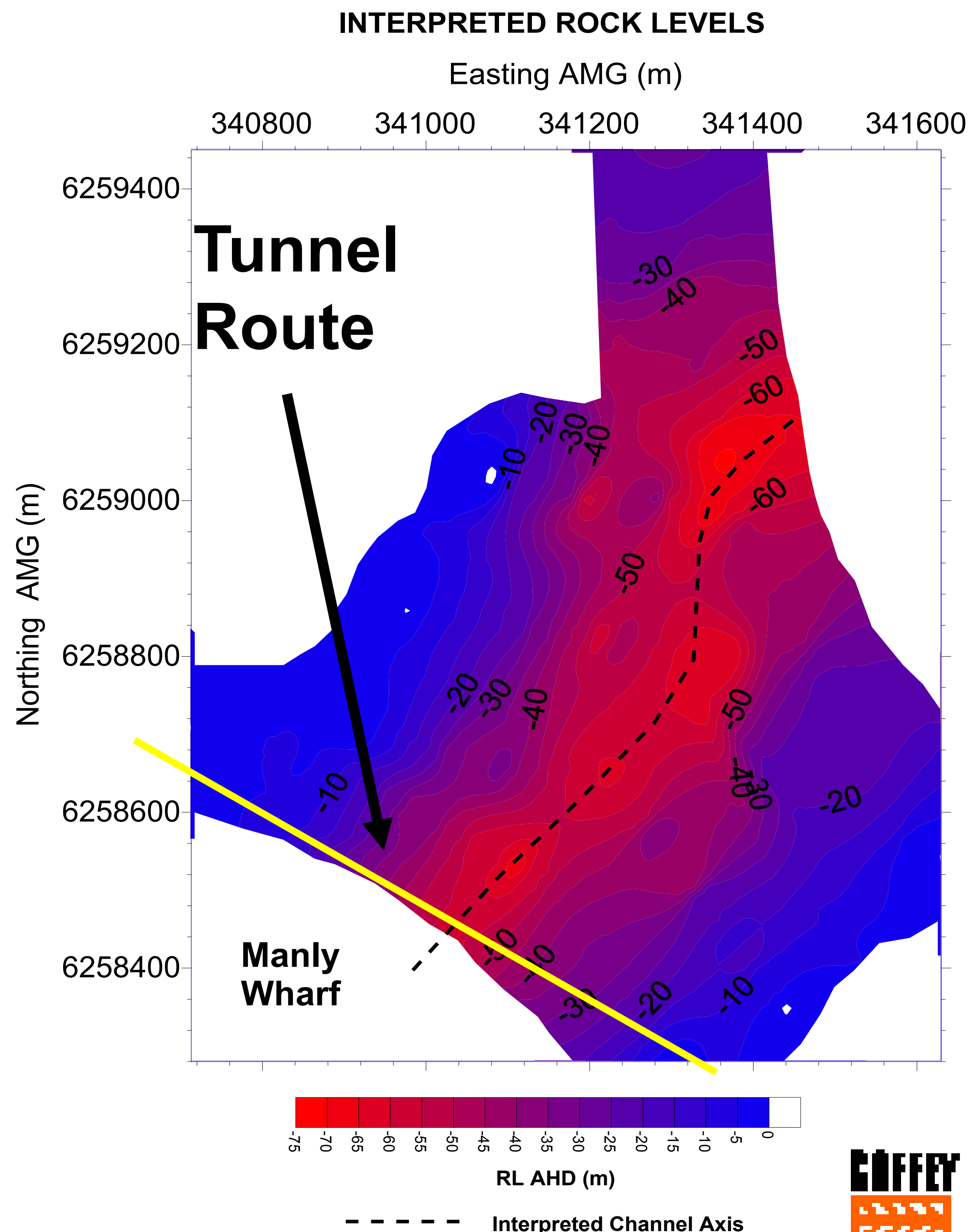
$$g = \frac{G\,m_1}{r^2}$$



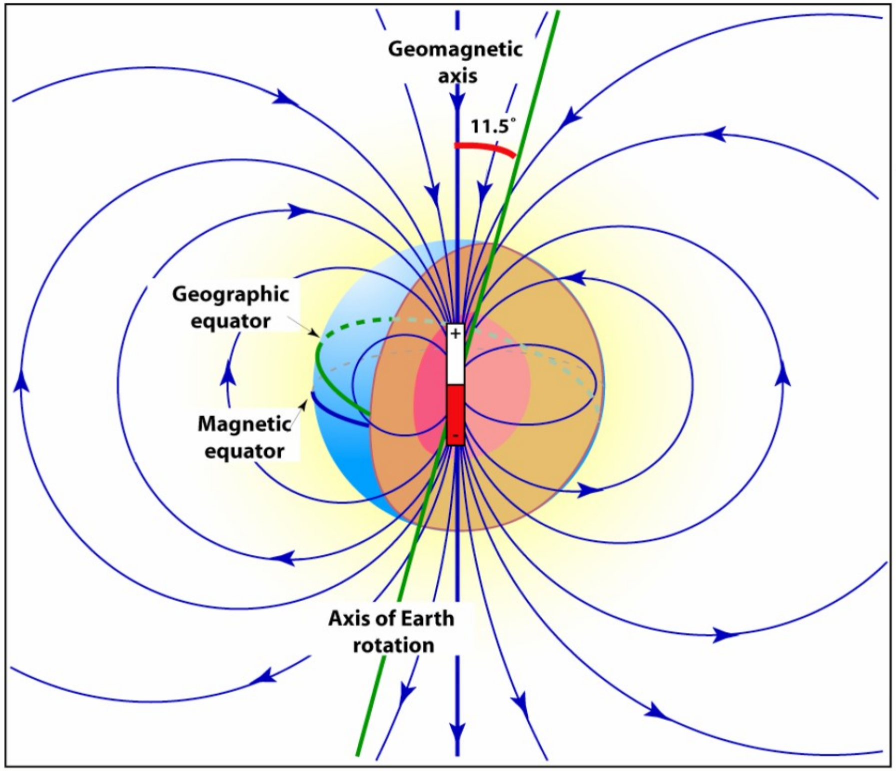

MANLY SAND SPIT

ROCK LEVELS BASED ON GRAVITY INTERPRETATION



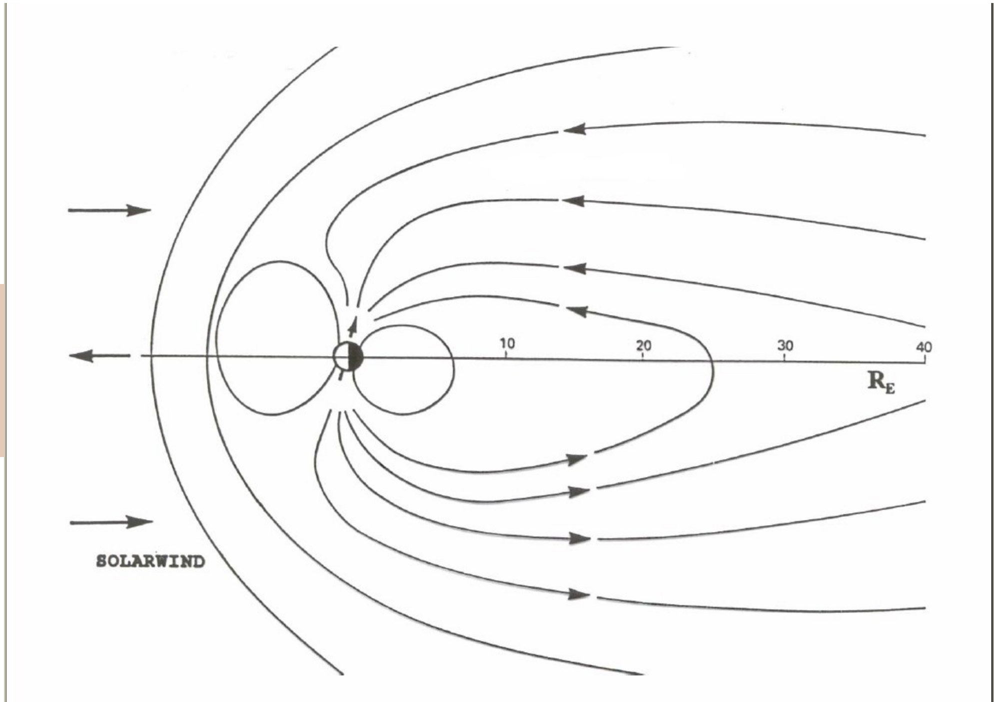


MAGNETICS

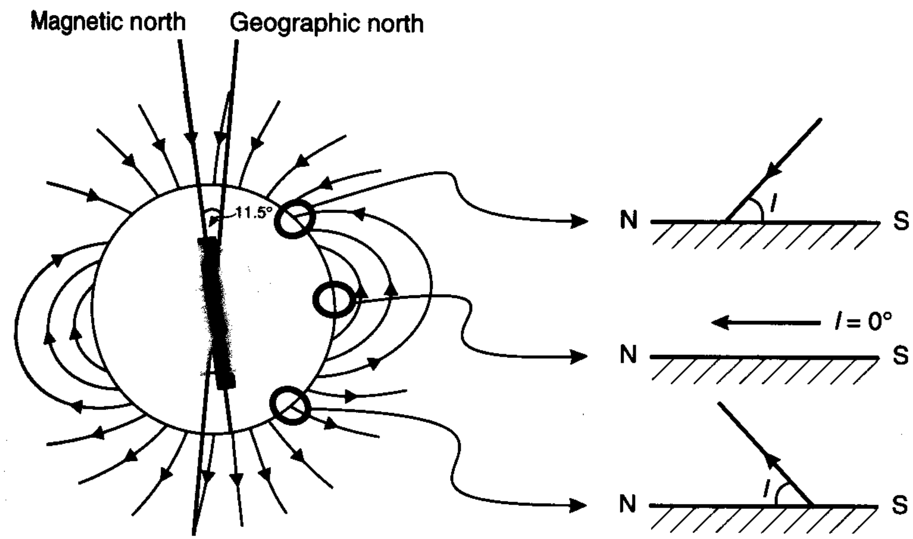


Internal component of the Earth's magnetic field

External component of the Earth's magnetic field



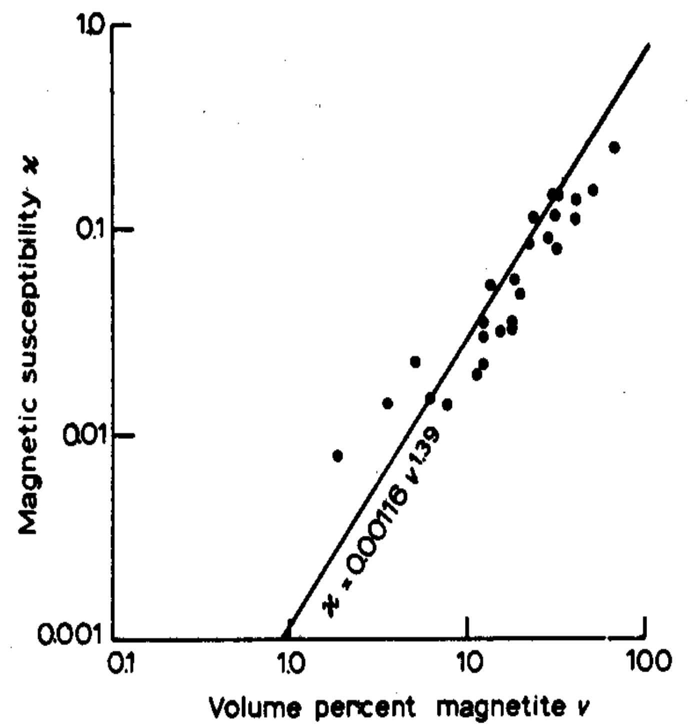
ROCK MAGNETISATION = *INDUCED* + REMANENT



F

$$\underline{\mathbf{M}} = \mathbf{k}\,\underline{\mathbf{F}}$$

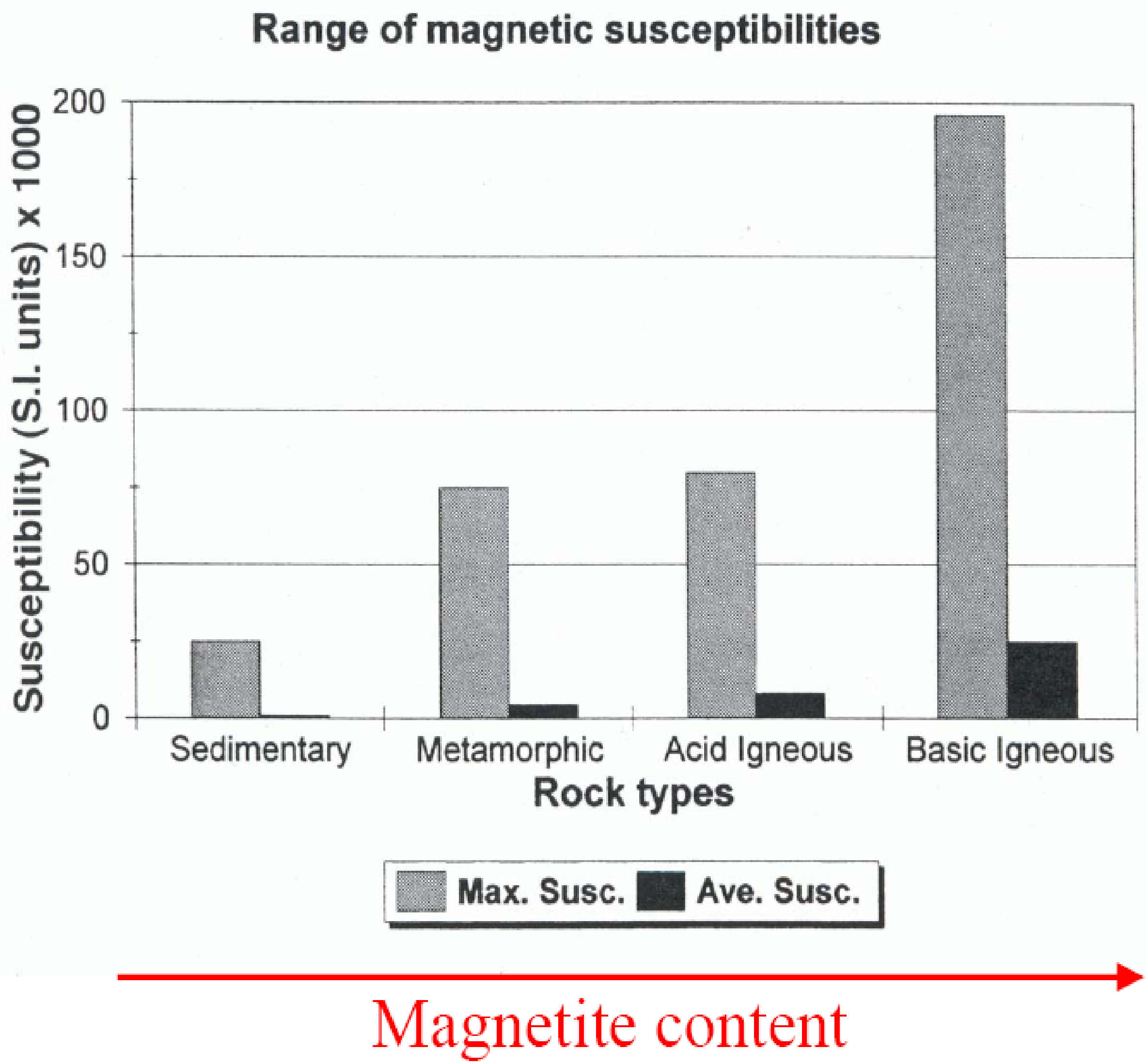
MAGNETIC METHODS



k

Magnetic Susceptibility

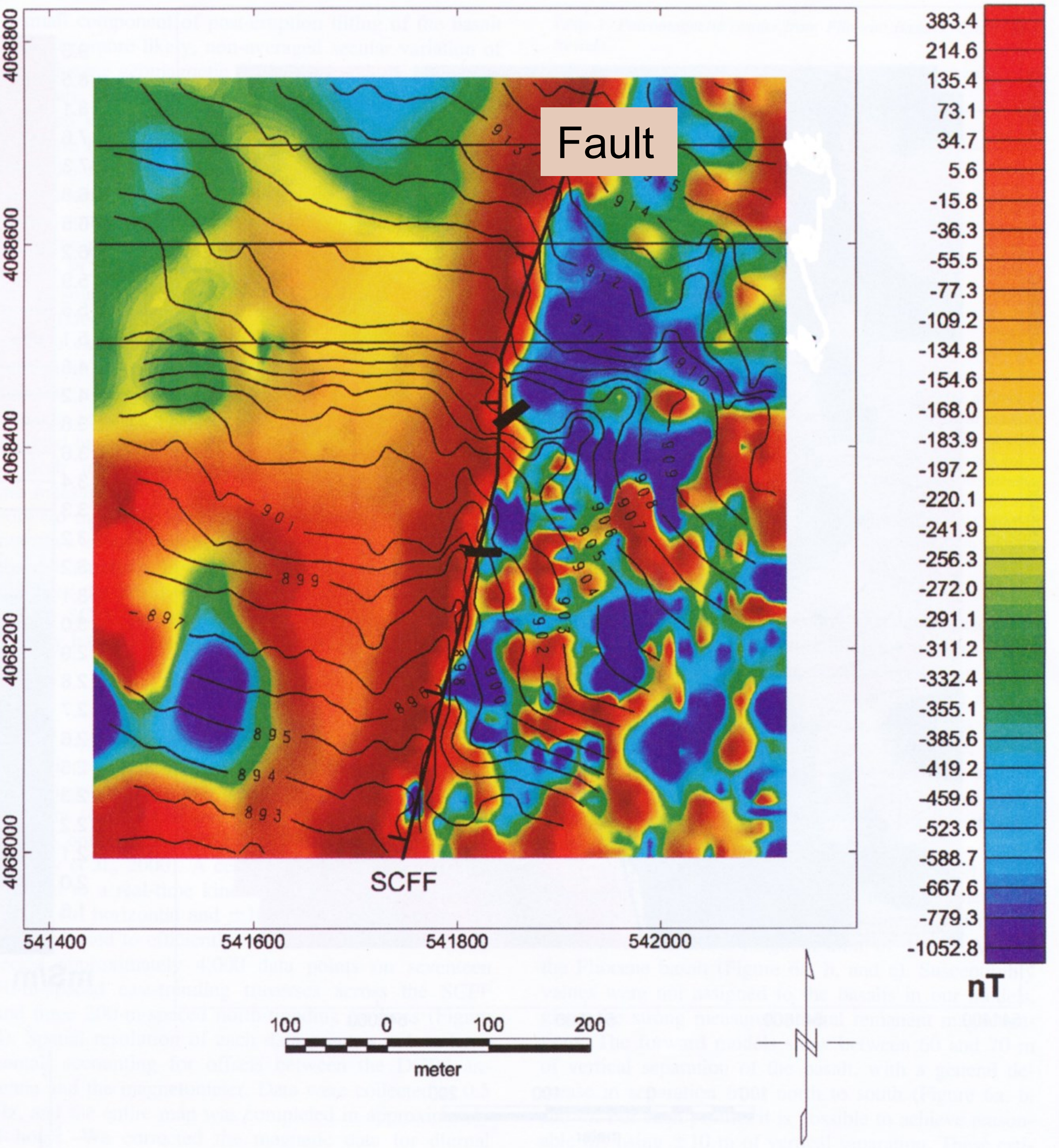
Magnetic properties of rocks



$$\vec{B} = (1 + k)\,\mu_0 \vec{H}$$

Magnetic properties of rock depend mainly on the concentration size, shape and dispersion of magnetite

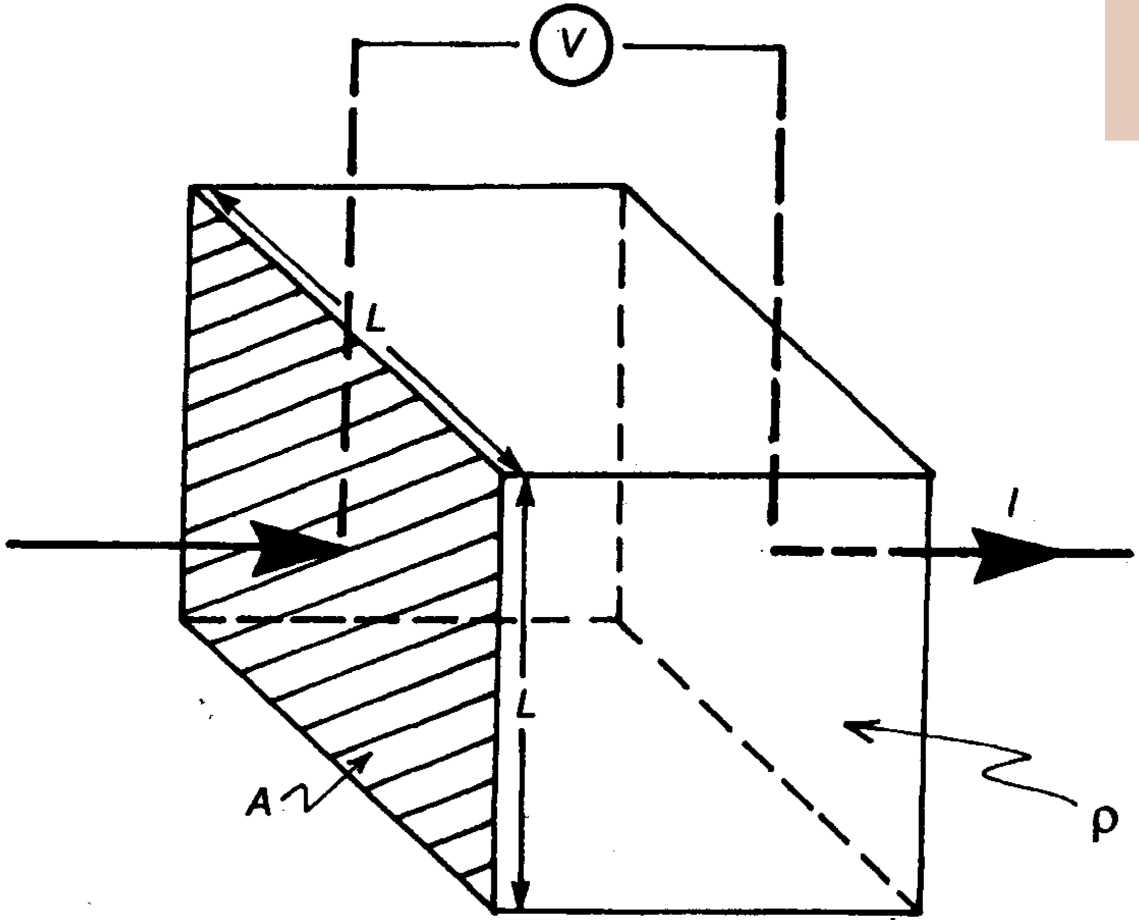
Magnetic map of fault zone

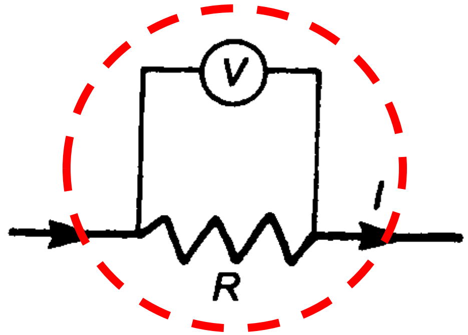


Resistivity

Ohms Law

R = V/I





RESISTIVITY (ρ)

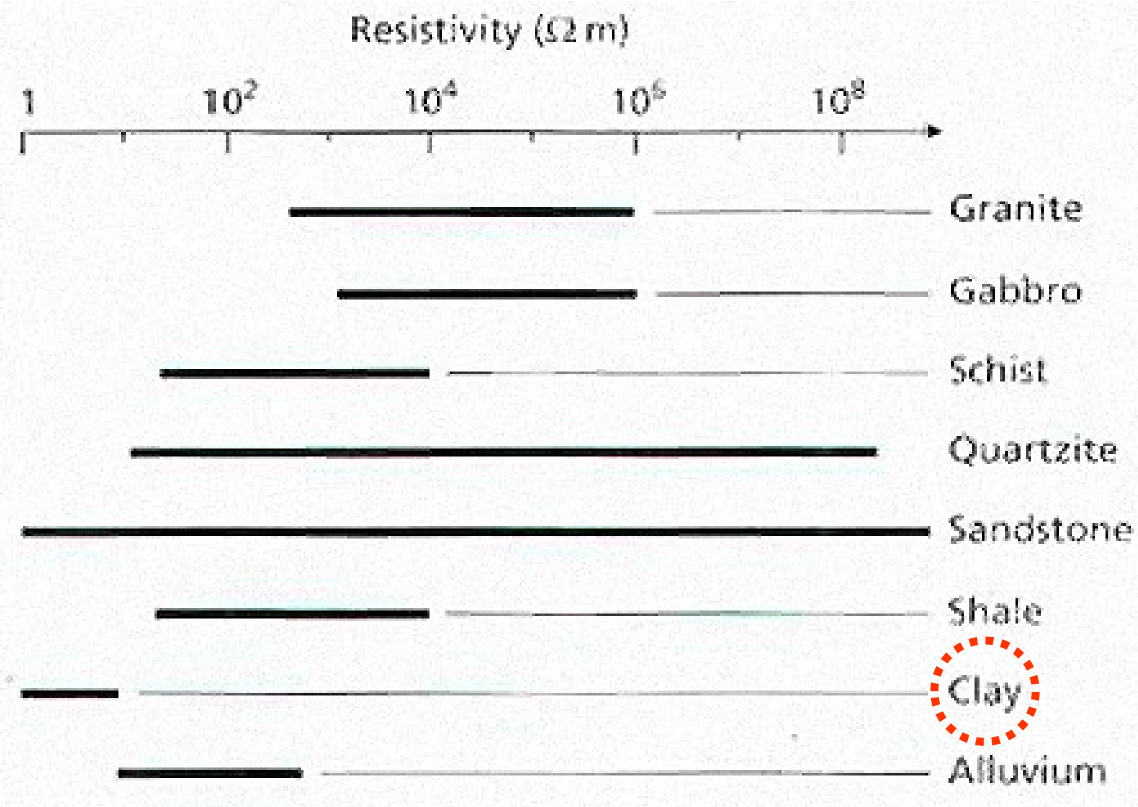
$$\rho = \frac{R\,A}{L} \text{ ohm·metres}$$

where $R = \dfrac{V}{I}$ ohms

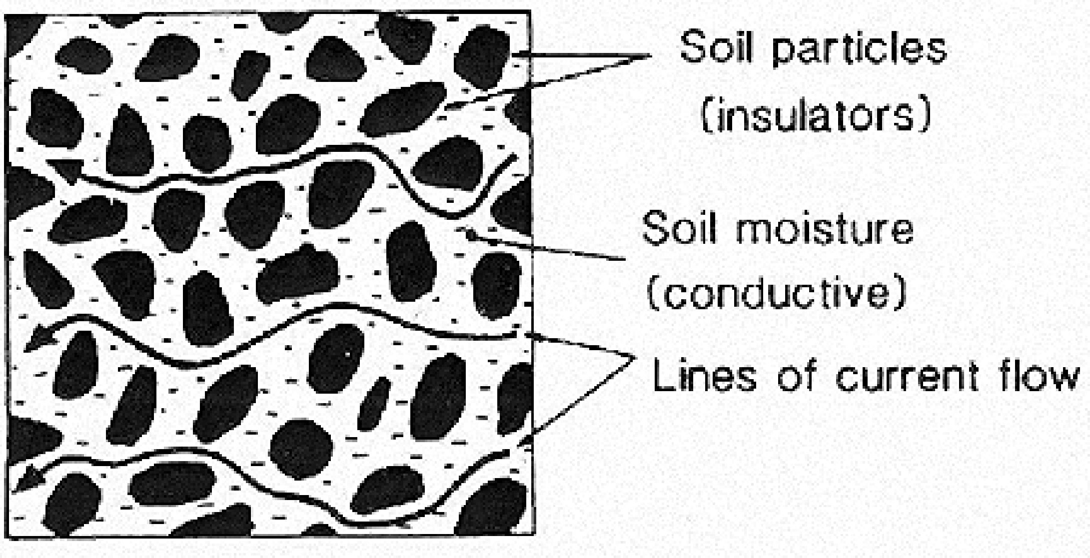
CONDUCTIVITY (σ)

$$\sigma = \frac{G\,L}{A} \text{ Siemens/metre}$$

where $G = \dfrac{I}{V}$ Siemens

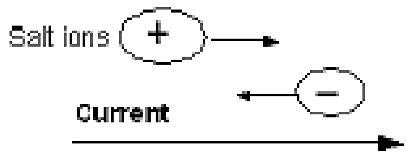


Electrical resistivity of earth materials



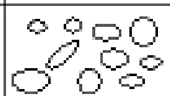
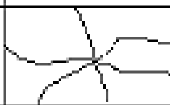
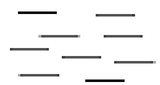
ELECTRICAL PROPERTIES OF ROCKS

→ **<u>THE ELECTRIC CURRENT</u>** FLOWS INTO THE GROUND THANKS TO THE IONS OF SALTS DISSOLVED IN THE WATER



+ ions: Na, Ca, K, ...

- ions: Cl, SO_4, NO_3, ...

TYPE OF POROSITY	TYPE OF WATER	TYPE OF ROCK	
matrix	free		sand, gravel
fracture	free		limestone, sandstone
adherence	bound		clay

→ **<u>THE RESISTIVITY OF ROCKS DEPEND ON:</u>**

- THE WATER CONTENT (Porosity)
- THE RESISTIVITY OF THE WATER
- THE CLAY CONTENT
- THE CONTENT IN METALLIC MINERALS

→ **<u>VALUES OF RESISTIVITY OF ROCKS:</u>**

0.1	ohm.m	SALTED WATER
1	ohm.m	MASSIVE SULPHIDE
10	ohm.m	CLAY
100	ohm.m	SAND, MARL
1 000	ohm.m	DRY SAND, LIMESTONE
10 000	ohm.m	HARD GRANITE, BASALT

CONDUCTIVITY AND SALINITY OF WATERS

- **CONDUCTIVITY** (Siemens) = 1 / resistivity (ohm.m)
- **USUAL UNIT** of conductivity = microS / cm

Conductivity (microS / cm) = 10^4 / resistivity (ohm.m)

- **SALINITY** (mineralization): Total Dissolved Salt (TDS)

TDS (mg / l) = 0.7 x conductivity (microS / cm)

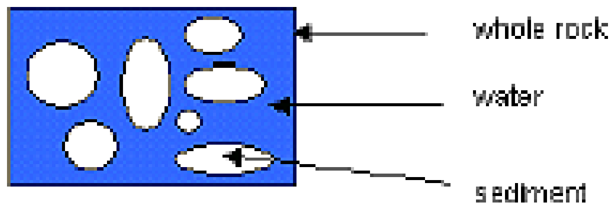
- **NUMERIC VALUES FOR VARIOUS TYPES OF WATER:**

Type of water	*Resistivity ohm.m*	*Conductivity microS / cm*	*Salinity mg / l*
very fresh	200	50	35
fresh	20	500	350
salted	10	1 000	700
very salted (sea water)	0.3	30 000	21 000

Usual rule for drinkable water: resistivity > 10 ohm.m ⟺ conductivity < 0.7 g/l

RESISTIVITY AND POROSITY OF ROCKS

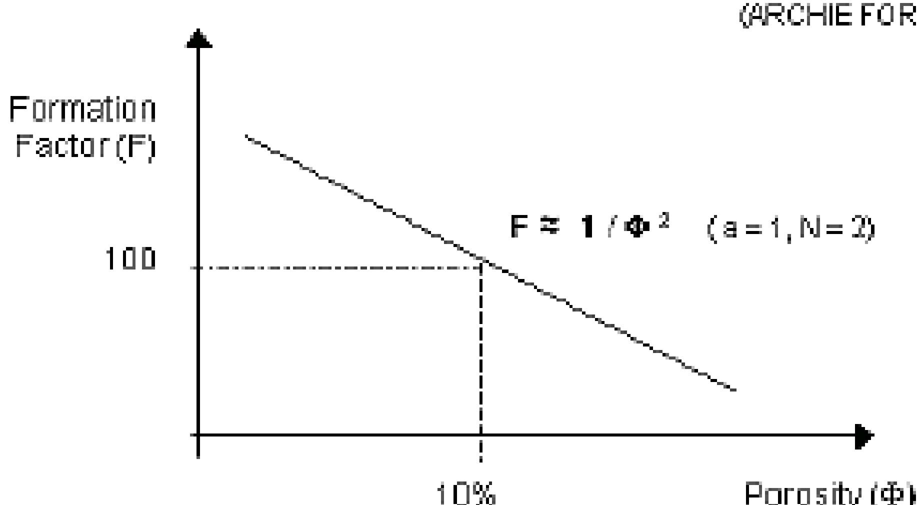
Relation between the resistivity of and the porosity for non clayey rocks



ROCK RESISTIVITY = F x WATER RESISTIVITY

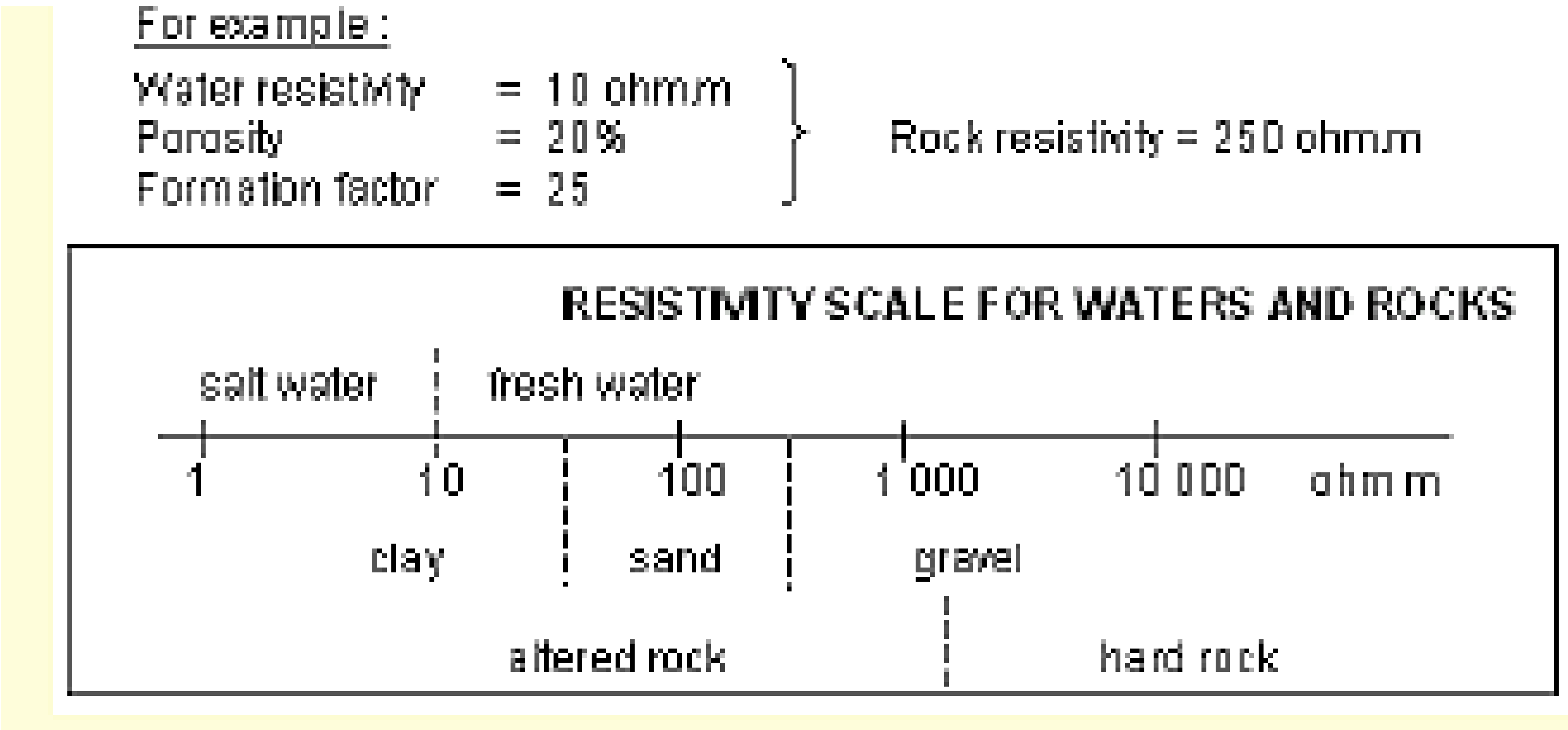
F = Formation Factor = a / (porosity)^N

(ARCHIE FORMULA)



For example :

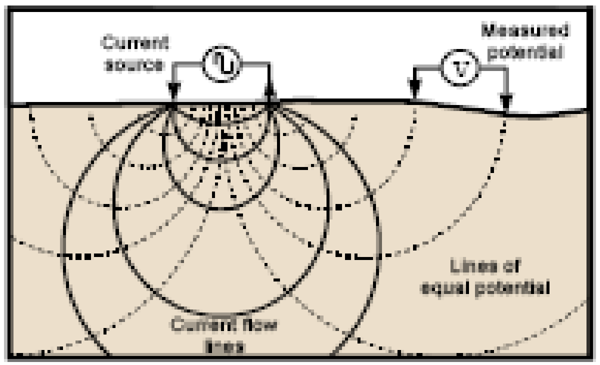
Water resistivity	= 10 ohm.m	Rock resistivity = 250 ohm.m
Porosity	= 20%	
Formation factor	= 25	



This is very site specific and need to be established for each site

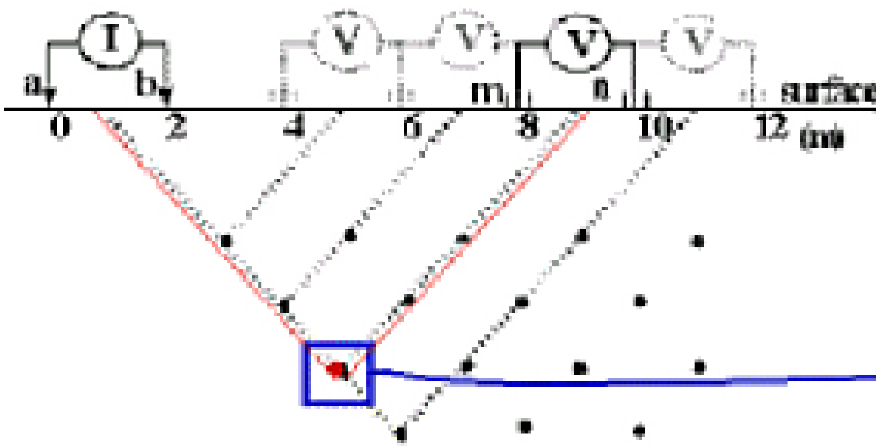
Direct Current (DC) Resistivity

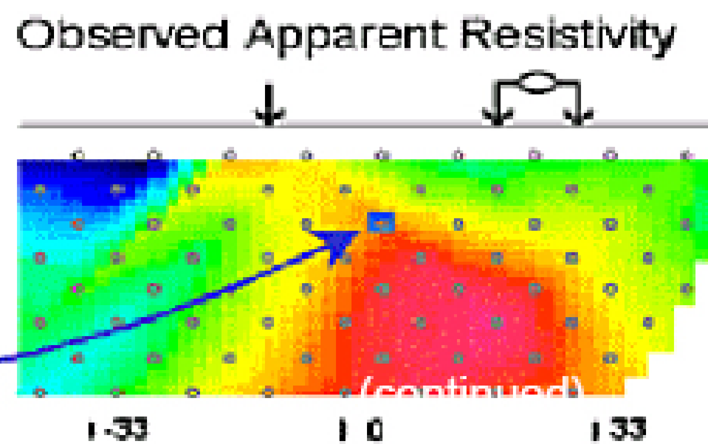
Archie's Law for Porous Media w/o clay

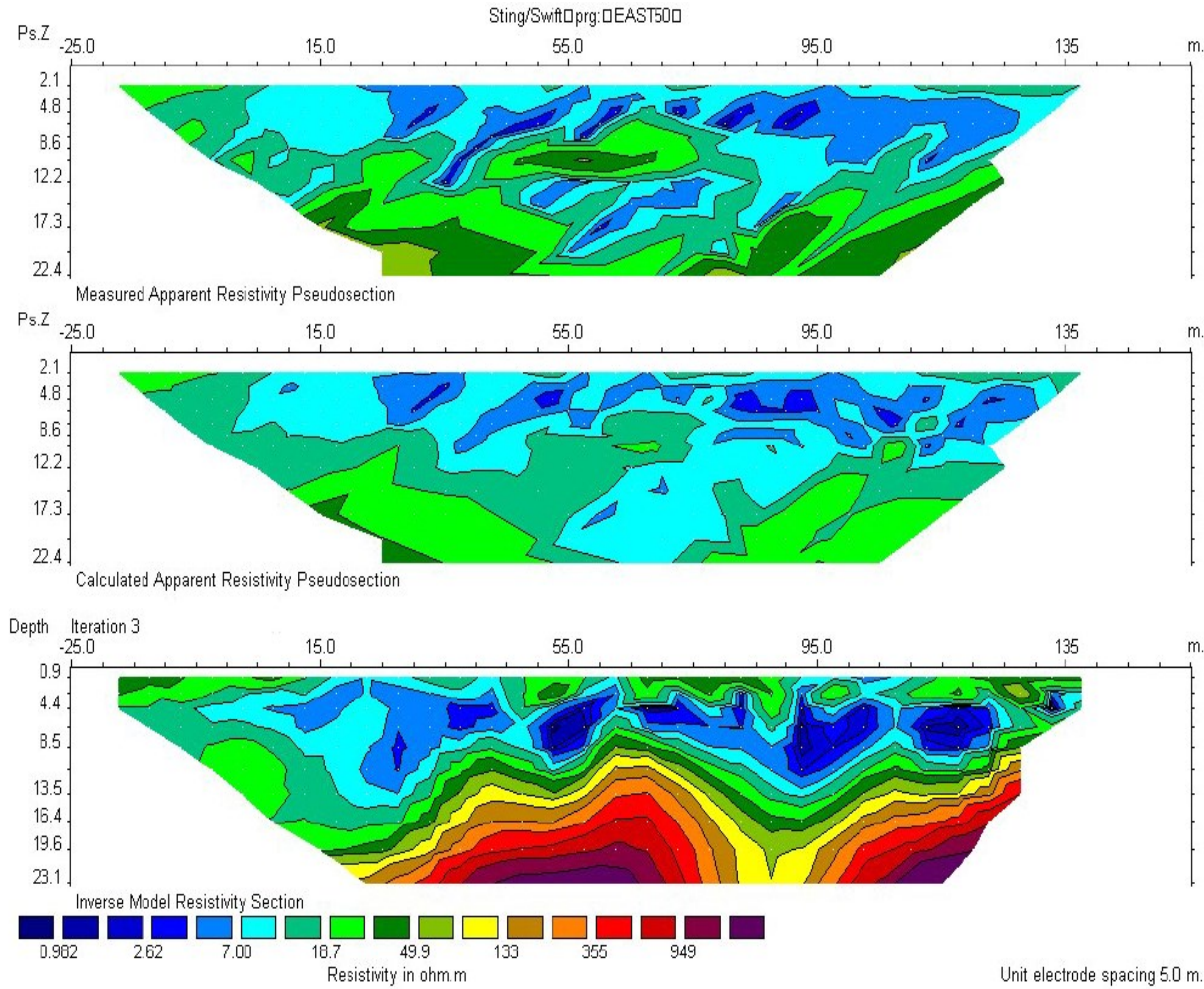


$$\rho_e = a\,\phi^{-m}\,S^{-n}\,\rho_w$$

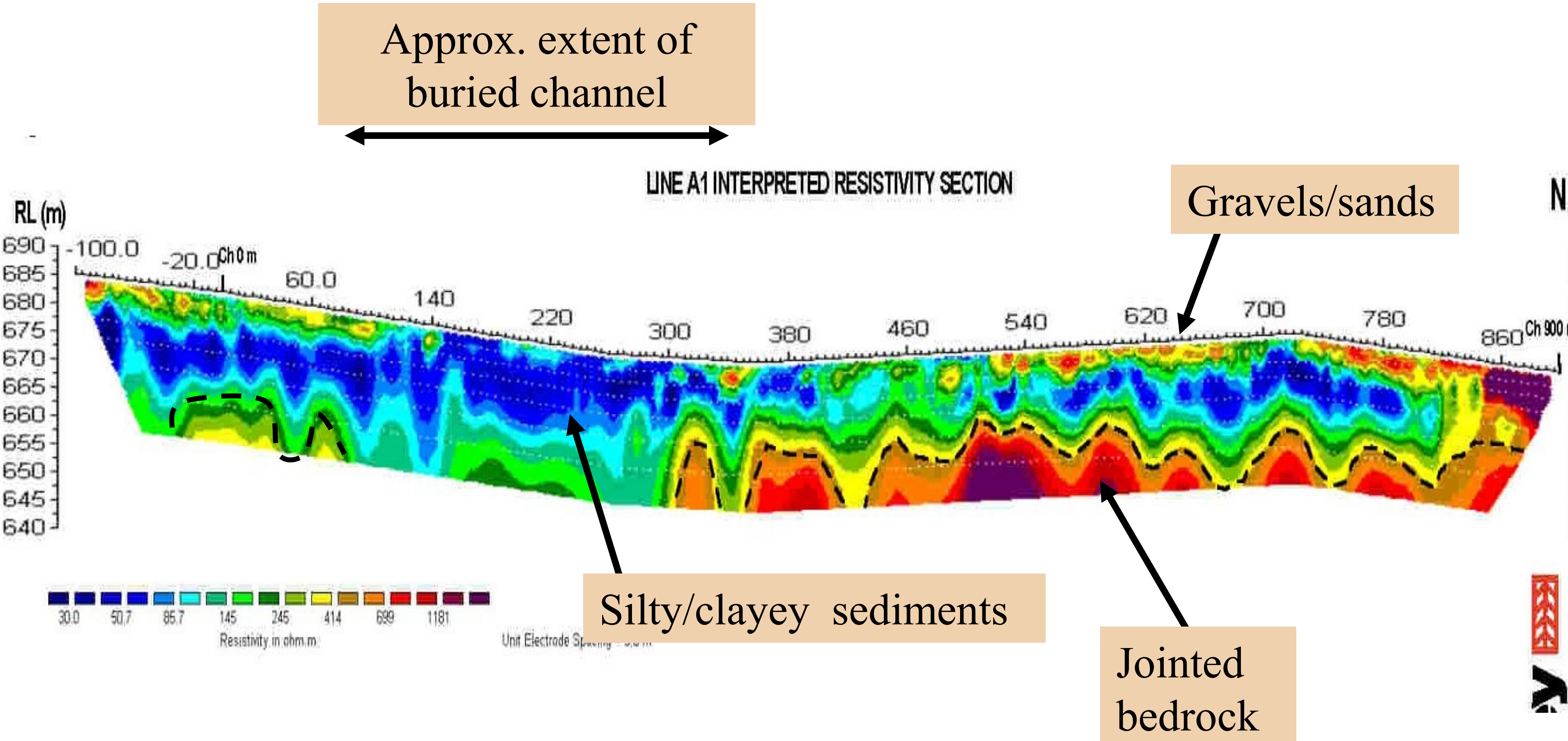
ρ_e = resistivity of the earth
ϕ = fractional pore volume (porosity)
S = fraction of the pores containing fluid
ρ_w = the resistivity of the fluid
n, a and m are empirical constants





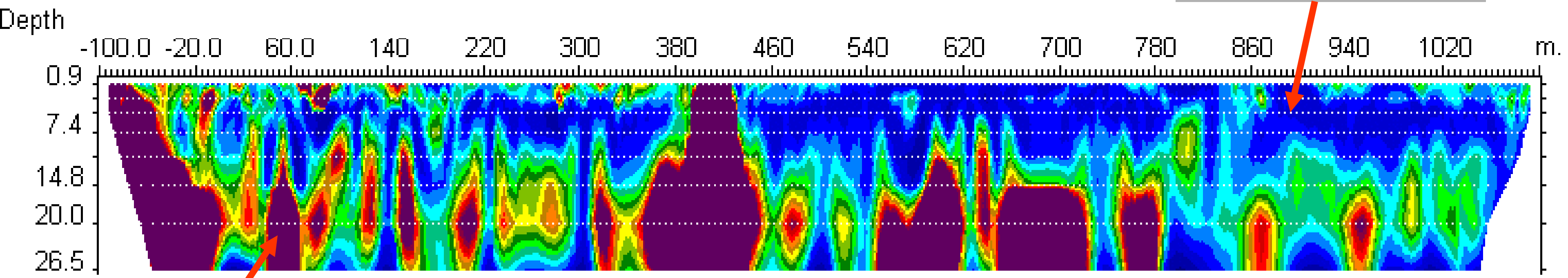


ELECTRICAL RESISTIVITY IMAGING


Approx. extent of buried channel
LINE A1 INTERPRETED RESISTIVITY SECTION
Gravels/sands
N
RL (m)
690
685
680
675
670
665
660
655
650
645
640
-100.0
-20.0
Ch 0 m
60.0
140
220
300
380
460
540
620
700
780
860
Ch 900 m
30.0
50.7
85.7
145
245
414
699
1181
Resistivity in ohm.m
Silty/clayey sediments
Jointed bedrock

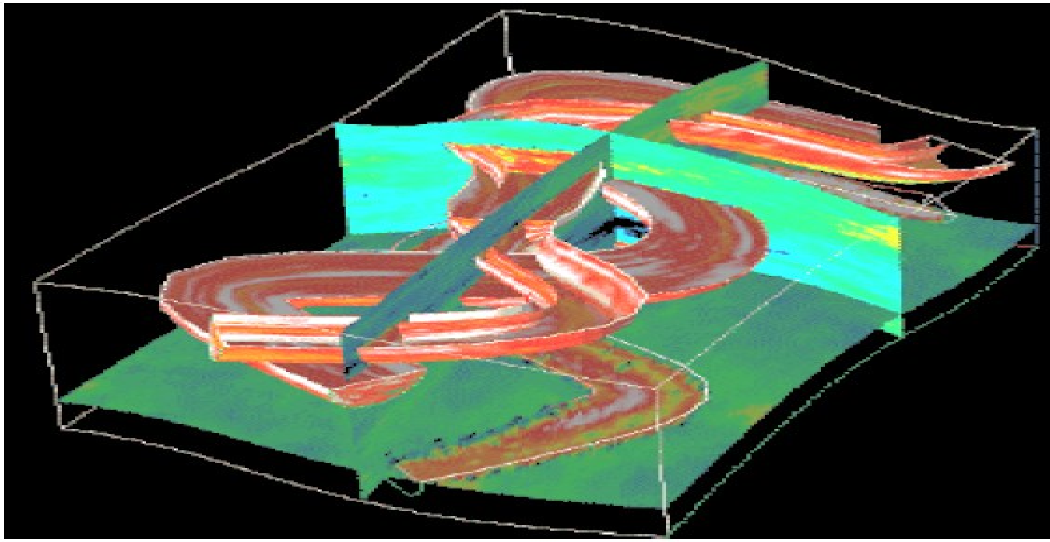
Electrical Resistivity Image Section showing repeated crossings of shallow and deep channels

Silts and clays low resistivity

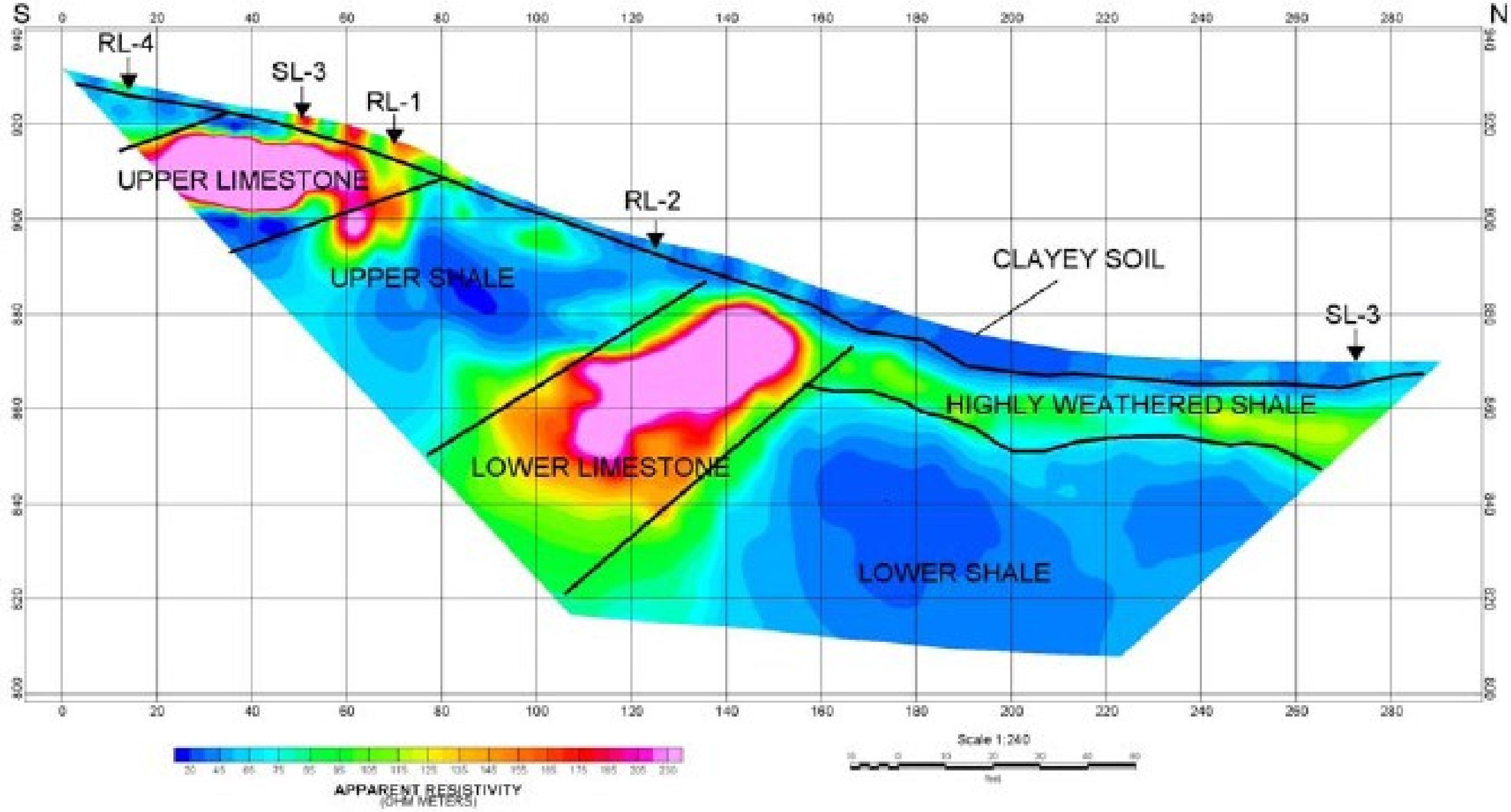


Sands/gravels high resistivity

Schematic of meandering channels



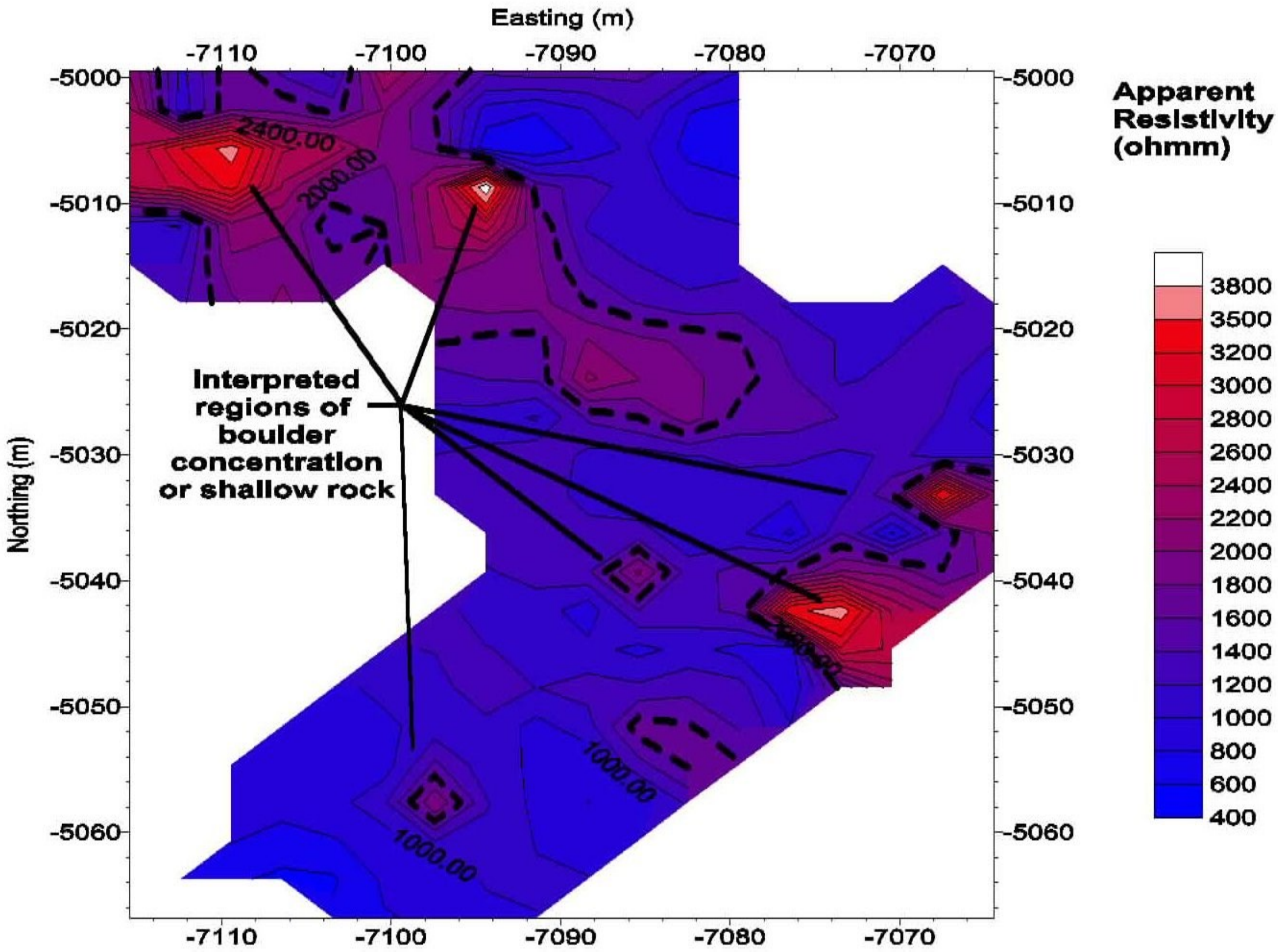
coffey



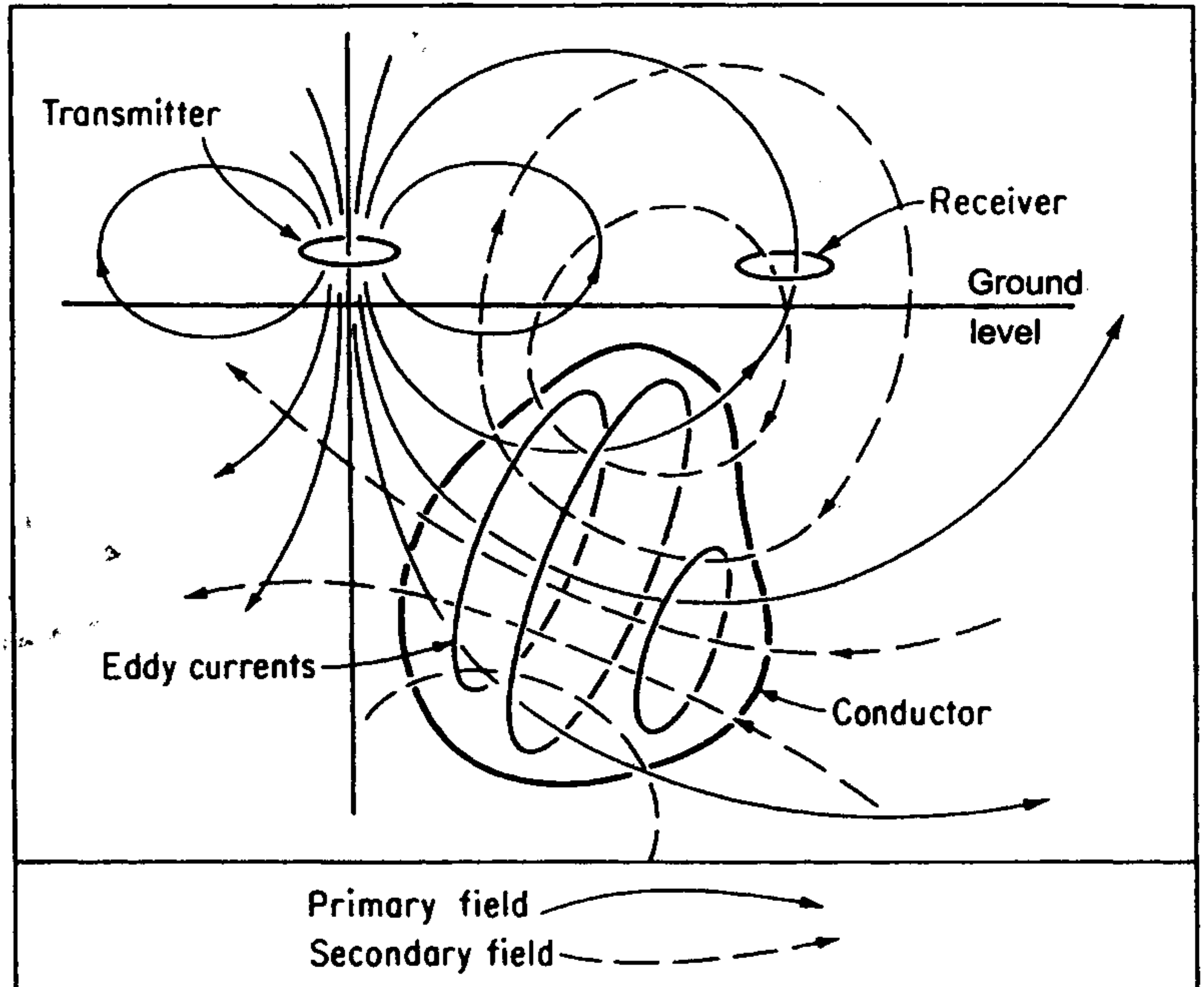
Lithological & soils mapping with Electrical Resistivity Imaging


Rock fall
hazard
AWAS

APPARENT RESISTIVITY CONTOUR PLAN
(n=5)

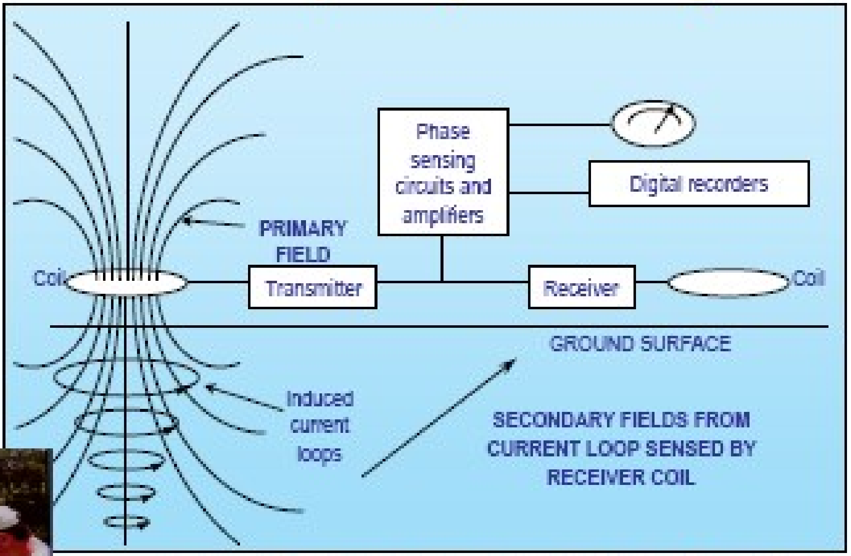


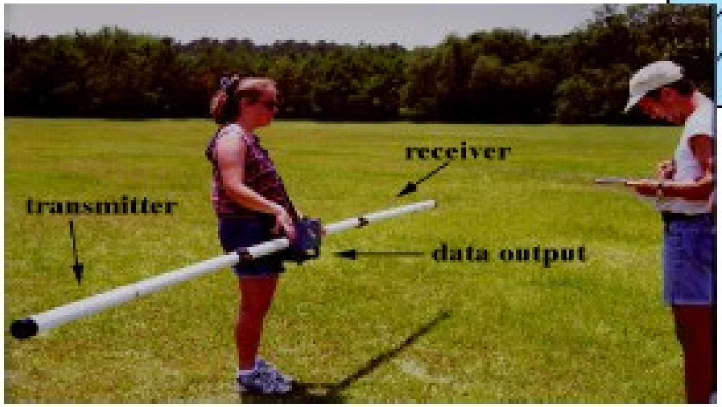
ELECTROMAGNETICS



Electromagnetic Induction (EMI) Surveys

- Active electromagnetic induction techniques
- Applications
  - Profiling
  - Sounding

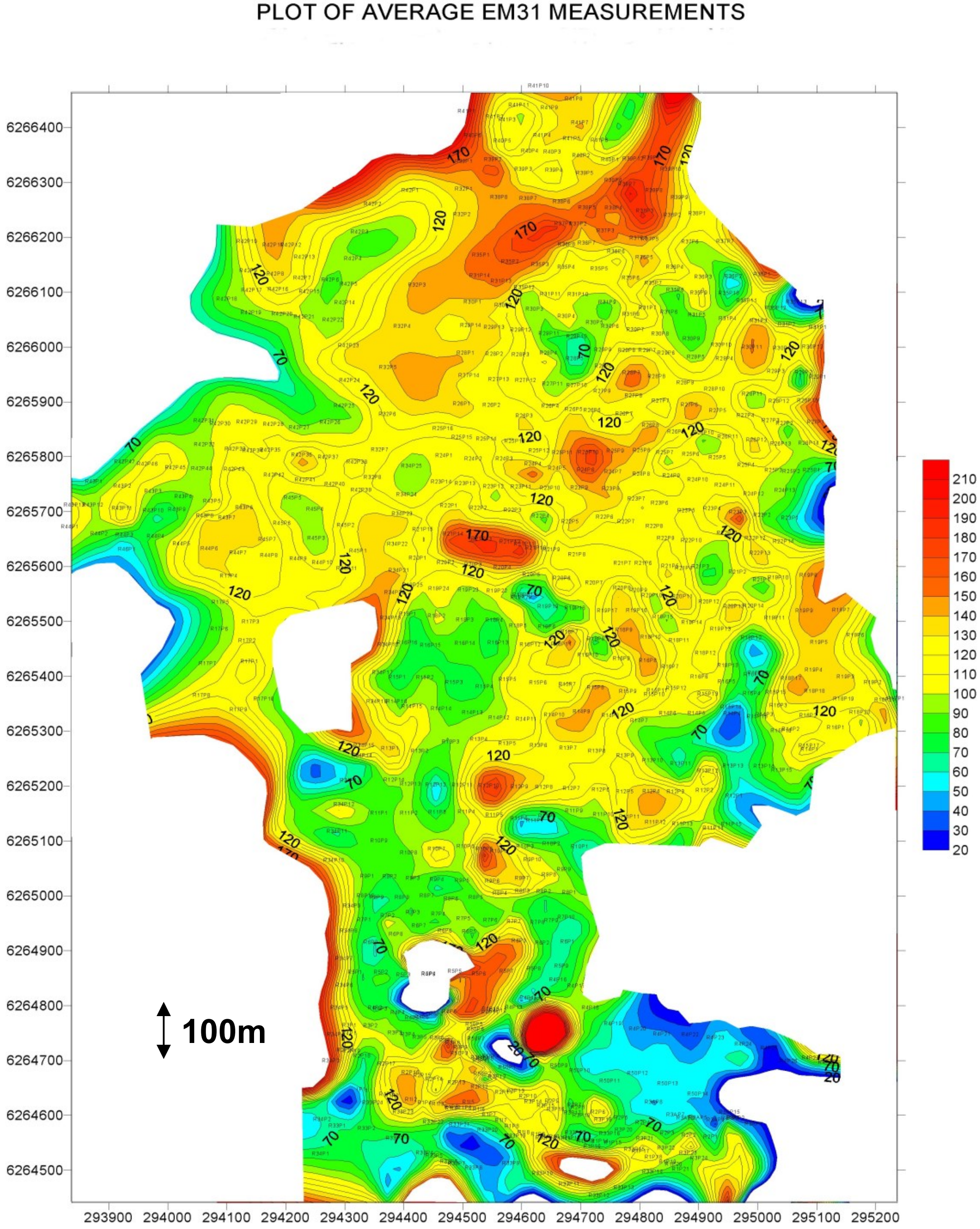




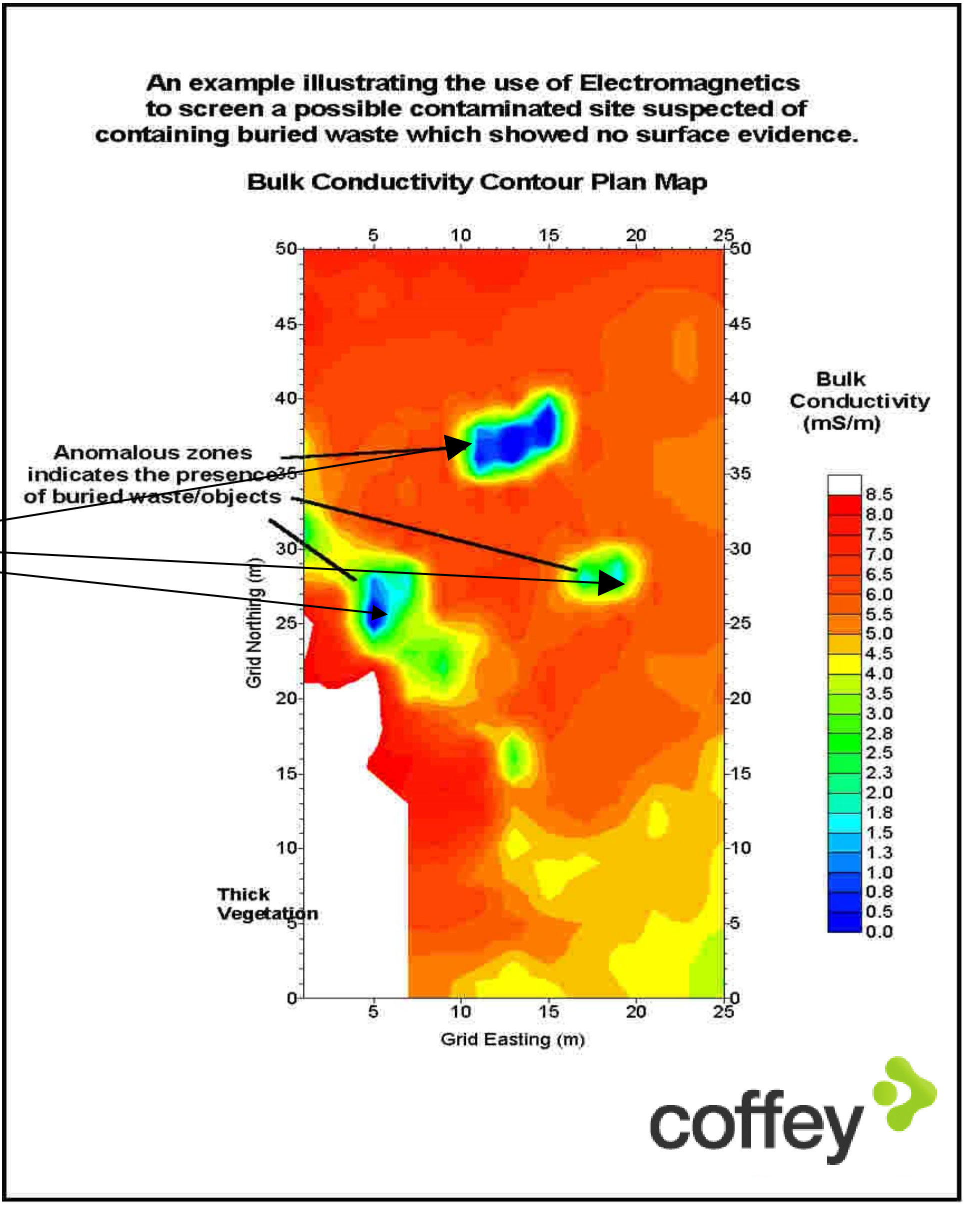
EM-31

EM-34

EM31 for salinity & shallow groundwater assessment

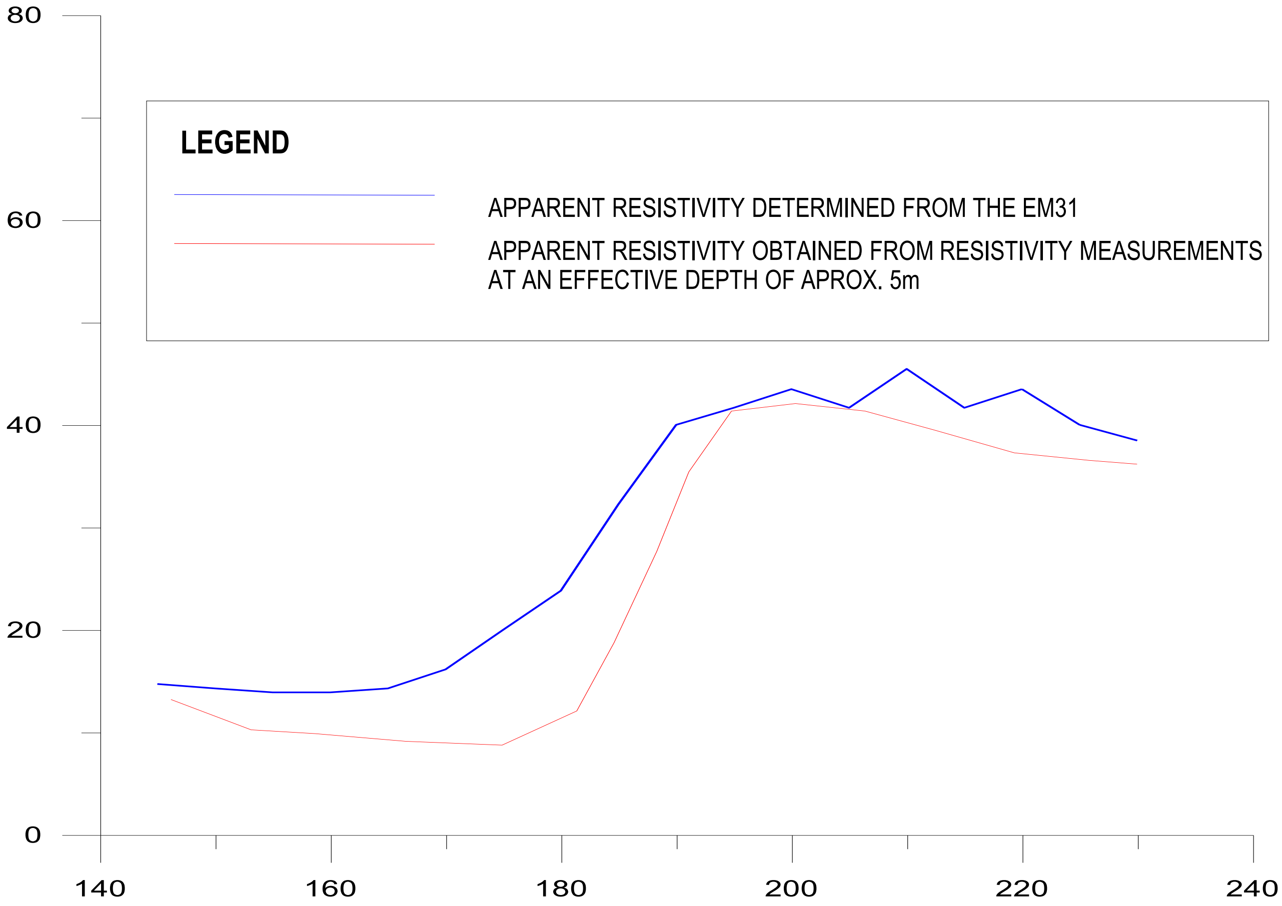


EM location of buried objects



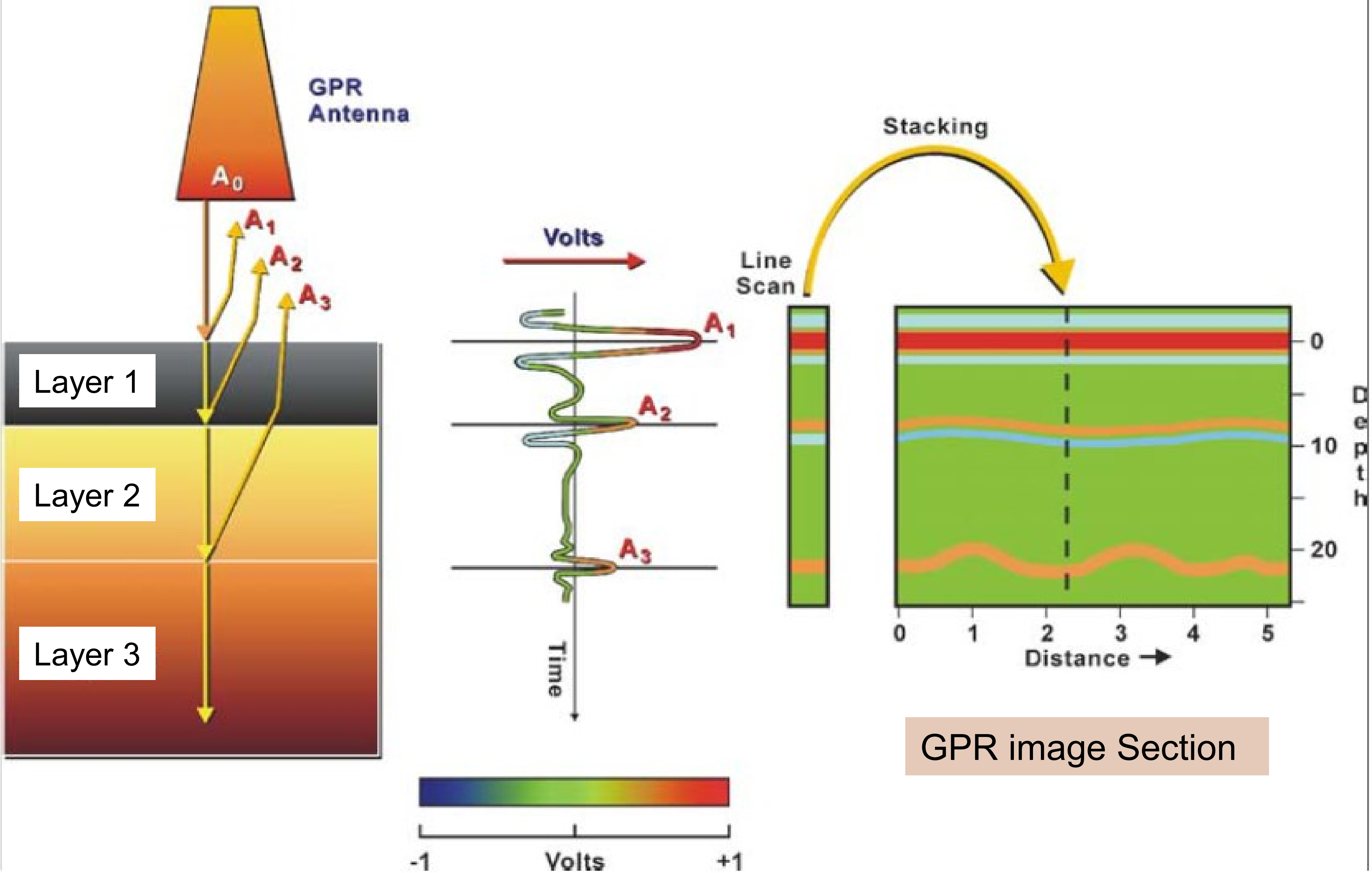
Buried objects

EM and Resistivity results should agree



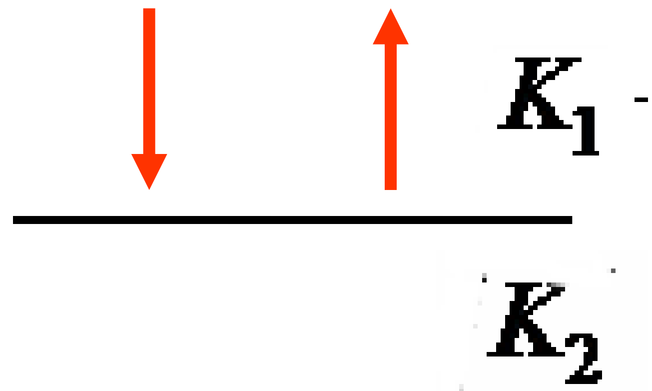
Ground Penetrating Radar

Principles of Ground Penetrating Radar



Radar reflection at soil/rock interfaces

$$R = \frac{\sqrt{K_1} - \sqrt{K_2}}{\sqrt{K_1} + \sqrt{K_2}}$$

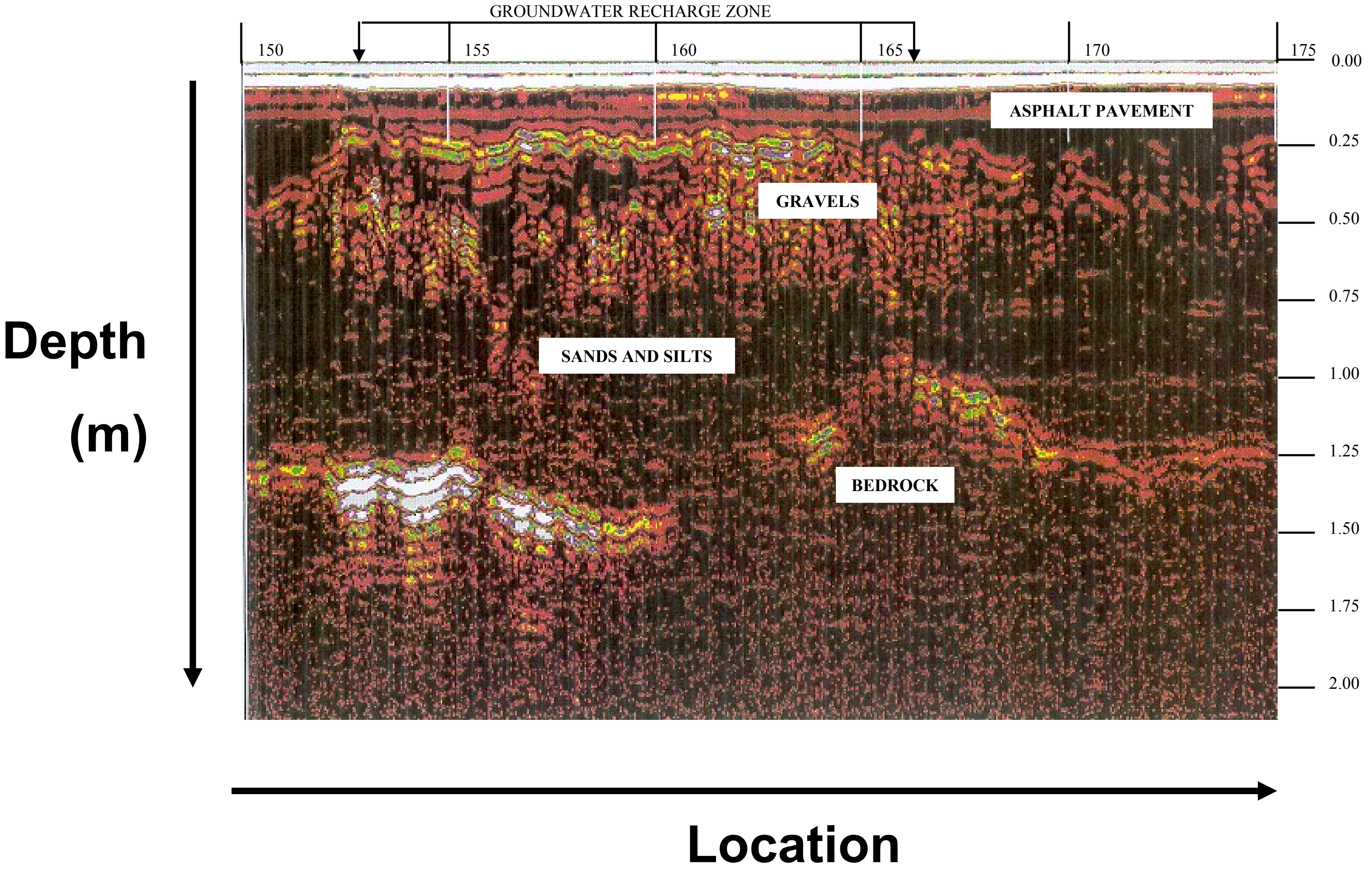


Reflected energy = R x Incident energy

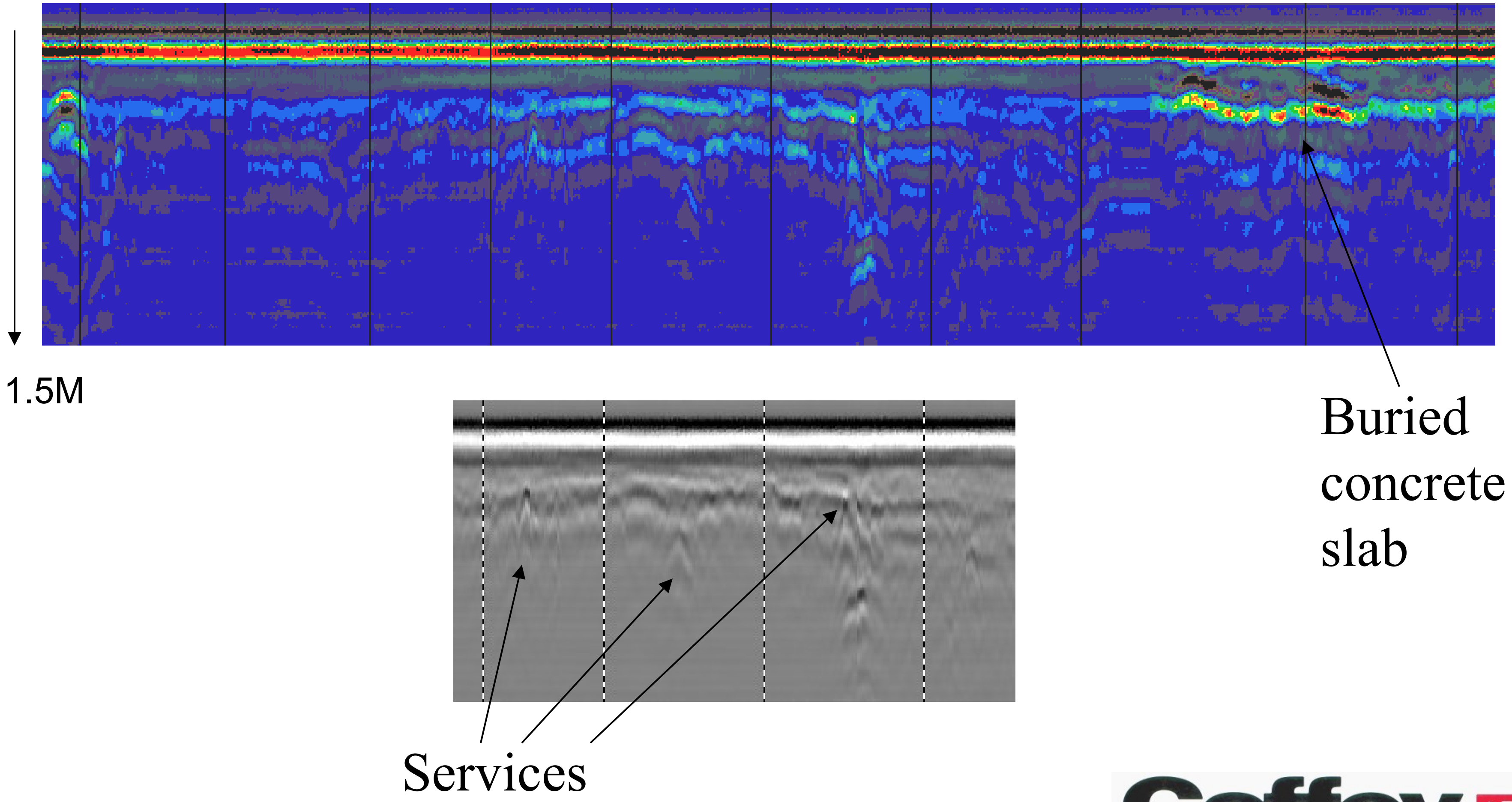
TYPICAL RELATIVE PERMITTIVITY, ELECTRICAL CONDUCTIVITY, VELOCITY AND ATTENUATION OBSERVED IN COMMON GEOLOGIC MATERIALS

MATERIAL	Dielectric Constant K	Conductivity σ (mS/m)	Velocity v (m/ns)	Attenuation α (dB/m)
Air	1	0	0.30	0
Distilled Water	80	0.01	0.033	$2x10^{-3}$
Fresh Water	80	0.5	0.033	0.1
Sea Water	80	$3x10^{3}$	.01	10^{3}
Dry Sand	3-5	0.01	0.15	0.01
Saturated Sand	20-30	0.1-1.0	0.06	0.03-0.3
Limestone	4-8	0.5-2	0.12	0.4-1
Shales	5-15	1-100	0.09	1-100
Silts	5-30	1-100	0.07	1-100
Clays	5-40	2-1000	0.06	1-300
Granite	4-6	0.01-1	0.13	0.01-1
Dry Salt	5-6	0.01-1	0.13	0.01-1
Ice	3-4	0.01	0.16	0.01

A GPR field record – screening an area

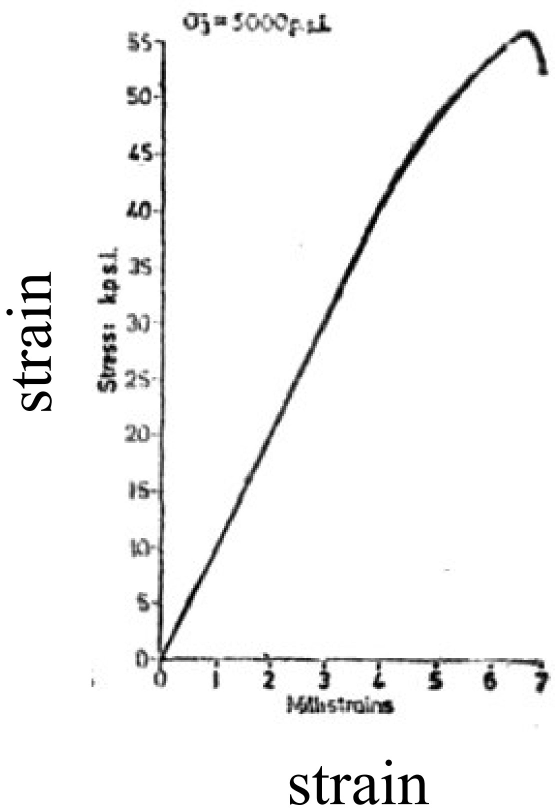


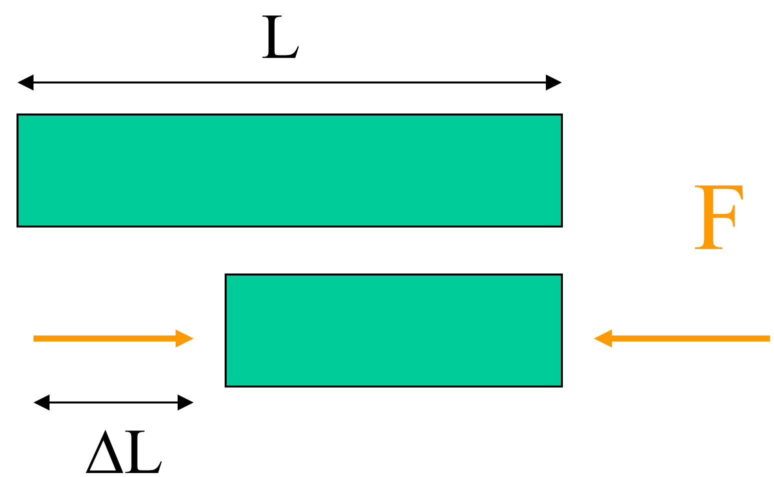
Application of GPR to Buried Services/Objects



Seismic Wave Propagation

Elastic Materials





$F = k * \Delta L/L$ (Hooke's Law)

k = Young's modulus

Seismic Waves

Body waves

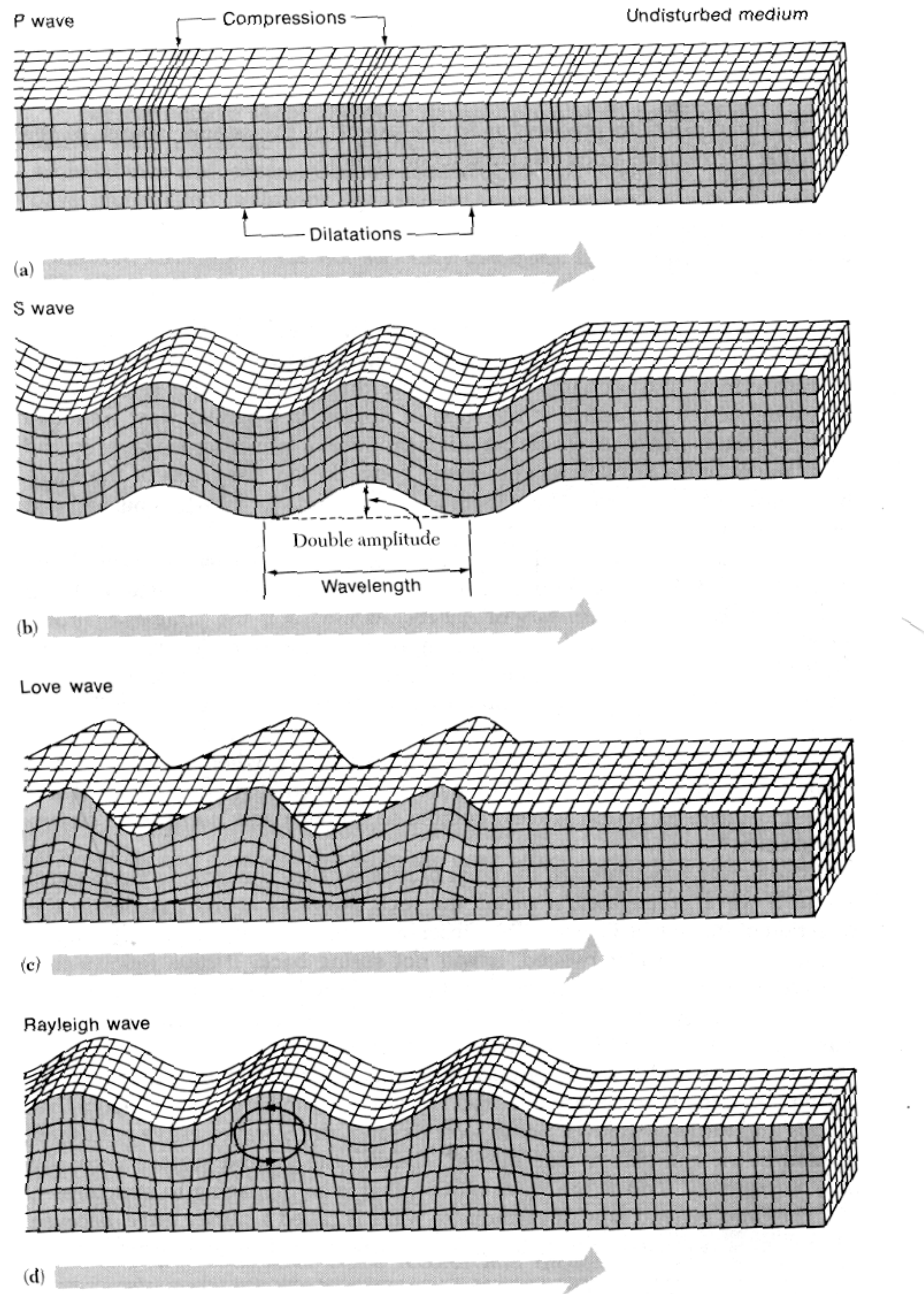
P

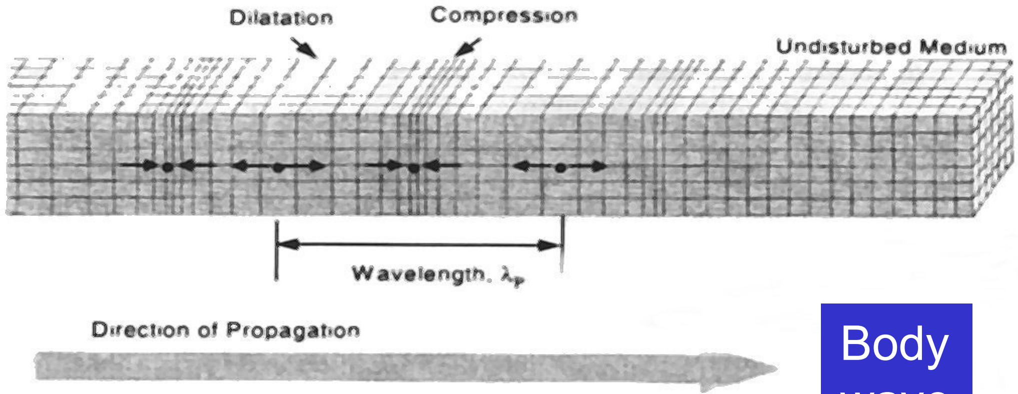
S

Surface Waves

Love

"Ground Roll" Rayleigh



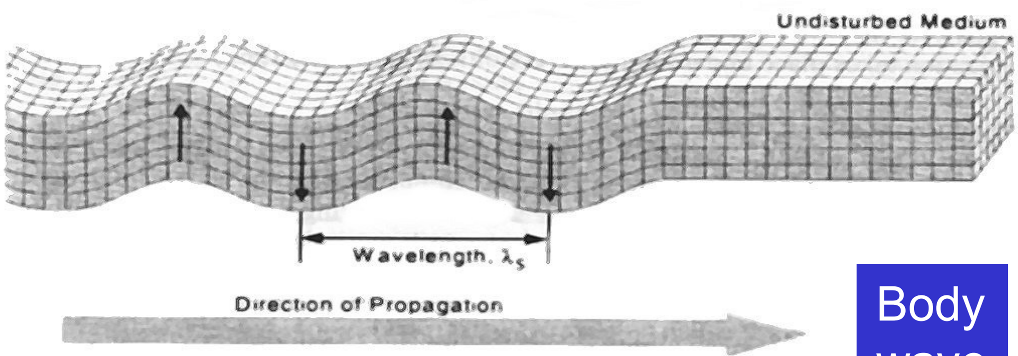


Compression (P) Wave

Body wave

$$V_p = \sqrt{\frac{\overline{K} + \frac{4}{3}\overline{G}}{\overline{\rho}}}$$

P-Wave

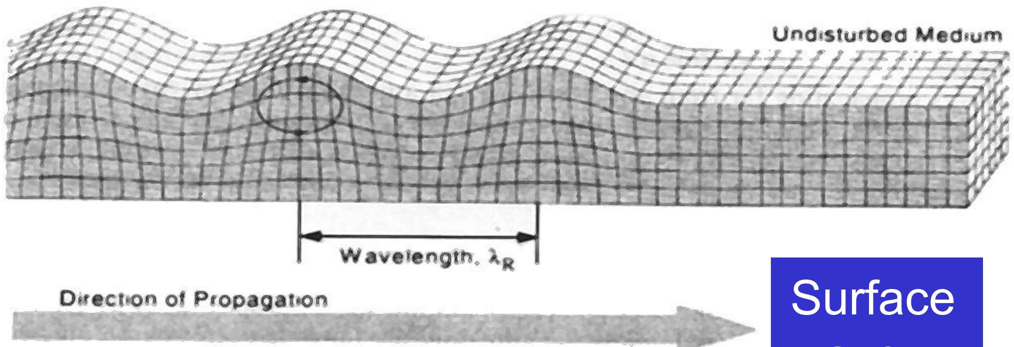


Shear (S) Wave

Body wave

$$V_s = \sqrt{\frac{\overline{G}}{\overline{\rho}}}$$

S-Wave



Rayleigh (R) Wave

Surface wave

$$V_R = 0.9V_s$$

R-Wave

Table I. COMPRESSIONAL SEISMIC WAVE VELOCITIES (m/s)	
VELOCITY	ROCK DESCRIPTION
200 – 400	Soil, unconsolidated surface deposits
400 – 1400	Unconsolidated clays, silts, unsaturated sands, gravels.
1400 – 1800	Saturated sands and gravels; compact clays and silts; completely weathered rocks.
1800 – 2400	Consolidated sediments, probably water saturated; highly weathered / fractured metamorphic and igneous rocks; weathered and or jointed sandstones and shales.
2400 – 3700	Shale, sandstones; weathered and or sheared metamorphic and igneous rocks and limestones.
3700 – 4500	Slightly weathered and or fractured igneous rocks. Limestones. Some very hard sandstone and shale.
4500 – 6000	Unweathered metamorphic and igneous rocks. Some limestones and dolomite.

Vp air ~ 340 m/s

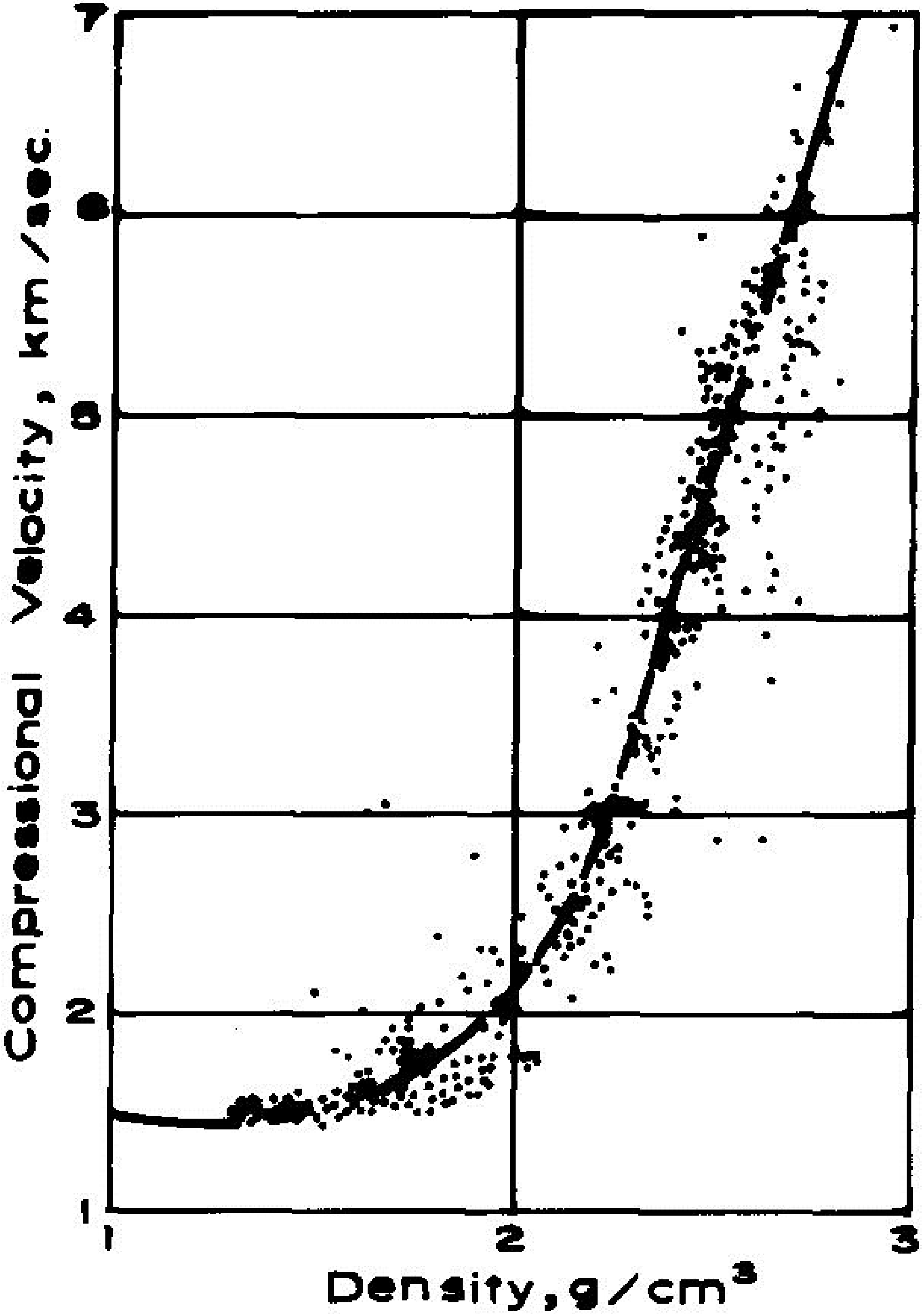
Vp water ~ 1370 m/s

Vp ice ~ 3200 m/s

Vp concrete ~ 3100 m/s – 4600 m/s

Vp steel ~ 5200 m/s

Vp



Material Parameters

Sands & Silts

Geotechnical Classification	SPT N-value	Friction angle, deg	Relative Density (%)
Very Loose	**<4**	**<30**	**<15**
Loose	**4 - 10**	**30 – 32**	**15 - 35**
Medium Dense	**10 - 30**	**32 – 35**	**35 - 65**
Dense	**30 - 50**	**35 – 38**	**65 - 85**
Very dense	**>50**	**>38**	**85 - 100**

SPT N-value	Geotechnical Classification	P-Wave Seismic Velocity (m/s)
0 – 4	**Very loose**	**<350 - 430**
4 – 10	**Loose**	**430 - 520**
10 – 30	**Medium dense**	**520 - 730**
30 - 50	**Dense**	**730 - 1680**
>50	**Very dense**	**>1680**

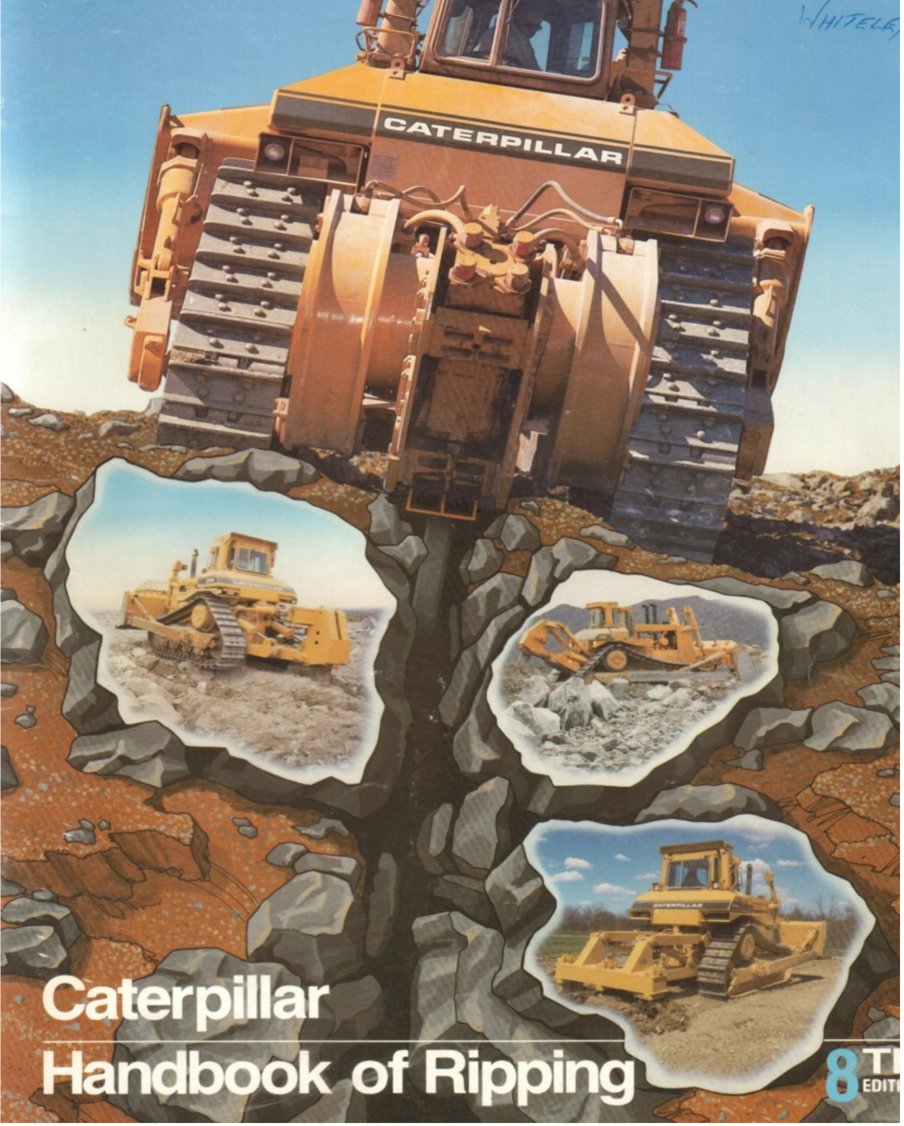
***ROCKS** (lab.)*

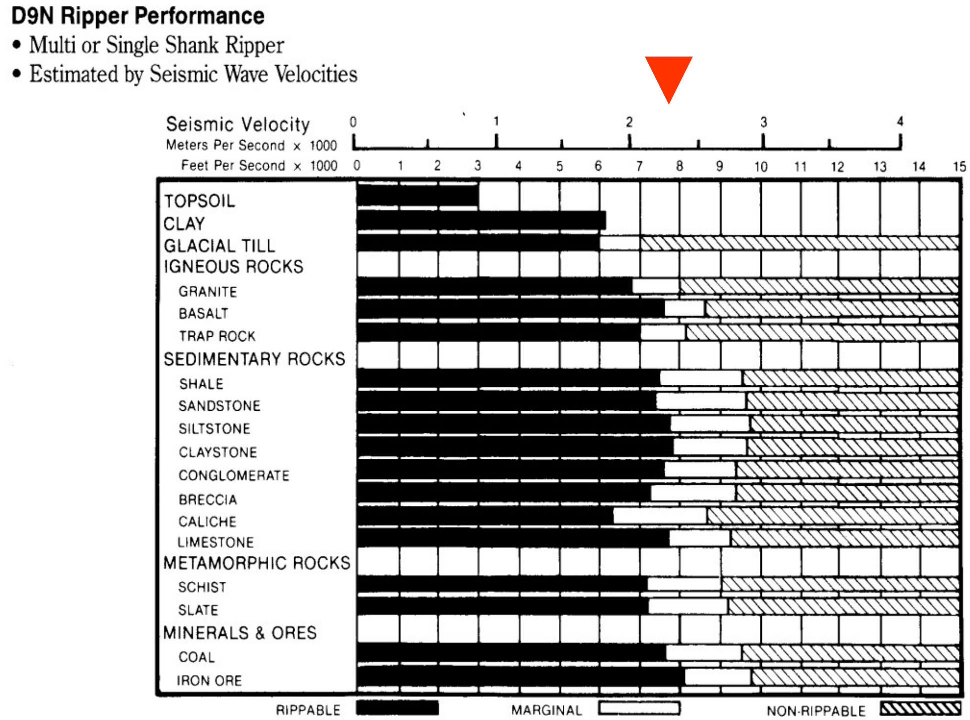
Unconfined

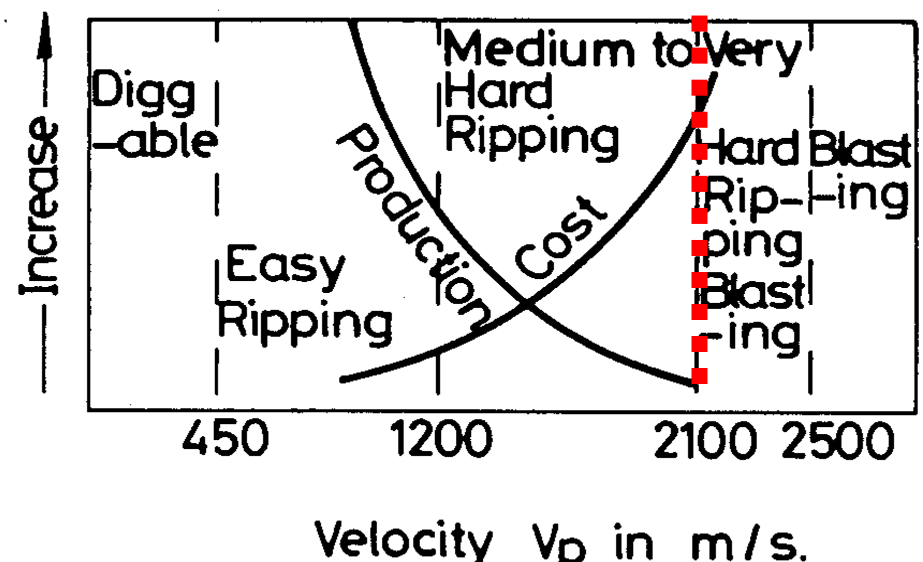
Compressive

Strength

UCS (MPa)	Geotechnical Classification	P- wave Velocity (km/s)
< 10	Low strength rock	< 2.0
10 to 20	Medium strength rock	2.0 – 2.5
20 to 60	High strength rock; stratified, jointed	2.5 – 3.5
> 60	Very high strength rock; stressed	3.5 – 7.0



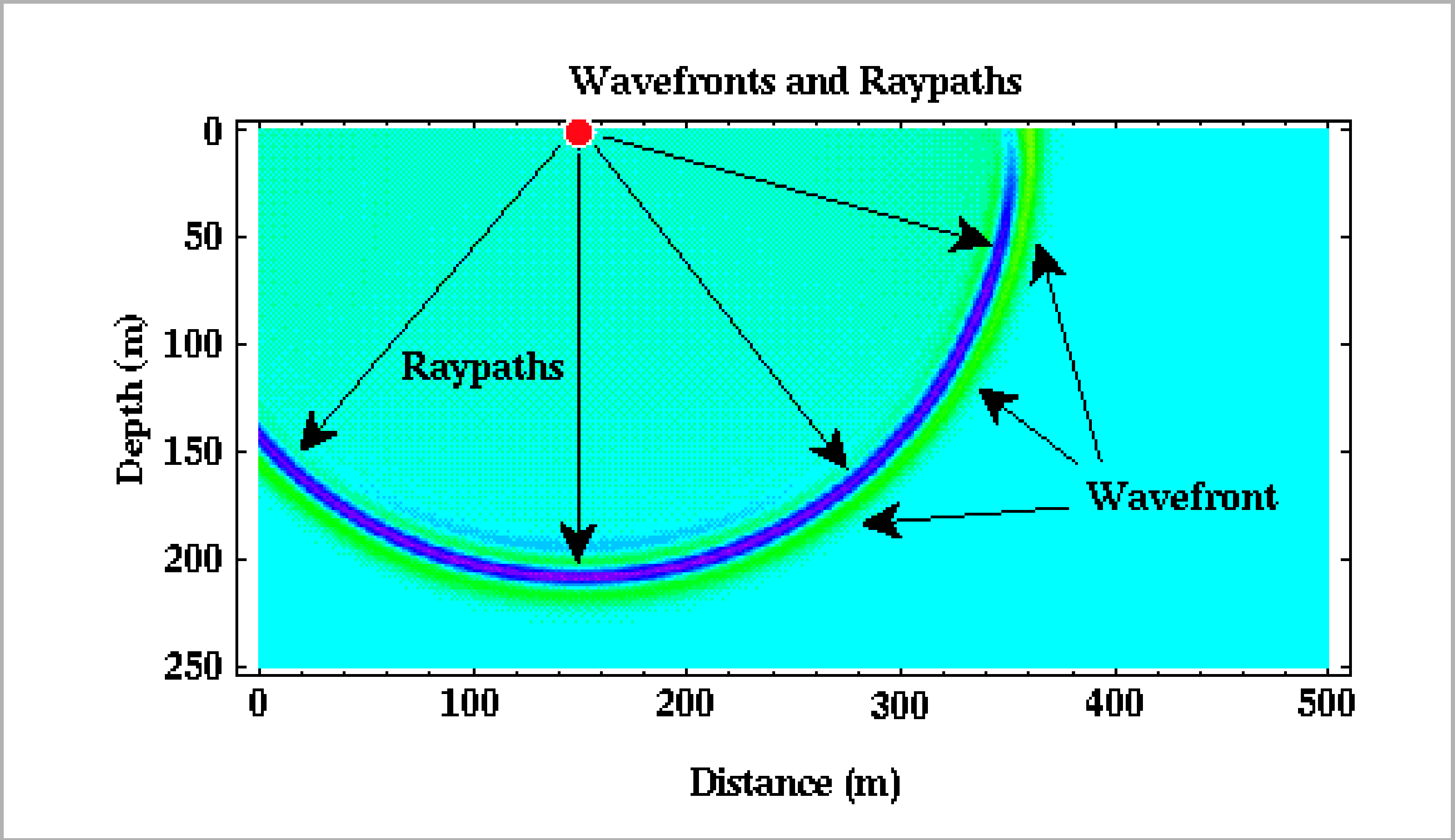




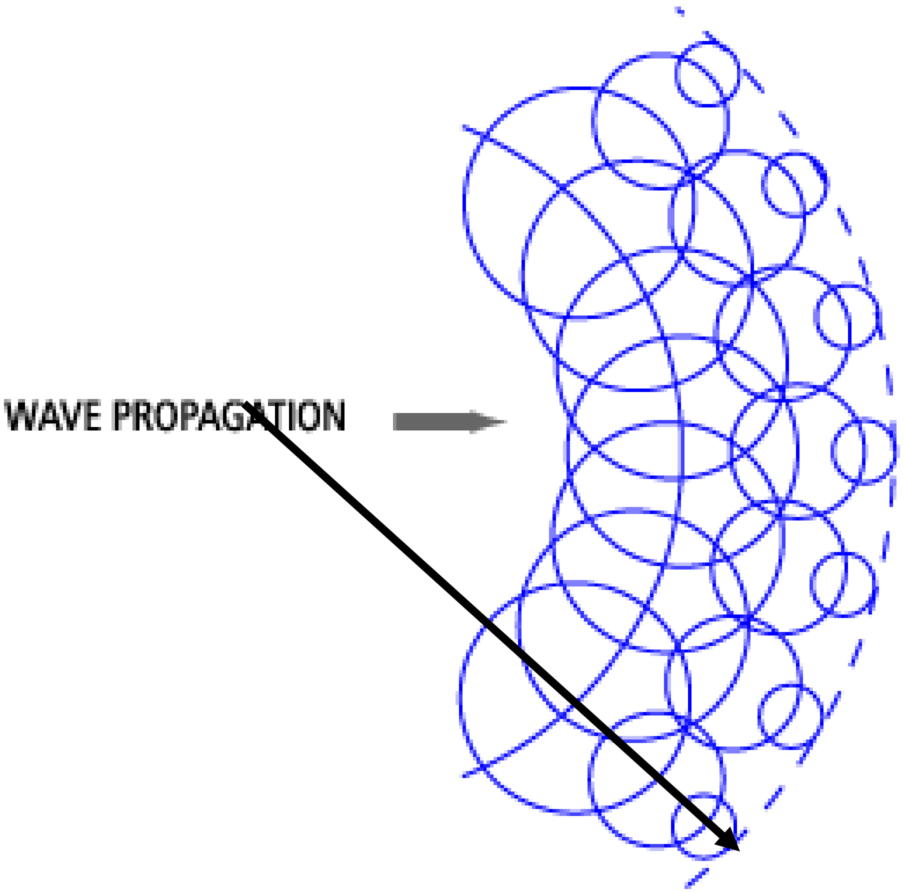
P-wave velocity & excavation


A major slope excavation
in highly variable materials
Ripped
Blasted
Blasted

Seismic body waves in a uniform half-space

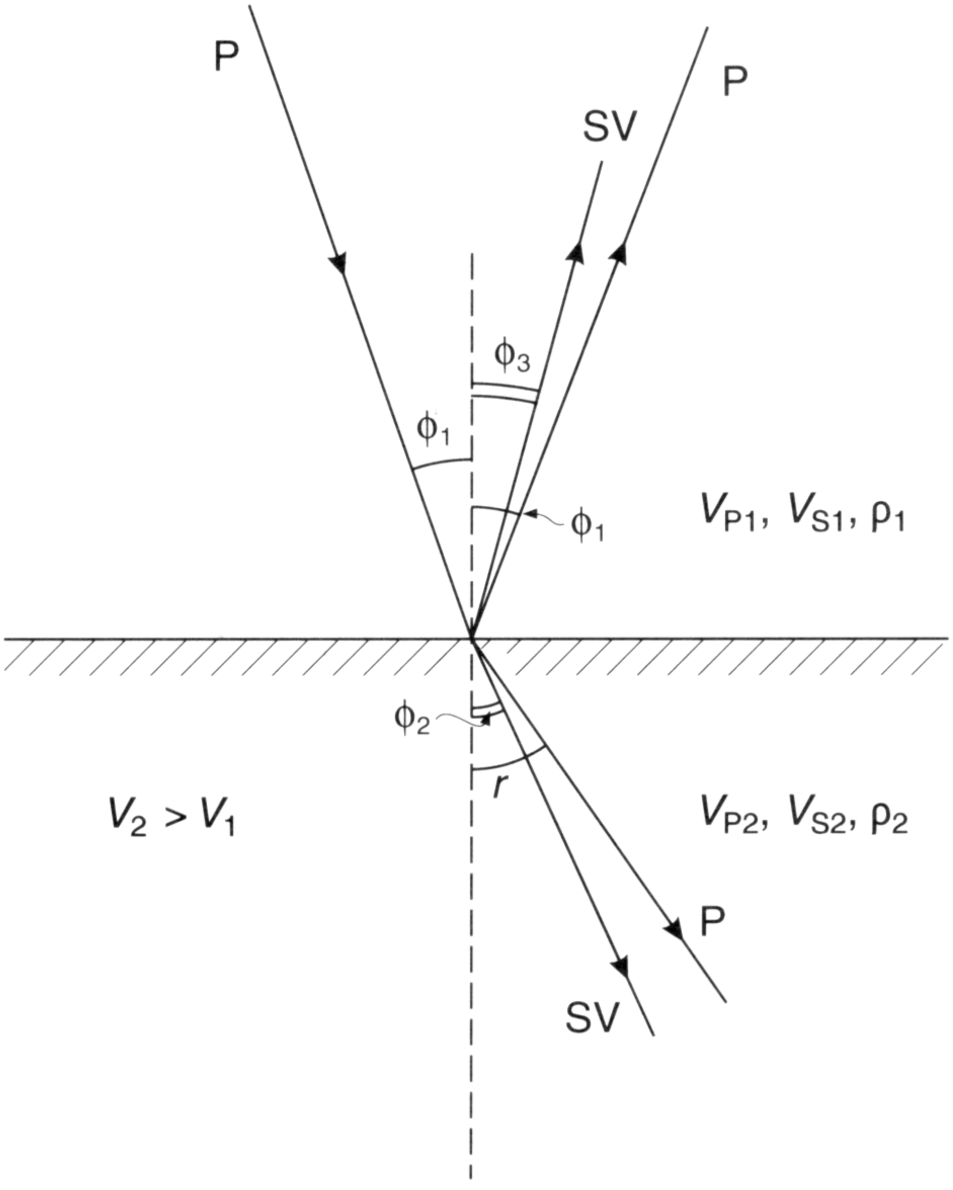


Huygen's Principle

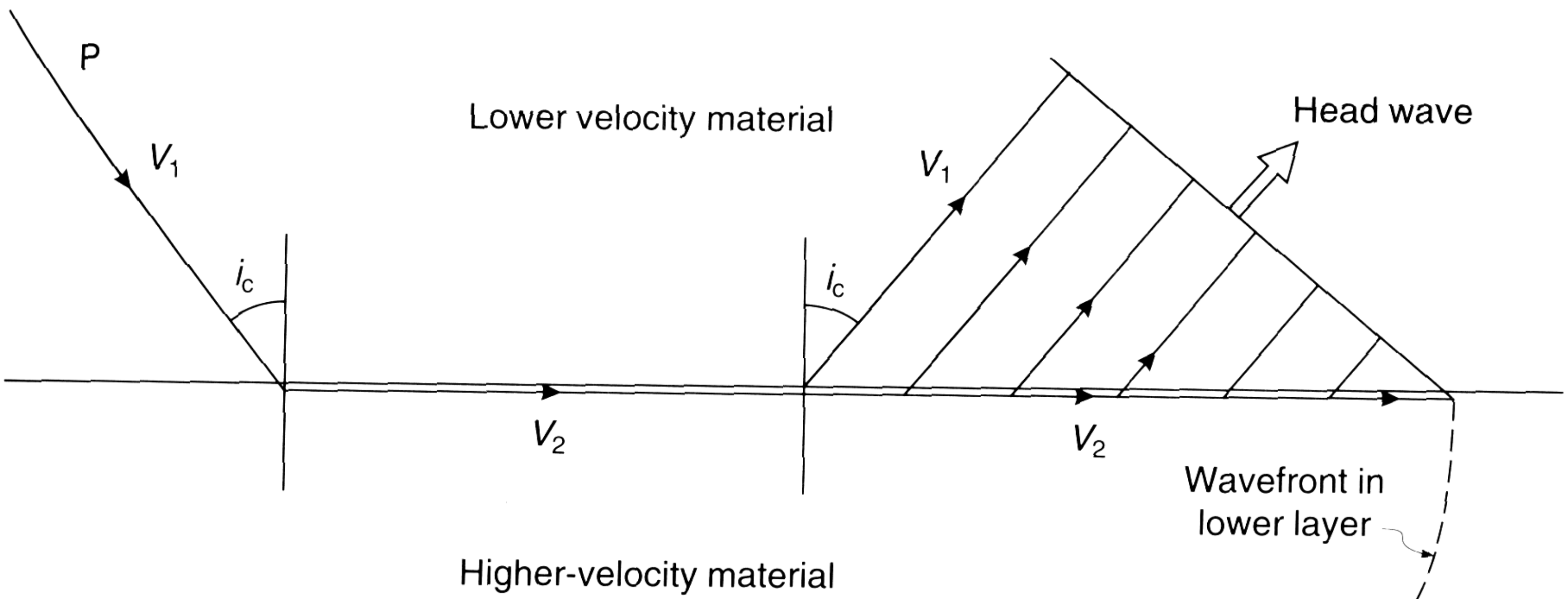


Snell's Law

$$\frac{\sin \phi_1}{Vp_1} = \frac{\sin \phi_2}{Vp_2} = \frac{\sin \phi_3}{Vs_3}$$

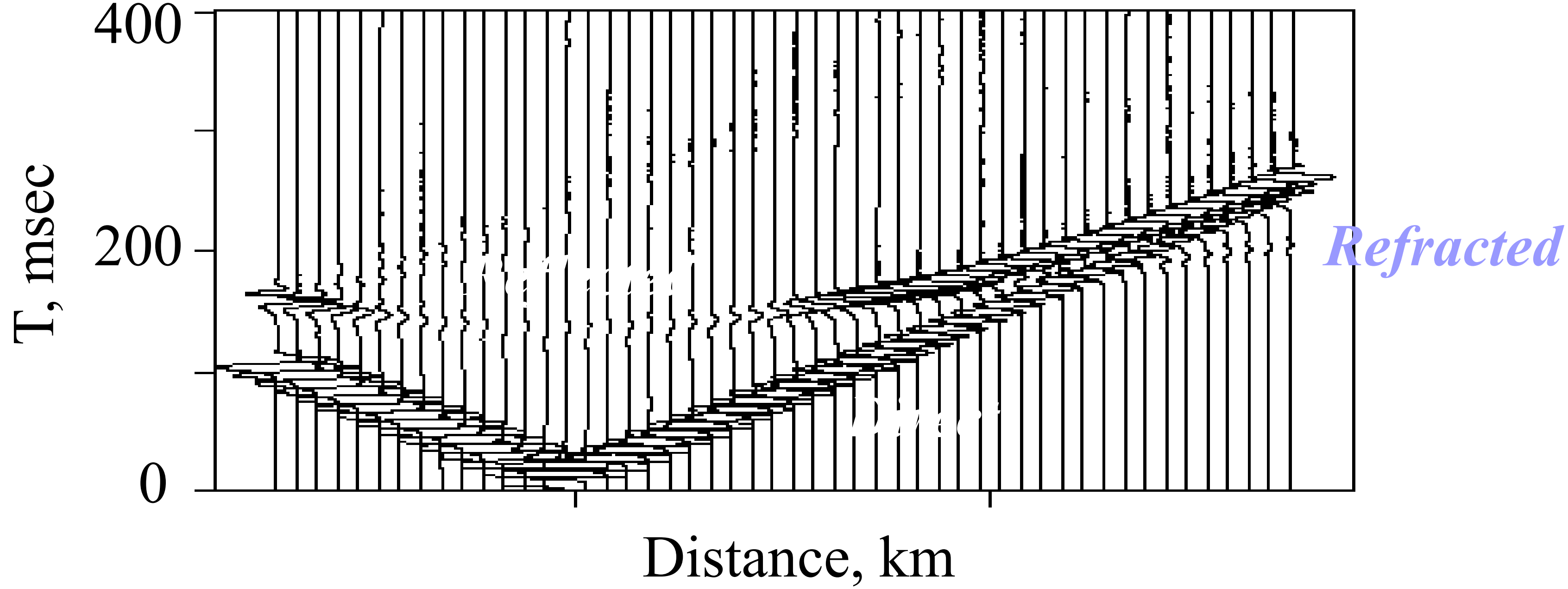


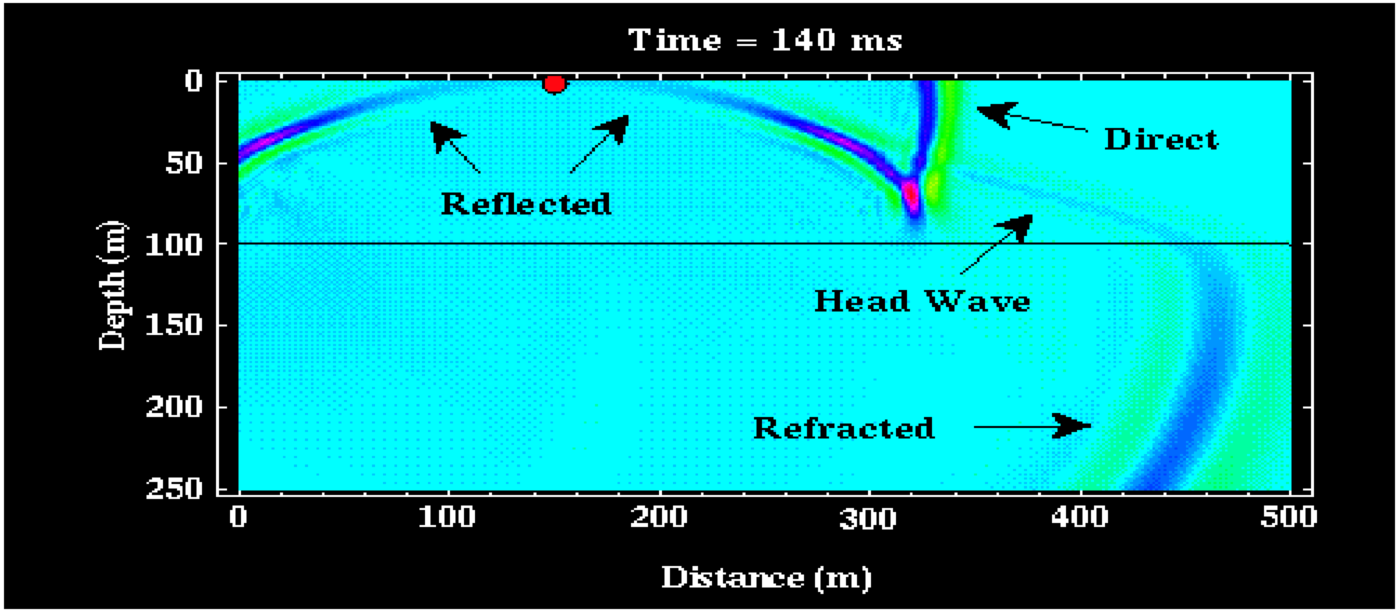
Critical Refraction

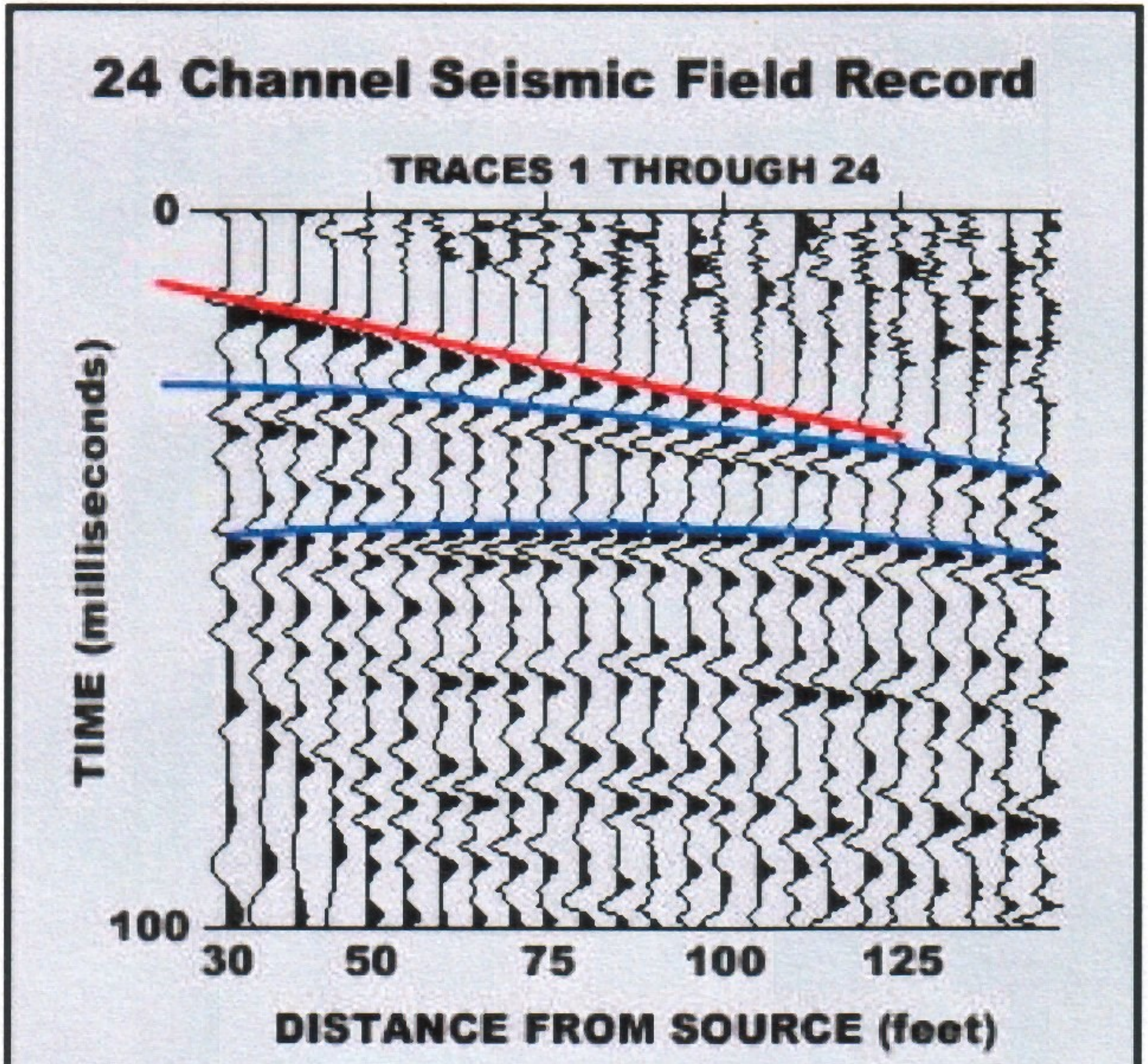


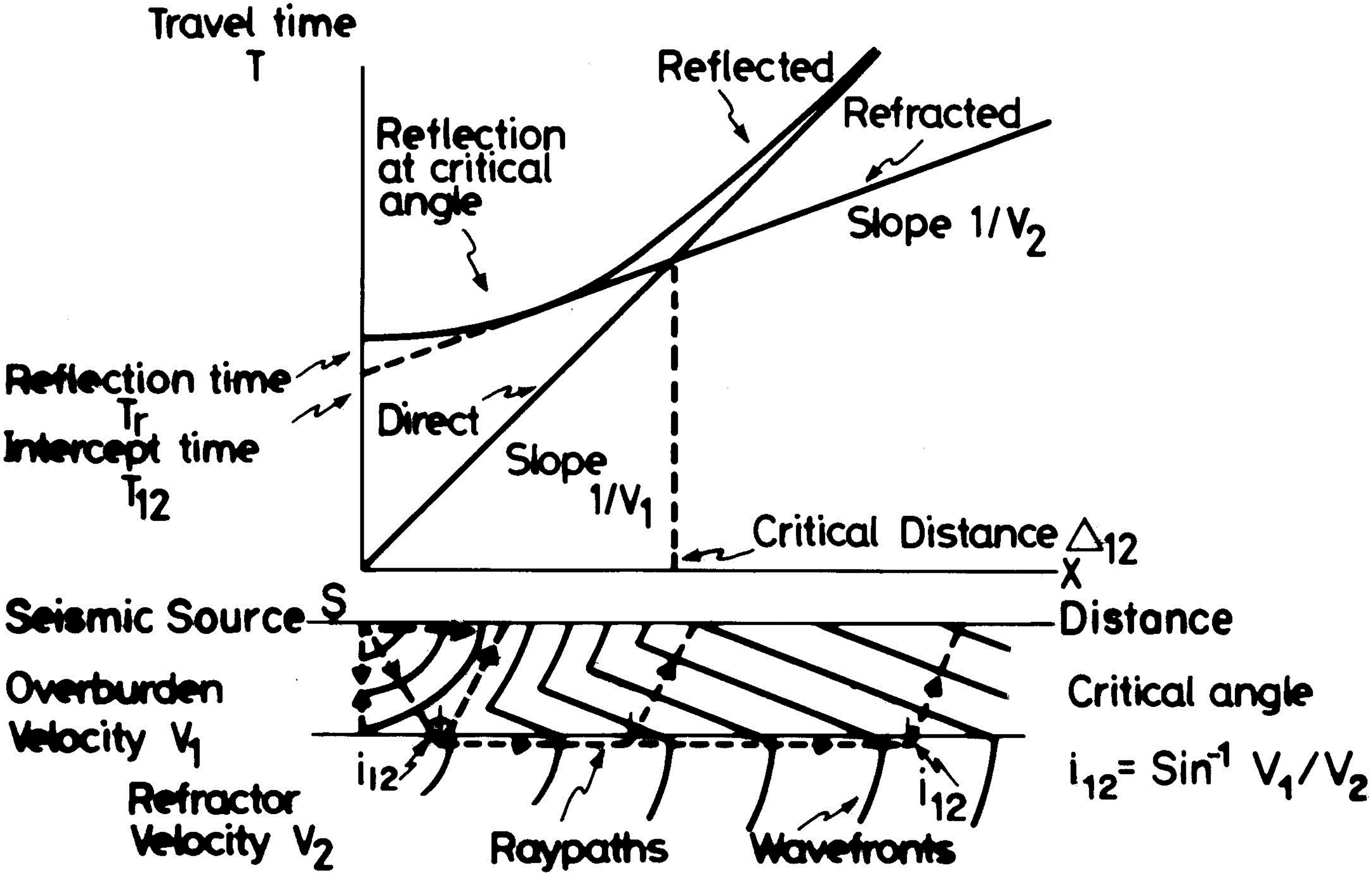
$$\frac{\sin i_c}{V_1} = \frac{\sin (90^o)}{V_2} \qquad \sin i_c = \frac{V_1}{V_2}$$

Reflection & Refraction





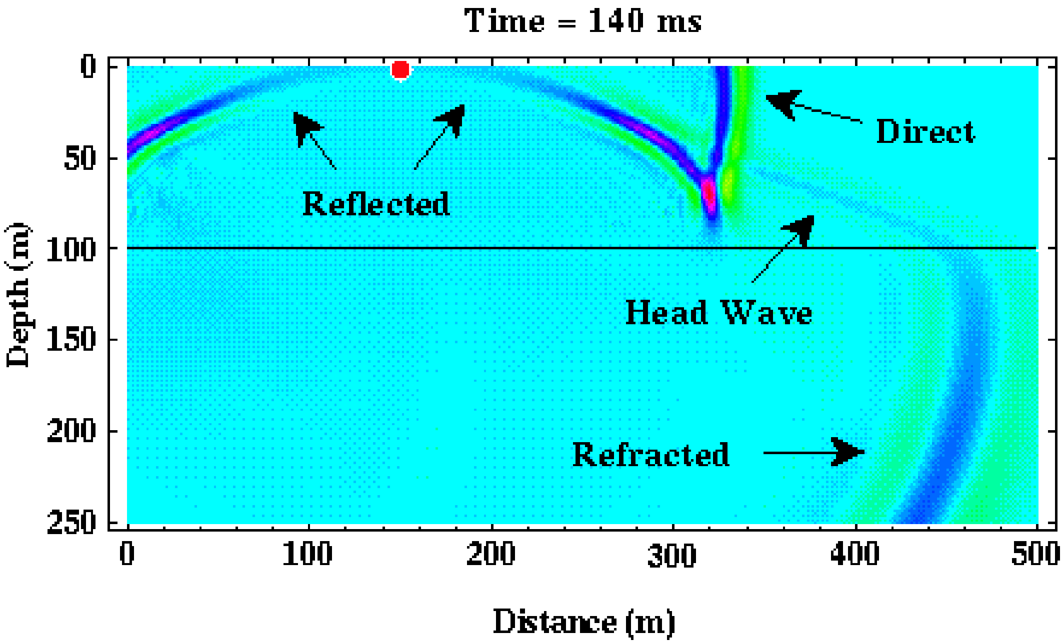

24 Channel Seismic Field Record
TRACES 1 THROUGH 24
0
100
TIME (milliseconds)
30
50
75
100
125
DISTANCE FROM SOURCE (feet)
REFLECTION
REFRACTION

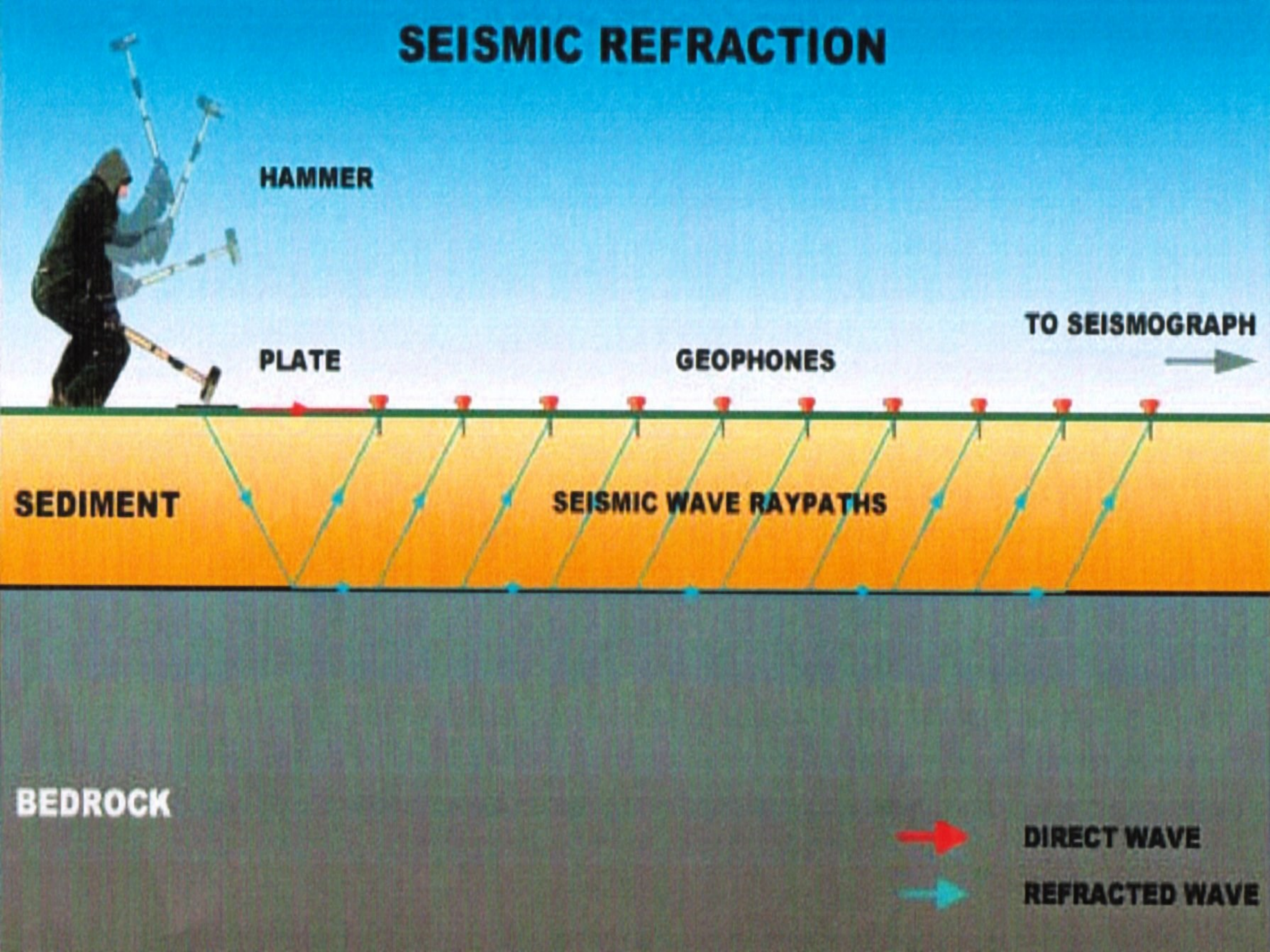


Travel time
T
Reflected
Refracted
Reflection
at critical
angle
Slope 1/V2
Reflection time
Tr
Direct
Intercept time
T12
Slope
1/V1
Critical Distance △12
X
S
Seismic Source
Distance
Overburden
Velocity V1
Critical angle
i12= Sin-1 V1/V2
i12
i12
Refractor
Velocity V2
Raypaths
Wavefronts

Seismic Refraction

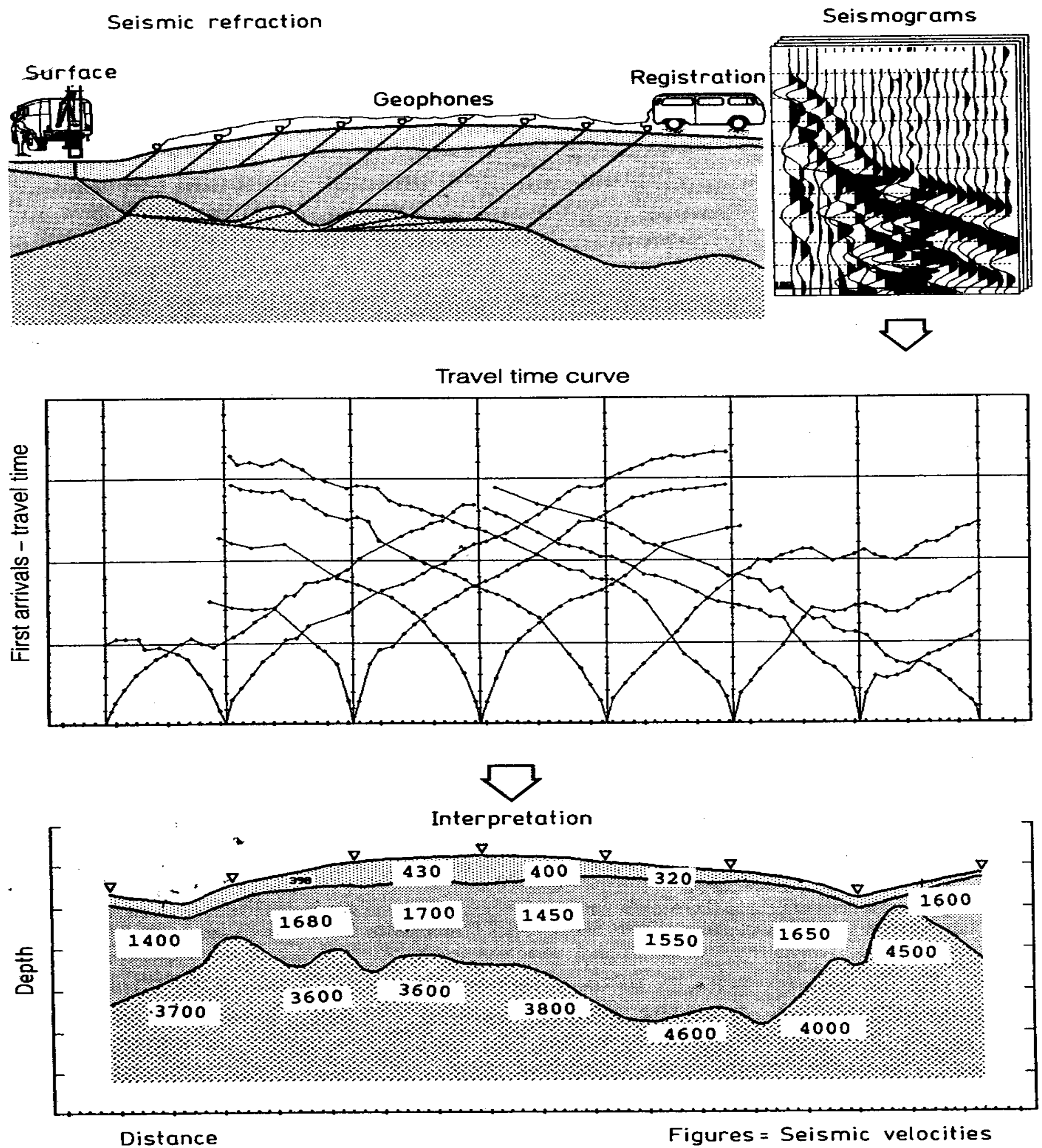
[Waves passing from slow to fast medium]



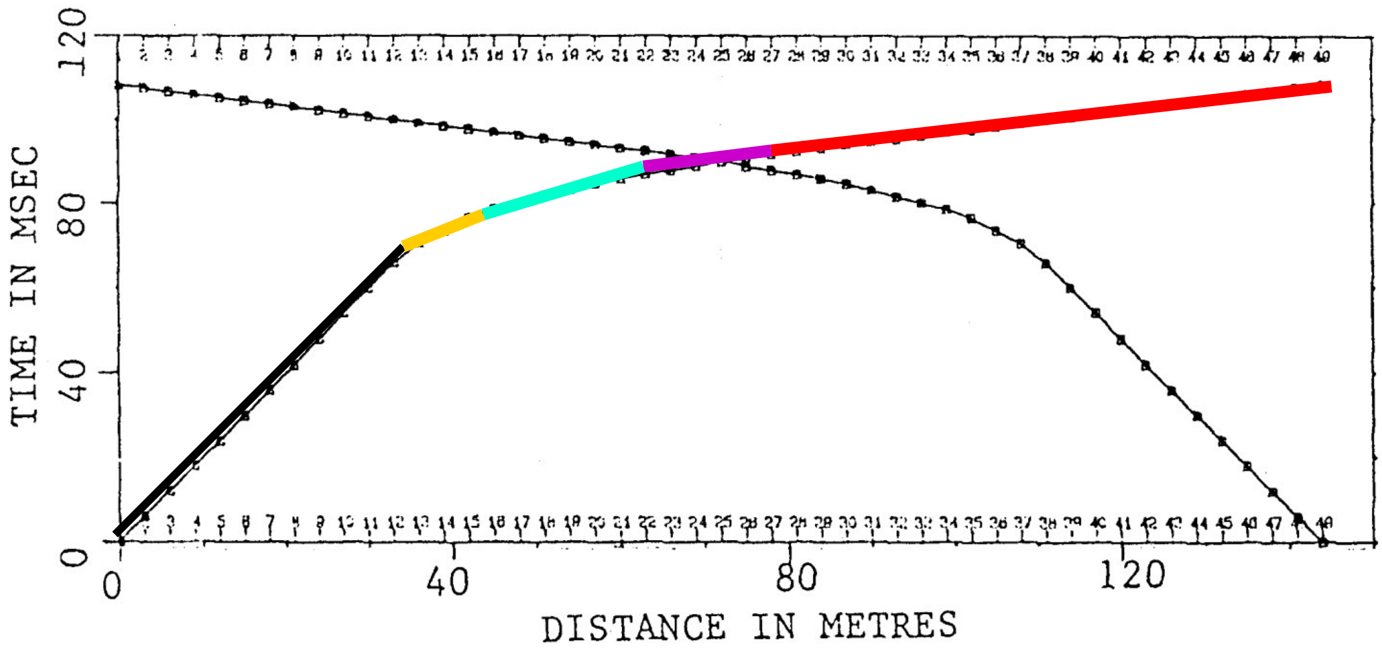


SEISMIC REFRACTION
HAMMER
PLATE
GEOPHONES
TO SEISMOGRAPH
SEDIMENT
SEISMIC WAVE RAYPATHS
BEDROCK
DIRECT WAVE
REFRACTED WAVE

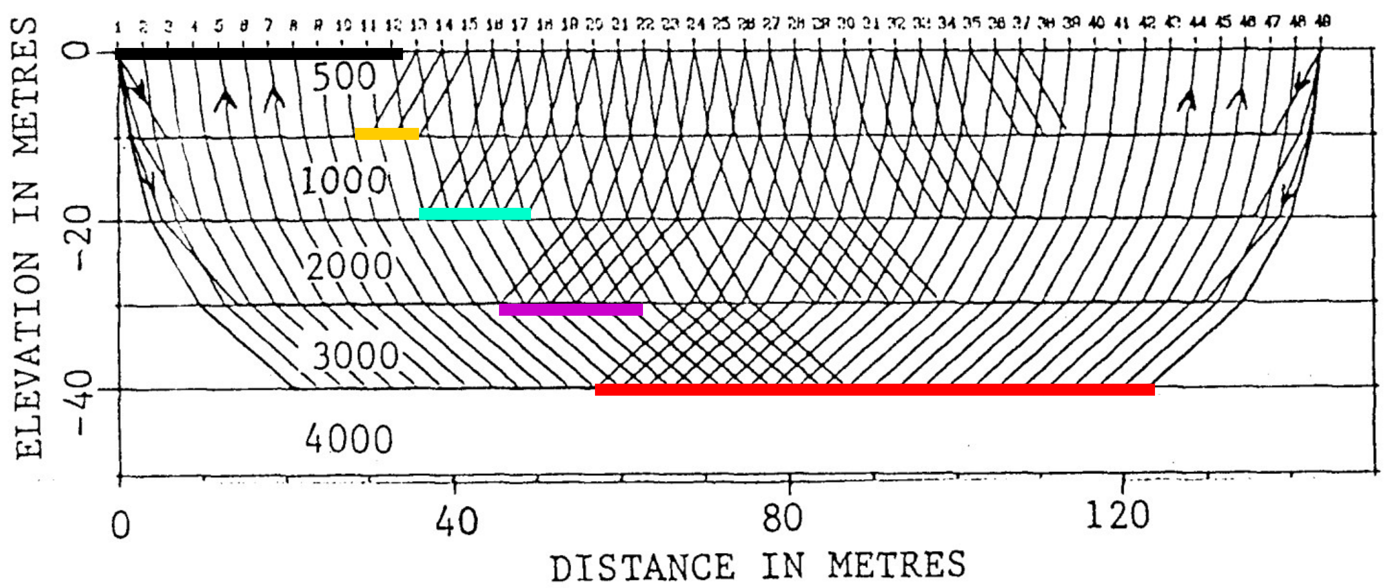
Seismic refraction uses critically refracted P-waves Waves



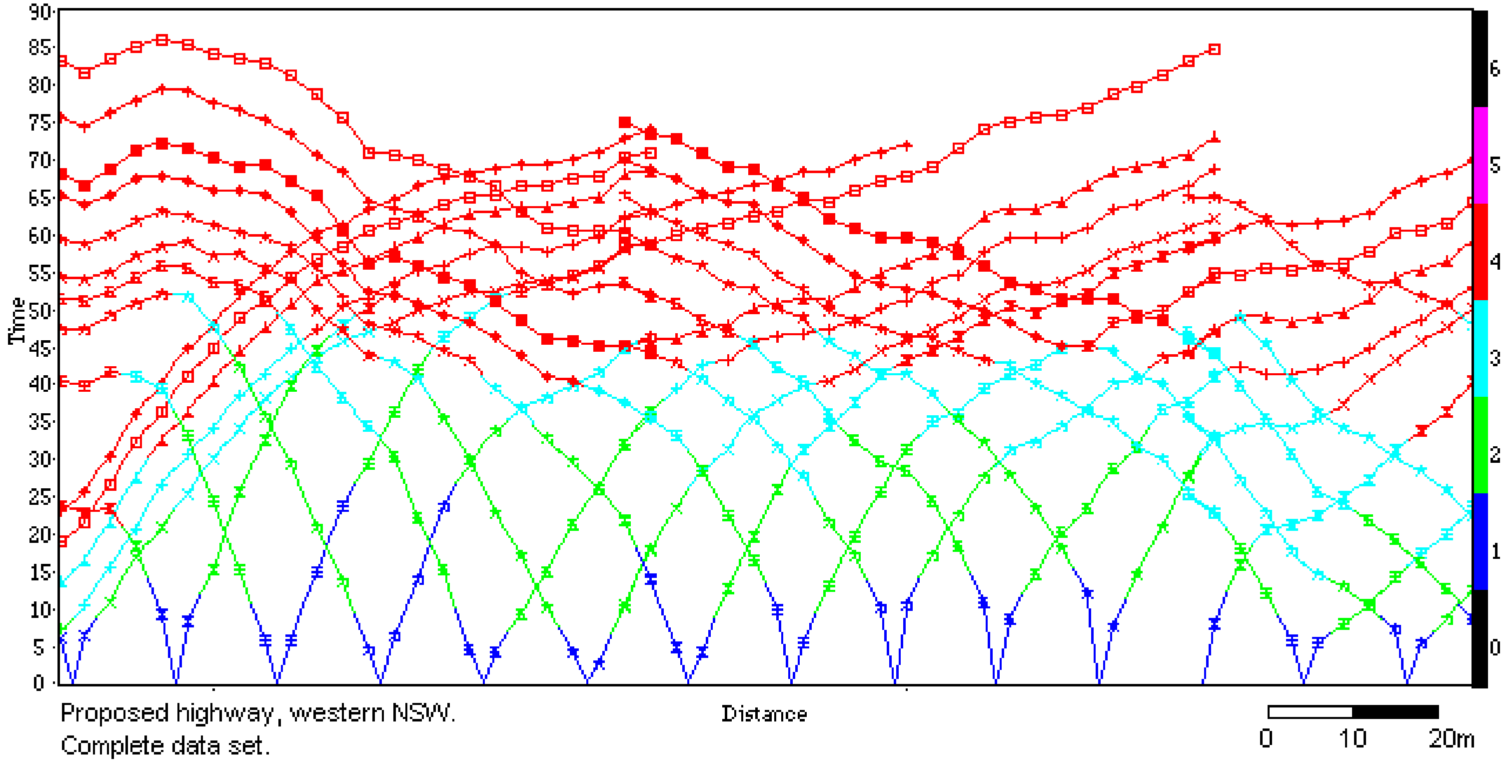
coffey



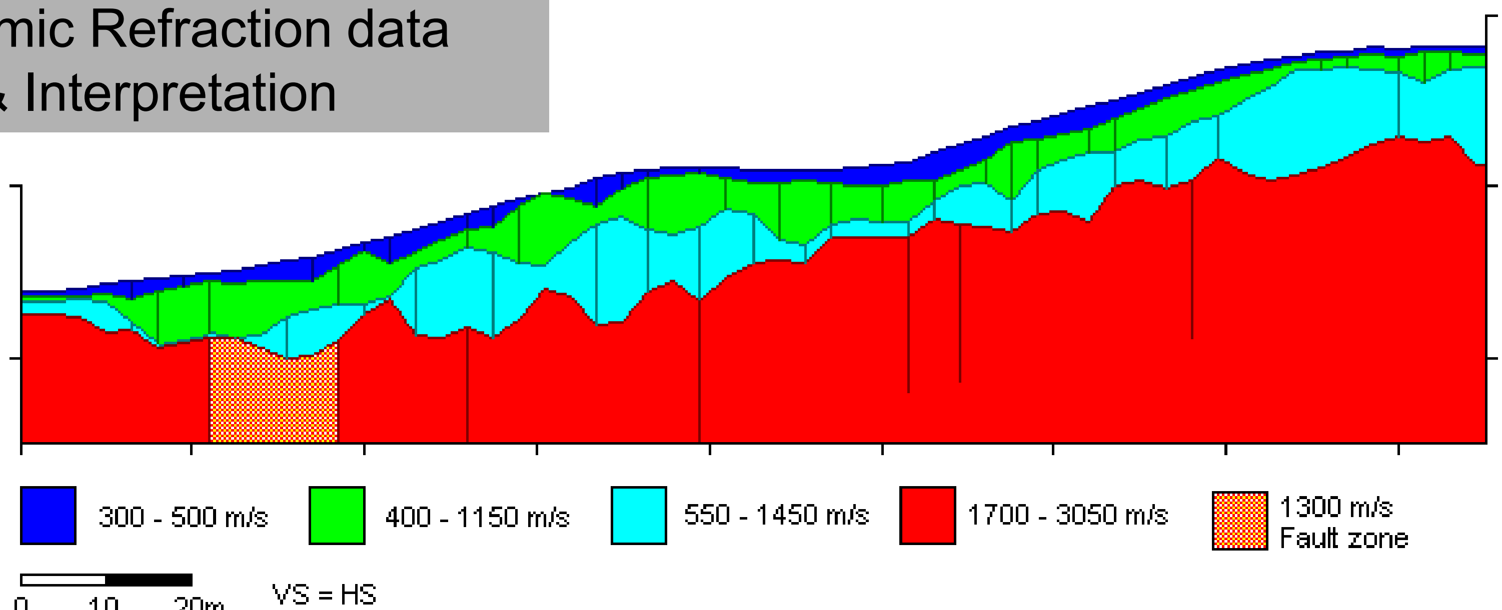
TIME IN MSEC
0
40
80
120
DISTANCE IN METRES



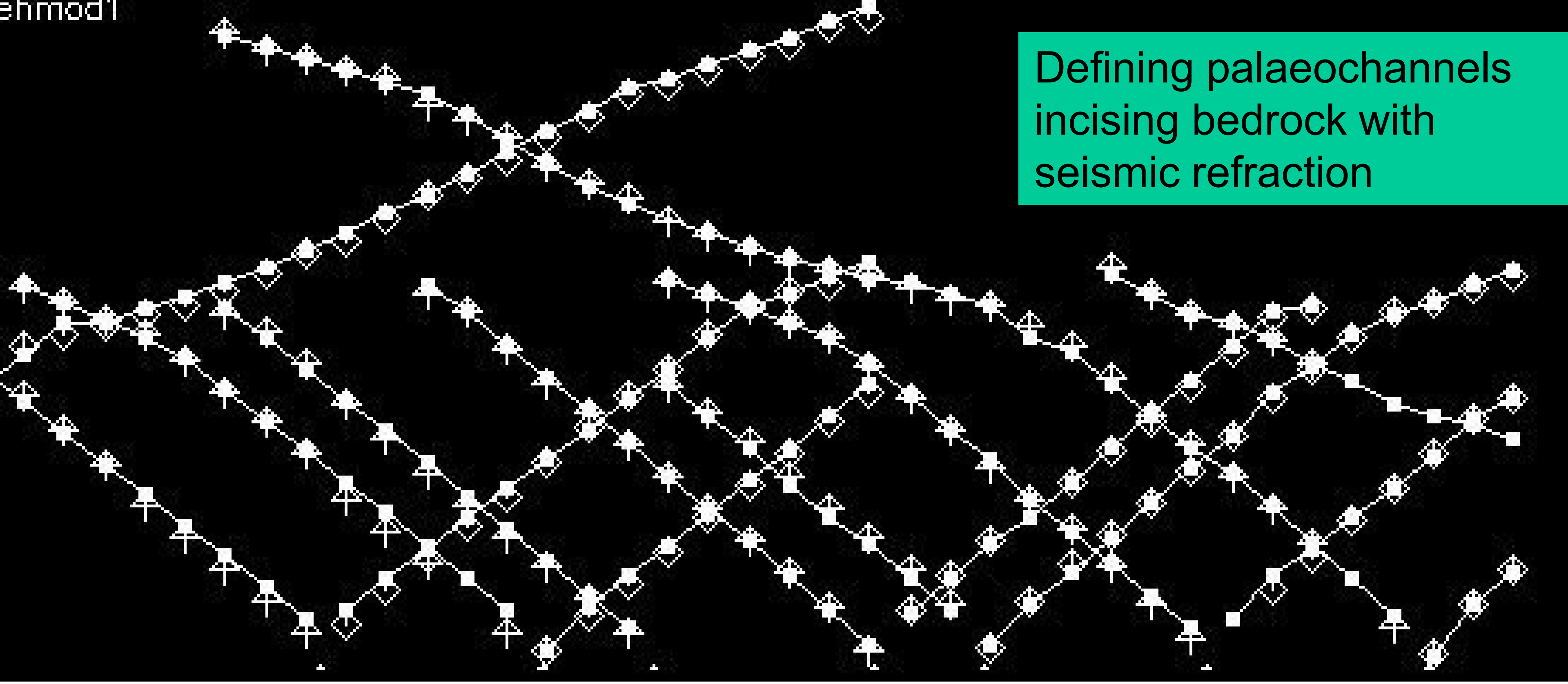
ELEVATION IN METRES
0
-20
-40
500
1000
2000
3000
4000
0
40
80
120
DISTANCE IN METRES

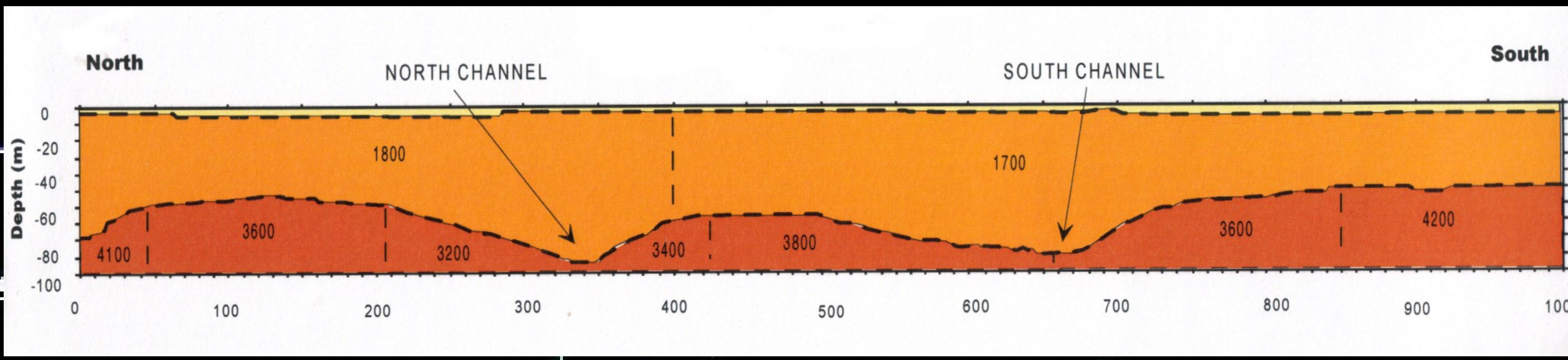


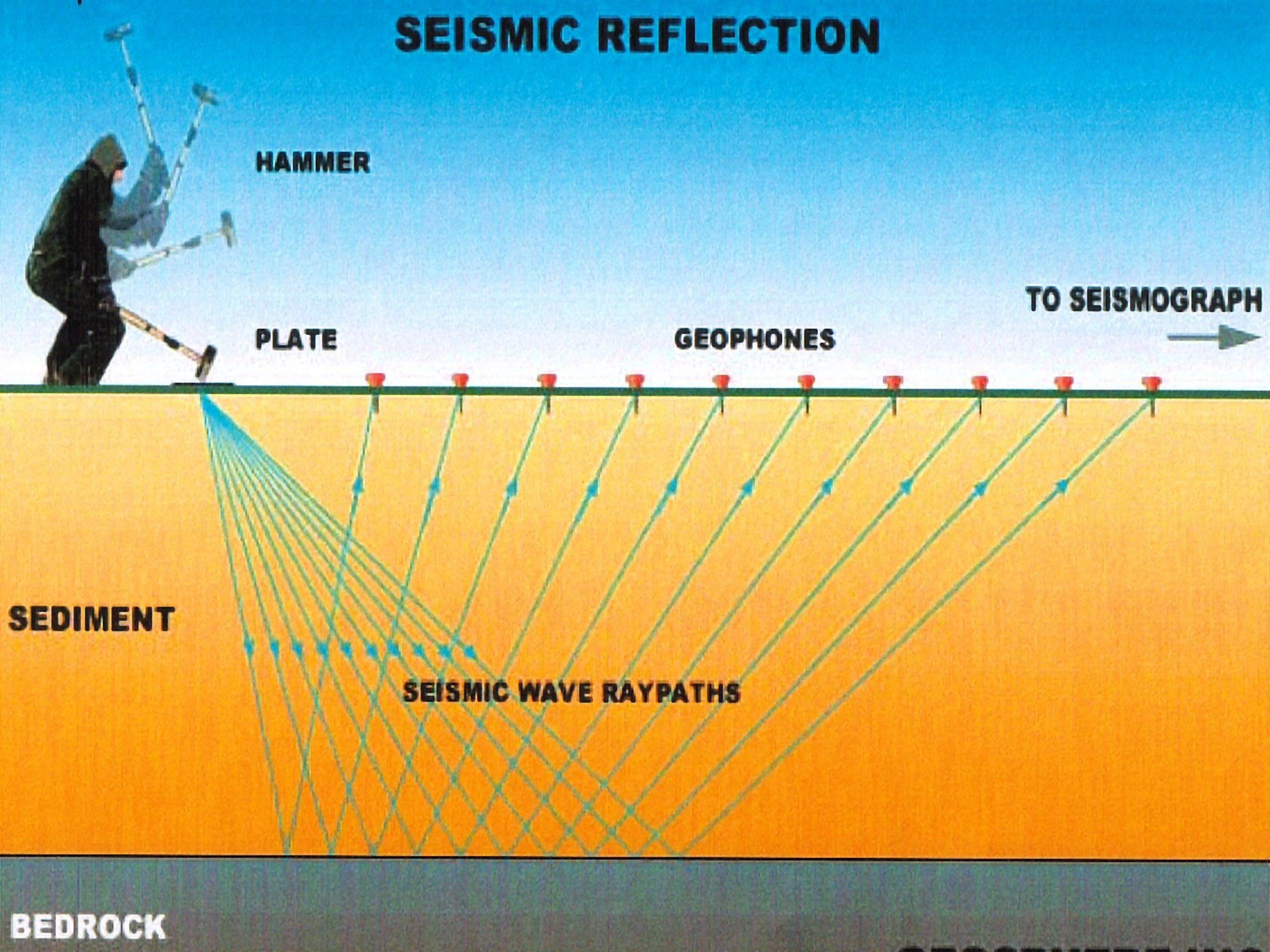
Seismic Refraction data set & Interpretation



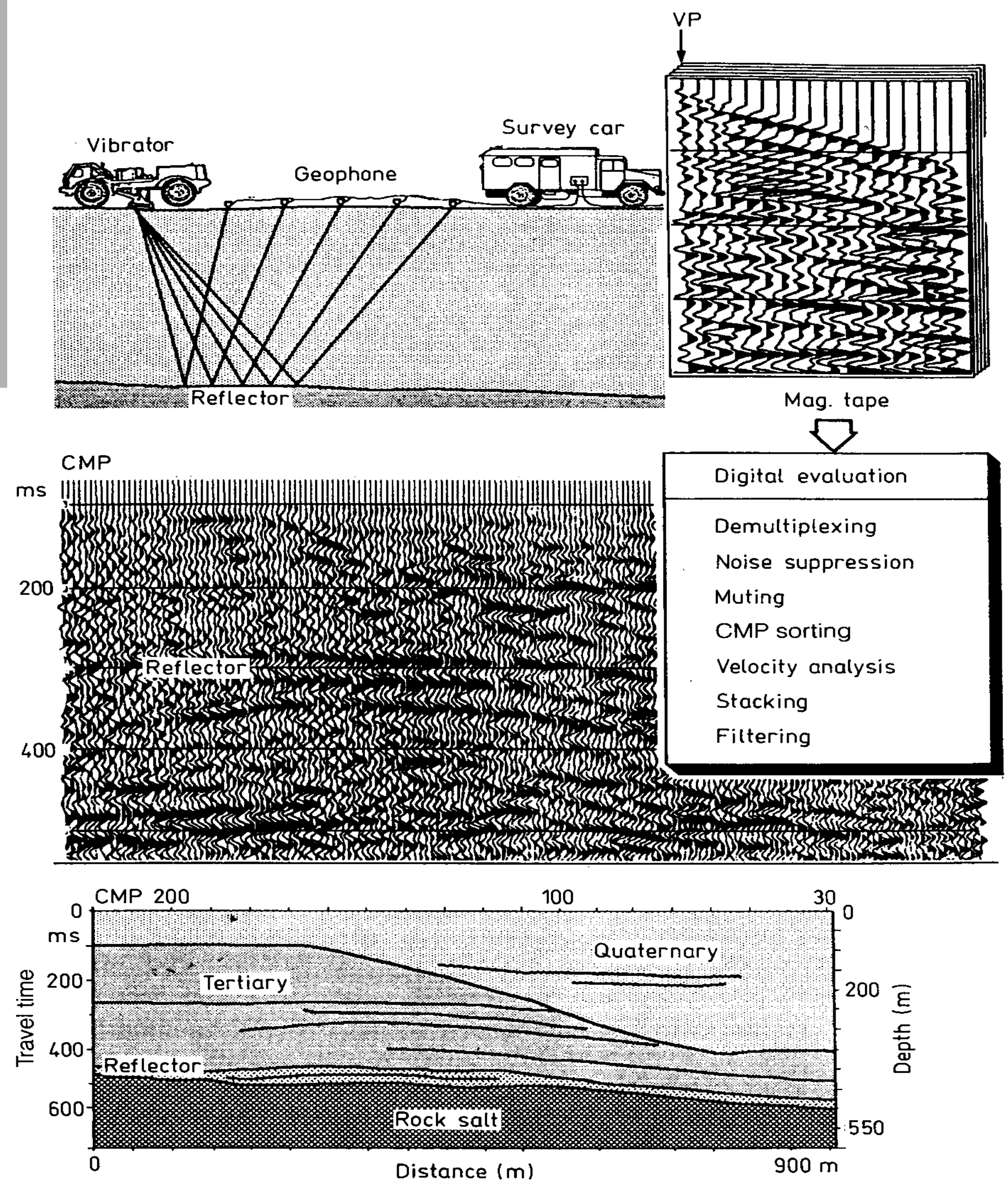
Defining palaeochannels incising bedrock with seismic refraction






SEISMIC REFLECTION
HAMMER
TO SEISMOGRAPH
PLATE
GEOPHONES
SEDIMENT
SEISMIC WAVE RAYPATHS
BEDROCK

Seismic Reflection uses reflected waves

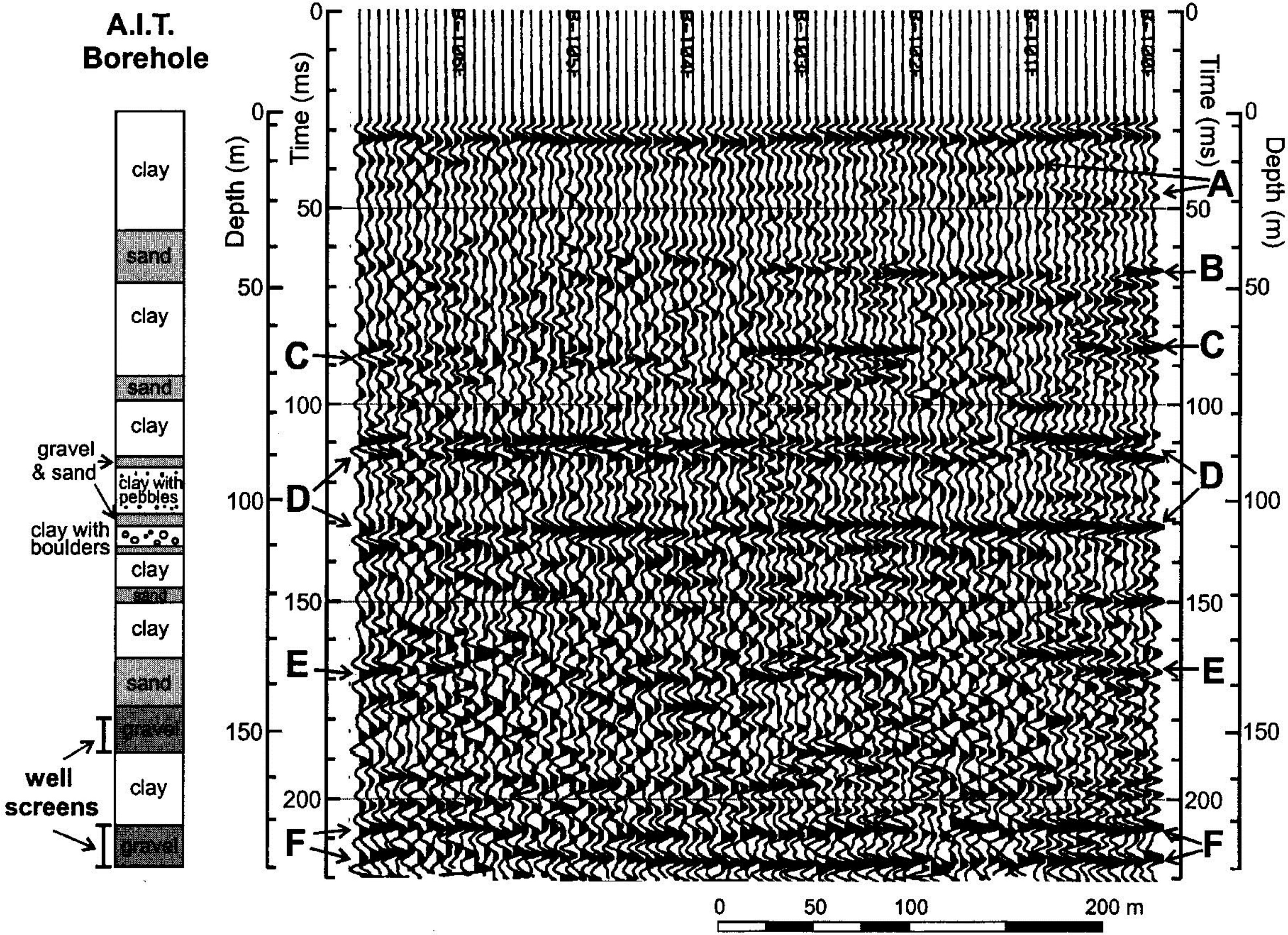


Field set-up for shallow seismic reflection

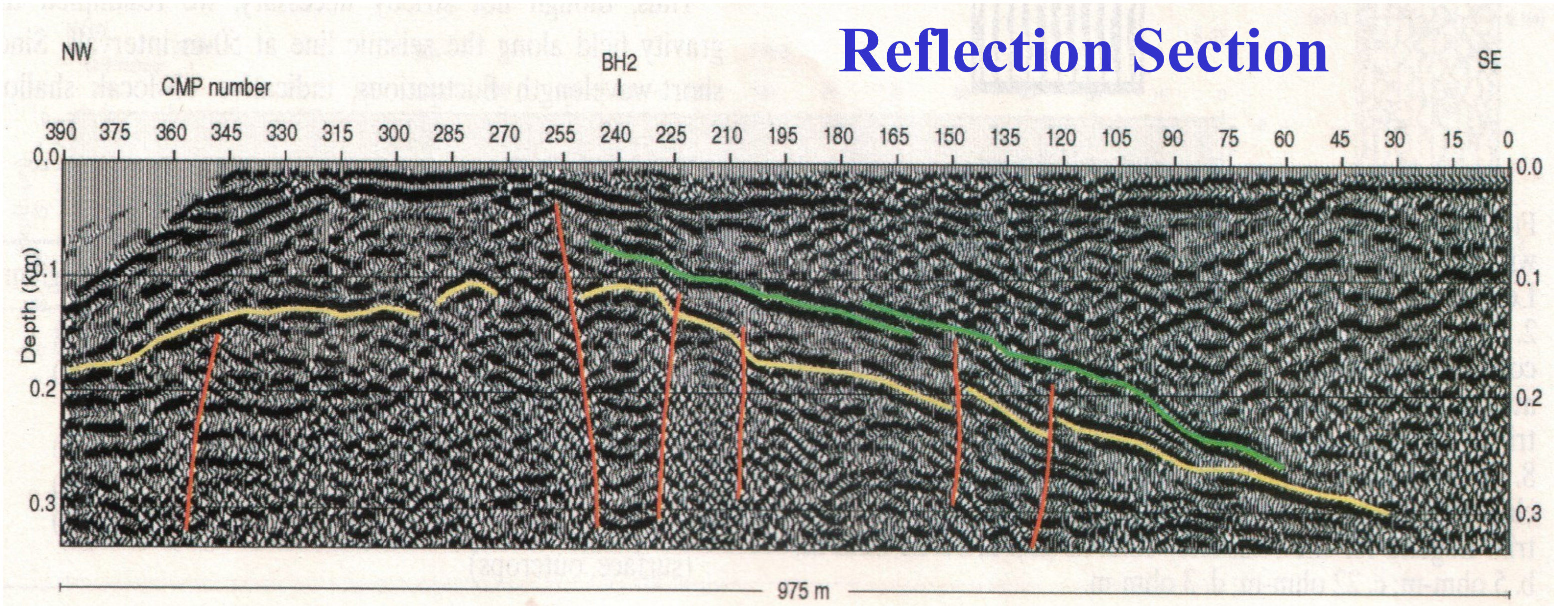
TRACING SHALLOW AQUIFERS WITH SEISMIC REFLECTION

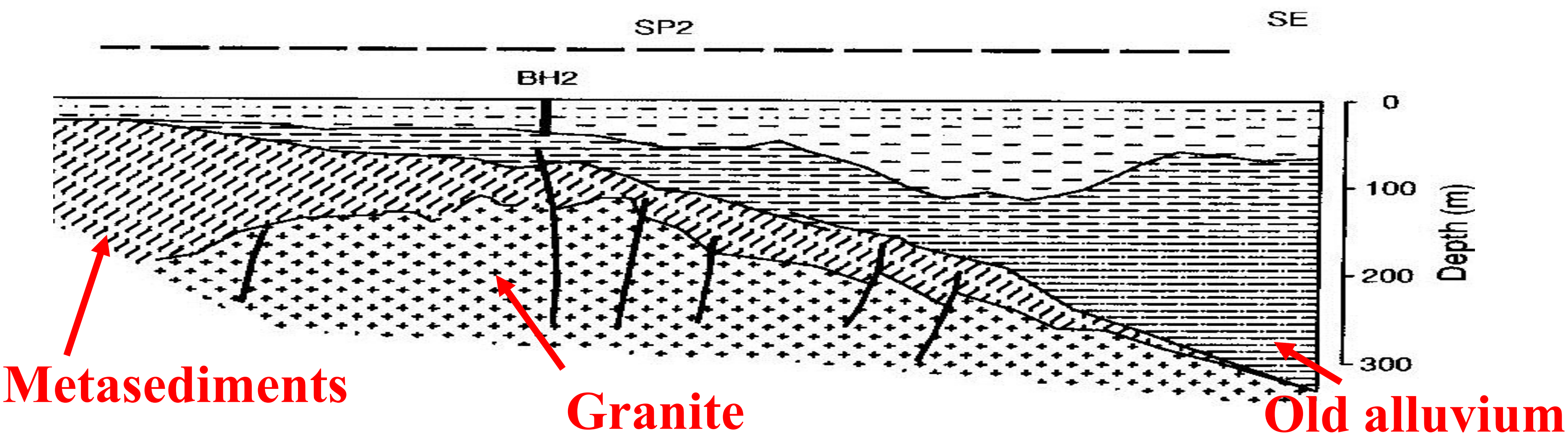
Alluvial sequence, Bangkok

Processed seismic reflection section



CDP Seismic Reflection Section

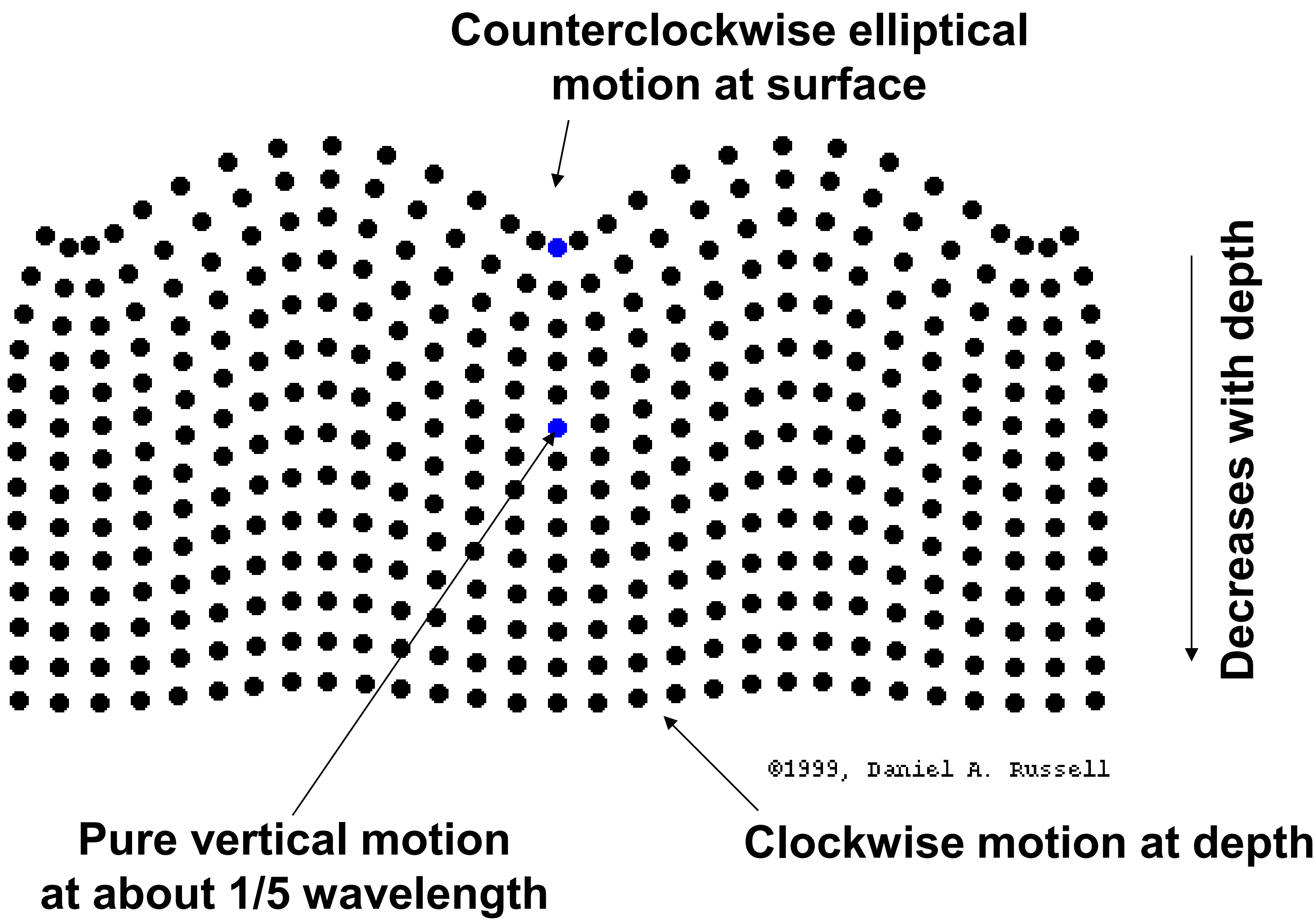




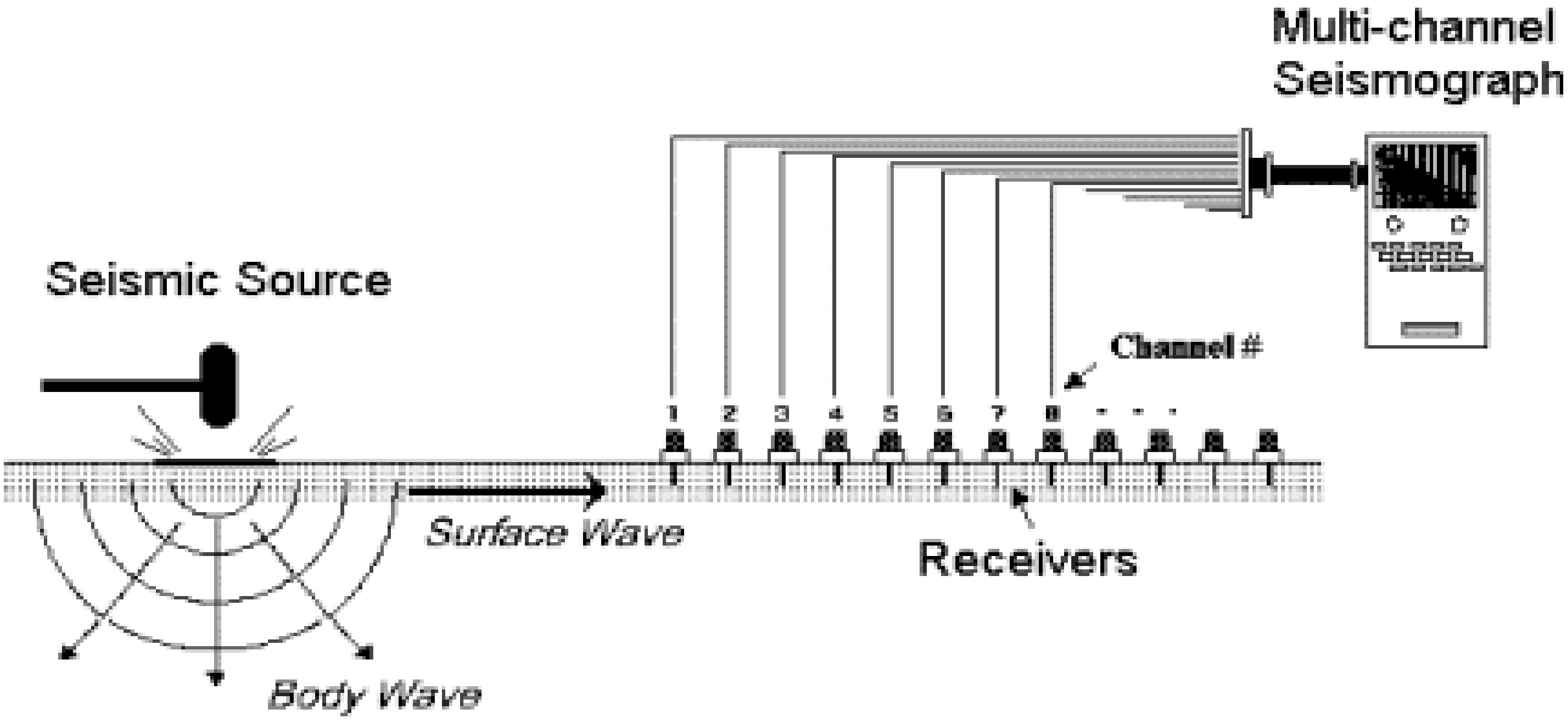
Surface Wave Seismic

Multi-channel Analysis of surface Waves (MASW)

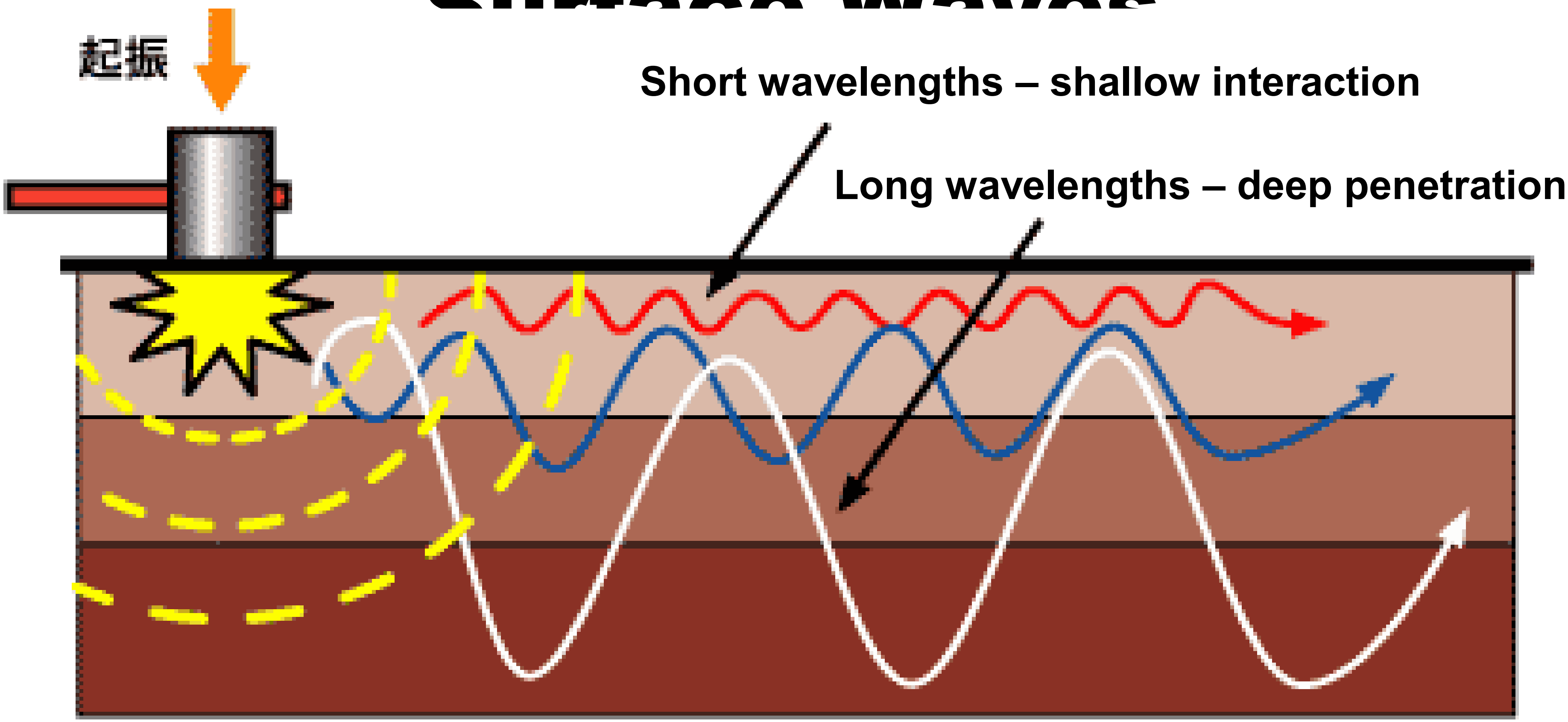
Rayleigh (R) wave motion



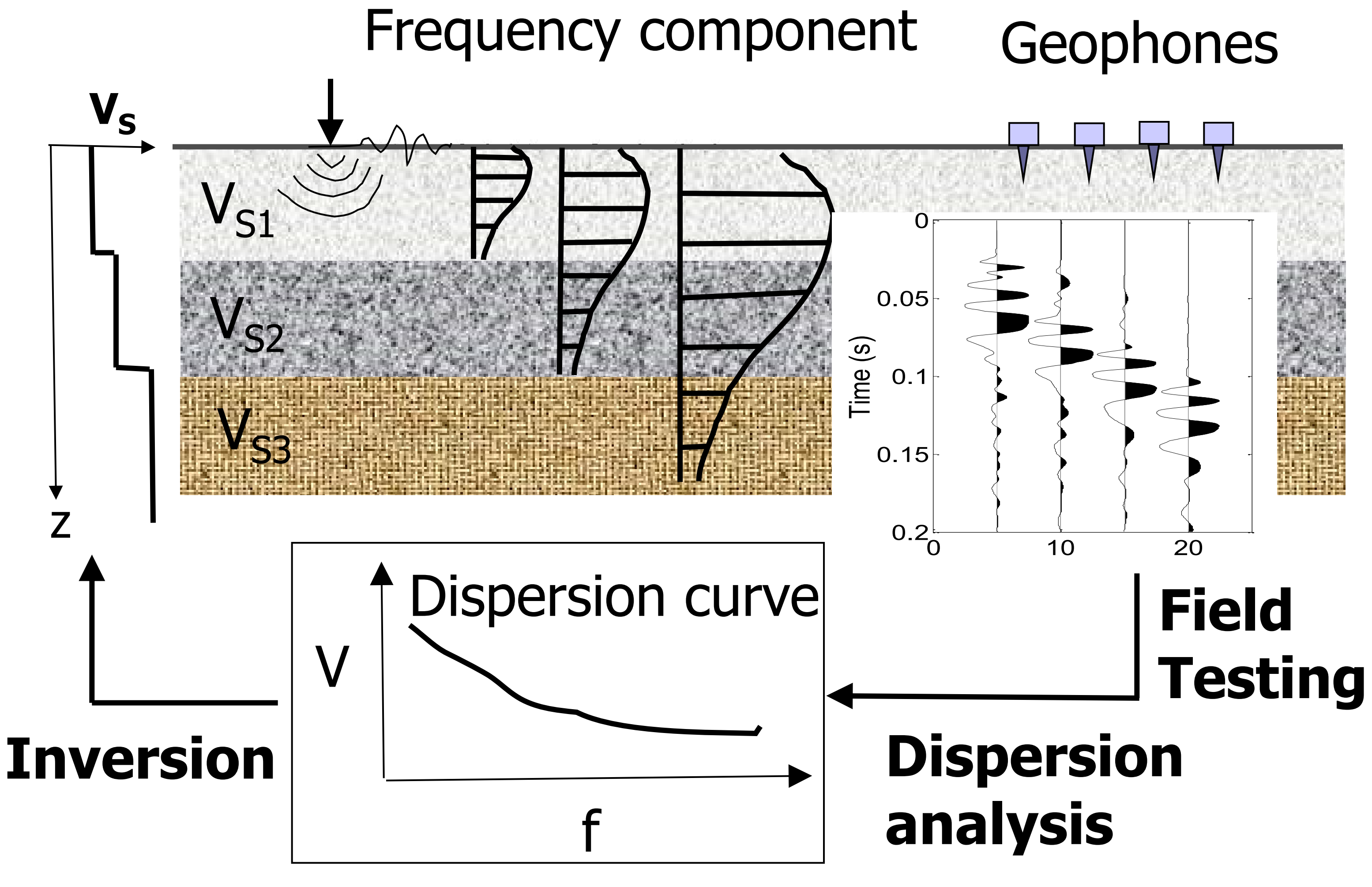
The MASW Method



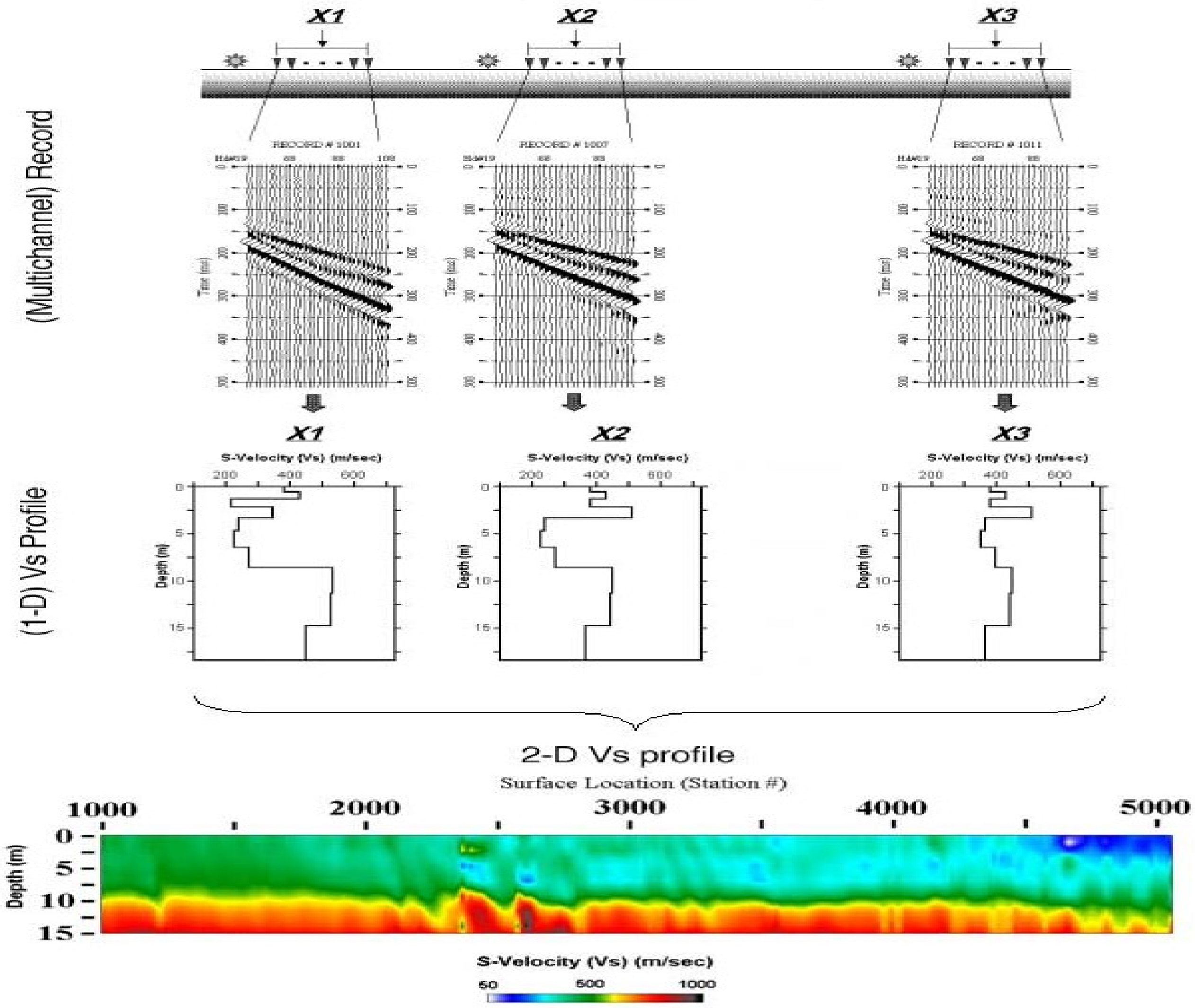
Layering effects on Surface Waves



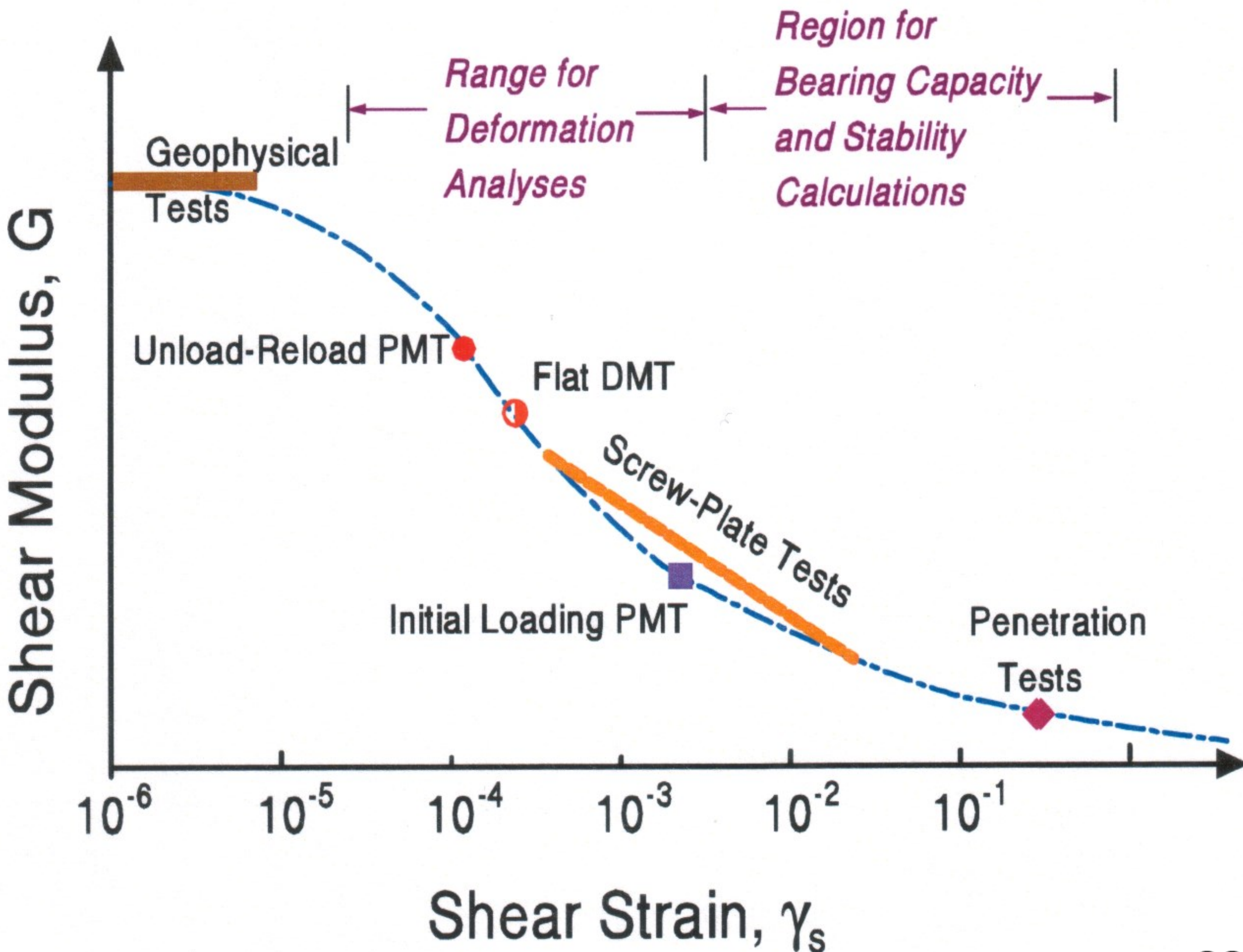
Basic Principle of Surface Wave Method



MASW Sections

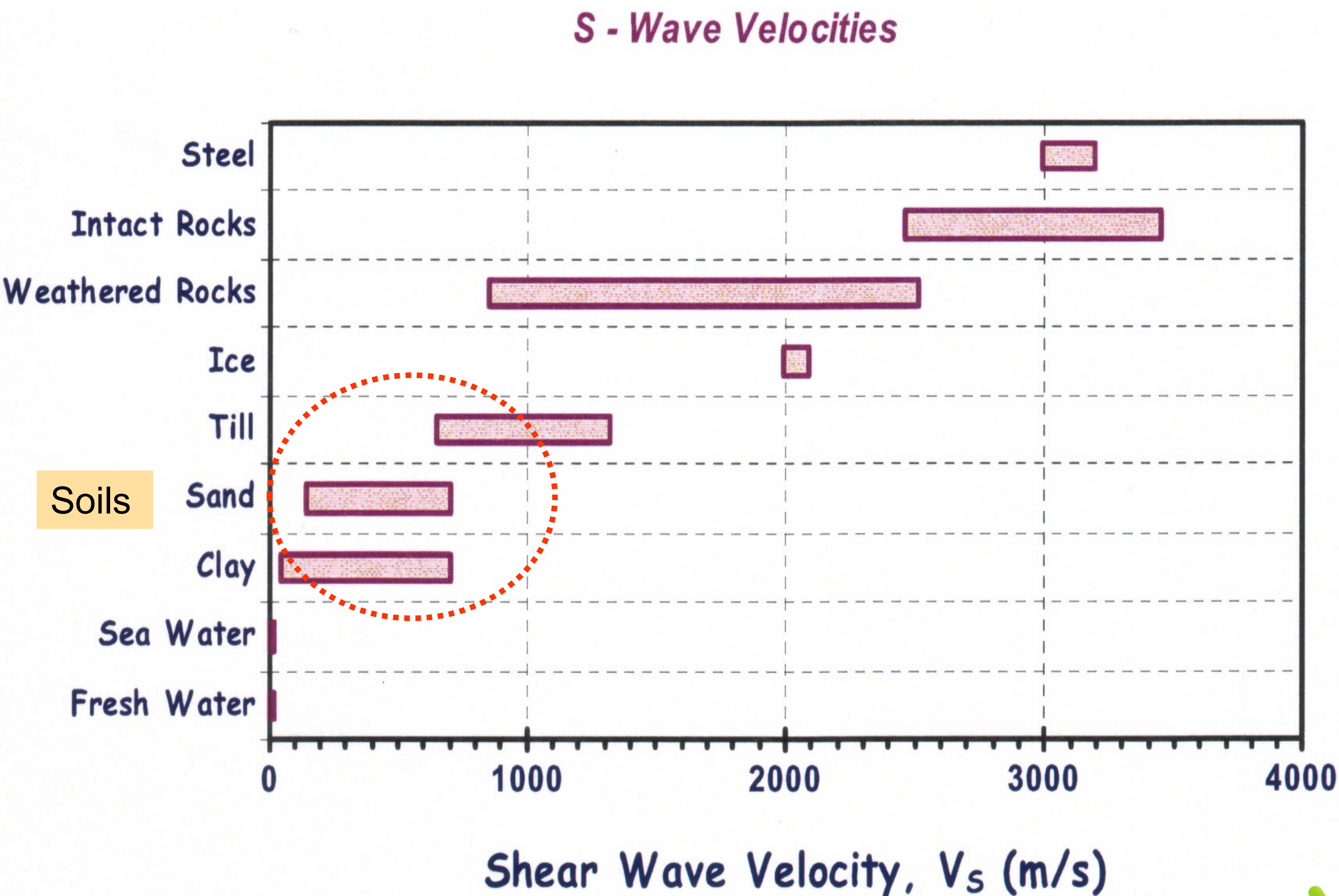


Landstreamer acquisition



Range for
Deformation
Analyses
Region for
Bearing Capacity
and Stability
Calculations
Geophysical
Tests
Unload-Reload PMT
Flat DMT
Screw-Plate Tests
Initial Loading PMT
Penetration
Tests
Shear Modulus, G
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Shear Strain, γ_s

coffey

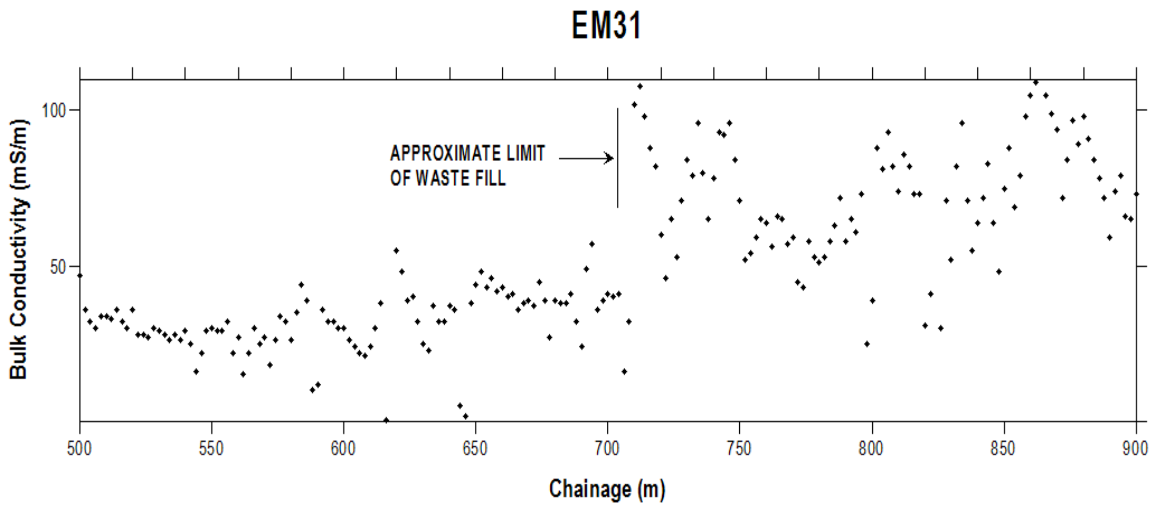


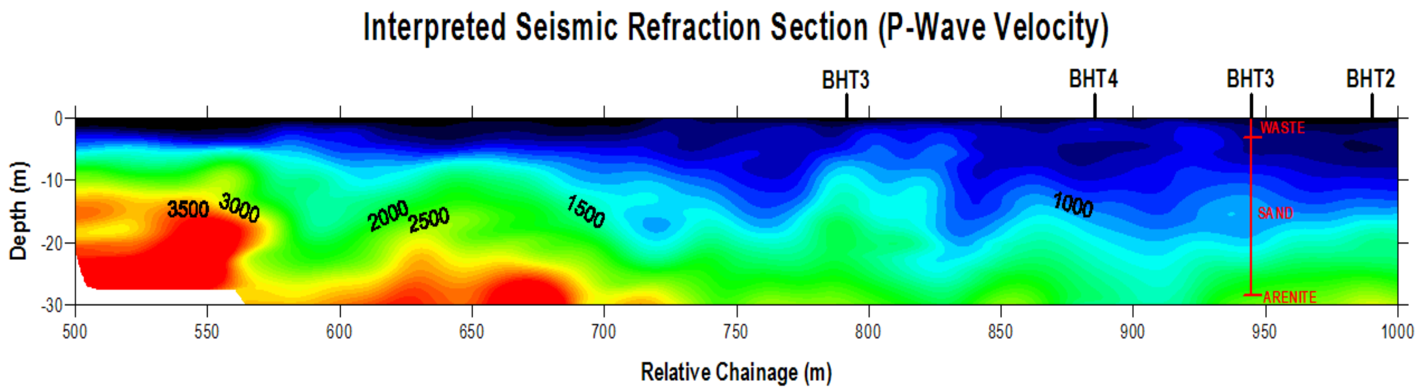
S - Wave Velocities
Steel
Intact Rocks
Weathered Rocks
Ice
Till
Sand
Clay
Sea Water
Fresh Water
Soils
0
1000
2000
3000
4000
Shear Wave Velocity, Vs (m/s)

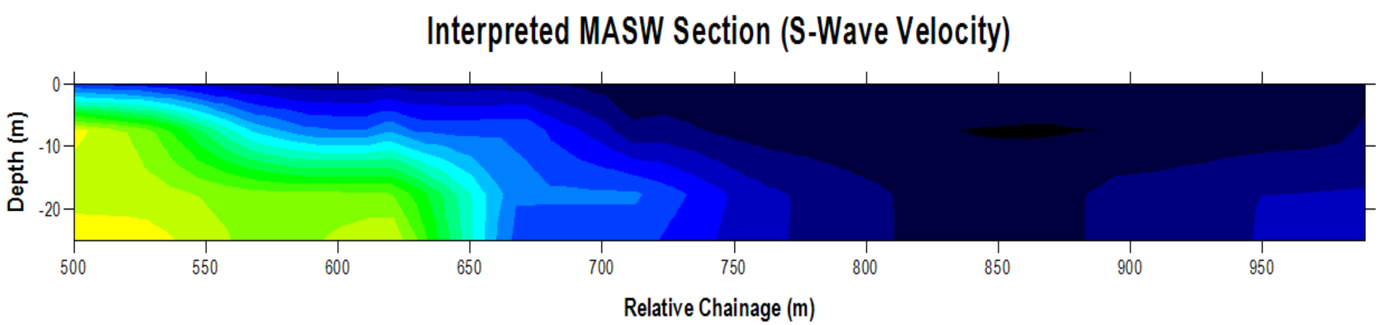
coffey

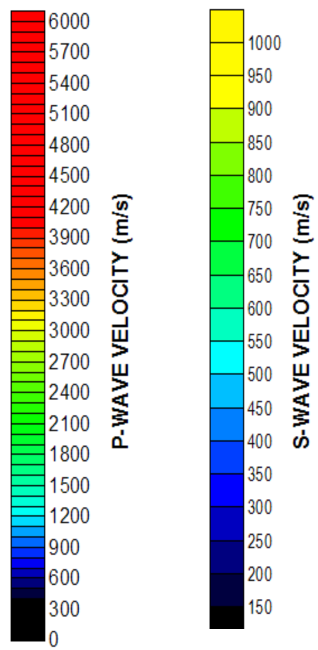
Geotechnical Classification	S-Wave Seismic Velocity (m/s)
Very soft soils	<100
Soft soils	100 to 300
Stiff soils	200 to 500
Very Stiff soils	500 to 900
Rock	>900

Combined EM & Seismic Technologies





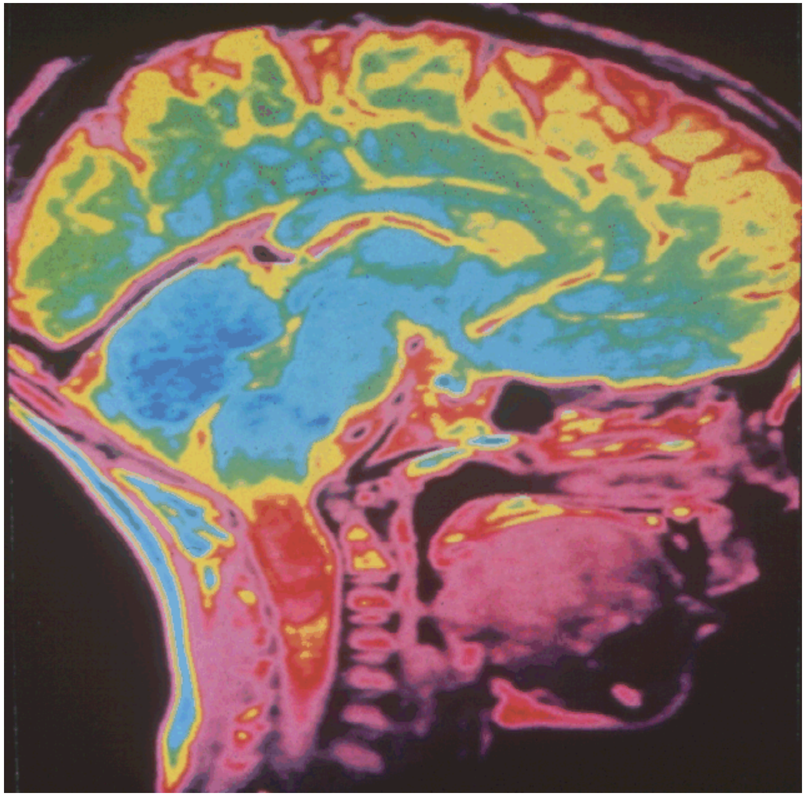


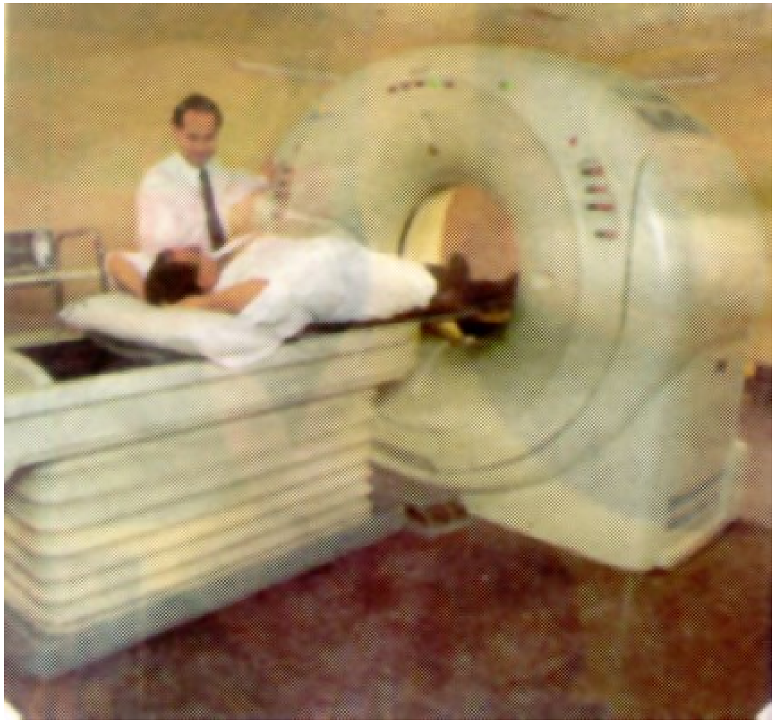


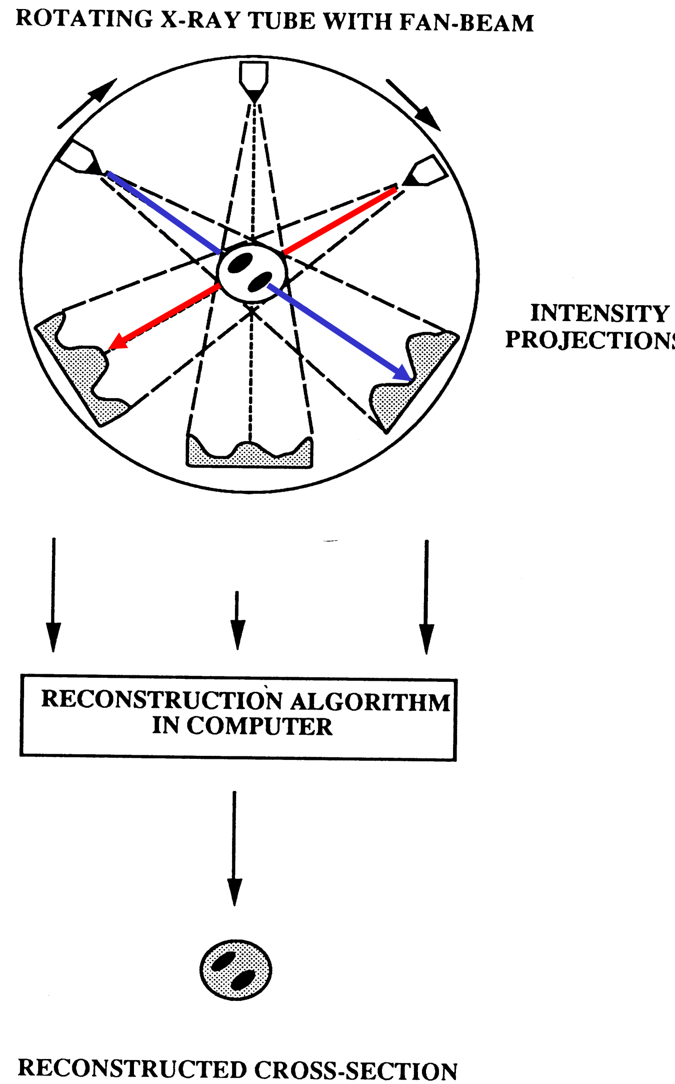
coffey

Seismic Tomographic Imaging from boreholes

MEDICAL IMAGING WITH COMPUTER AIDED TOMOGRAPHY (CAT or CT scanning)

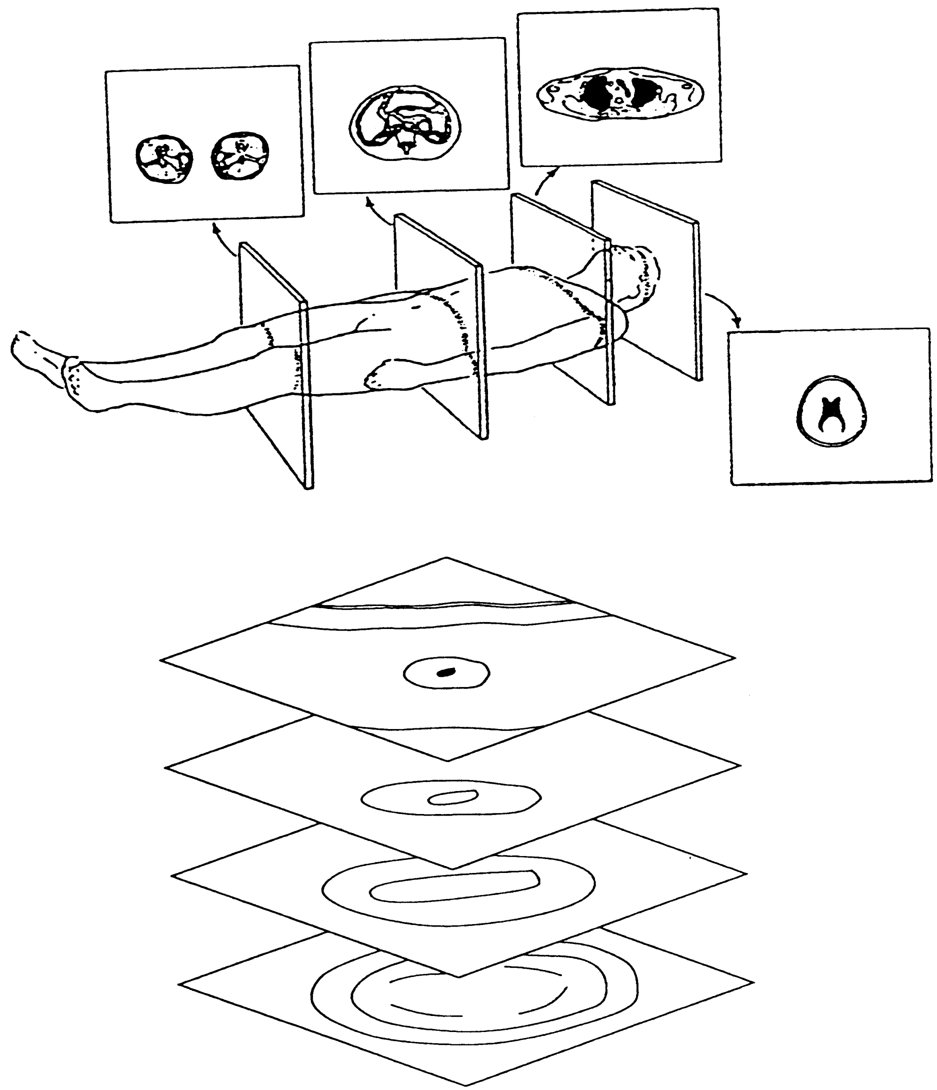






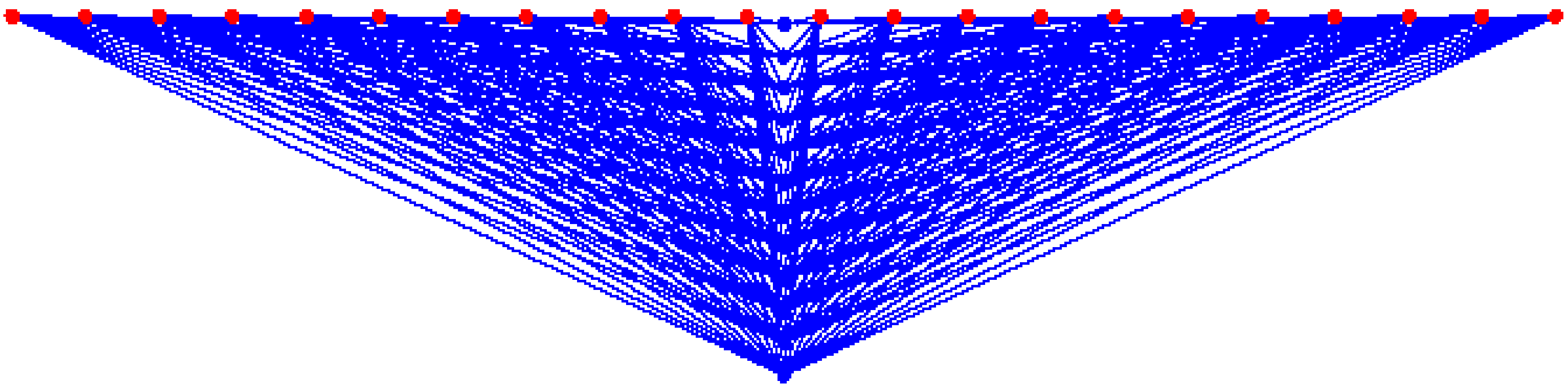
ADVANCED PROCESSING

A 3D IMAGE IS CONSTRUCTED FROM A SERIES OF SLICES IN 2D IMAGE PLANES



Single Borehole - Site Uniformity Seismic (SUBS) Test

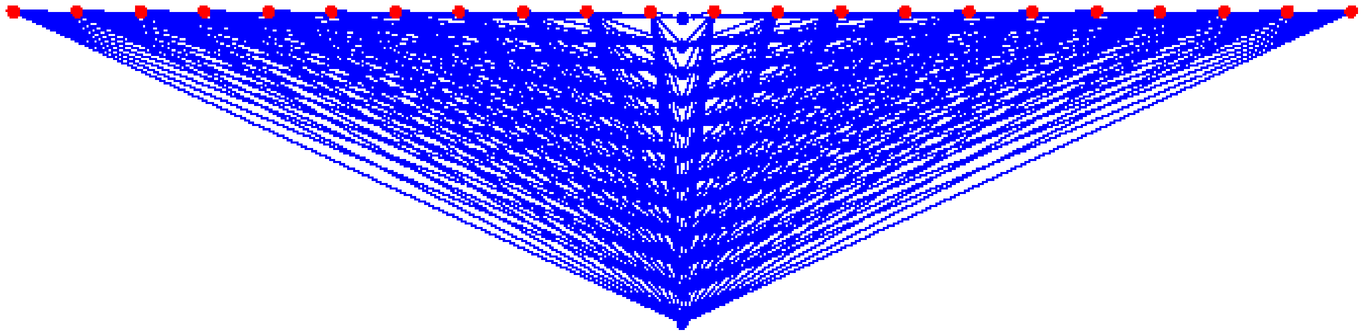
Seismic raypath section – uniform earth



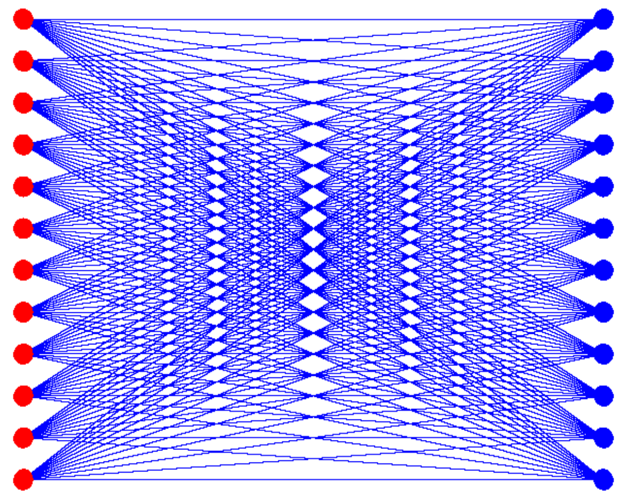
SUBS

- **extends the radius of investigation of borehole**
- **is calibrated at the borehole with a Vertical Seismic Profile (VSP)**

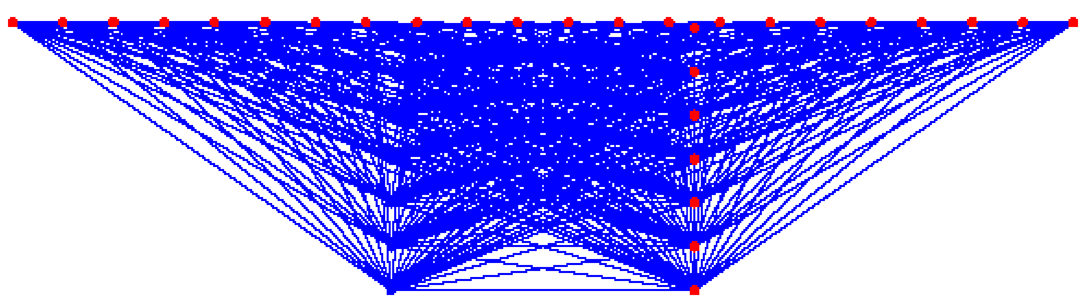
Deploying the borehole seismic array



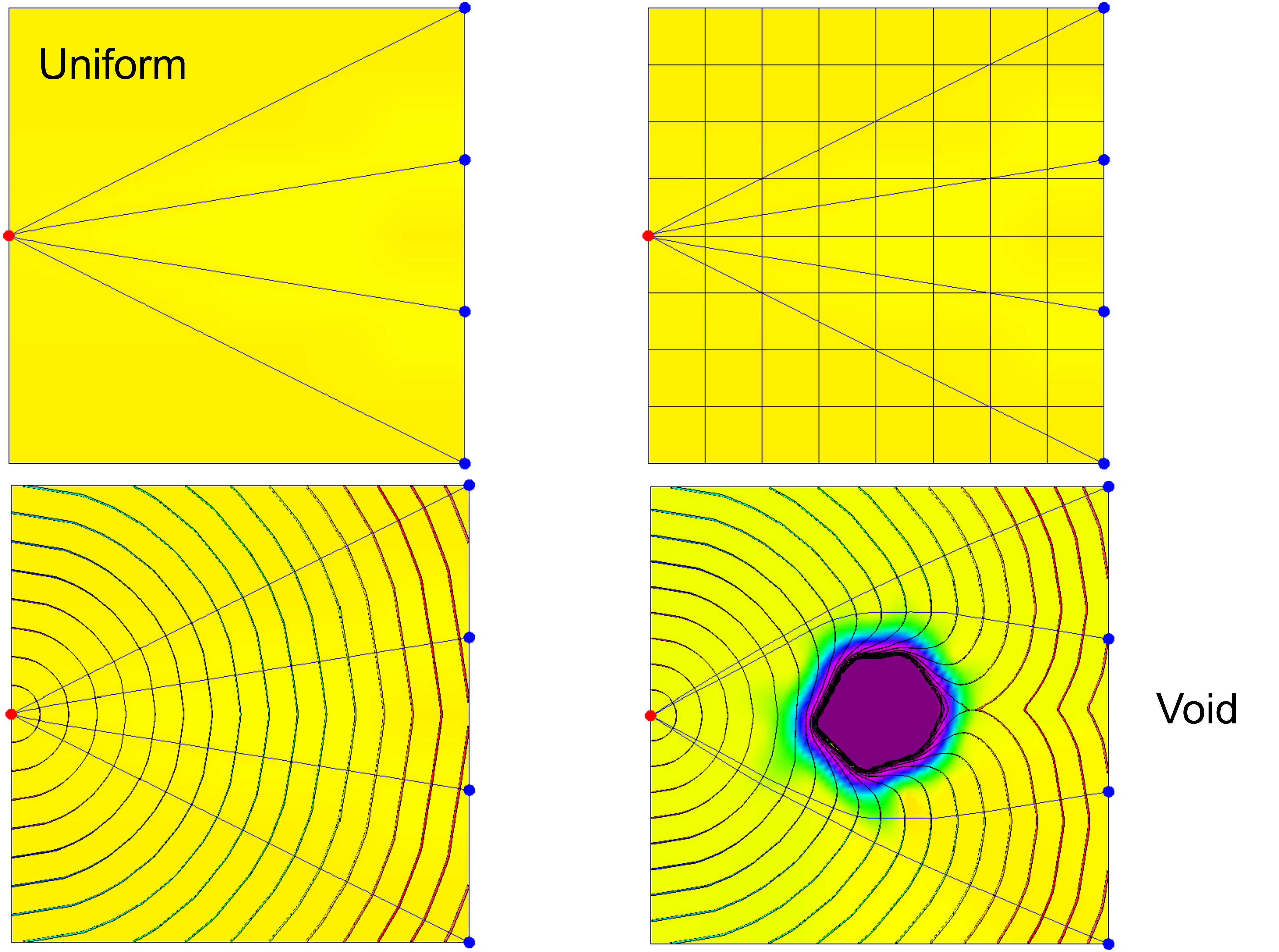
SUBS only



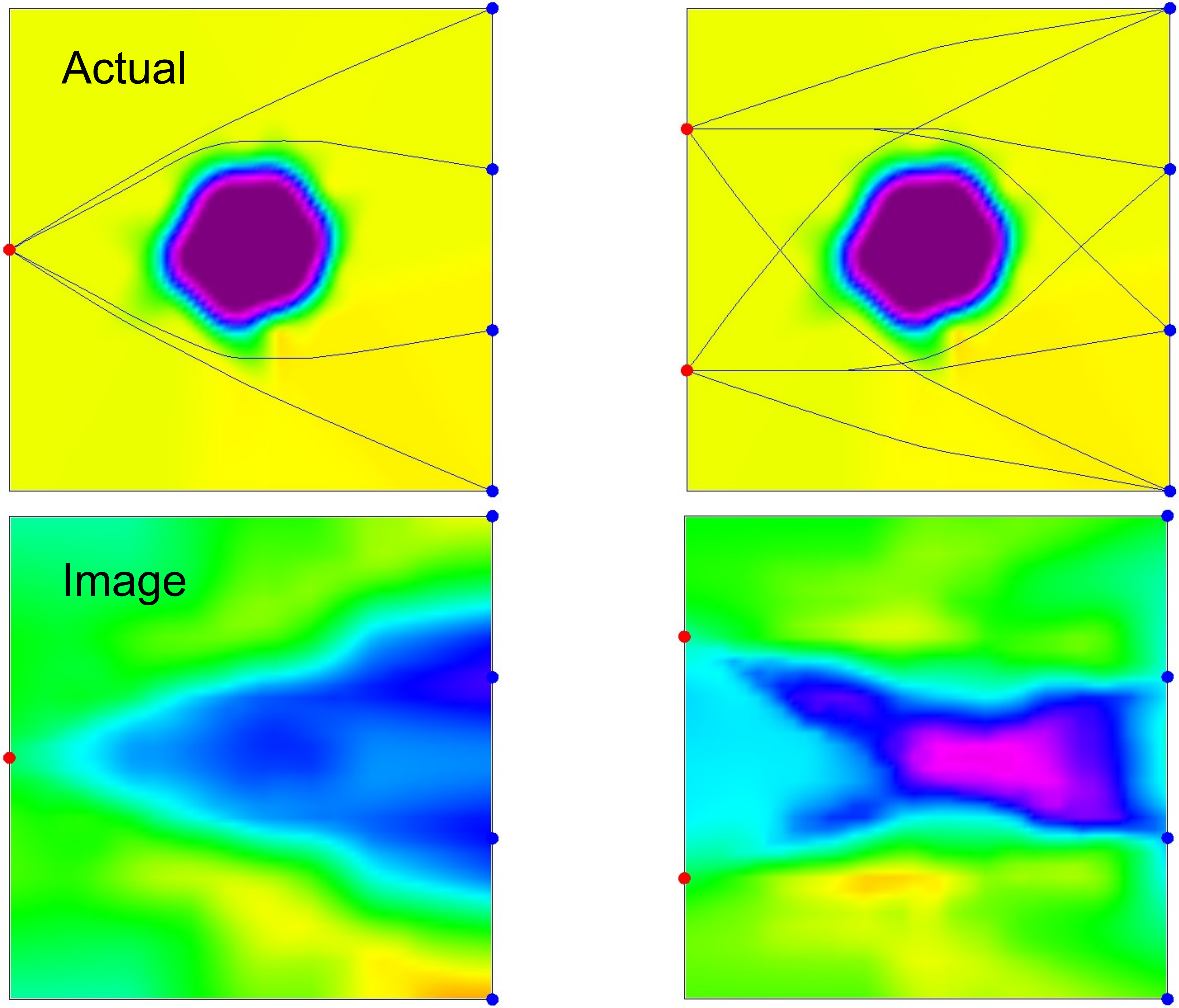
Crosshole only

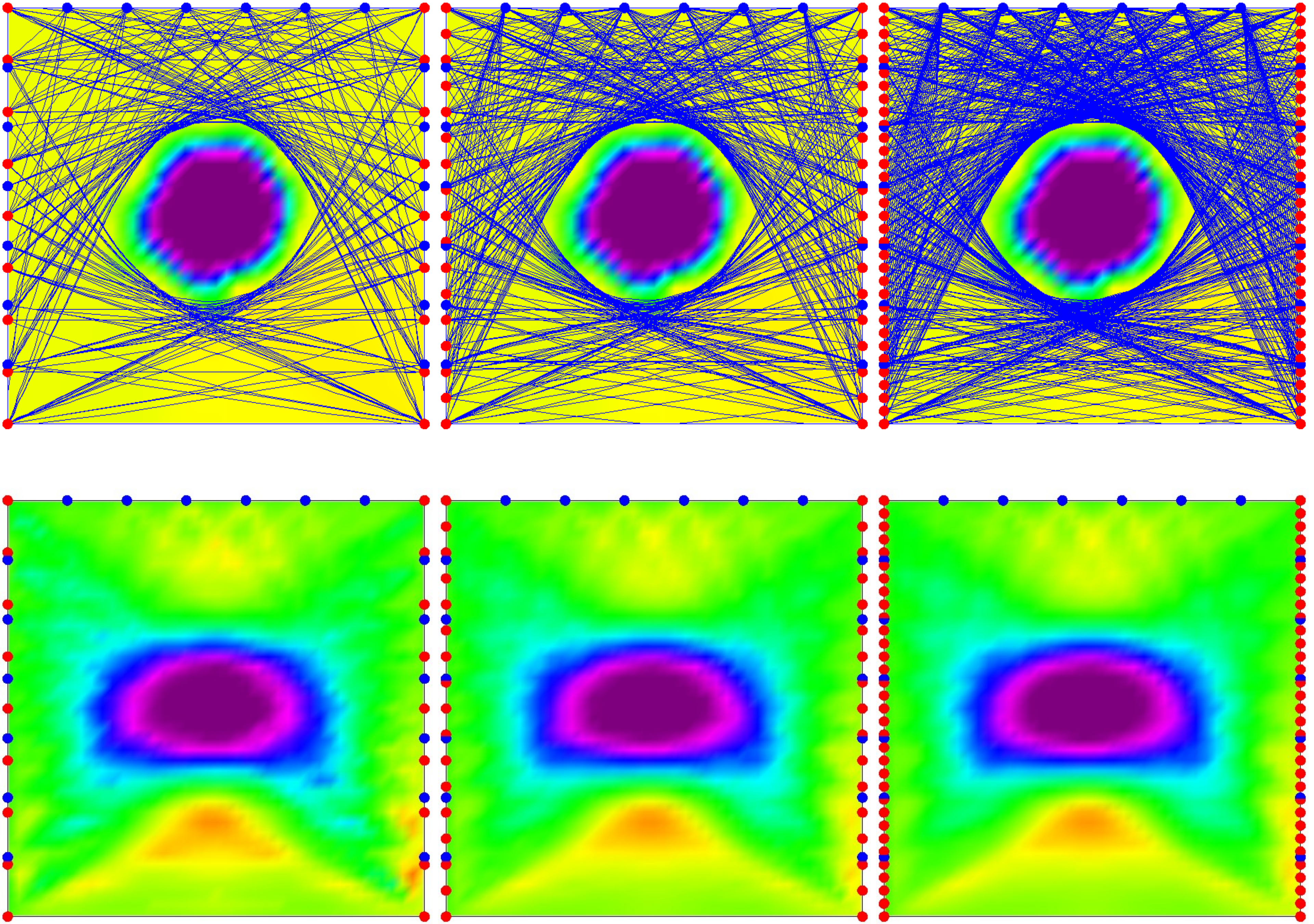


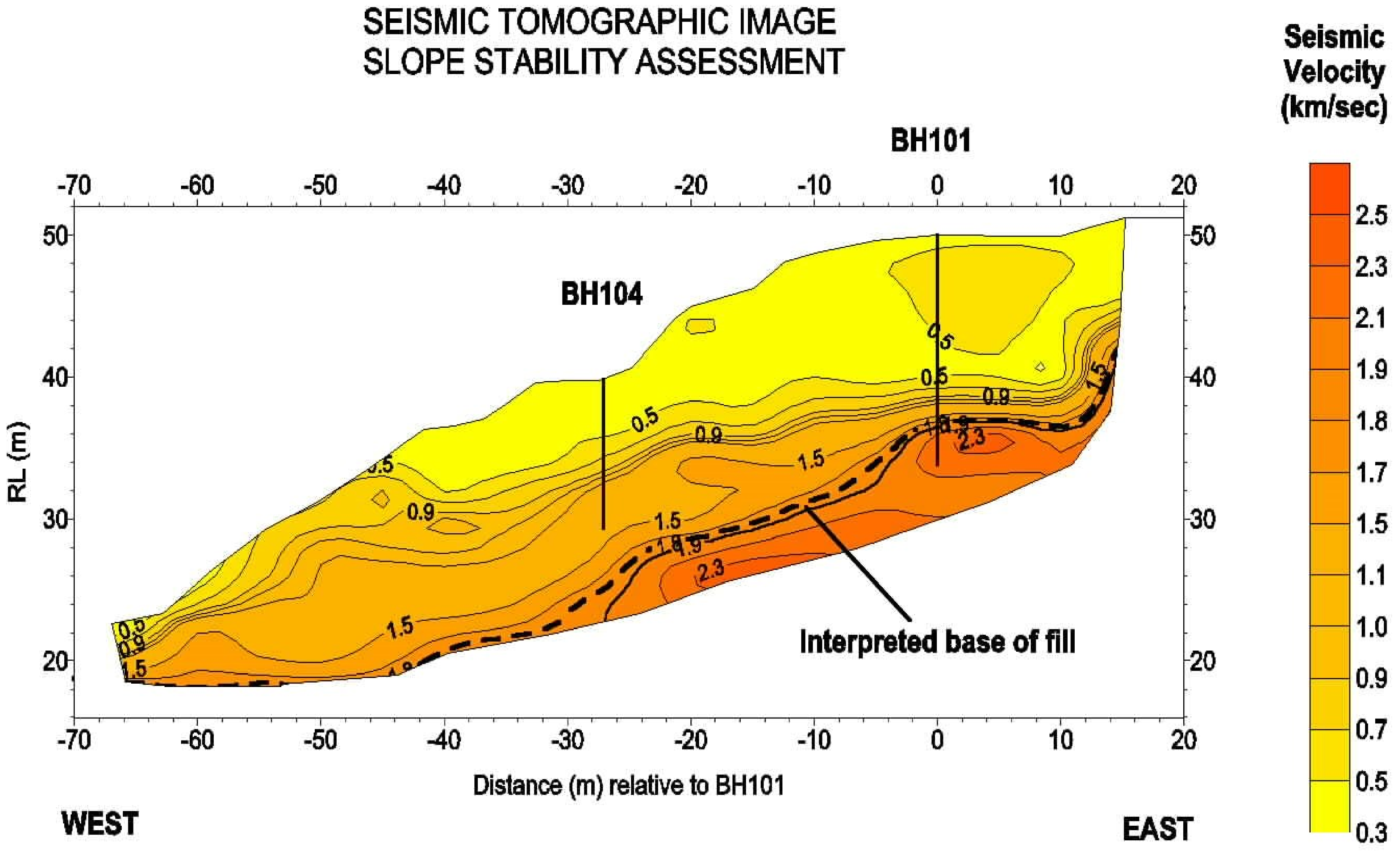
SUBS + Crosshole



Uniform
Void


Actual
Image

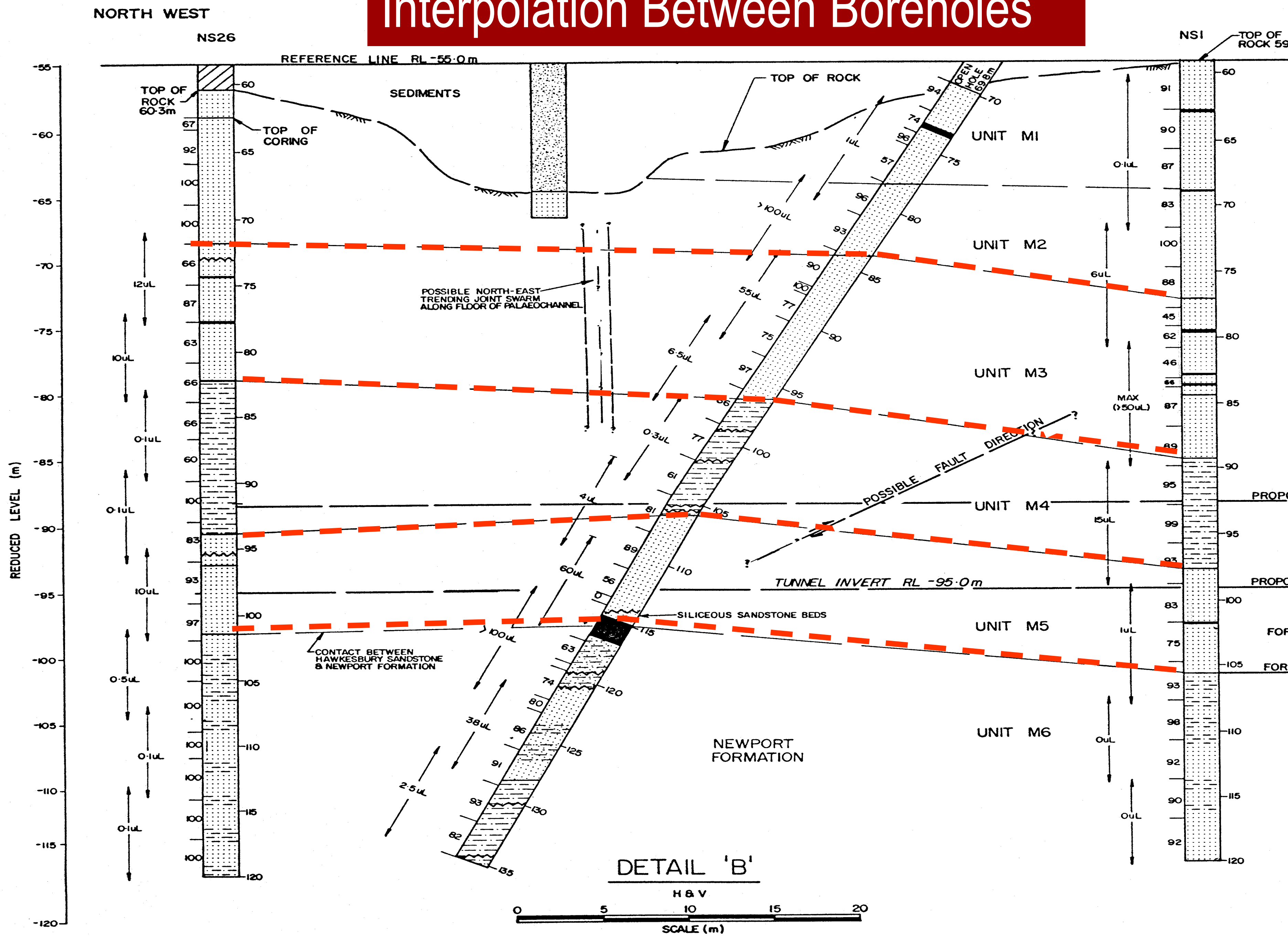




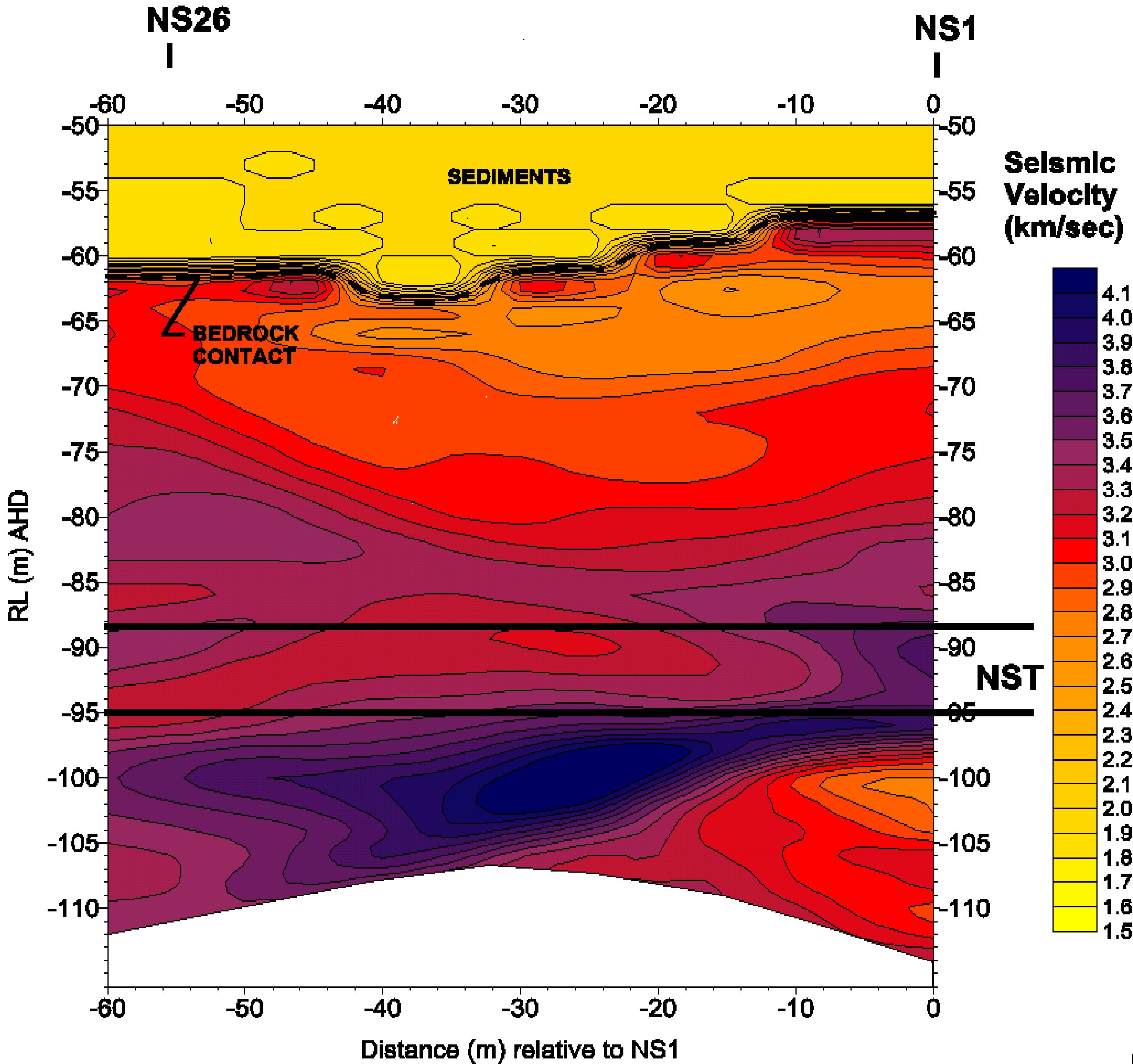
SEISMIC TOMOGRAPHIC IMAGE
SLOPE STABILITY ASSESSMENT
Seismic Velocity (km/sec)
BH101
BH104
RL (m)
Distance (m) relative to BH101
Interpreted base of fill
WEST
EAST
2.5
2.3
2.1
1.9
1.8
1.7
1.5
1.1
1.0
0.9
0.7
0.5
0.3


Manly Wharf
MANLY SAND SPIT - Crosshole seismic imaging of fractured rock in base of palaeochannel

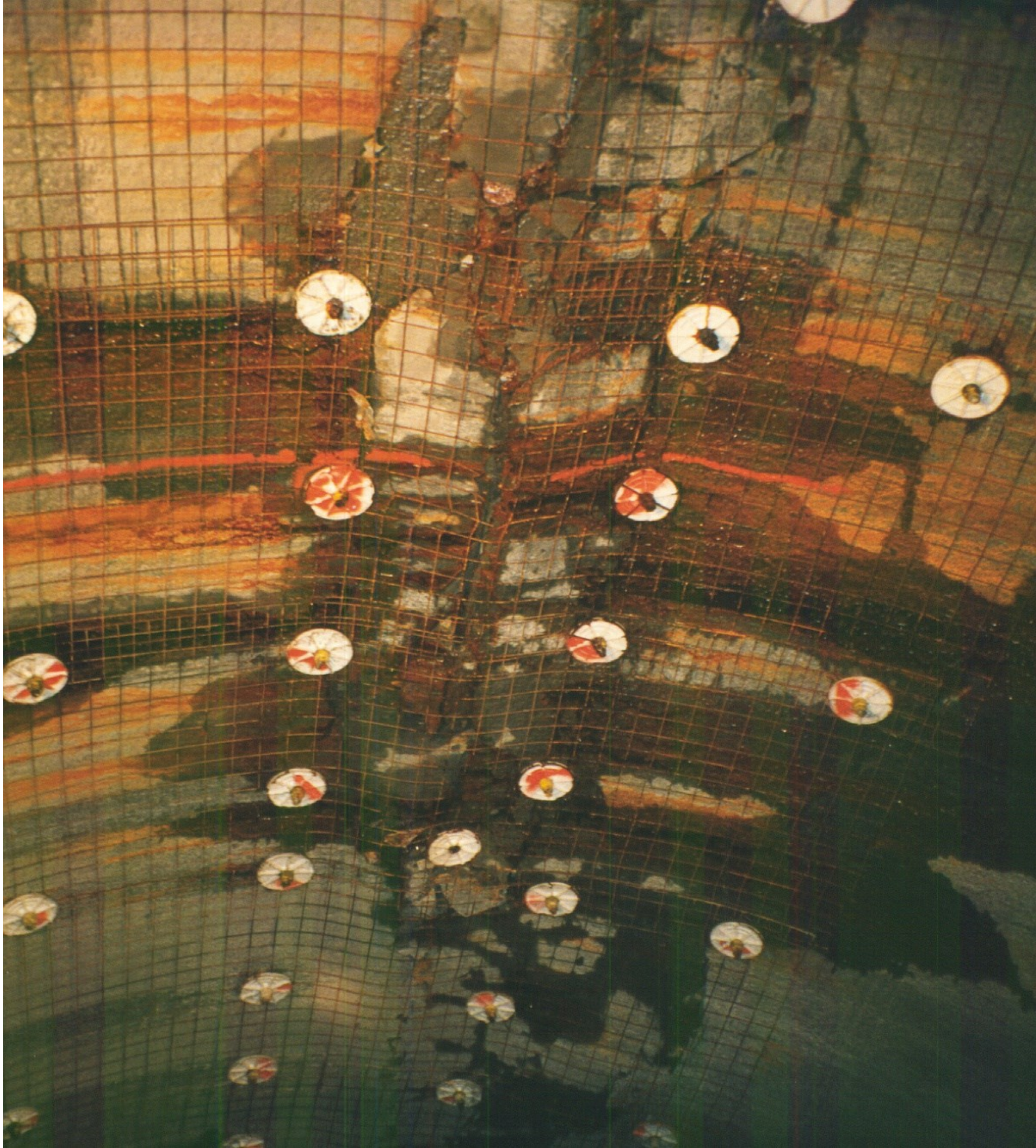
Interpolation Between Boreholes



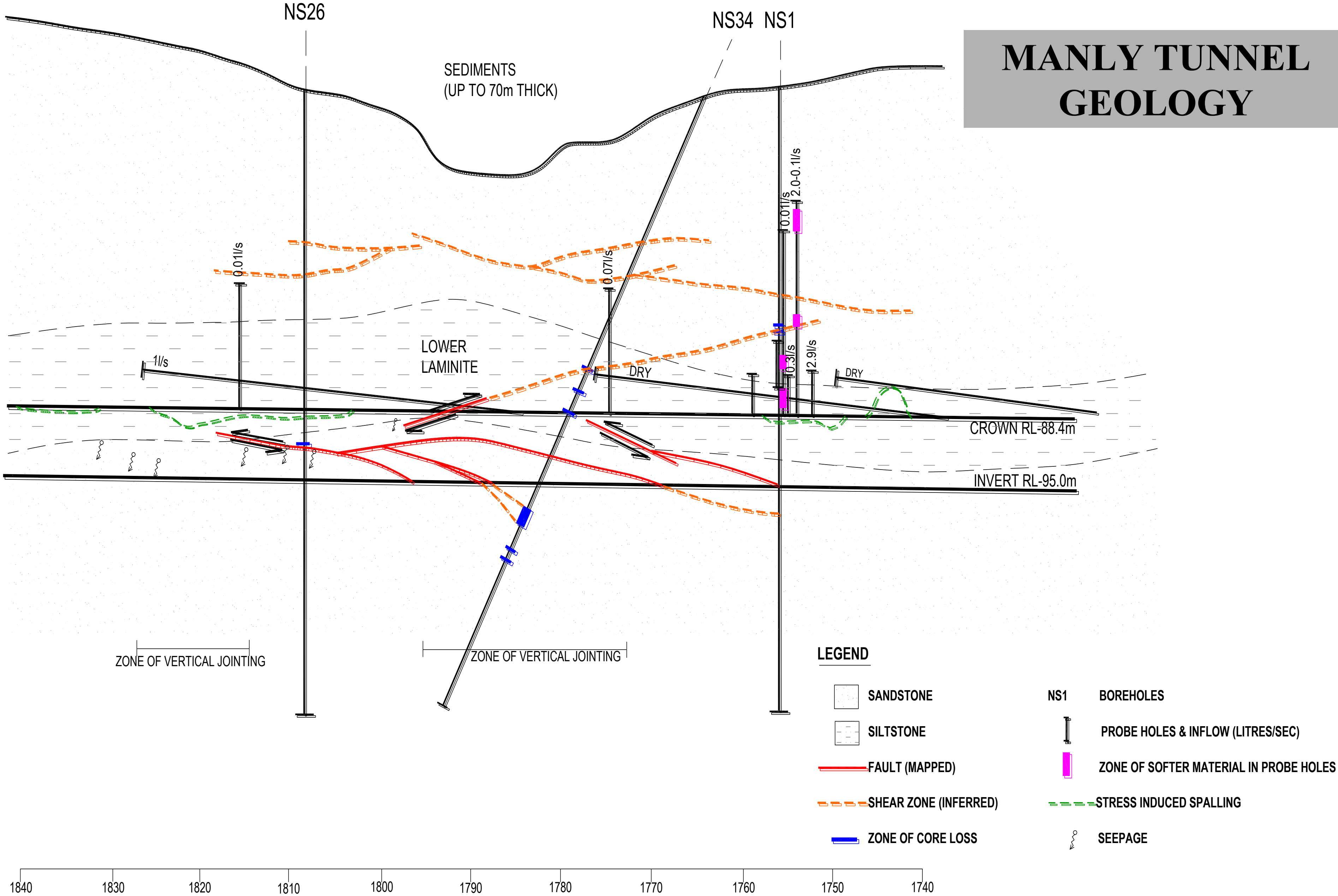
Manly crosshole seismic image



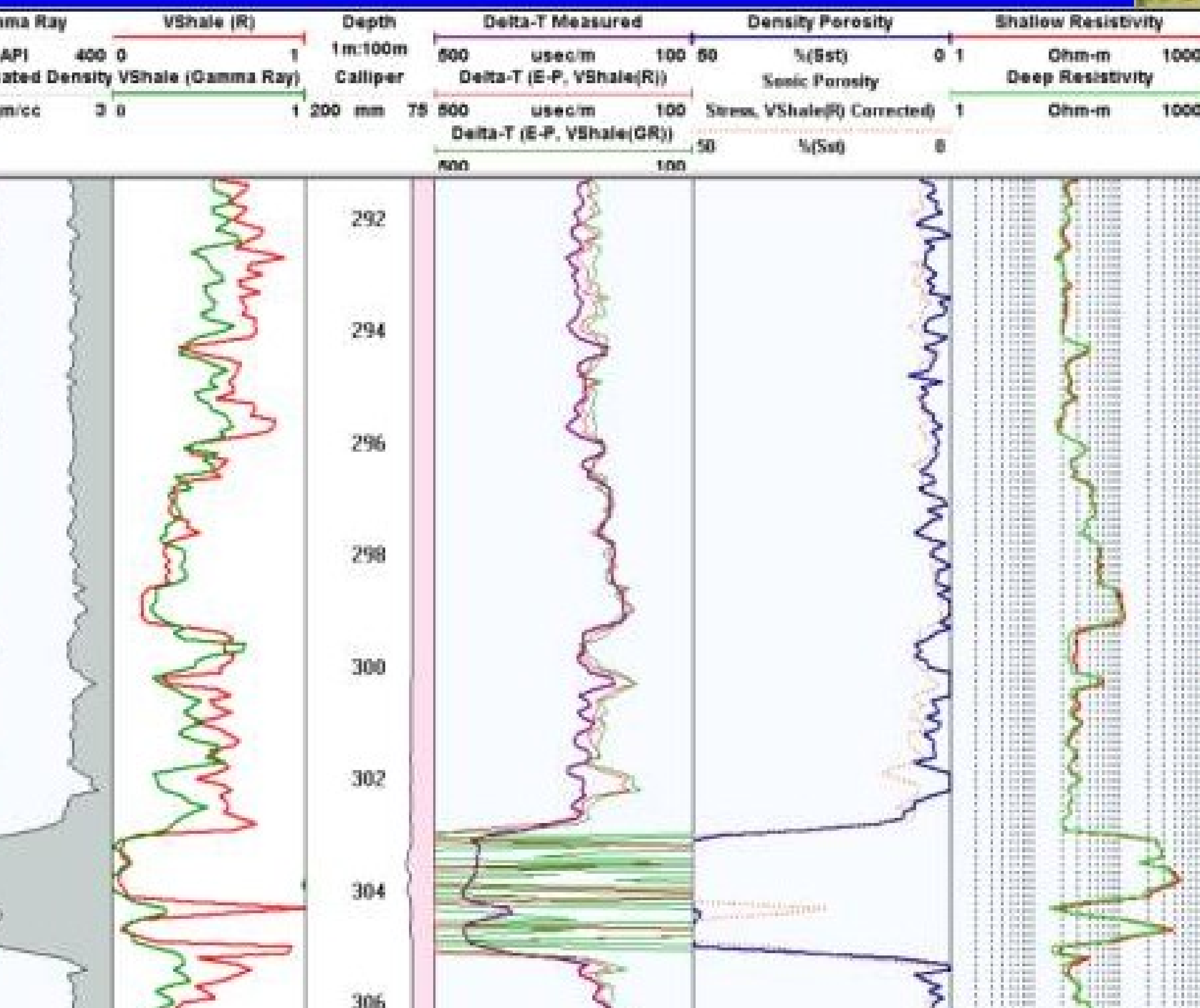
ROOF CONDITIONS BENEATH MANLY PALAEOCHANNE L

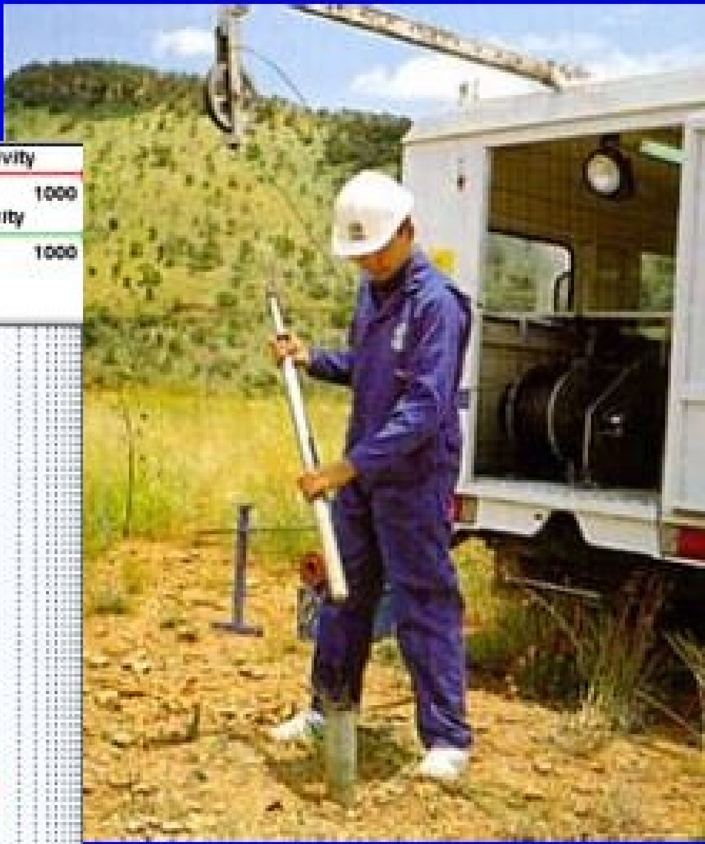


MANLY TUNNEL GEOLOGY



Geophysical or Wireline Logging





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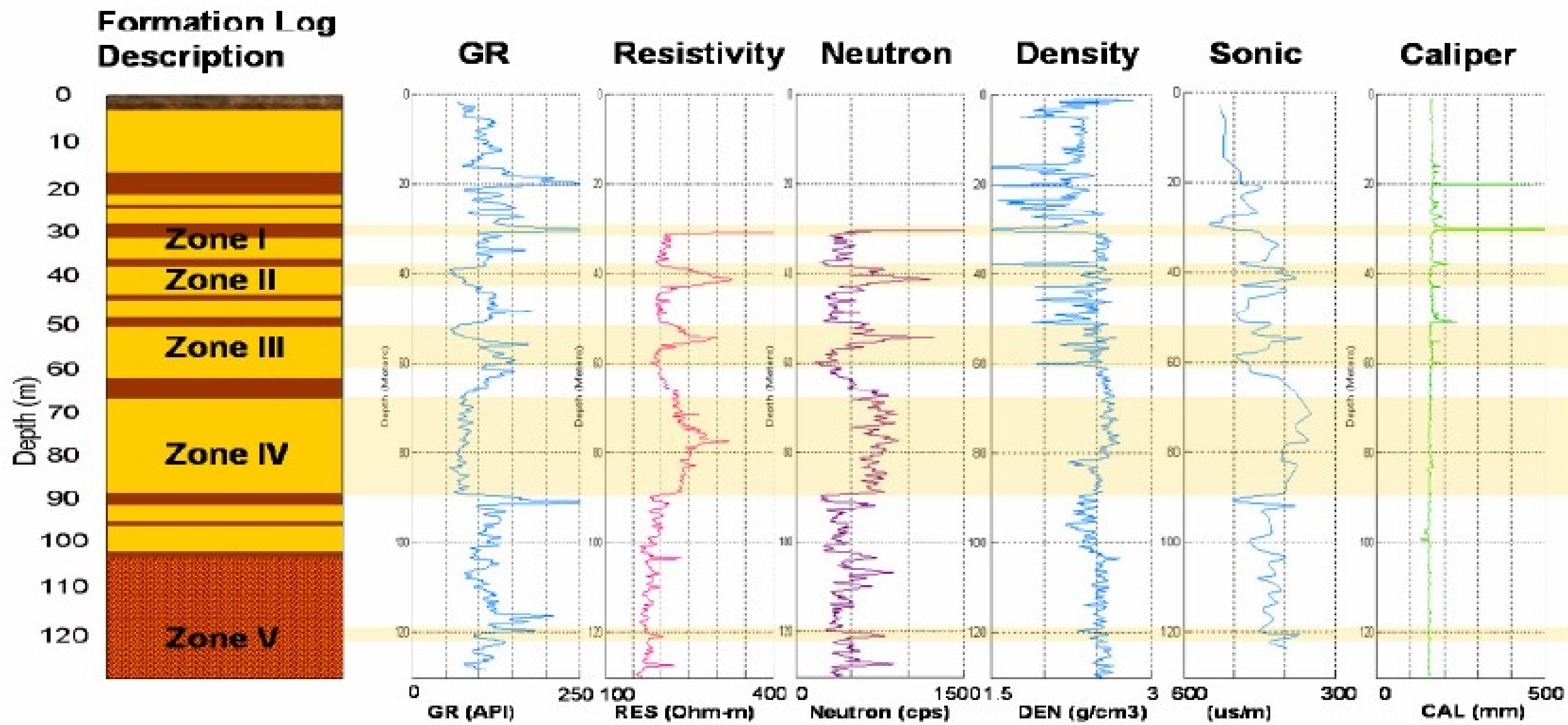
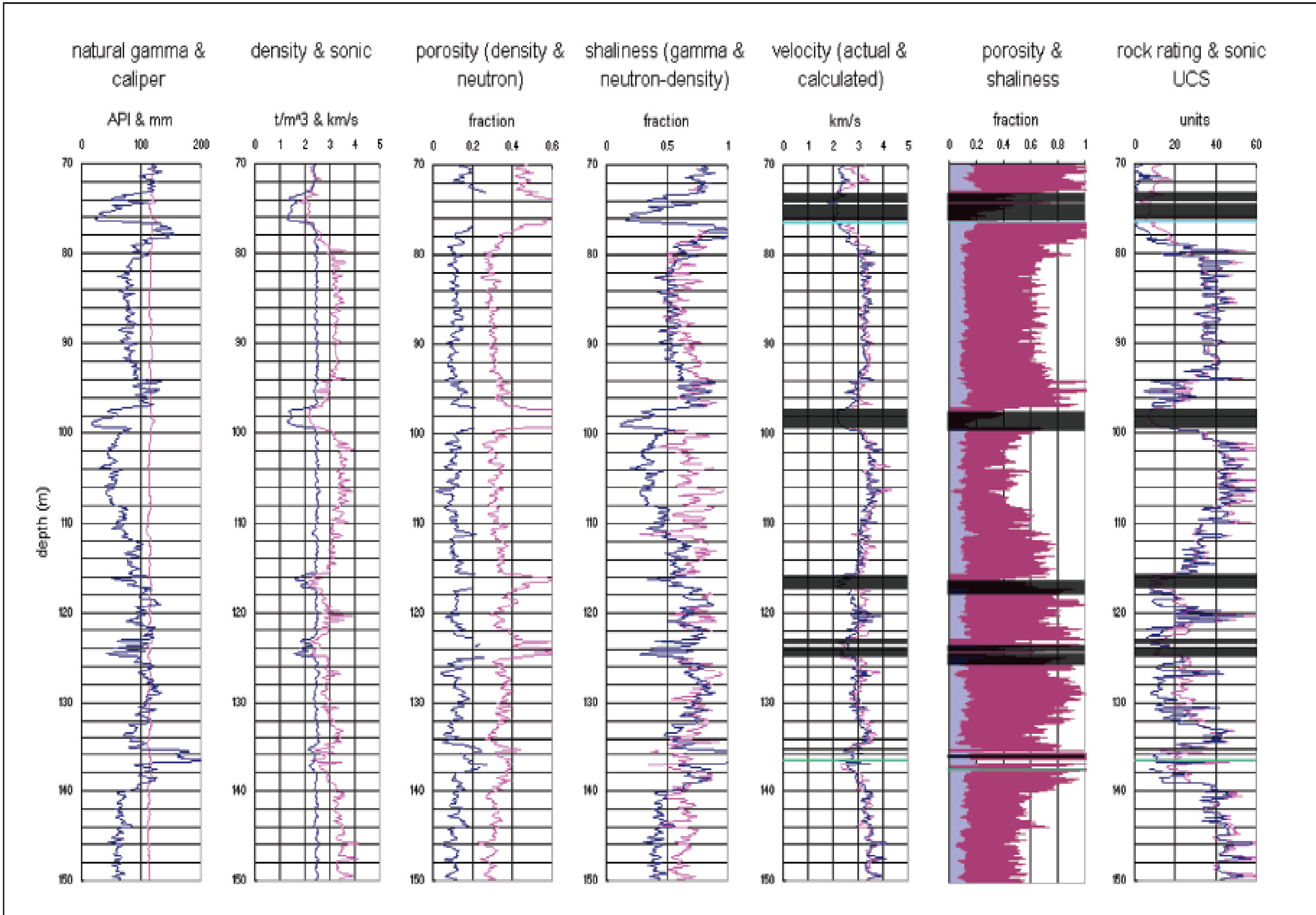
Stratigraphic correlation and formation parameter determination – different geophysical logs in the same borehole

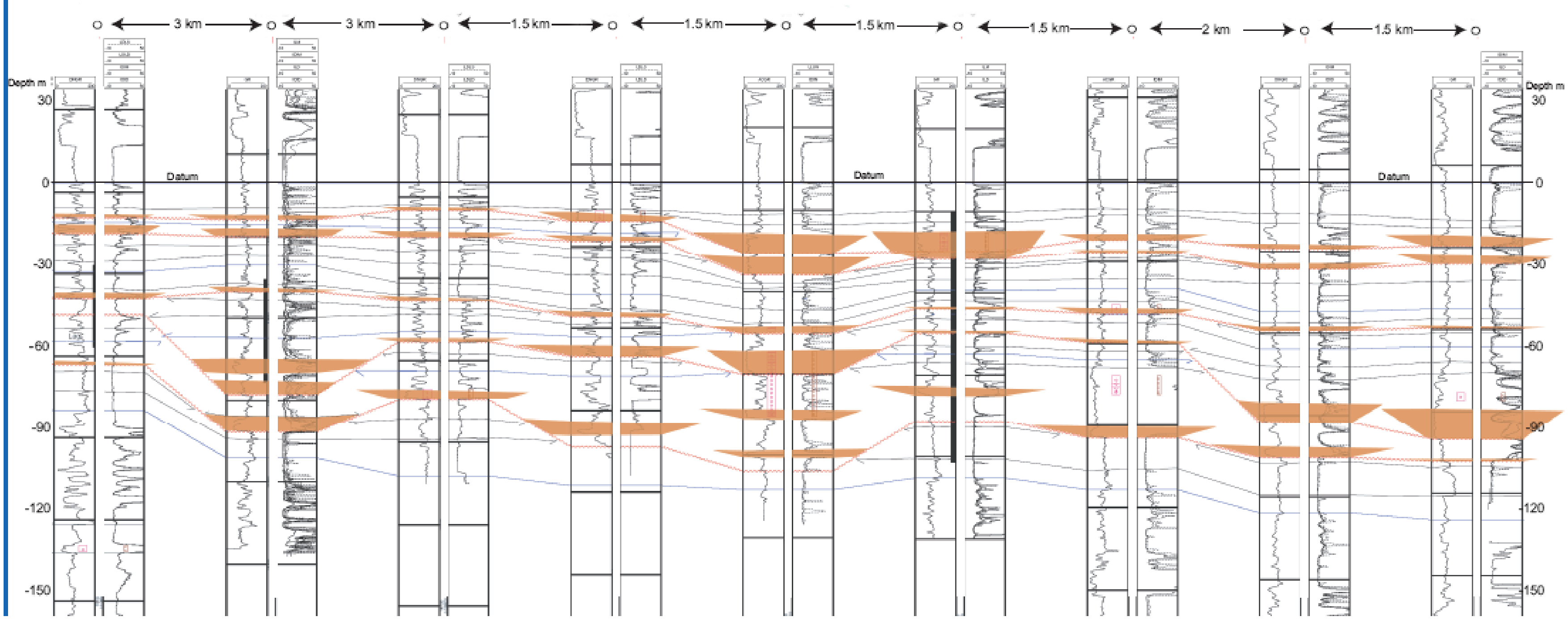


Porous Zones	ϕ	Sw
I	0.58	0.12
II	0.42	0.56
III	0.5	0.44
IV	0.34	0.72
V	0.36	0.79

Quantitative Geophysical Log Analysis – Formation parameter determination



Stratigraphic correlation – the same geophysical logs in different boreholes



Incised valley fill/ fluvial channel

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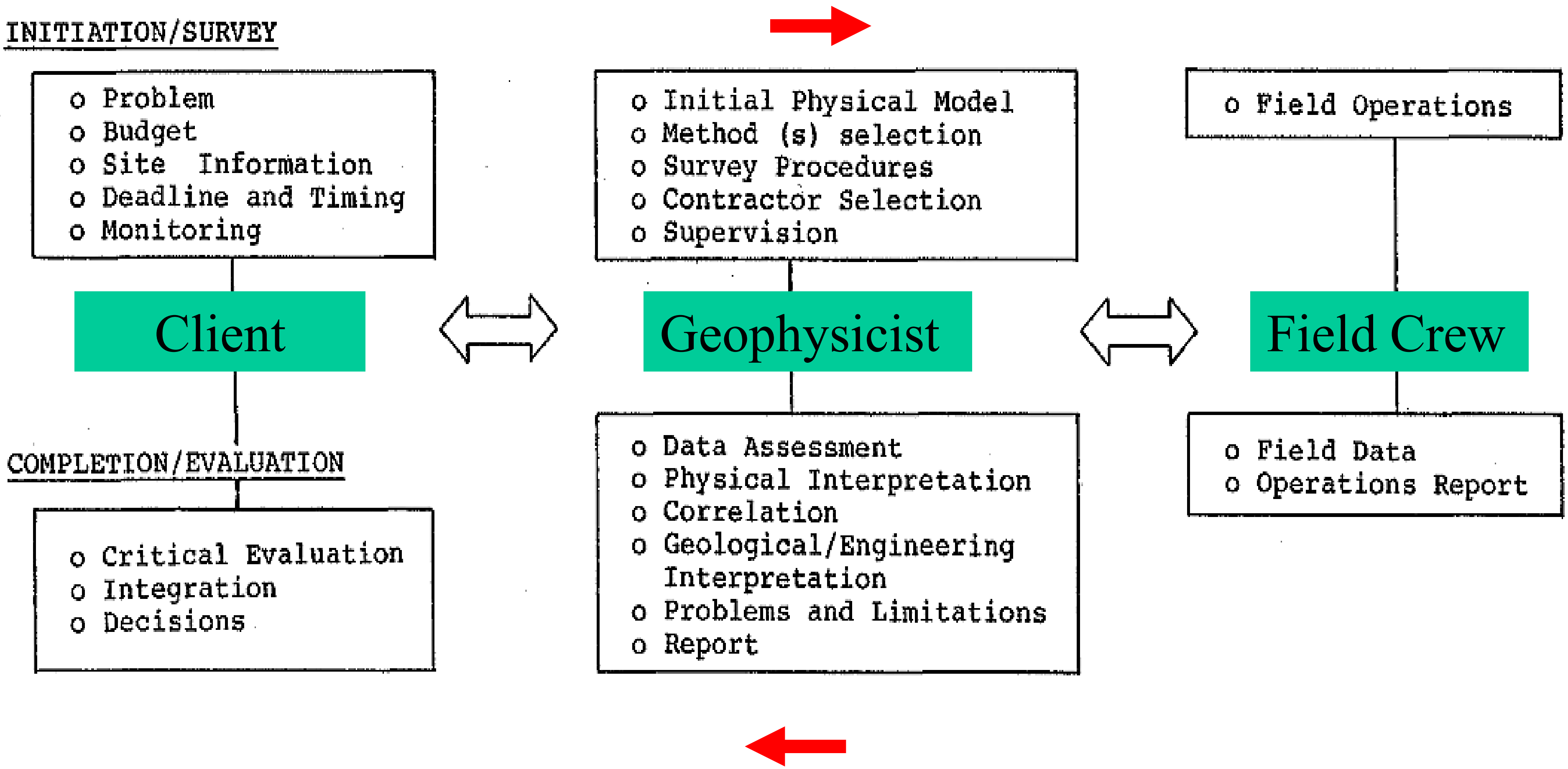
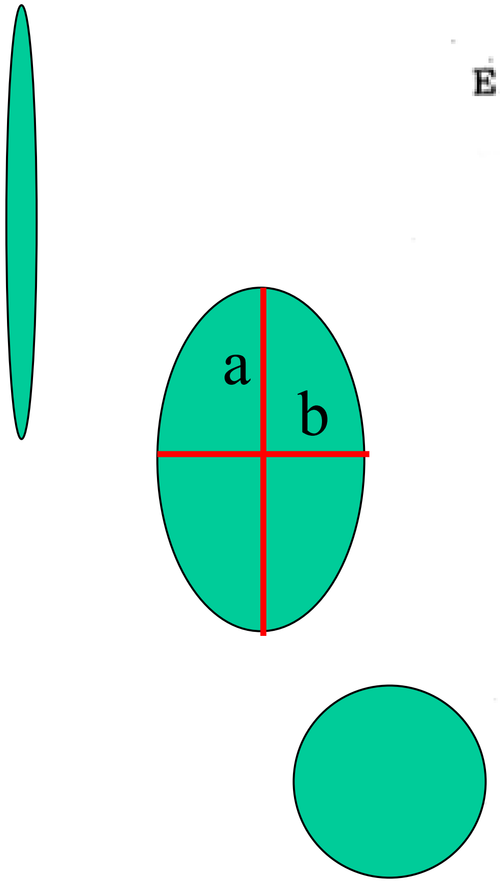
Designing Geophysical Survey/ Testing Programs

Functions and Operations Flowchart for Geophysical Surveys



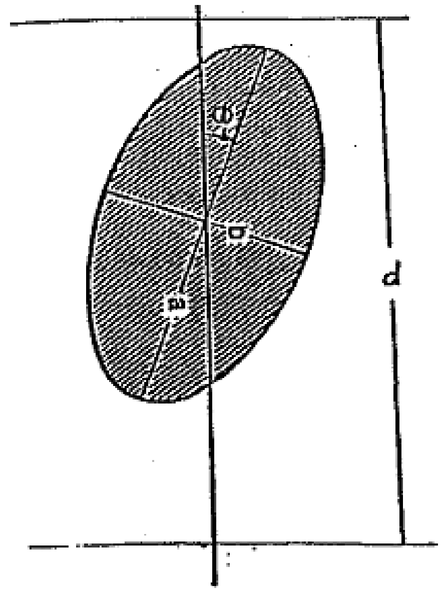
Various Elliptical Targets



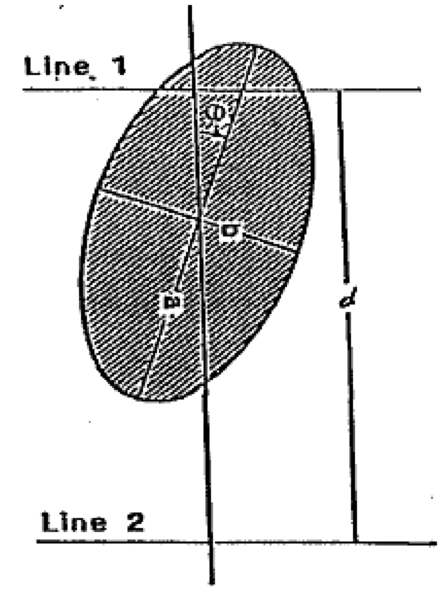
Ellipticity	Description	Common Targets
0.1-0.2	Elongate or two-dimensional	Contact, fault, shear, dyke, channel, buried-pipe, tunnel.
0.3-0.5	Lenticular	Alluvial deposits, caverns, landfill, old mine workings.
0.6-1.0	Equidimensional	Engineering site, water table, sedimentary layers, weathering and bedrock surface, intrusive stock.

Ellipticity = b/a

Geophysical profiling of elliptical targets with parallel survey lines

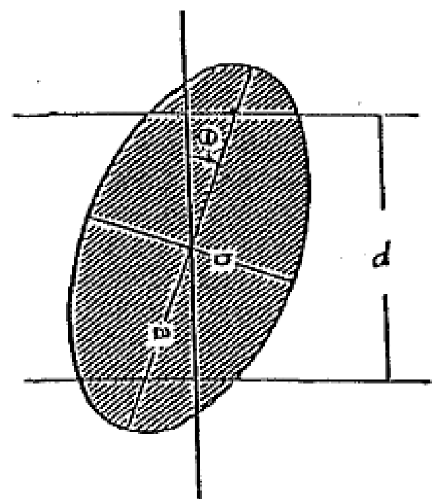


Missed

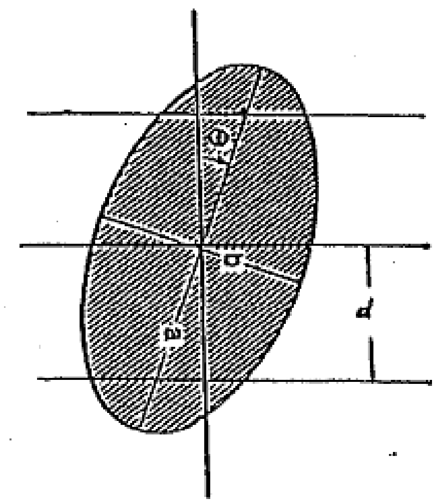


Detected

d/a = relative line spacing



Confirmed



Delineated

Assessing Search Efficiency

C = cost index

$$C = N/P$$

where, N = number of line-km of geophysical data gathered per sq. km of area covered.
P = probability of detection (0 impossible, 1 certain).

However,

$$N \propto \frac{1}{\frac{d}{a}}$$

where d/a = relative line spacing.

A cost factor (K) may be further defined as,

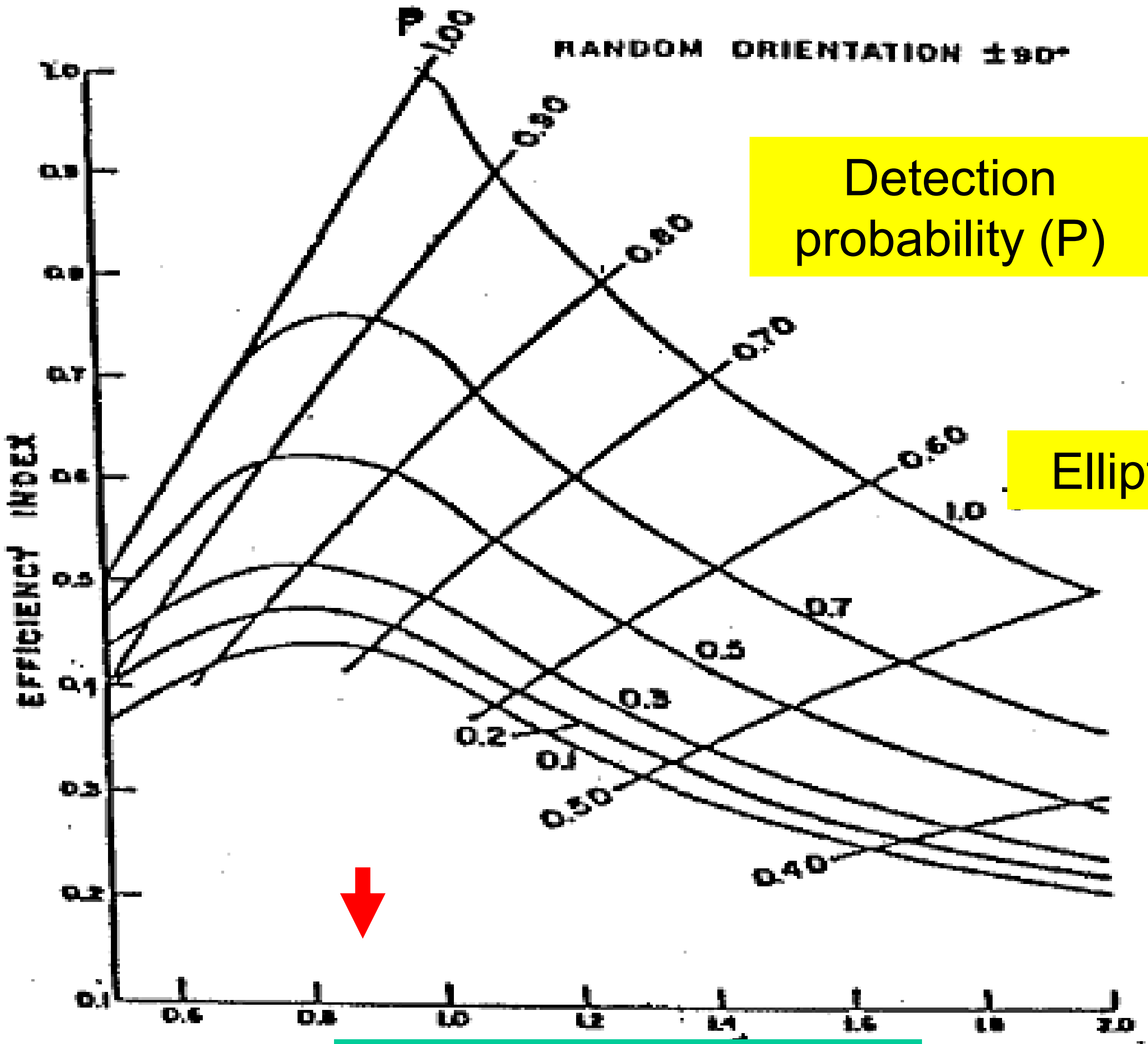
$$K = \frac{a}{pd}$$

and from this a search efficiency index may be defined,

$$E = \frac{\text{Detection probability}}{\text{Cost Factor}}$$

$$= p^2 \, d/a$$

Search efficiencies for **detection** of a buried elliptical target of unknown orientation with geophysical profiling



Detection probability (P)

Ellipticity (b/a)

Search Efficiency (E)

Relative Line Spacing (d/a)