Seismic modeling of Pekisko porosity

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ABSTRACT

Seismic data have been acquired over a localized Pekisko structure which has secondary porosity development due to the dolomitization of Pekisko limestone. A seismic amplitude anomaly occurs at the Pekisko level in this structure.

A series of normal incidence P-P models and non-normal incidence P-P and P-SV synthetic gathers were produced to test the seismic response of Pekisko porosity development. The development of Pekisko porosity produces a decline in the amplitude of the Pekisko event on normal incidence models and produces a decrease in amplitude of the Pekisko event with increasing offset on the synthetic gathers.

This modeling indicates that the seismic amplitude anomaly on the seismic data in this area could be caused by Pekisko porosity development.

INTRODUCTION

A study was undertaken to determine the nature of an amplitude anomaly that occurs on P-wave seismic data in the Pekisko Formation in the study area.The objective of this study was to determine if this anomaly on seismic data could be caused by porosity development in the Pekisko Formation.

The study area is located in Alberta but due to the confidential nature of the seismic data no specific location will be given. The study area is located approximately 6 miles west of the Pekisko subcrop edge. The Pekisko in this study area form localized structures which override the regional dip and form structural traps. There is an increase in Pekisko porosity due to dolomitization of the limestones which produces secondary porosity. This secondary porosity has developed in the middle of the Pekisko Formation in the study area and this porosity is the reservoir for hydrocarbons.

A series of normal incidence seismic models and non-normal incidence synthetic gathers (source-receiver offset) were generated using P-wave sonic logs from the wells in the area. These models were created to determine how porosity development in the Pekisko Formation affects the seismic response of this formation.

GEOLOGICAL BACKGROUND

In the study area, Mississippian age sediments are potential targets for hydrocarbon (gas) exploration. The primary target for most exploration in this area has been the middle Mississippian age Pekisko Formation.

The Pekisko Formation is conformably underlain by the Banff Formation and is overlain by conformable sediments of the Shunda Formation (Figure 1). The Pekisko appears to have been deposited as a cyclical shallow lime mud bank with areas of bioclastic debris, oolitic-calcispheric shoals and scattered coralline patch reefs in the Mission Canyon-Madison-Livingstone Eperic seas (Gettis, 1991). The orientation of the banks of bioclastic debris and the oolithic shoals are closely associated with the topographic highs on the underlying Banff Formation. The Pekisko became a karsted erosional surface. The percolating waters along the Paleozoic unconformity formed solution channels and enhanced porosity and permeability of the reservoir through leaching and partial dolomitization especially towards the erosional edges.

SEISMIC DATA AND MODELING

A small structure occurs at the Pekisko Formation level on seismic data on seismic line A (Figure 2). The amplitude of the Pekisko peak decreases in this structure. This decrease in amplitude may be produced by an increase in porosity in the Pekisko Formation in this structure. Porosity development in the Pekisko limestones decreases the sonic velocity of the Pekisko Formation on sonic logs and this may cause a decrease in the acoustic impedance contrast between the Pekisko Formation and the porous overlying Shunda Formation. This decline in sonic velocity on logs also occurs in the wet porosity on sonic logs so this decline in sonic velocity is not an artifact of the gas saturation.

Normal incidence modeling

Two normal incidence seismic models were created using GMA's LogM software. These models were created to determine the seismic response of Pekisko porosity in the study area. These models used a tight Pekisko well and a porous Pekisko well to model the seismic response of Pekisko porosity.

The first model used well A (Figure 3) as the tight well and well B (Figure 4) as the porous Pekisko well. The A well has 10 meters of pay in the Pekisko Formation based on a 4% porosity cutoff. The B well has an exceptionally thick Pekisko Formation and has well developed Pekisko porosity. The B well has 24 meters of pay in the Pekisko Formation. The A well was modified to remove the Pekisko porosity and this modified well was included in the model to observe how the seismic response of the Pekisko Formation varies from no Pekisko porosity to well developed Pekisko porosity. A depth model of these wells was created on the GMA which consisted of the sonic logs of wells A, B and modified A as well as the linearly interpolated sonic logs. A seismic response model of the depth model (Figure 5a) was created using a 35 Hz. zero-phase Ricker wavelet. The 35 Hz. Ricker wavelet was chosen as it produced the best match between synthetic data and seismic data in this area.

The seismic response of increasing Pekisko porosity is a decrease in amplitude of the peak representing the Pekisko Formation. The Banff shale formation changes from a trough to a peak which slightly increases in amplitude with increasing Pekisko porosity. The A well is located within a 100 meters of seismic line B in the study area. Seismic line B and the well location are shown in Figure 6. A small structure occurs on seismic line B at the well location and the Pekisko peak decreases in amplitude.

A second normal incidence model was created which used well A and well C (Figure 7) as the tight and porous wells. The C well has well developed porosity and 25 meters of pay in the Pekisko Formation. The seismic response model for these wells is presented in Figure 5b. The seismic response of increasing Pekisko porosity is a decrease in amplitude of the peak representing the Pekisko Formation in this model. The Banff Shale Formation changes from a trough to a peak which slightly increases in amplitude with increasing Pekisko porosity. In both normal incidence models an increase in Pekisko porosity is indicated by a decrease in amplitude of the peak representing the Pekisko Formation. The Banff Shale changes from a trough to a peak which increases in amplitude with increasing Pekisko porosity.

Non-normal incidence modeling

A series of non-normal incidence synthetic gathers were created from the P-wave sonic logs of wells A, B and D (Figures 3, 4 and 8) using the program described in Howell et al. (1991). This program requires a shear wave sonic log to calculate Poisson's ratio for each formation. The wells drilled in the study area are old wells from the 1960's and 1970's and they were logged using only standard p-wave sonic logging tool. The only full wave form sonic log that could be found which logged the Mississippian section were in the Medicine River area of Alberta (township 39 range 3 W5M). Miller et al. (1990) examined logs from this area and found that the Vp/Vs ratio for the Pekisko Formation ranged from 1.98 at 1% Pekisko porosity to 1.78 at 7% Pekisko porosity. A series of of P-P and P-SV offset synthetics were created for each well with the Vp/Vs ratios ranging from 1.80 to 2.0. The synthetic gathers were created using one Vp/Vs ratio for the entire log. The synthetic gathers were created using a trace spacing of 100 meters and offsets ranging from 100 to 2400 meters.

It was found that the P-P synthetic gathers for each well were unaffected by the variation in the Vp/Vs ratio. The P-P synthetic gathers presented in this paper will only use a Vp/Vs ratio of 1.87 which is approximately in the middle of the Vp/Vs ratio range that Miller et al. (1990) found for the Pekisko Formation. This Vp/Vs ratio is also very close to the average Vp/Vs ratio of 1.89 for limestones determined by Miller et al. (1990). Since the Pekisko Formation in the study area is overlain and underlain by limestones this modeling should produce an accurate response for the Pekisko Formation. The P-P synthetic gathers were created using a peak frequency of 40 Hz. which corresponds to a seismic bandwidth of 10-70 Hz which compares favorably with the seismic data's 12-80 Hz. bandwidth.

Four P-SV synthetic gathers were created over each well using Vp/Vs ratios of 1.80 and 2.0 and wavelet peak frequencies of 20 and 35 Hz. The 20 Hz peak frequency synthetic gathers were unable to resolve any of the Mississippian age formations so they will not be presented in this paper.

The P-P synthetic gather for well A which is a tight Pekisko well is shown in Figure 9. The Nordegg, Shunda, Pekisko and Banff formations were identified on these synthetics by creating a zero-offset synthetic from the p-wave sonic log using GMA's LogM software. The Nordegg, Shunda, Pekisko and Banff formations all have a constant amplitude with increasing offset. The two 35 Hz. P-SV synthetic gathers for well A are presented in Figures 10 and 11. The Nordegg, Shunda, Pekisko and Banff events all show an increase in amplitude with offset on each of the offset synthetics but the maximum amplitude of each of these events is much stronger on the synthetic with the Vp/Vs ratio equal to 1.80 as compared to the synthetic with the Vp/Vs ratio equal to 2.0.

The P-P synthetic gather for well B which is a porous Pekisko well is shown in Figure 12. The Nordegg and Shunda formations on this synthetic combine together to produce one peak with increasing offset. The peak which represents the Pekisko Formation decreases in amplitude with increasing offset and becomes a trough at far offset. The amplitude of the Pekisko event at near zero offset is smaller than the amplitude of the Pekisko event at the same offset for well A. The peak which represents the Banff Formation also decreases slightly in amplitude as offset increases. The two 35 Hz. P-SV synthetic gathers for well B are shown in Figures 13 and 14. The Nordegg, Banff and Shunda events each have a higher amplitudes on the gather with the Vp/Vs ratio equal to 1.8 as compared to the gather with the Vp/Vs ratio equal to 2.0. The peak which represents the Pekisko Formation has a larger maximum amplitude on the gather with the Vp/Vs ratio equal to 2.0 as compared to the gather with the Vp/Vs ratio equal to 1.80. The peak representing the Pekisko reaches its maximum amplitude at 1100 meters on the gather with Vp/Vs ratio equal to 1.8 verses 1400 meters on the gather with Vp/Vs ratio equal to 2.0. The Pekisko peak on both gathers increases in amplitude up to a certain offset then declines rapidly with further increases in offset

The P-P synthetic gather for well D is shown in Figure 15. The events representing the Nordegg and Shunda formations on this gather have a moderate decrease in amplitude with offset. The peak which represents the Pekisko Formation only has a slight decrease in amplitude with offset. The amplitude of the Pekisko peak at near zero offset on this well is similar to the amplitude of the Pekisko peak at the same offset on the A well which is the tight well. This shows the importance of offset modeling because normal incidence models would produce similar amplitudes for the Pekisko event on both the tight and porous Pekisko wells. The two P-SV synthetic gathers for the D well are presented in Figures 16 and 17. The Nordegg event on the gather with the Vp/Vs ratio equal to 1.8 has a much stronger increase in amplitude with offset compared to the gather with the Vp/Vs ratio equal to 2.0. The Shunda peak has a larger increase in amplitude with offset on the gather with the Vp/Vs ratio equal to 2.0 as compared to the gather with the Vp/Vs ratio equal to 1.8. The Pekisko peak on both gathers has a similar maximum amplitude and the amplitude of this peak increases till the mid offsets and then decreases with further increases in offset.

The P-P synthetic gathers indicate that Pekisko porosity development produces a decline in amplitude of the Pekisko peak with increasing offset. This is shown on the synthetic gathers of wells B and D which have good Pekisko porosity while well A which is tight does not have any decrease in amplitude of the Pekisko peak with increasing offset. The P-SV synthetic gathers also indicate that Pekisko porosity development produces a decline in amplitude of the Pekisko peak with offset. One difference between the P-P and P-SV gathers is that the decline in amplitude of the Pekisko peak with offset in the porous Pekisko wells occurs at far offset on the P-P gathers and mid offsets on the P-SV gathers. This indicates that offsets used for acquisition of P-SV seismic data for AVO analysis can be much shorter (approximately 3/4 of the offset used for P-P data in this case) then offsets used for P-P data acquisition.

CONCLUSION

The modeling of Pekisko porosity development indicates that the amplitude anomaly on the seismic data in these localized structures could be caused by Pekisko porosity development.

The normal incidence models all produce a decrease in amplitude of the Pekisko event when Pekisko porosity development occurs. The amplitude of the Pekisko event on the offset gather remains constant with increasing offset for the tight well and decreases in amplitude with increasing offset for the porous wells.

The P-SV offset gathers produce a much stronger amplitude variation with offset than the P-P gather for the porous Pekisko wells. This indicates that the acquisition of P-SV surface data would help to define Pekisko porosity. A problem with P-SV data may be the acquisition of high enough frequency data to resolve the Pekisko porosity. The modeling for this study indicated that a peak frequency of 20 Hz. provided no resolution of the Mississippian formations but at a peak frequency of 35 Hz. the Mississippian formations were resolved. The resolution of Mississippian formations occurs somewhere between a peak frequency of 20 to 35 Hz. If there is a problem acquiring surface P-SV data with this high frequency it would suggest the use of P-SV VSP's as an exploration aid in the study area for definition of Pekisko porosity

FUTURE WORK

Possible future work in this study area includes a continuation of the synthetic gather modeling using shear wave sonic logs which would allow a continuous variation on Poisson's ratio through the Pekisko Formation. This would allow modeling of not only the Pekisko porosity variation but also variation in the gas saturation in the wells.

ACKNOWLEDGEMENTS

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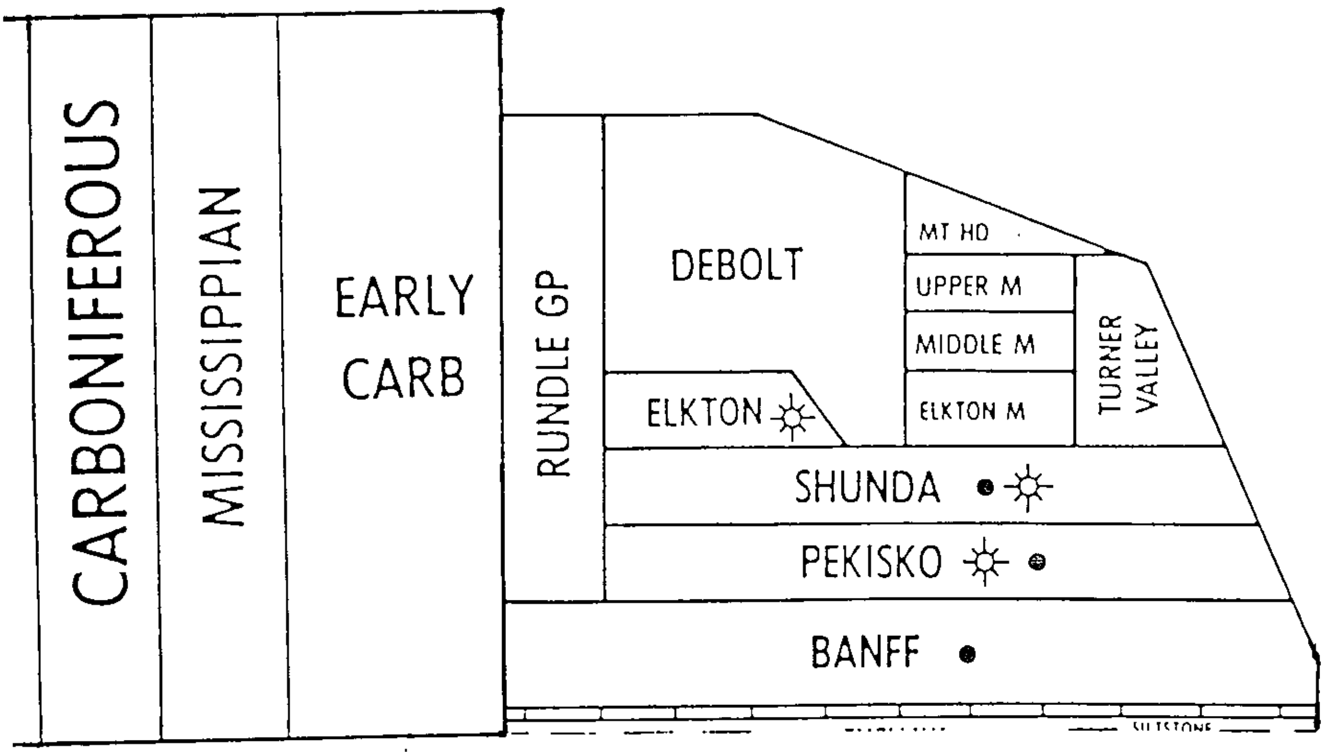


FIG. 1. Correlation chart (Agat Laboratories, 1988)

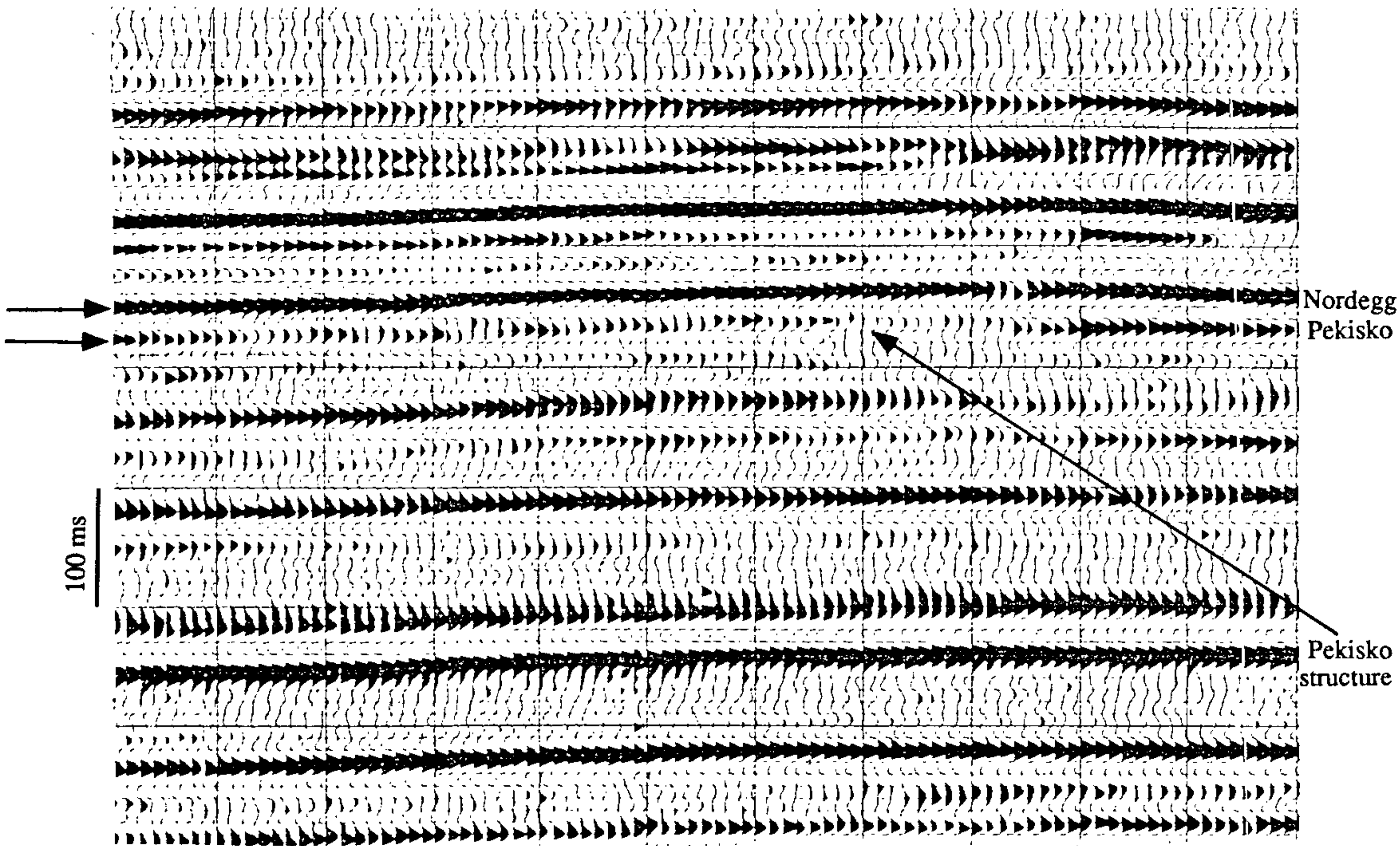


FIG. 2. Seismic line A

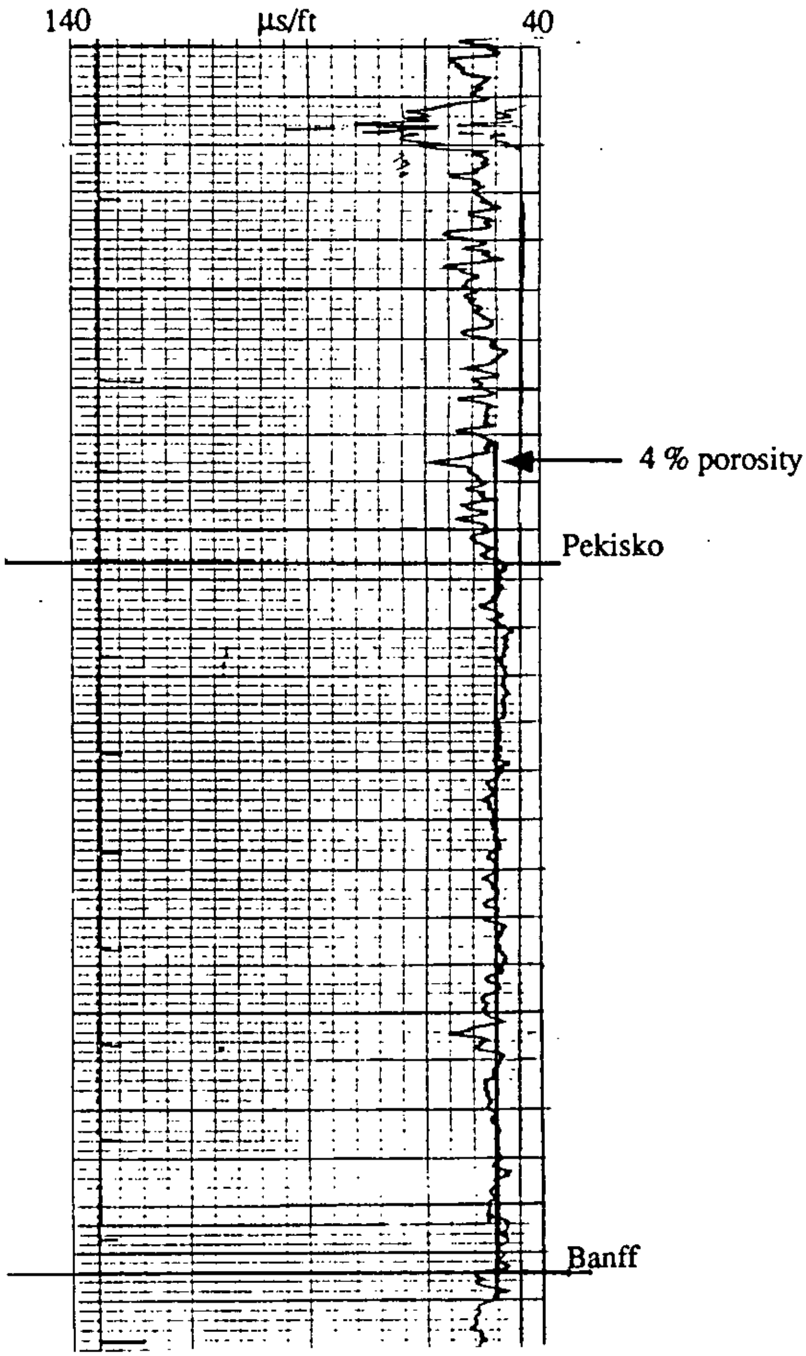


FIG. 3. Sonic log well A

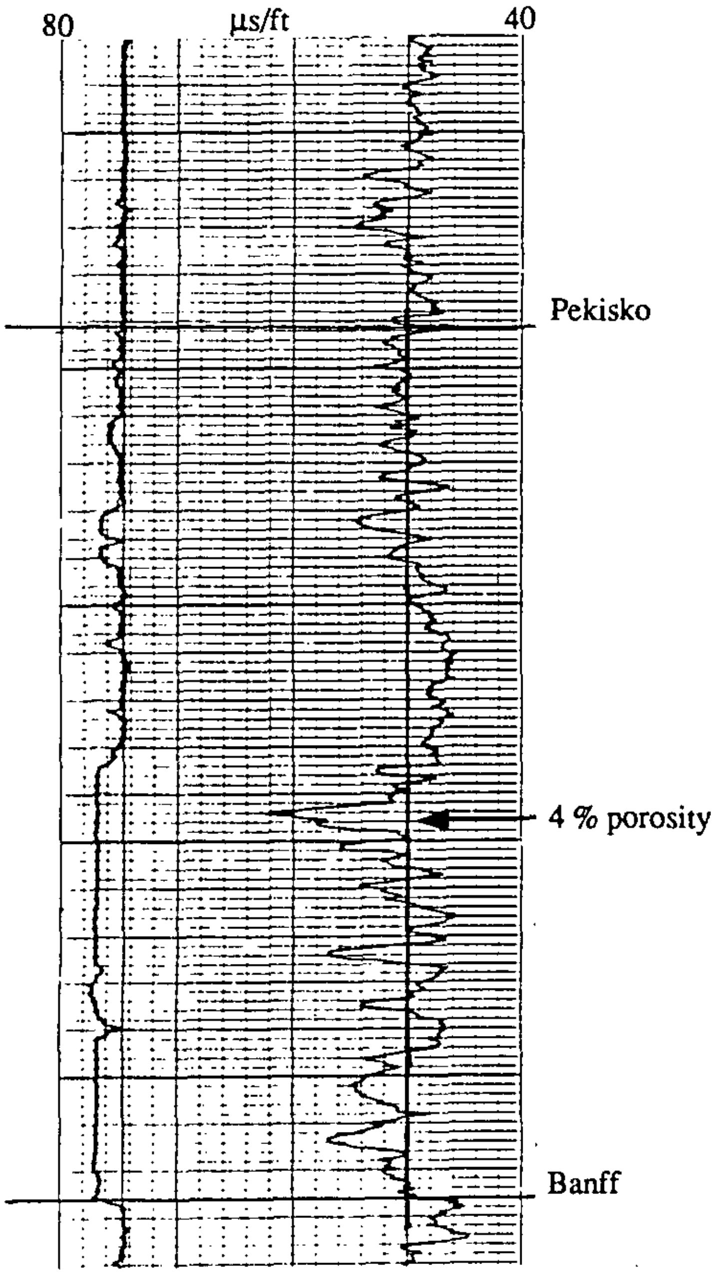
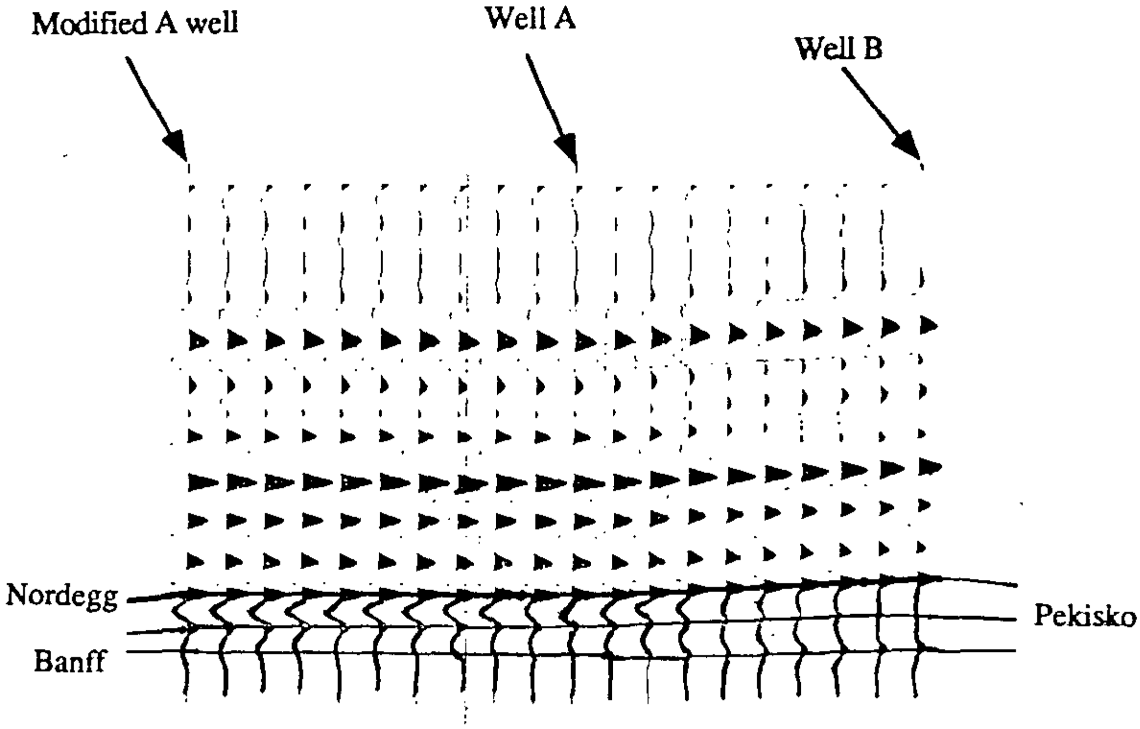
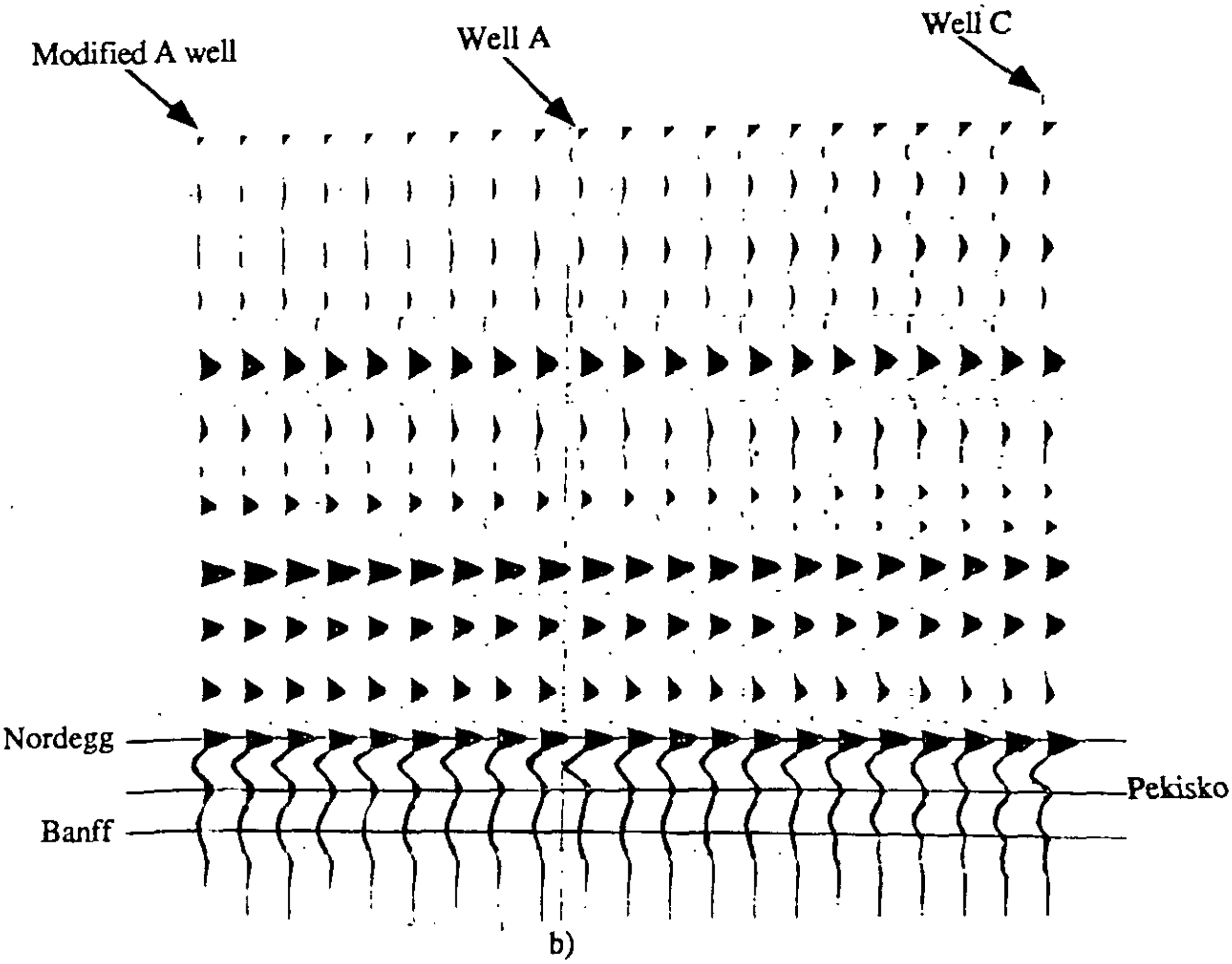


FIG. 4. Sonic log well B



a)



b)

FIG. 5. Normal incidence models a) well A - well B b) well A - well C

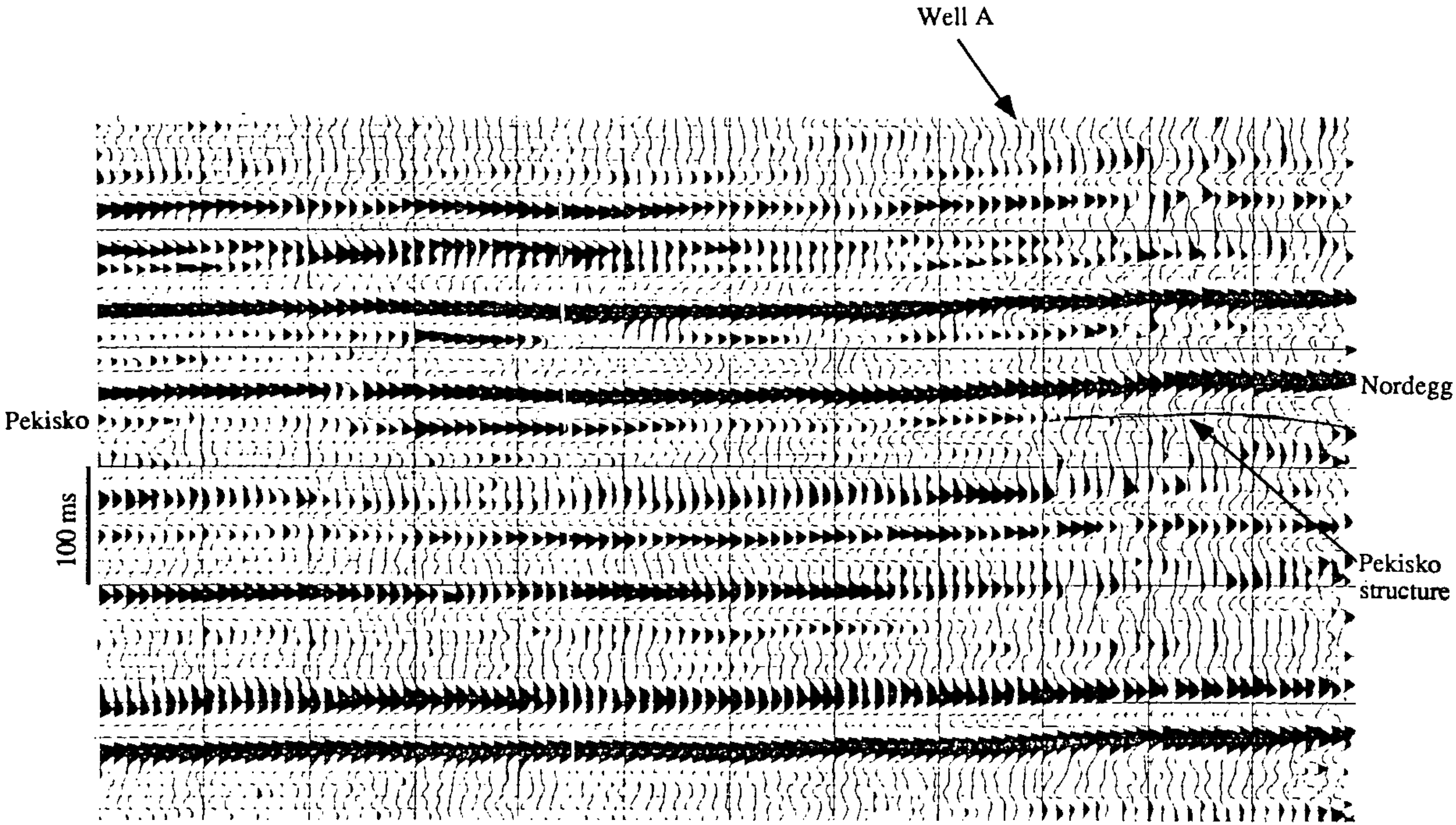


FIG. 6. Seismic line B

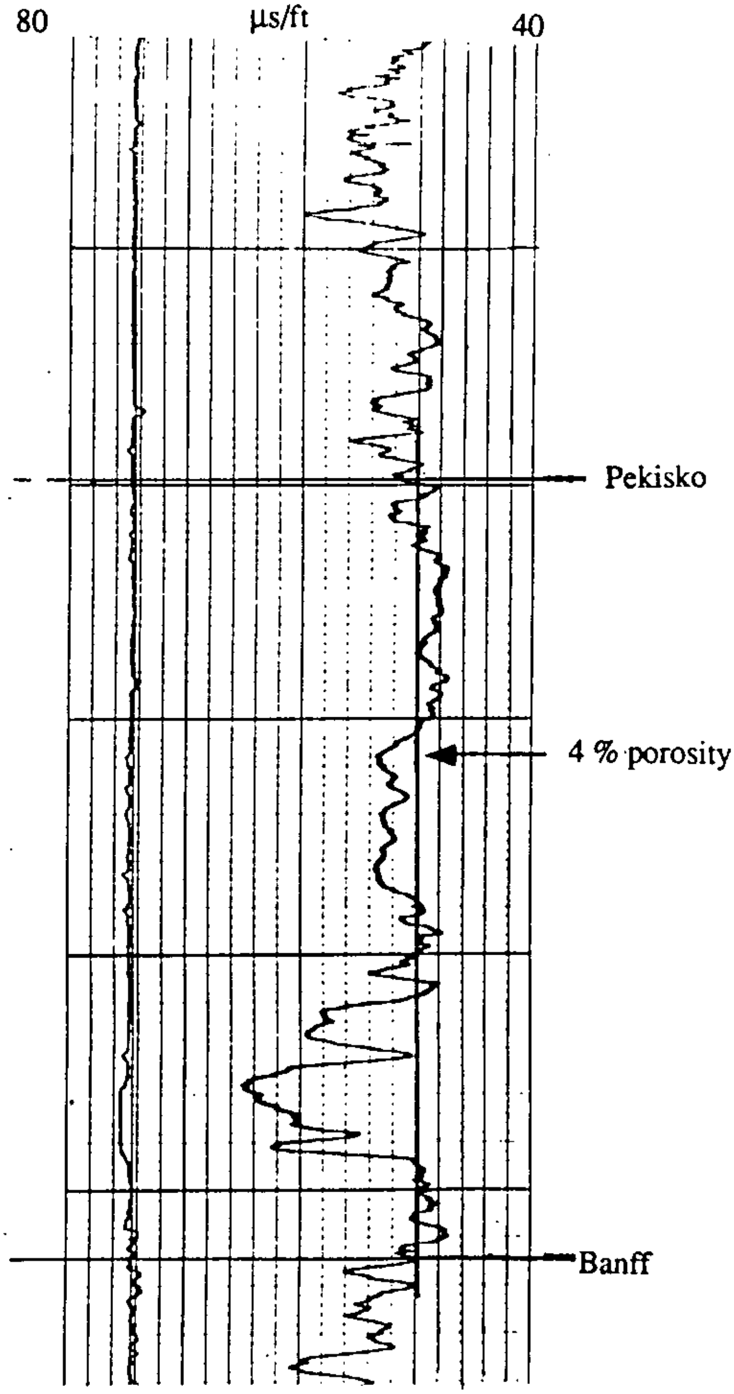


FIG. 7. Sonic log well C

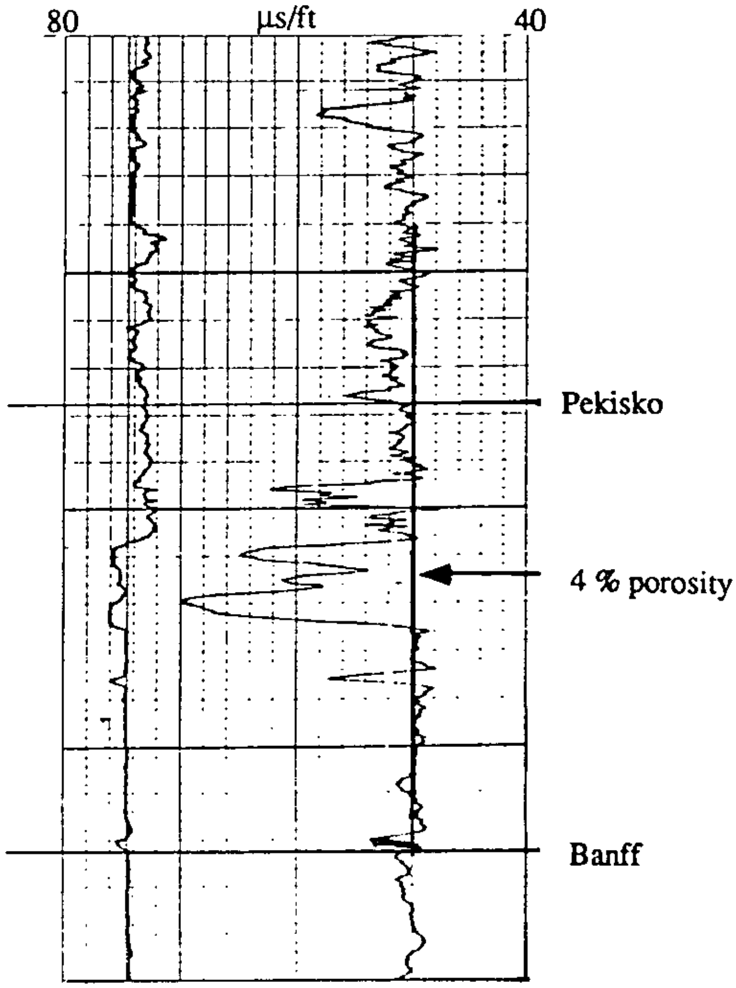


FIG. 8. Sonic log well D

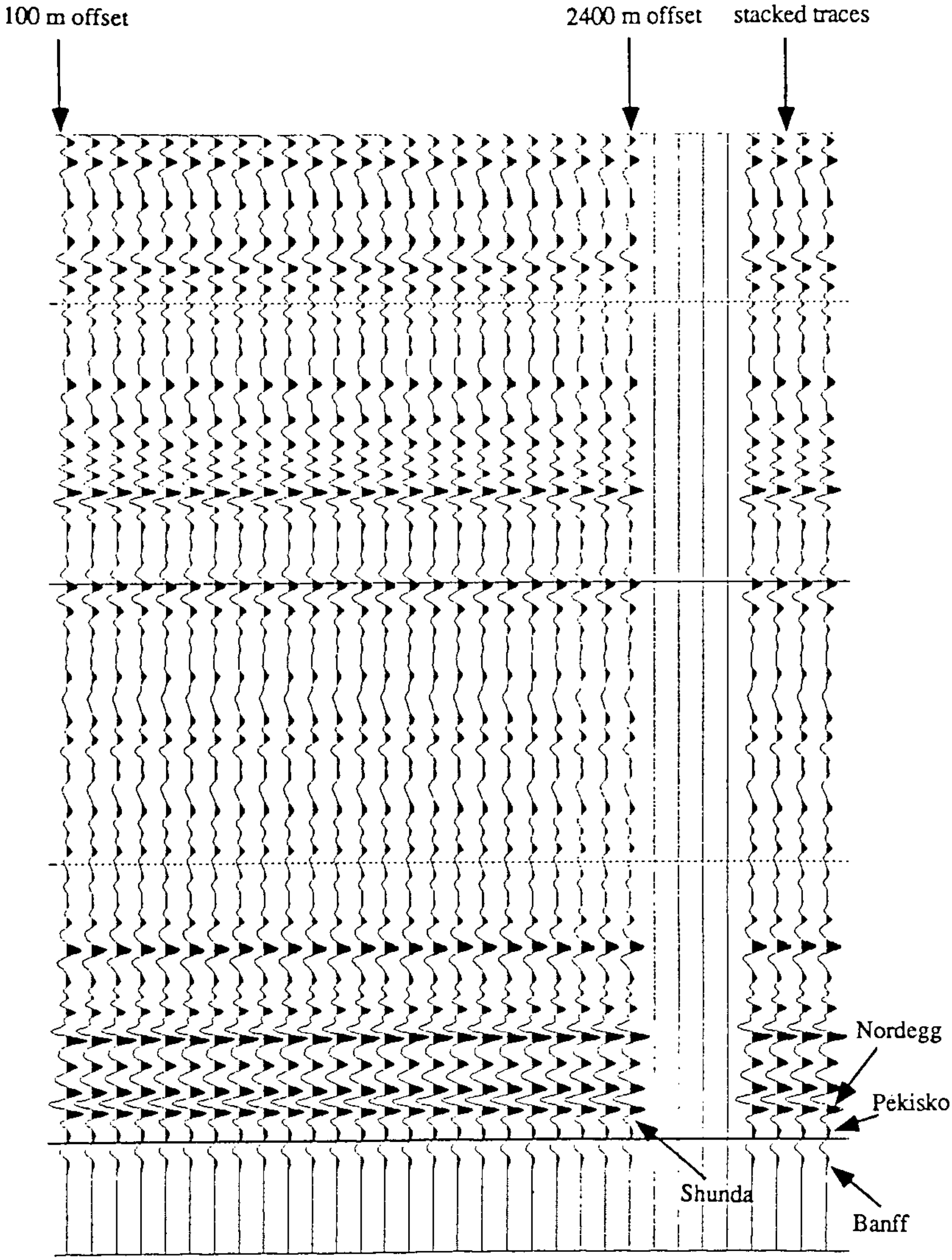


FIG. 9. P-P synthetic gather for well A

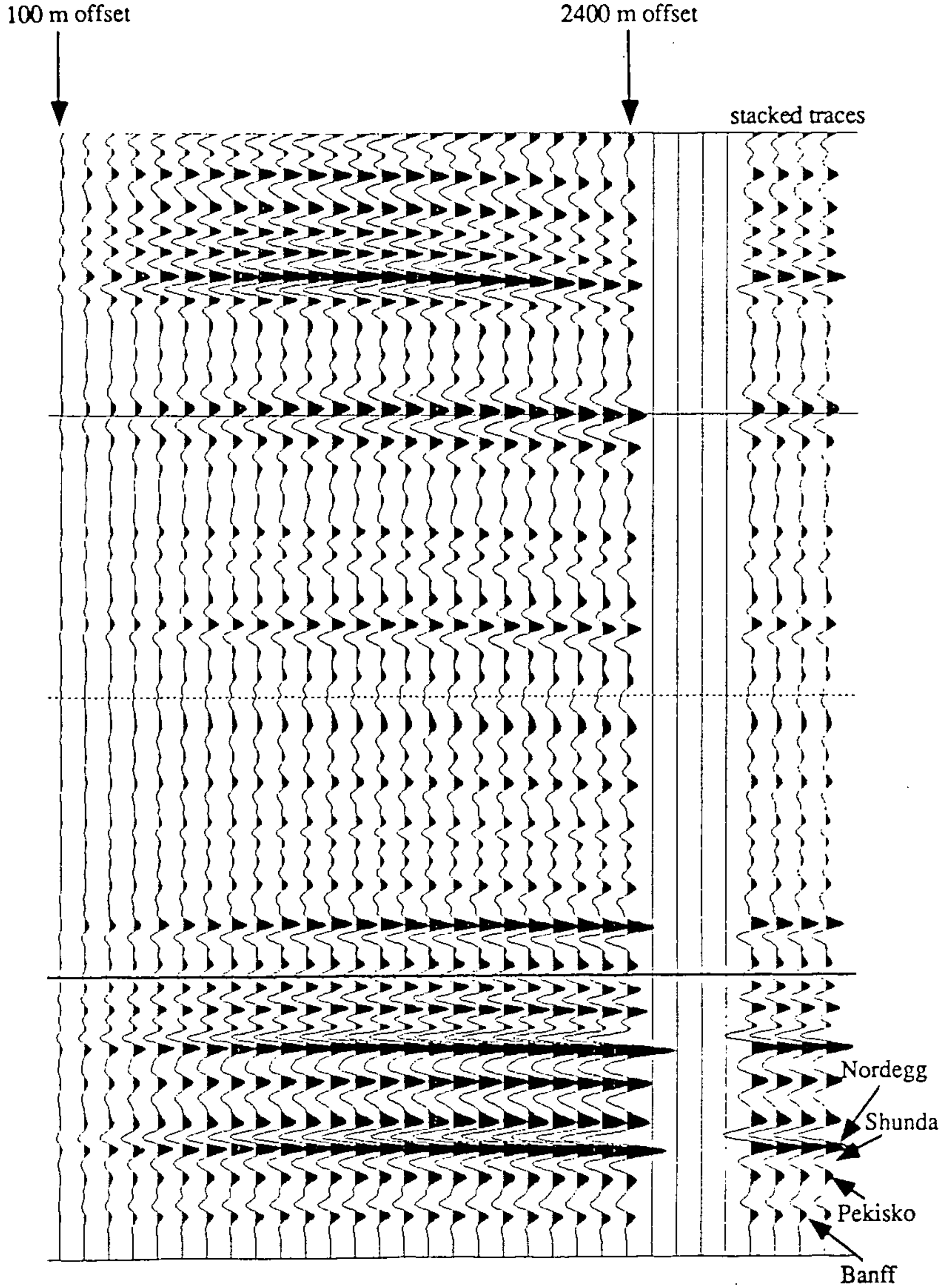


FIG. 10. P-SV synthetic gather for well A with Vp/Vs = 1.80

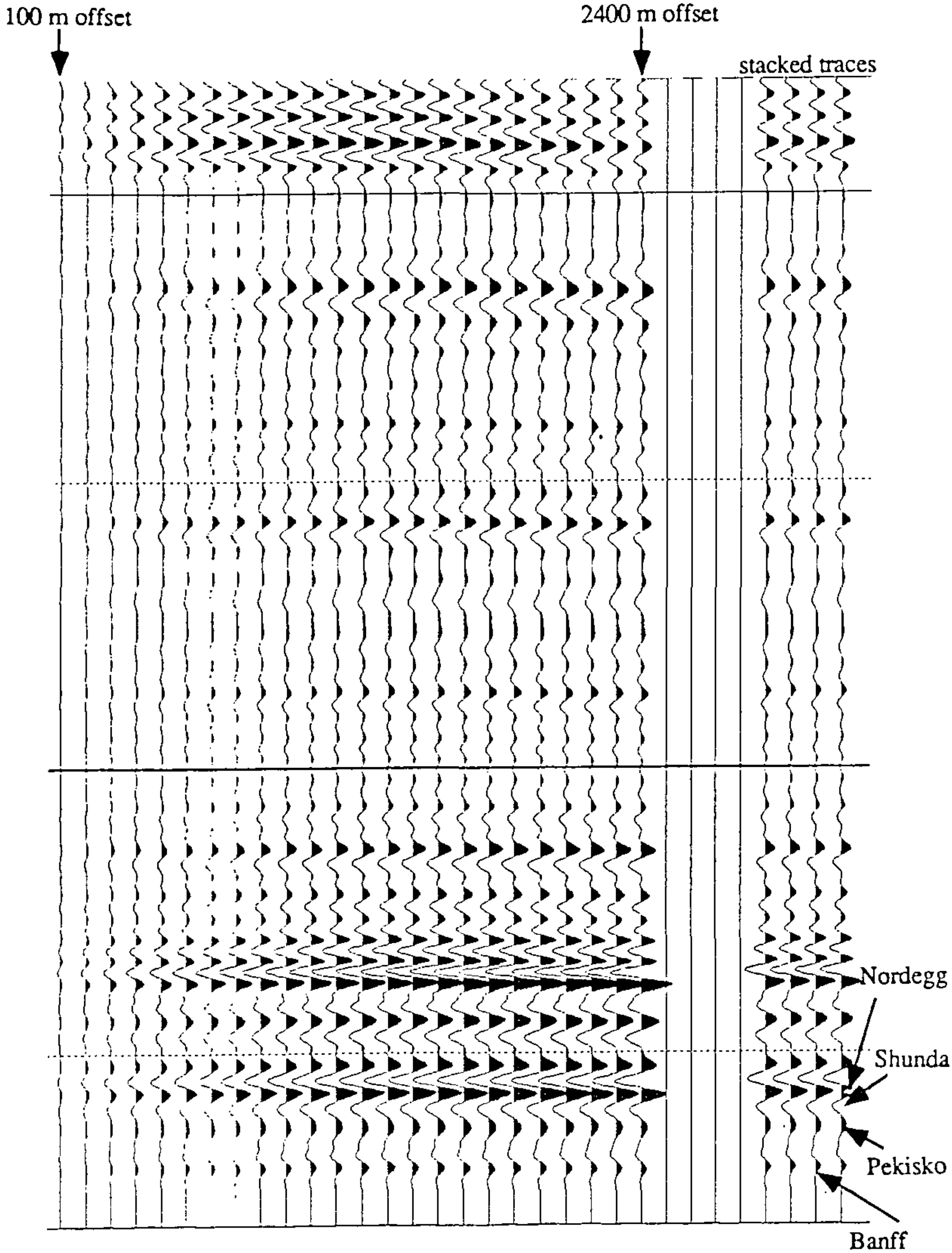


FIG. 11. P-SV synthetic gather for well A with Vp/Vs = 2.0

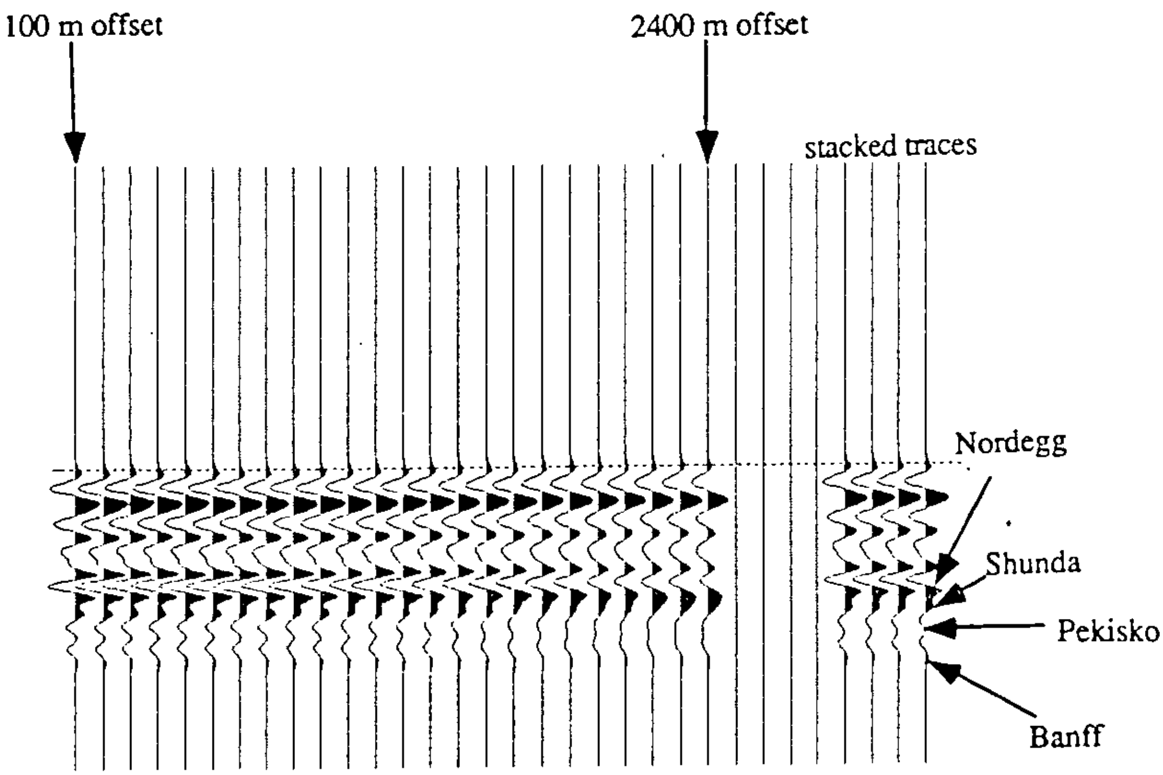


FIG. 12. P-P synthetic gather for well B

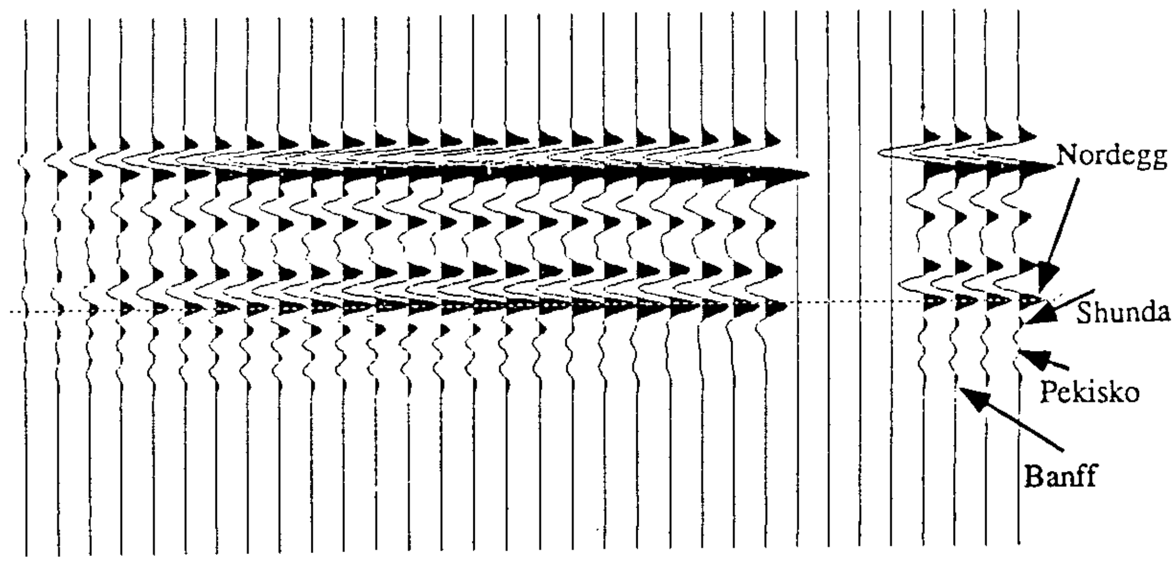


FIG. 13. P-SV synthetic gather for well B with Vp/Vs = 1.80

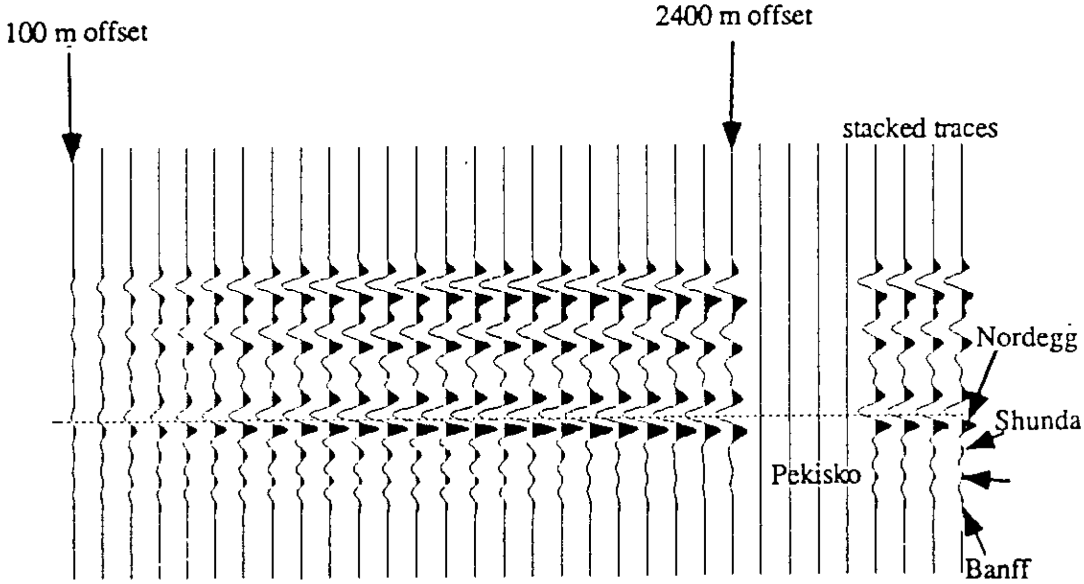


FIG. 14. P-SV synthetic gather for well B with Vp/Vs = 2.0

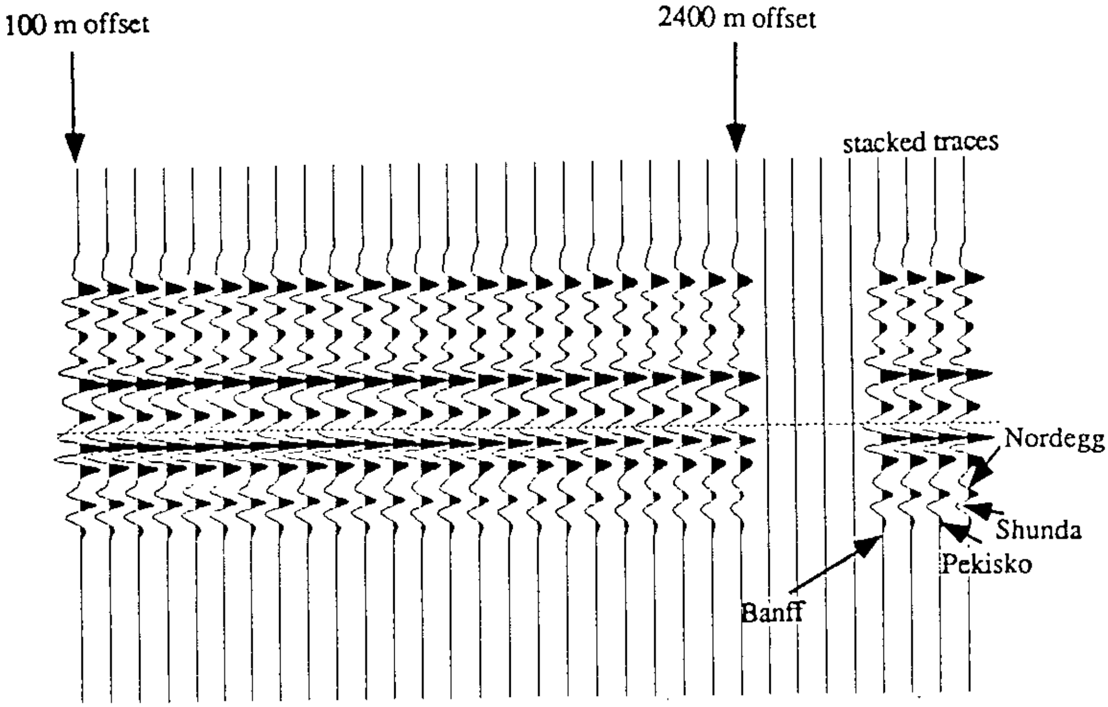


FIG. 15. P-P synthetic gather for well D

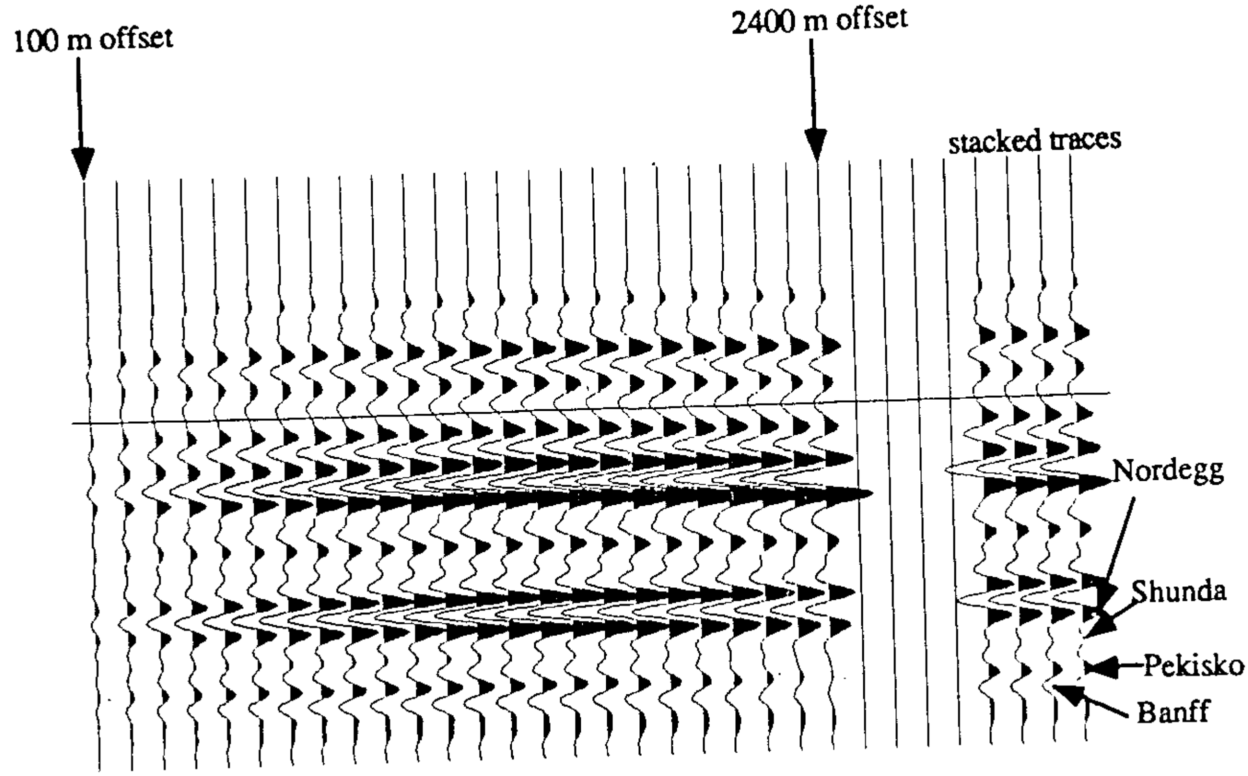


FIG. 16. P-SV synthetic gather for well D with Vp/Vs = 1.80

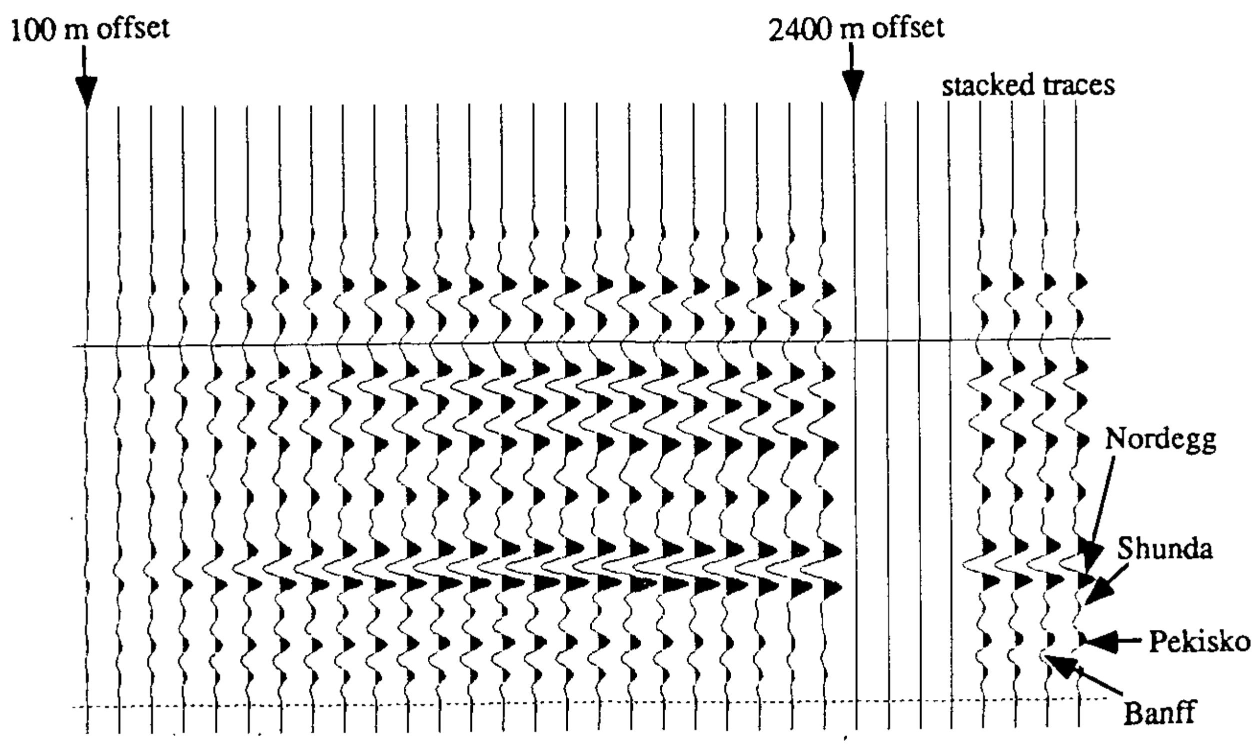


FIG. 17. P-Sv synthetic gather for well D with Vp/Vs = 2.0