МПВ

Метод преломленных волн

Составил

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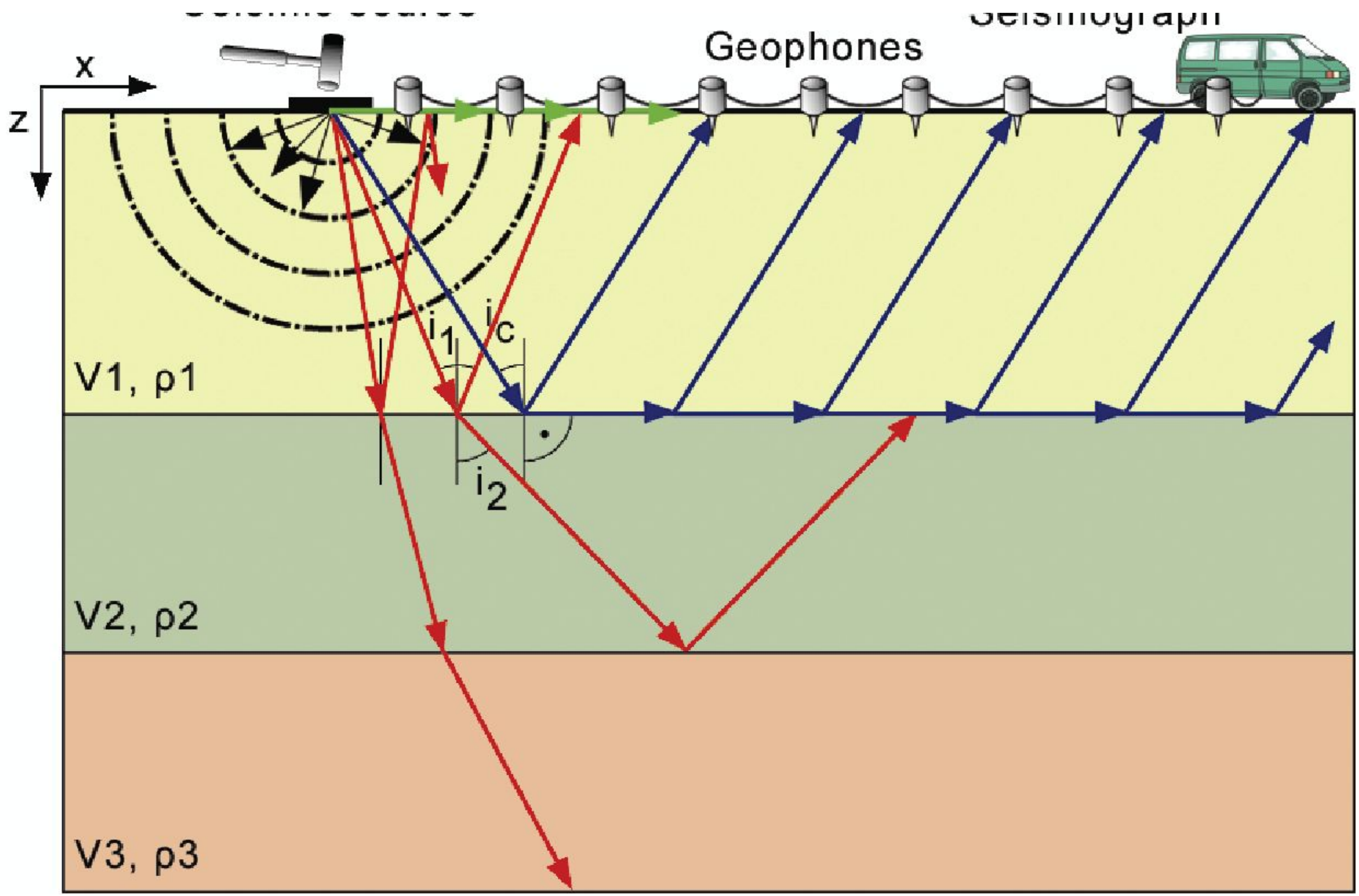
Основной источник – курс разведочной геофизики для студентов непрофильных специальностей Стэндфордского университета.

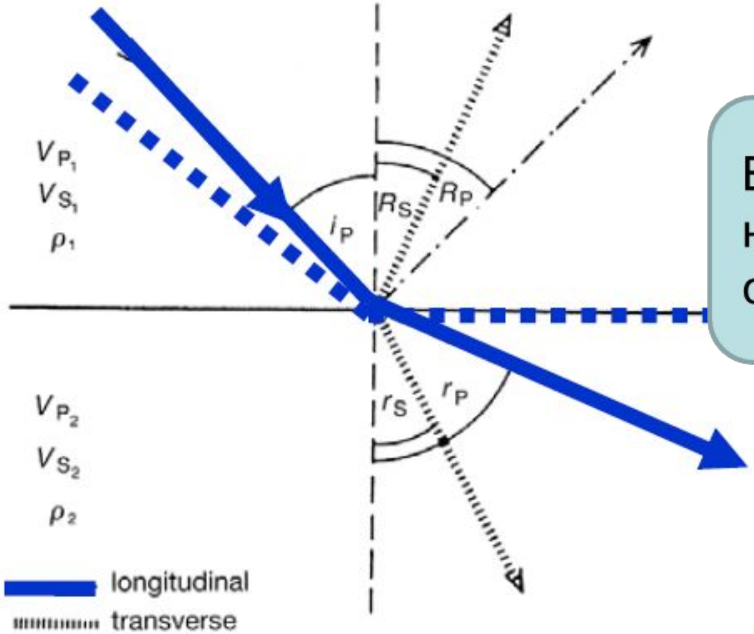


Geophones
x
z
i1
ic
i2
V1, ρ1
V2, ρ2
V3, ρ3

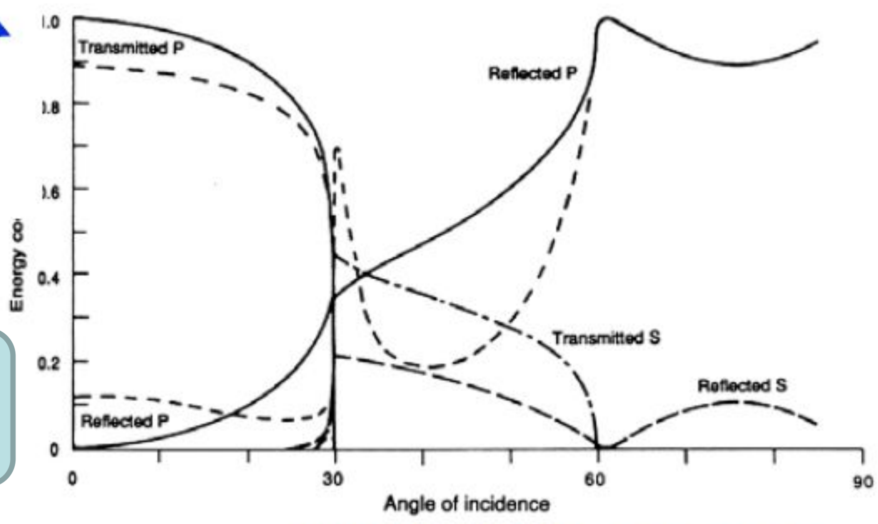
Критическое падение

Когда r_p=90° $i_p = i_c$ Критический угол равен

$$\sin i_C = \frac{V_{P1}}{V_{P2}}$$



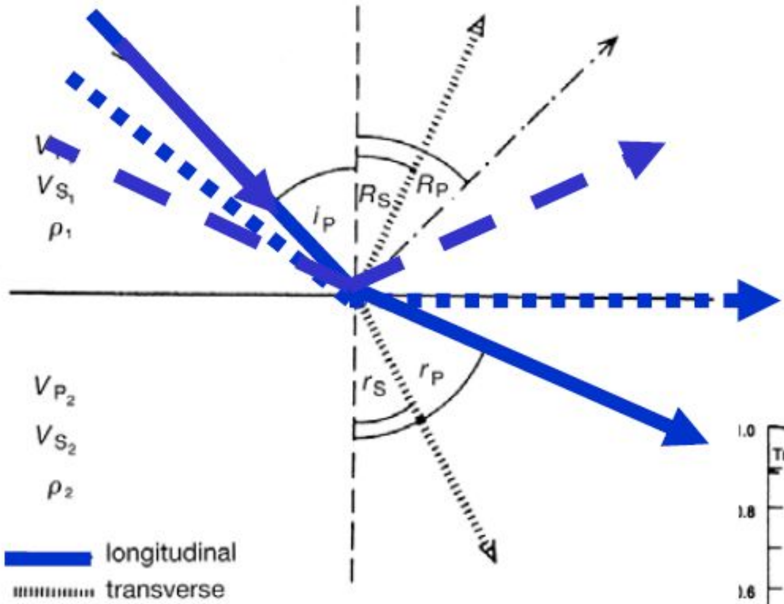
Волна упавшая под критическим углом на границу, распространяется вдоль не со скоростью V_2 в нижнем слое. $V_2 > V_1$



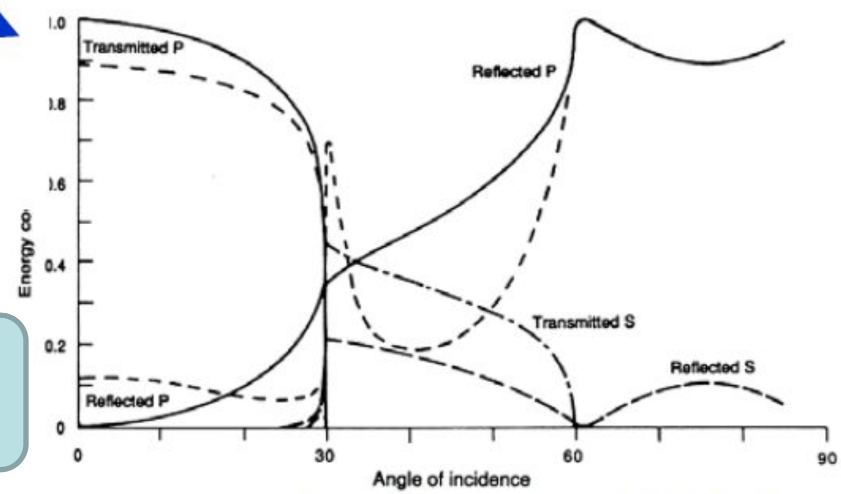
Коэфициенты отражения-преломления

Applied Geophysics – Refraction I

Закритическое падение



Когда угол падения >i_c вся энергия волны отражается.

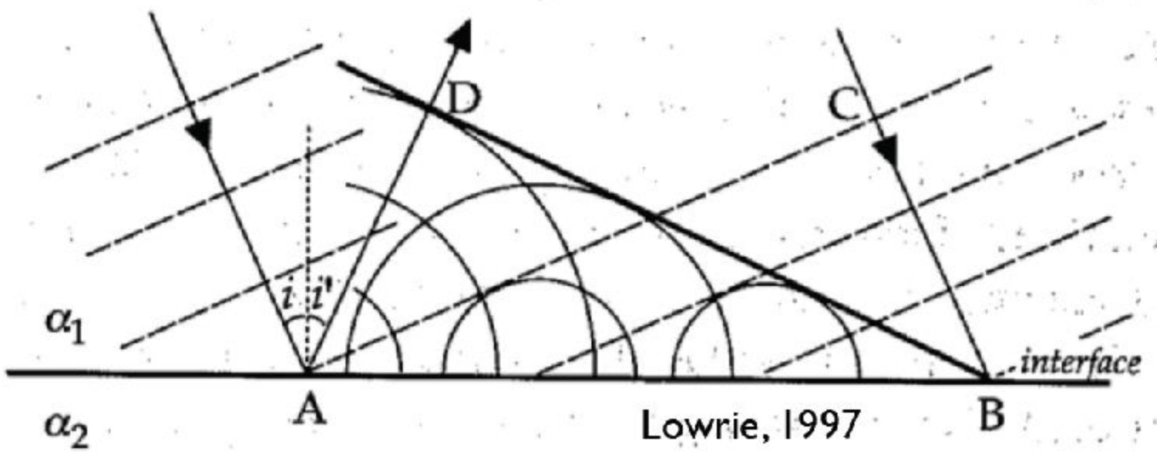


Applied Geophysics – Refraction I

Коэфициенты отражения-преломления

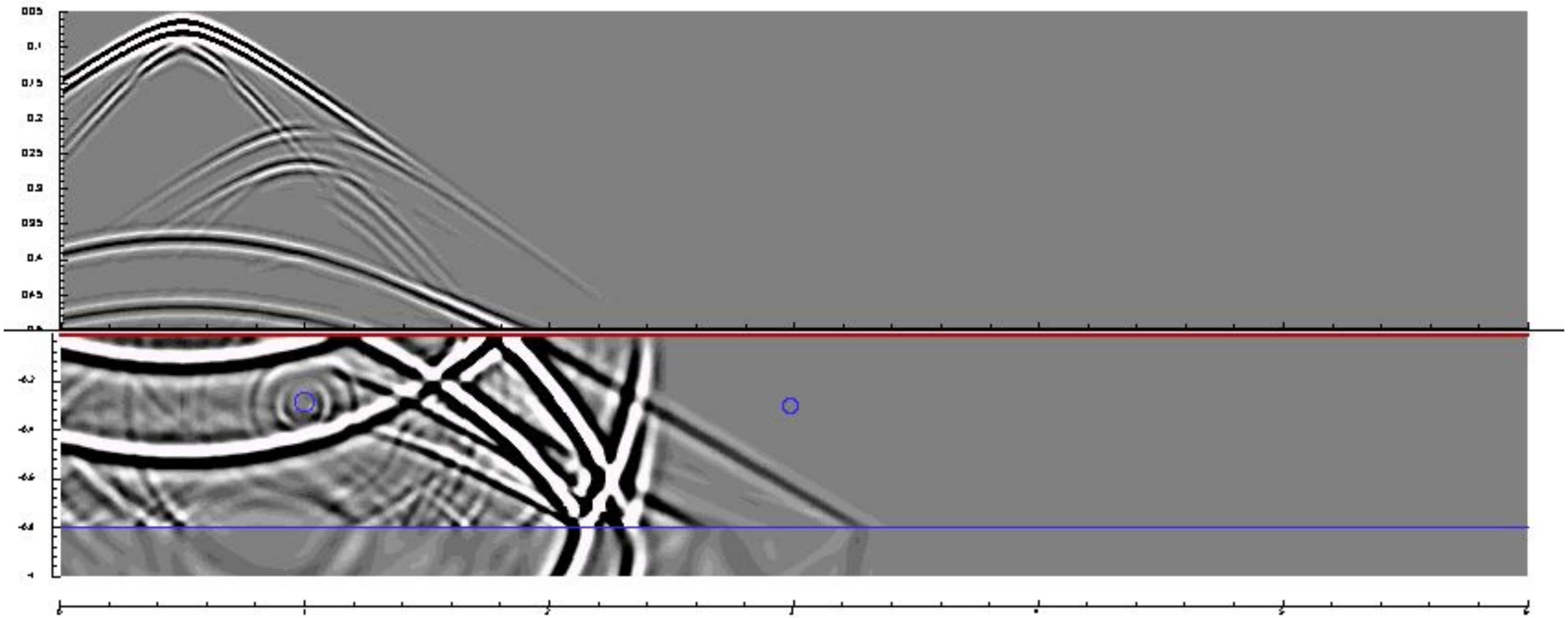
The law of reflection using Huygens wavelets

The angle of reflection is equal to the angle of incidence.



- During the time that wavefront AC travels from intersecting at A to intersecting at B, secondary waves travel from A to D.
- AD = CB, so angles are also equal.

Волновое поле



Пример

Горизонтальная граница

Уравнение годографа прямой :

$$T = \frac{x}{V_1}$$

И головной волны:

$$T = T_{SB} + T_{DD'} + T_{BD}$$

$$T = \frac{2h_1}{V_1 \cos i_c} + \frac{x - 2h_1 \tan i_c}{V_2}$$

$$T = \frac{x}{V_2} + \frac{2h_1\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

T = ax + b

Наклон определяется скоростью, глубина точкой пересечения.

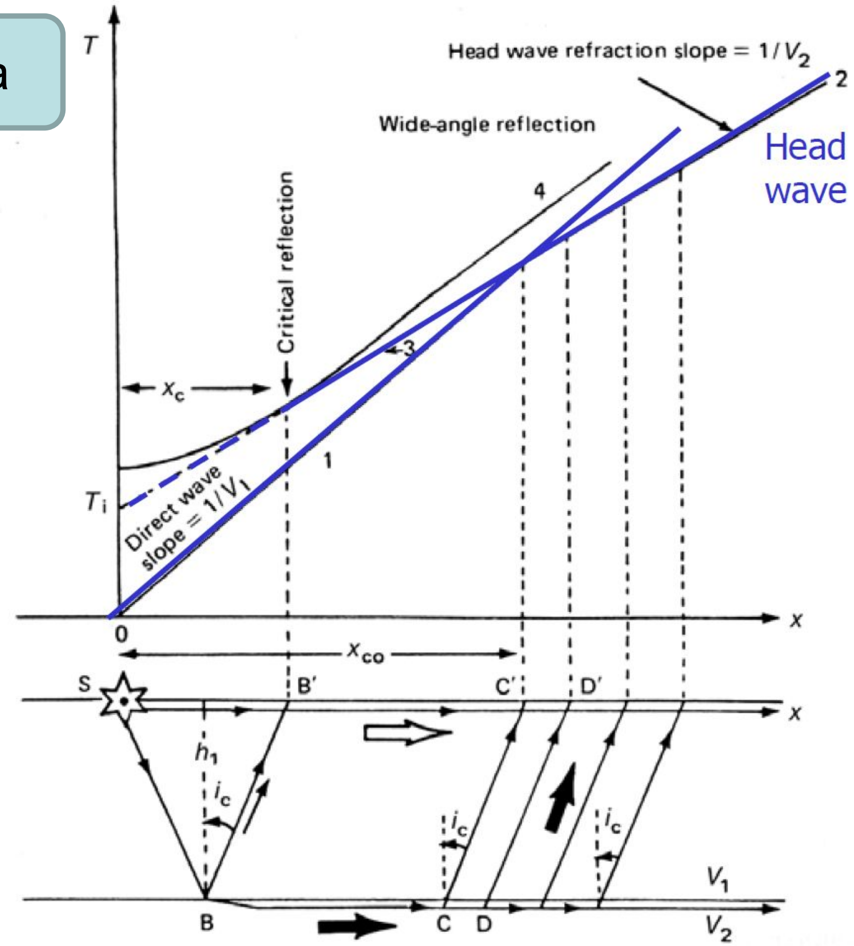


Fig. 4.34 Principle of the seismic refraction method. Travel-time curves for direct waves, critically refracted waves (head waves), late refracted arrivals, and reflected waves are shown by numbers 1–4, respectively. Note that critically refracted waves start arriving after a critical distance x_c, but they overtake the direct waves at a crossover distance x_{co}.

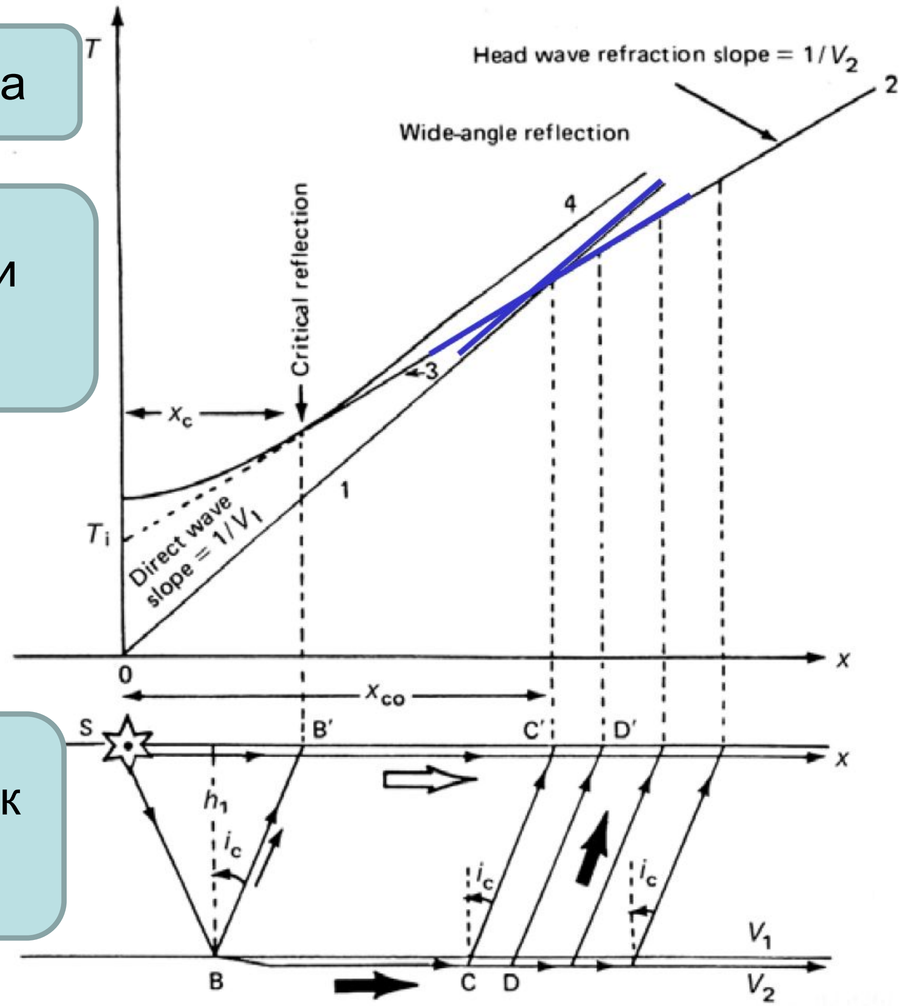
Горизонтальная граница

Точка пересечения годографов головной и прямой волны определяется:

$$\frac{x_{co}}{V_1} = \frac{x_{co}}{V_2} + \frac{2h_1\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

$$x_{co} = 2h_1 \frac{\sqrt{V_2 + V_1}}{\sqrt{V_2 - V_1}}$$

-альтернативный подход к определению мощности



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Horizontal interface

Crossover distance, x_{co}

Where the direct and head wave cross. Their travel times are equal:

$$\frac{x_{co}}{V_1} = \frac{x_{co}}{V_2} + \frac{2h_1\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

$$x_{co} = 2h_1 \frac{\sqrt{V_2 + V_1}}{\sqrt{V_2 - V_1}}$$

Another approach to obtaining layer thickness

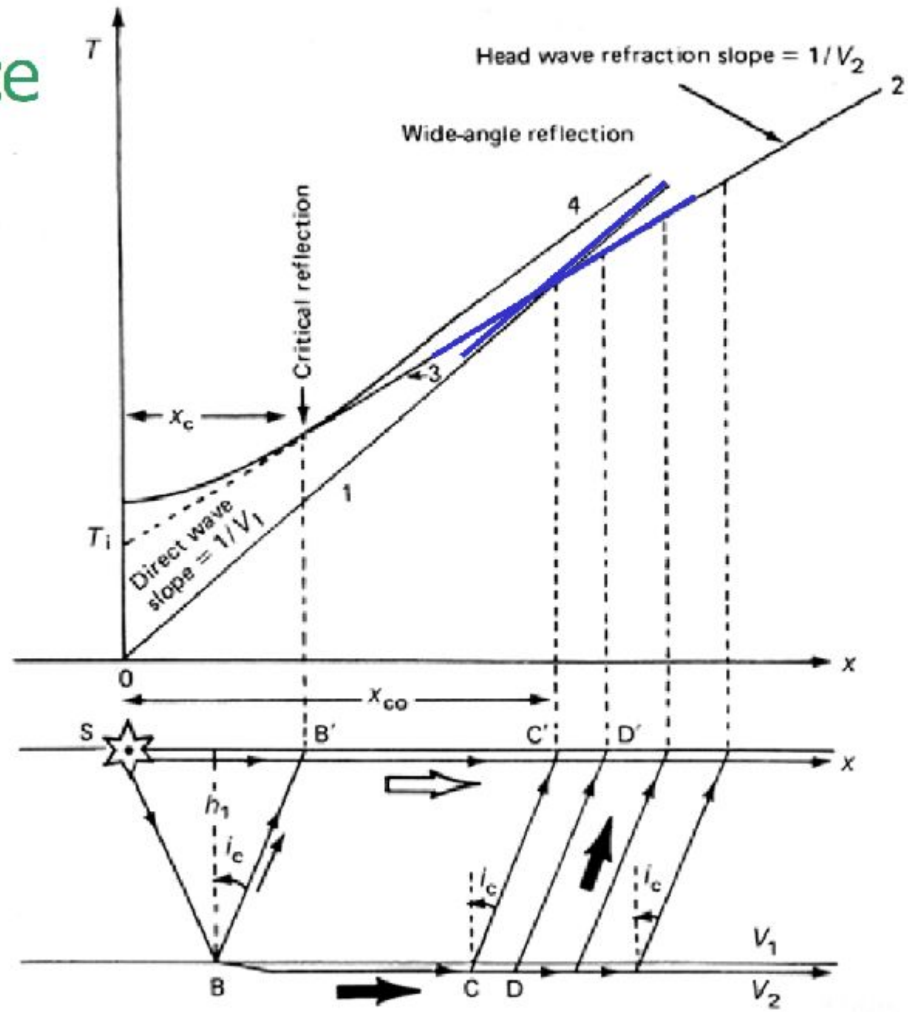


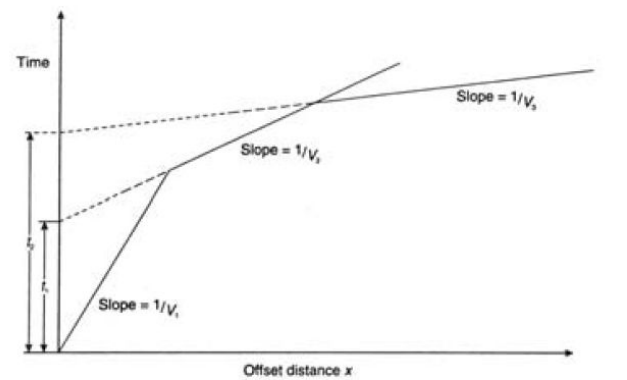
Fig. 4.34 Principle of the seismic refraction method. Travel-time curves for direct waves, critically refracted waves (head waves), late refracted arrivals, and reflected waves are shown by numbers 1–4, respectively. Note that critically refracted waves start arriving after a critical distance x_c, but they overtake the direct waves at a crossover distance x_{co}.

Трехслойная модель

Traveltime

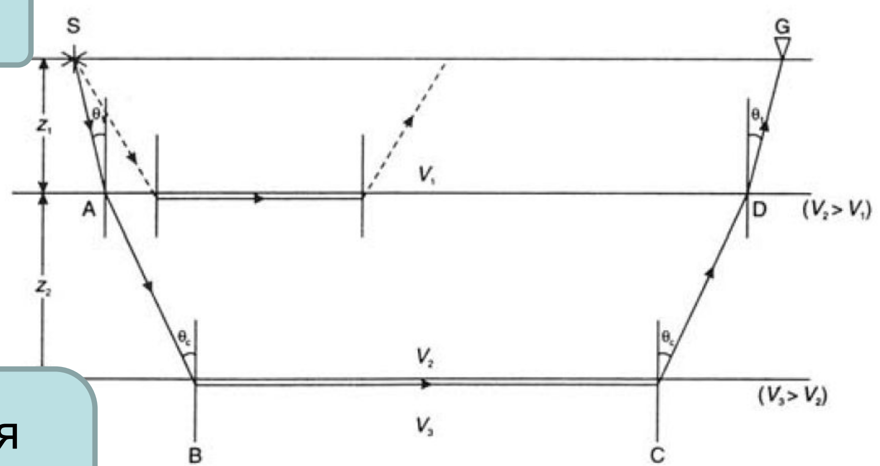
$$T_{SG} = \frac{SA}{V_1} + \frac{AB}{V_2} + \frac{BC}{V_3} + \frac{CD}{V_2} + \frac{DG}{V_1}$$

$$T_{SG} = \frac{2z_1}{V_1 \cos\theta_1} + \frac{2z_2}{V_2 \cos\theta_c} + \frac{x - 2z_1 \tan\theta_1 - 2z_2 \tan\theta_c}{V_3}$$



После преобразования

$$T_{SG} = \frac{x}{V_3} + \frac{2z_1\sqrt{V_3^2 - V_1^2}}{V_3V_1} + \frac{2z_2\sqrt{V_3^2 - V_2^2}}{V_3V_2}$$



V1 V2 V3 из кажущихся скоростей, глубины по точкам пересечения.

Multiple-layered models

For multiple layered models we can apply the same process to determine layer thickness and velocity sequentially from the top layer to the bottom

Head wave from top of layer 2:

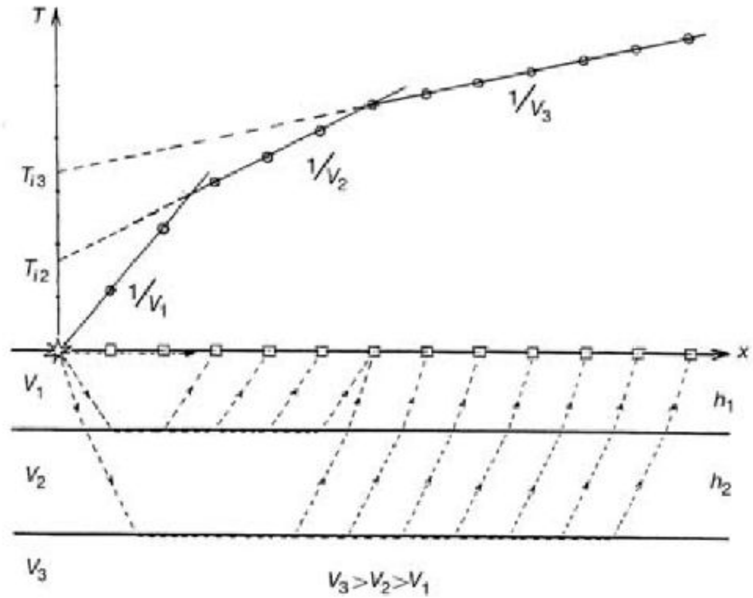
$$T = \frac{x}{V_2} + \frac{2h_1\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

Head wave from top of layer 3:

$$T = \frac{x}{V_3} + \frac{2h_1\sqrt{V_3^2 - V_1^2}}{V_3 V_1} + \frac{2h_2\sqrt{V_3^2 - V_2^2}}{V_3 V_2}$$

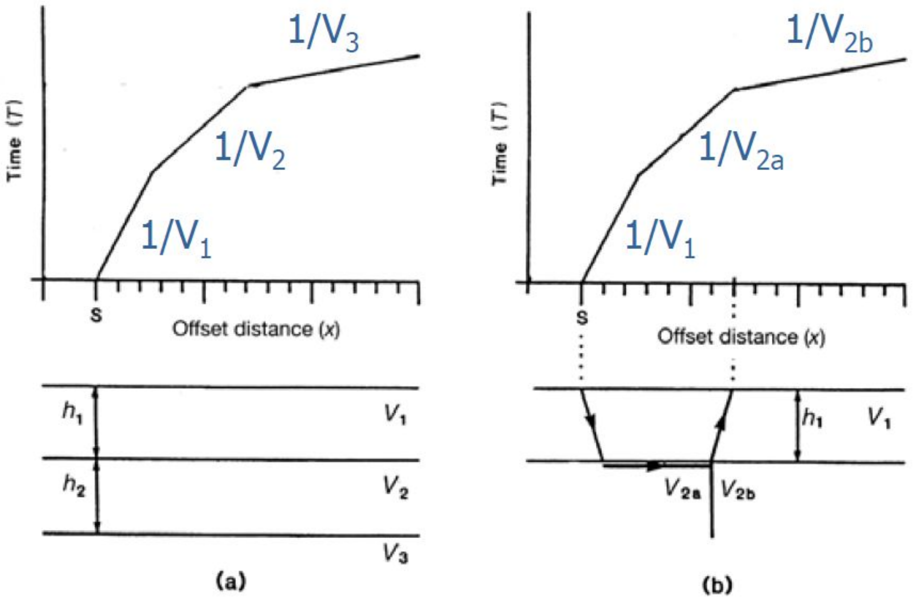
Head wave from top of layer n:

$$T = \sum_{j=1}^{n-1}\left(\frac{2h_j\sqrt{V_n^2 - V_j^2}}{V_n V_j}\right) + \frac{x}{V_n}$$



Горизонтальный и вертикальный контраст скоростей

Кривизна единичного годографа головных волн может быть описана как трехслойной средой так и двухслойной, с вариацией скорости во втором слое.



Head wave continues into 2b

Горизонтальный и вертикальный контраст скоростей

Сравнение и различие влияния на годограф преломленной волны вертикальной и горизонтальной неоднородности разреза.

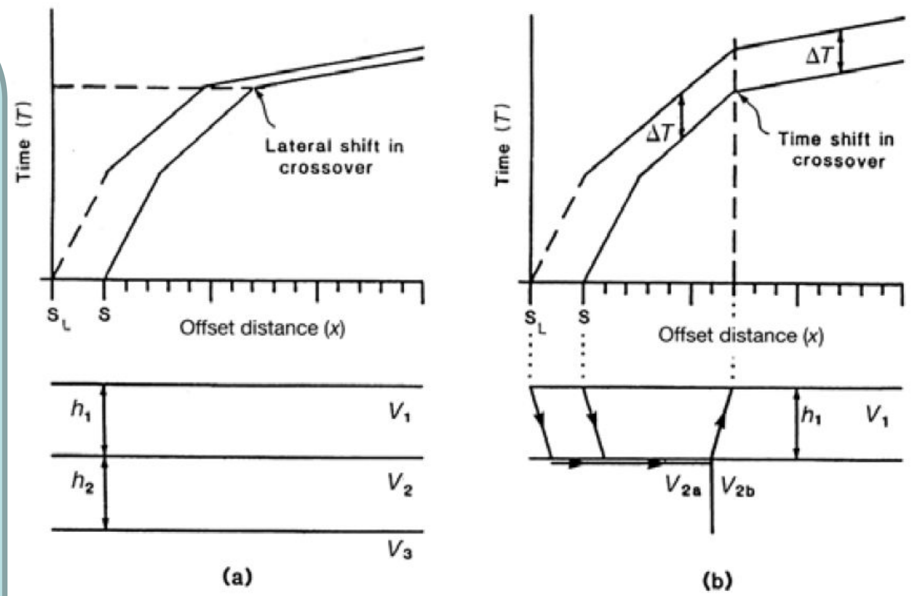


Fig. 4.36 Identical travel-time curves arising from a single shot S over (a) a horizontal three-layer earth, and (b) a two-layer earth with lateral velocity change in the second layer. The ambiguity can be resolved by an additional long offset shot, S_L. Dashed lines on long offset travel-time curves are segments of the travel-time curves that would be observed if geophones were placed between S and S_L. The three-layer case (a) can be distinguished from the two-layer case (b) by noting a lateral shift in the crossover point in the first case and a vertical shift in the crossover point in the second case. (Modified from Lankston, 1990.)

Mapping vertical contacts

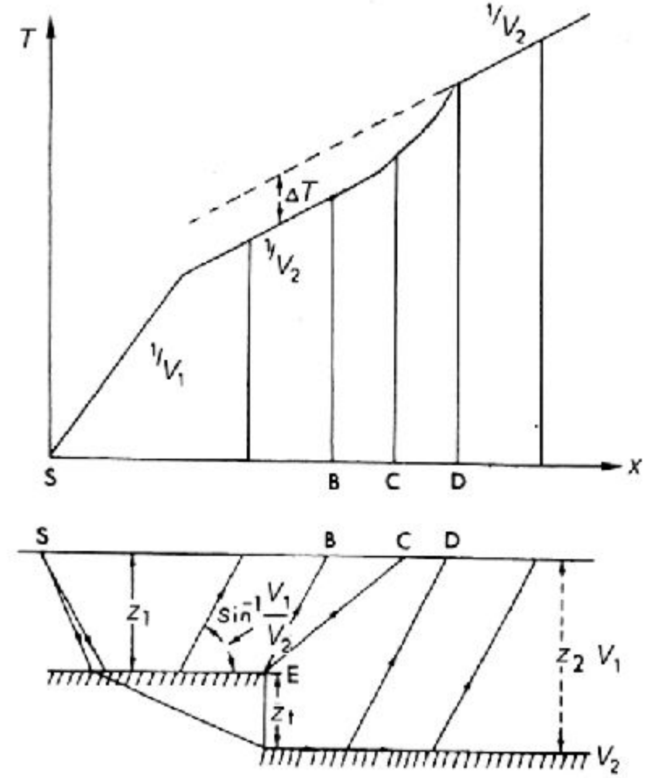
Small offsets

A vertical step causes an offset on the traveltime curve

- The relation of velocity to the slope remains unchanged
- The offset can be calculated from the time offset, ΔT

$$z_t = \frac{\Delta T V_2 V_1}{\sqrt{V_2^2 - V_1^2}}$$

- Diffractions link the two head wave curves
- Depth, z1, is calculated from the intercept in the usual way



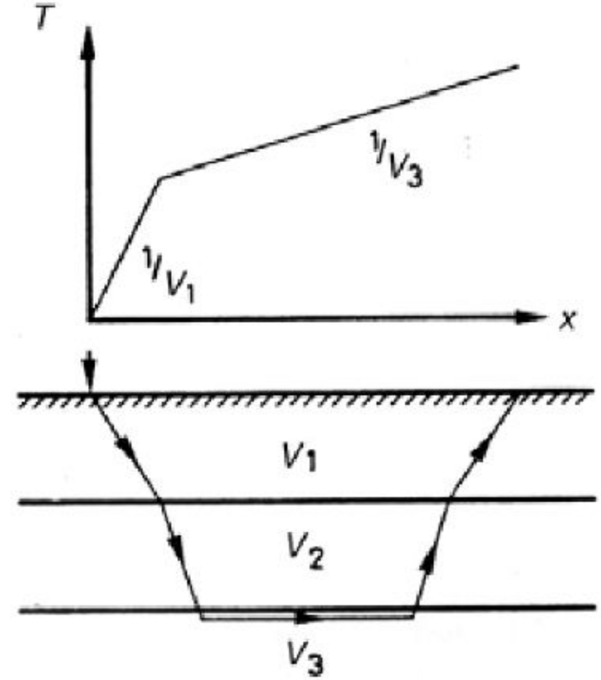
Limitations

Low velocity layers

- **They are completely invisible to the refraction method**
- **They will cause miss-interpretation of the depth of lower lying layers**

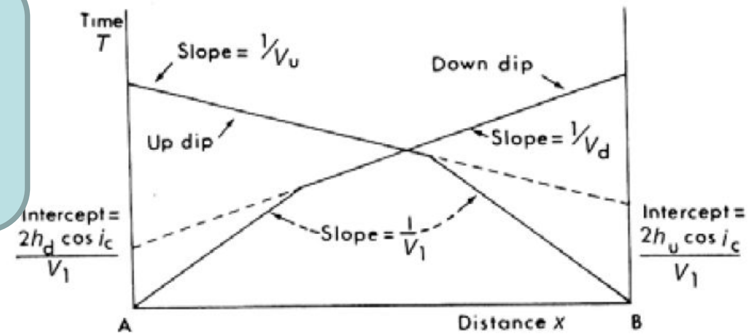
  The intercept of the refraction from layer 3 will be dependent on the thickness and velocity in layer 2

- **Lower layers appear deeper than they are**

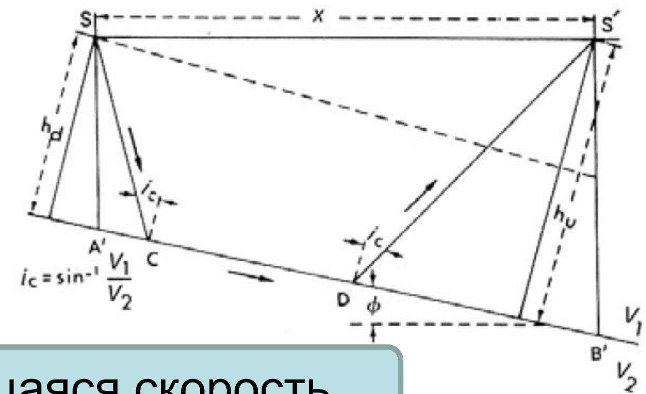


$V_2 < V_1 < V_3$

Годограф Преломленной волны для случая наклонной границы.



$$T_d = \frac{SC}{V_1} + \frac{CD}{V_2} + \frac{DS'}{V_1}$$



$$T_d = \frac{h_u + h_d}{V_1 \cos i_c} + \frac{x - \left[(h_u + h_d)\tan i_c\right]}{V_2}$$

После тригонометрических преобразований получим

Ф-ла Годографа по падению и кажущаяся скорость

$$T_d = \frac{x \sin(i_c + \phi)}{V_1} + \frac{2h_d \cos i_c}{V_1} \qquad V_d = \frac{V_1}{\sin(i_c + \phi)}$$

Ф-ла Годографа по восстанию и кажущаяся скорость

$$T_u = \frac{x \sin(i_c - \phi)}{V_1} + \frac{2h_u \cos i_c}{V_1} \qquad V_u = \frac{V_1}{\sin(i_c - \phi)}$$

Кстати…где V2?

Dipping layer traveltime

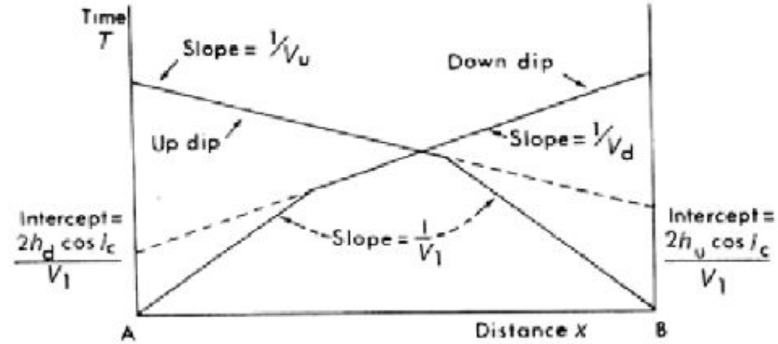
Given

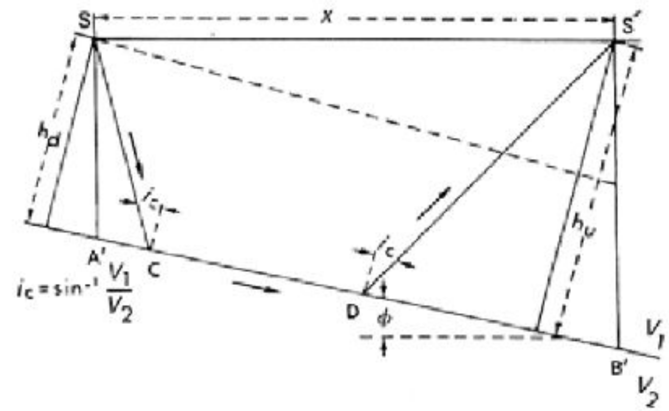
$$V_d = \frac{V_1}{\sin(i_c + \phi)} \qquad V_u = \frac{V_1}{\sin(i_c - \phi)}$$

We can solve for:

$$\phi = \tfrac{1}{2}\left[\sin^{1} {V_1}\!/\!{V_d} - \sin^{1} {V_1}\!/\!{V_u}\right]$$

$$i_c = \tfrac{1}{2}\left[\sin^{-1} {V_1}\!/\!{V_d} + \sin^{-1} {V_1}\!/\!{V_u}\right]$$





V_2 then obtained from: $\sin i_c = \frac{V_1}{V_2}$

Finally, the intercept times can be used to determine the perpendicular distance to the reflector:

$$T_{id} = \frac{2h_d \cos i_c}{V_1} \qquad T_{iu} = \frac{2h_u \cos i_c}{V_1}$$

Real Earth "flat" layers

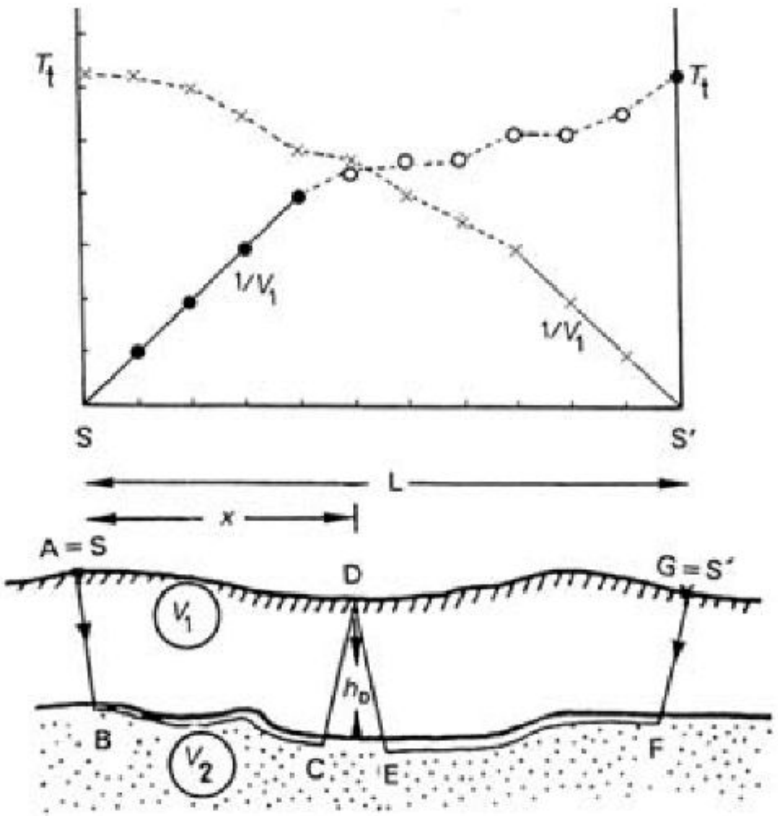
Although the interfaces between real Earth layers are not perfectly flat, head waves still travel along them

Analysis methods:

Best-fit straight line through the points provides some kind of average layer thickness and velocity though the error may be unacceptable

Special analysis techniques:

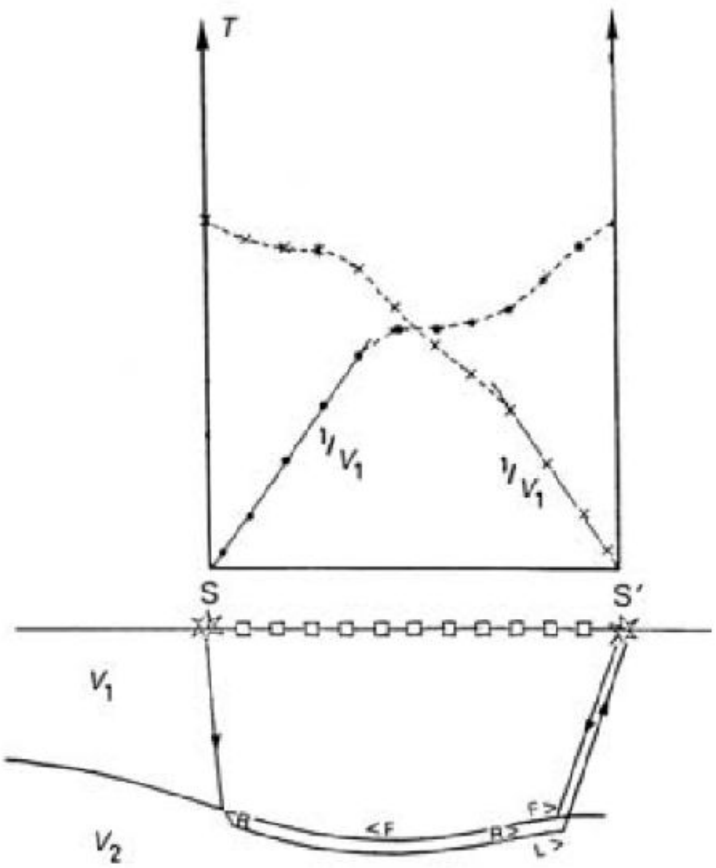
- **Phantom arrivals**
- **Delay time**
- **Plus-minus**



Phantom arrivals

Undulating surface

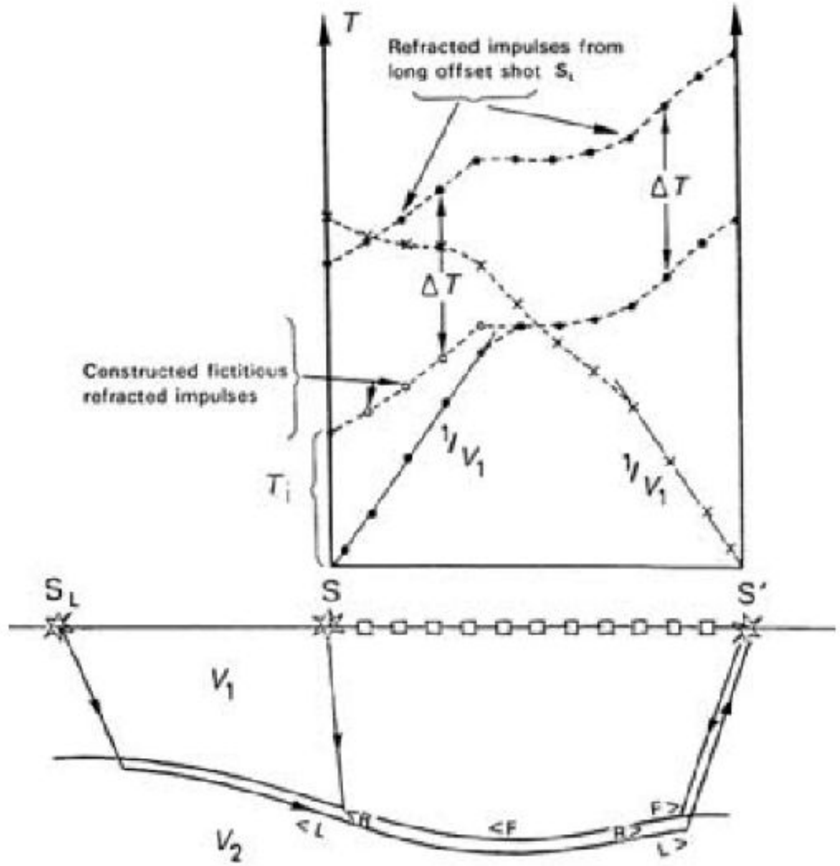
- Cannot extrapolate the head wave arrival time curve back to the intercept
- How do we determine layer thickness beneath the shot, S?



Phantom arrivals

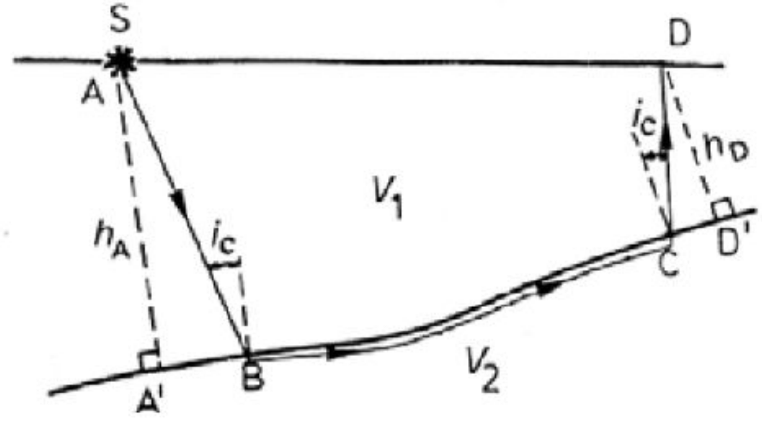
1. Shoot a long-offset shot, S_L
2. The head wave traveltime curves for both shots will be parallel, offset by time ΛT
3. Subtract ΔT from the S_L arrivals to generate fictitious 2nd layer arrivals close to S – the phantom arrivals
4. The intercept point at S can then be determined: T_i
5. Use the usual formula to determine perpendicular layer thickness beneath S

$$T_i = \frac{2h_s\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$



Separation of delay times

Delay time is the difference between the slant path traveltime (AB) and the traveltime along the refractor beneath (A'B)



Delay time below shotpoint S:

$$\Delta T_S = \frac{AB}{V_1} - \frac{A'B}{V_2}$$

$$\Delta T_S = \frac{h_A}{V_1 \cos i_c} - \frac{h_A \tan i_c}{V_2}$$

$$\Delta T_S = \frac{h_A \sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

Likewise, beneath D:

$$\Delta T_D = \frac{h_D \sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

The delay time is related to the perpendicular depth beneath the geophone. If we know the delay time, V_1 and V_2 then we can calculate the depth.

Separation of delay times

Determining the delay time beneath a geophone, ΔT_D:

Total traveltime ABFG:

$$T_t = \frac{L}{V_2} + \Delta T_S + \Delta T_{S'}$$

Total traveltime ABCD:

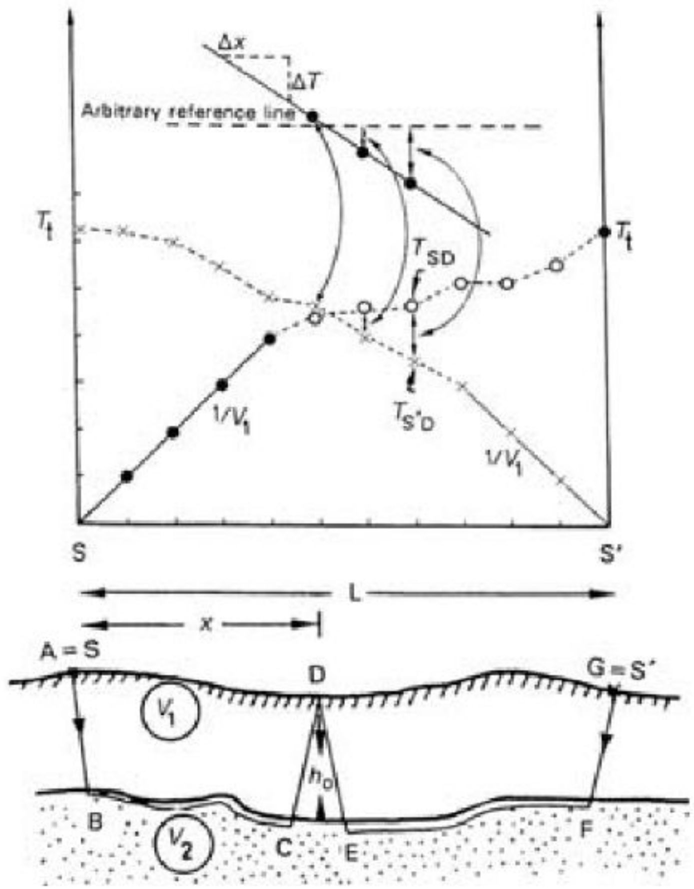
$$T_{SD} = \frac{x}{V_2} + \Delta T_S + \Delta T_D$$

Total traveltime GFED:

$$T_{S'D} = \frac{L-x}{V_2} + \Delta T_{S'} + \Delta T_D$$

"plus"

Adding the equations for T_{SD} and $T_{S'D}$ and using the equation for T_t we obtain an equation for ΔT_D :



$$\Delta T_D = \frac{T_{SD} + T_{S'D} - T_t}{2}$$

➔ **determine ΔT_D from a reversed refraction line**

Separation of delay times

Determining velocity, V_1 V_2:

Direct arrival slope = $1/V_1$

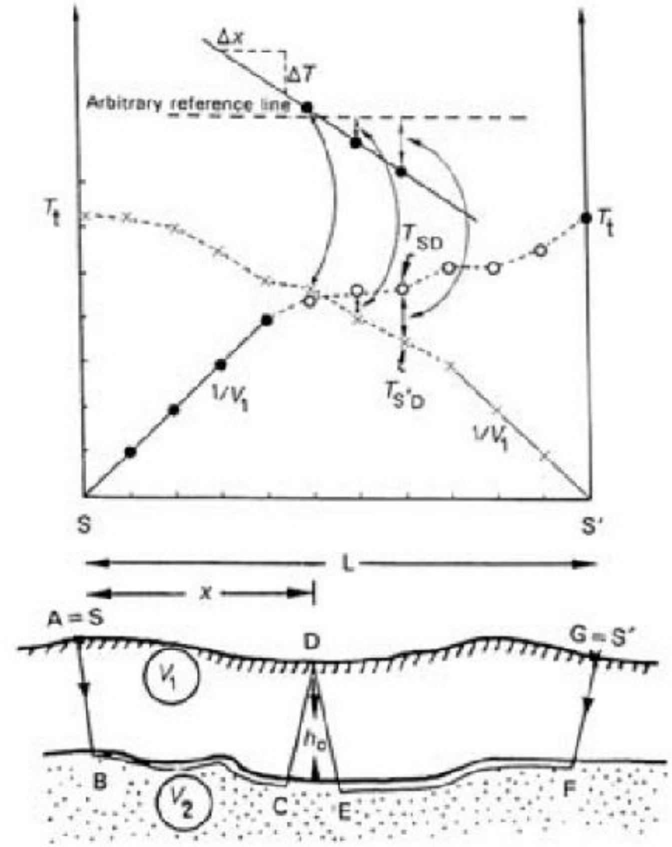
"minus"

Subtracting the equations for T_{SD} and $T_{S'D}$ we obtain the equation:

$$T_{SD} - T_{S'D} = \frac{2x}{V_2} - \frac{L}{V_2} + \Delta T_S - \Delta T_{S'}$$

$$y = ax + b$$

- Plotting (T_{SD} - $T_{S'D}$) against x the slope is $2/V_2$
- Variations in the slope reflect lateral variations in velocity



The plus-minus method

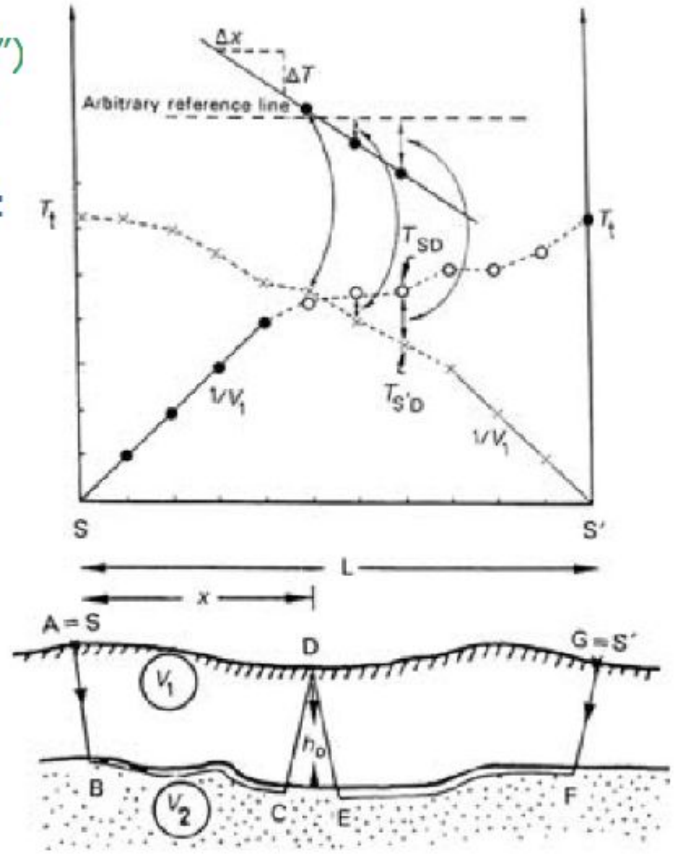
Given the delay time ΔT_D, (from the "plus") and the velocities V_1 (from direct arrival) and V_2 (from the "minus)

We can calculate the perpendicular depth:

$$\Delta T_D = \frac{h_D \sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

Note: we need to see refracted arrivals from both forward and reverse shots (three geophones only in figure)

Use long offset shots to collect necessary data for all geophones

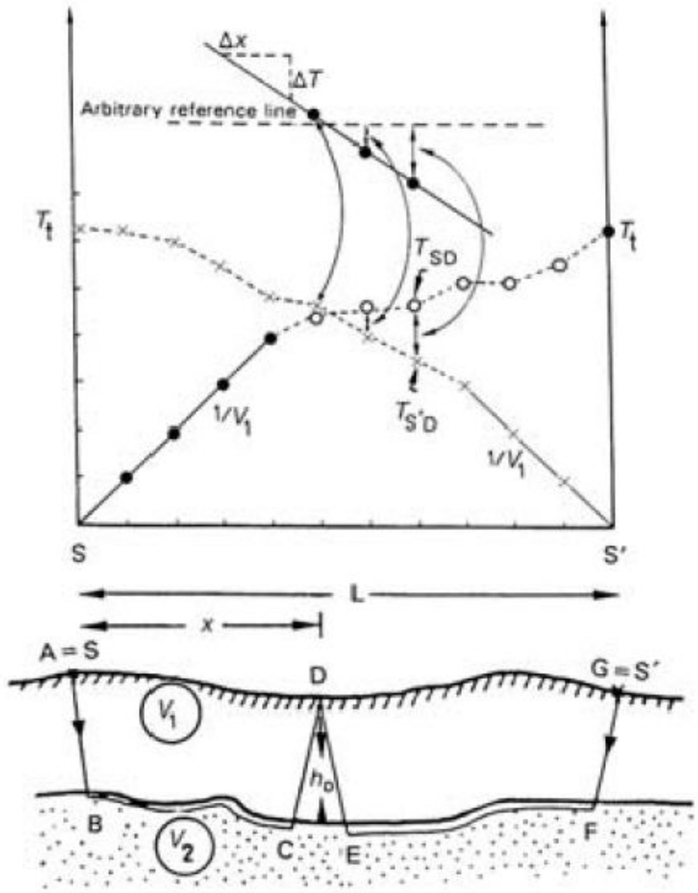


The plus-minus method

Assumptions and approximations

1. The relief on the refractor must be small compared to the depth
2. Geometric relations assume a small refractor dip (dip < 10 deg)
3. Refractor assumed to be planar between the two points of emergence to a given geophone (ie between C and E)

   So that ΔT_D is equal when shooting from both sides

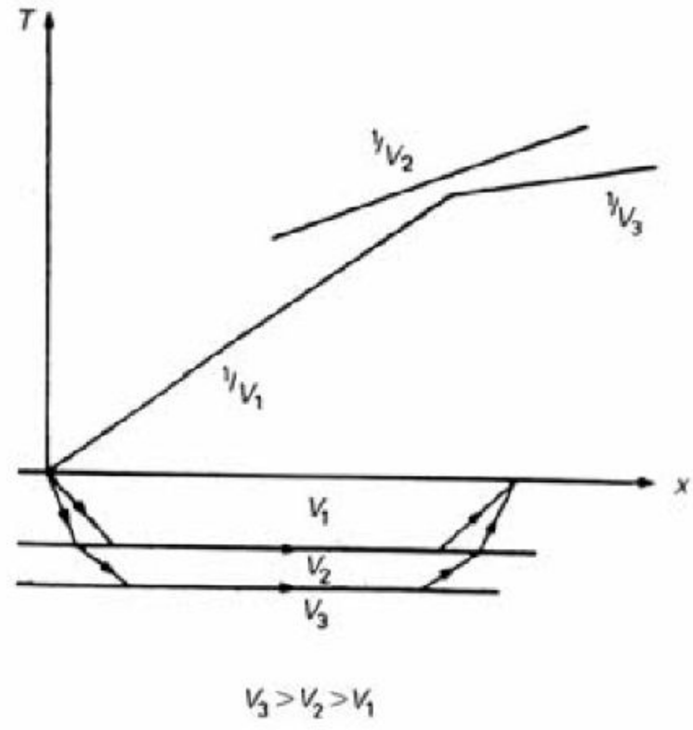


Limitations
Hidden layers

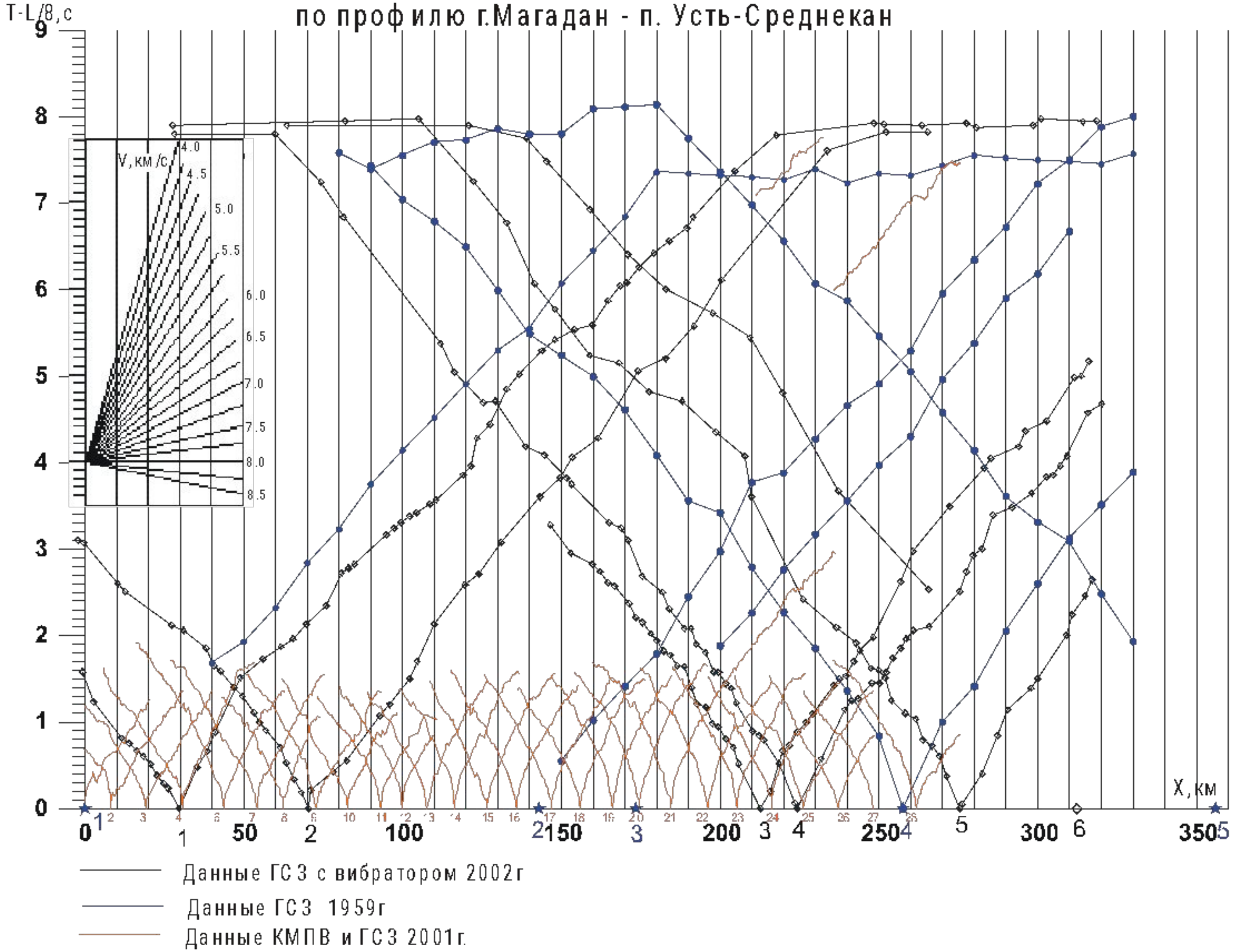
- **If a layer is thin it may never produce a first arrival**

  Either the direct or refraction from a lower (much higher velocity layer) is always first

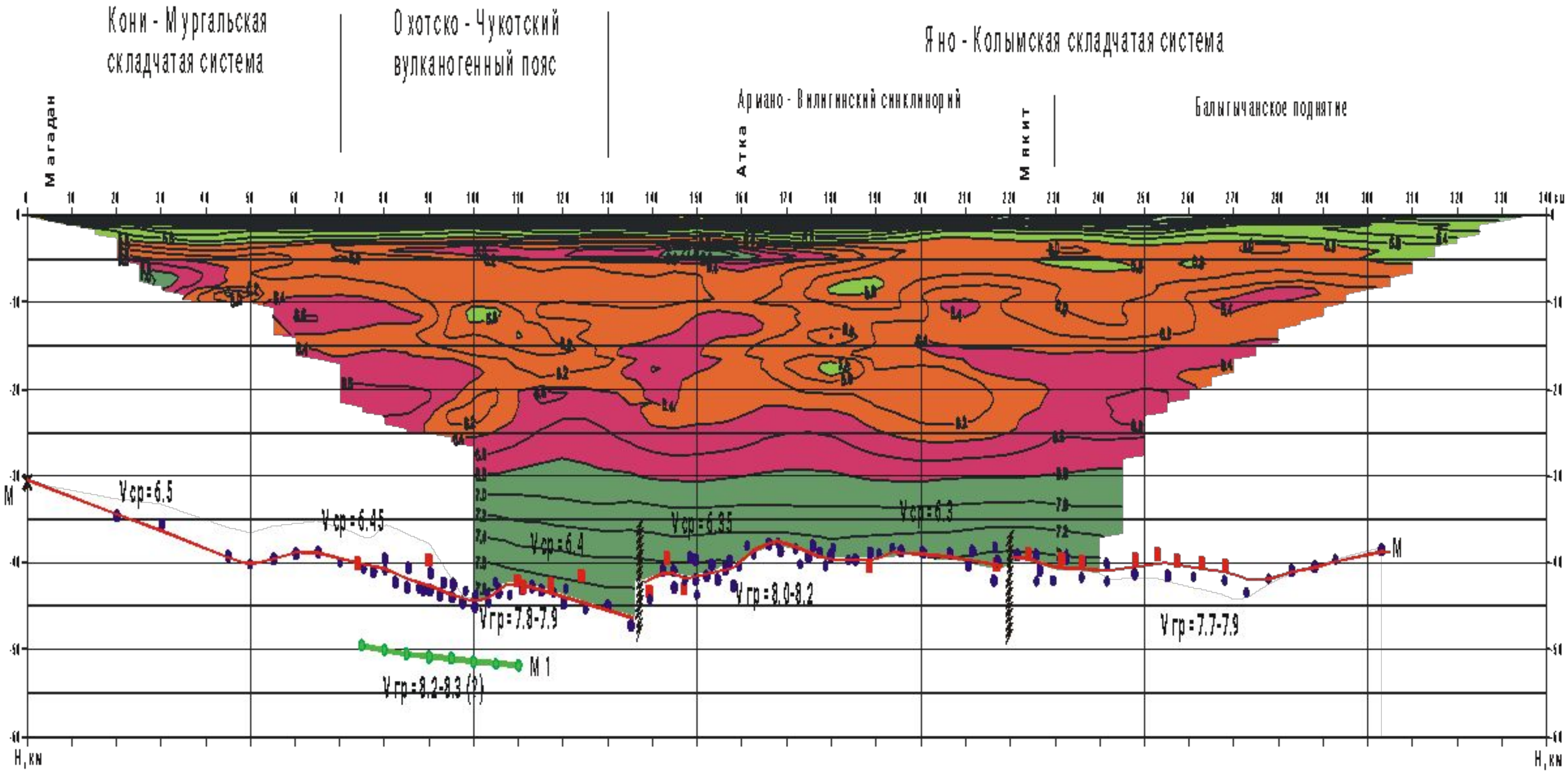
- **Lower layers always appear too shallow as a layer has been missed**



Редуцированные годографы волн в первых вступлениях по профилю г.Магадан - п. Усть-Среднекан



Сейсмотомографический разрез по Южно-Магаданскому участку профиля 2-ДВ (по материалам ГСЗ и КМПВ)



Условные обозначения

Глубины до поверхности Мохоровичича по данным отраженных и преломленных волн, с карты рельефа М (морские работы 50-х годов) Х Глубины до поверхности М1(?) по данным широкоугольных отраженных волн

Граница М — Граница М1 — Vср, Vг Значения средних и граничных скоростей в км/с — Слои консолидированной коры: Гранитогнейсовый, Гранулитовый, Базитовый

Зоны изменения граничных скоростей по поверхности Мохоровичича (возможные зоны глубинных разломов)