Synthetic Seismograms in Viscoelastic Media: II. Application

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The results presented in this article are a direct application of the equations derived in the preceding paper (*I. Theory*). Problems that have occurred in our trials are similar to those we had in our previous report (*SEP*-26, p. 221-230), therefore we have solved them in the same manner. Different cases are presented in the following lines.

1. Liquid-Solid case: 1 Head wave.

Three different cases are presented here. For the three of them velocities and densities remain the same. They are:

First medium: liquid (water)		
P-velocity	v_P	1500 m/s
Density	ρ	1 g/cm^3

Second medium: semi-infinite solid		
P-velocity	v'_P	2500 m/s
S-velocity	v'_S	1200 m/s
Density	ρ'	2 g/cm^3

Since $v'_S < v_P$, we get one critical angle and one head wave.

Since we are working in viscoelastic media, velocities are frequency dependent. The reference frequency at which they are taken is set for convenience at 1 Hz. This is a low frequency for our source wavelet spectrum.

The values taken for the quality factor Q are also at the 1 Hz reference frequency, they are:

a) Fig 1-4-7. *No attenuation, No Q contrast*:

First medium: liquid (water)		
P-quality factor	Q_P	10000

Second medium: semi-infinite solid		
P-quality factor	Q'_P	10000
S-quality factor	Q'_S	10000

b) Fig 2-5-8. *Q contrast*:

First medium: liquid (water)		
P-quality factor	Q_P	10000

Second medium: semi-infinite solid		
P-quality factor	Q'_P	14
S-quality factor	Q'_S	10

c) Fig 3-6-9. *High attenuation, No Q contrast*:

First medium: liquid		
P-quality factor	Q_P	10

Second medium: semi-infinite solid		
P-quality factor	Q'_P	10
S-quality factor	Q'_S	10

Comparing figures corresponding to each of these three cases, bring us to the following conclusions:

1. When there is no Q-contrast, (cases a and c), the wave velocities are different between elastic and viscoelastic cases. Higher frequencies than the reference frequency travel faster in a viscoelastic medium.

There is also an amplitude effect we were expecting: a low quality factor implies high attenuation.

A third type of effect can be observed: it is the modification of the frequency content between a wave traveling in an elastic medium and a wave traveling in a viscoelastic medium. Attenuation implies that we are loosing proportionally more high frequencies than low frequencies and so the signal we record is more spread out in a viscoelastic case than in an elastic one.

2. It is important also to consider the differences occurring between case a and b. Case a has nearly no attenuation ($Q_P = 10000$) and no Q-contrast, while case b has the same first medium attenuation as case a, with low Q in the second medium.

We observe that the effects of a Q-contrast appear mainly near critical angle, and that there is an increase of amplitude of post-critical reflections in the Q-contrast case with respect to the *No* Q-contrast one.

Another expected effect is that the amplitude of the head wave is smaller in the Q-contrast case. This is due to the fact that the head-wave is traveling in the highly attenuating second medium.

2. Liquid-solid case: 2 Head waves.

Two different cases are presented here. For both of them velocities and densities are the same, that is:

First medium: liquid (water)		
P-velocity	v_P	1500 m/s
Density	ρ	1 g/cm^3

Second medium: semi-infinite solid		
P-velocity	v'_P	3200 m/s
S-velocity	v'_S	1900 m/s
Density	ρ'	2.5 g/cm^3

As here $v'_S > v_P$, we are having two critical angles and therefore two head waves.

The reference frequency is the same as in the 1 head-wave cases, ($w_0 = 1\ Hz$). For the quality factors, the values at this reference frequency are:

a) Fig 10-12. *No attenuation, No Q contrast*:

First medium: liquid (water)		
P-quality factor	Q_P	10000

Second medium: semi-infinite solid		
P-quality factor	Q'_P	10000
S-quality factor	Q'_S	10000

b) Fig 11-13. *Q contrast*:

First medium: liquid (water)		
P-quality factor	Q_P	10000

Second medium: semi-infinite solid		
P-quality factor	Q'_P	33
S-quality factor	Q'_S	20

The comparison of these two cases lead us to the same type of conclusions as in the 1 head-wave cases.

The amplitudes of the head waves which are propagating in attenuating media are smaller than the ones propagating in non-attenuating media. The frequency spectrum is also shifted to low frequencies.

For the reflections, there is a very slight effect near critical angle, but it seems that the acoustic impedance contrast is overwhelmingly high and masks the Q-contrast effect.

Besides that, we remark that the amplitude of the PP head-wave is much weaker than the PS one. This forces us to overclip the plots, emphasizing wrap-around.

In figure(12), the wrap-around energy is higher than in figure(13), because it was padded with less zeros. The PP head-wave being higher amplitude did not need so much padding.

The small amplitude of the PP head-wave with respect to the PS one is something well known in well-logging data concerning measurements of velocities and quality factors.

It seems possible that this type of synthetic could be used to infer S-quality factors from actual borehole data, knowing the P-quality factor.

ACKNOWLEDGMENTS

We thank M. Yedlin for suggesting the source waveform function.

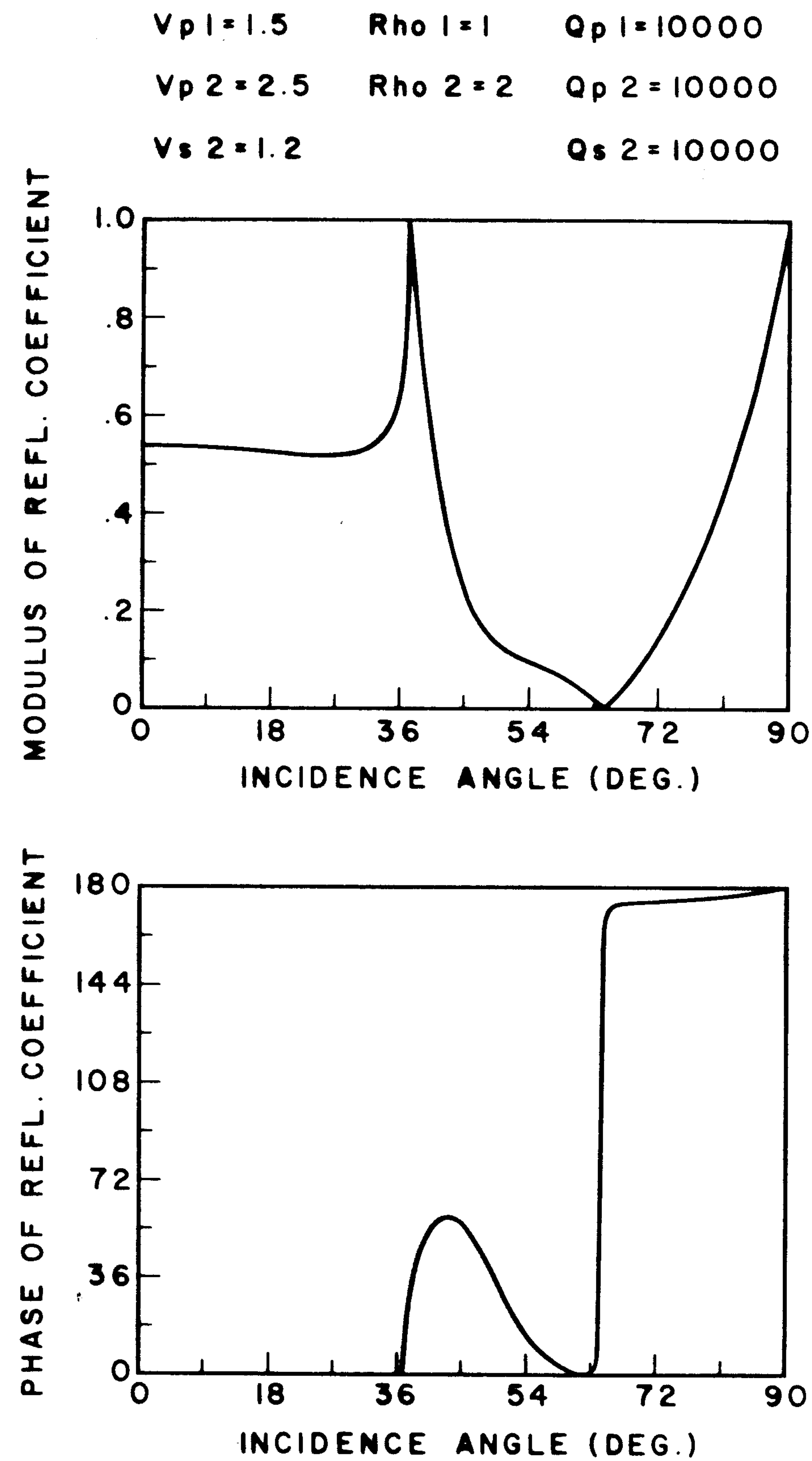

FIG. 1. 1-Head-wave case:
Modulus and phase of Reflection Coefficient. No attenuation included.

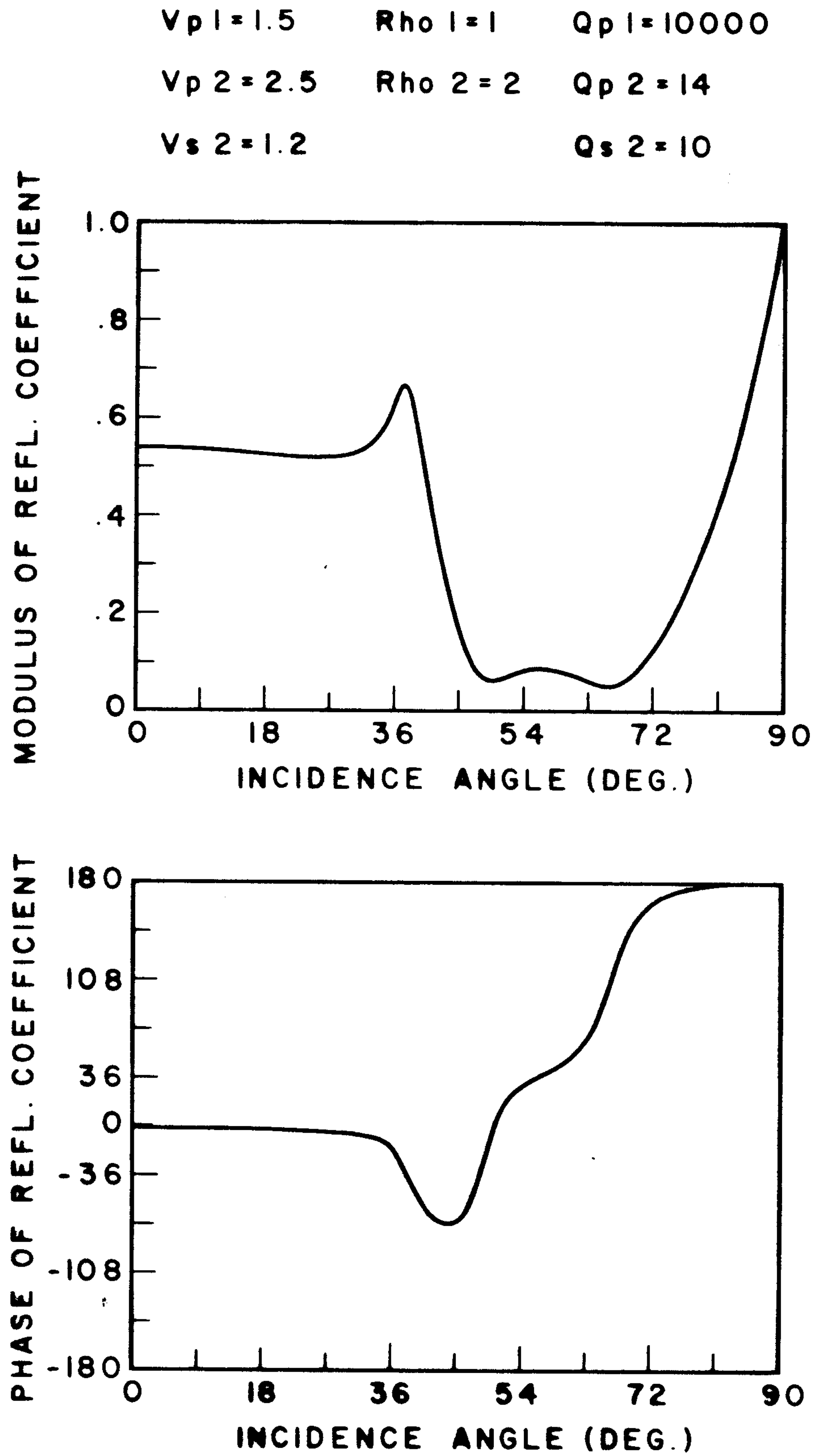

FIG. 2. 1-Head-wave case:
Modulus and phase of Reflection Coefficient. Attenuation and Q-contrast included.
These are frequency-dependent plots due to velocity dispersion in the second medium. The frequency chosen here is the reference frequency (1 *Hz*).

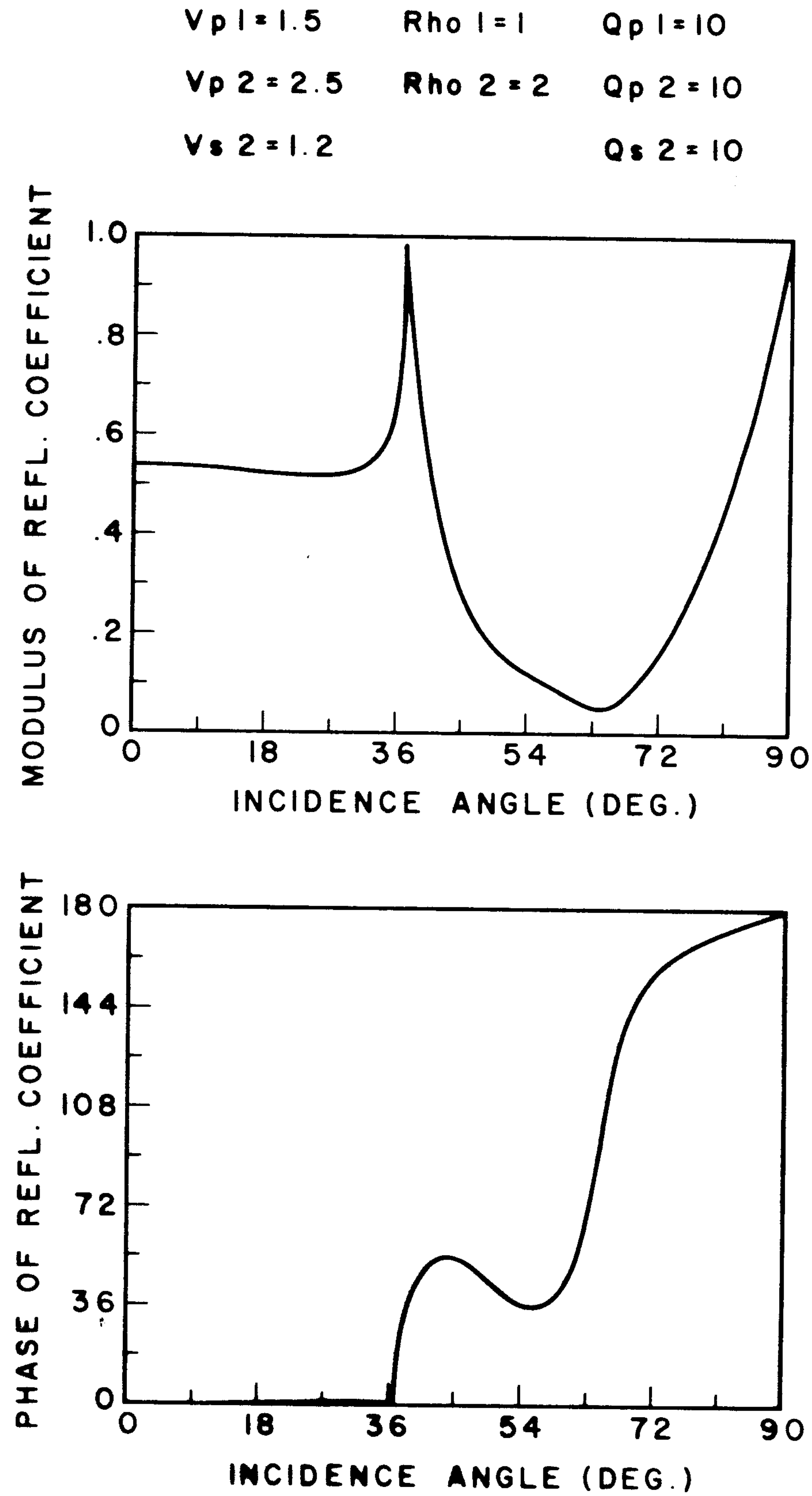

FIG. 3. 1-Head-wave case:
Modulus and phase of Reflection Coefficient. High attenuation and No Q-contrast.
Observe the small differences with figure 1 because there is no Q-contrast in both cases.
This figure is also plotted at the reference frequency.

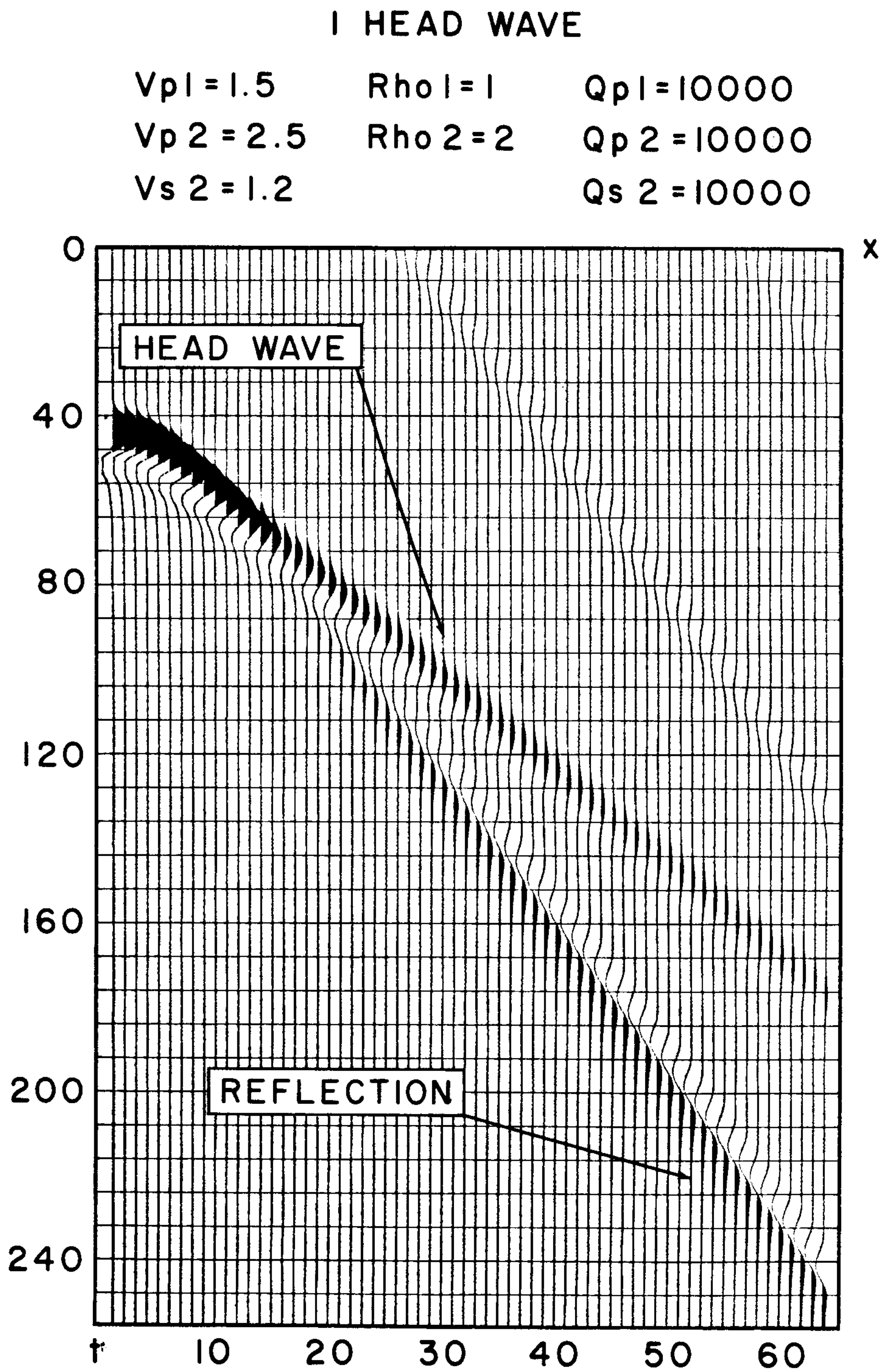

FIG. 4. 1-Head-wave case:
Synthetic seismogram. No attenuation included.
The parameters used to generate it are: $dx = 86\ m$, $dt = .032\ s$.

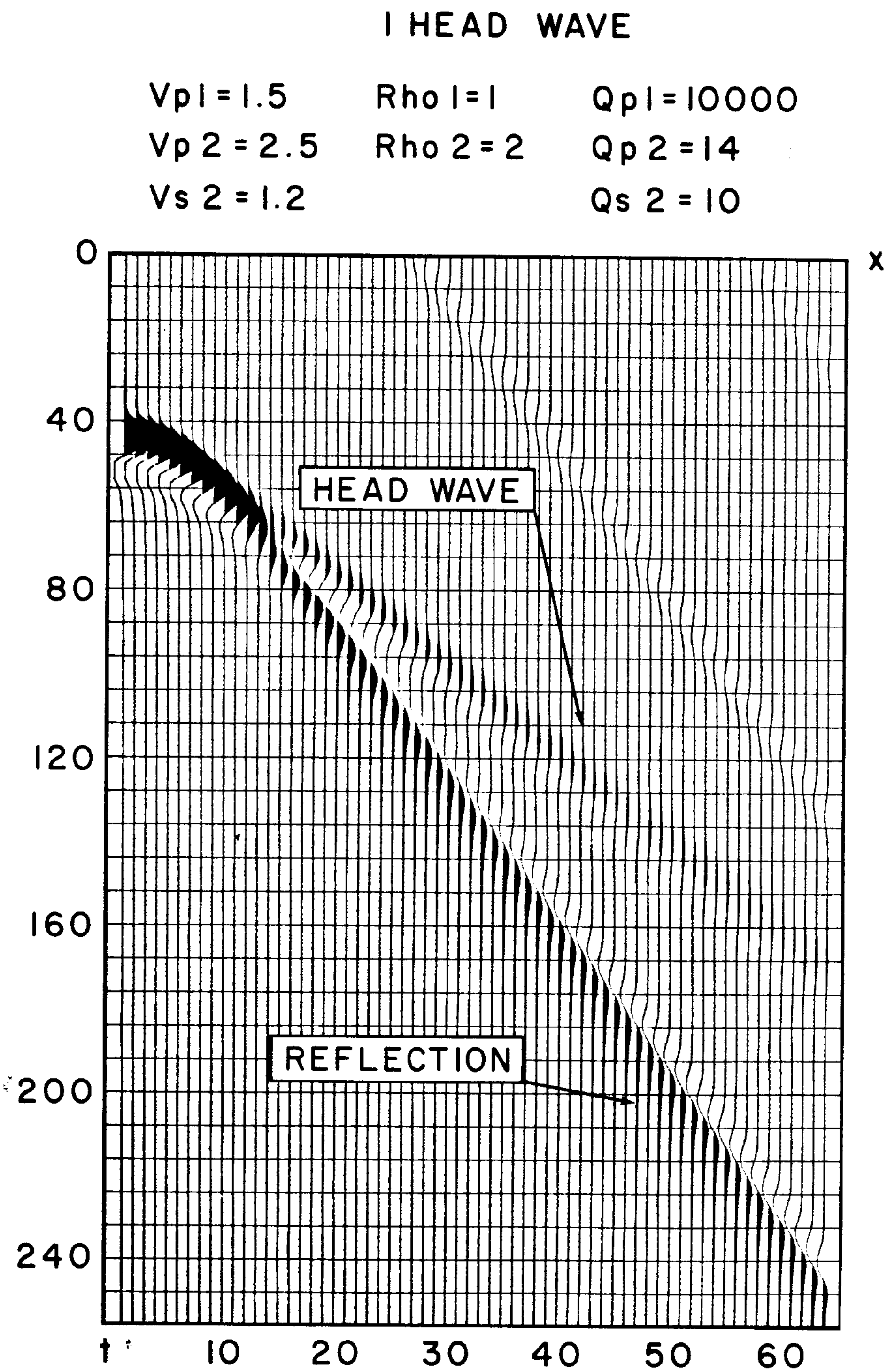

FIG. 5. 1-Head-wave case:
Synthetic seismogram. Attenuation and Q-contrast included.
Same clip value and parameters as in figure 4. Note the increase of amplitude of postcritical reflection and the decrease of amplitude of the head-wave with respect to figure 4. Note also the difference in arrival time for the head-wave.

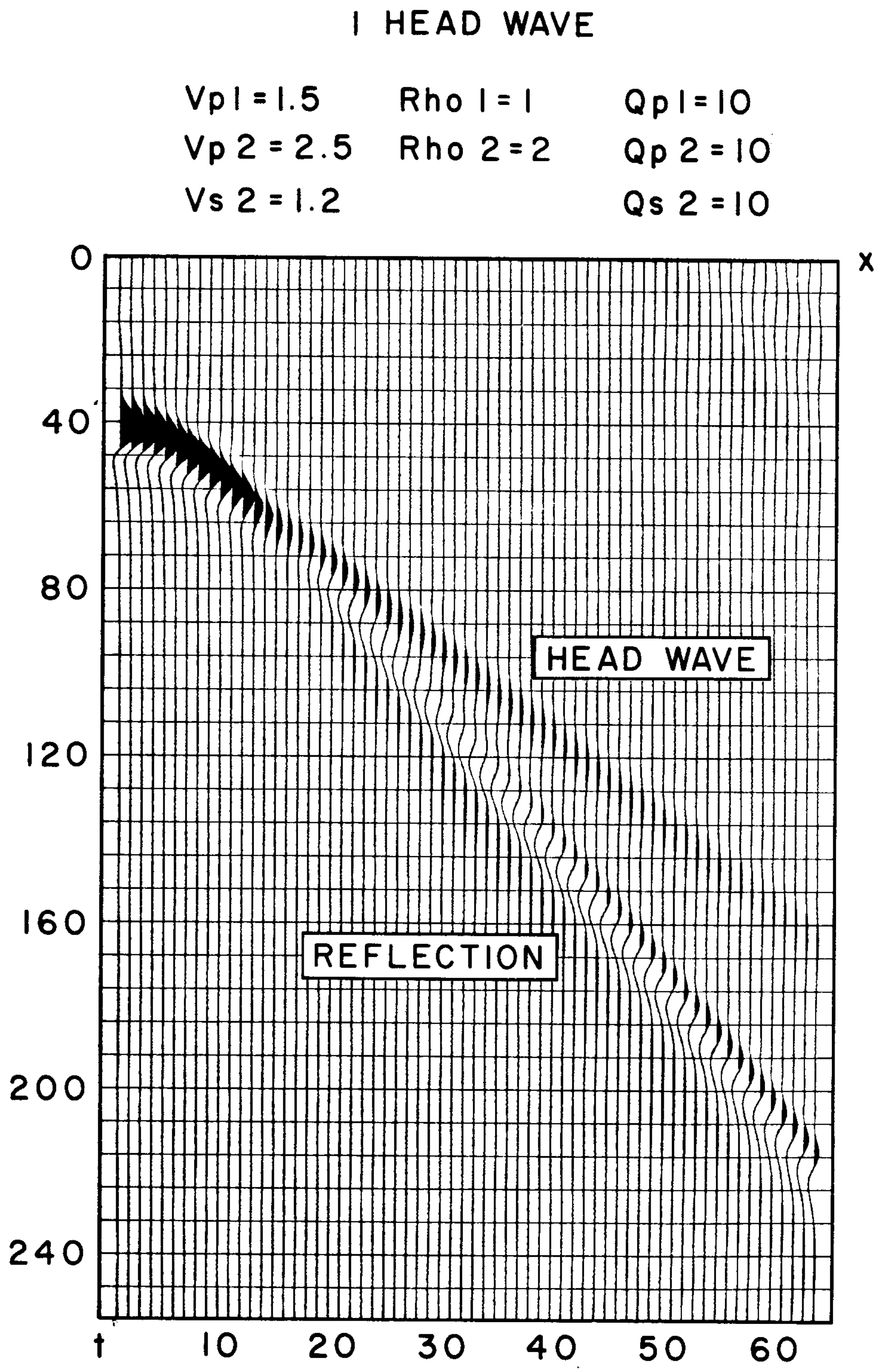

FIG. 6. 1-Head-wave case:
Synthetic seismogram. High attenuation and no Q-contrast.
Same clip value and parameters as in figure 4. Note the decrease of amplitude of the reflection and the decrease of amplitude of the head wave with respect to figure 4. Note also the differences in arrival times for the reflection and the head-wave.

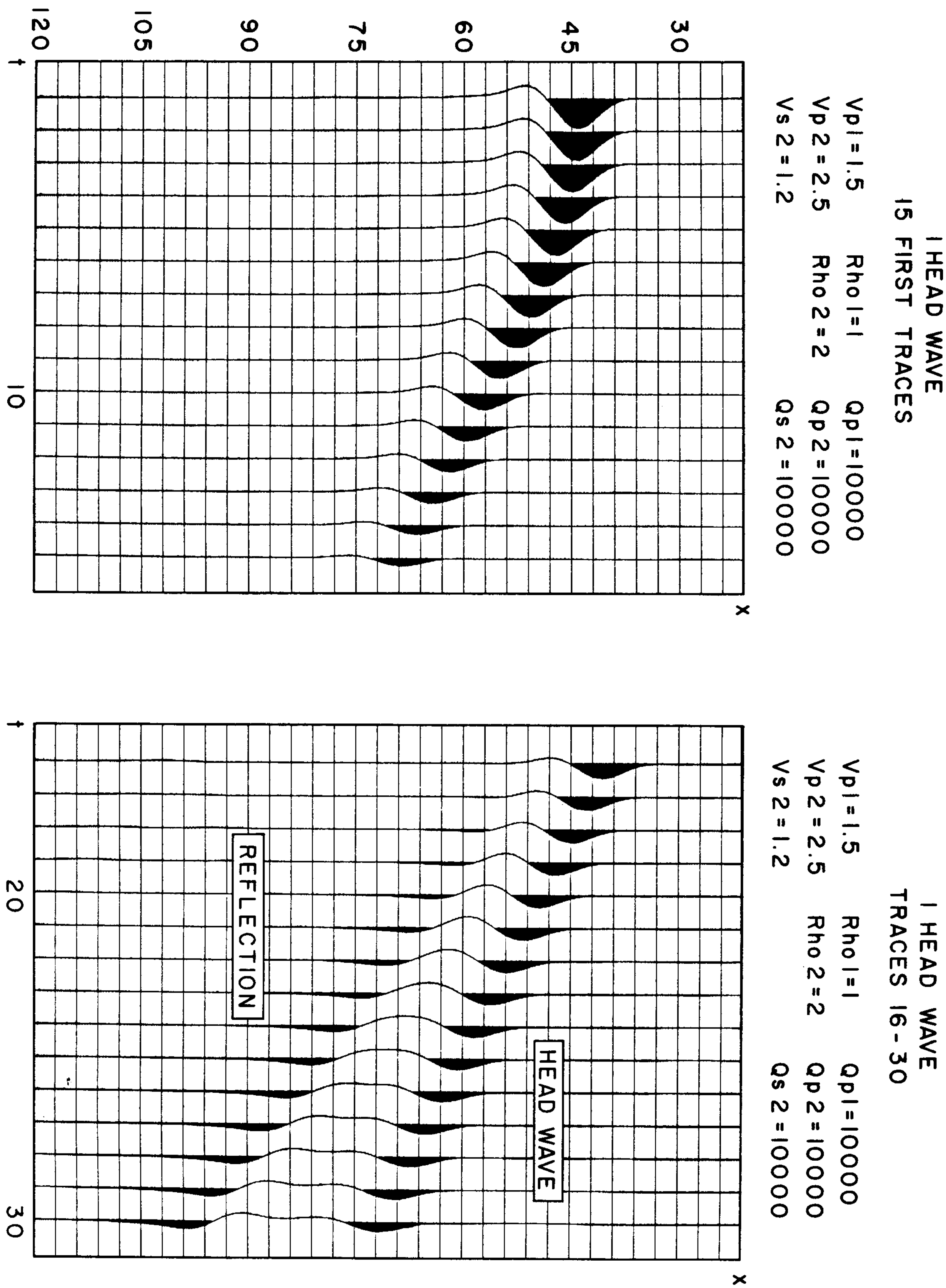

FIG. 7. 1-Head-wave case: No attenuation included. Window of figure 4. Left: traces 0-15. Right: traces 16-30. The figures are not clipped at the same value. These are the reference figures to compare with figures 8 and 9.

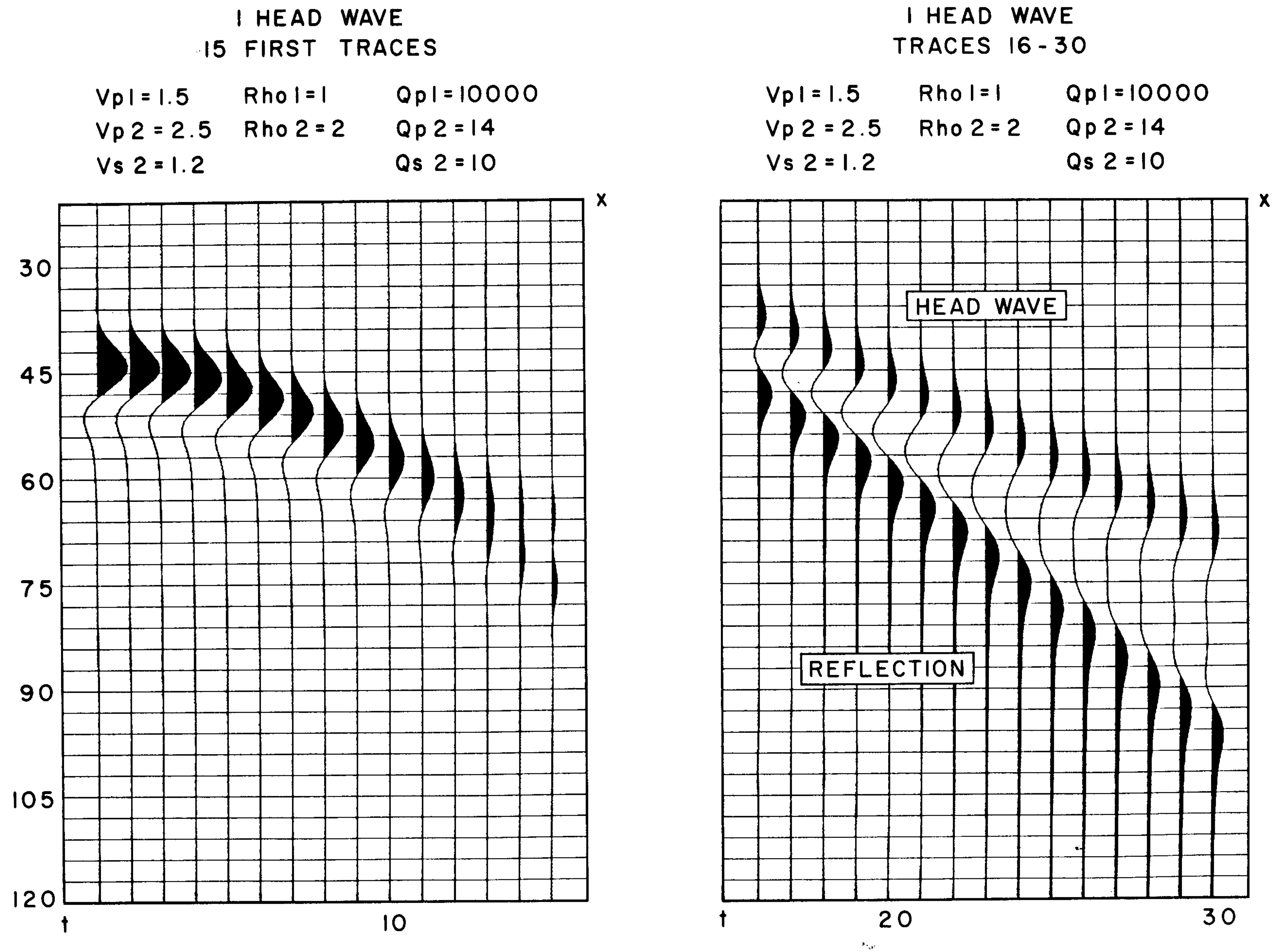

FIG. 8. 1-Head-wave case: Attenuation and Q-contrast included. Window of figure 5. Same traces and clip values as in figure 7. Remarks done in figure 5 are emphasized here.

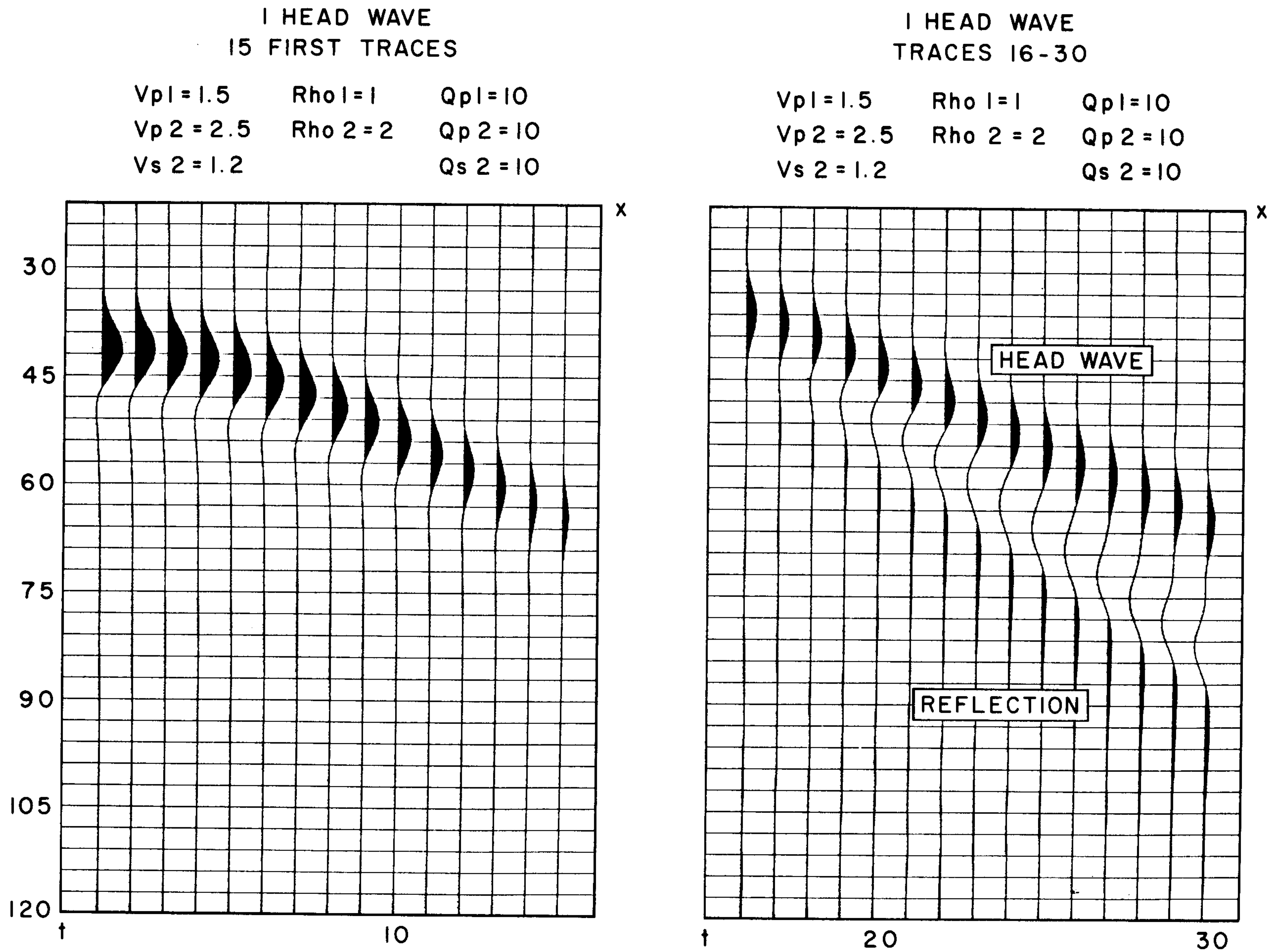

FIG. 9. 1-Head-wave case: High attenuation and no Q-contrast. Window of figure 6. Same traces and clip values as in figure 7. Remarks done in figure 6 are emphasized here.

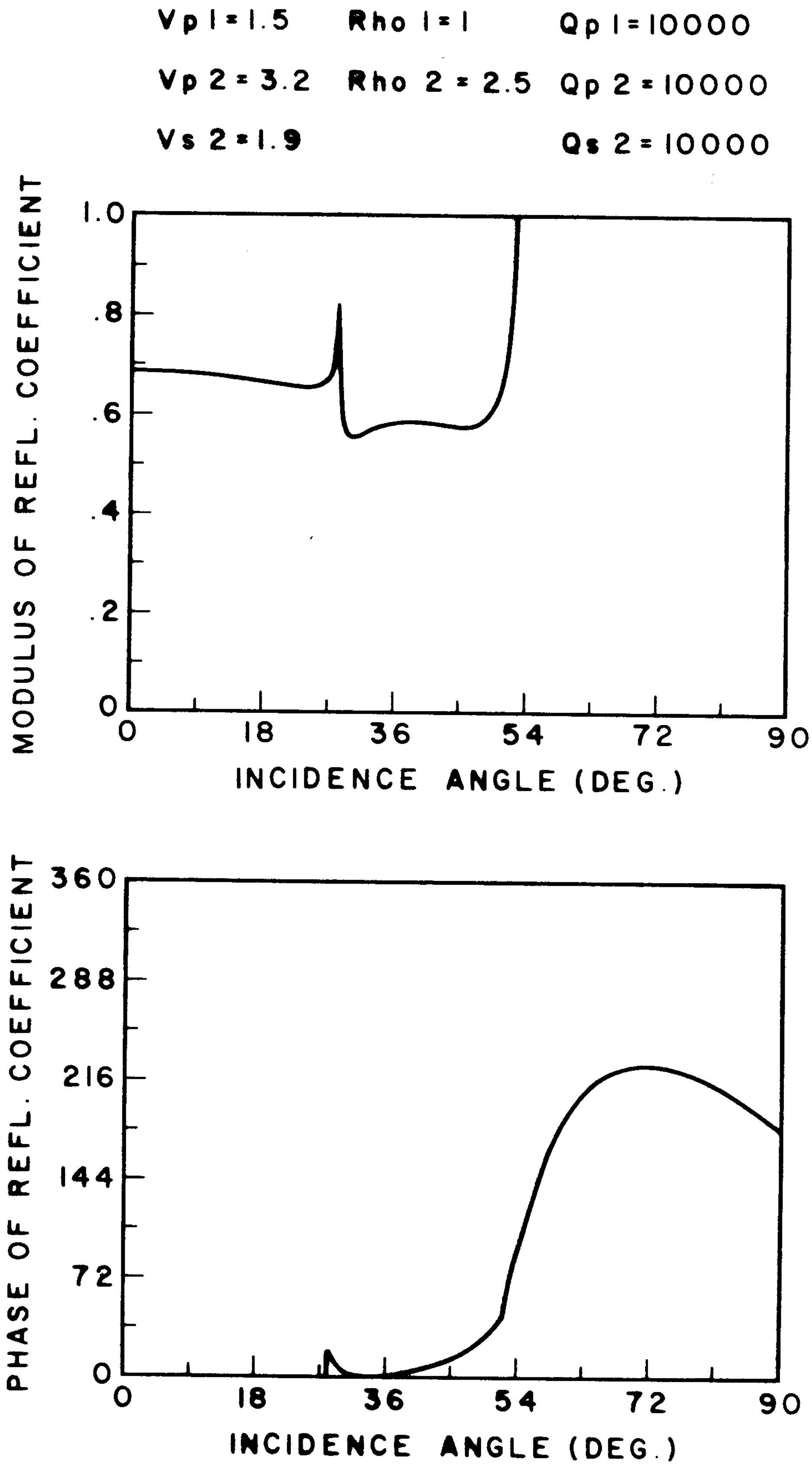

FIG. 10. 2-Head-waves case:
Modulus and phase of the reflection coefficient. No attenuation included.

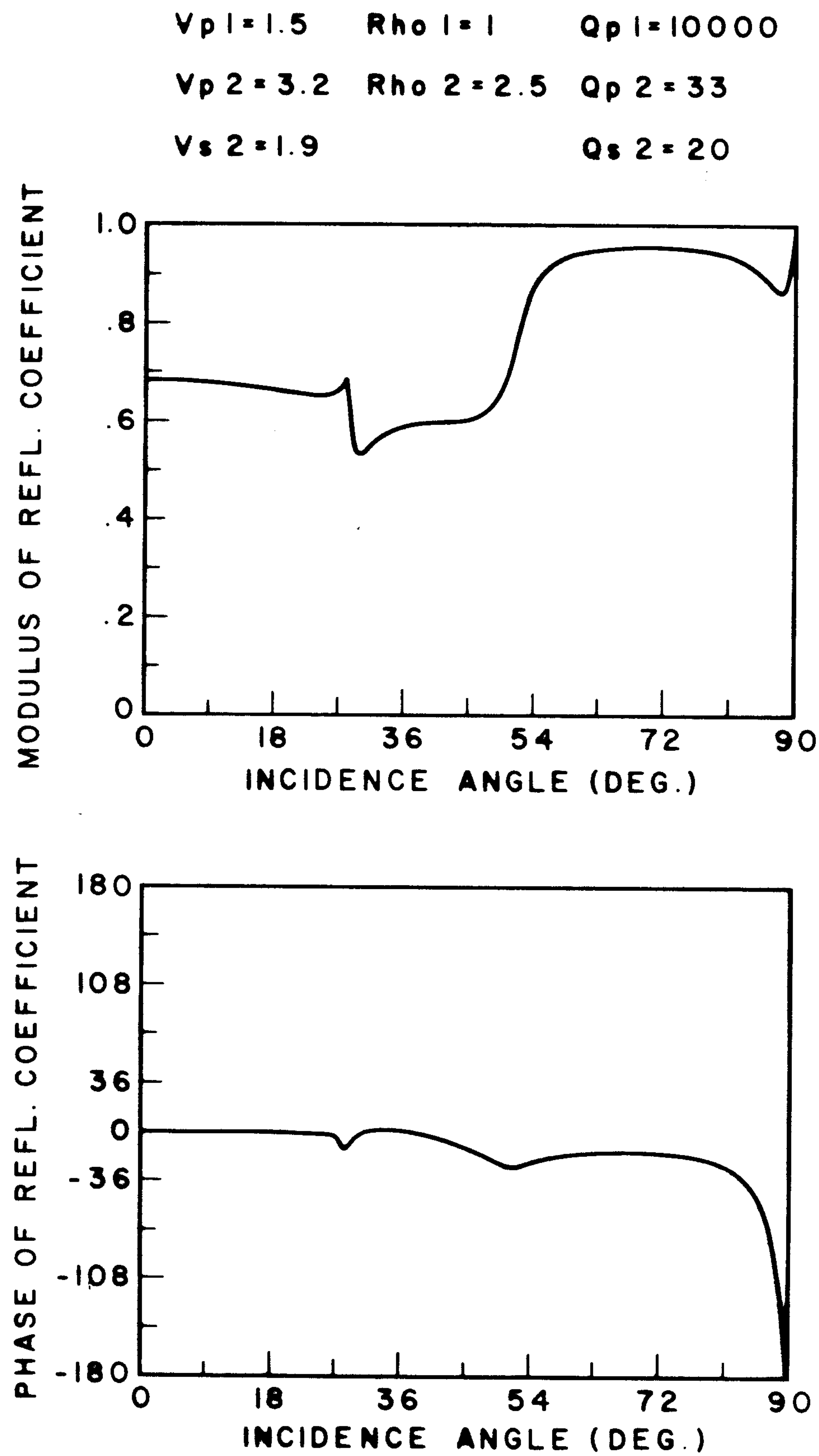

FIG. 11. 2-Head-waves case:
Modulus and phase of the reflection coefficient. Attenuation and Q-contrast included. The plots are frequency dependent and were generated with the reference frequency.

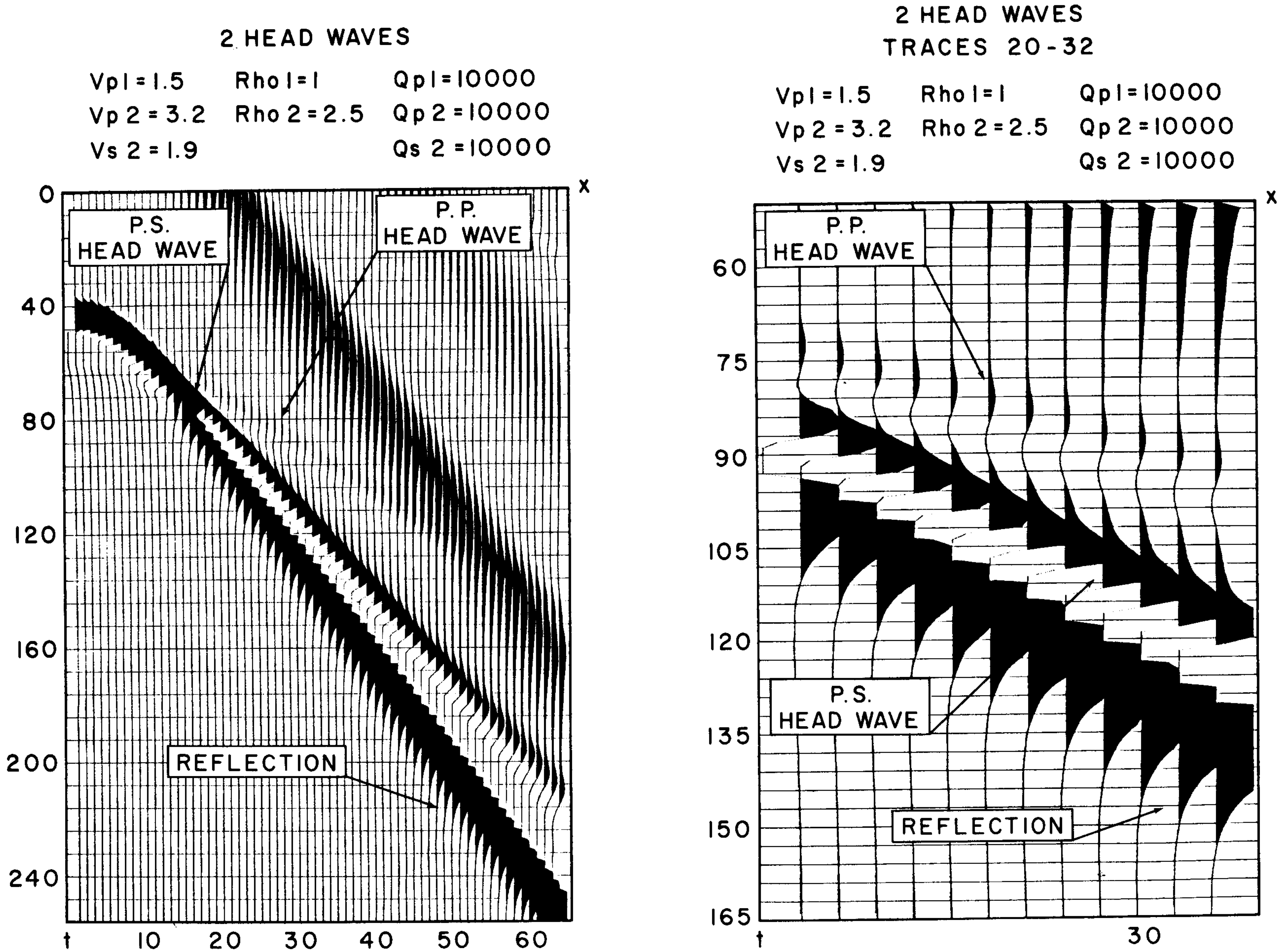

FIG. 12. 2-Head-waves case:
Synthetic seismogram. No attenuation included. The parameters used to generate it are the same as in figure 4. Left: Full seismogram. Right: Window, traces 21-32. These are reference figures for figure 13. Note the small amplitude of the PP head-wave with respect to the PS one.

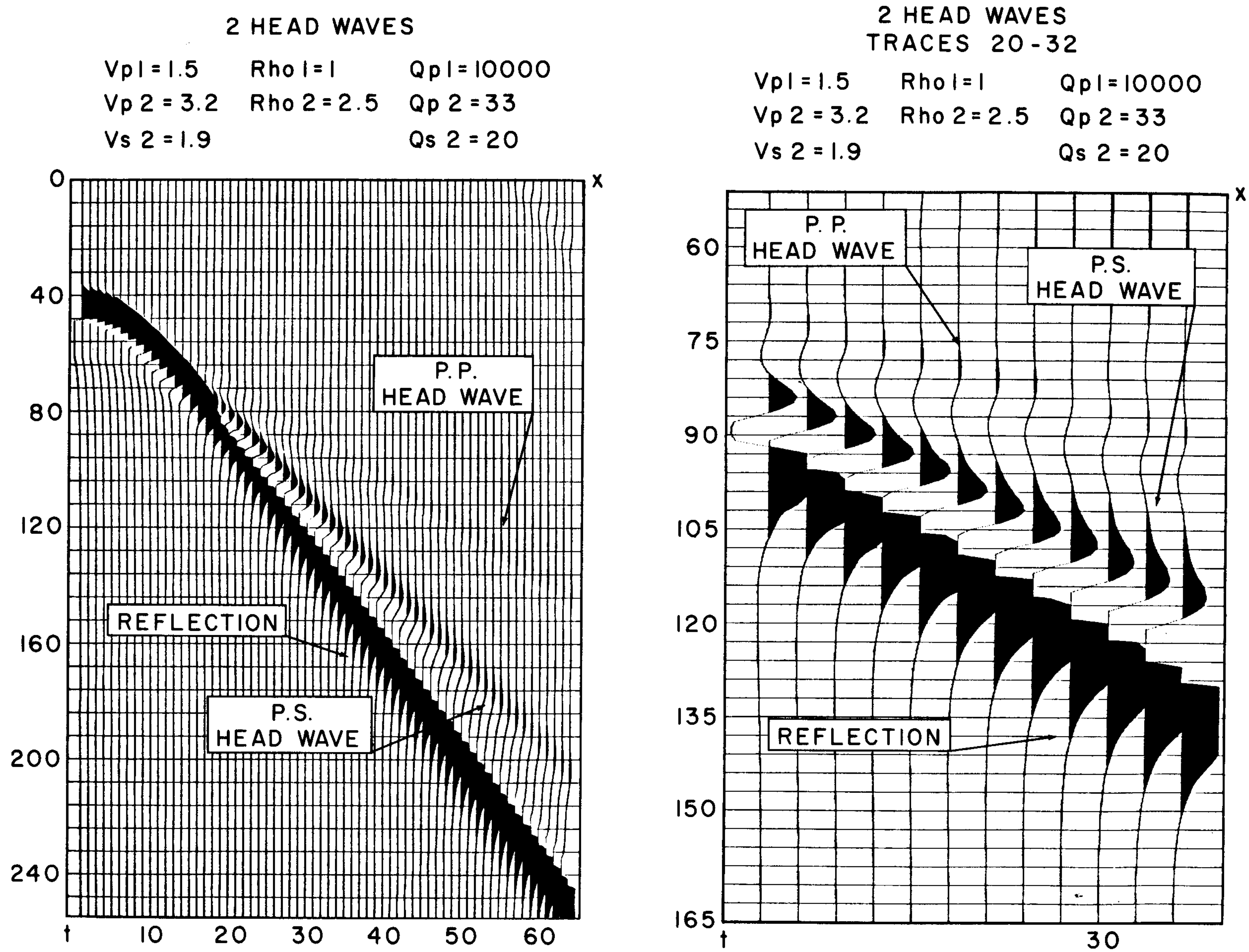

FIG. 13. 2-Head-waves case:
Synthetic seismogram. Attenuation and Q-contrast included. The parameters used to generate it are the same as in figure 4. Left: Full seismogram. Right: Window, traces 21-32. These figures were padded with more zeroes than figure 12. Note the smaller amplitude of both head-waves with respect to the previous case. Note also the differences in travel-times for both head-waves.