# *Shallow Seismic Refraction Methods for excavation assessment*

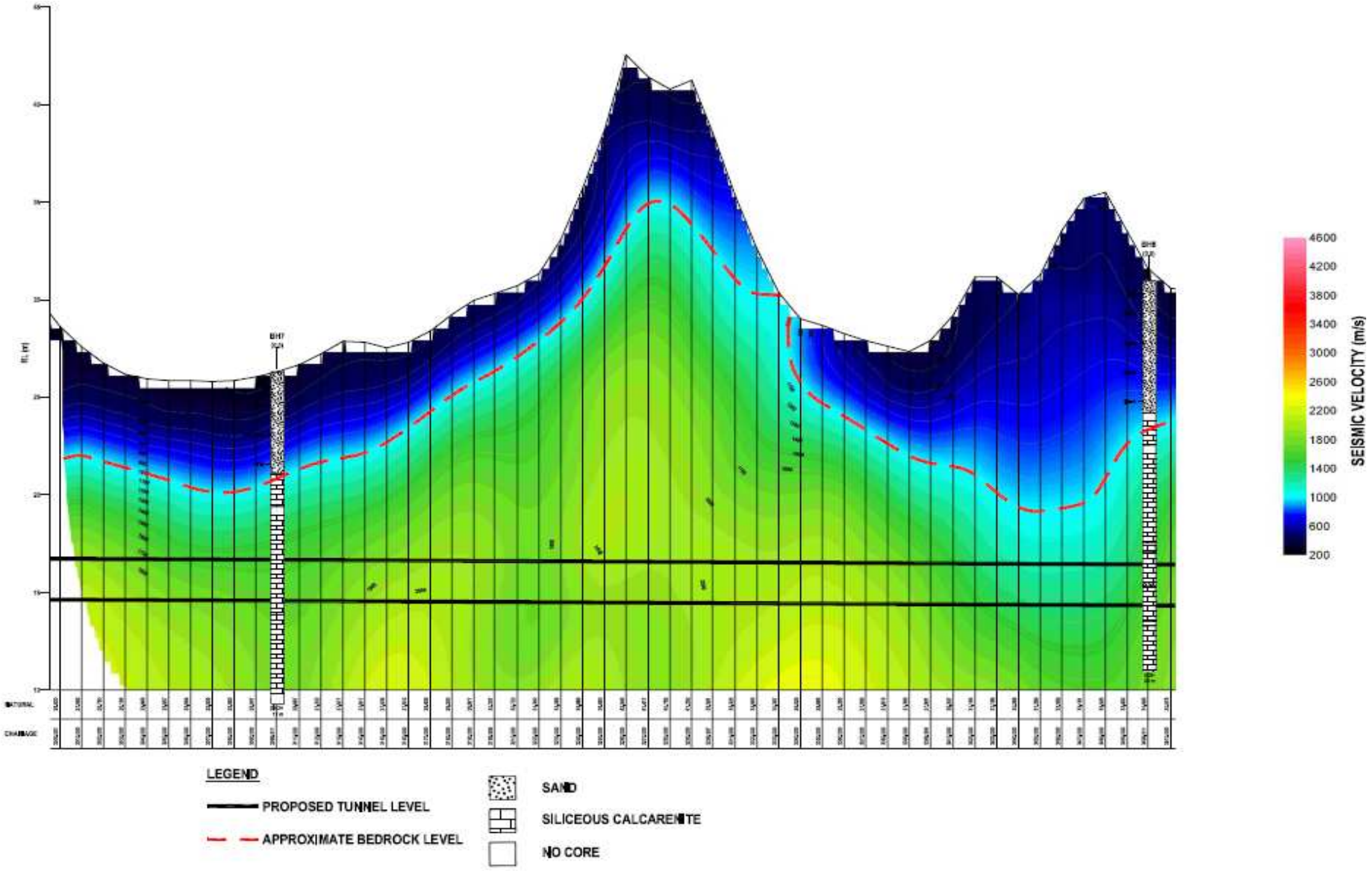


Table I. COMPRESSIONAL SEISMIC WAVE VELOCITIES (m/s)

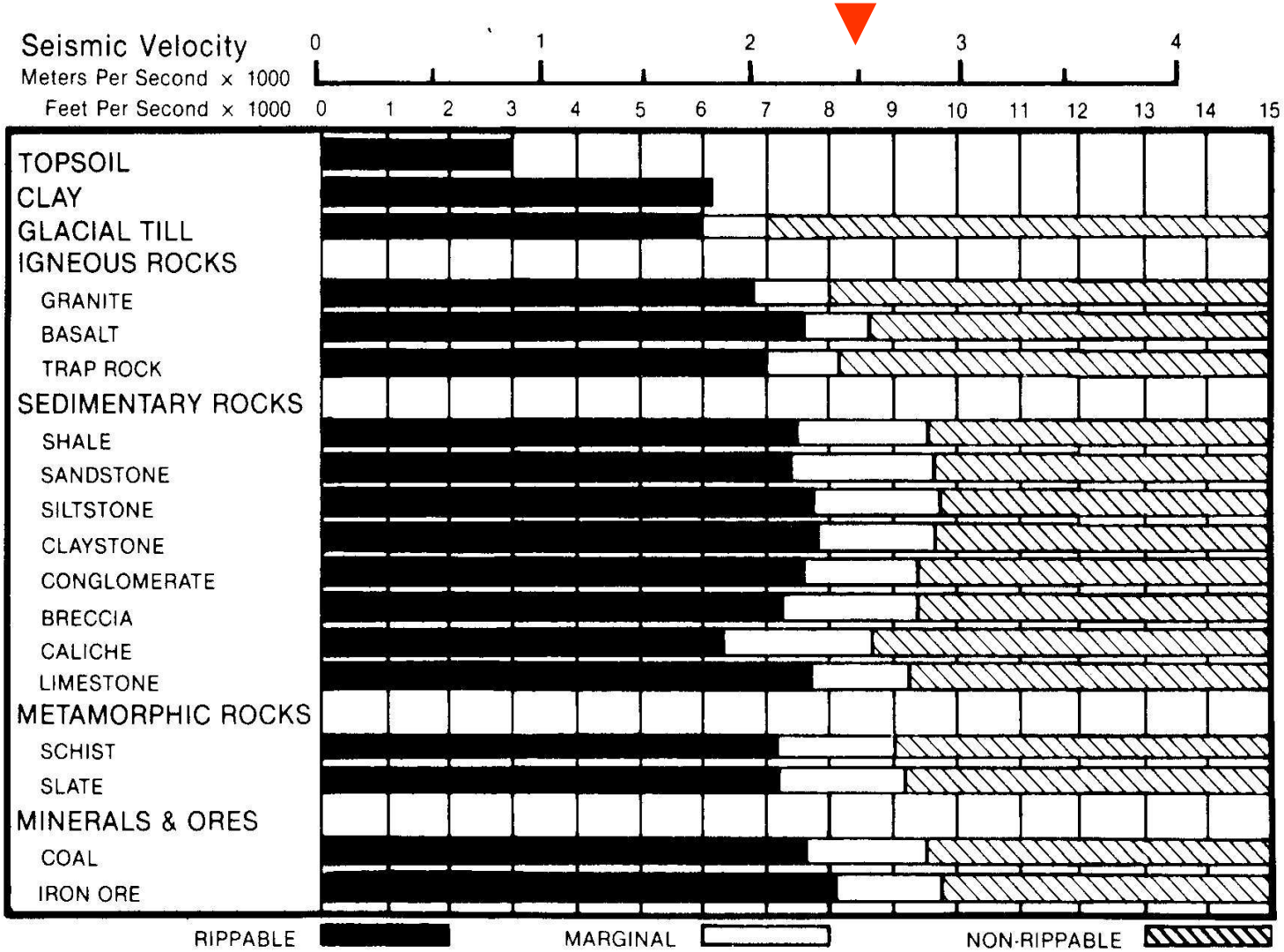
| VELOCITY | ROCK DESCRIPTION |
|---|---|
| 200 – 400 | Soil, unconsolidated surface deposits |
| 400 – 1400 | Unconsolidated clays, silts, unsaturated sands, gravels. |
| 1400 – 1800 | Saturated sands and gravels; compact clays and silts; completely weathered rocks. |
| 1800 – 2400 | Consolidated sediments, 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. |

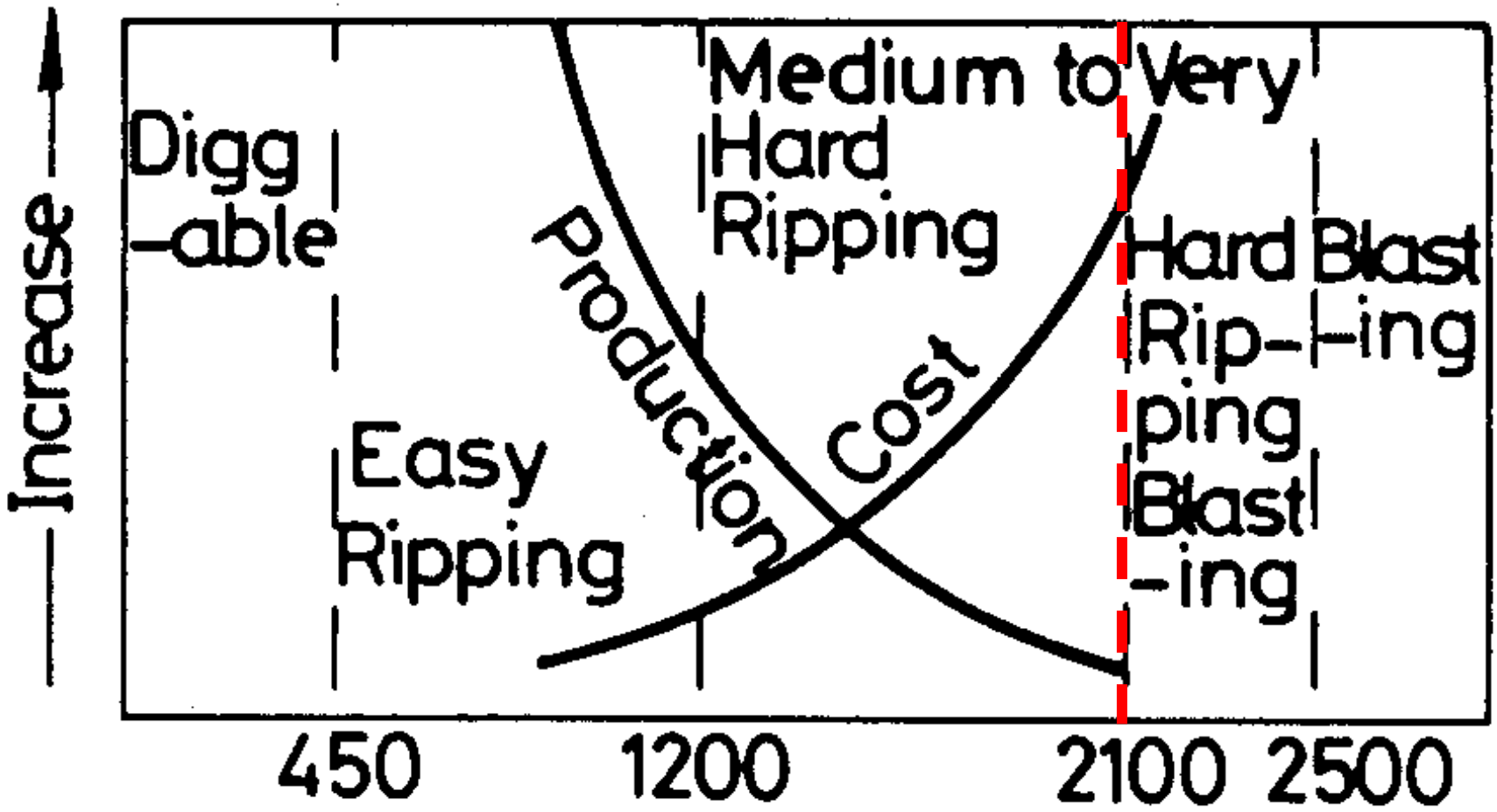
| | | |
|---|---|---|
| Vp air | ~ | 340 m/s |
| Vp water | ~ | 1370 m/s |
| Vp ice | ~ | 3200 m/s |
| Vp concrete | ~ | 3100 m/s – 4600 m/s |
| Vp steel | ~ | 5200 m/s |

# Caterpillar Rippability Charts

**D9N Ripper Performance**

- Multi or Single Shank Ripper
- Estimated by Seismic Wave Velocities




Rippability & Productivity

# Productivity Charts

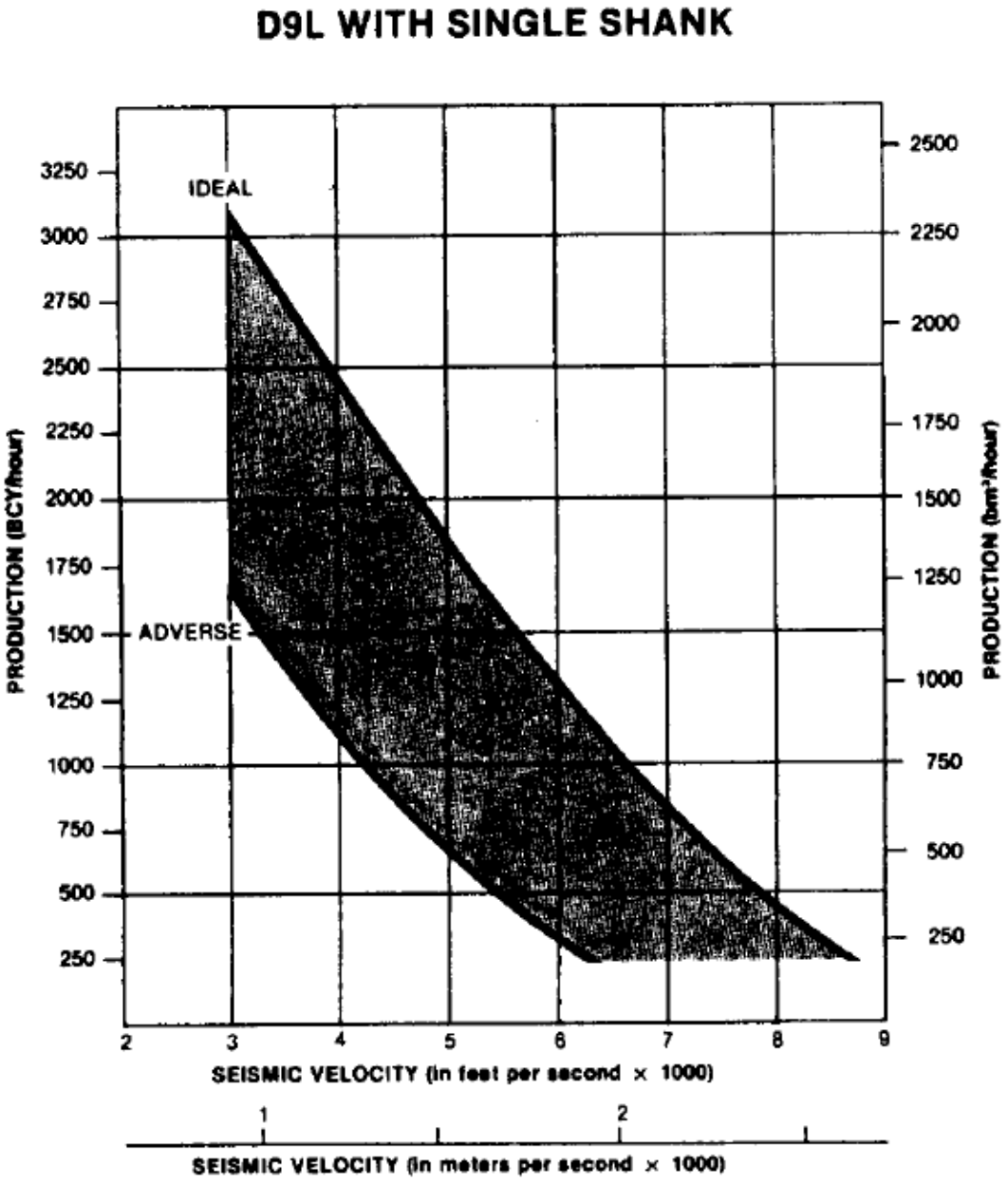



**FIGURE 2**
**Caterpillar chart for estimating ripper production for D9L Bulldozer (from Caterpillar 1986)**

# Weaver's Rippability Chart

*Fig.1 Rippability Rating Chart*

| Rock class | I | II | III | IV | V |
|---|---|---|---|---|---|
| **Description** | Very good rock | Good rock | Fair rock | Poor rock | Very poor rock |
| **Seismic velocity (m/s)** | >2150 | 2150-1850 | 1850-1500 | 1500-1200 | 1200-450 |
| **Rating** | 26 | 24 | 20 | 12 | 5 |
| **Rock hardness** | Extremely hard rock | Very hard rock | Hard rock | Soft rock | Very soft rock |
| **Rating** | 10 | 5 | 2 | 1 | 0 |
| **Rock weathering** | Unweathered | Slightly weathered | Weathered | Highly weathered | Completely weathered |
| **Rating** | 9 | 7 | 5 | 3 | 1 |
| **Joint spacing (mm)** | >3000 | 3000-1000 | 1000-300 | 300-50 | <50 |
| **Rating** | 30 | 25 | 20 | 10 | 5 |
| **Joint continuity** | Non continuous | Slightly continuous | Continuous-no gouge | Continuous-some gouge | Continuous-with gouge |
| **Rating** | 5 | 5 | 3 | 0 | 0 |
| **Joint gouge** | No separation | Slight separation | Separation <1mm | Gouge <5mm | Gouge >5mm |
| **Rating** | 5 | 5 | 4 | 3 | 1 |
| **Strike and dip orientation** | Very unfavourable | Unfavourable | Slightly unfavourable | Favourable | Very favourable |
| **Rating** | 15 | 13 | 10 | 5 | 3 |
| **Total rating** | 100-90 | 90-70* | **70-50** | 50-25 | <25 |
| **Rippability assessment** | Blasting | Extremely hard ripping and blasting | **Very hard ripping** | Hard ripping | Easy ripping |
| **Tractor horsepower** | | 770/385 | **385/270** | 270/180 | 180 |
| **Tractor kilowatts** | | 575/290 | **290/200** | 200/135 | 135 |

# Minty & Kearns – Geological Factors Rating

Job _____

Location _____

Rock Type _____

Structure _____

**ROCK SUBSTANCE FACTORS**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Weathering | Residual Soil -12 | Extremely Weathered -10 | Highly Weathered -7 | Moderately Weathered 0 | Slightly Weathered 5 | Fresh 10 | Silicified 12 |
| Rock Strength | Extremely Weak -12 | Very Weak -10 | Weak -7 | Medium Strong 0 | Strong 5 | Very Strong 10 | Extremely Strong 12 |
| Groundwater Conditions | Wet 0 | Moist 1 | Completely Dry 3 | | | | |

Sub Total _____

**ROCK DEFECT FACTORS**

| | | | | |
|---|---|---|---|---|
| Condition of Discontinuities: Continuity | Continuous 0 | Non Continuous 5 | | |
| Surface Roughness | Polished - Smooth 0 | Rough 1 | Very Rough with Small Steps 2 | |
| Separation (Average width of opening) | Wide > 20 mm 0 | Narrow 2-20 mm 1 | Closed to tight 0-2 mm 2 | Cemented 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Average Spacing of Discontinuities | Very Narrow < 6 mm 0 | Narrow 6-20 mm 5 | Mod. Narrow 20-60 mm 10 | Mod. Wide 60-200 mm 15 | Wide 200-600 mm 20 | Very Wide 600 mm-2 m 25 | Ext. Wide over 2 m 30 |

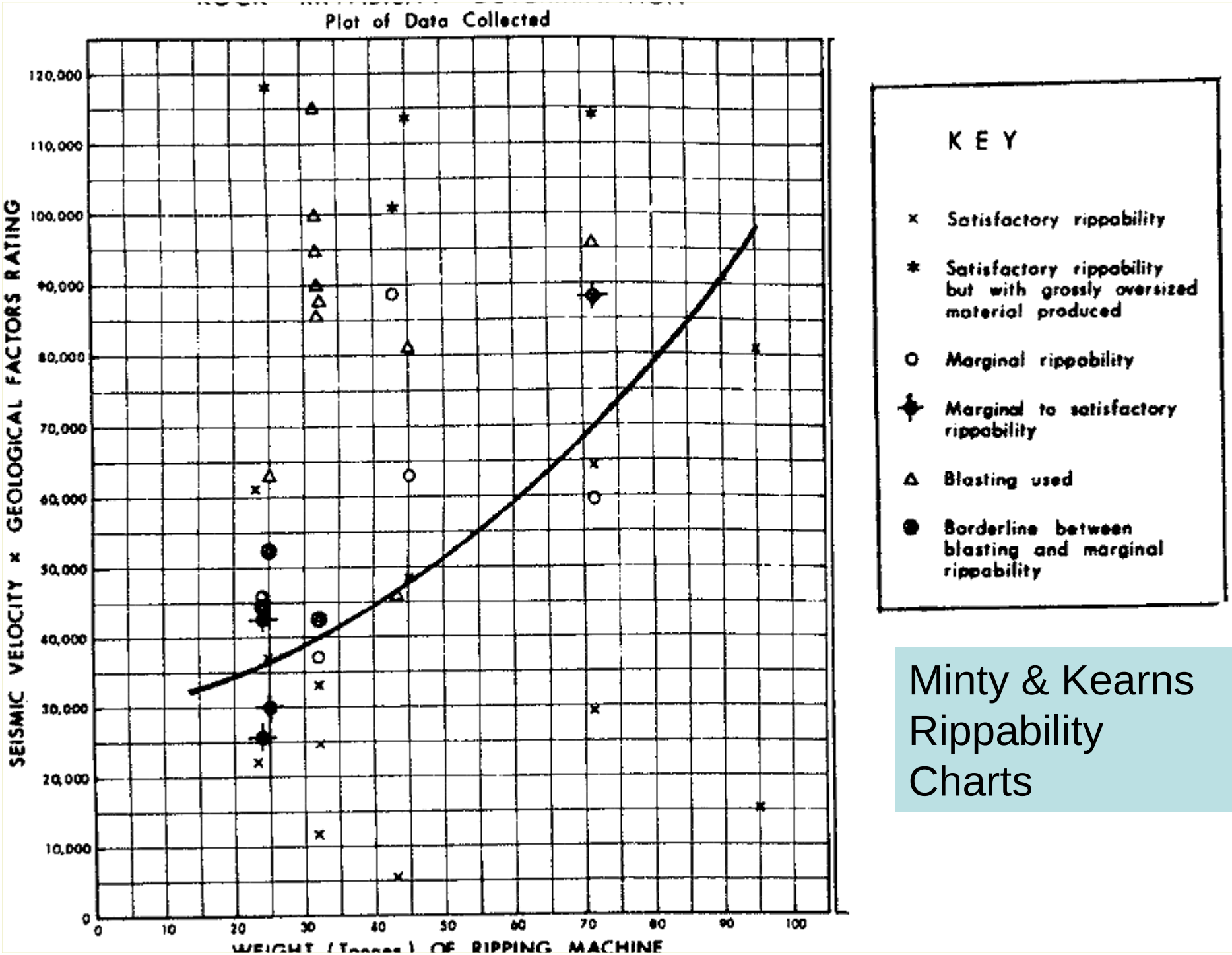
| | | | | | | |
|---|---|---|---|---|---|---|
| Discontinuity Orientation | Dip 0-20° Un-favourable 13 | Strike Perpendicular to Ripping Direction | | | | Strike Parallel to Ripping Direction | |
| | | With Dip | | Against Dip | | | |
| | | Dip 20-45° Favourable 5 | Dip 45-90° Very Favourable 3 | Dip 20-45° Un-favourable 13 | Dip 45-90° Fair-Favourable 6 | Dip 20-45° Fair 10 | Dip 45-90° Very Un-favourable 15 |

Sub Total _____

Total Ratings

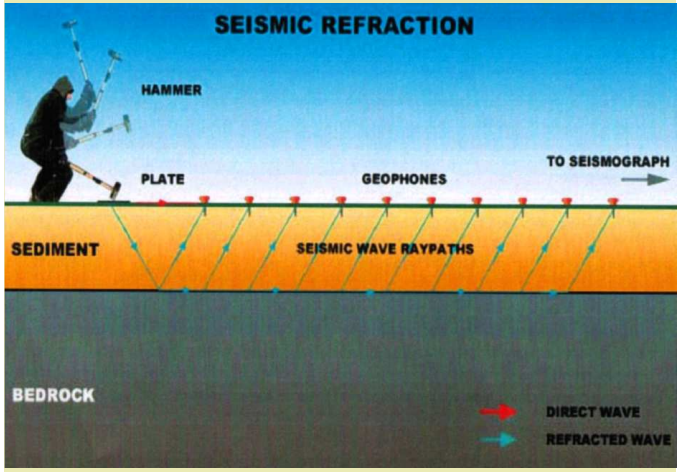
Value _____

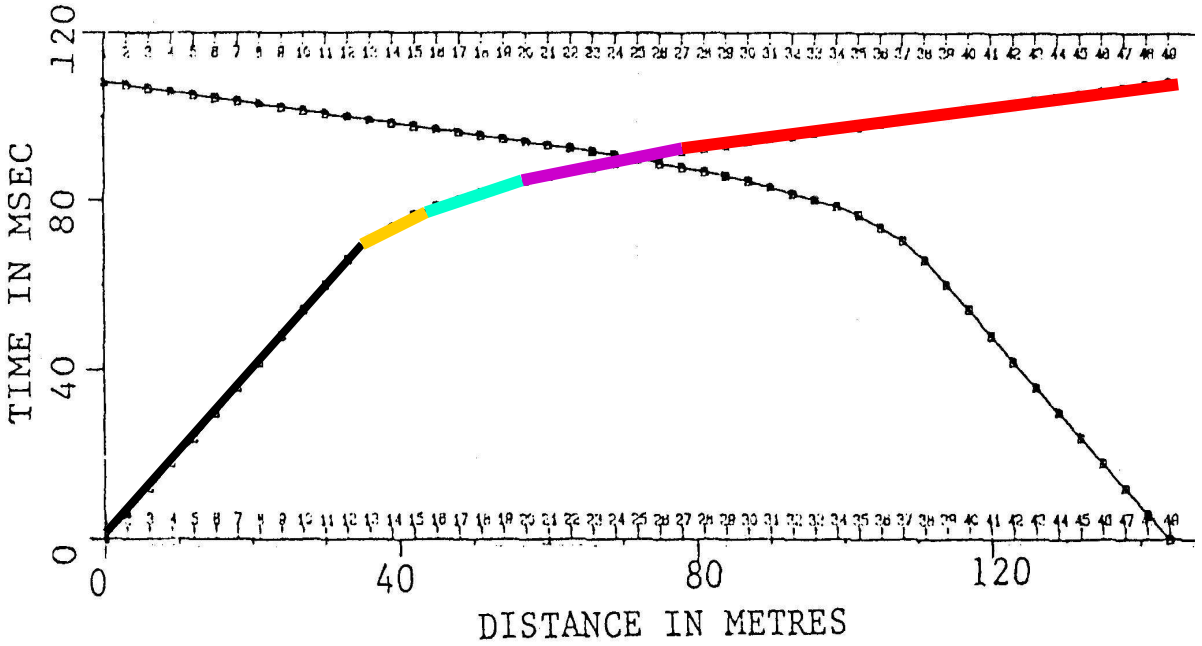
Minty and Kearns Geological Factors Rating Chart (Minty and Kearns, 1983)

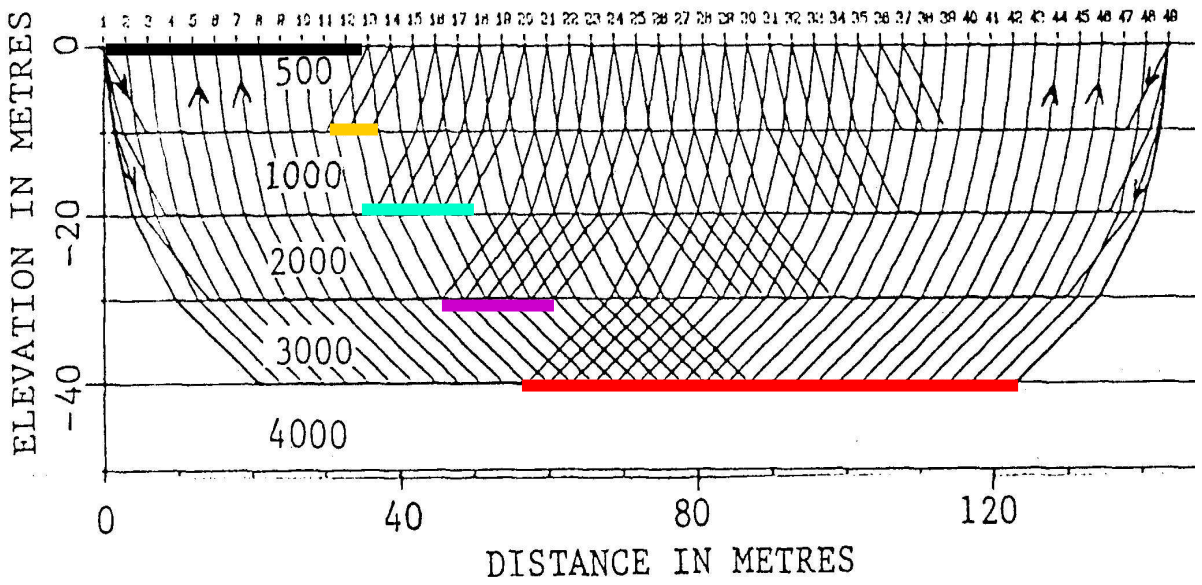



Minty & Kearns Rippability Charts

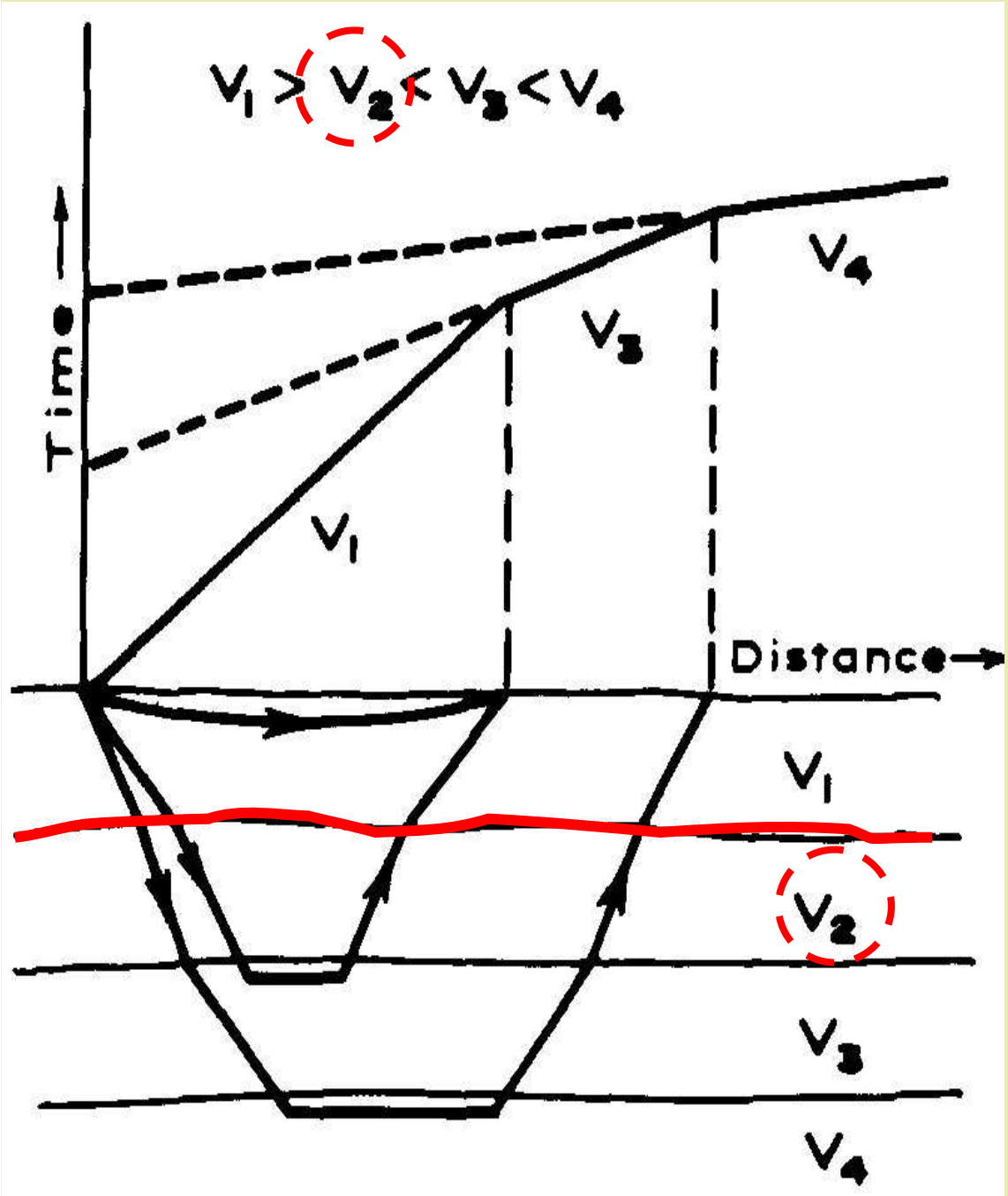
# Segmentation of T-X plots in a layered earth model




# Seismic Raypath Diagram



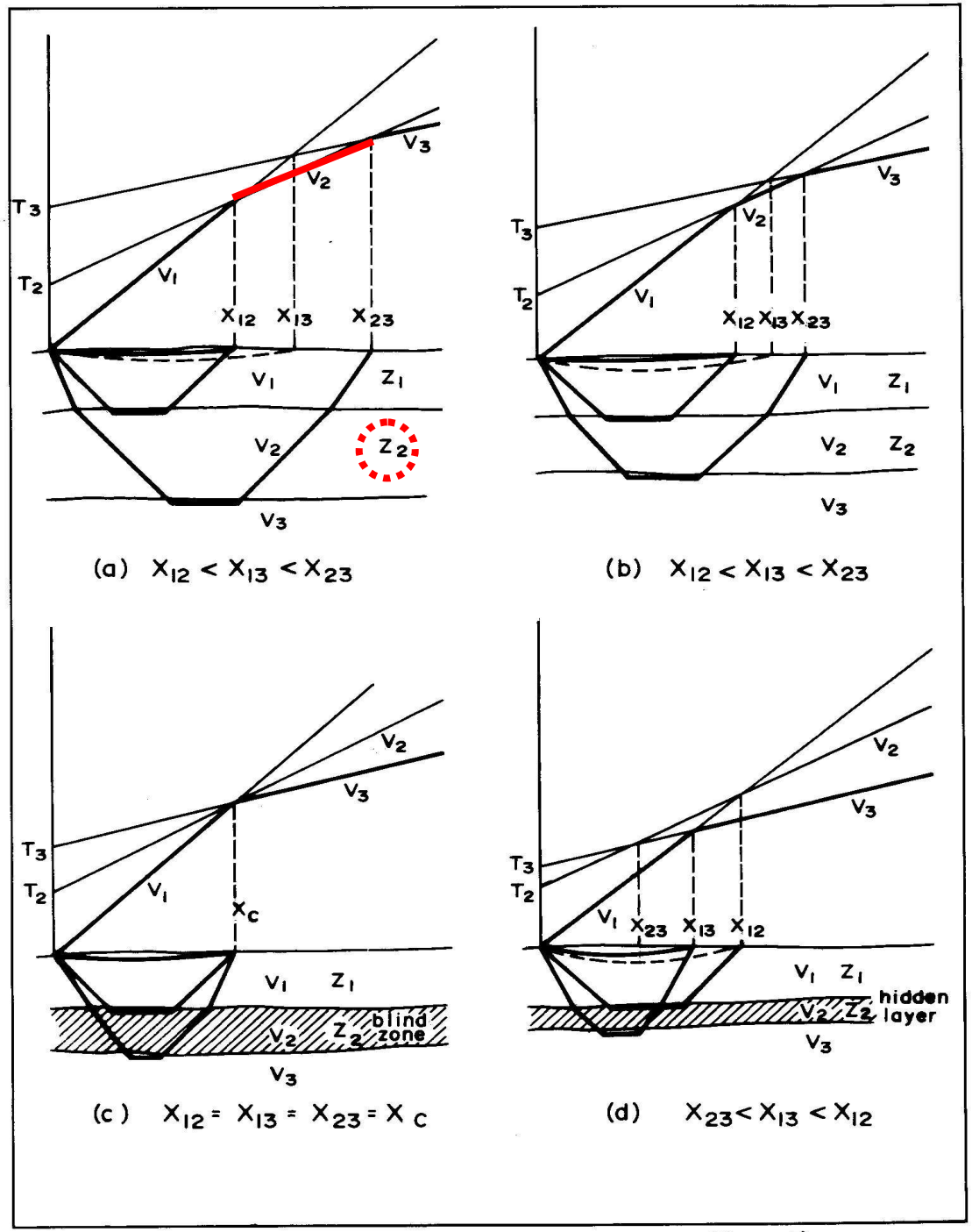

Limitation:

**Inaccurate layer thicknesses**

Example:

**Alluvials beneath basalts**

**VELOCITY REVERSALS**




**Limitation:**

**Resolution of thin layers**

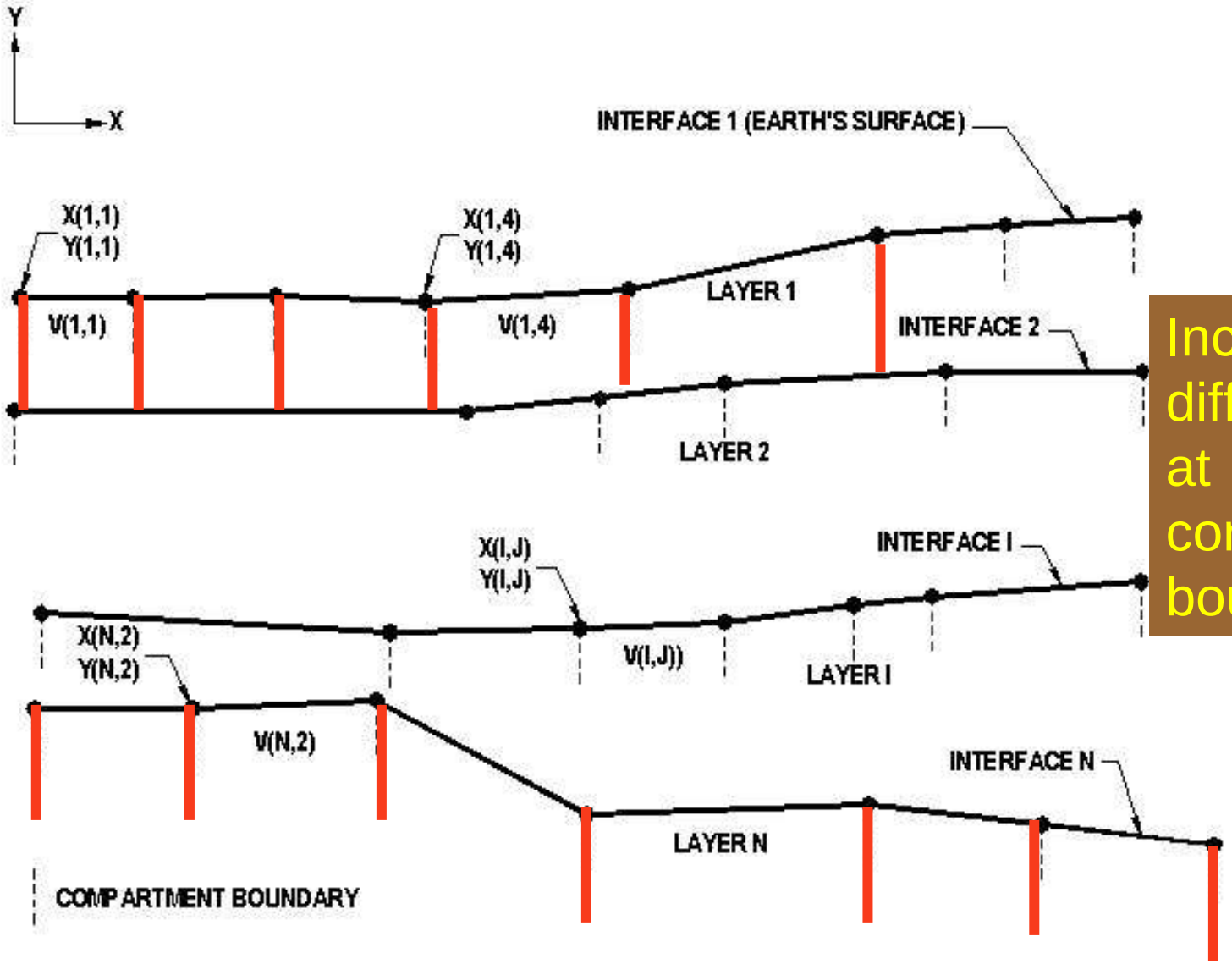
**Example:**

**Basal gravel layers**

**HIDDEN LAYERS**

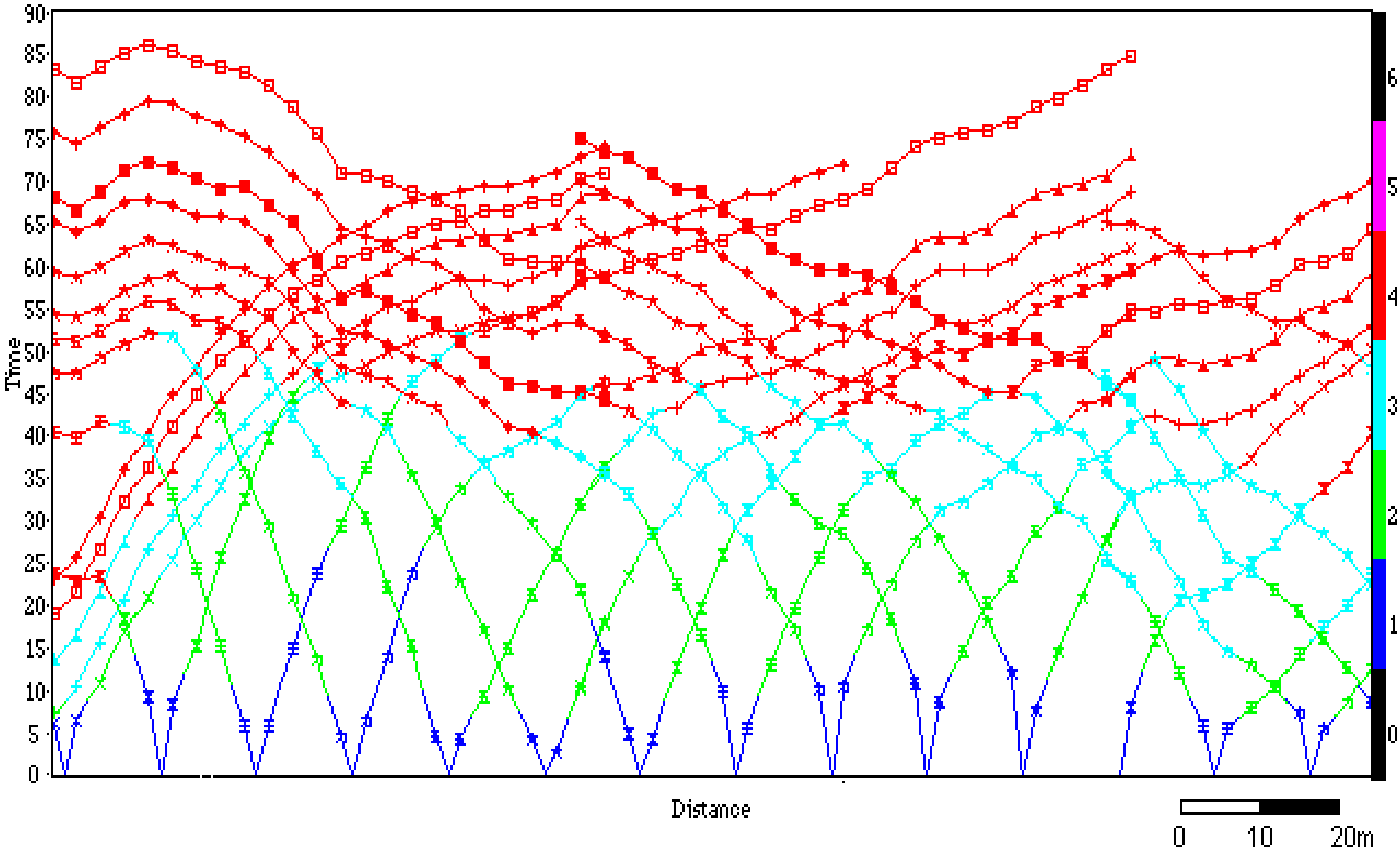
# First arrival ray tracing with a compartmented 2D model

VIRT – Visual Interactive Ray Tracing

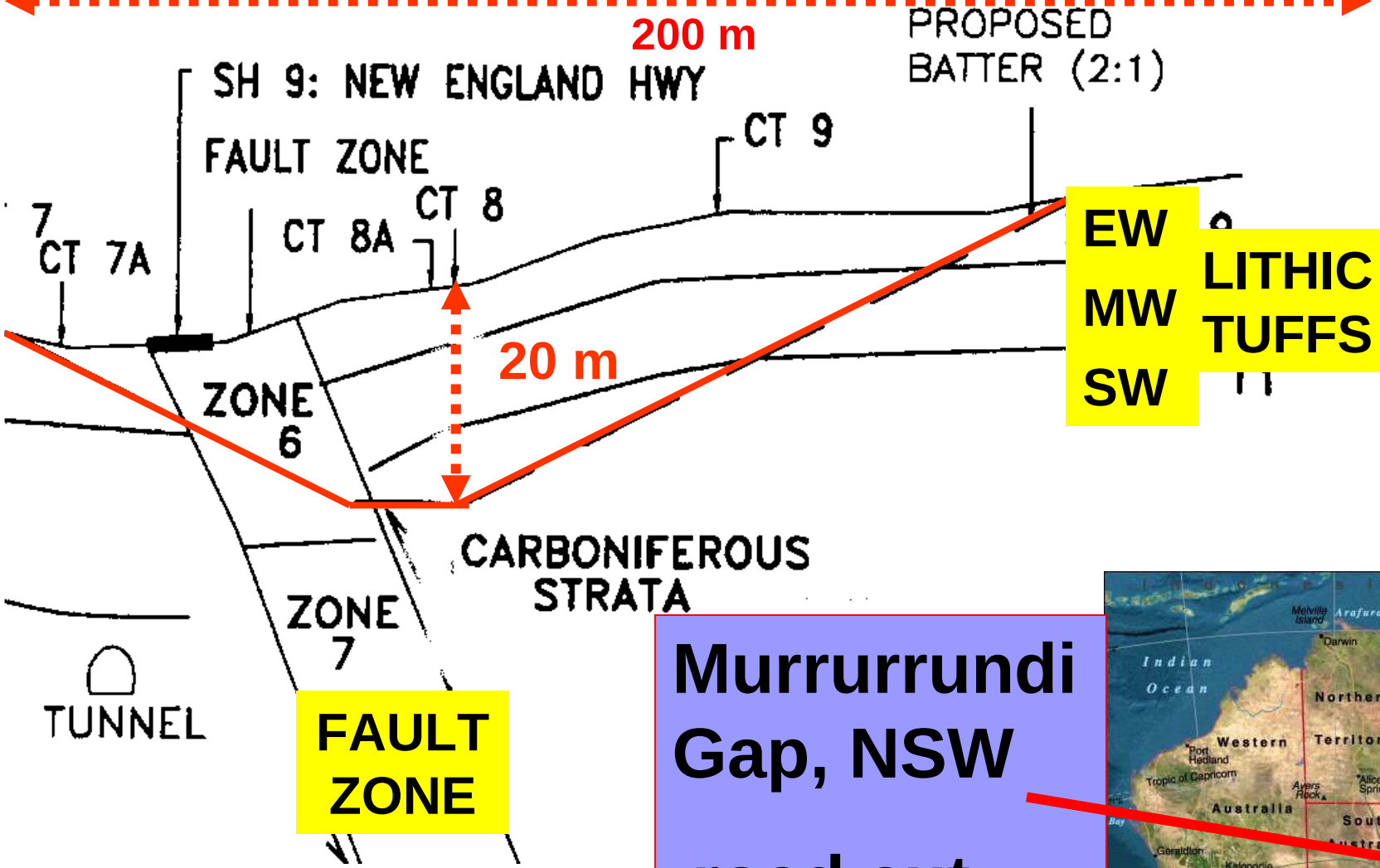



Include diffractions at compartment boundaries

# First arrival T-X plots

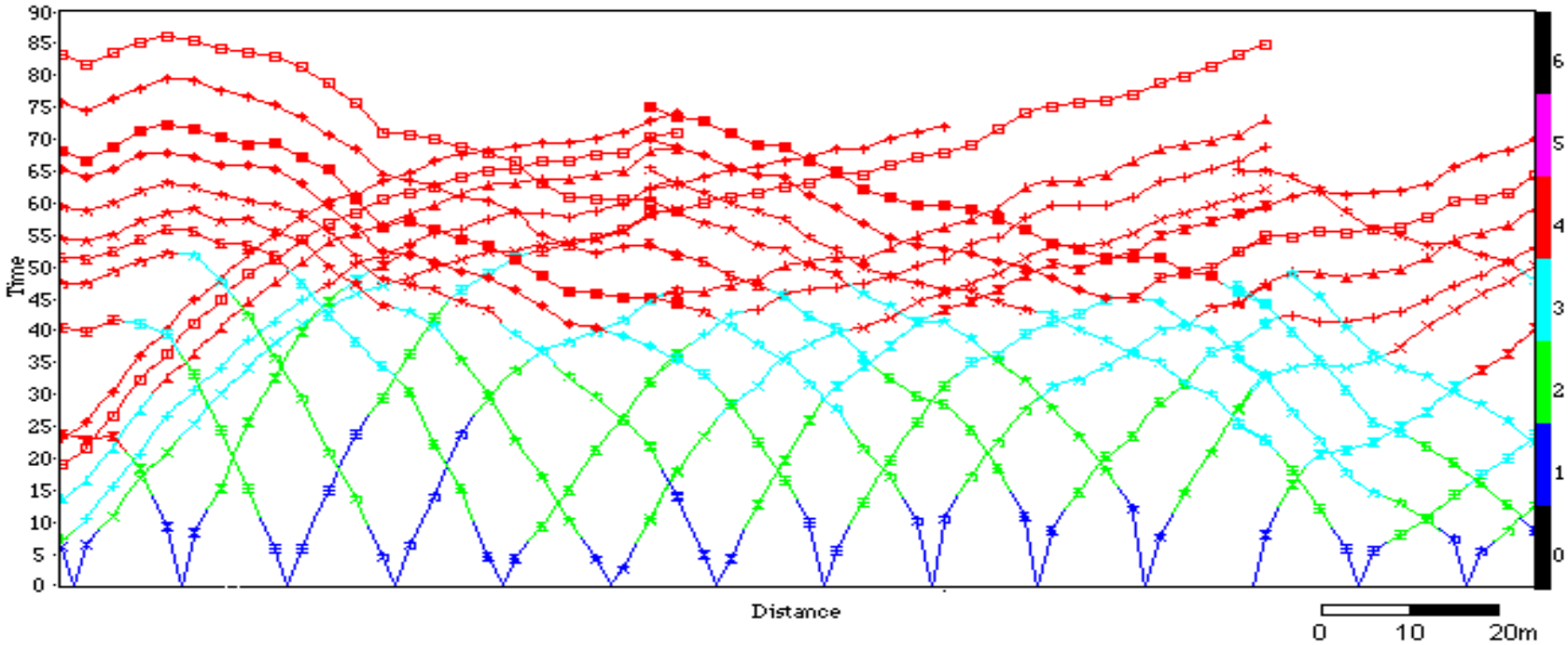


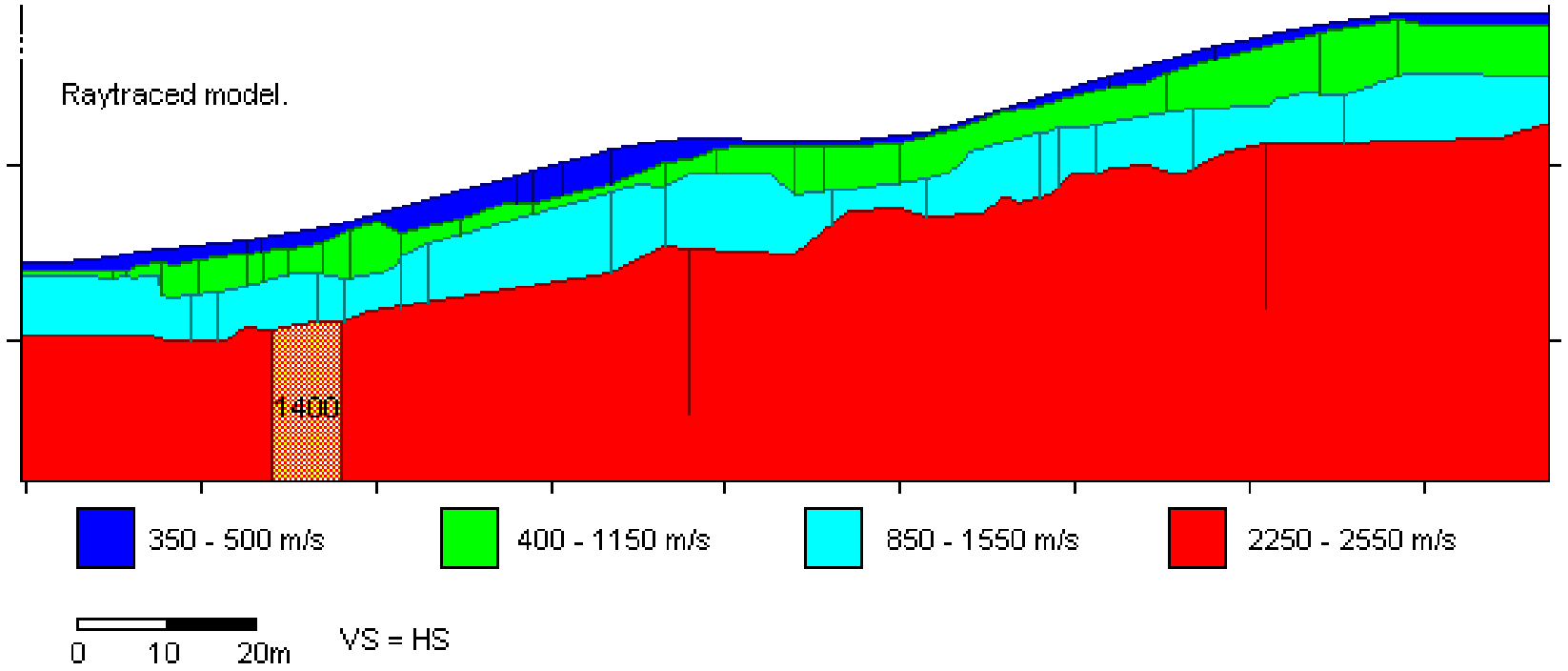
# Seismic Refraction Profile

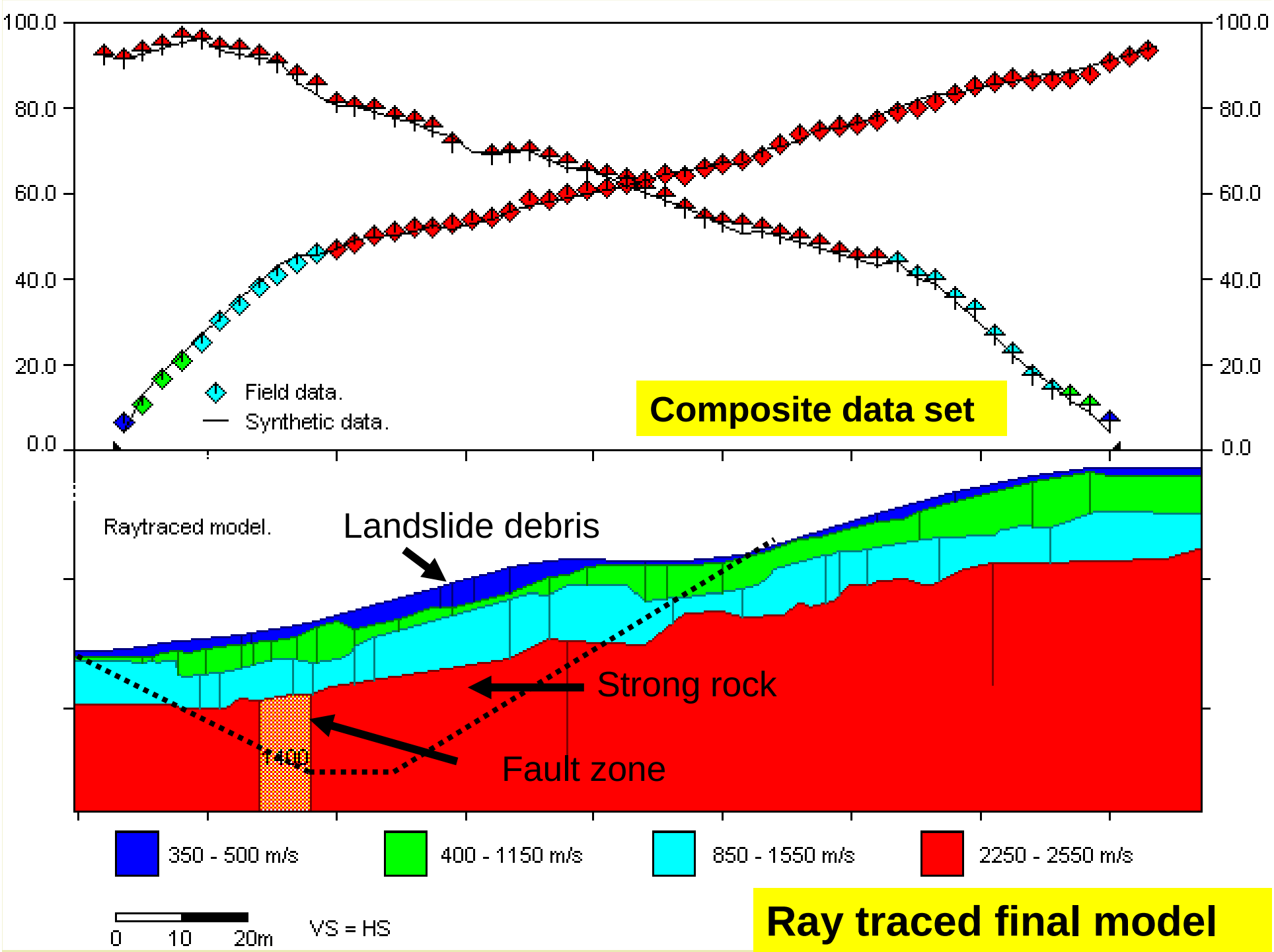



**Murrurrundi Gap, NSW**

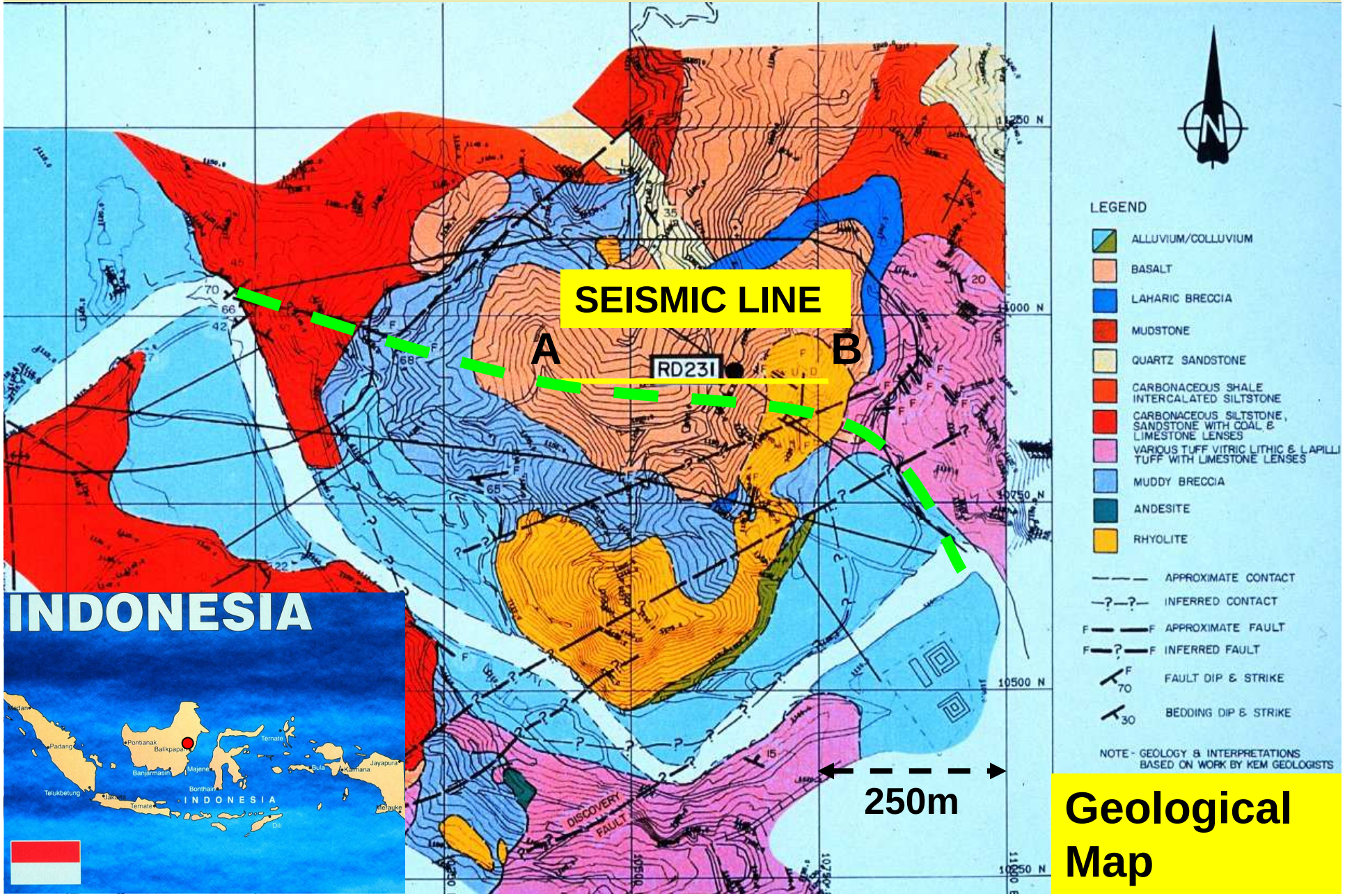
**road cut**


Time
Distance
0
10
20m
6
5
4
3
2
1
0

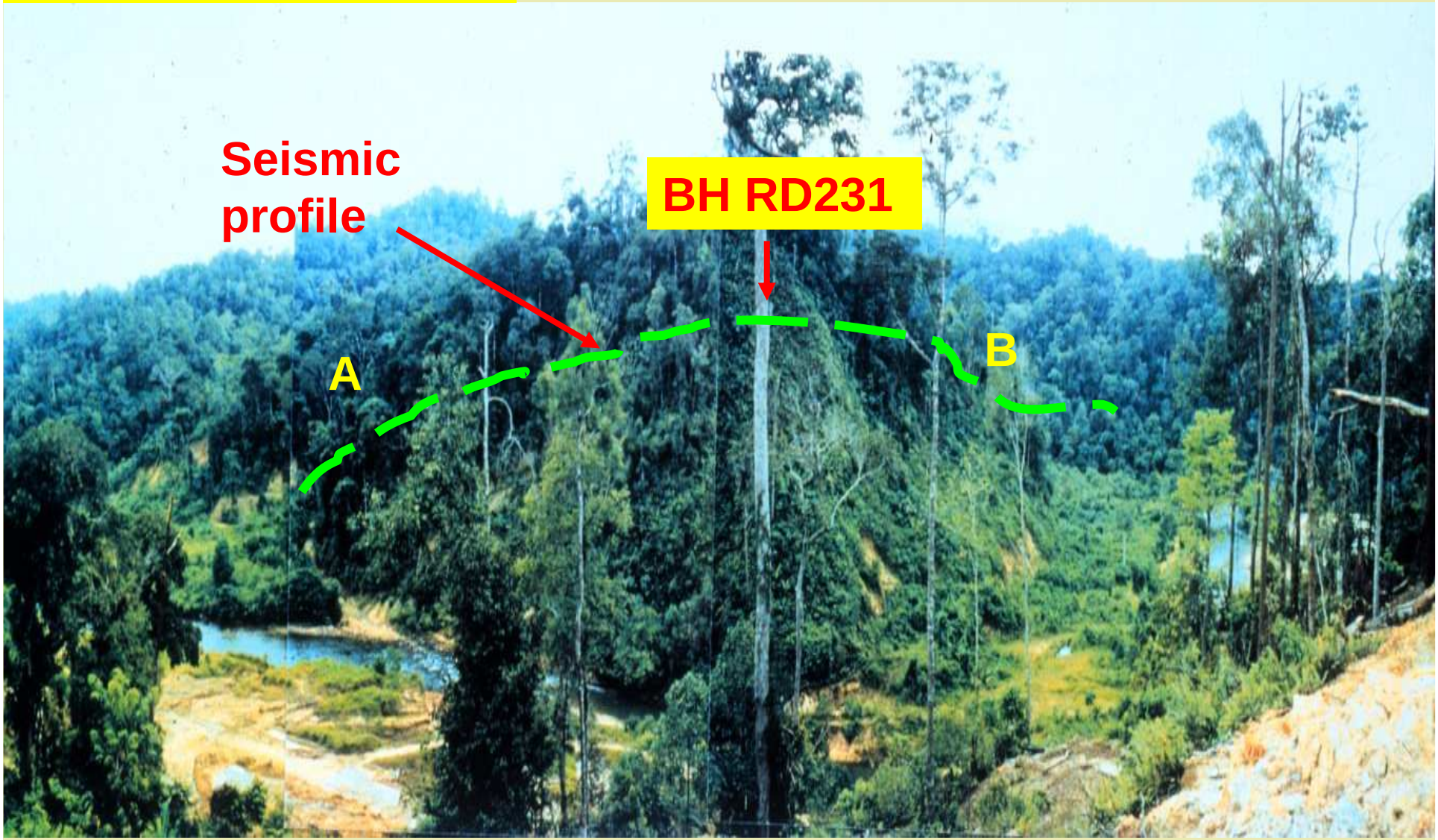

Raytraced model.
1400
350 - 500 m/s
400 - 1150 m/s
850 - 1550 m/s
2250 - 2550 m/s
0
10
20m
VS = HS


100.0
80.0
60.0
40.0
20.0
0.0
Field data.
Synthetic data.
Composite data set
Raytraced model.
Landslide debris
Strong rock
Fault zone
1400
350 - 500 m/s
400 - 1150 m/s
850 - 1550 m/s
2250 - 2550 m/s
0
10
20m
VS = HS
Ray traced final model

# KELIAN GOLD MINE – RIVER DIVERSION

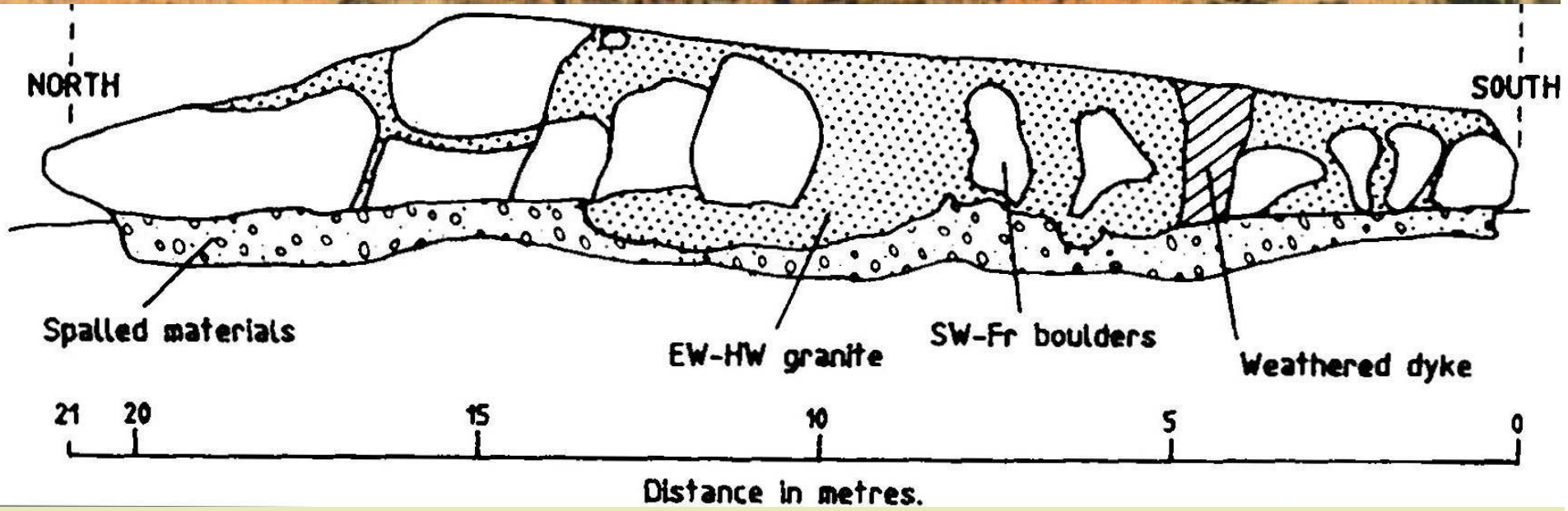


# The Kelian River



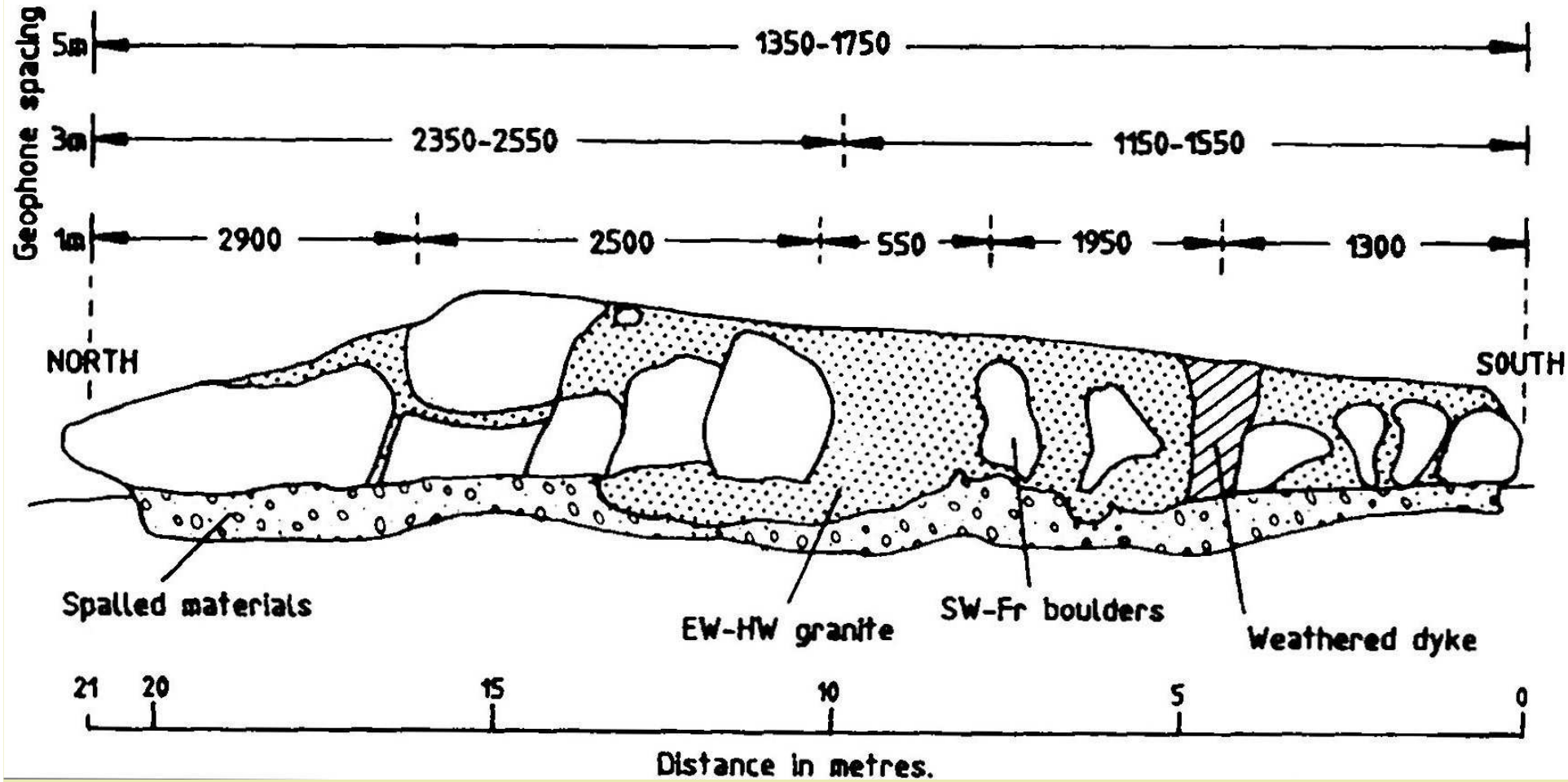
# RIVER DIVERSION DURING CONSTRUCTION

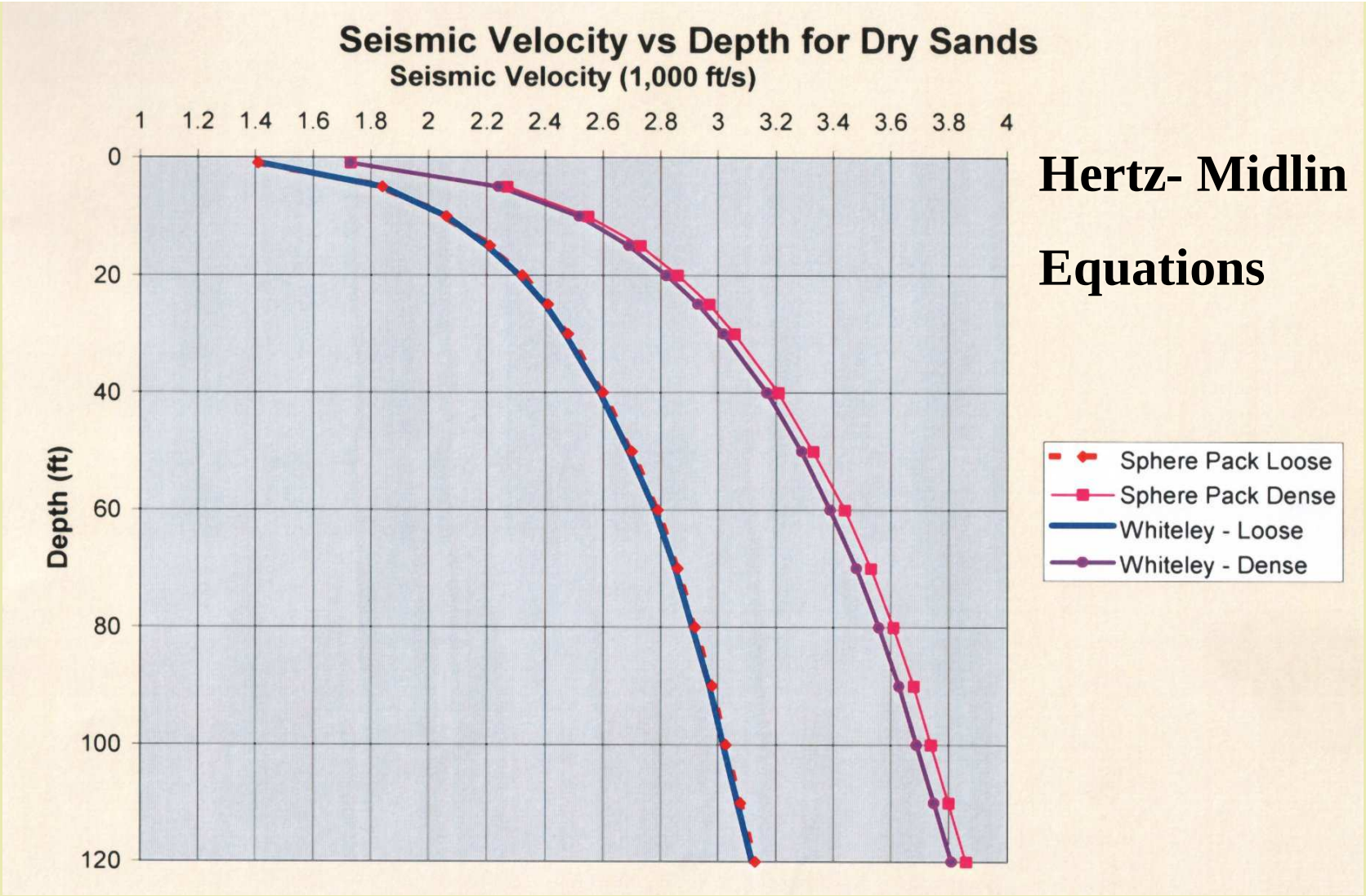

Extreme variability in regolith, NSW
15
10
15
10
21
20


NORTH
SOUTH
Spalled materials
EW-HW granite
SW-Fr boulders
Weathered dyke
21
20
15
10
5
0
Distance in metres.

# Effect of different geophone spacings

**Velocity m/s**





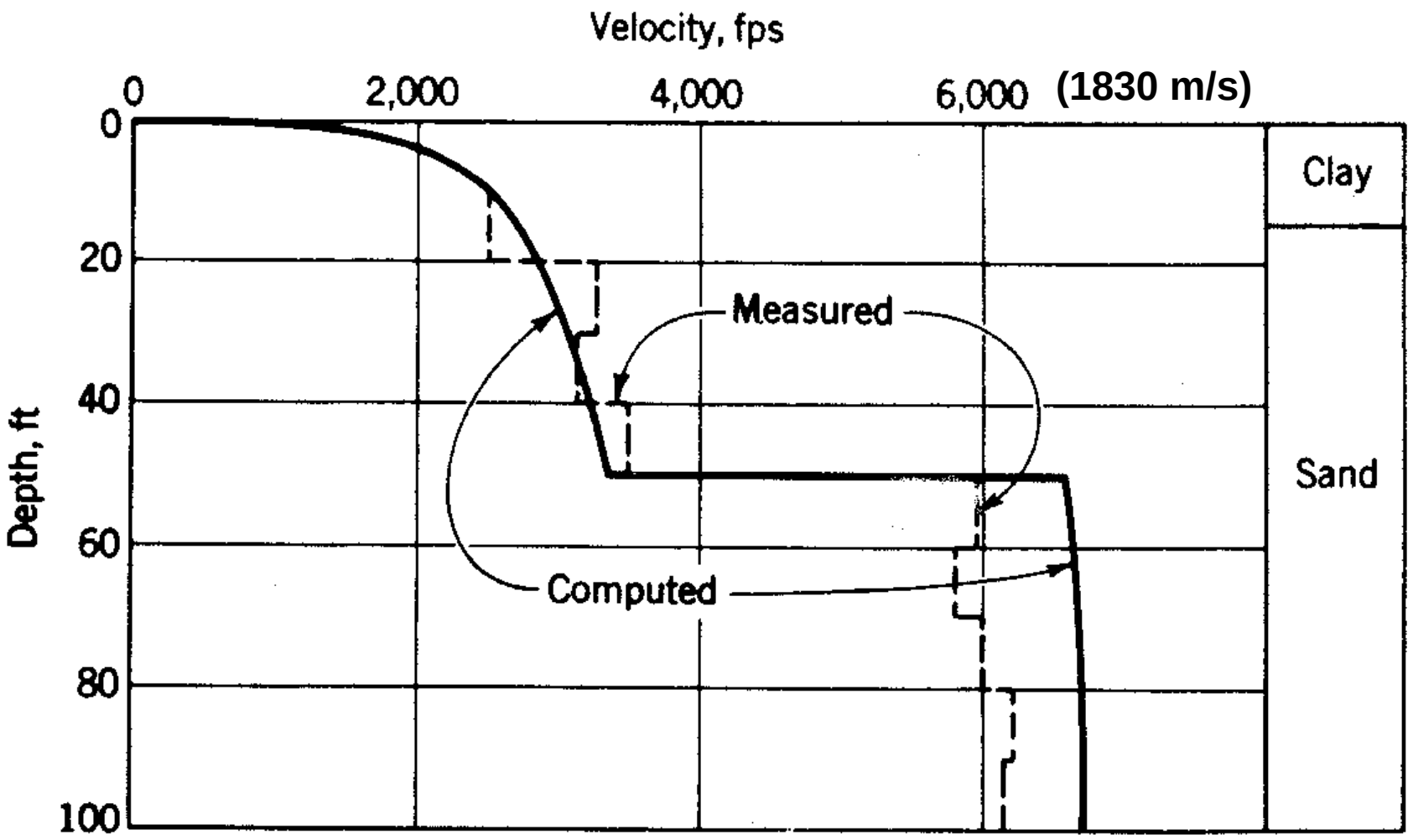

z

**Hertz- Midlin**

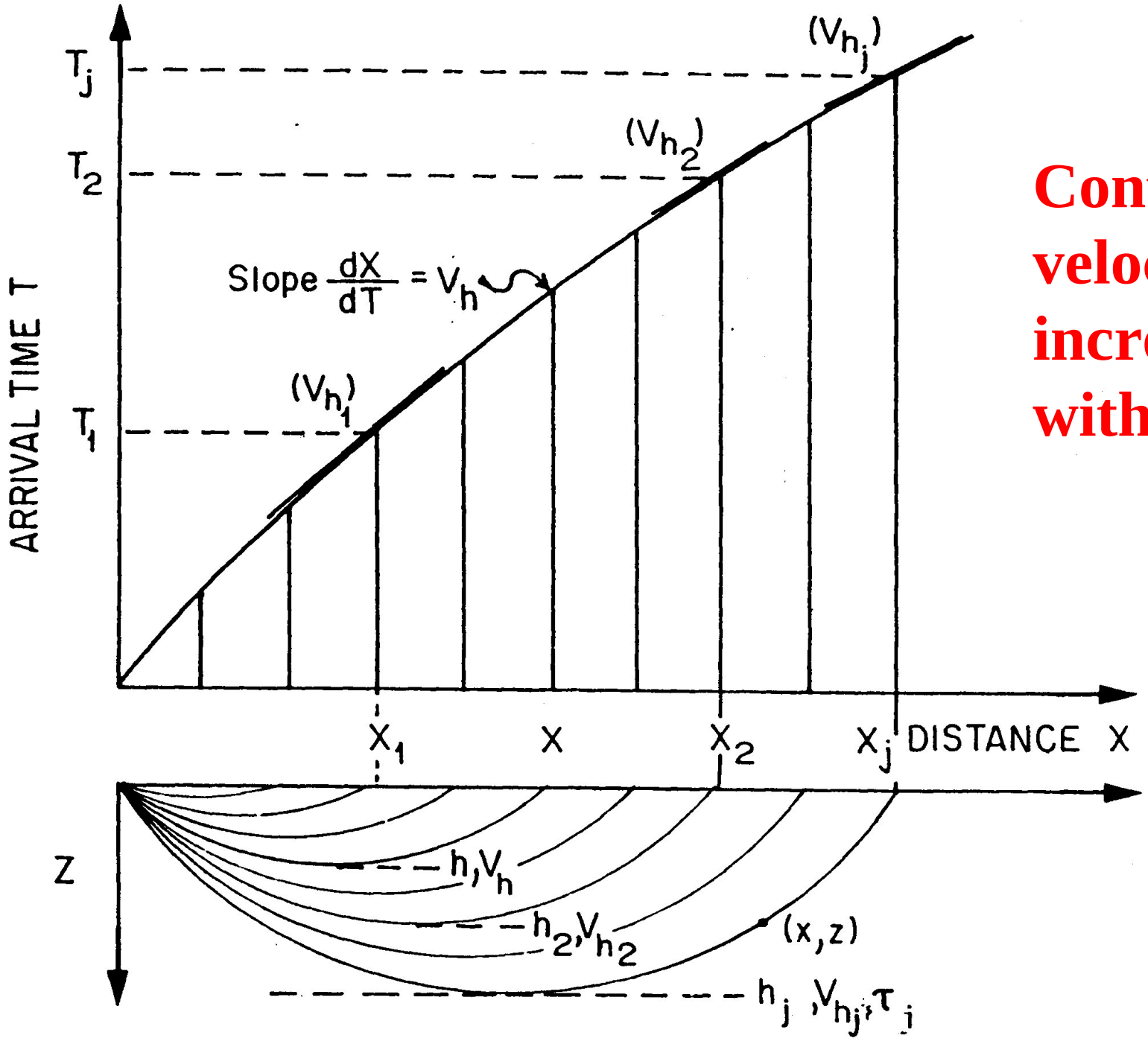
**Equations**

$$V_z = V_0(1 + \alpha z)^{1/n}$$

$$V_z = \beta z^{1/6}$$




**Compressional speed in a face-centered cubic array of quartz spheres compared with speeds measured in loose sand by White and Sengbush.**




**Continuous velocity increase with depth**

FD solutions to the 2D Eikonal equation

$$\left(\frac{\partial t}{\partial x}\right)^2 + \left(\frac{\partial t}{\partial z}\right)^2 = (1/V(x,z))^2$$

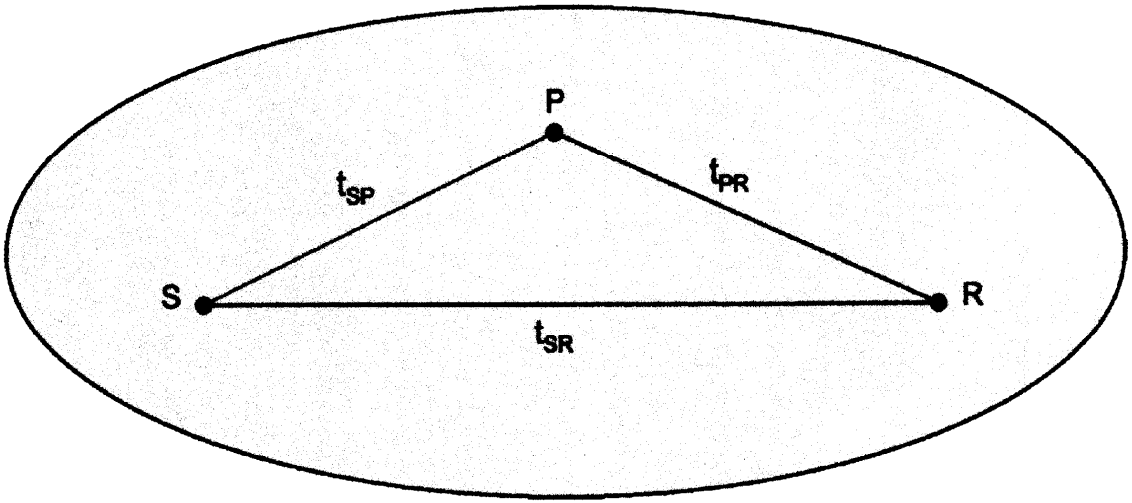
Wavefront Eikonal Traveltime Tomography (WET)

after Schuster & Quintus-Bosz (1993)

+

Fresnel Volume approach within inversion algorithm

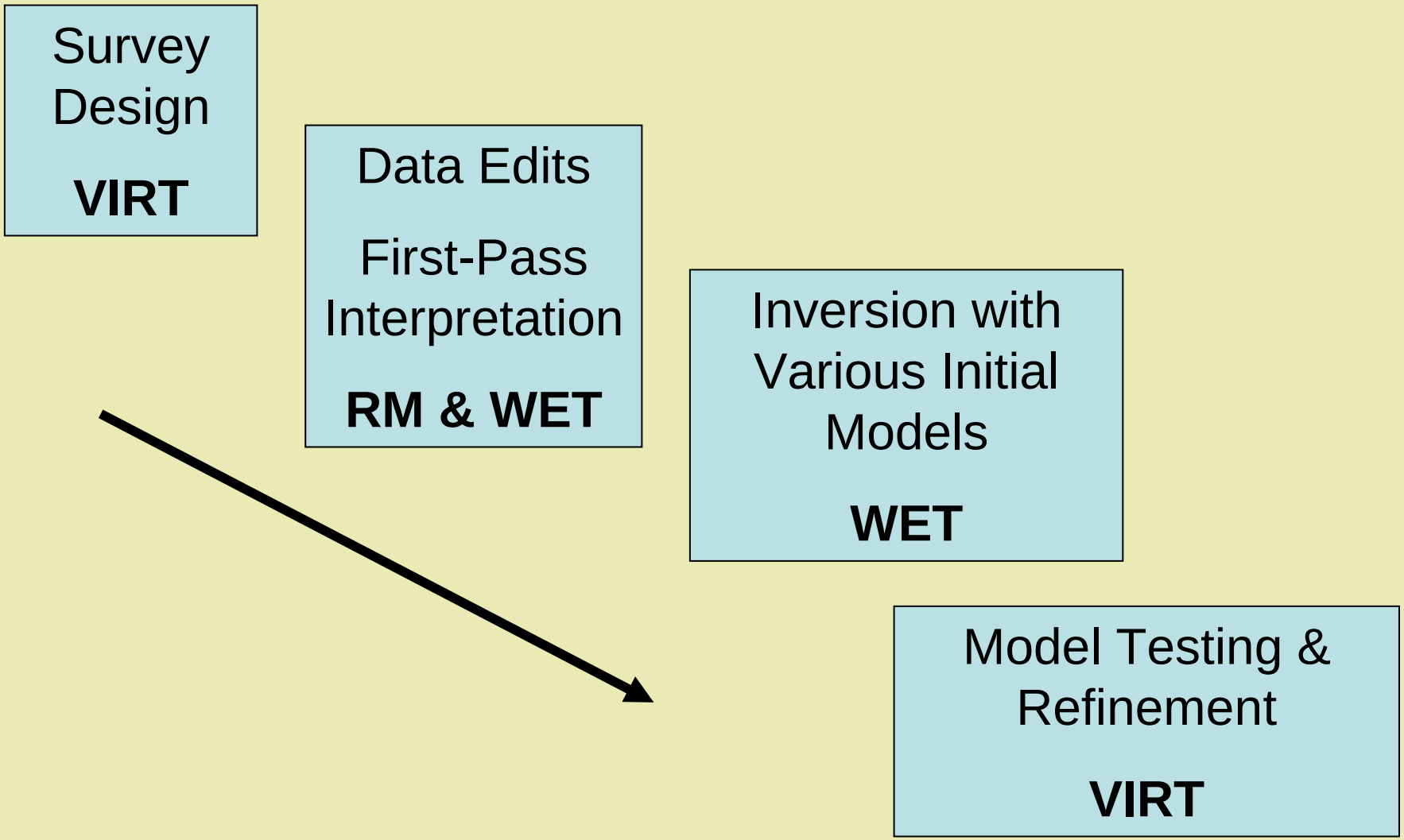
after Watanabe et al. (1999)



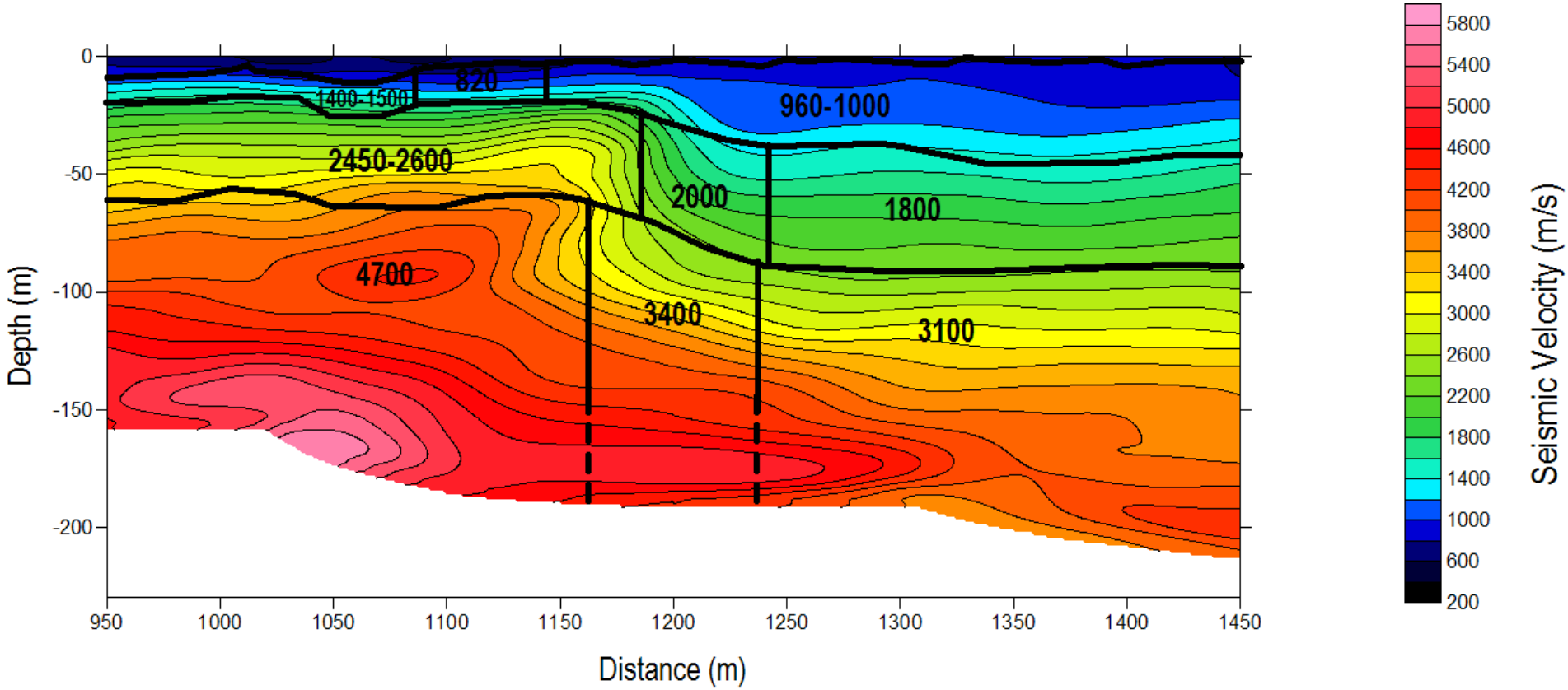

$$t_{SP} + t_{PR} - t_{SR} \leq 1/2f$$

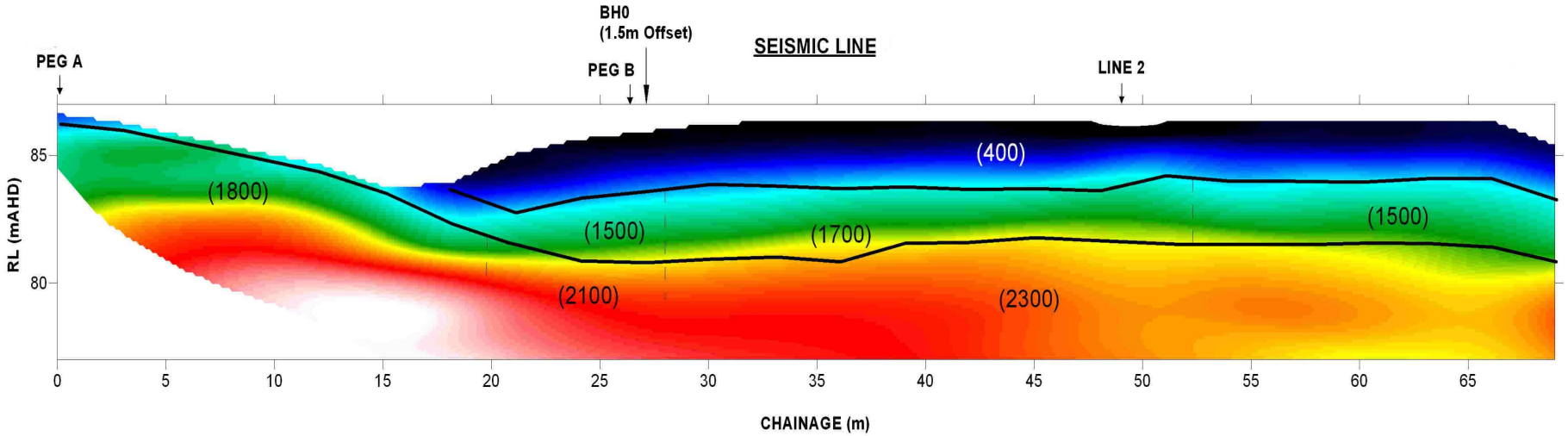
RAYFRACT software

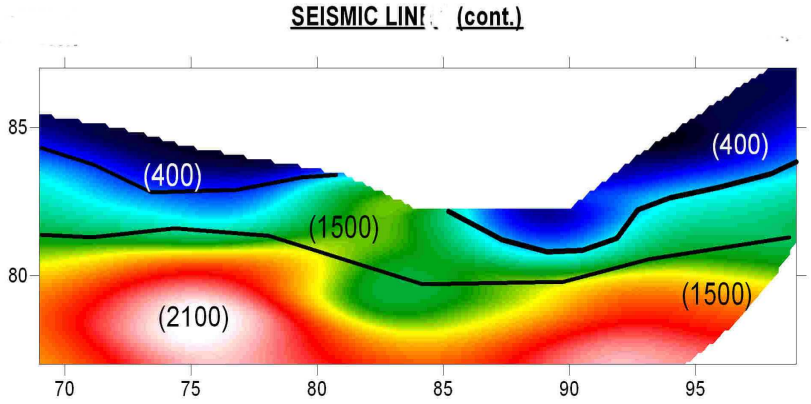
# Shallow Refraction Interpretation Scheme for Detailed Regolith Mapping

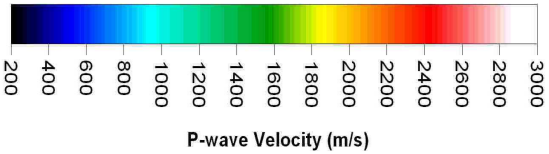


# Comparison of VIRT & WET Interpretations






Seismic refraction interpretation with both Discrete and Continuous velocity earth models

**LEGEND**

Interpreted Seismic Interface for Discrete Model

(2300) Seismic Velocity for Discrete Model (m/s)

Approximate Location of Lateral Velocity Variation