

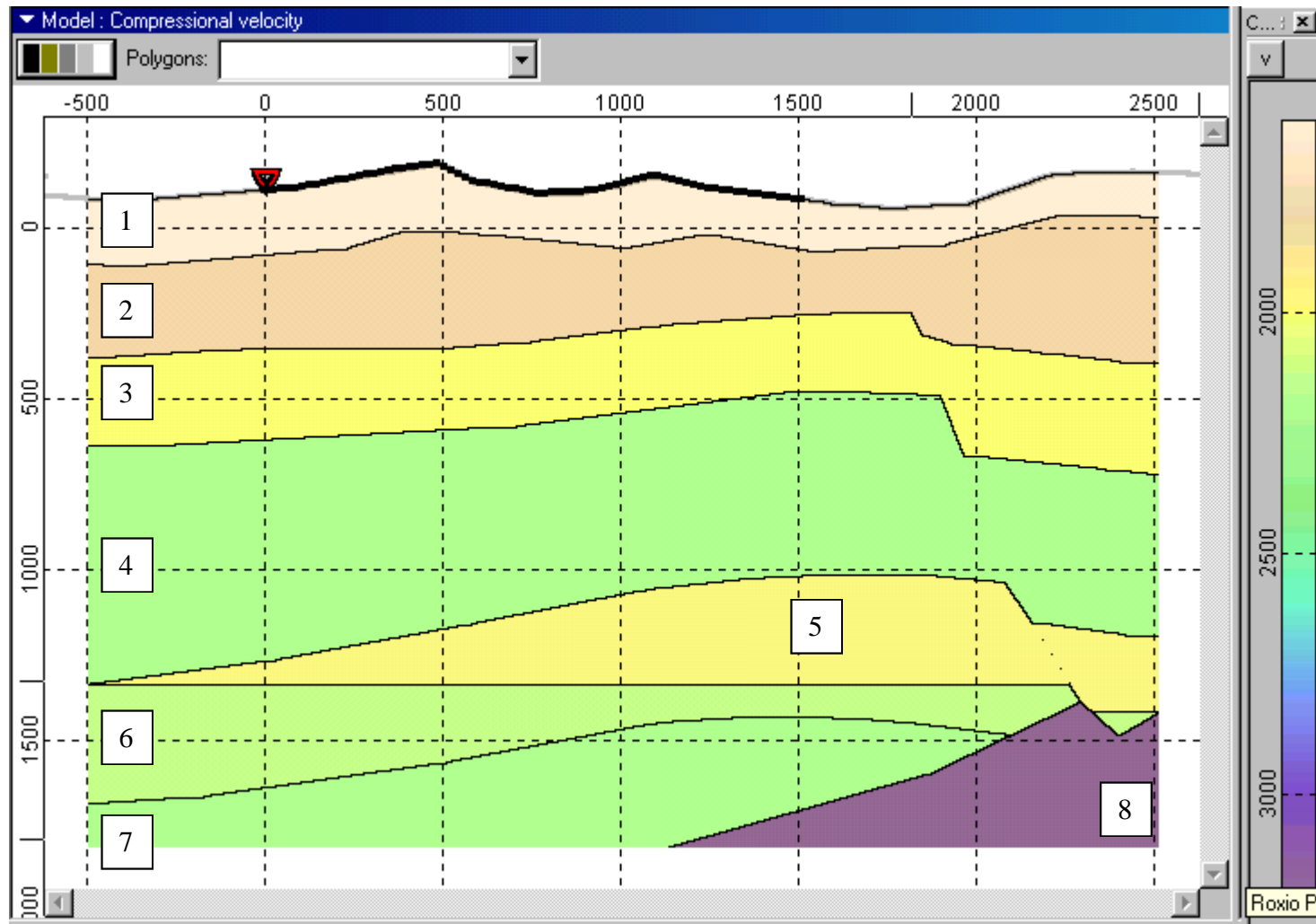
# AVO modeling in TESSERAL package

- **AVO modeling can be performed for complex media:** isotropic, anisotropic, absorbing, gradient, thin-layered, for plain and curved reflecting boundaries.
- Package estimates the **influence of complex geological structure on the measured AVO attributes.**
- **AVO modeling can be done in anisotropic medium for different angles of reflecting boundary and anisotropy axes.**
- **Influence of thin-layering and Q attenuation on AVO effects** in seismic frequencies band can lead to skipping of big multilayered deposit



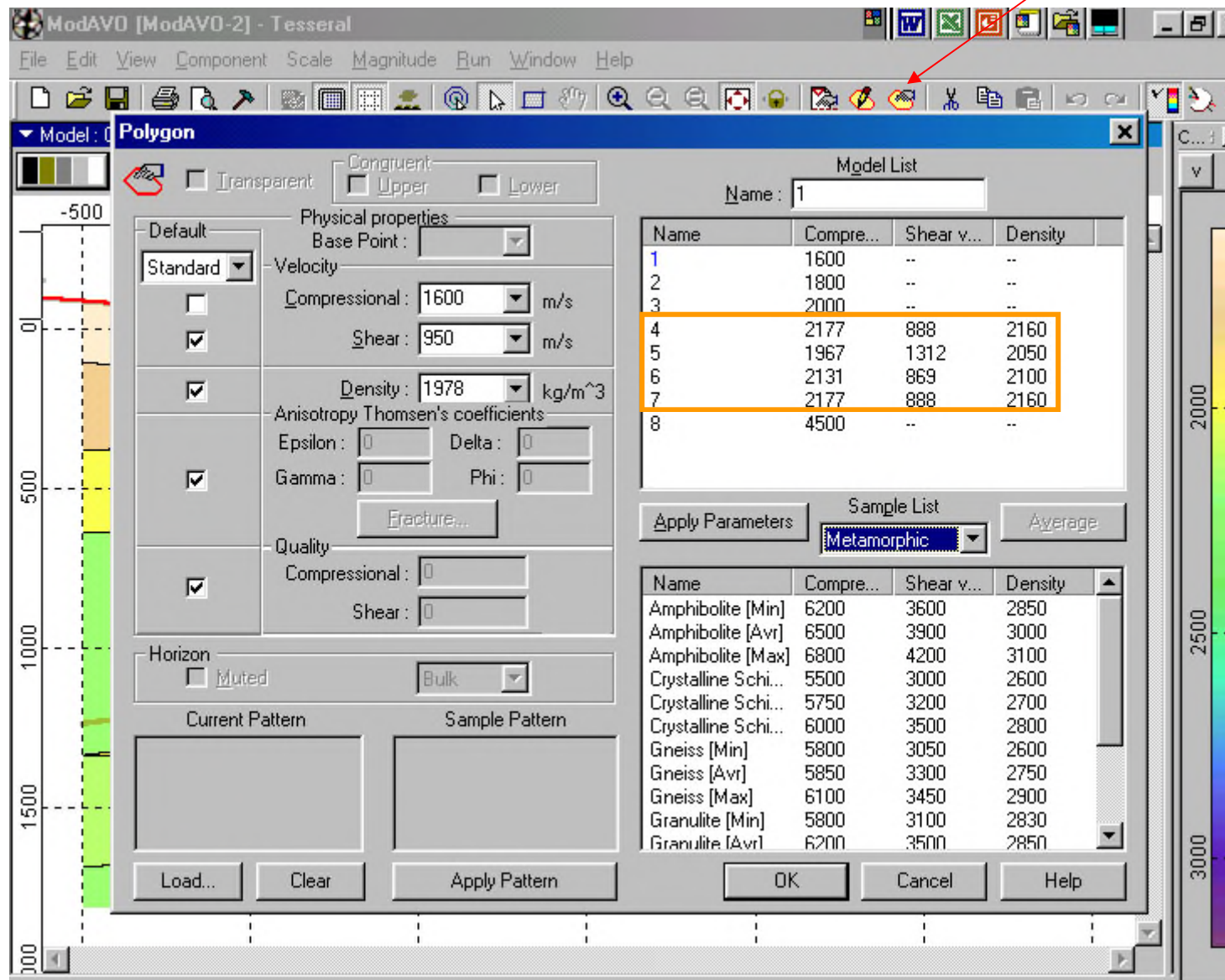
[www.tesseral-geo.com](http://www.tesseral-geo.com)

# Workflow



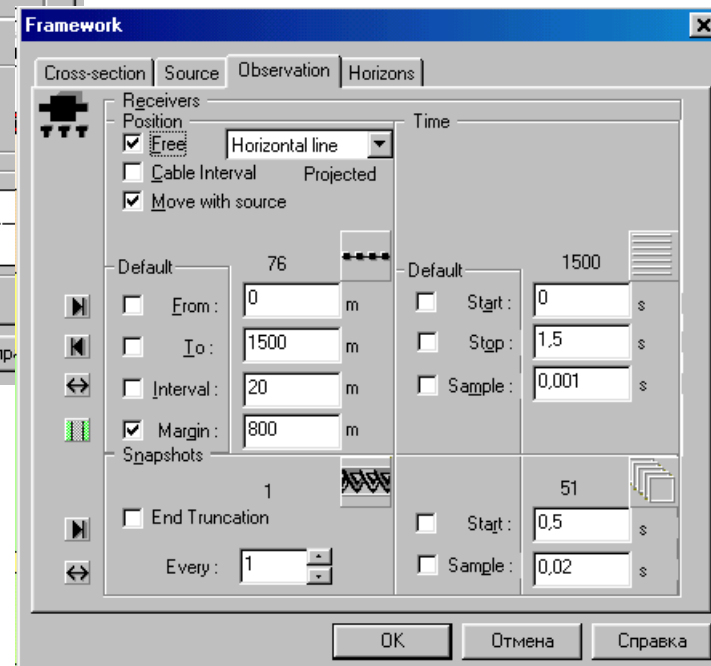
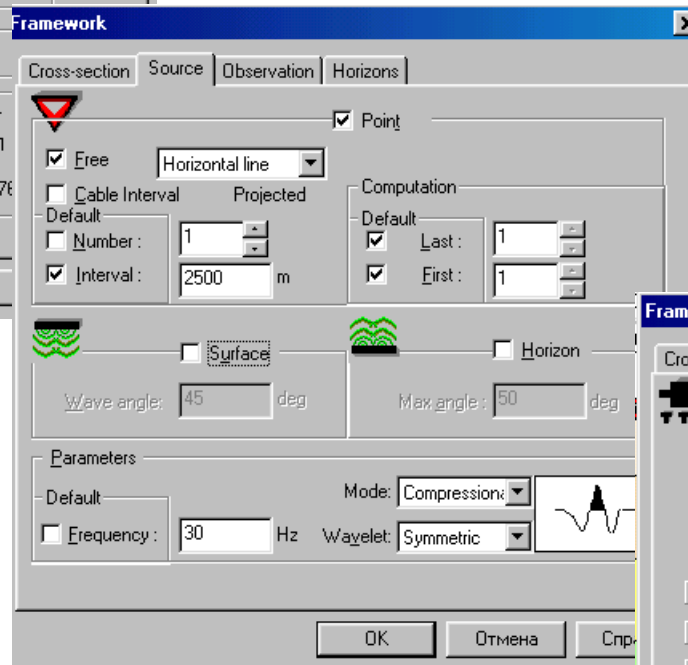
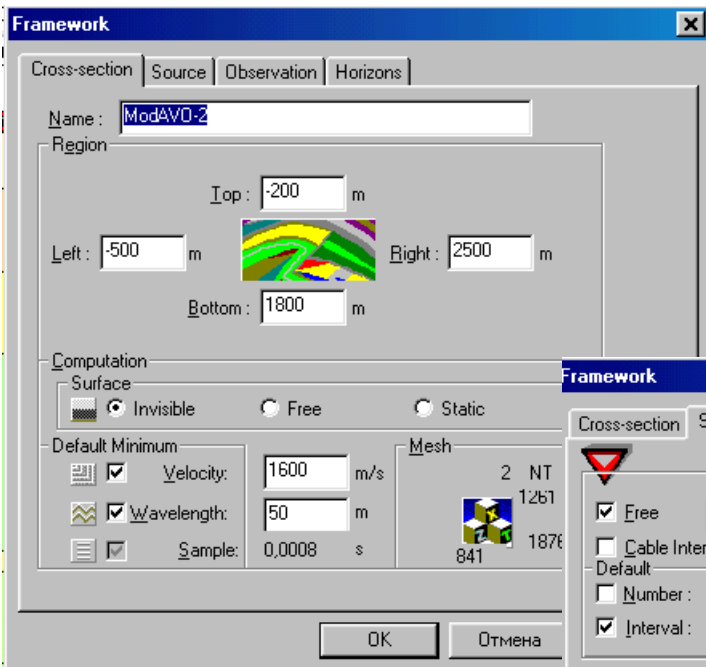
**Source model**

## Layers velocity and density parameters appear after pushing toolbar button

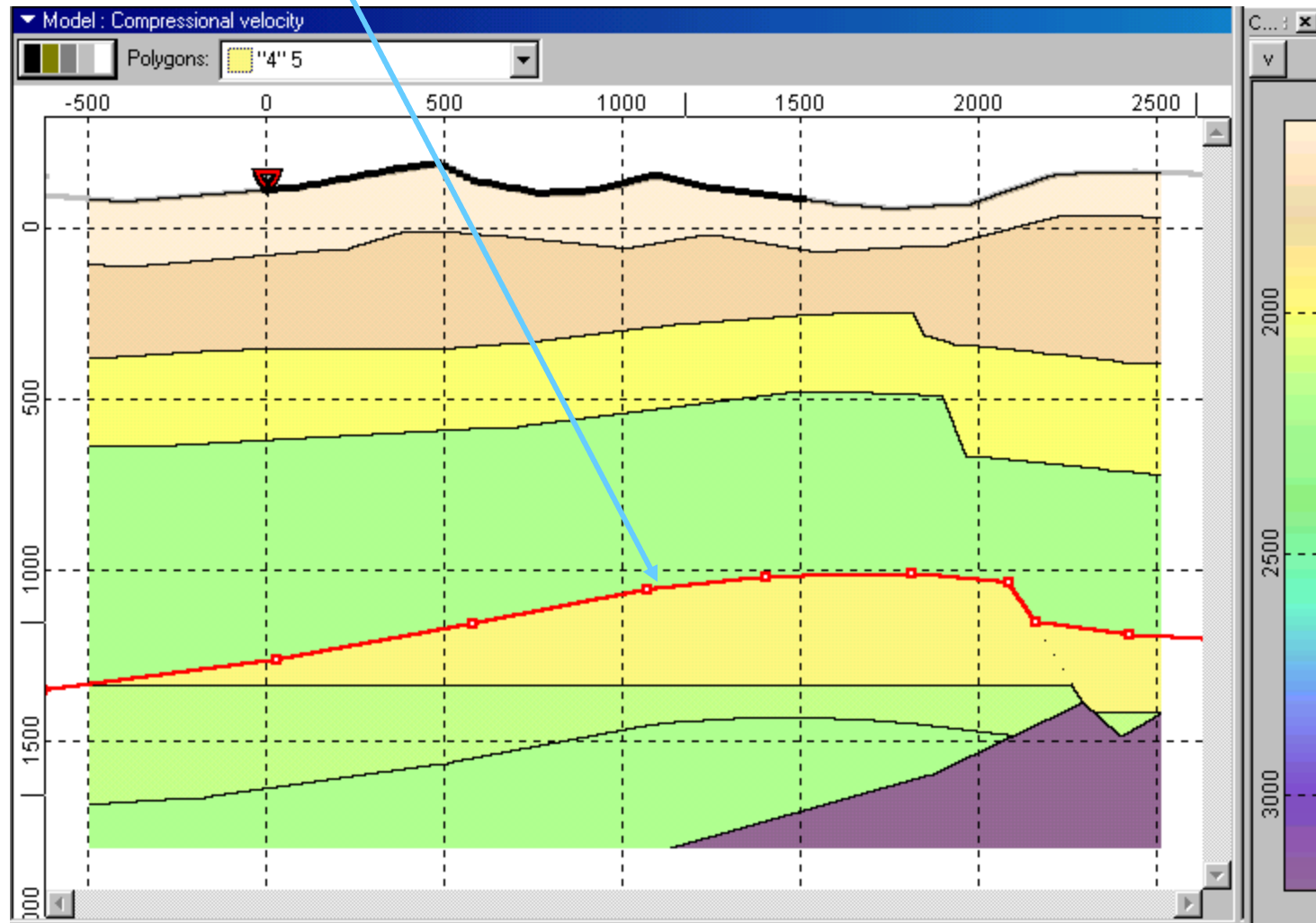


Within rectangle are shown parameters of layer 4,5,6 and 7, which constitute Ostrander's model used as example at AVO modeling.

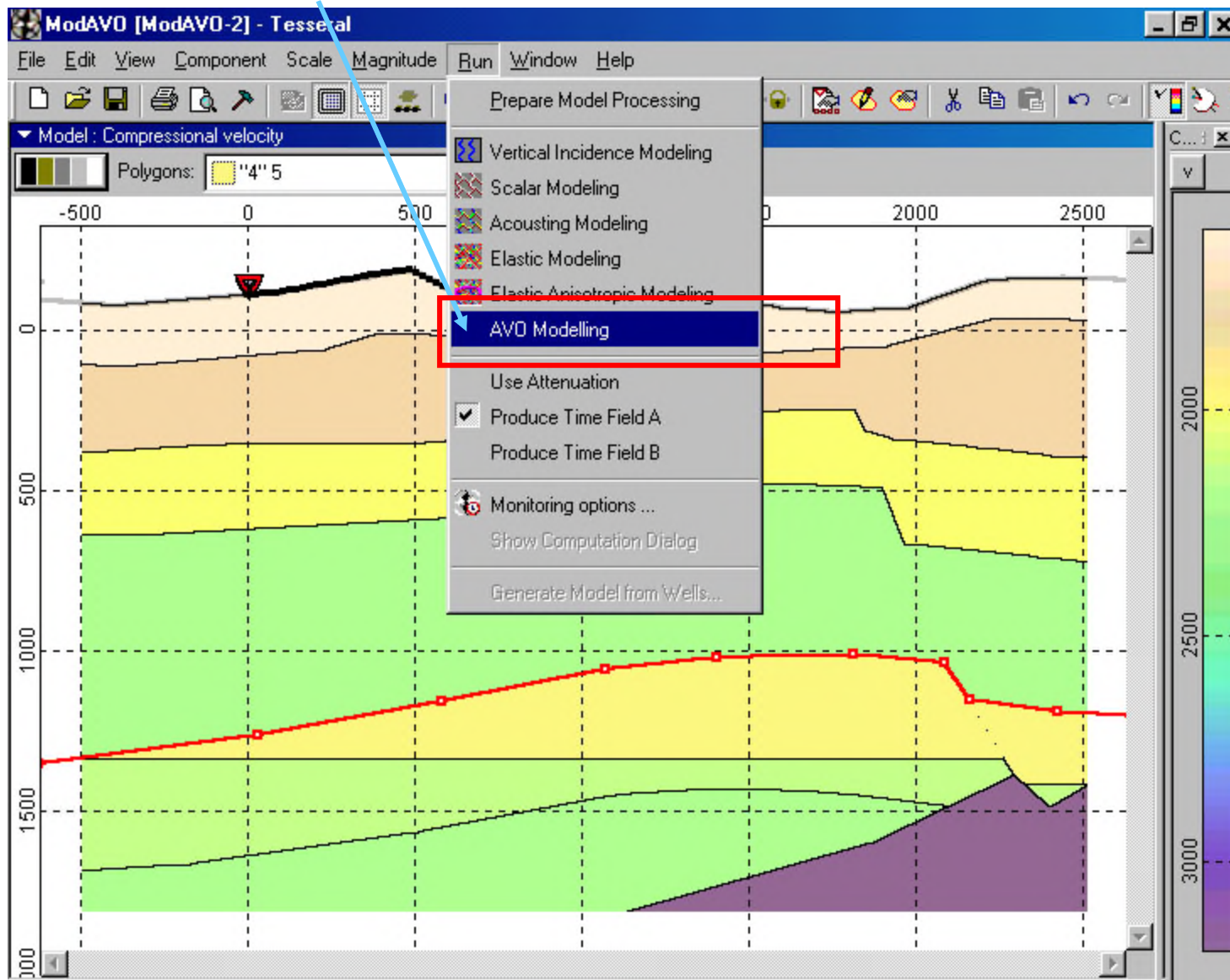
Model parameters which were entered using pages of «Framework» dialog.



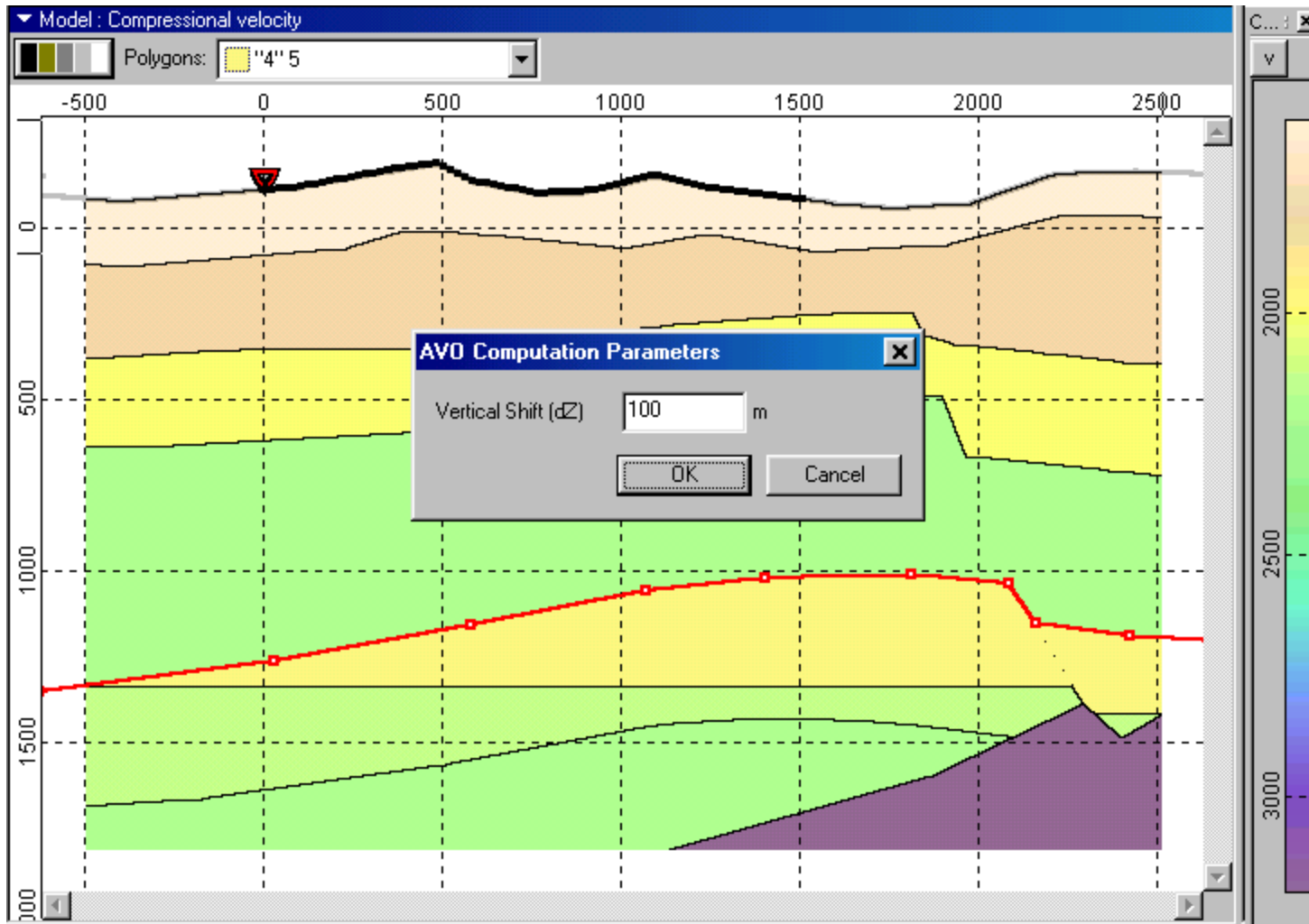
Select the target boundary (for which AVO modeling will be done)



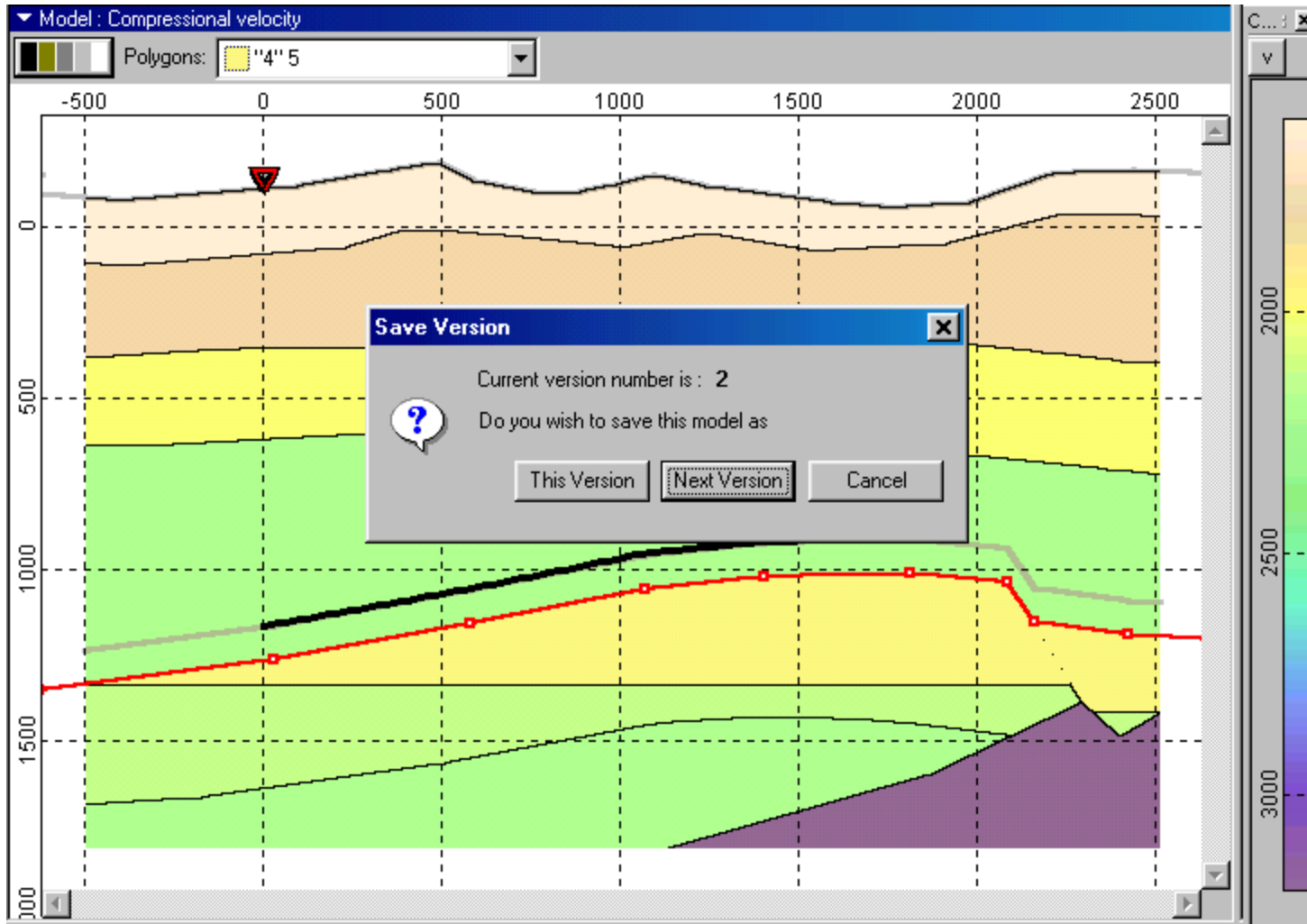
Menu item *Run* shows modeling modes.  
Choose *AVO Modeling*.



After pushing *AVO Modeling* appears dialog where value of shift over active target boundary is entered. It is enough in this to have 100m for reliable reflection correlation.

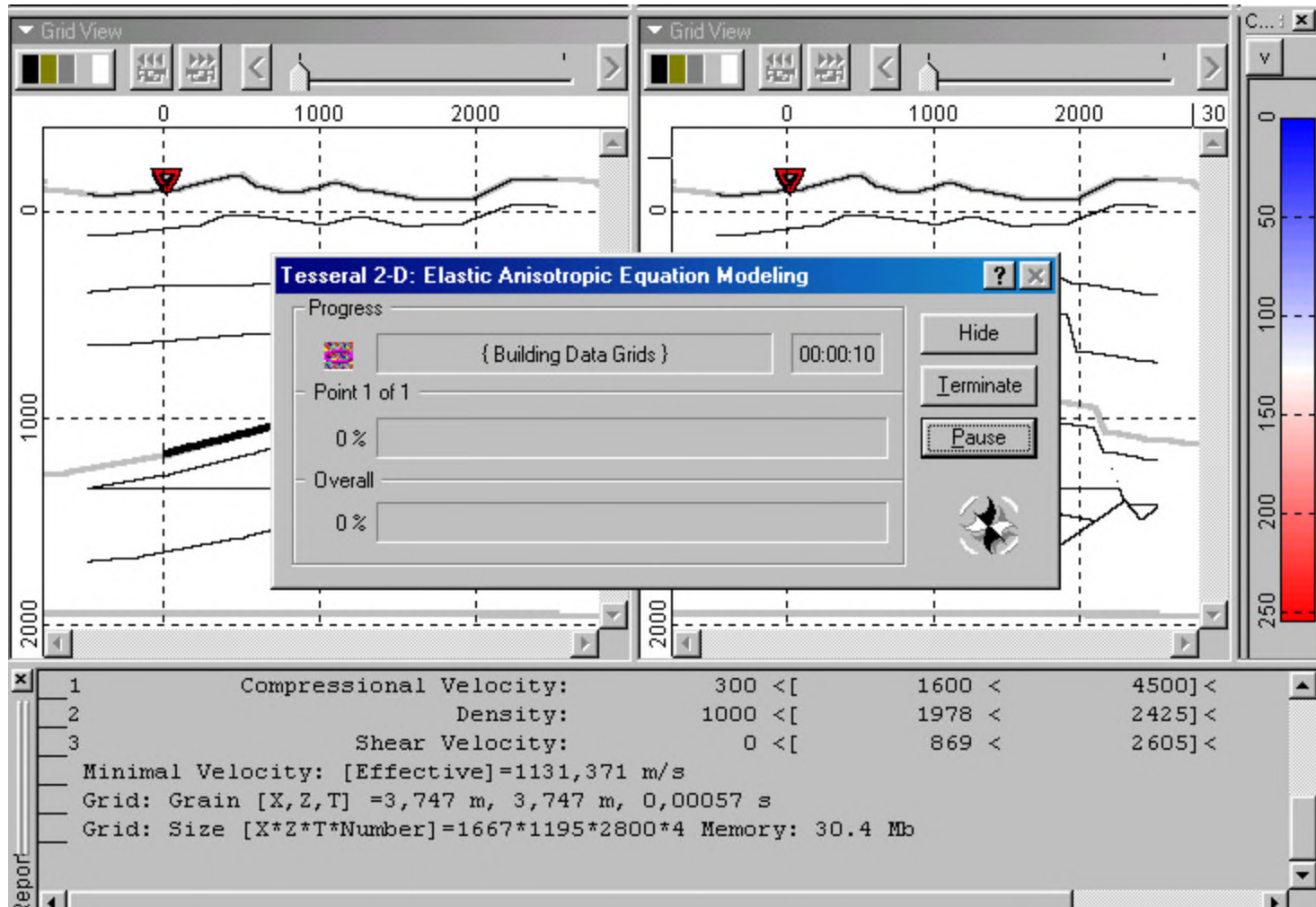


Then request about saving of modified (with shifted receiver line over target boundary) model appears.

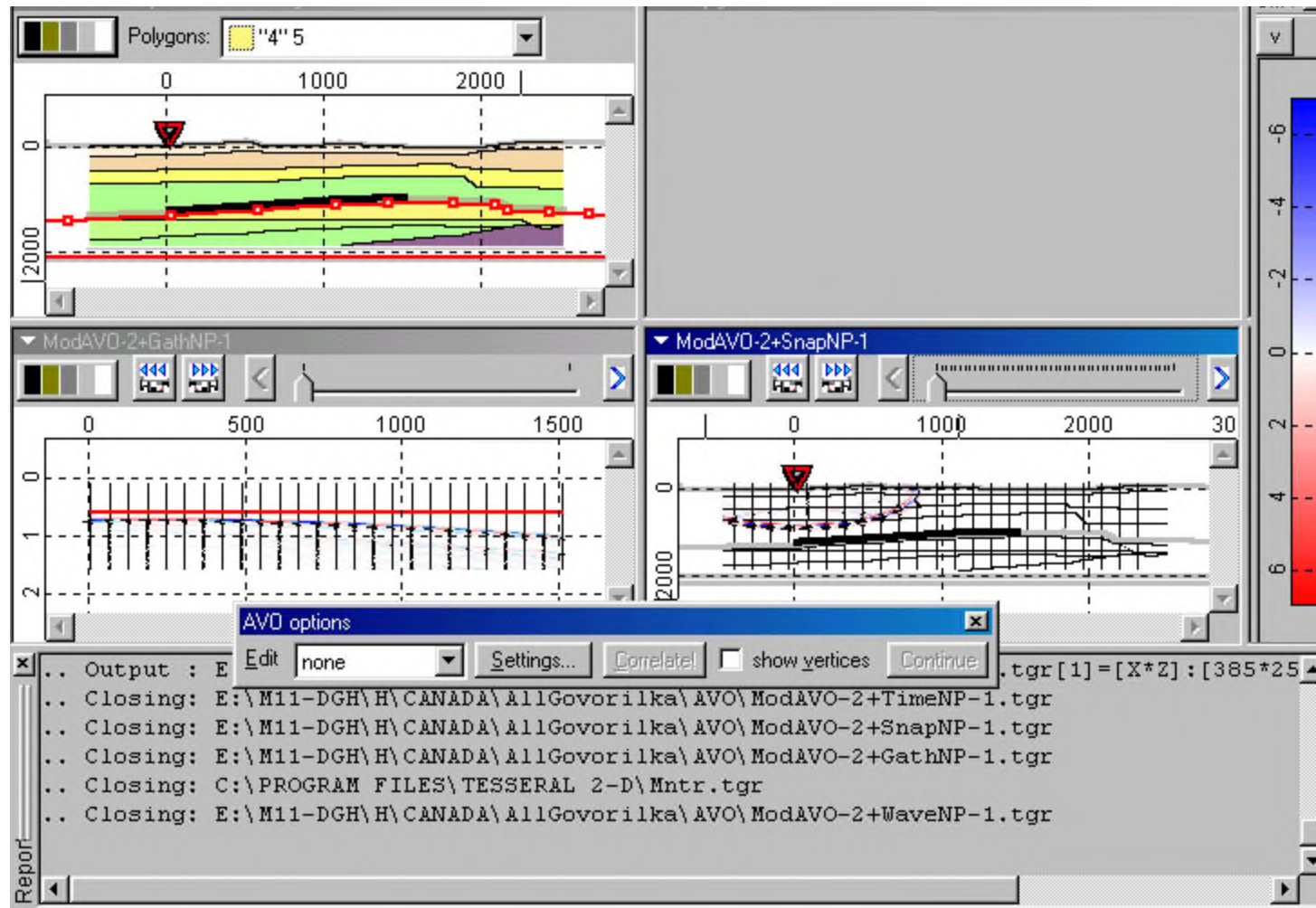




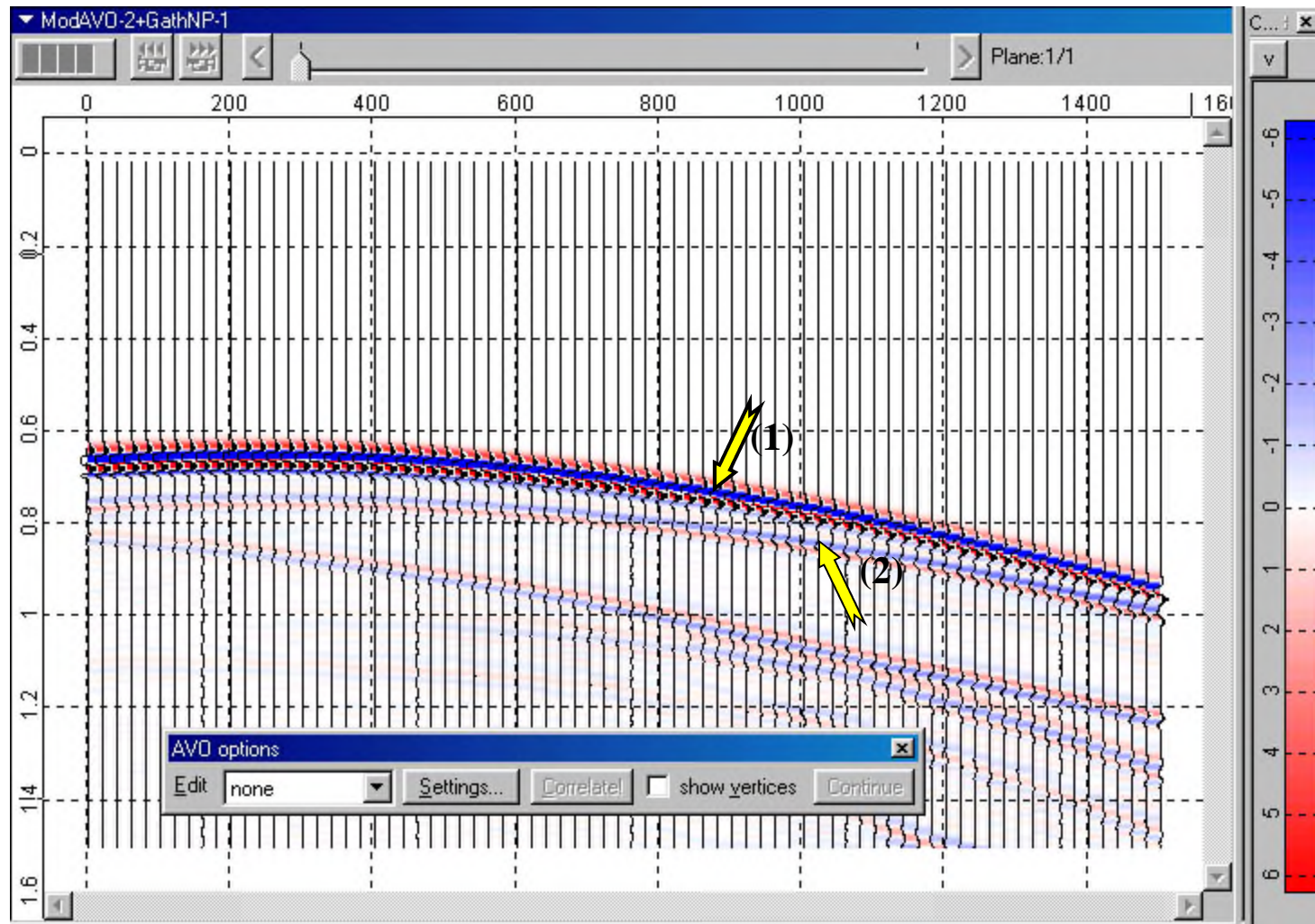
**Window at initial calculation stage.**  
**Current report is presented in lower panel.**



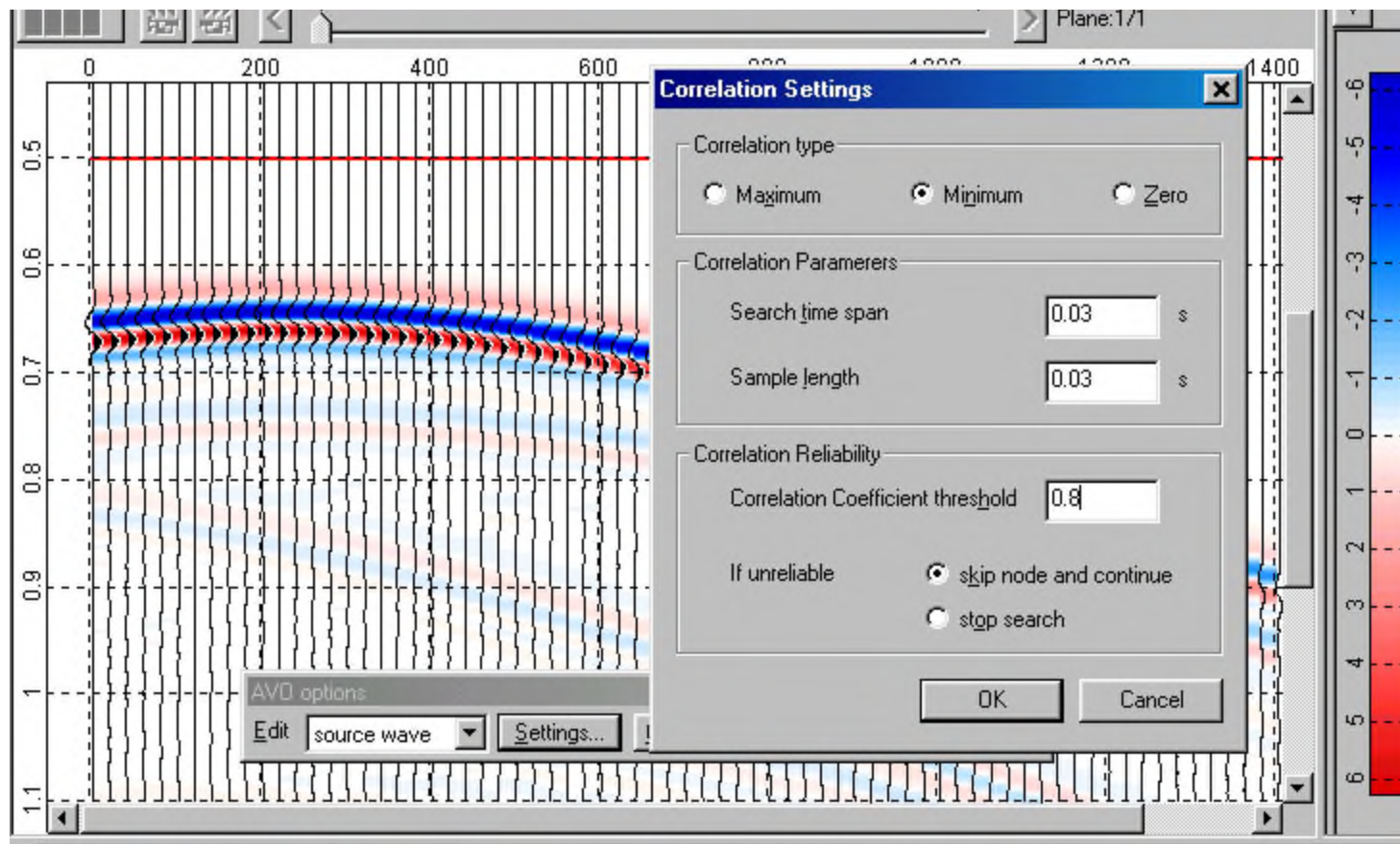
Window after calculation is finished : upper left panel – source model; lower left panel - synthetic shotgather (ModAVO-2+GathNP-1.tgr); lower right panel – wavefield snapshot at its start time (ModAVO-2+SnapNP-1.tgr). Calculated time field ( ModAVO-2+TimeNP-1.tgr) can be visualized in regular manner. Dialog «AVO options» appears automatically and allows manipulate with AVO calculations.



To better correlate source and reflected wave it is useful to magnify image, and fit appropriate signal amplification. In given shotgather with arrows are shown: incident source wave (1) and target reflected wave (2).

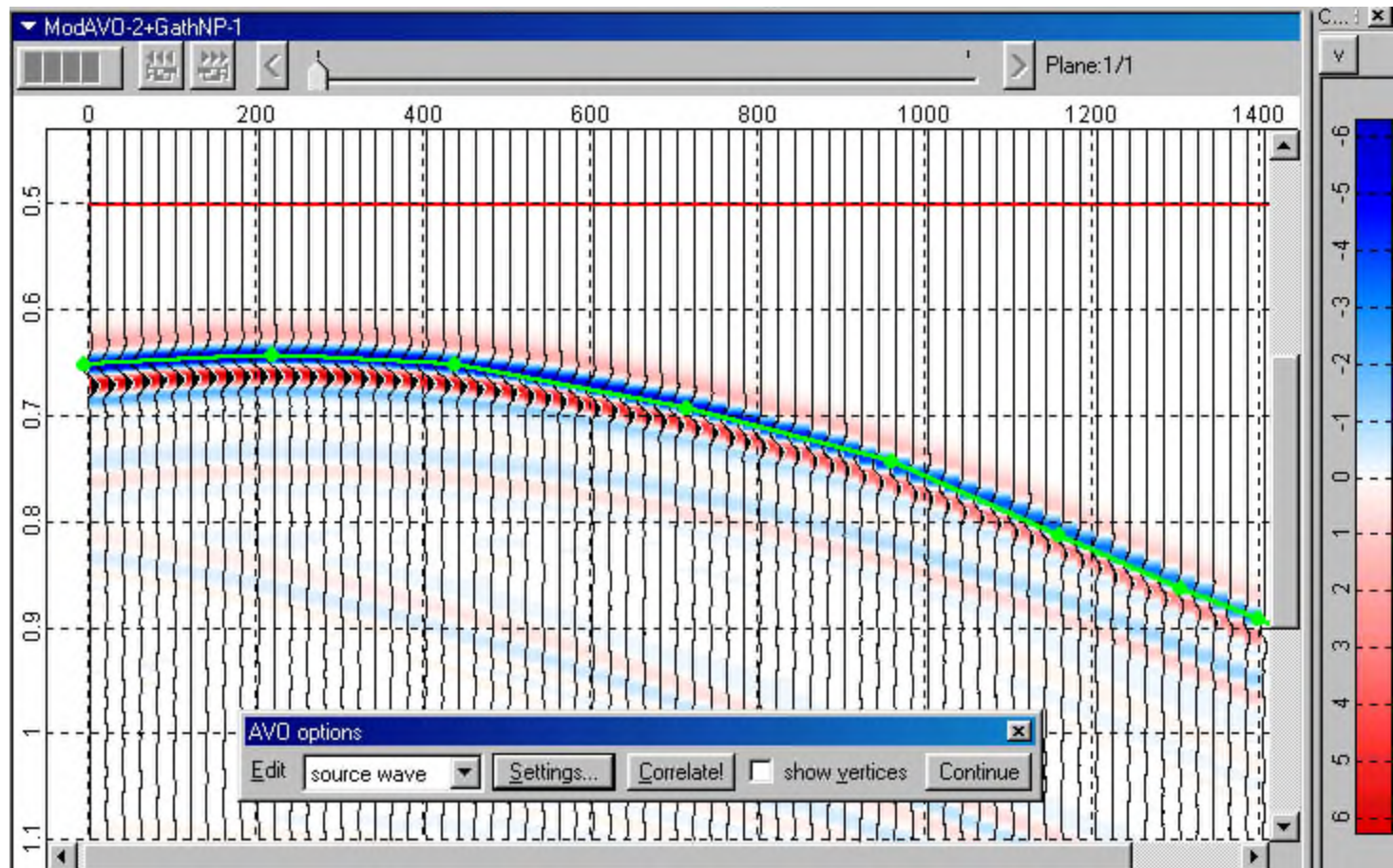


In “AVO options” dialog let initially choose incident wave (source wave). After pushing «Settings» button «Correlation Settings» dialog appears. Choose correlation type by *Minimum* (when free observation surface effect is suppressed (*Invisible*, Fig.3) propagating downward signal has negative polarity). In time window for searching maximum of correlation function (*Search time span*) and in one for comparable signals (*Sample length*) correspondingly enter 0.03 s and 0.03. Correlation coefficient threshold (*Correlation Coefficient threshold*) value let be 0.8. Below this value there is no automatic correlation.

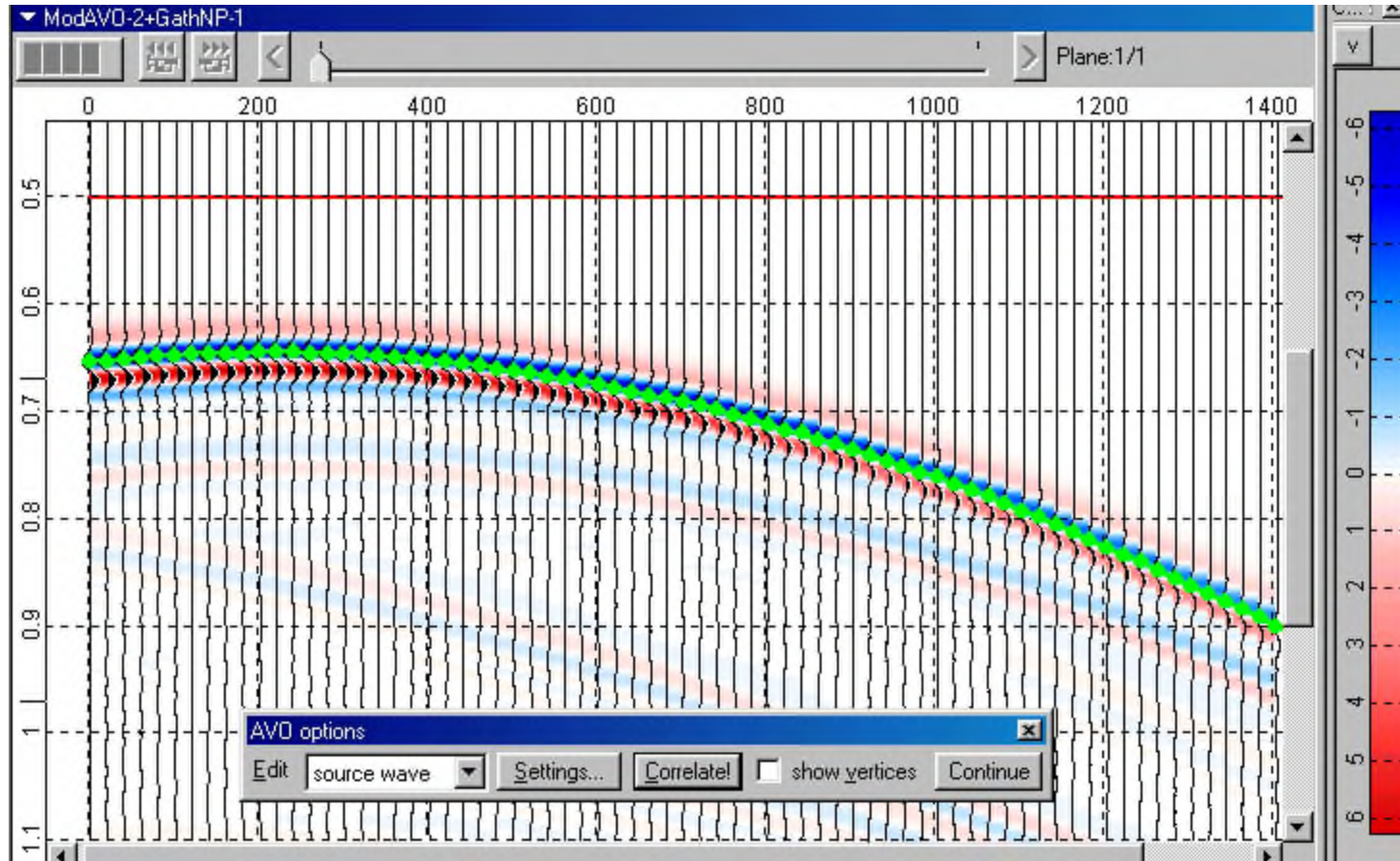




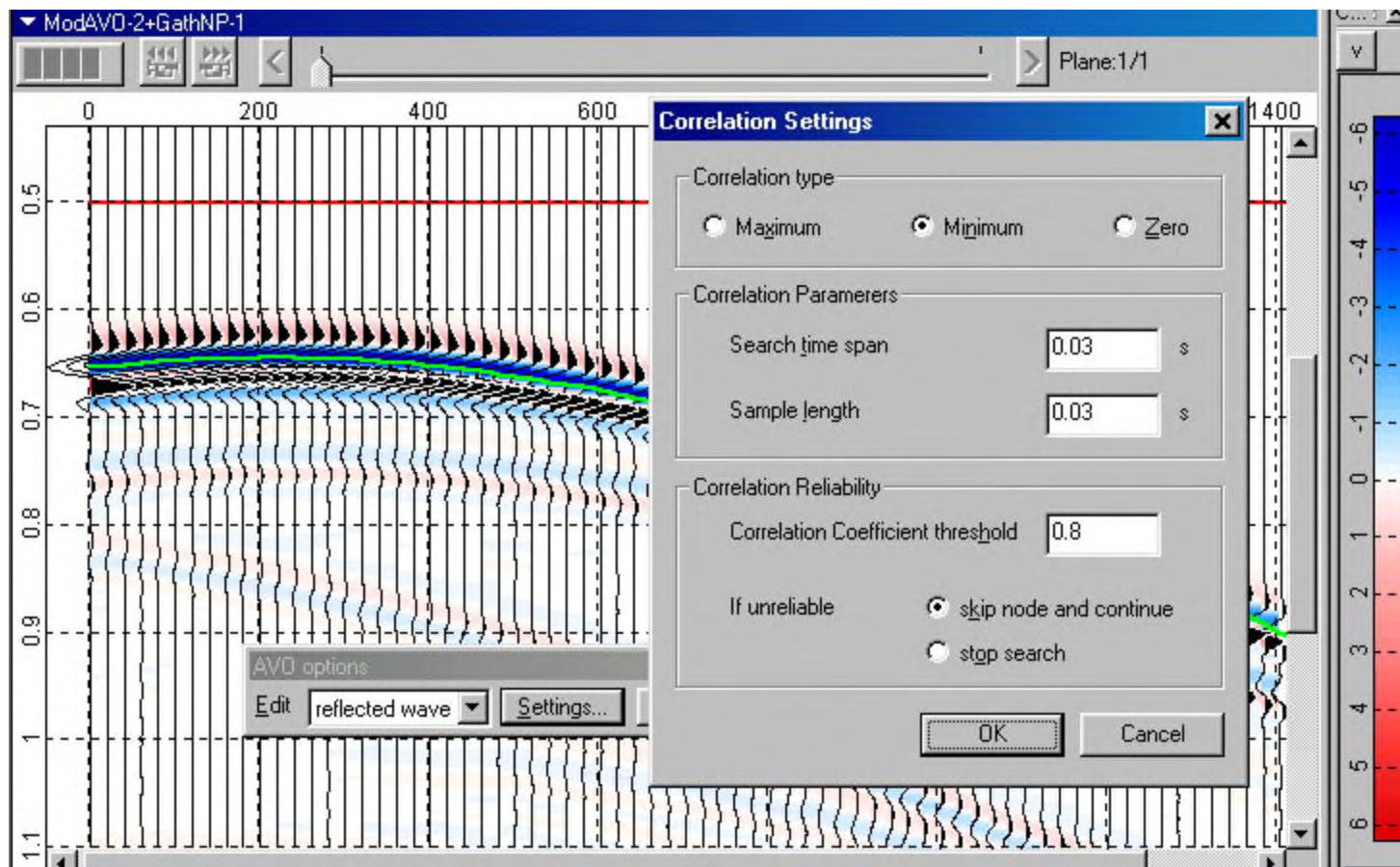
Sparsely pointing with left mouse button (LMB) let trace incident wave minimum. Right mouse button clicking ends correlation line tracing.



Pushing «*Correlate*» button in “*AVO options*” dialog leads to automatic target boundary correlation.

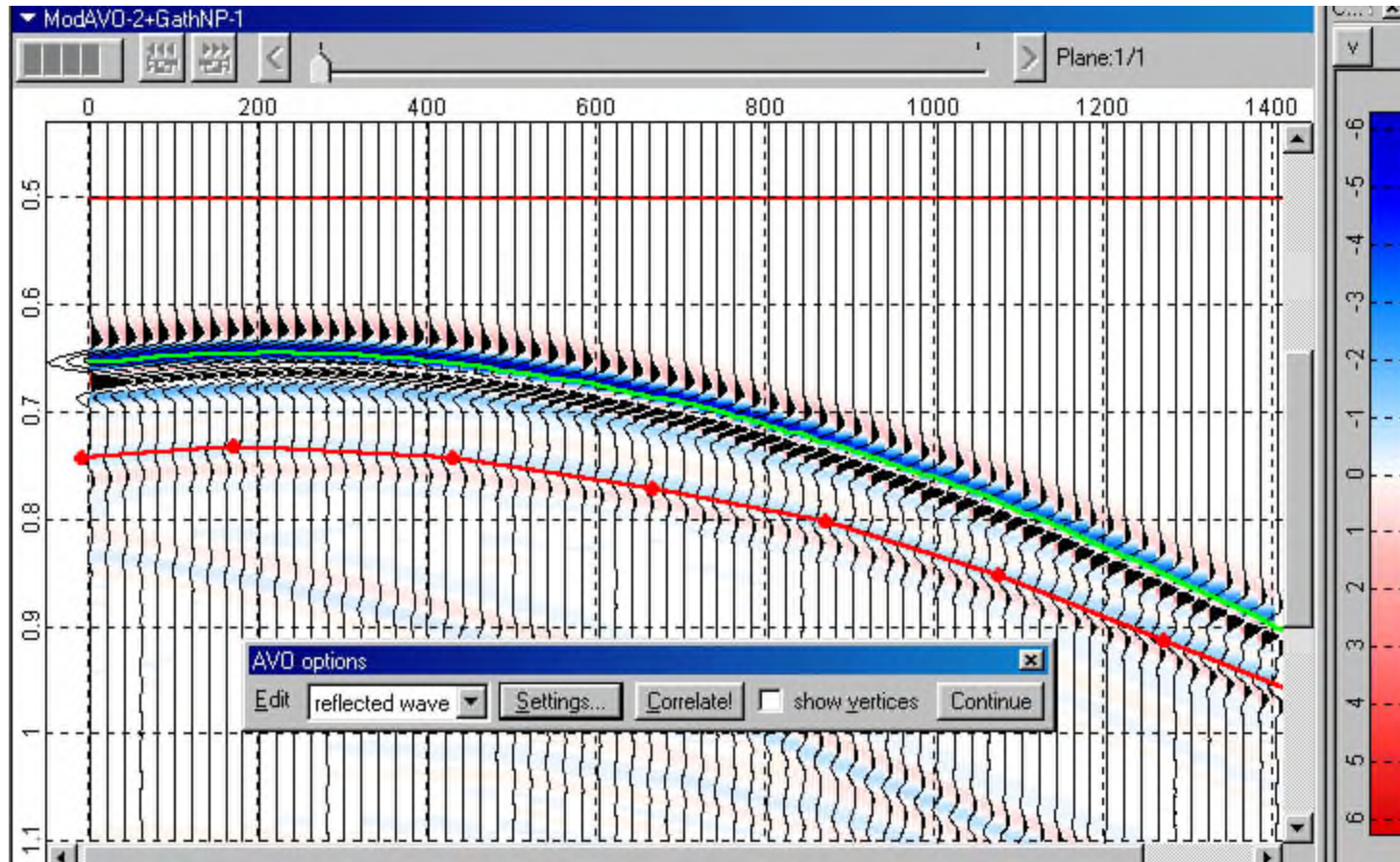


Similar sequence of actions is applying for correlation of target reflected wave. In «*Edit*» control in «*AVO options*» dialog choose «*reflected wave*». In «*Correlation Settings*» dialog leave in this case previously set parameter. Let notice, that choosing minimum as main reflected wave extreme is caused by negative reflection coefficient on the target boundary in given model.



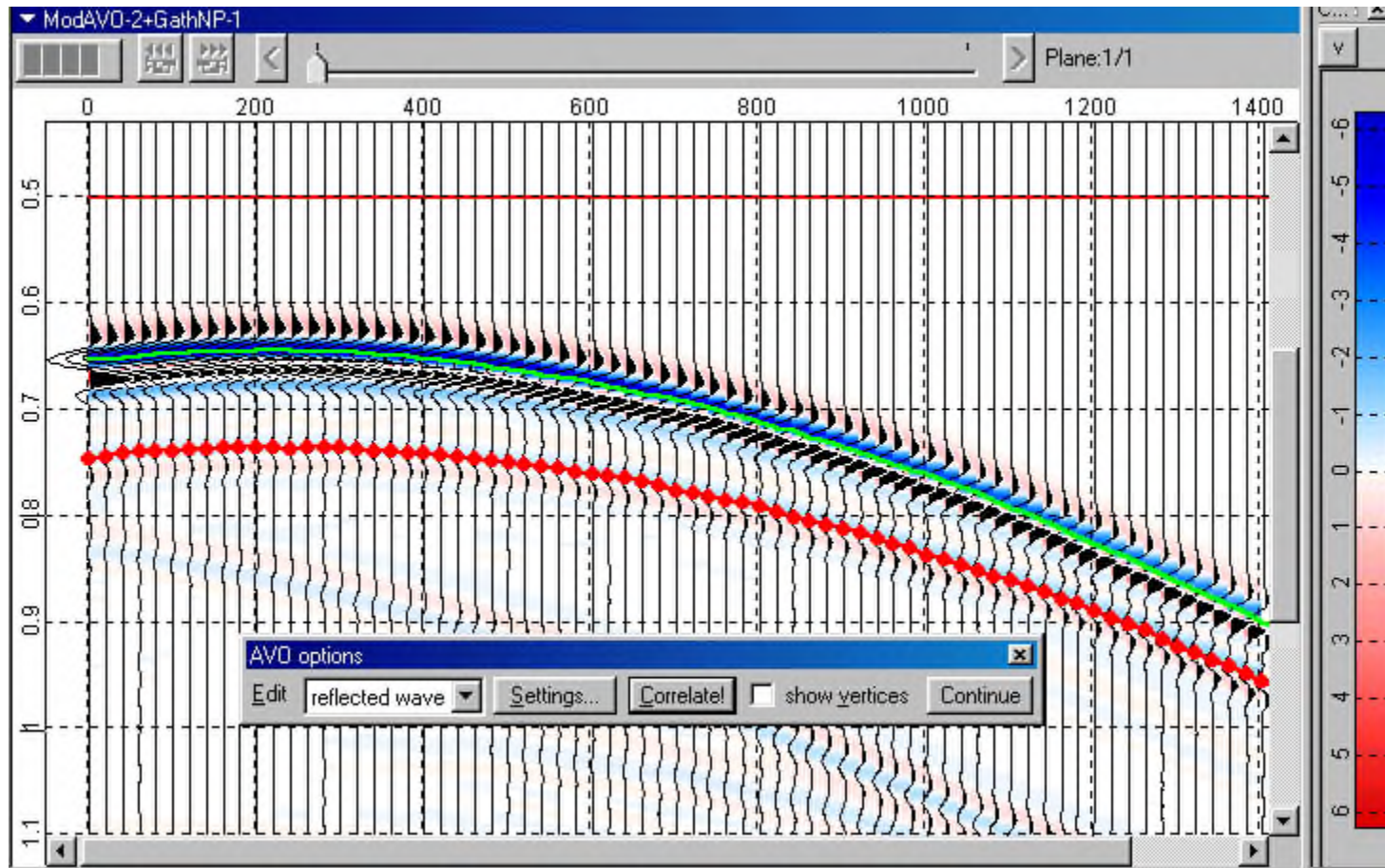


After manual correlation of reflected wave minimum panel looks in like this.

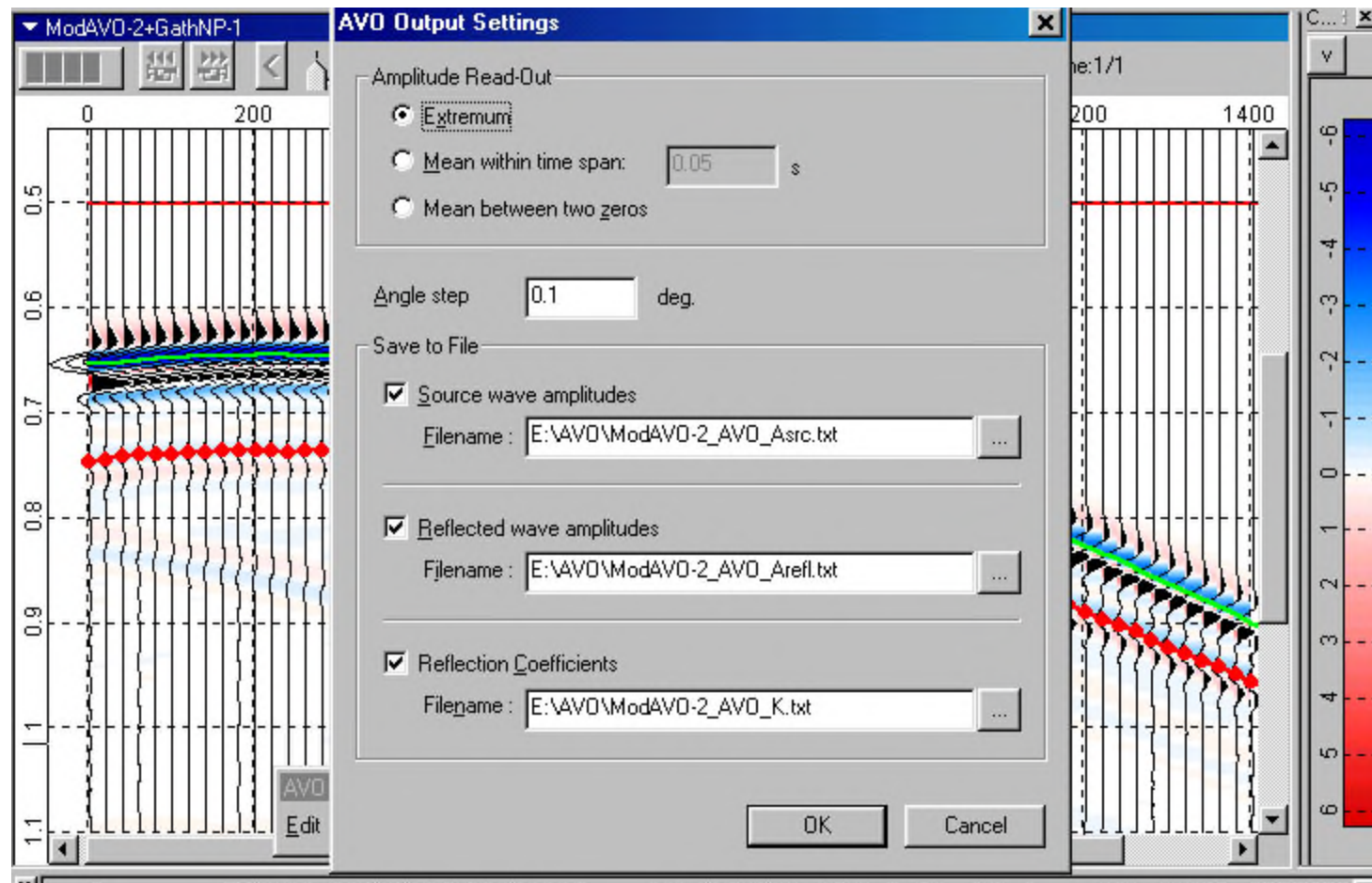




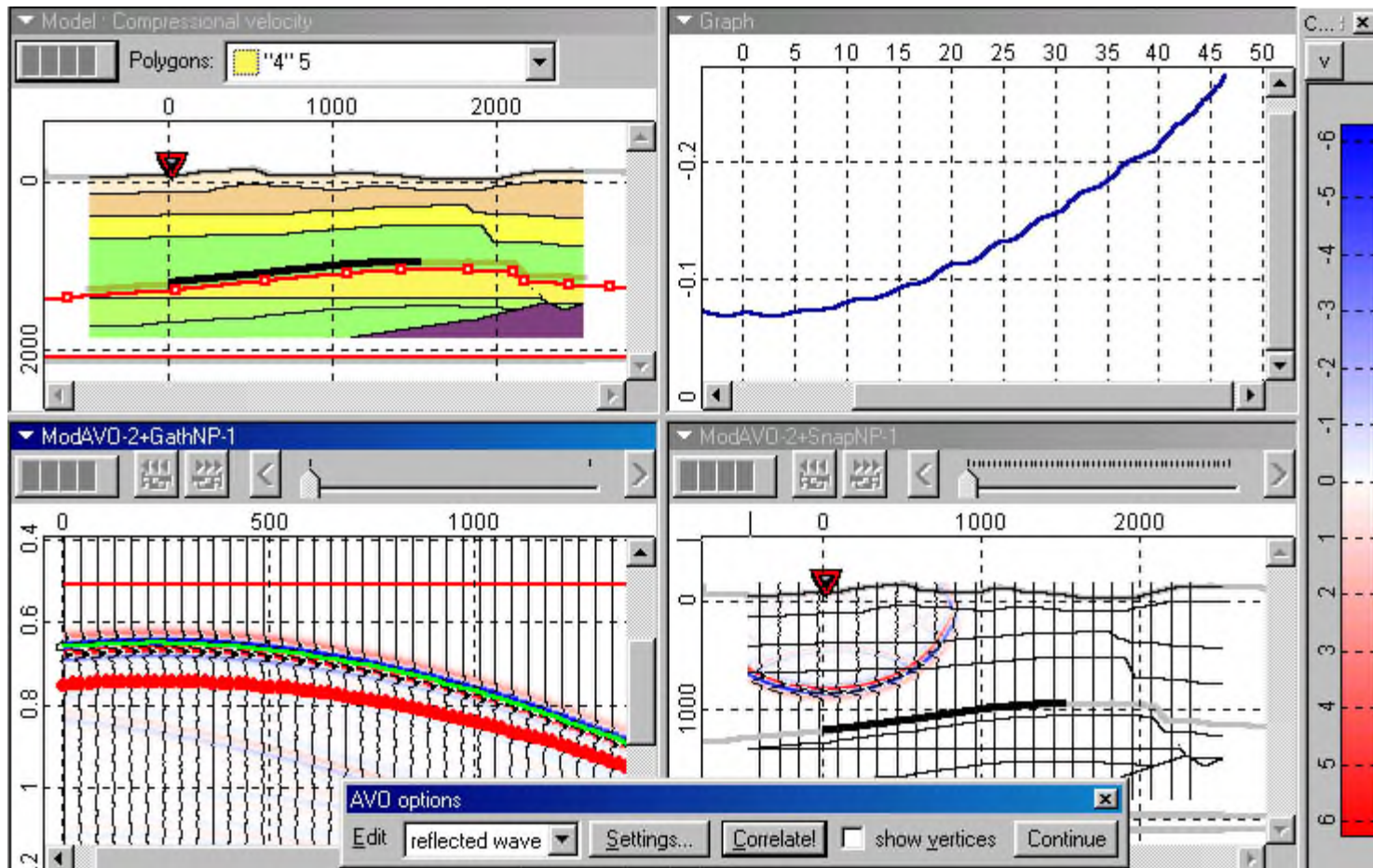
After pushing button «*Correlate*» in «*AVO options*» dialog automatic correlation of reflected wave is executed and panel looks like this.



After pushing button «Continue» in dialog «AVO options» appears dialog «AVO Output Settings», where leave defaults: *Extremum* – calculation of AVO using signal extremums, *Angle step* – step of AVO calculation by 0.1 degree and paths and names of resulting text files (incident (source) wave amplitude, reflected wave amplitude and AVO (reflection coefficient) value).

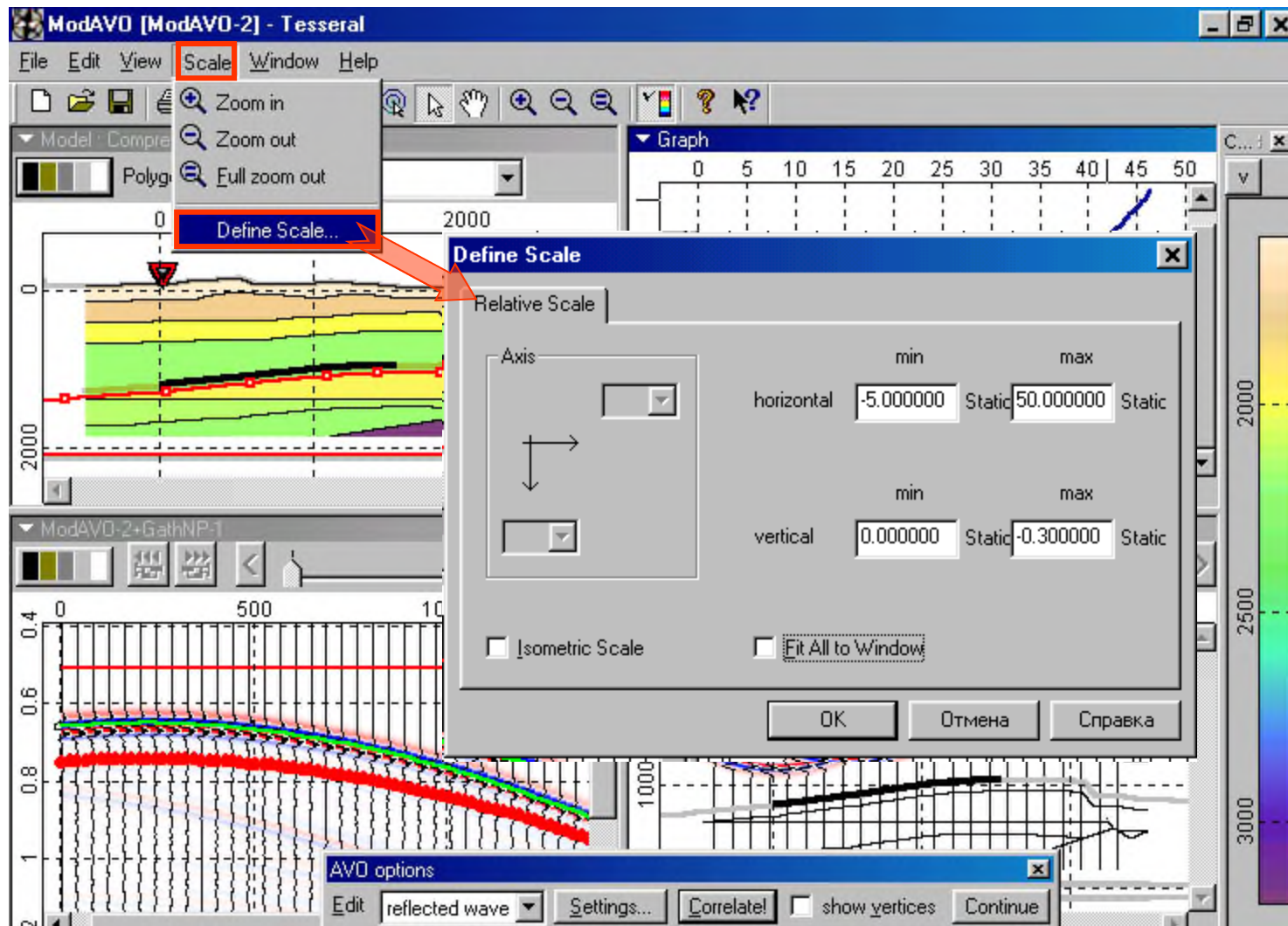


After dialog «AVO Output Settings» is complete image of AVO graph appears in right left panel (*Graph*) - reflection coefficient values as function of wave incidence angle.

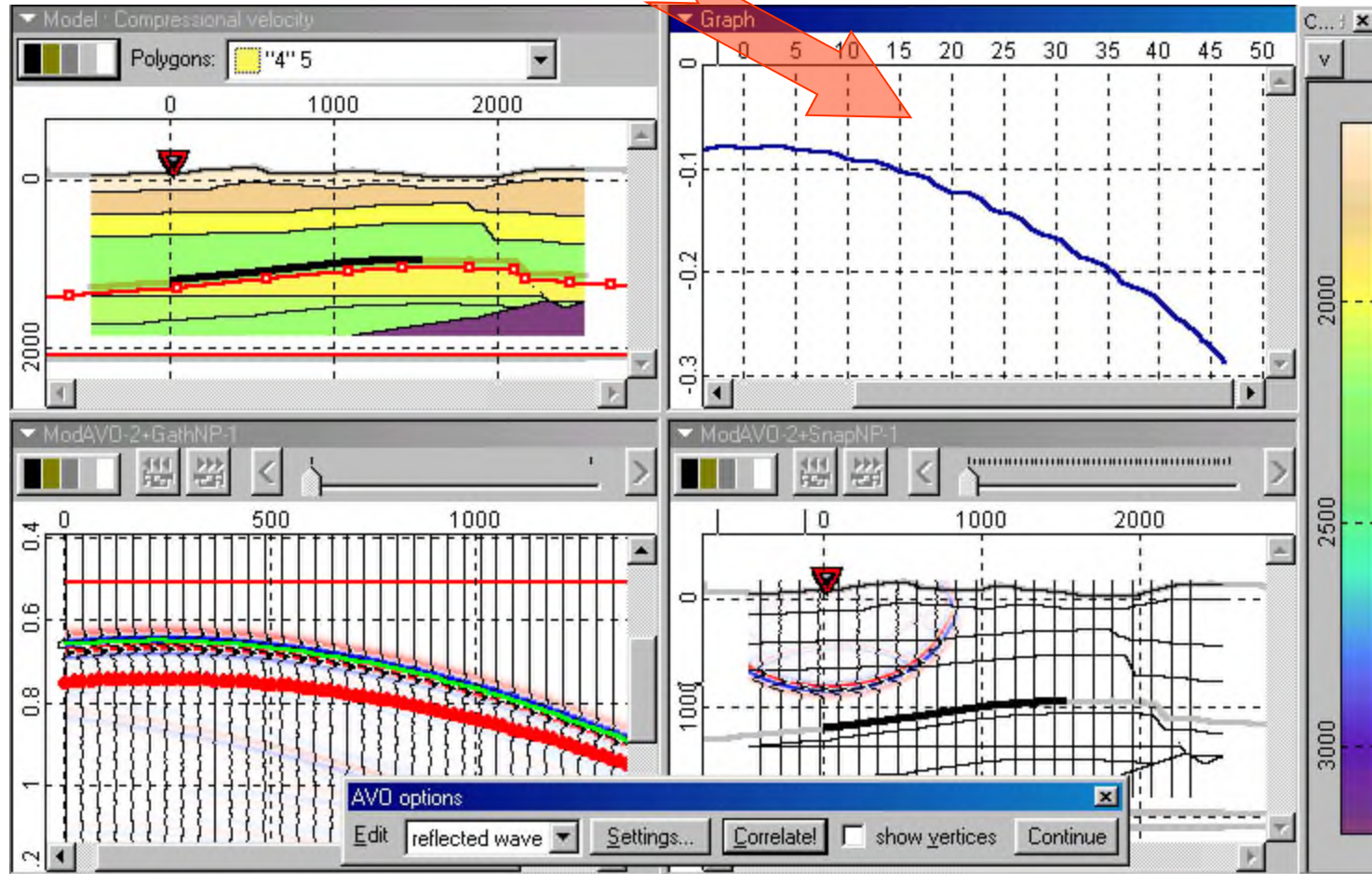




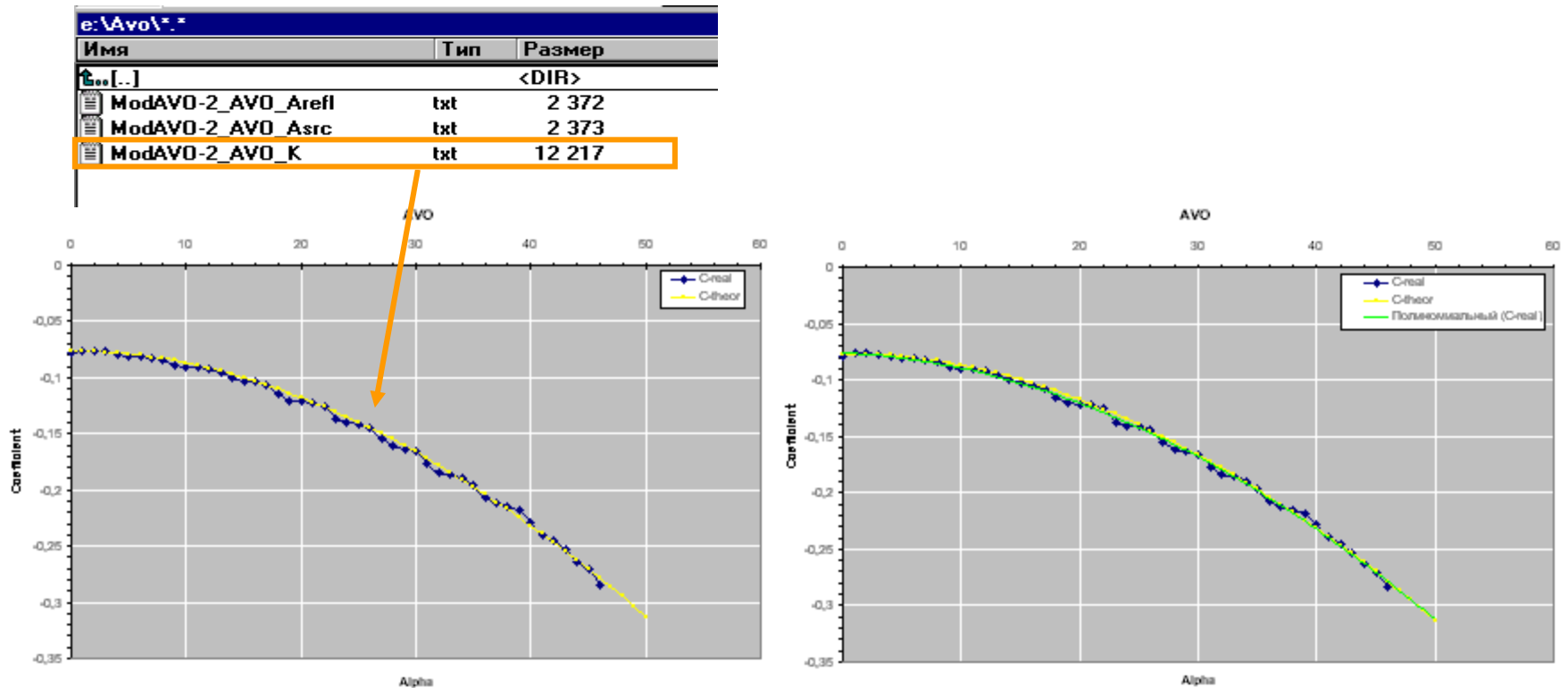
If necessary, you can adjust scale and graph frame using « *Scale*», and then «*Define Scale*» menu items.



In correspondence with entered in «*Define Scale*» dialog values is adjusted image of AVO graph.

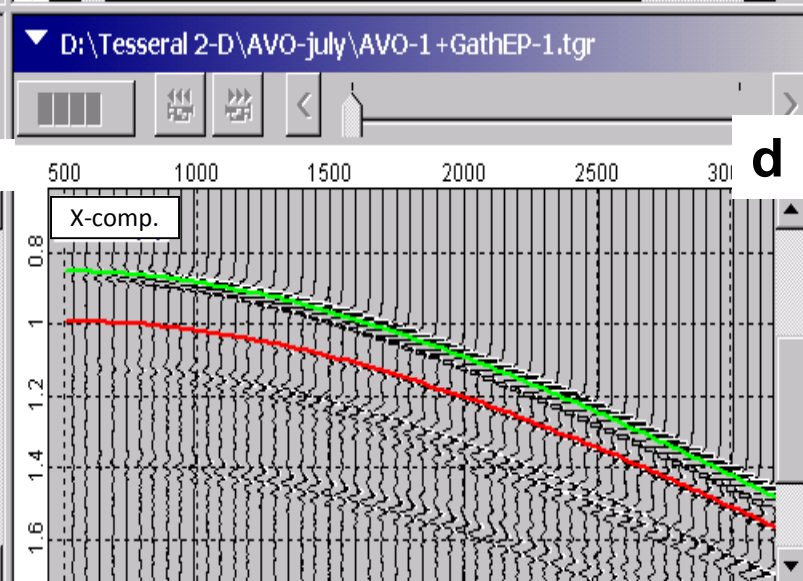
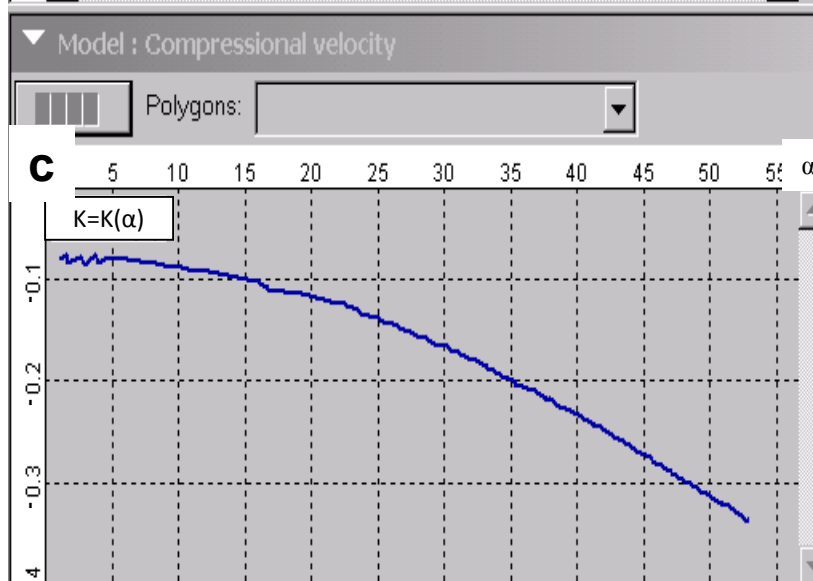
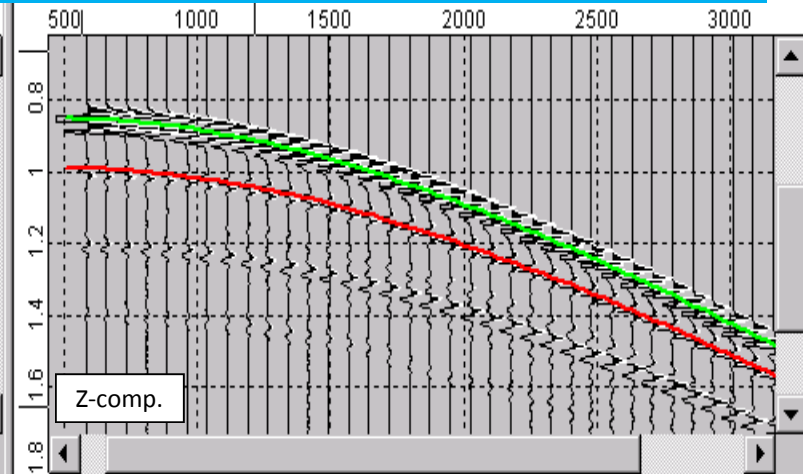
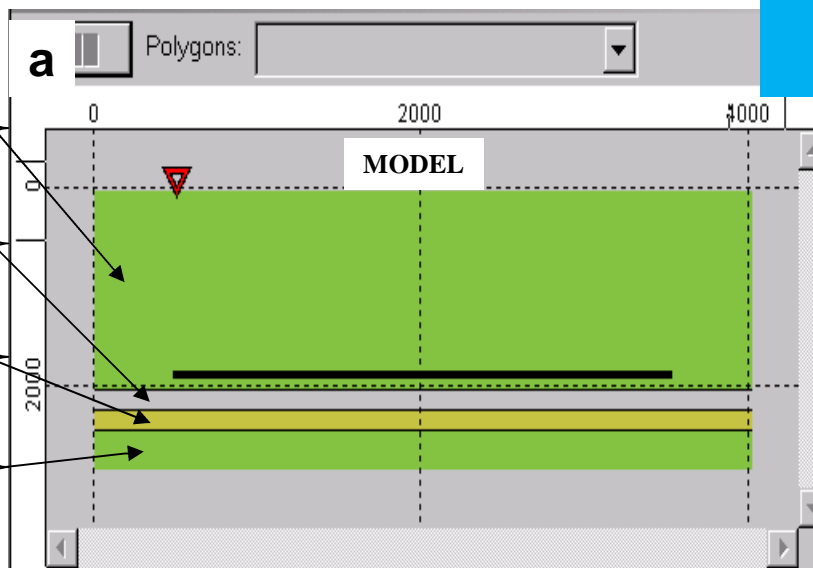


In work folder are kept three text files: first two are amplitude values of Z- and X-component and calculated by them incidence angles for direct and reflected waves, third - is the target dependency of reflection coefficient from the incidence angle. Those data can be easily analyzed in Excel. In lower figures is shown such presentation, where with black color is done real AVO graph, green - its polynomial approximation, yellow - theoretical AVO values.



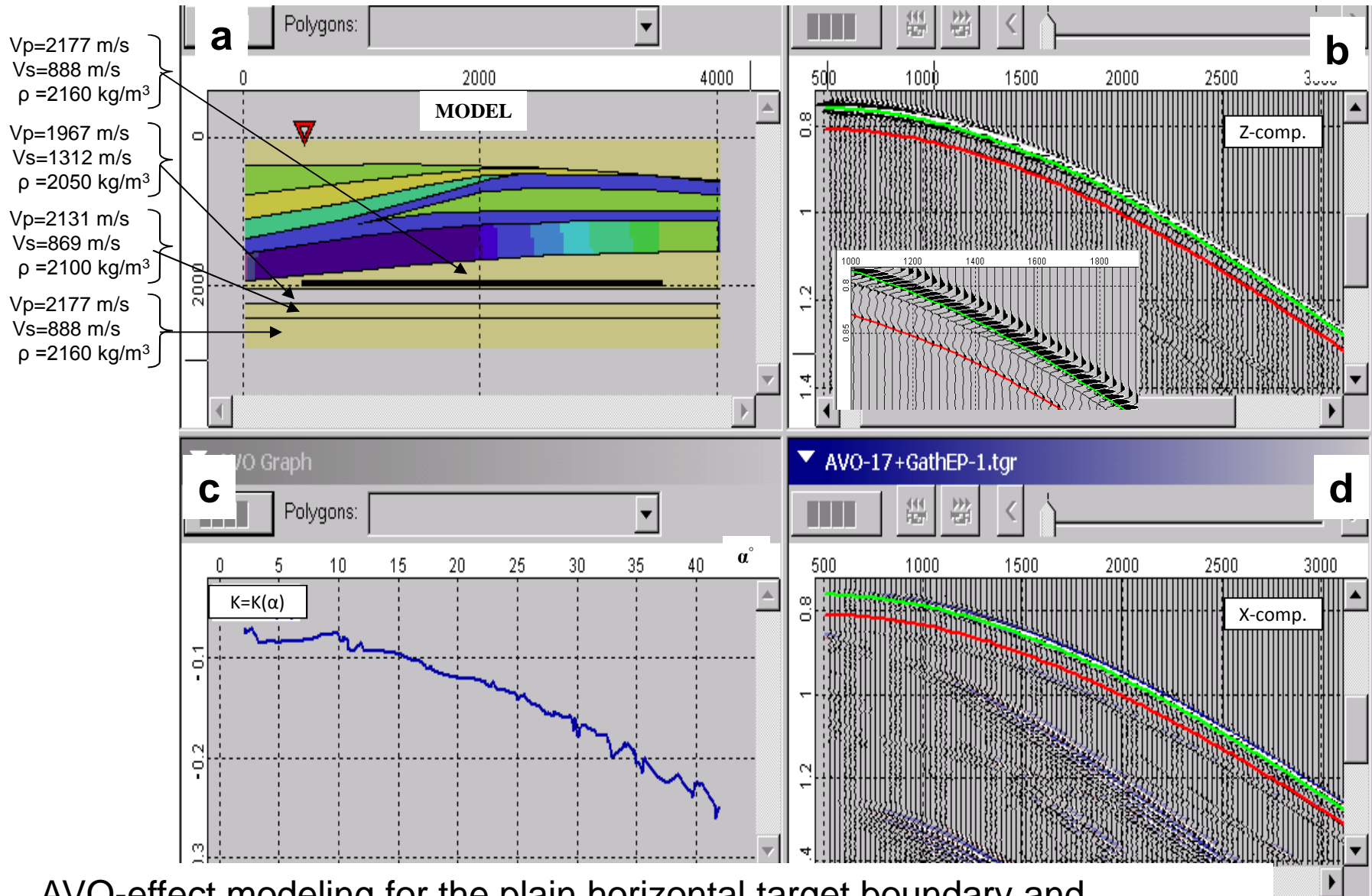
# Example 1

- 1 -  $V_p=2177$  m/s  
 $V_s=888$  m/s  
 $\rho=2160$  kg/m<sup>3</sup>
- 2 -  $V_p=1967$  m/s  
 $V_s=1312$  m/s  
 $\rho=2050$  kg/m<sup>3</sup>
- 3 -  $V_p=2131$  m/s  
 $V_s=869$  m/s  
 $\rho=2100$  kg/m<sup>3</sup>
- 4 -  $V_p=2177$  m/s  
 $V_s=888$  m/s  
 $\rho=2160$  kg/m<sup>3</sup>



AVO-effect modeling for the plain horizontal target boundary and homogeneous overlaying thickness. Legend: a - model; b – CSP seismogram for Z-component; c – graphic of AVO dependency; d - CSP seismogram for X component

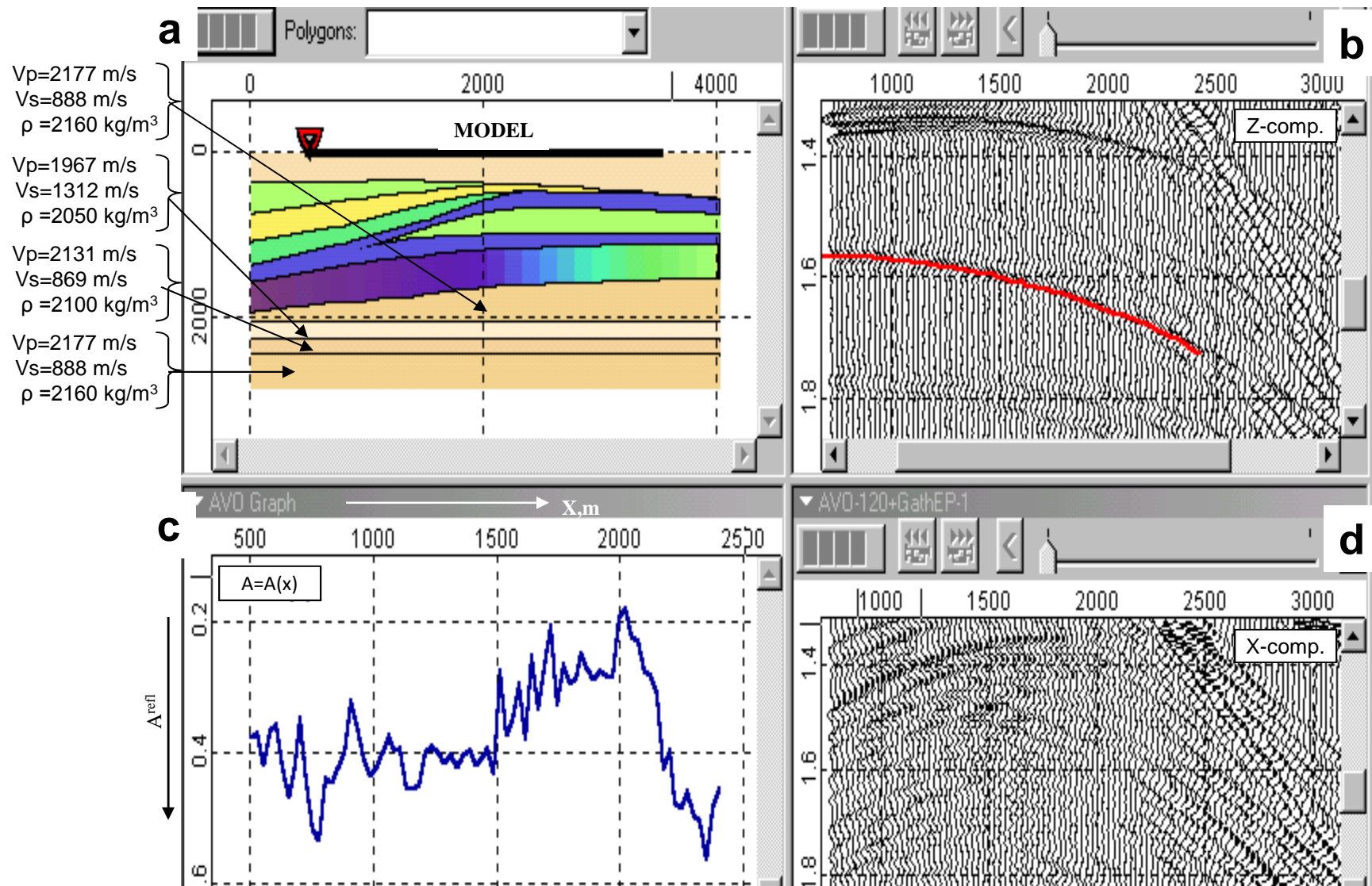




AVO-effect modeling for the plain horizontal target boundary and heterogeneous complexly built overlaying thickness.

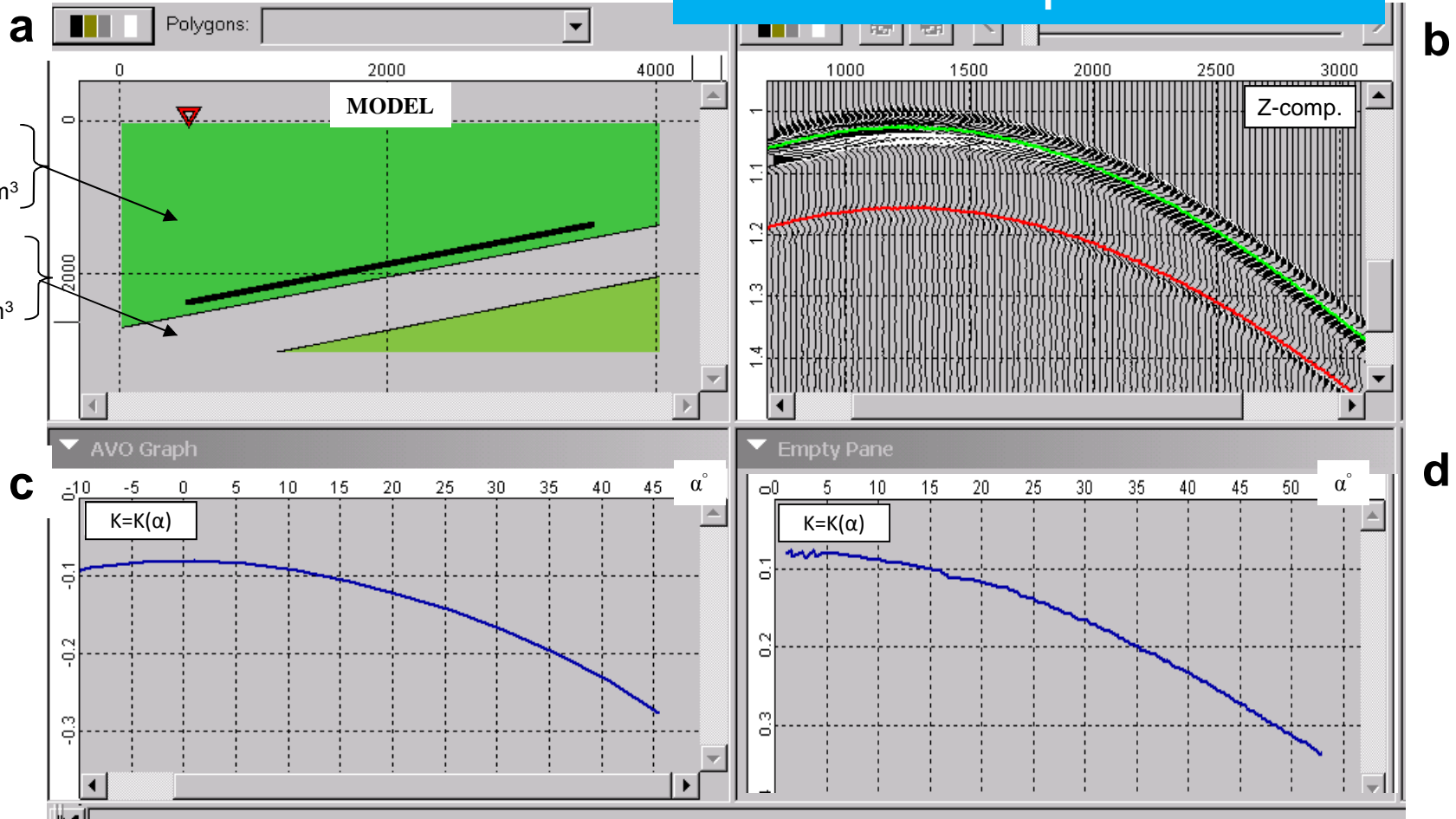
Legend: a - model; b – CSP seismogram for Z-component; c – graphic of AVO dependency; d - CSP seismogram for X component





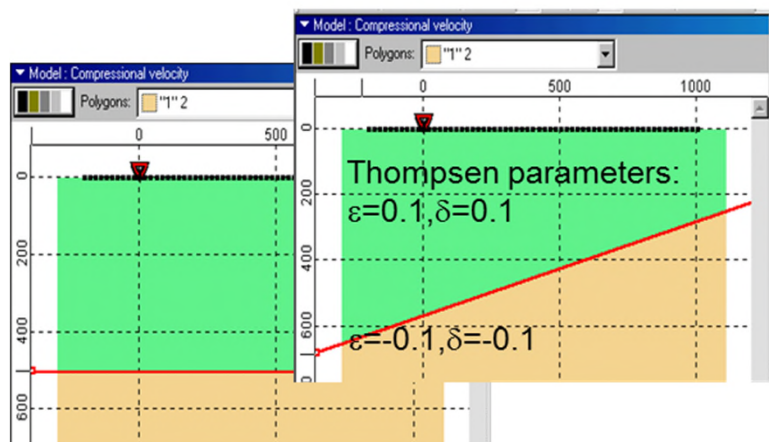
AVO-effect (amplitudes) modeling for the plain horizontal target boundary and heterogeneous complexly built overlaying thickness. Receivers are positioned on the model surface. Legend: a - model; b – CSP seismogram for Z-component with marked reflected wave; c – graphic of amplitudes of extremes of target wave; d - CSP seismogram for X component.





## Example 2

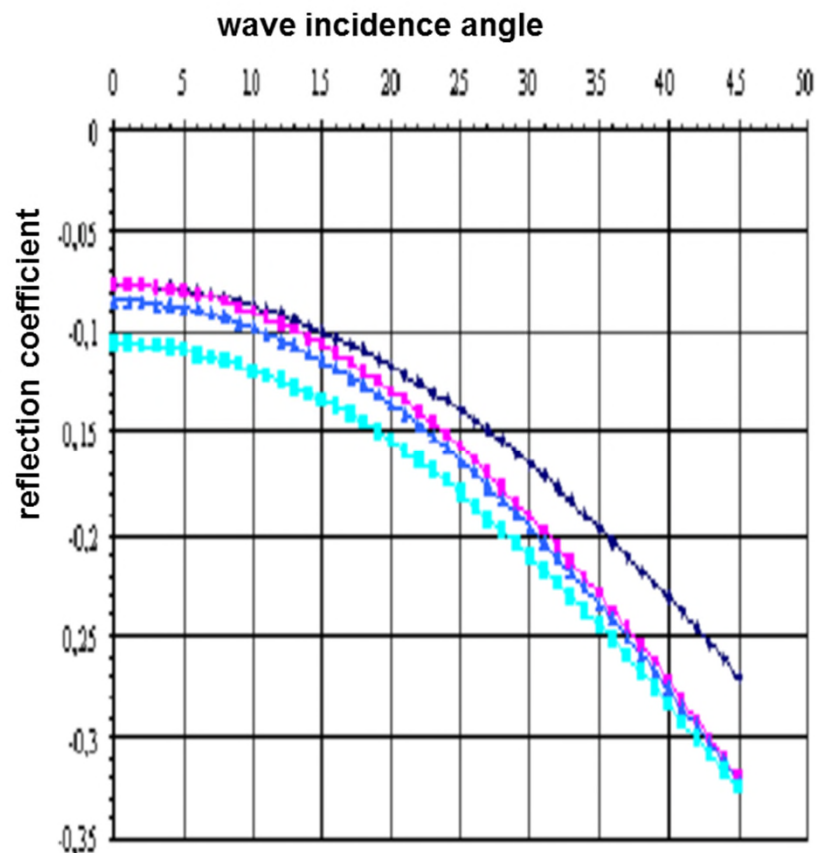


AVO-effect modeling for the included (angle  $18.8^\circ$ ) target boundary and homogeneous overlaying thickness. Receivers are positioned over the reflecting boundary. Legend: a - model; b) CSP shotgather; c - AVO dependency for the model with inclined target reflector; d - AVO dependency for the model with horizontal target reflector.

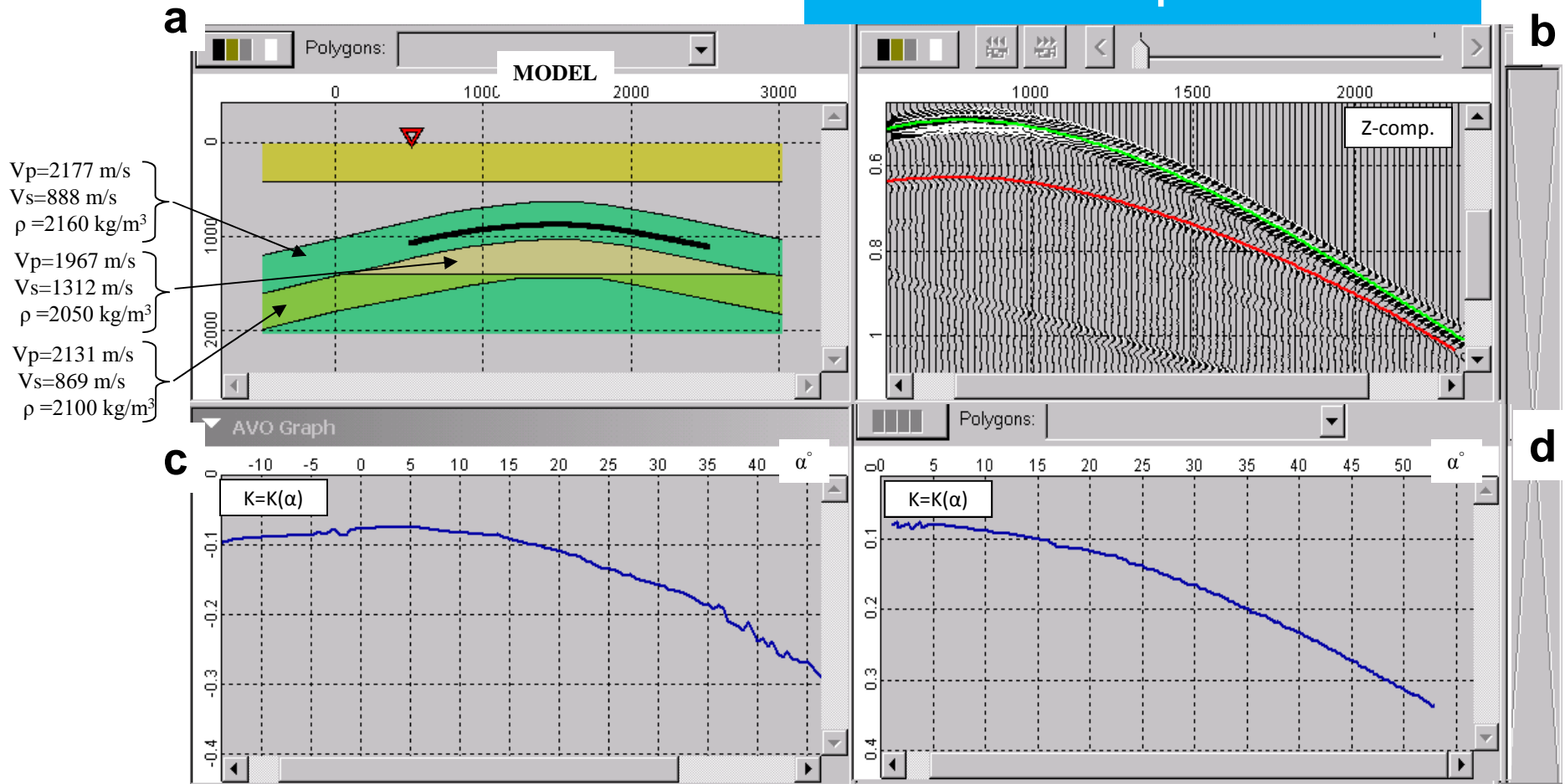
# AVO modeling in anisotropic medium for different angles of reflecting boundary and anisotropy axes.



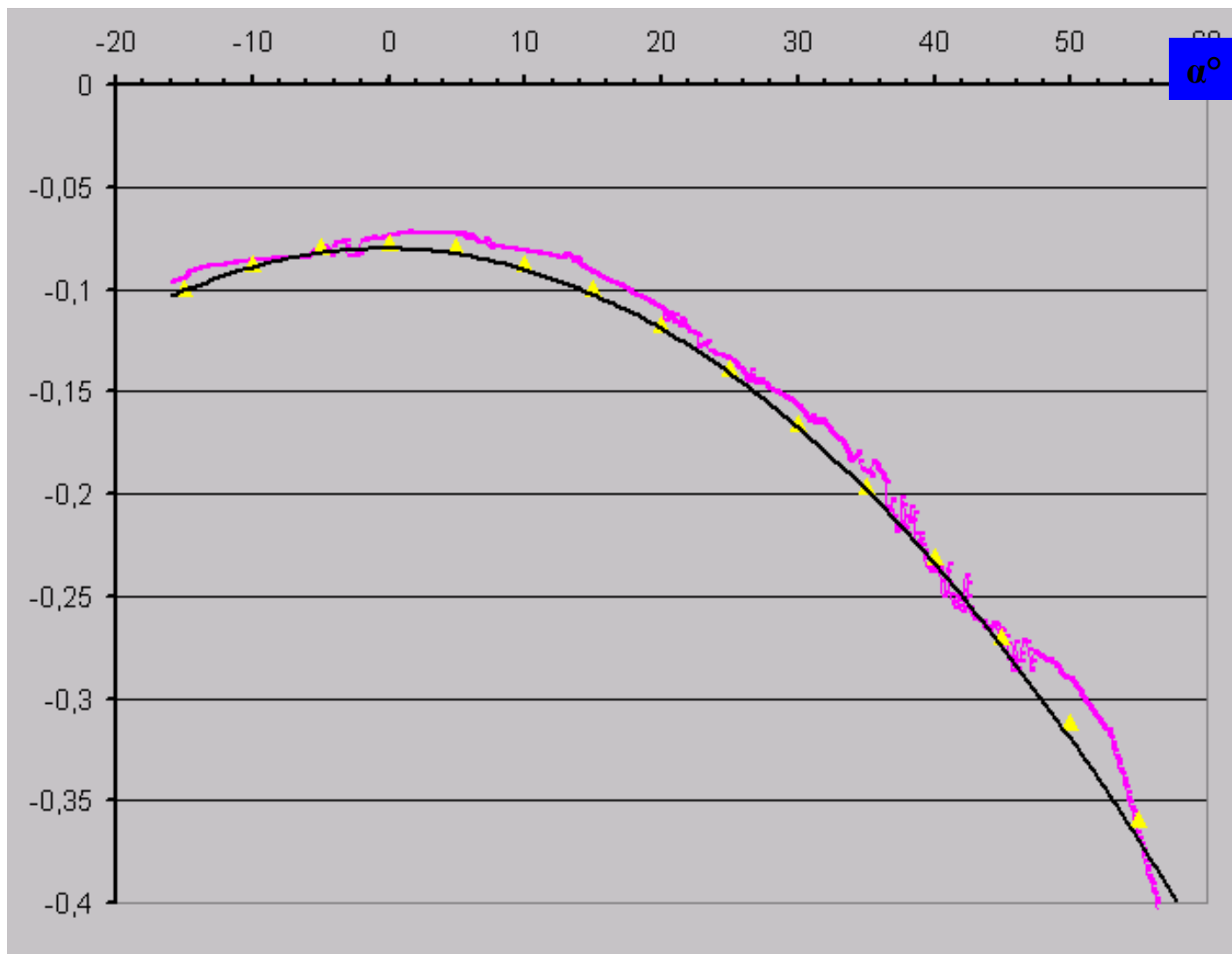
-  Isotropic medium, boundary inclination -  $0^\circ$
-  Anisotropic medium, inclination -  $0^\circ$
-  Anisotropic medium, inclination -  $15^\circ$
-  Anisotropic medium, inclination -  $30^\circ$



# Example 3



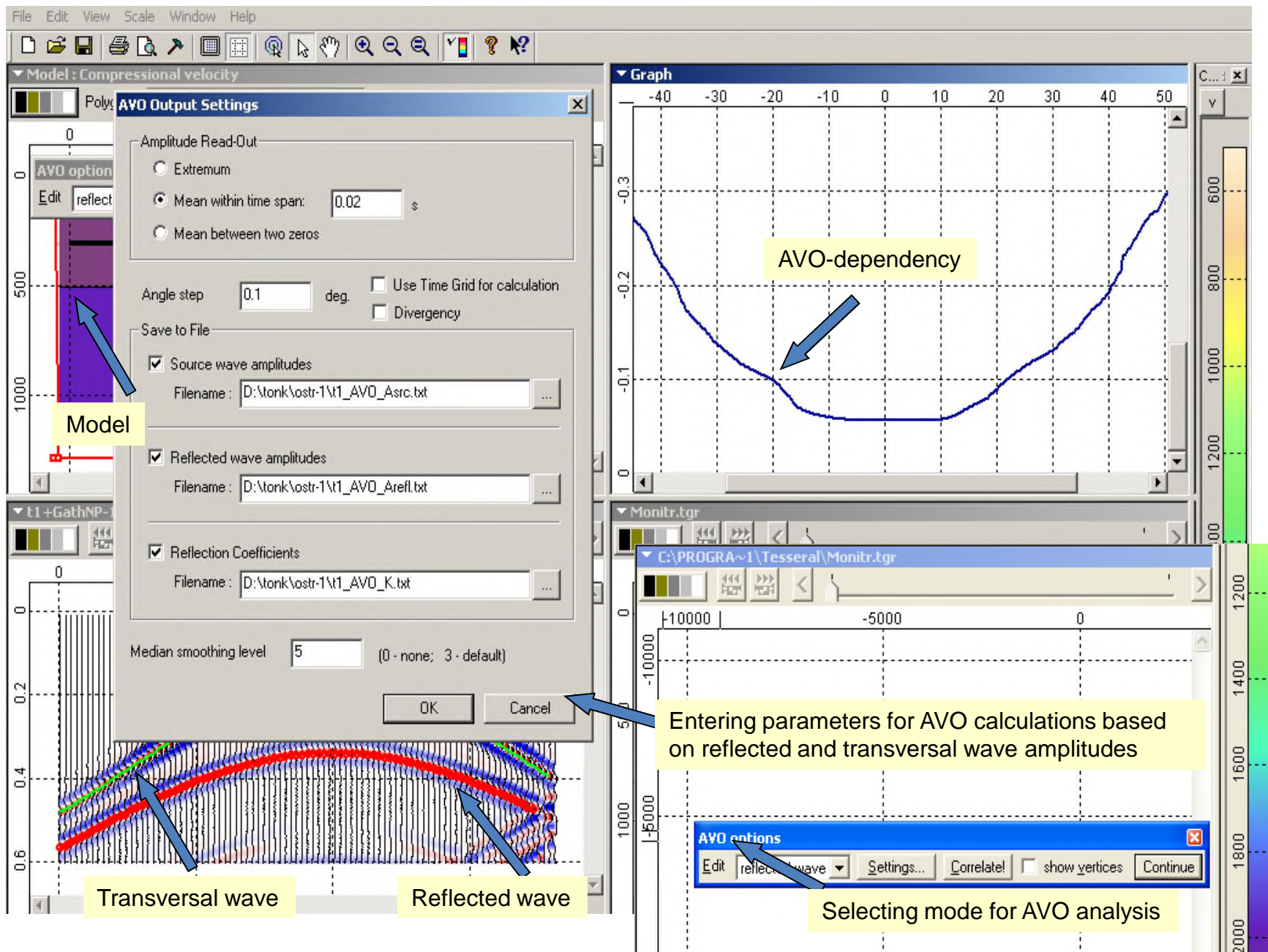
AVO-effect modeling of the anticlinal target reflector. Legend: a – model with anticlinal target reflector; b – CSP shotgather; c – CSP-dependency for anticlinal target reflector; d – CSP-dependency for model with plain horizontal target reflector.



**Comparison of AVO-effect modeling data using Tesseral package with calculated (theoretical) AVO values.**

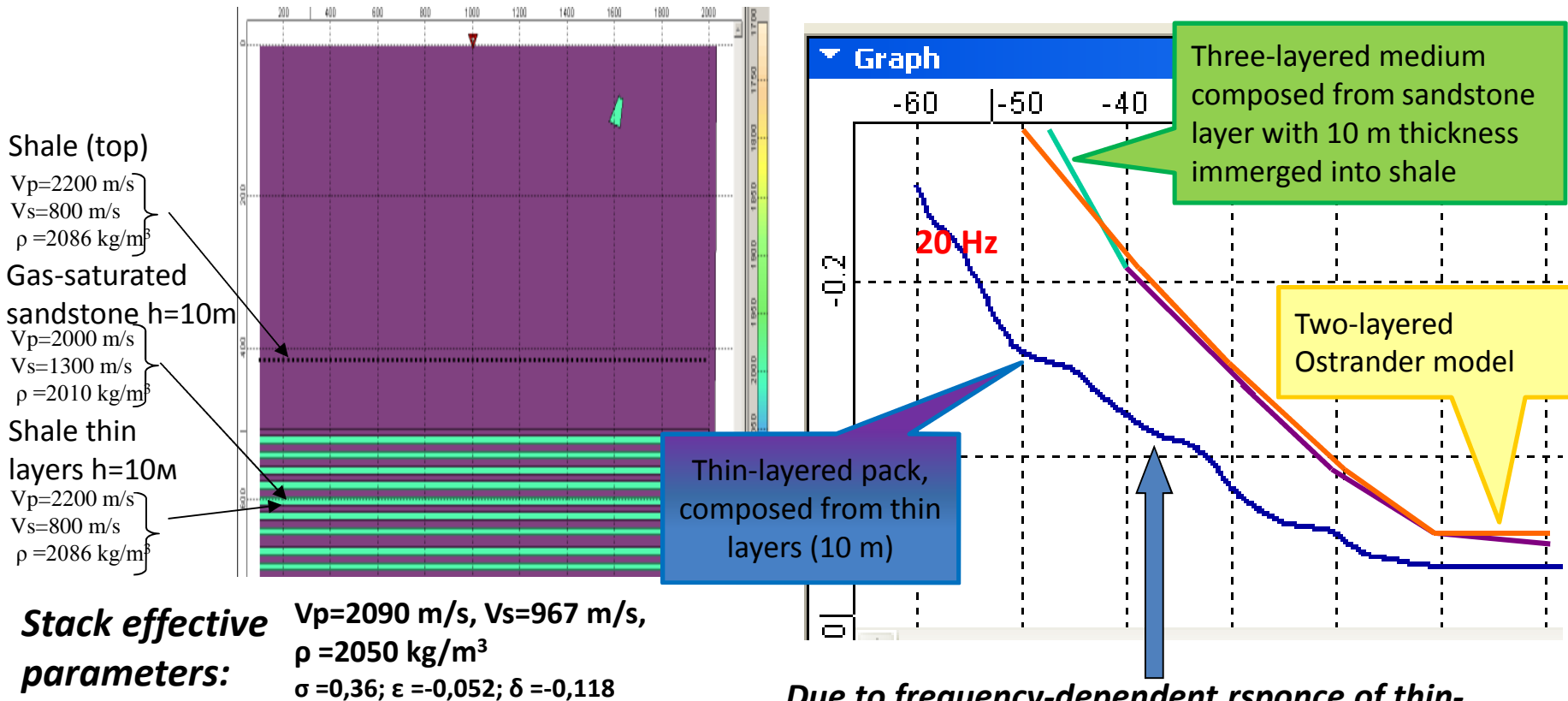
- AVO curve for the inclined plain reflector ( $18.8^o$ )
- AVO curve for the model antilinal reflector
- Theoretical AVO values for the plain target reflector



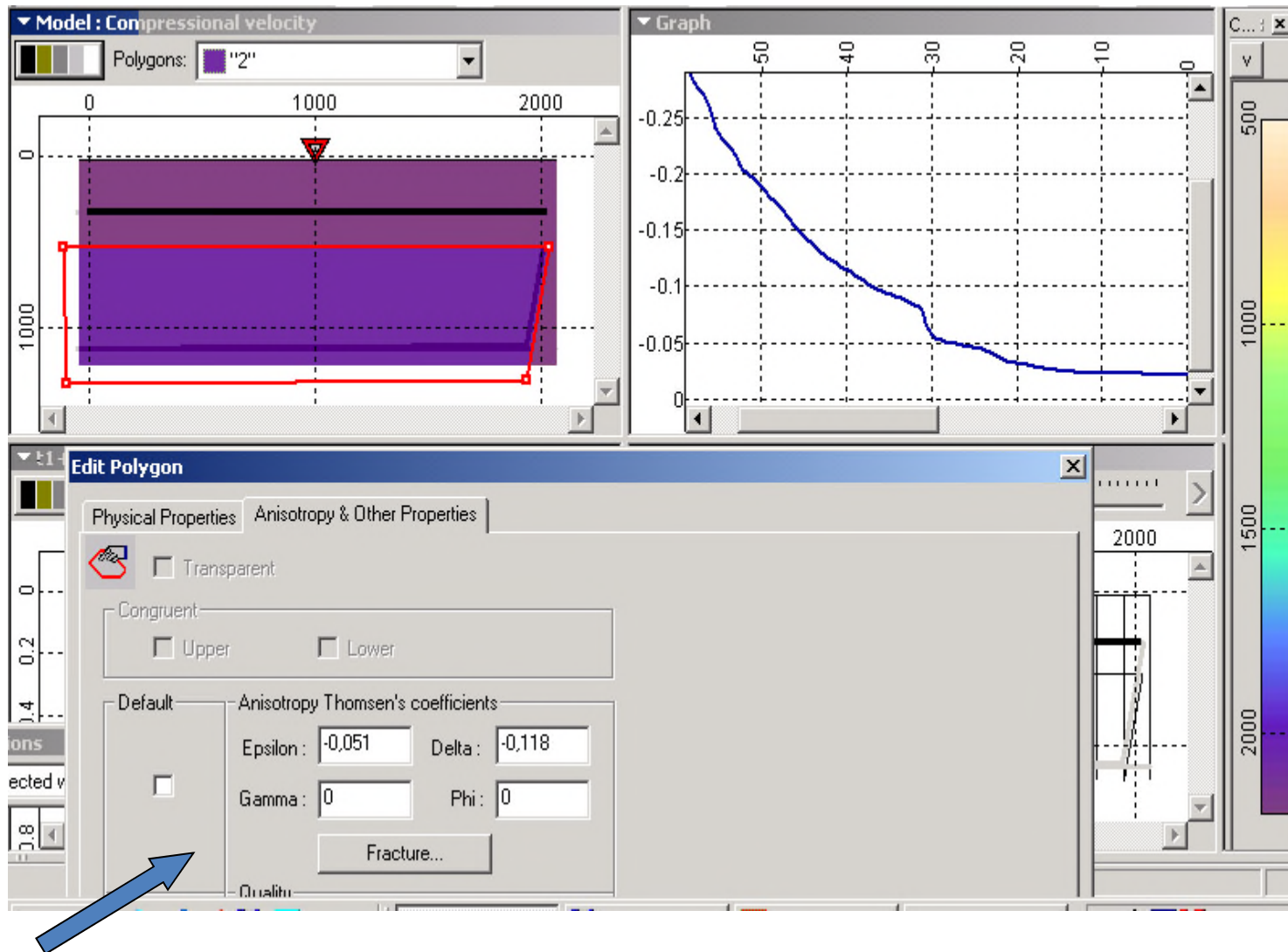


Two-layered **Ostrander model**. Upper boundary – shale, lower – gas-saturated sandstone. Parameters as shown in Slide 1. Wavelength - 100m, calculation grid cell size - 1.4m

# Influence of thin-layering, absorption and fracturing on AVO effects

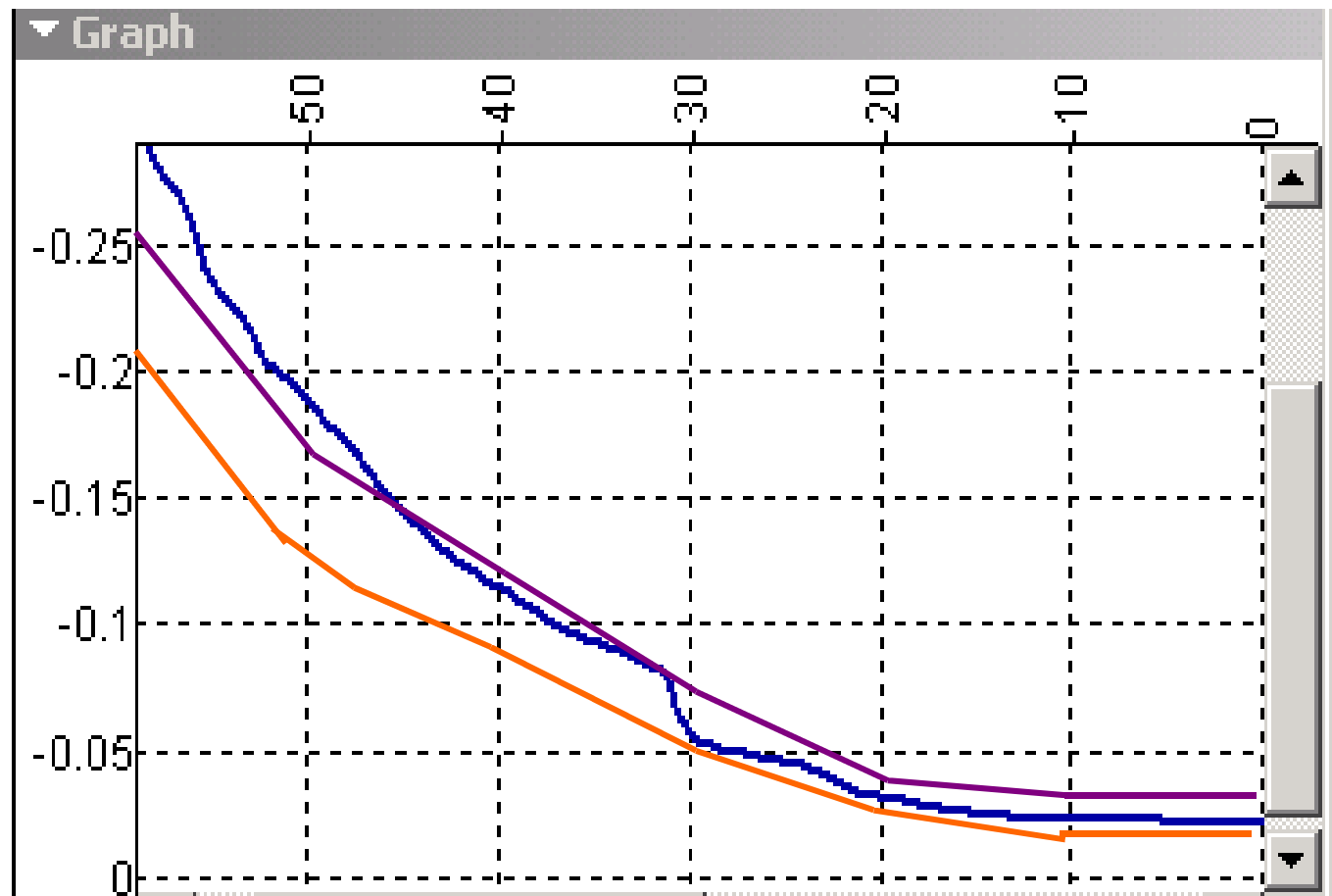


*Due to frequency-dependent response of thin-layered stack AVO-curve for multilayered model is considerably lower than for two-layered and three-layered ones.*



**Effective analogue of thin-layered thickness** with anisotropy taken into account





**Comparison of AVO curves** from effective models corresponding to thin-layered pack with **taking and not taking quasi-anisotropy** into account. When quasi-anisotropy is not taken into account estimation of Poisson coefficient in lower cross-section part is  $\sigma=0.36$ , and when is taken into account  $\sigma=0.33$

- Thin-layered pack 1
- Taking quasi-anisotropy into account
- Not taking quasi-anisotropy into account

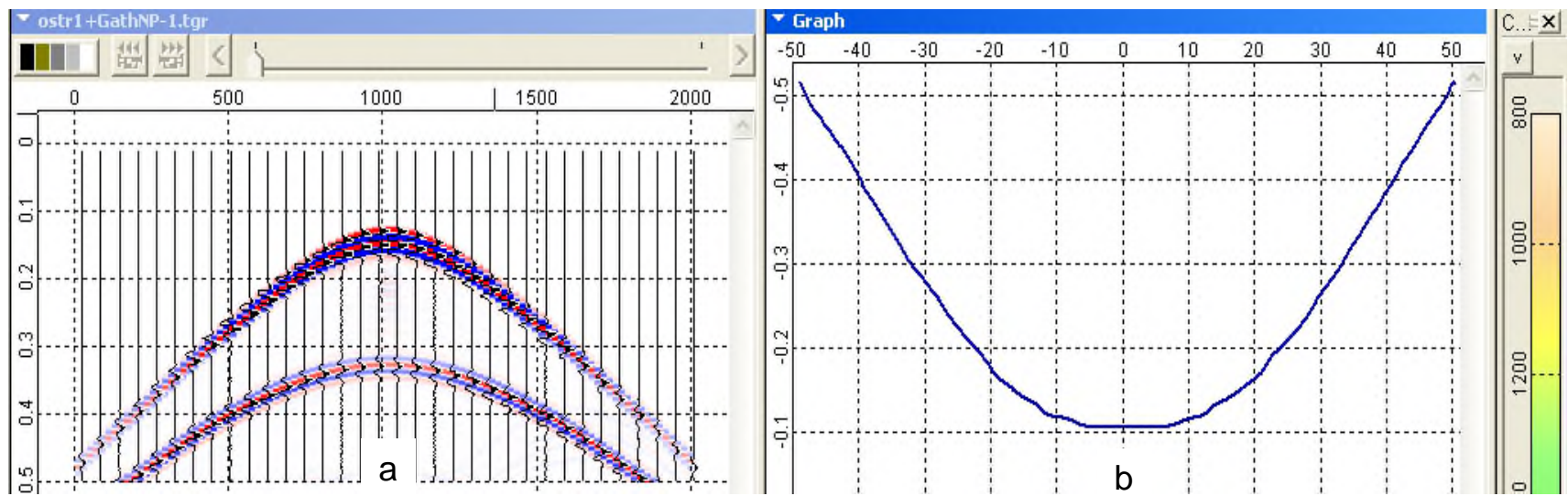


Fig. 1

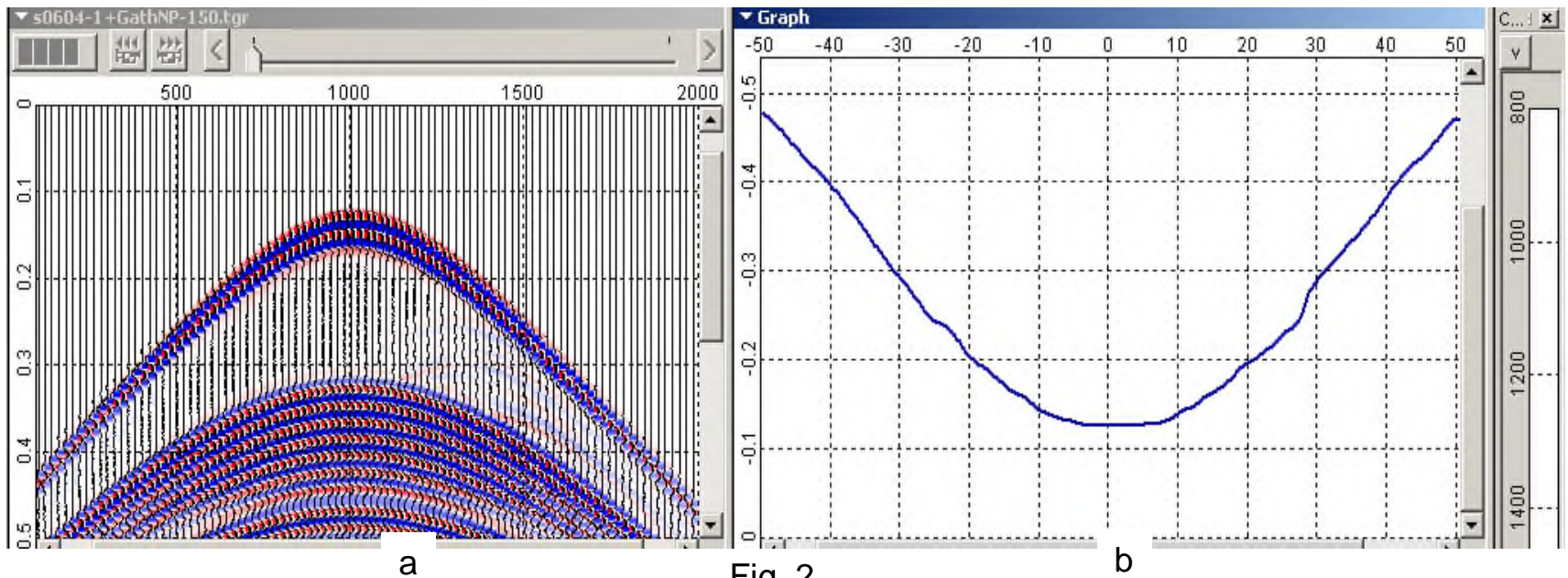
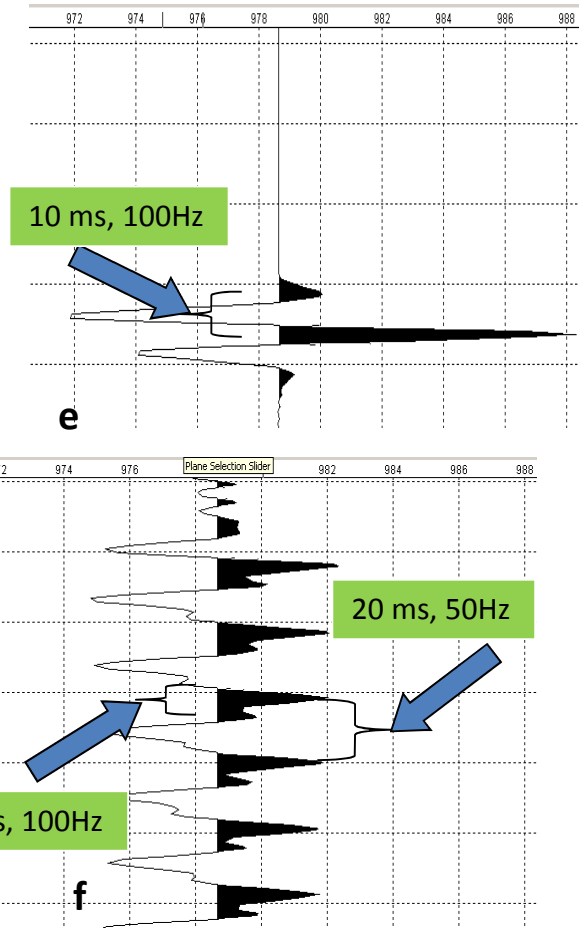
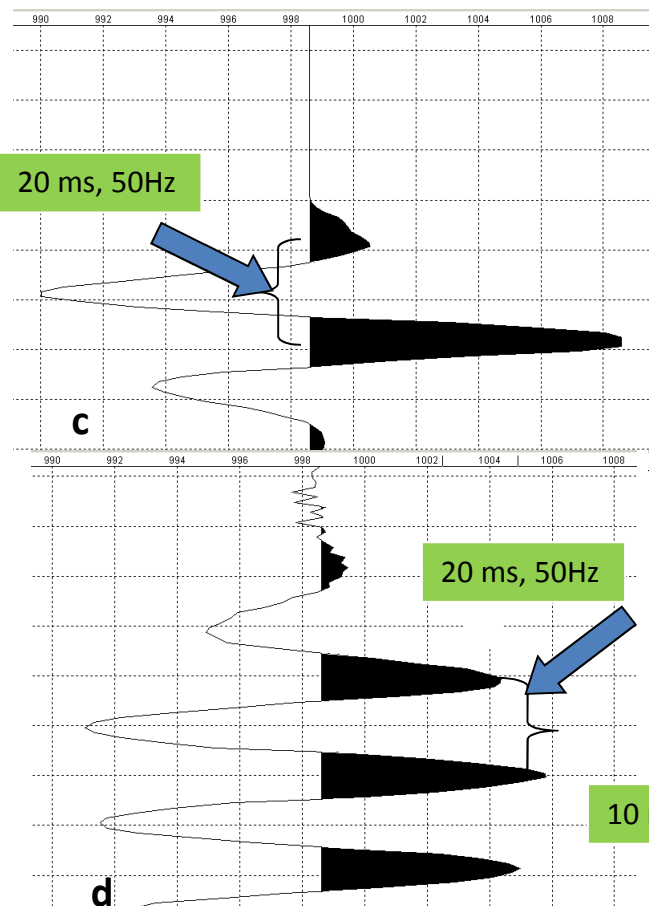
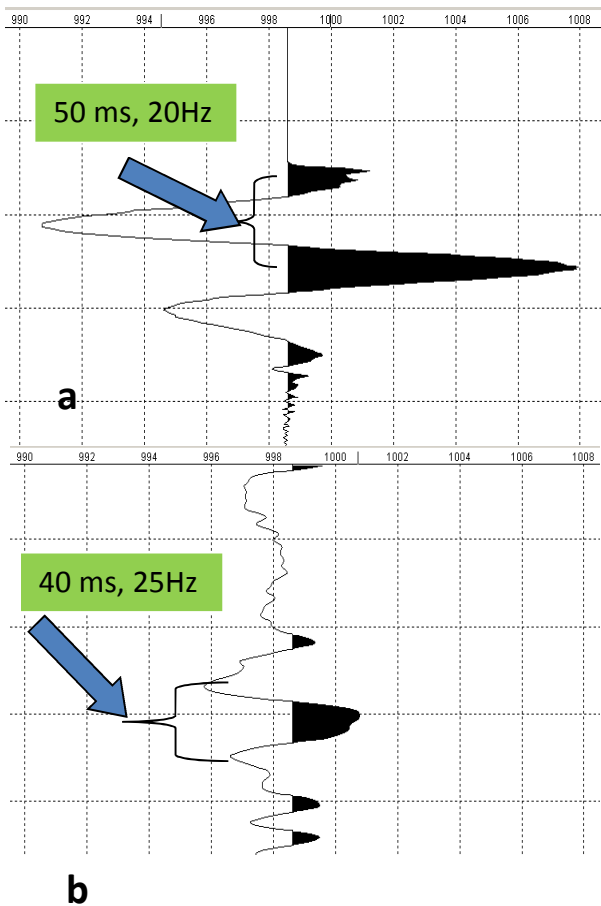


Fig. 2

Fig.1 and fig.2 are shown **shotgathers** (a) and **AVO curves** (b) for three-layered and multilayered model correspondingly for signal frequency 50 Hz, equal to first resonance frequency in thin-layered pack at normal incidence. 34



**Comparison of the signal form before and after coming through thin-layered pack in different frequency bands at normal incidence of wave on boundary.**

a – signal , corresponding to incident wave at pick frequency of specter 20Hz

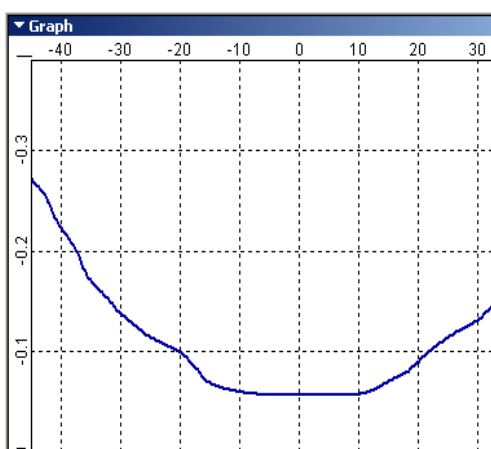
b - signal , corresponding to reflected from pack wave at pick frequency of incident signal specter 20Hz

c - signal , corresponding to incident wave at pick frequency of specter 50Hz (frequency of first extremum in amplitude-frequency characteristic of pack at normal wave incidence)

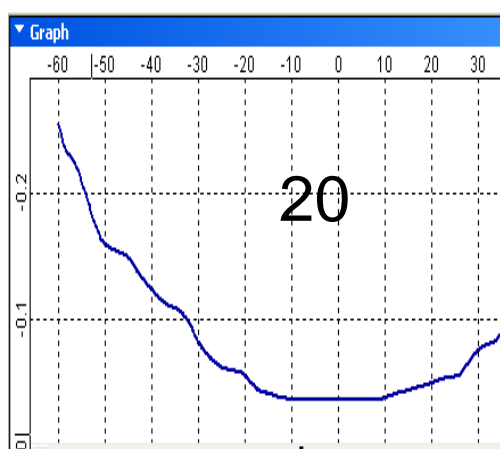
d- signal , corresponding to reflected from pack wave at pick frequency of incident signal specter 50Hz

e - signal , corresponding to incident wave at pick frequency of specter 100Hz (frequency of second extremum in amplitude-frequency characteristic of pack at normal wave incidence)

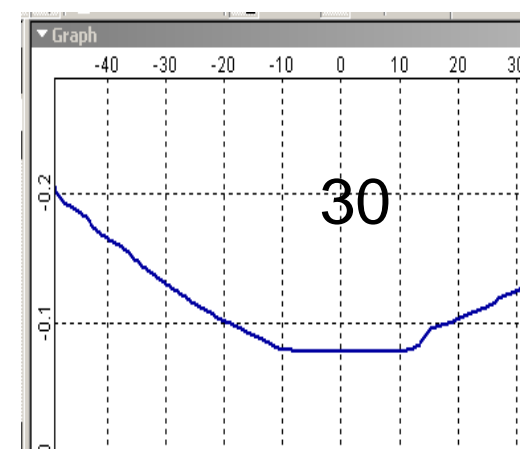
f - signal , corresponding to reflected from pack wave at pick frequency of incident signal specter 100Hz



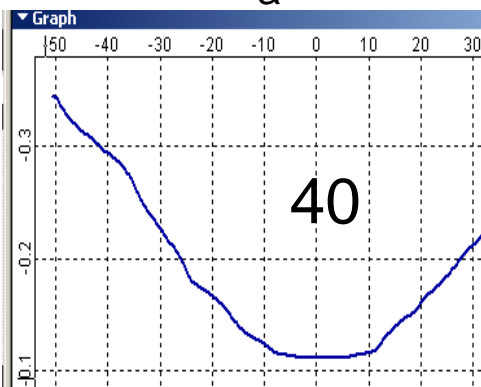
a



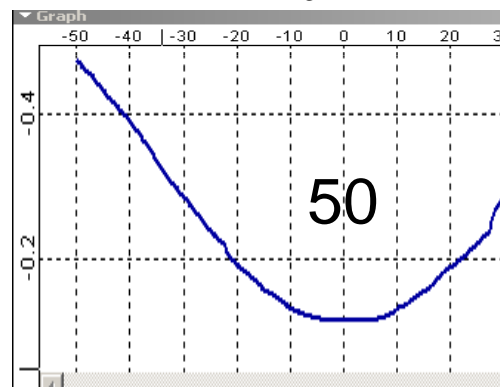
b



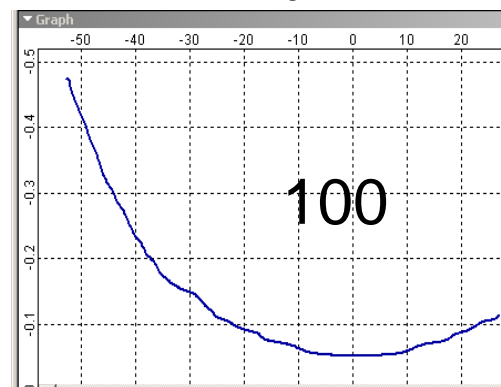
c



d



e



f

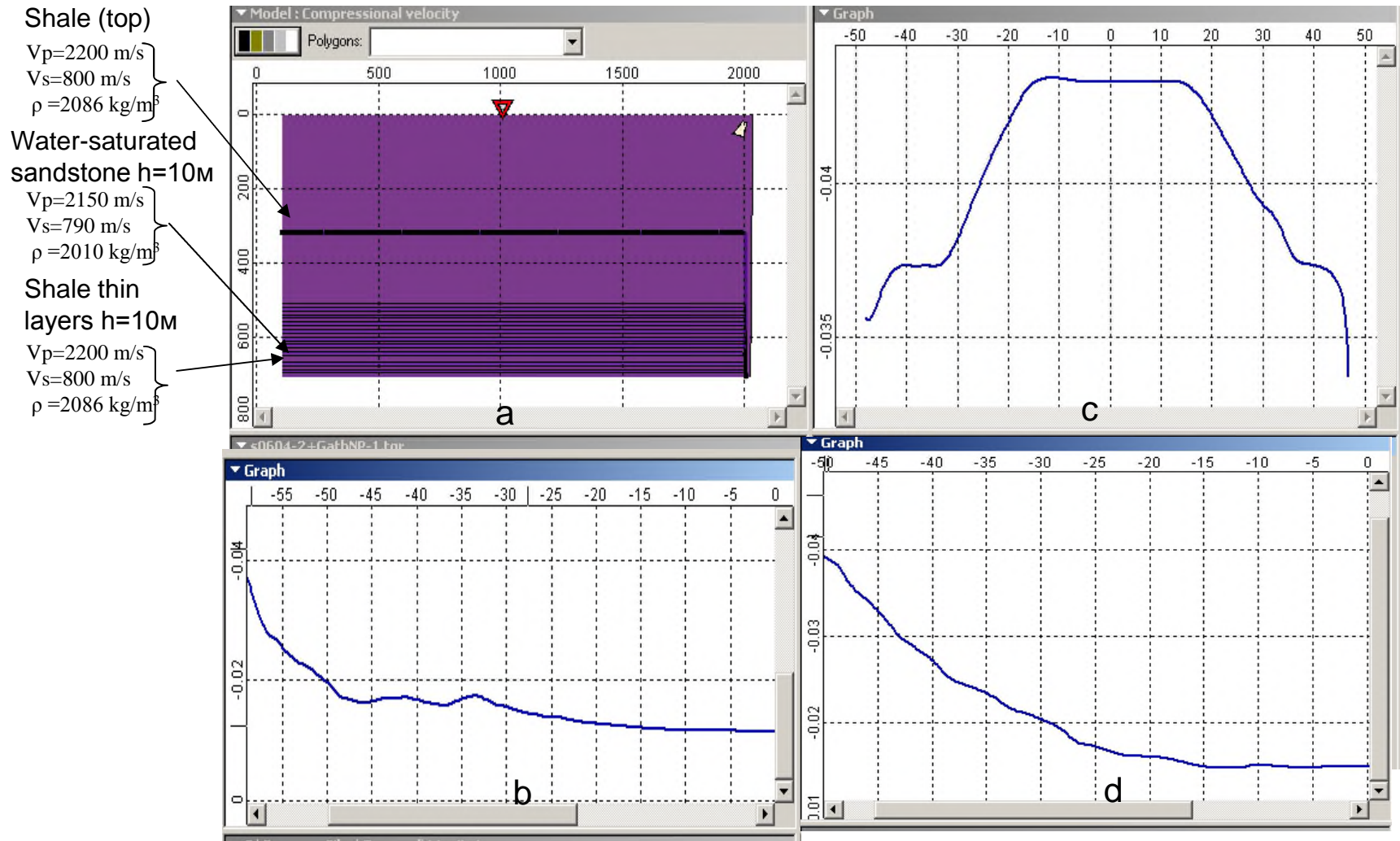
**Comparison of AVO curves obtained at different frequencies for thin-layered pack and two-layered model:**

- a – two-layered model,
- b – multilayered model at pick signal frequency 20Hz,
- c – multilayered model at pick signal frequency 30Hz,
- d – multilayered model at pick signal frequency 40Hz,
- e – multilayered model at pick signal frequency 50Hz,
- f – multilayered model at pick signal frequency 100Hz,

Considerable difference of graphics requires application of different scales for them

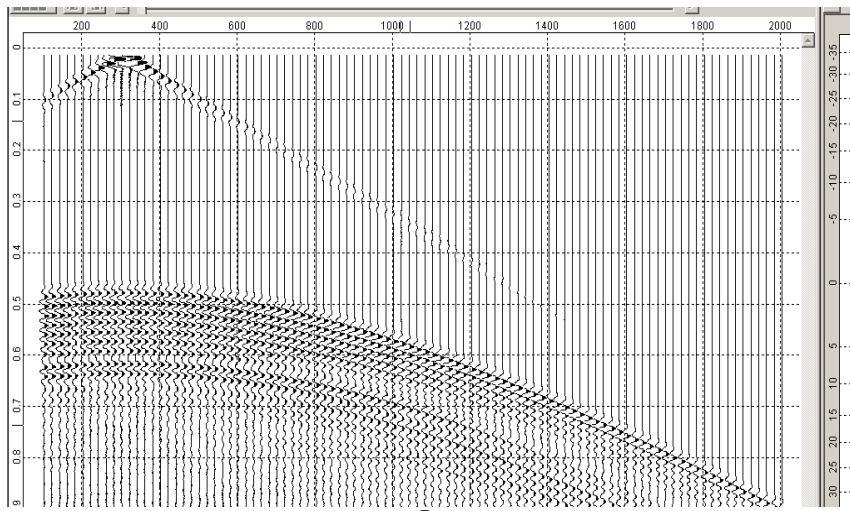
The highest gradient in graph is observed at pick frequency 50Hz, to which corresponds resonance of given pack. Next extremum, which have smaller amplitude for signal of given form is observed at



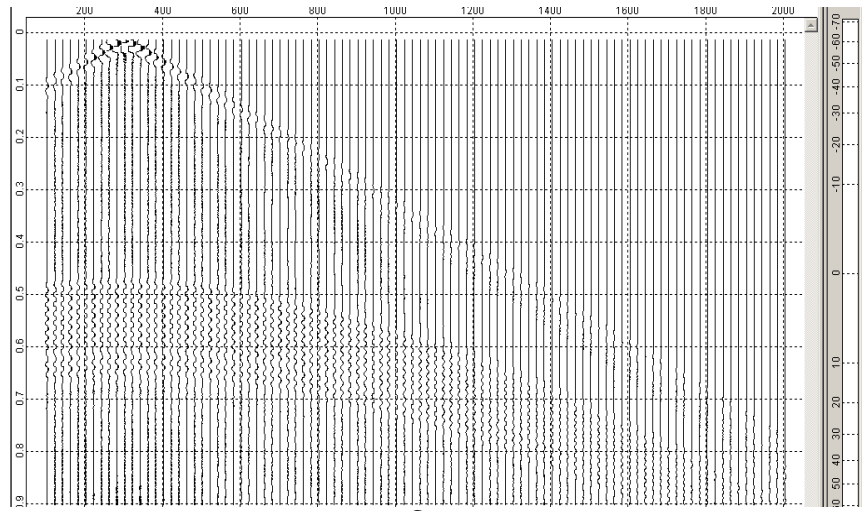


### AVO curves for water-saturated thin-layers pack:

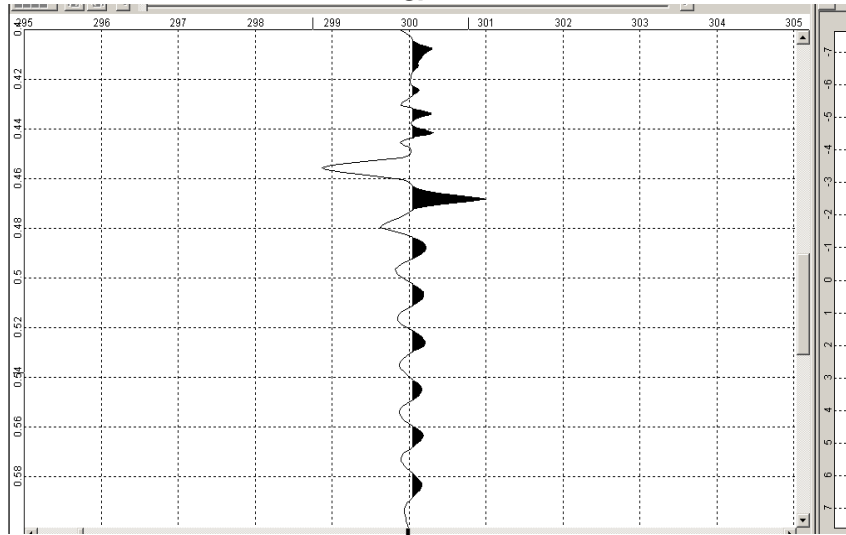
- a – model
- b – AVO graph for signal pick frequency 20Hz
- c – AVO graph for signal pick frequency 50Hz (first resonance frequency)
- d – AVO graph for signal pick frequency 100Hz (second resonance frequency)



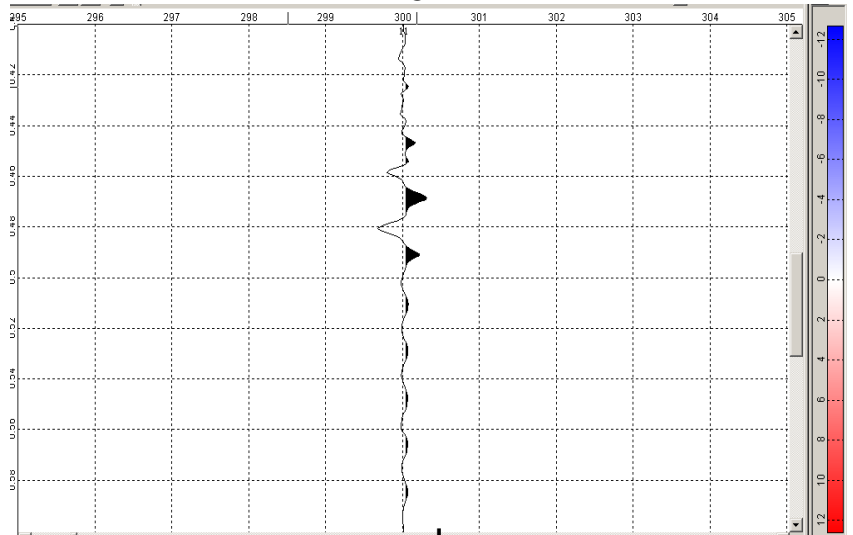
a



c



b



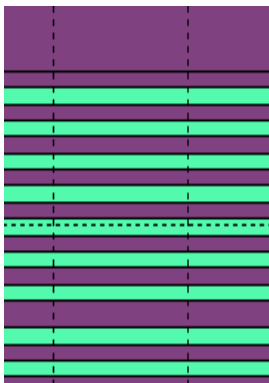
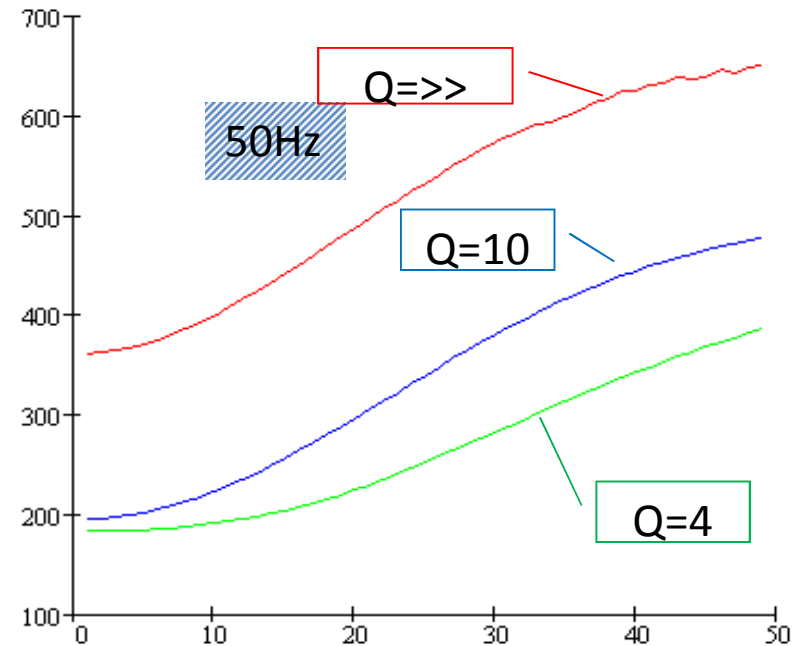
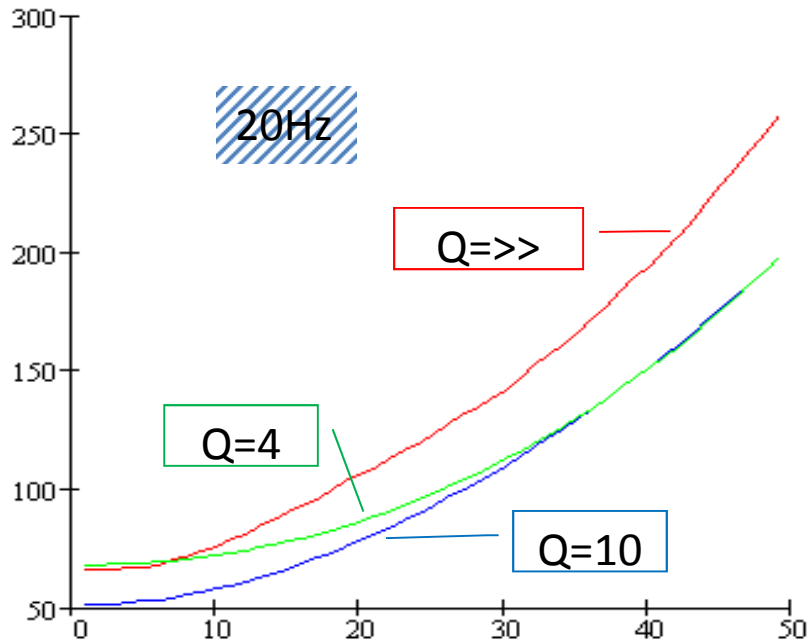
d

**Comparison of shotgathers** obtained in conditions of thin-layered gas-saturated pack (a) and thin-layered water-saturated pack (c) at signal excitation frequency 50Hz, equal to first extremum frequency of amplitude-frequency characteristic of packs at wave normal incidence.

Traces obtained in result of focusing of reflected wave on imaginary source (MIGW procedure):

In case of gas-saturated pack (b) amplitude of summed signal is 3 times bigger, but frequency is 14% lower than for water-saturated pack (d)

- Model with absorption



**Reflection coefficients for PP-waves depending on wave incidence angle on thin-layered pack (x1000).**

Source is generating Riker wavelet with 20Hz frequency (left picture) and 50Hz (right picture).

**Red** curves – medium **without** absorption,  
**blue** – with quality **Q=10** and  
**green** – with quality **Q=4**.

# Model with absorption

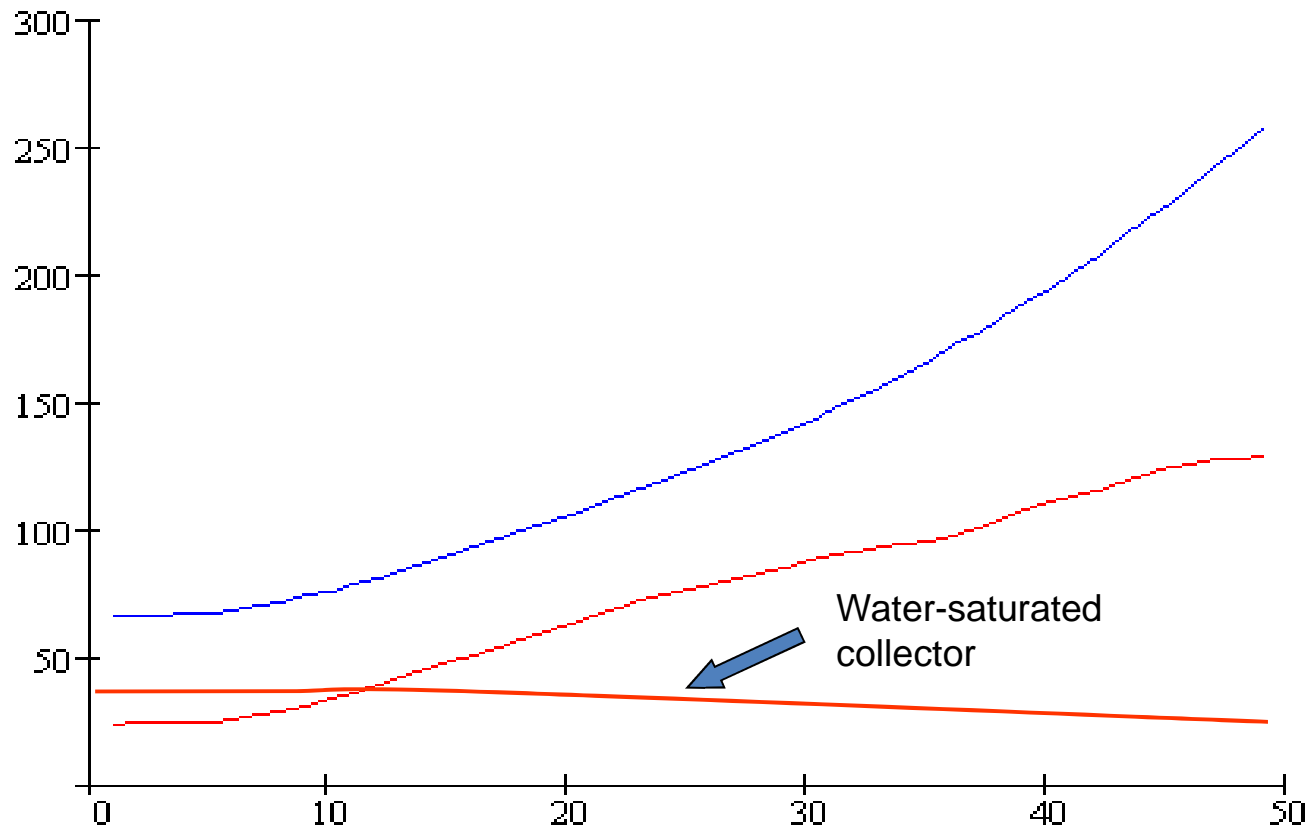


Fig.6

## Influence of fracturing on AVO effect:

Red curve - at  $\Delta_N=0,30$   $\Delta_N=0,60$

Blue curve – without fracturing. Frequency 20Hz

Comment: fracturing effects emulate absorption effects.



# 3D AVO and Fracturing Effect

Without  
fracturing:

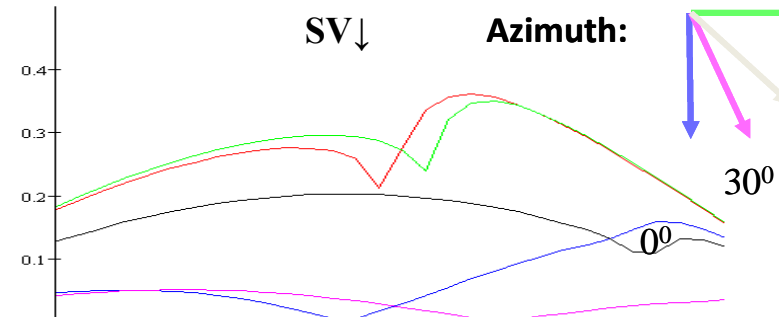
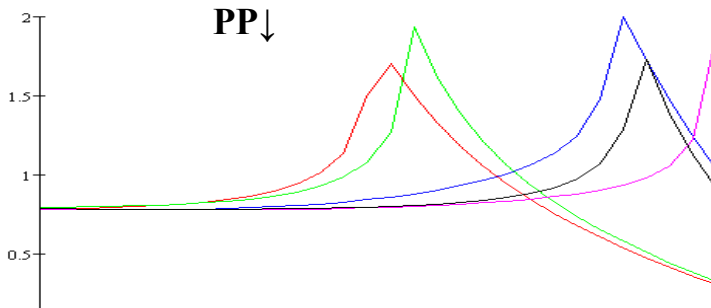
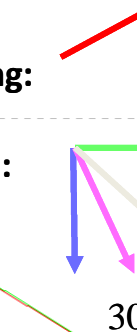
90°

Profile line

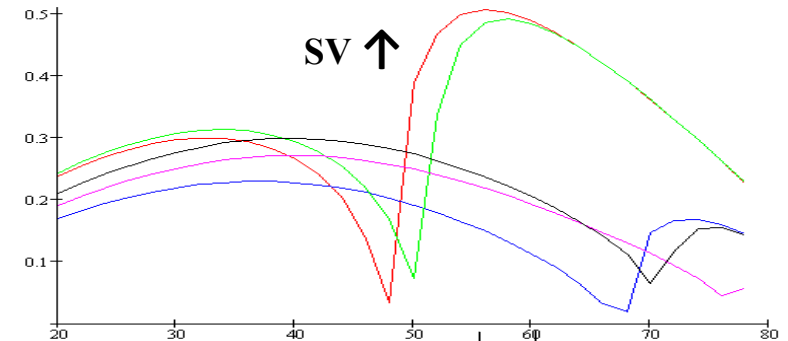
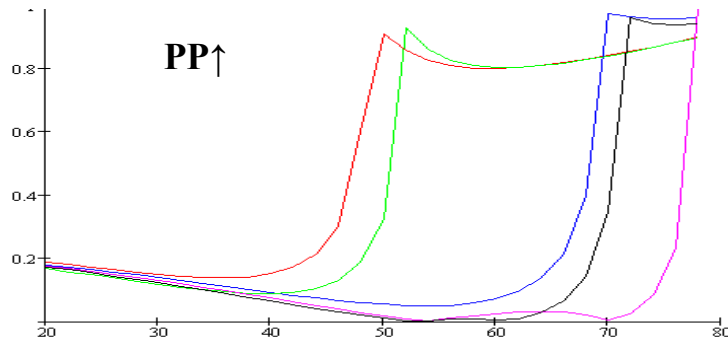
45°

30°

Azimuth:



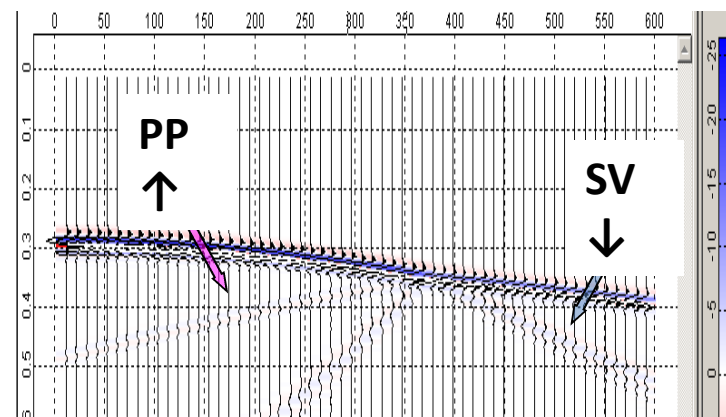
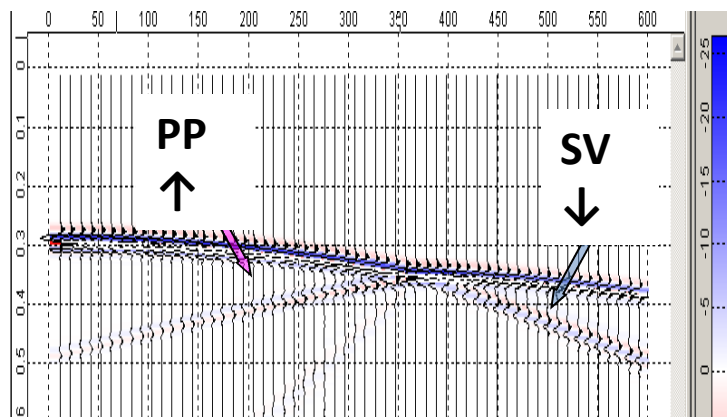
AVO effect on the contact of the transversally isotropic media and a fractured media



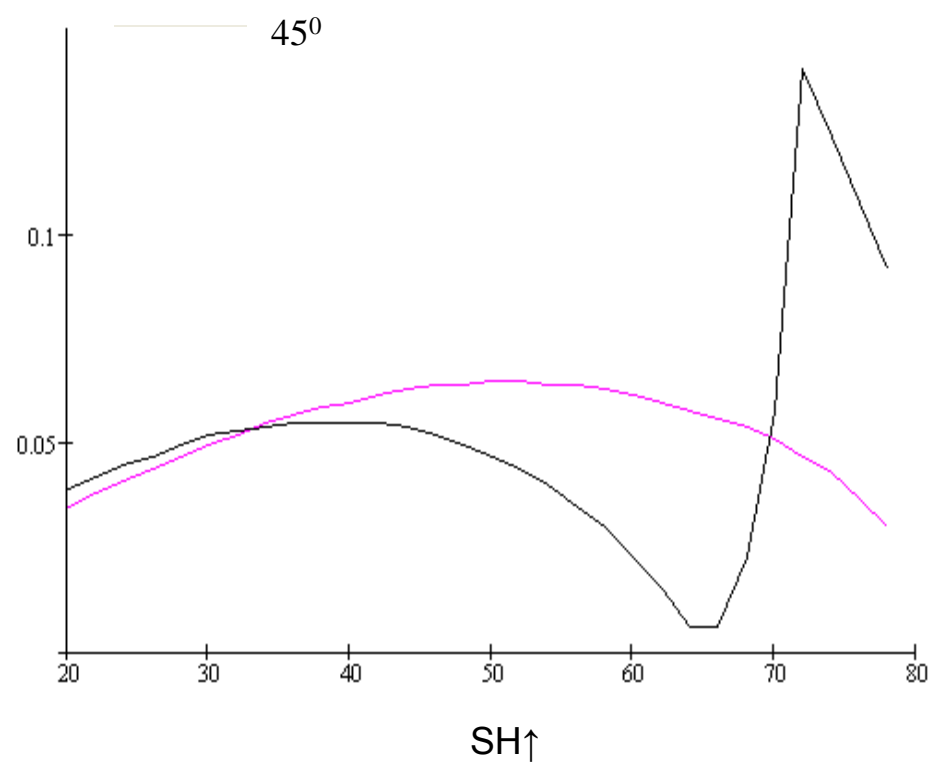
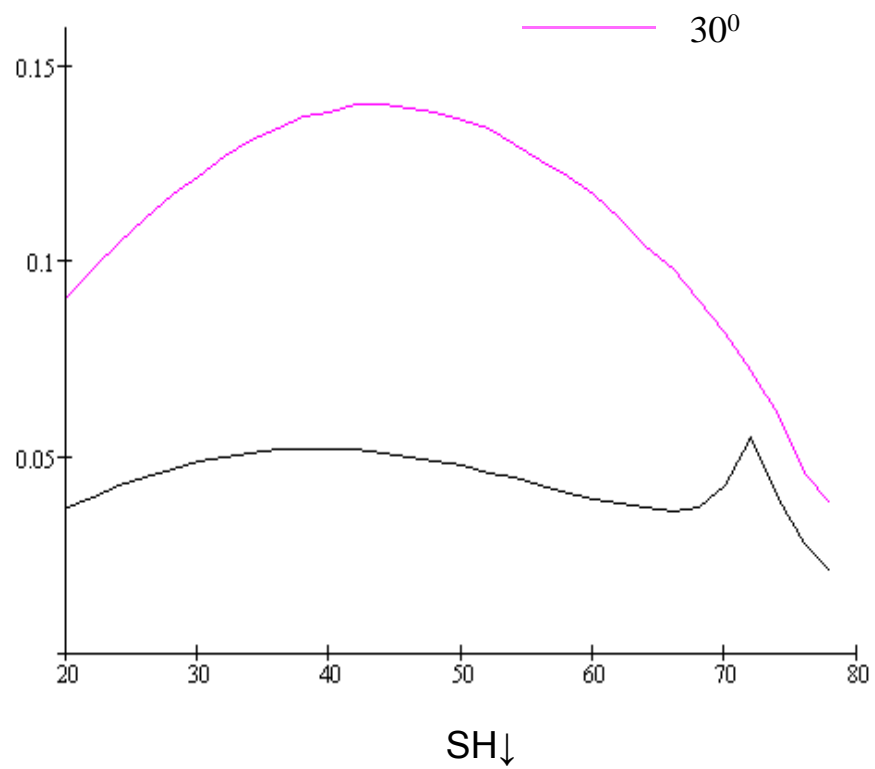
Along fracturing

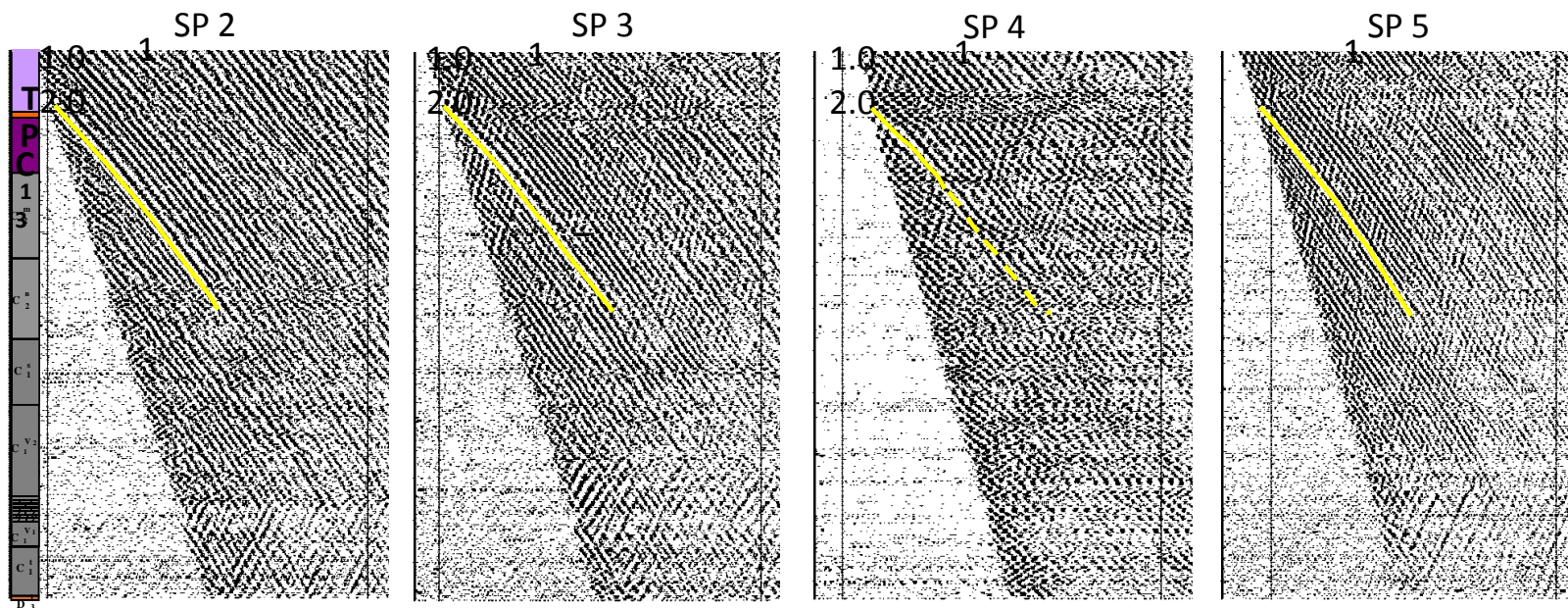


Across fracturing



Example of  
fracturing  
modeling for  
VSP





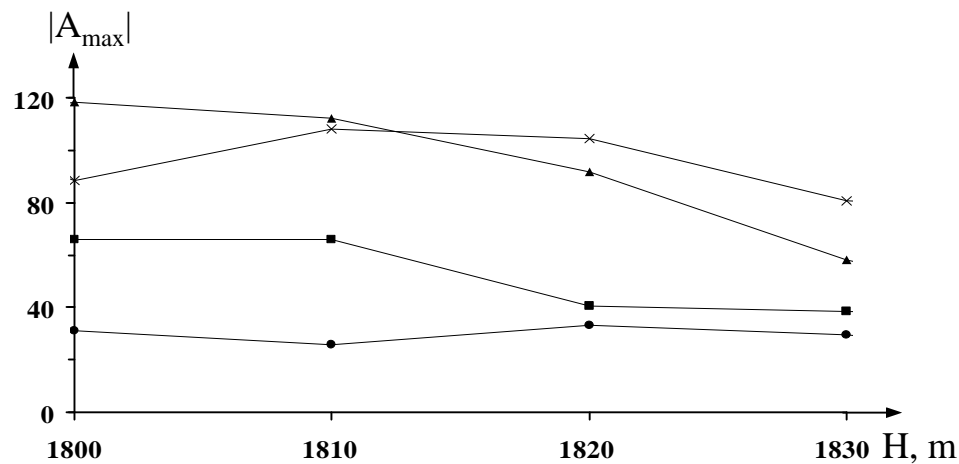
L=1480 m

L=1320 m

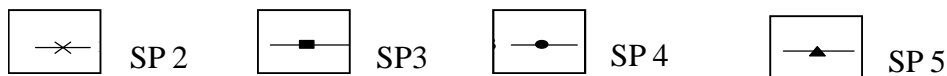
L=1630 m

L=1480 m

VSP shotgathers in well **SG-1** With yellow color are highlighted **transmitted converted waves**



Graphics of **dependency of transition coefficient for converted waves** on depth for different shot points. Fracturing direction is predicted along line connecting SP3 and SP4



# Summary

- **AVO modeling can be performed for complex media:** isotropic, anisotropic, absorbing, gradient, thin-layered, for plain and curved reflecting boundaries.
- Package estimates the **influence of complex geological structure on the measured AVO attributes.**
- **AVO modeling can be done in anisotropic medium for different angles of reflecting boundary and anisotropy axes.**
- **Influence of thin-layering and  $Q$  attenuation on AVO effects** in seismic frequencies band can lead to skipping of big multilayered deposit

**AVO in preresonant and resonant ranges of  
a thin-layered periodic pack**

*EAGE Convention,  
Vienna, 2006.*

N. MARMALYEVSKYY, Y. ROGANOV, A. KOSTYUKEVYCH, Z. GAZARIAN