Geological Survey of Canada

Open File 2847

Multi-channel Seismic Reflection Profile Across Endeavour Segment, Juan de Fuca Ridge

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Introduction

Two multi-channel seismic reflection lines form a transect of crust created at the Endeavour segment of the Juan de Fuca ridge (Fig. 1 and 2). This open file presents the data and discusses processing used to stack and migrate the sections. The first line, 85-03, was collected in 1985 across the rift valley and covers crust 0-1 ma on both the Pacific and the Juan de Fuca plates. The second line, 89-15, was collected in 1989 and covers the Juan de Fuca plate between 1 and 4.2 ma. Each line will be discussed separately. Contract processing of line 85-03 was presented in an open file by Yorath et al. (1987) and line 89-15 is in Rohr et al (1992). Work presented here is a reprocessing of both lines that focused on axial structure of the rift valley and layer 2A; part of the reprocessing line 85-03 is published in Rohr et al. (1988). Contract processing of 85-03 imaged the axial reflector and moho well but missed the layer 2A events, and velocity analyses on line 89-15 aimed at layer 2A were too sparse to image the event consistently.

Sediment Thickness Map

Using PGC 1978, 1988, 1989, 1990 and 1992 single-channel seismic reflection surveys (Davis et al., 1992), and multi-channel lines 89-15 and 85-03, a sediment thickness map (Fig. 3) was generated over the Juan de Fuca plate. Two-way travel times for the sediment layer were picked directly from photocopies of the original seismic sections, posted onto a composite seismic basemap and hand contoured at a 0.1 s contour interval. In the abyssal plain the seafloor is nearly flat so this map can be considered a map of basement topography. The western limit of sediment cover and areas of zero sediment were refined using a Sea Beam bathymetry map (Davis et al., 1987).

Potential Field Data

Magnetic Data

Magnetic data were collected using a towed Barringer proton precession magnetometer. Survey lines were oriented ENE and spaced 10-12 km apart. Readings were corrected for diurnal variation and subtracted from the 1985 International Geomagnetic Reference Field to yield the anomalies shown in Fig. 4. The map covers anomaly 1 (1 ma) on the Pacific plate to anomaly 3 (5 ma) on the Juan de Fuca plate.

Gravity Data

Gravity data were collected from a shipboard platform using a Lacoste-Romberg SL1 gravimeter simultaneously with magnetic data collection. Readings were reduced as free-air anomalies (Fig. 5) using the International Gravity Standardisation Net (IGSN 1967) and are generally considered accurate to +/- 2mGal. Variations are no more than 40 mGal above the young Juan de Fuca plate.

Multi-channel Seismic Reflection Data

Line 85-03

Line 85-03 was collected by Geophoto Services Inc. on the M/V *Edward O. Vetter* in April, 1985. The airgun array consisted of 50 guns in four strings spread over a width of 60 m for a nominal total volume of 100.1 L (6110 in^3); pressure was 2000 psi. During data collection the array was towed at 12 m depth and after an initial decrease ran at 98.3 L (6000 in^3). The streamer consisted of 120 channels; each 25 m long and consisting of 15 hydrophones 1.66 m apart. The first trace was at 300 m and the last at 3300 m. The streamer was towed between 15 +/-2 m depth. Ten depth transducers monitored depth; cable levellers next to each transducer helped maintain desired depth. Wind was only 5 kt and with a sea state of 1, noise on the streamer was 1-1.5 microbars. The streamer feather angle varied from 5-9°. Navigation was by Loran; six transit satellite fixes were recorded while the 60 km line was shot. Shots were fired every 50 m as determined by navigation. Data were recorded for 16 s on a DFS V at a 4 ms sample rate with filters of 5-64 Hz. 9-track field tapes are in SEGB format at 1600 bpi.

Shotpoints were corrected for geometrical spreading with a 3 db/s gain that began at the seafloor and was applied for 6 s. Shotpoints were f-k filtered from -1 to 7 ms/trace (Fig. 16) to reduce noise scattered from the seafloor. The dominant frequencies on the data are 10-40 Hz with a notch at 17 Hz (Fig. 17). The multiple was surgically muted so it would not overmigrate into the section later on. Since moho is usually 2 s below the basement reflector, it was safe to apply this mute without destroying moho reflections.

The data were then sorted into common-midpoint gathers (cmp) using a geometry that combined adjacent gathers. So, instead of working with 30-fold gathers 12.5 m apart we worked with 60-fold gathers 25 m apart.

Velocity analysis consisted of constant velocity stacks (CVS) on the entire line 1500-2300 m/s every 50 m/s and 2100-3500 m/s every 100 m/s. Two displays were made of the results: one with fixed gain and the other with an automatic-gain-control (AGC) of 400 ms for shallow crustal data and 750 ms for the deeper crustal structure (Fig.s 18 and 19). Moho velocities were picked from CVS stacks since it was largely not visible in individual gathers and the amount of moveout is small. Velocities for layer 2A were fine-tuned by examining gathers that had a constant velocity normal-moveout (CVNMO) applied (Fig. 20 and 21). Gathers every 500-1000 m were analysed with this approach; they were selected based on lateral velocity changes seen in the CVS, for location on a coherent section of 2A and for good signal-to-noise on 2A within each gather. Stacking velocities varied from 1650-2000 m/s and two-way travel-time below seafloor varied from 0.3 to 0.5 s for the Layer 2A arrivals (Fig. 6, 8, and 20). Stacking velocities could be picked with errors of +/-25 to 100 m/s and times could usually be picked +/- 8 ms. Between shotpoints 125 and 500, where sediments cover basement, basement velocities were analysed every kilometer with CV NMO displays from 1480-1520 m/s at 5 m/s intervals. Litle variation could be seen in moho reflections as a function of stacking velocity in this area, so a nominal velocity of 3200 m/s was chosen. Stacking velocities for the axial reflector and intermediate reflectors could be chosen within 100 m/s and stacking velocities for moho from SP 780-1125 could be picked with uncertainties of +/- 200 m/s (Fig. 19).

Once velocities had been picked, the data were stacked. A stack of the data using a conventional approach to constructing the time-stacking velocity function results in poor images of the layer 2A event compared with the CVS. For good images that include the seafloor and moho, a constant-velocity window was created about the 2A event i.e. stacking velocity appropriate for 2A was specified at a time above and below the actual event. This is less than optimal to image the seafloor but the seafloor is a robust event that stacks in almost no matter what velocity is used. We considered it more important to produce a section with good images of 2A and moho.

After stack the data were band-pass filtered from 8-30 Hz. AGC was applied with a 300 ms window and a 750 ms window begining at 5500 ms (Fig. 6 and 8). A water-bottom mute was applied. Data are displayed at two scales; one which allows the entire crustal section to be easily seen and a second that allows detail in layer 2A to be observed.

To migrate the data constant-velocity Stolt f-k migrations were first run. Appropriate velocities were picked from these runs then a 1-d function was applied in the f-k domain. A final iteration created a 2-d velocity grid following variations in topography smoothly and an fx-migration was applied (Fig. 7 and 9). A water-bottom mute was applied and migrations are also displayed at two different scales.

As a test we stacked data recorded from the first eight traces (300-475 m offset) to see if any reflectors could be imaged using a large airgun array and near-offset data only. No events other than the seafloor could be seen in either a fixed or time-variant section (Fig. 22) demonstrating that the extra fold generated by the multi-channel streamer is necessary in this region.

Line 89-15

A 100 km long multi-channel seismic reflection line, Line 89-15, was collected by Digicon in October, 1989, on M/V Geo Tide (Fig. 2). Other data collected in that survey were for a site survey on the continental margin for Ocean Drilling Program. A 127.8 L (7800 in^3) tuned airgun array was fired at a pressure of 1900 psi. It was at a depth of 9 m and averaged 124.5

L (7600 in^3) during shooting. Shots were fired every 50 m as determined by Loran-C with satellite fixes. A 3600 m long streamer consisted of 144, 25 m long groups; the near trace was at 183 m. Four compasses, eleven depth transducers and eleven depth controllers complete the streamer. The streamer depth varied from 10-12 m and feather angles varied from 1 to 9°. Wind speed was 15 kt and the sea state was 4-6 during data collection so average noise before shooting was 17 microbars. Data were recorded on a DSS-240 for 10 s; filters were set at 3 and 80 Hz which left a lot of low-frequency noise on the field records. Output was SEGY 9-track tapes at 6250 bpi.

The shotpoints were corrected for geometrical spreading at 6 db/s starting at the seafloor, and an f-k filter from -3 to 10 ms/trace has been applied to reduce noise from seafloor diffractions. Shotpoints were sorted into 36-fold cmp's.

Velocity analysis also relied on constant-velocity stacks as well as constant velocity NMO gathers. CVS were generated with velocities ranging from 1700 to 2200 m/s at 50 m/s increments (Fig. 23). The 2A arrival is distinct in time and velocity from the interbed multiple between the seafloor and basement (Fig. 24). Using the CVS panels, a ballpark velocity was chosen for the constant NMO correction of the gathers. Every fifth gather was NMO corrected with a constant velocity. Gathers from continuous basement and layer 2A events with clean, strong sediment-basement interface and base of layer 2A arrivals are present were selected for further analysis, at locations approximately 1 km apart. The CVS panels were then carefully checked to ensure that a good location had been chosen for analysis. In order to have as strong a base of layer 2A reflector as possible it was necessary to perform a common offset stack of five adjacent cmp's grouped around each location selected for analysis. At these locations gathers were then iteratively NMO corrected with constant velocities at 25 m/s increments until the base of layer 2A was optimally flattened and thus the best possible NMO correction for the event was obtained (Fig. 25 and 26). These velocities were later used for interval velocity calculations.

Where basement had low relief velocity analysis of the seafloor and the sediment-basement interface representative cmps were selected approximately 3 km apart. For the seafloor a constant velocity NMO correction was performed using velocities ranging from 1465 to 1490 m/s at 5 m/s increments. For the sediment-basement interface velocities ranging from 1475 to 1510 m/s at 5 m/s increments were used.

After SP 1300 the sediment-basement interface became so rough (Fig. 3) that the approach to velocity analysis changed somewhat. It was no longer possible to find reliable stacking velocities at 1 km intervals. Much care had to be taken to select suitable locations for analysis where the top and base of layer 2A were reasonably flat and continuous and exhibited clean, strong reflectors within the gather. Good locations tended to be unevenly spaced, sometimes 1.5 or 2 km apart, and it was necessary to determine the velocity for the sediment-basement interface at each location instead of at 3 km intervals. The velocity range chosen for constant velocity NMO correction for the sediment-basement interface was 1490 to 1600 m/s at 5 m/s intervals; velocities for the base of Layer 2A were selected as before. Two-way travel-times were picked from the NMO corrected gathers at selected locations for the top of the seafloor, the sediment-basement interface and the base of layer 2A.

To obtain stacking velocities for Moho, constant velocity stacks were generated from 3000 to 5000 m/s at 200 m/s increments (Fig. 27 and 28). Two-way travel-times were picked from the CVS stack best depicting the Moho reflector.

In order to generate a stacked section the velocities determined through constant velocity NMO analysis for the seafloor, the sediment-basement interface and Moho were utilized. CVS panels were used to choose stacking velocities best depicting the base of layer 2A event. The number of velocities selected depended on the number of velocities required to produce the display best portraying the 2A event. The velocities thus selected were used to generate velocity functions for stacking. Each stack underwent several iterations as the velocity function was improved to produce a section with all events optimally depicted (Fig. 10, 12 and 14). A comparison between velocities picked from NMO and CVS analysis shows that the two give largely the same results with NMO allowing for finer discrimination which is useful in interpreting interval velocities (Fig. 29).

A time-variant bandpass was applied to the data; 8-30 Hz from 0-5250 ms and 8-20 Hz from 5254 to 6900 ms with 500 ms linear transition between the two. A time-variant gain was also applied; AGC with a 400 ms window from 0 to 5496 ms and 750 ms from 5500 to 6900 ms. A seafloor mute was applied. Adjacent traces were stacked in order to further enhance the signal to noise ratio. Migration was as for 85-03 (Figure 11, 13 and 15).

Comparison

The longer streamer length used in 89-15 allowed layer 2A events to be recorded since they shifted to larger offsets under sedimented older crust. The longer streamer also provided better discrimination of velocities for moho. Although the fold was higher and the airgun array larger on line 89-15 was than line 85-03, there is not a significant improvement in signal/noise in the final stacks. There were higher noise levels during shooting for 89-15, but the poor imaging of moho is most likely because the source used for 89-15 was centred at too-high frequencies (Fig. 17). It had little energy at 10 Hz which is the frequency of moho reflections seen on 85-03. Layer 2A events are about 20 Hz on 85-03. Energy above 20 Hz in oceanic crust appears to just scatter and create noise.

Acknowledgements

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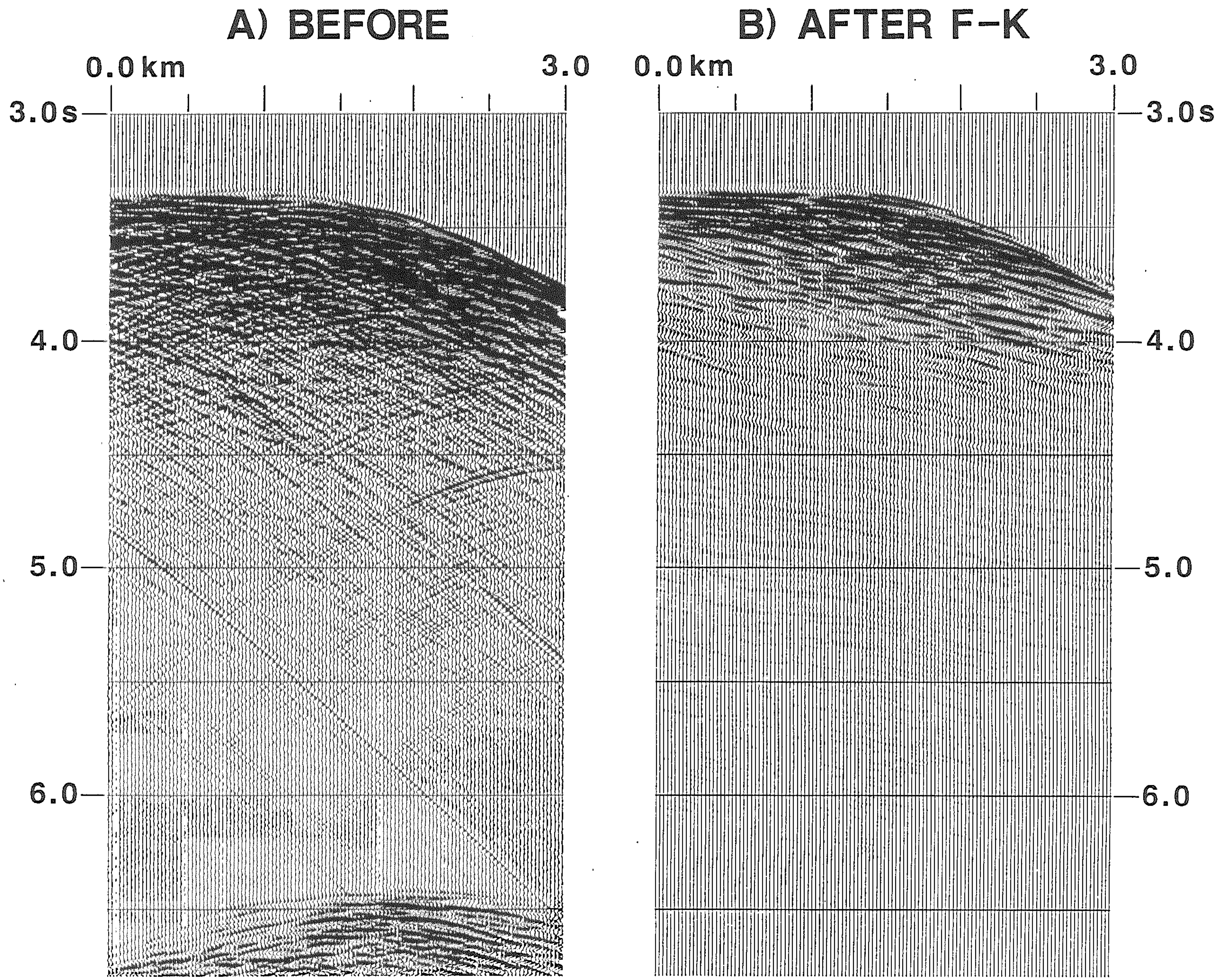

Figure 16. Shot gather from line 85-03 a) before and b) after f-k filter of -1 to 7 ms per trace. The multiple has been surgically muted.

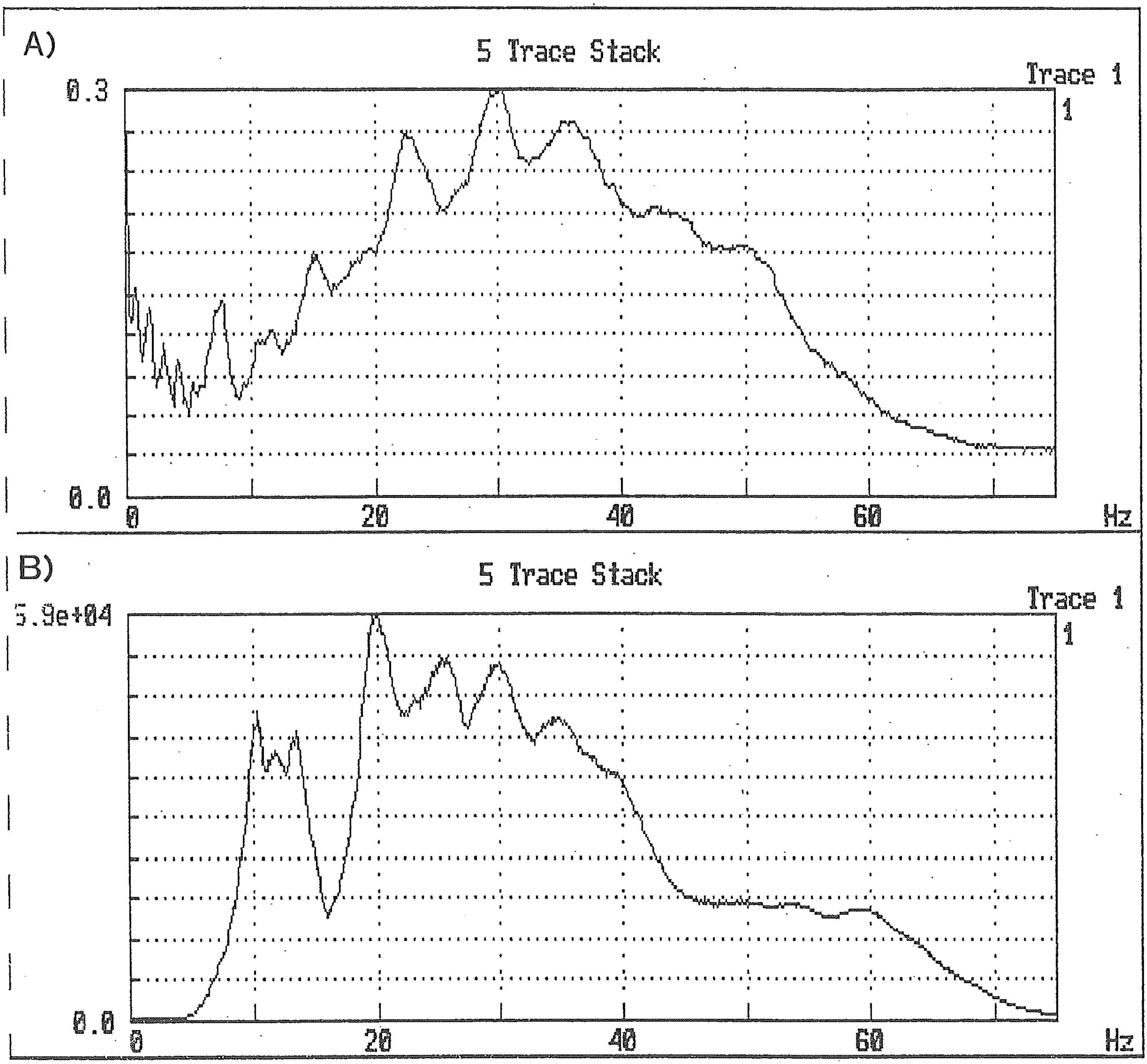

Figure 17. Spectrum of unfiltered shot gathers a) 89-15 and b) 85-03. Note significant energy around 10 Hz in 85-03 which is lacking in 89-15. Lack of low-end filter during acquisition of 89-15 resulted in low-frequency (0-8 Hz) energy from the well-known phenomenon of cable strum.

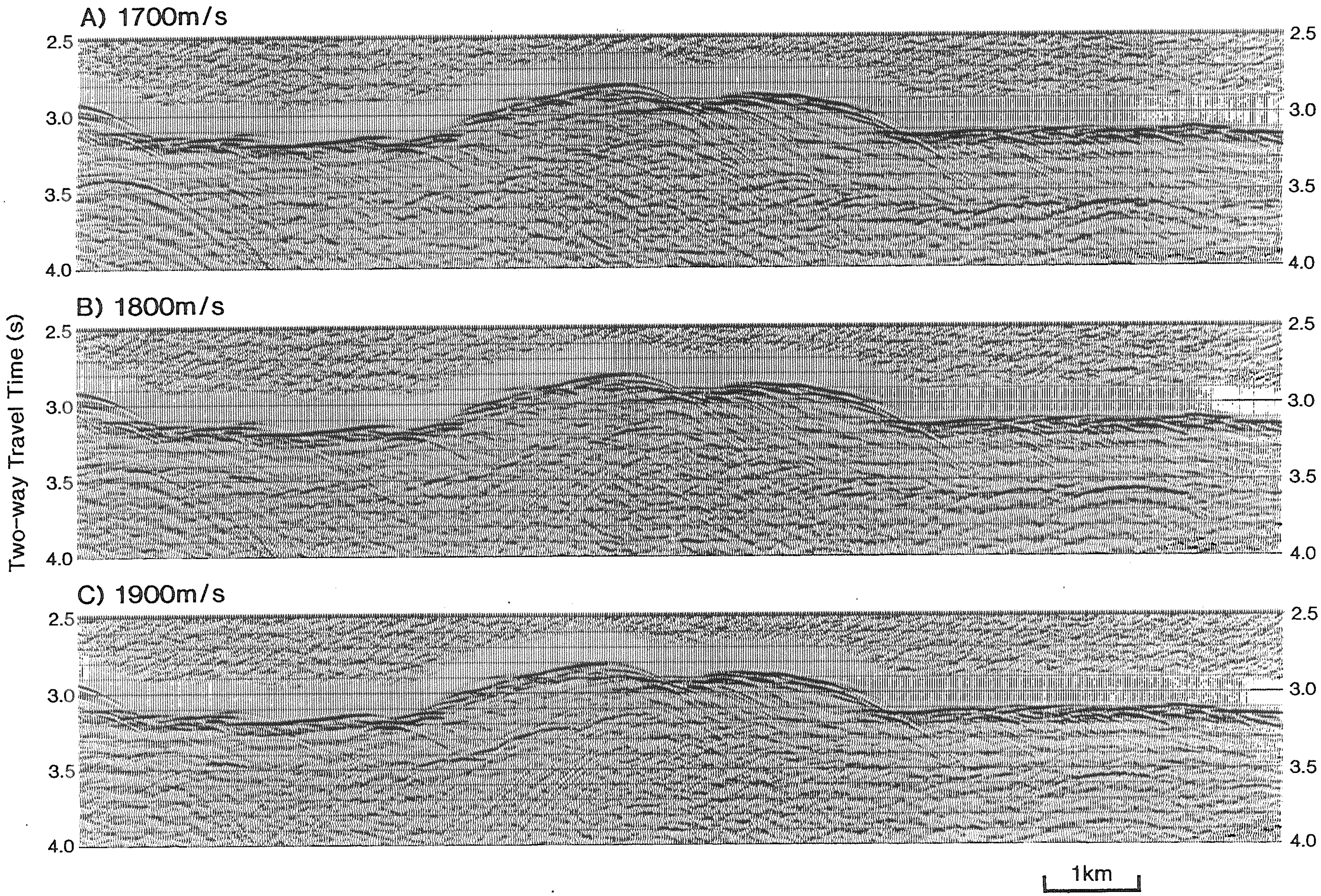

Figure 18. Constant velocity stacks showing velocity heterogenity for 2A on line 8503 from shotpoint 590-830. Automatic gain control over a 400 ms window was applied to each stack. The ridge axis is imaged in the center of the plot; east of the ridge and 0.5 s below the seafloor the 2A event is well imaged in a) at 1700 m/s but has been almost stacked out in c) by using 1900 m/s. In the western flank of the ridge 2A is imaged well by using 1900 m/s and is not visible using 1700 m/s.

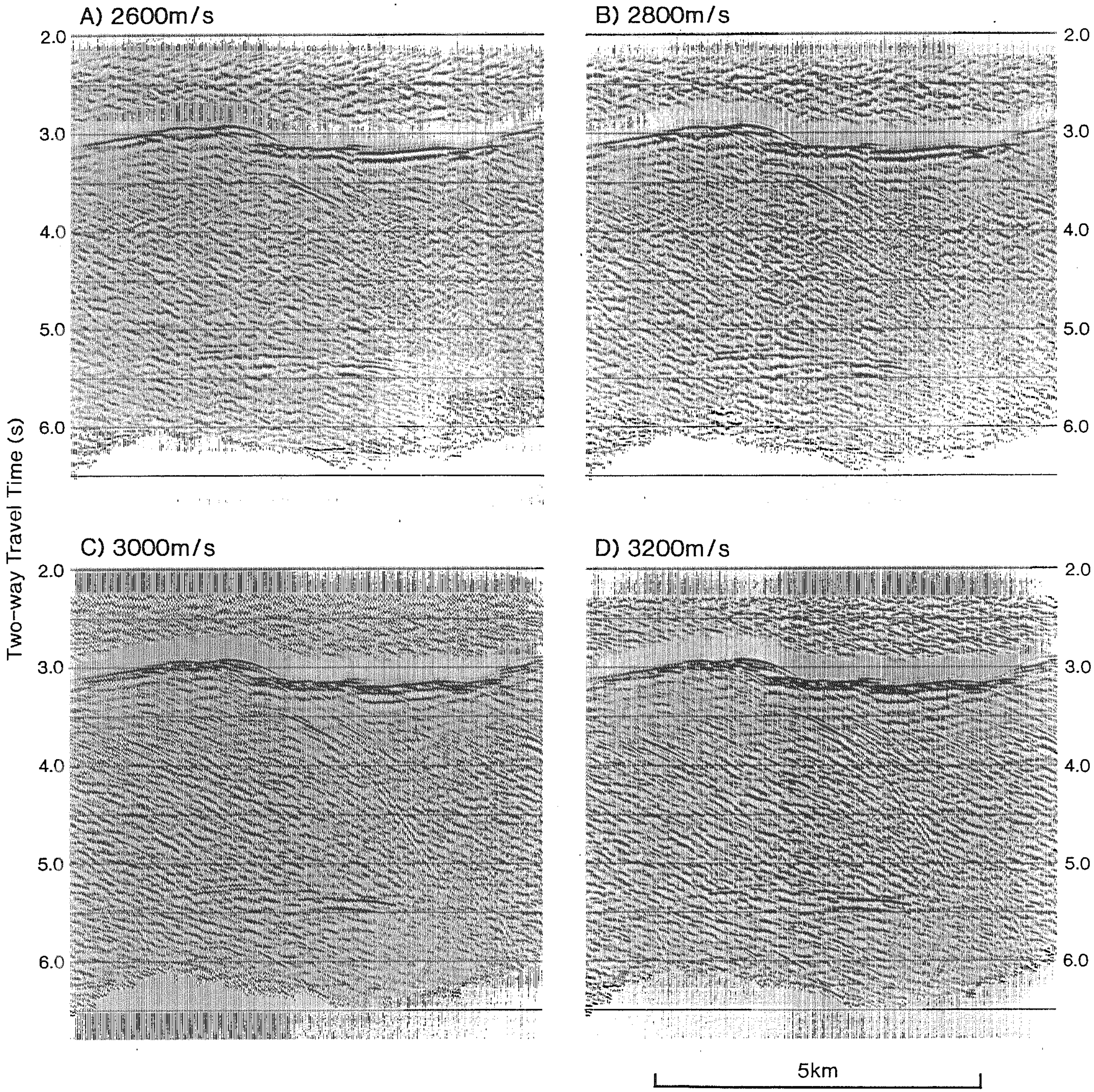

Figure 19. Constant velocity stacks for moho on line 85-03 from shotpoint 770-860. Automatic gain control over a 500 ms window was applied to each stack. 3000 m/s does a good job on segment of moho imaged; easternmost reflections are slightly better with 3200 m/s; entire segment is poorly imaged at 2600 and 2800 m/s.

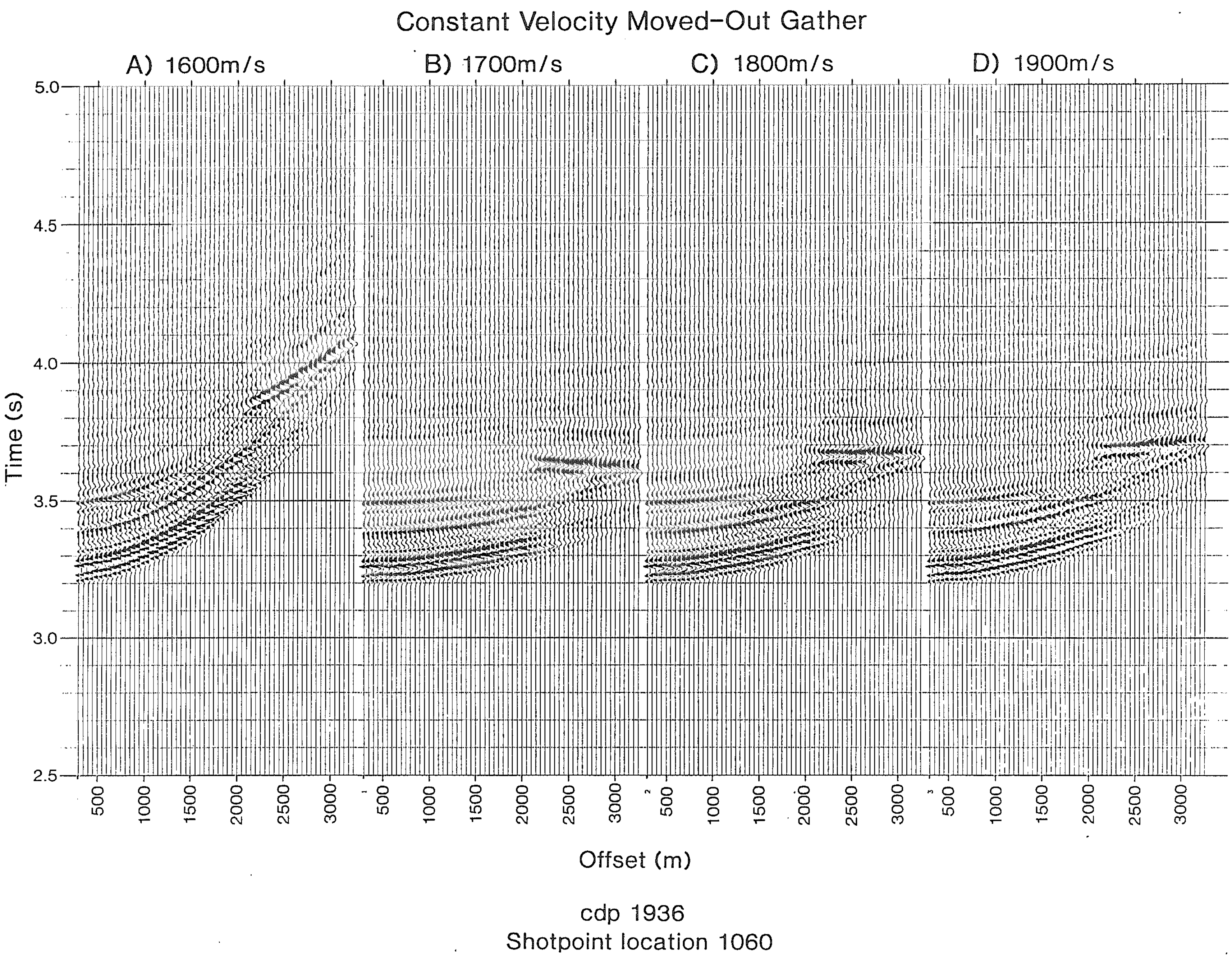

Figure 20. Constant velocity normal moveout of gather 1960 at shotpoint location 1060 a) with no moveout, moved out with b) 1700 m/s b) 1800 m/s and c) 1900 m/s. 1800 m/s flattens the arrivals whereas the 1900 m/s undercorrects and 1700 m/s overcorrects the data. Note attenuation of seafloor reflection at far offsets by f-k filter.

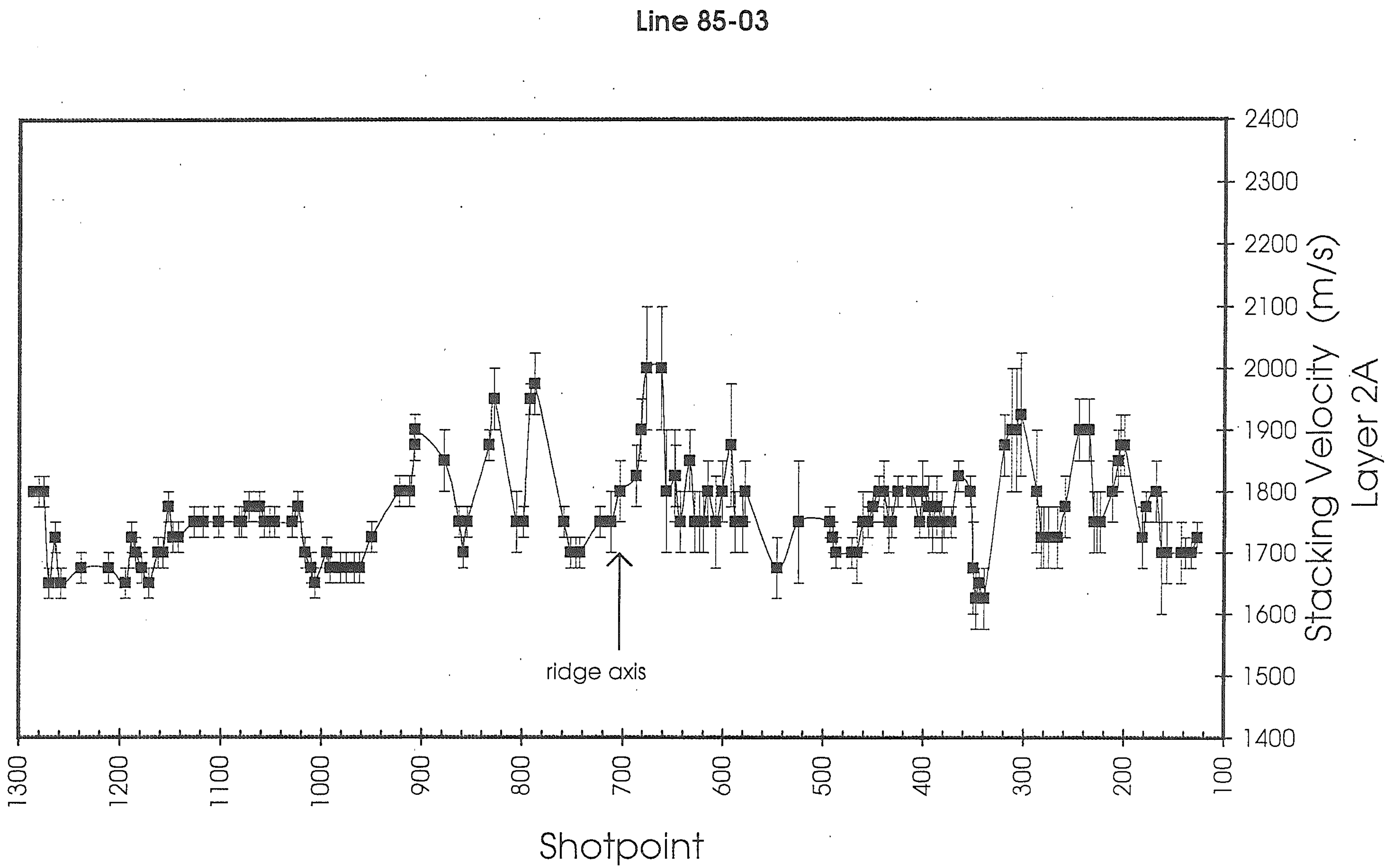

Figure 21. Compilation of stacking velocities for 2A on line 85-03.

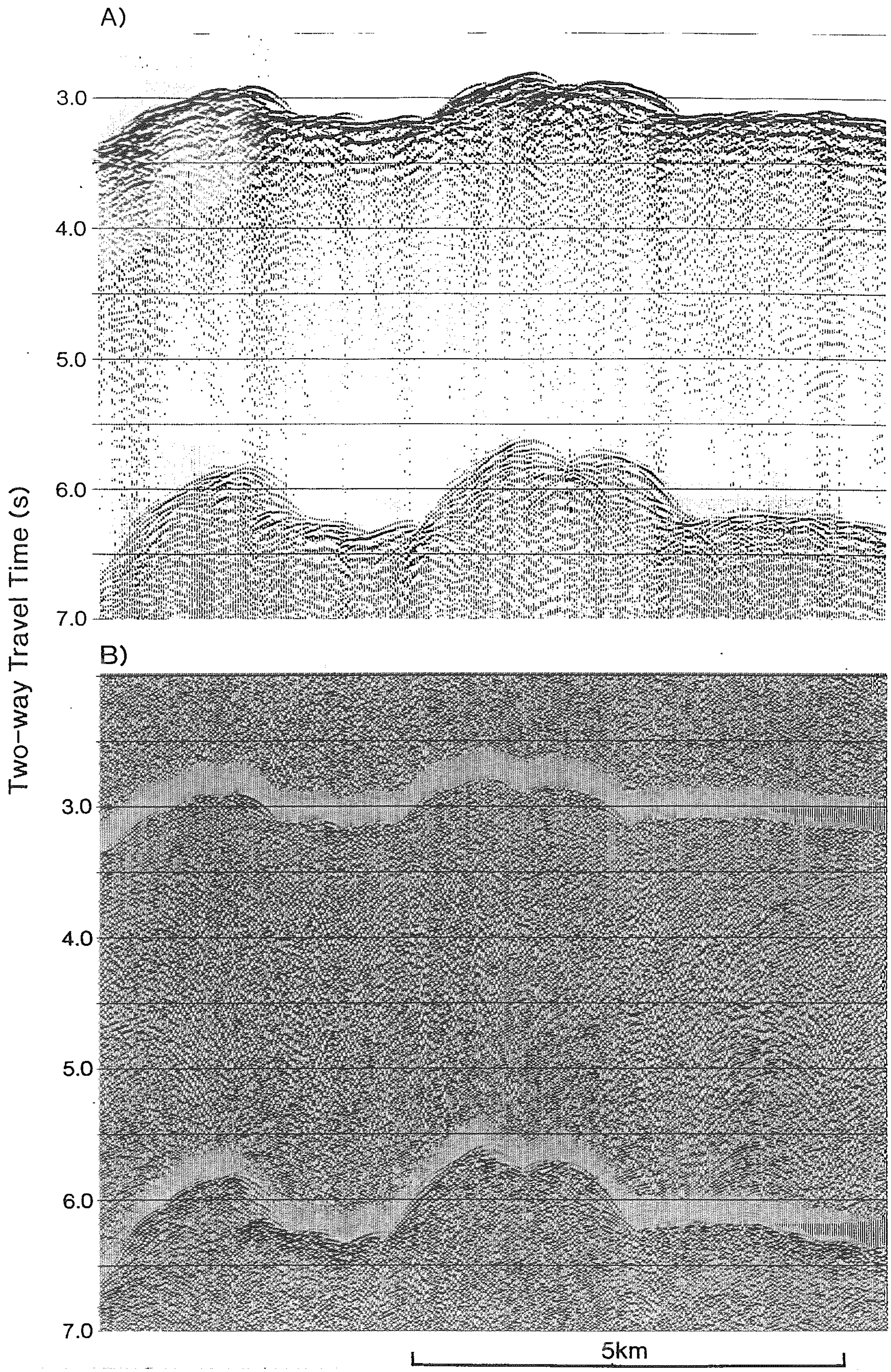

Figure 22. Stack of near-offset (300-500 m) data recorded on streamer during line 85-03 from shotpoint 580-900 a) no processing and b) with bandpass from 8-30 Hz, predictive deconvolution and automatic-gain-control over a 500 ms window. No reflectors beyond the seafloor can be discerned.

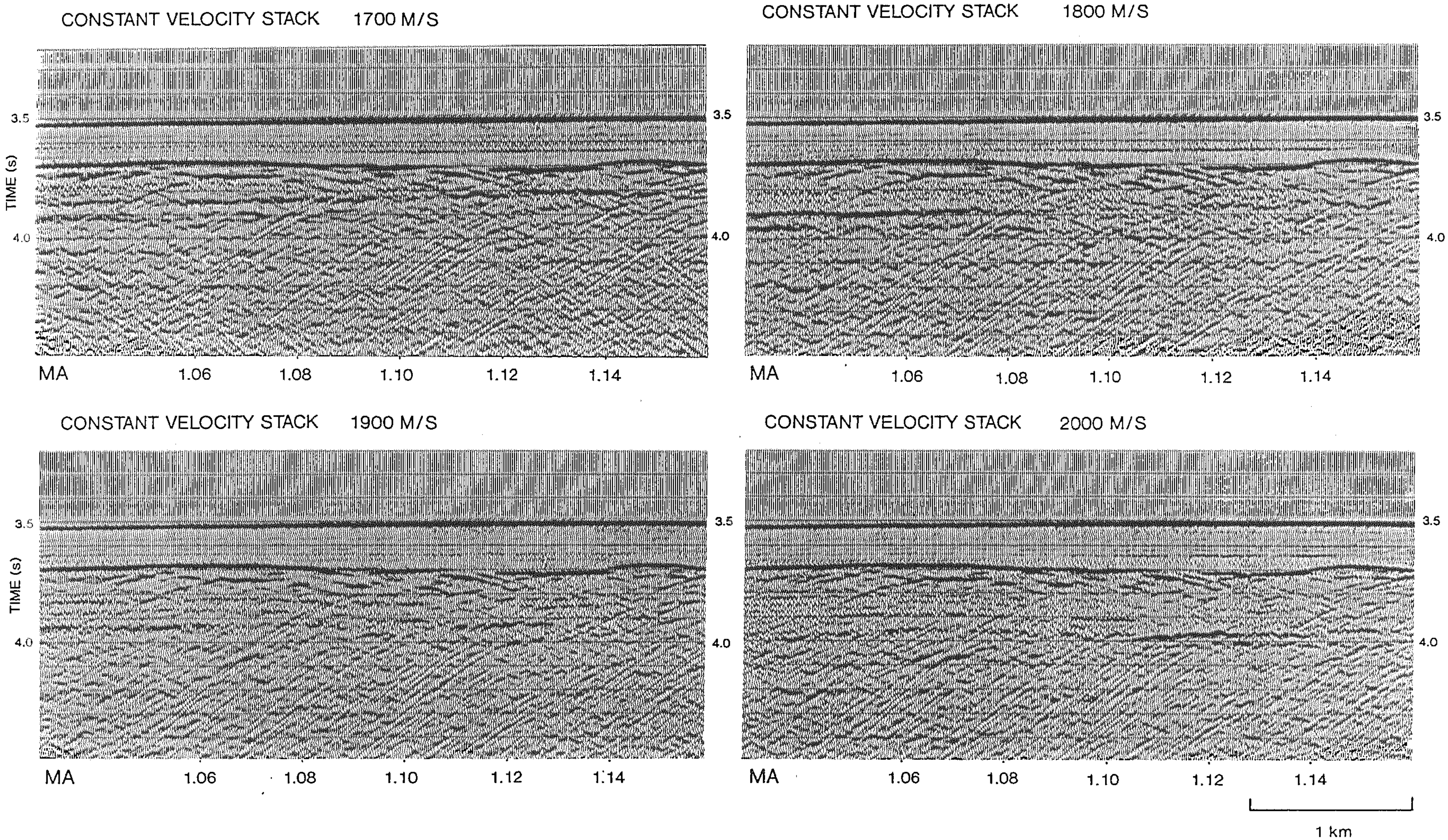

Figure 23. Constant velocity stacks showing velocity heterogenity for 2A on line 89-15 from shotpoint 202 to 285. 1800 m/s images the 2A event well on the western section but only 1 km away 2000 m/s images 2A.

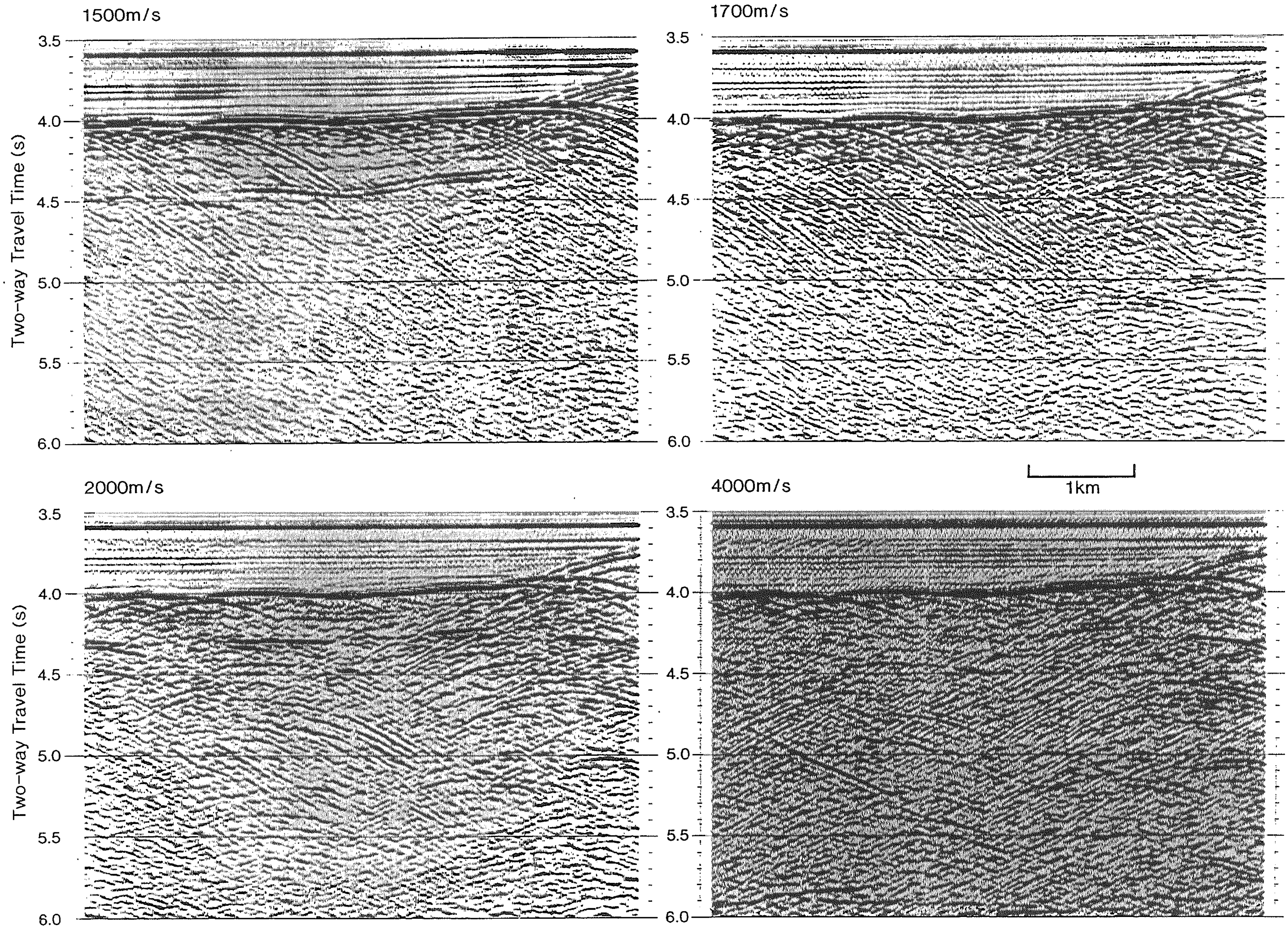

Figure 24. Constant velocity stacks from line 89-15 at shotpoint locations 1492 to 1592. A) Stack at 1500 m/s clearly shows multiple between the seafloor and basement 0.4 s below the seafloor which is attenuated by stacking at higher velocities e.g. b) 1700 m/s. In c) 2000 m/s clearly stacks in the layer 2A event 0.3 s below the seafloor. In d) the 4000 m/s stack the moho reflector can be seen 2 s below basement.

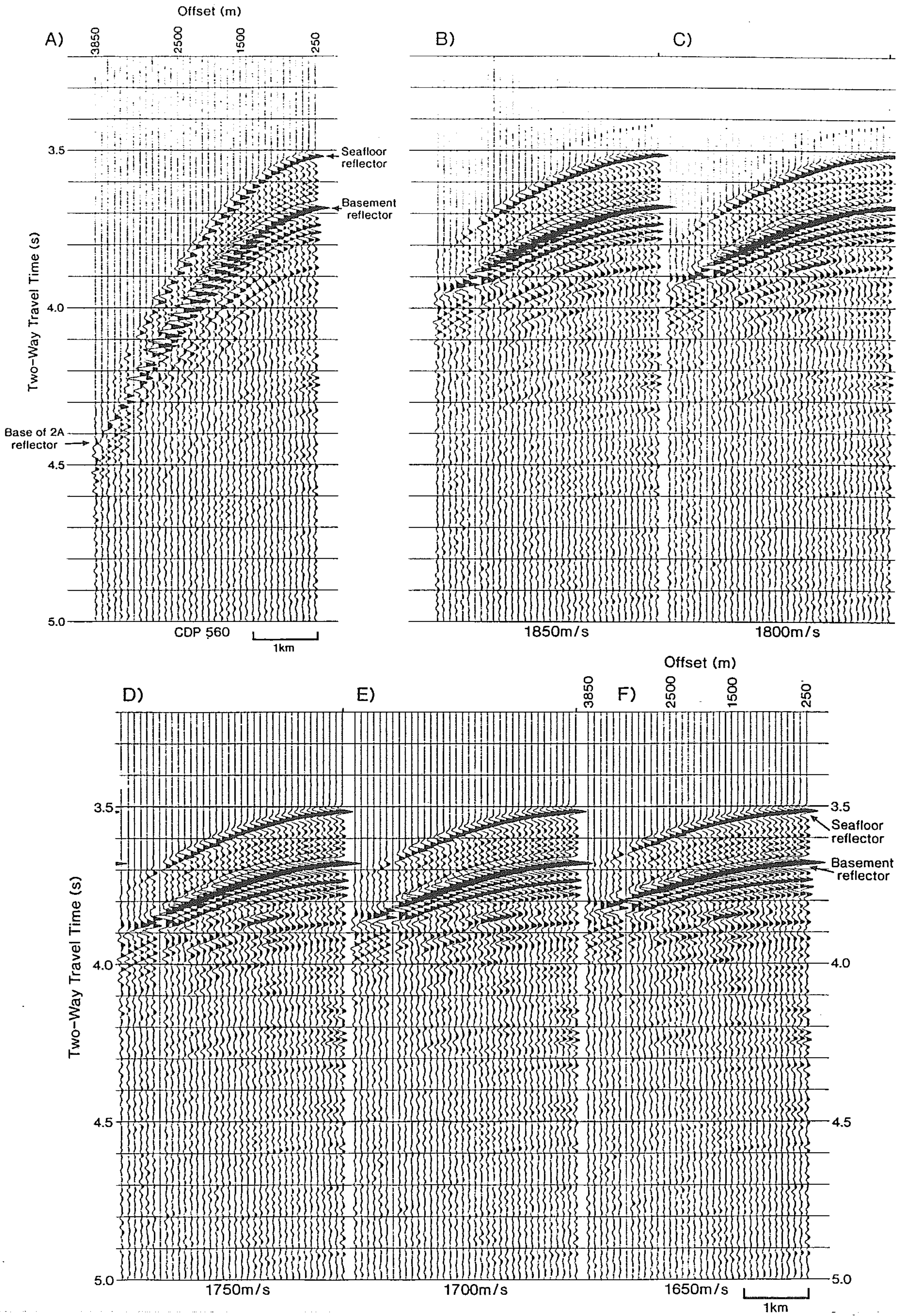

Figure 25. Common-midpoint 560 with a) no moveout and b) through f) is a co,,om-offset stack of cmp's 558-562 with normal moveout varying from 1650 to 1850 m/s. The 2A arrivals can only be seen in the last few traces crossing the basement reflector. There's not much difference between 1700 m/s, 1750 m/s and 1800 m/s but 1650 m/s has overcorrected the data and 1850 m/s has undercorrected.

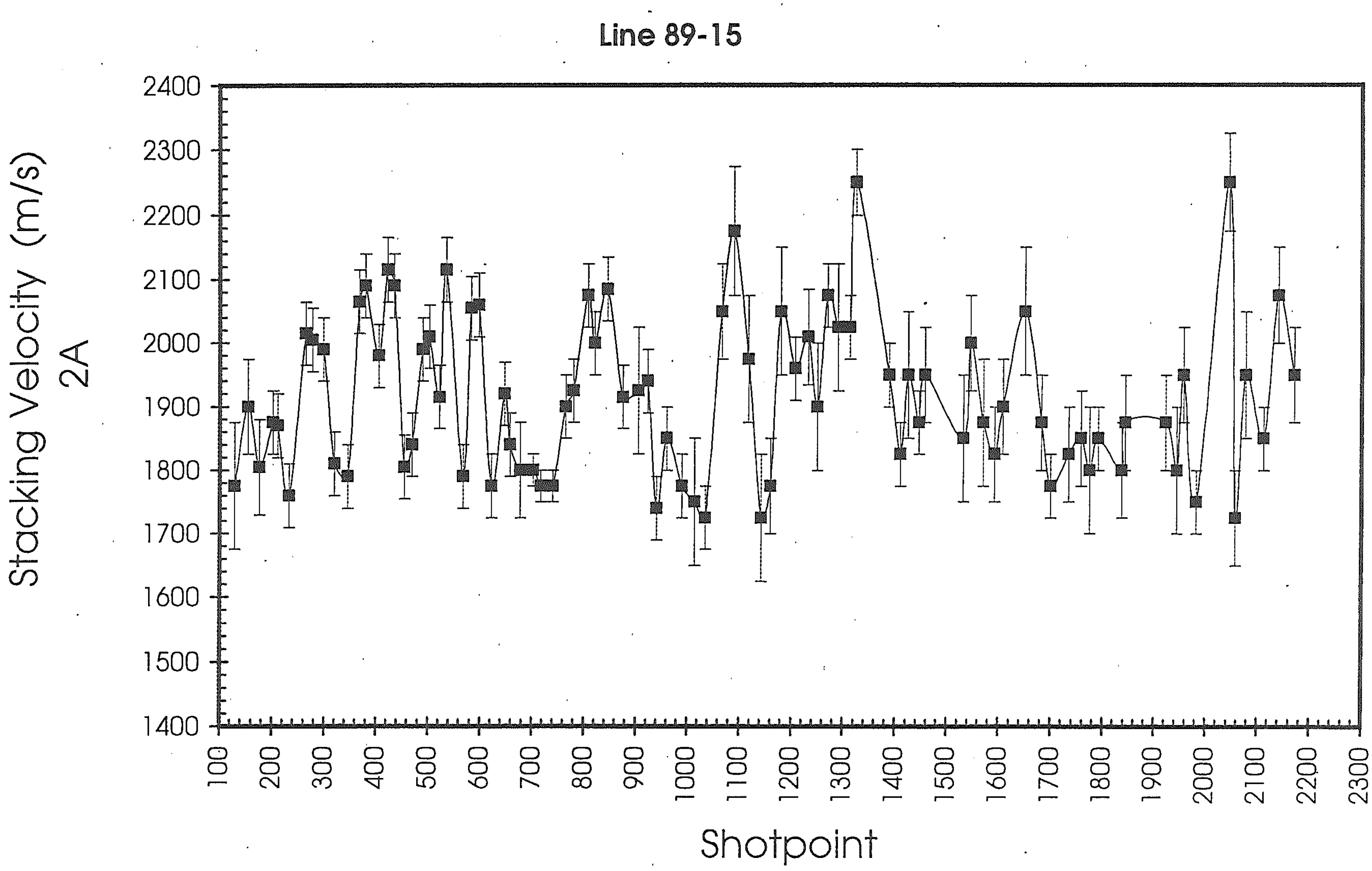

Figure 26. Compilation of stacking velocities for 2A event from line 89-15.

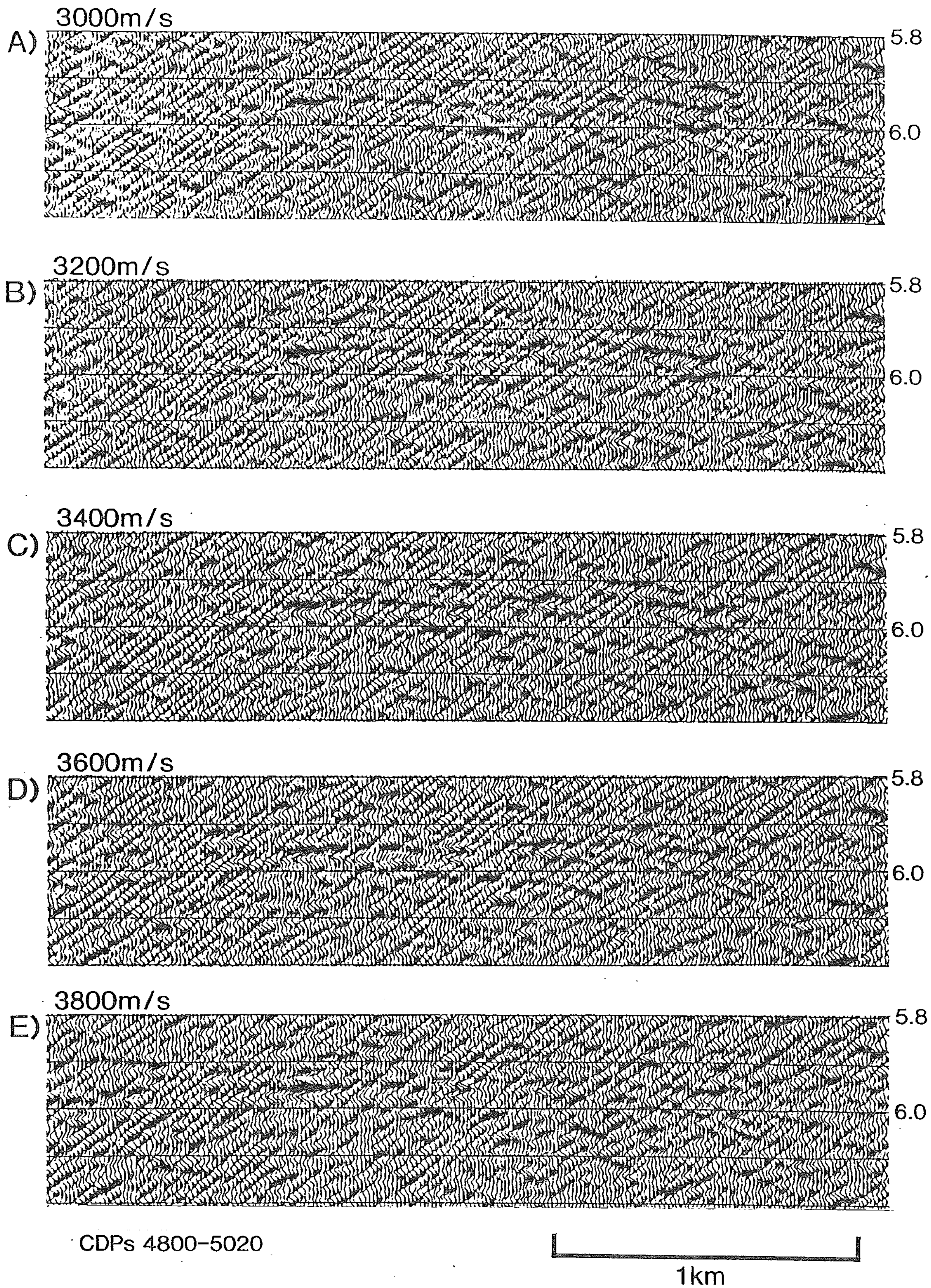

Figure 27. Constant velocity stacks for moho on line 89-15 from cmp's 4800-5020 at shotpoint locations 1283-1338 from 3000 to 3800 m/s. Automatic gain control over a 750 ms window was applied to each stack. Although there is much high-frequency noise differences between the stacks can be seen. 3400 m/s was chosen as the appropriate stacking velocity.

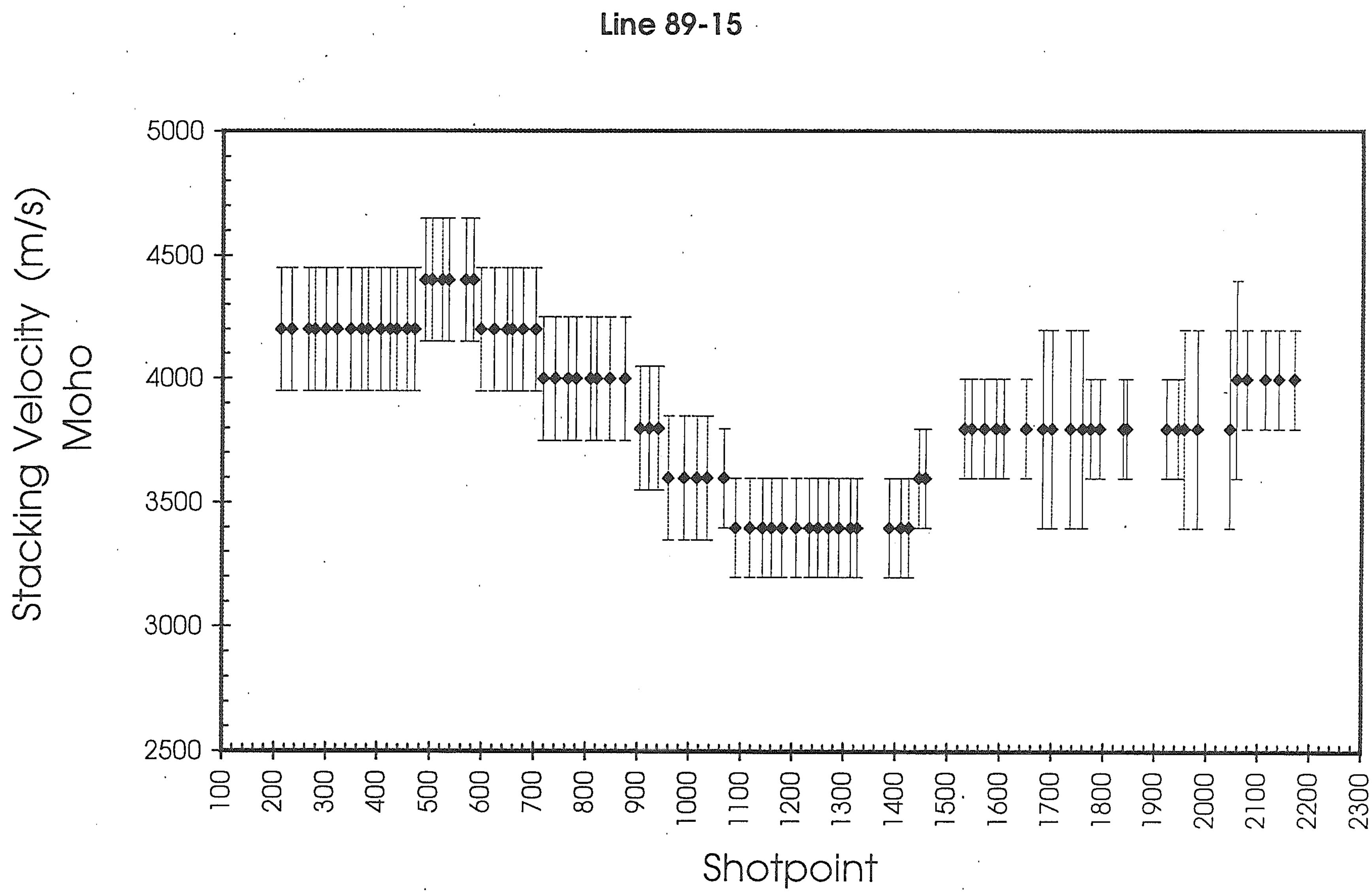

Figure 28. Compilation of stacking velocities for moho.

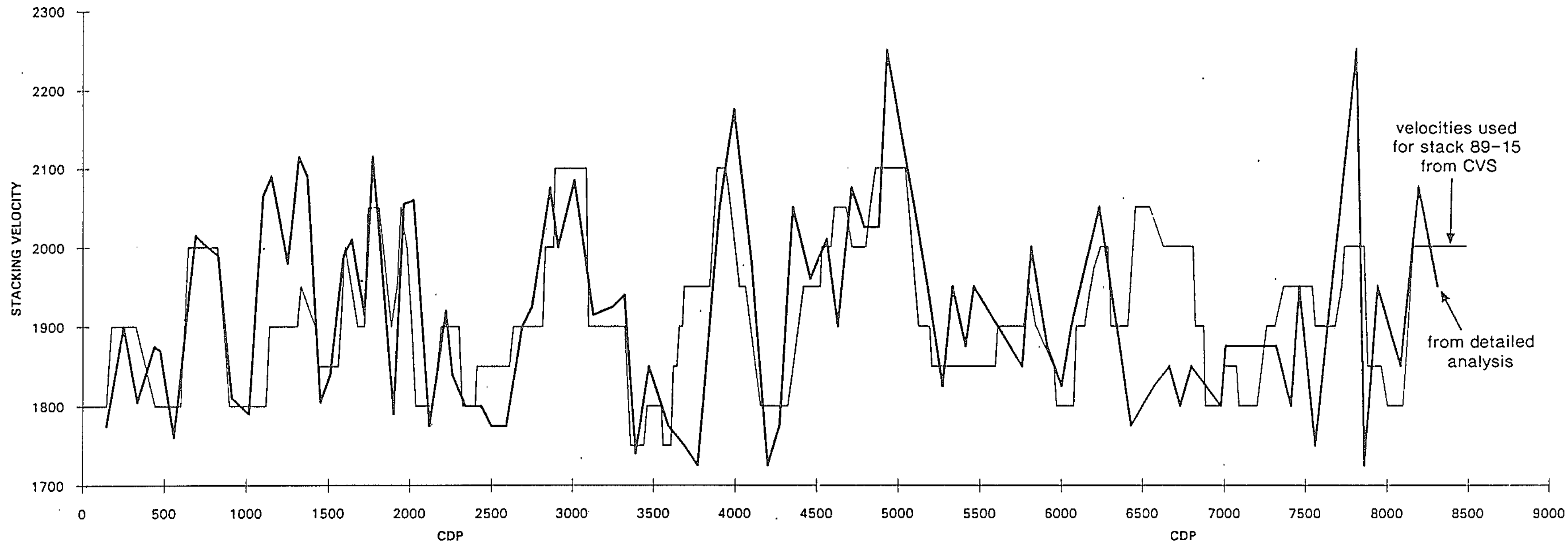

Figure 29. Comparison of stacking velocities picked from constant velocity stacks and normally moved out gathers. They generally are in good agreeement.