Progress Report on Migration and Interpretation of the JAPEX Japan Trench Line

Rick Ottolini

One of the more intensely studied subduction regions is that off northeast Japan [1]. In April 1980, at the sponsors meeting of the Stanford Exploration Project (SEP), the Japan Petroleum Exploration Company (JAPEX) gave us a common depth point stack data tape of a marine seismic reflection line crossing this trench [2]. We have been applying the most recent techniques of migration imaging on our VAX computer to aid geological interpretation of this section. Preliminary results have been quite good in cleaning up cleaning up diffractions and clarifying the geometry of subsurface reflectors. The descending slab reflections terminate relatively close to the surface. The overlying plate pinches out at the surface about 10 kilometers and half way down slope from the trench axis. In between there is a 3 kilometer thick lens of material with reflections dipping sub-parallel to the descending slab witch may be accreted sediments.

Geologic Description of the Unmigrated Section

The general tectonic setting of this line is a subduction-forearc region. A schematic model of a subduction-forearc region is shown in figure 2. Figure 3 is a geologic cross-section compiled from reflection seismic, area geophysical, and well hole data gathered during Leg 56 of the Deep Sea Drilling Project (DSDP) in 1978 [1]. The Japan Trench has relatively fast convergence and a steep dipping subduction slab. Refraction surveys measure crustal velocities to within thirty kilometers of the trench axis. There was subaerial uplift in early Tertiary and subsequent subsidence probably due to convergence lithospheric flexuring and landward migration of the trench axis. Well core and geophysical evidence of volcanism also supports a further seaward location of the trench axis at earlier times.

The unmigrated JAPEX line is plotted in figure 4. Letters identify interesting features on this section:

(a) Seaward extension of the Cretaceous angular unconformity seen onshore;

(b) Cross-section along the narrow axis of elongate sediment pond; The flat lying sediments appear undeformed.

(c) Terminus of the overlying plate. Hypothesis as to its nature include:

   (i) Undeformed slope sediments, or

   (ii) Highly deformed slope sediments, and/or

   (iii) Accreted subduction prism, and/or

   (iv) Subduction erosion of overlying plate.

No evidence supports an exotic body between the trench and Japan proper.

(d) Possible trench sediment pond with undeformed, flat lying sediments;

(e) Subduction slab; There may be some internal deformation and faulting. The slab terminates in a set of diffractions.

(f) Are these reflectors part of the subduction slab or overlying plate?

(g) Seafloor multiple reflection;

Migration Processing

This JAPEX section contains many confusing events that migration imaging would clear up. Seafloor diffractions almost totally obscure the nature of the overlying plate terminus at (c) on figure 4. Other diffractions hide the Cretaceous unconformity (a) and internal structure of the subduction slab (e). Both depth and lateral velocity variations distort true thicknesses and slopes such as the depth relationship of the (f) reflectors to the subduction slab and the angle of subduction. Irregular seafloor topography may add false structure to subsurface reflectors, for example, complicating the (f) reflectors. Migration collapses diffractions and move dipping subsurface reflectors to their proper locations in the earth, often improving their lateral continuity. In addition, migration converts a time image into a true depth image and improves overall signal to noise.

Previous migration processing of this dataset have been reported by Nasu et al [2] and Marachi et al [3]. It is shown in figure 6. We hope to use the migration expertise developed at the SEP to improve these results. This dataset poses several challenges to migration processing:

(1) The total number of data samples was six times larger than any previous migration attempt at the SEP. Thus we decided on a two fold migration strategy. First, we migrate the entire section at less than optimal resolution in order to retain the overall

geologic picture. (The migrated section in this report.) Second, we migrated geologically interesting portions at full resolution. (No such results included in this report.)

(2) Lateral velocity variations strongly affect the quality of migration. Of four migration algorithms tried -- f-k, diffraction summation, phase shift, and finite difference -- only the last one handles lateral velocity variations and starts to give satisfactory results. Unfortunately, it is also the most expensive of the four algorithms. The experiments with other migration methods are not described in this report.

(3) A good velocity model of the subsurface is a prerequisite to a good migration. It also aids lithological interpretation. For the preliminary migration result reported in this paper, we used the same velocity model used by JAPEX [2] for time to depth conversion in their processing. It is shown in figure 5. Comparing this velocity model to the migration result of figure 7, there are some discrepancies between the velocity contours and the geology. Problems with this model are partly due to that it was derived through conventional reflection seismic velocity estimation methods. One problem is to properly locate subsurface velocities which are originally measured along traveltime trajectories. One ideally would like to migrate the measured time-velocity map, but this is a chicken-or-egg first problem. Another problem is a degradation of velocity resolution due to relatively short recording cables for the traveltimes involved.

There are several ways to improve the velocity model. First, is to make better use of the conventional velocity estimates, specifically by better pre-locating the measured velocities. Second, is to measure velocity from of the stacked section itself in one of two ways. Measuring velocities from diffractions is one method. The velocity model which produces the best focused migration image is the other method. Finally, we may use abundant associated geophysical and geologic data [1] to constrain our velocities. Among the geophysical data are refraction lines, DSDP hole sonic logs, and core sample velocities. Lithologic assumptions may constrain velocities in the manner of Bloxsom [4].

We use the 45 degree finite difference algorithm described by Godfrey and Jacobs [5] and Kjartansson [6] and programmed by Dave Hale. It contains the latest innovations for dealing with arbitrarily severe lateral velocity variations and grid effects developed at the SEP. First we construct a velocity grid for each output depth point by interpolating between midpoint velocity profiles. We kept only every other trace and every third time sample to make the dataset more manageable. For this dataset, we do the initial downward continuation through most of the water layer using the economic phase shift algorithm. Then we specify at which output depth points we wish to see the migrated results. Here there is a tradeoff between the quality and economy of migration. The result in this report took three days at background priority on a time sharing VAX computer with an array processor.

The migration result in figure 7 was quite successful at collapsing annoying diffractions, improving definition of many reflectors, and producing a depth section. However, there are few artifacts of migration processing, many of which can be cleared up in future migrations.

(1) Smile shaped noise off of the sides of the section and seafloor are mostly due to using the phase shift method to downward continue through the water layer. We now know how to use this algorithm more carefully in order to prevent this effect.

(2) The gradual decrease in resolution towards the base of the section is due to several unavoidable causes. First, increasing velocities mean that the same traveltime frequencies sample coarser depth intervals. Second, attenuation compounds this first problem by lowering the traveltime frequency content of the data. Finally, the truncation of data at the boundaries of the input data weakens amplitudes and decreases lateral resolution of reflectors near the boundaries.

(3) The near surface sediment layering, especially with the sediment pond by (b), is fainter in the migrated second than the unmigrated section. This is caused by using a too coarse depth sampling when running the migration program.

(4) An imperfect velocity model introduces artifacts in the migrated result. One example is the kink in the subduction slab near the edge of the seismic section at (b). Another example is the discontinuity of the seafloor reflector in the vicinity of (c).

(5) The finite recording cable length puts a limit on the steepest dips that can be recorded. In addition, the finite difference migration algorithm doesn't work for steep reflectors. This may explain why the steepest segment of the seafloor reflector near (c) is not visible and the Cretaceous angular unconformity at (a) is indistinct.

(6) The seafloor multiple at (g) persists through the migration.

Preliminary Interpretation of the Migrated Section

The following interpretation should not be taken too seriously because of flaws in the migration. I also do not have much experience in interpreting subduction zone data. Figure 8 is a line drawing of the migrated section of figure 7 and a useful reference for the following interpretation. Figure 9 is a line drawing of an unmigrated seismic line run just south of the line in this report [1]. It is quite similar to our line drawing.

Figures 10 and 11 are expanded details of the unmigrated and migrated subduction slab. The subduction slab clearly continues to about trace 790 with an average dip of six degrees. This migration was unable to clarify whether the reflectors at (f) are part of the subduction slab. A better rendering of the velocity structure above (f) may lead to a better migration image of (f). The relatively tight undulations in (f) are unlikely totally attributable to seafloor topography or velocity model effects. The upper slab exhibits surface structure in the form of normal faulting. This does not seem to be a migration artifact. he faulting may be a result of flexure tension.

Figures 12 and 13 are expanded details of the unmigrated and migrated terminus of the overlying plate at (c). The reflectors at the upper part of the trench slope are nearly flat. This is probably the relatively undeformed edge of the overlying plate. There is a set of reflectors dipping about 15 degrees beneath these flat reflectors, extending from traces 490 to 870. This could be an accretion sediment prism exhibiting imbricated thrust faults. It is about 20 kilometers wide, 3 kilometers thick, and about half of it is exposed at the seafloor.

Future Plans

Much work remains to be done in improving the migration, particularly developing a better velocity model. In the next migration experiment, I intend to incorporate velocity information collected by the DSDP [1]. In addition, there are a number of geologic and geophysical problems this dataset may address.

(1) What is the nature of the terrace trough basin (b) and other smaller sedimentary basins along the trench slope and seafloor?

(2) Can anything be learned about the proposed mid-terrace volcanic rocks?

(3) What is the nature of the continental basement?

(4) What can be learned about the Moho?

(5) Both stacking and migration can be used to estimate subsurface velocity. This velocity information may help determine lithology.

(6) The depth image of the sediments may facilitate the calculation of deposition and subsidence rates.

(7) We need to calculate the maximum dips visible on the seismic section in the manner of Bloxsom [5].

(8) The velocity and reflector picture of the subsurface given by reflection seismology may be compared against other geophysical and geologic investigations to seen how well it correlates. One possibility is to compare stacking velocities to refraction lines and well hole sonic logs.

REFERENCES

[1] Initial Report of the Deep Sea Drilling Project, Legs 56 and 57, Sites 434-440, Part 1, 1980
[2] Nasu, N., et al, "Multi-channel Seismic Reflection Data Across the Japan Trench", Ocean Research Institute, University of Tokyo, March 1979
[3] Matsuzawa, A., Tamano, T., et al, "Structure of the Japan Trench Subduction Zone from Multi-channel Seismic-Reflection Records", Marine Geology, Vol 35, page 171, 1980
[4] Bloxsom, "Migration and Interpretation of Deep Crustal Seismic Reflection Data", Thesis, Stanford University, 1980
[5] Godfrey, R. and Jacobs, A., "A Program for Stable Migration", SEP Report 16, page 97, 1979
[6] Kjartansson, E., "Wave Equation Variable Velocity and Attenuation", SEP Report 15, page 1, 1979

Appendix: JAPEX Dataset Parameters

Line number	78-4
Sponsor	Ocean Research Institute, University of Tokyo
Date	early 1978
Location	40N 144E off northeast Japan
Shot spacing	50 meters
Group spacing	50 meters
Geophone groups	48
Stacking	24 fold
Midpoints	2048
Midpoint spacing	25 meters
Time samples	2750
Sampling rate	4 milliseconds
First time	4.5 seconds
Last time	15.5 seconds
Pre-NMO decon:	
prediction	4 milliseconds
autocorrelation	2 seconds
operator	120 milliseconds
Velocity analysis	every 5 kilometers (200 midpoint separation)
Post-NMO decon:	
prediction	4 milliseconds
autocorrelation	3 seconds
operator	320 milliseconds
Bandpass	9-45, 7-40, 5-30 Hertz

List of Figures

Figure 1: Base map showing location of line 78-4, seven DSDP holes, and bathymetry. [2]

Figure 2: Schematic model of subduction-forearc region. [1]

Figure 3: Schematic cross section of forearc region off northeast Japan compiled from DSDP Leg 56 results.

Figure 4: Unmigrated stack of JAPEX line analyzed in this paper. Labeled features are described in text.

Figure 5: Subsurface velocity model used as input to migration program. Contoured at .5 kilometer intervals.

Figure 6: Migration of this dataset performed by JAPEX. The migration algorithm was probably a time-to-time diffraction summation followed by a time-to depth conversion.

Figure 7: 45 degree finite difference migration done at the SEP. The velocity model of figure 5 was used as input. Artifacts and geologic interpretation are described in text.

Figure 8: Line drawing of migrated section of figure 7.

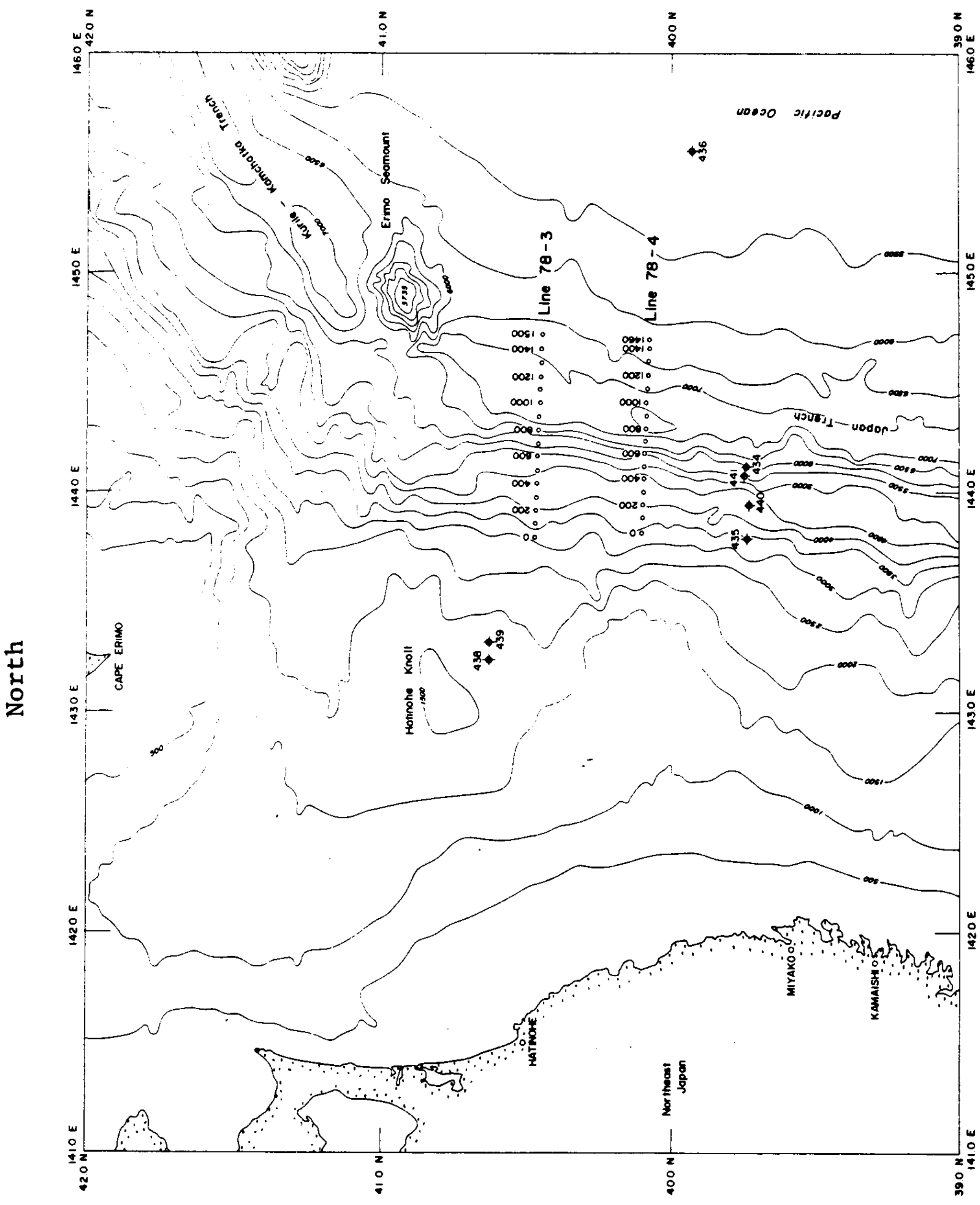
Figure 9: Line drawing interpretation of unmigrated reflection seismic line running near the dataset of this report. [1] The line goes through the DSDP holes south of line 78-4 in figure 1.

Figure 10: Expanded detail of unmigrated subduction slab.

Figure 11: Expanded detail of migrated subduction slab.

Figure 12: Expanded detail of unmigration terminus of overlying plate.

Figure 13: Expanded detail of migrated terminus of overlying Plate.


North
Pacific Ocean
Kurile - Kamchatka Trench
Erimo Seamount
Line 78-3
Line 78-4
Japan Trench
Hachinohe Knoll
CAPE ERIMO
HATINOHE
MIYAKO
KAMAISHI
Northeast Japan
434
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41 0 N
40 0 N
39 0 N
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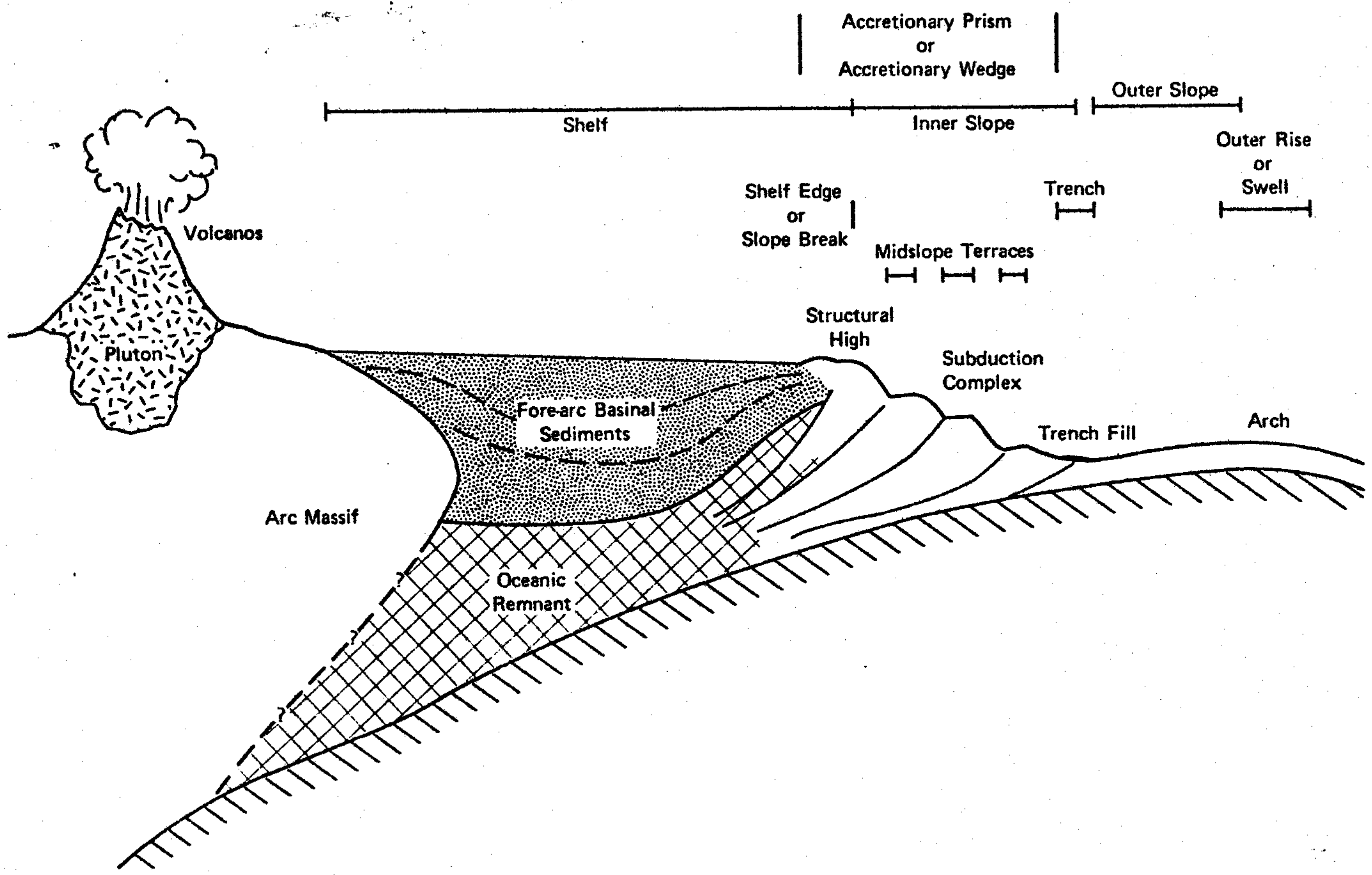
142 0 E
143 0 E
144 0 E
145 0 E
146 0 E

Figure 1.


Accretionary Prism
or
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Outer Rise
or
Swell
Shelf Edge
or
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Trench
Midslope Terraces
Volcanos
Pluton
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Subduction
Complex
Fore-arc Basinal
Sediments
Trench Fill
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Arc Massif
Oceanic
Remnant

Figure 2.

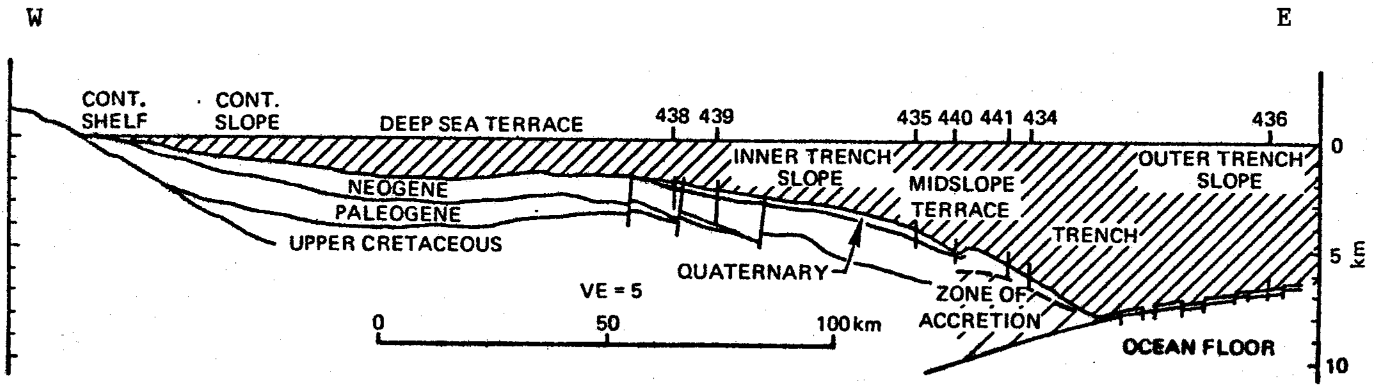
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Figure 3.

JAPEX 78-4 Unmigrated Stack

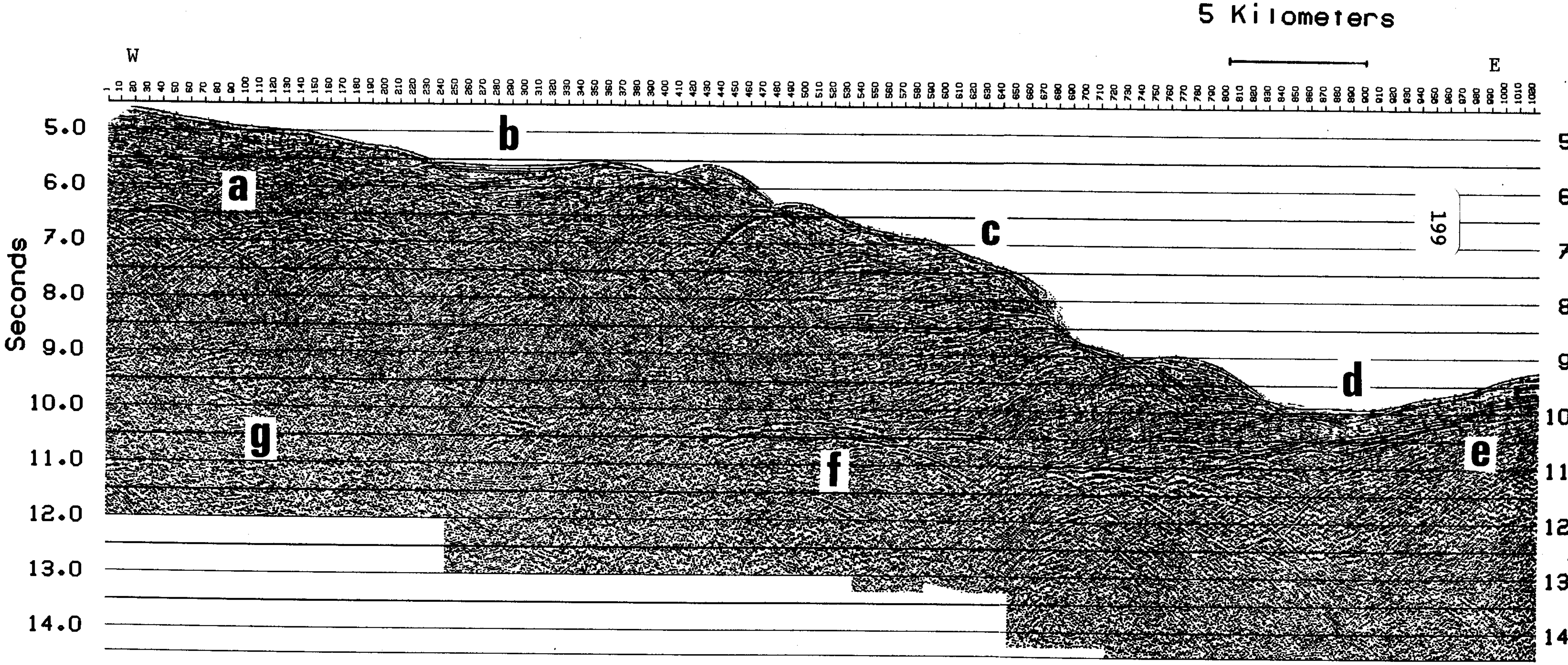

Figure 4.

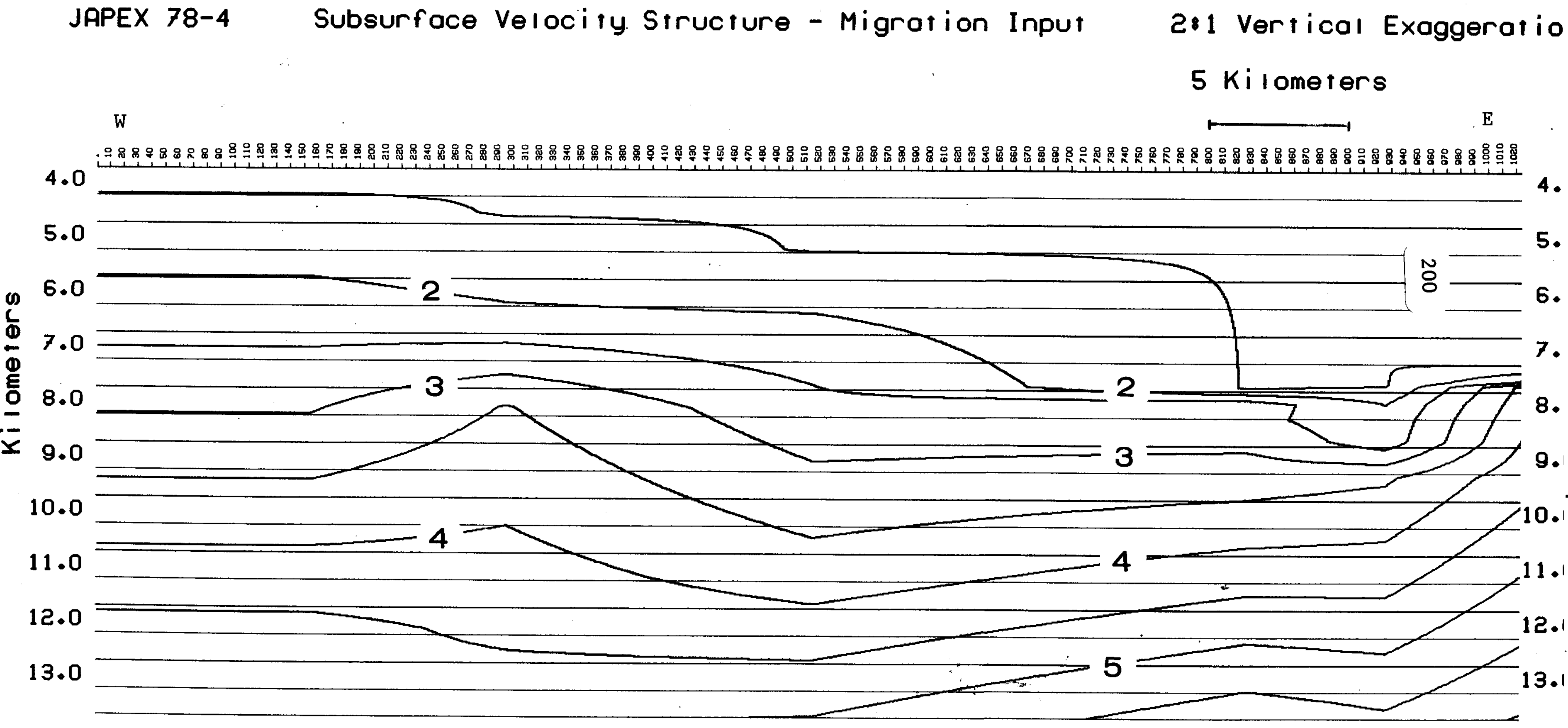JAPEX 78-4
Subsurface Velocity Structure - Migration Input
2:1 Vertical Exaggeratio
5 Kilometers
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Figure 5.

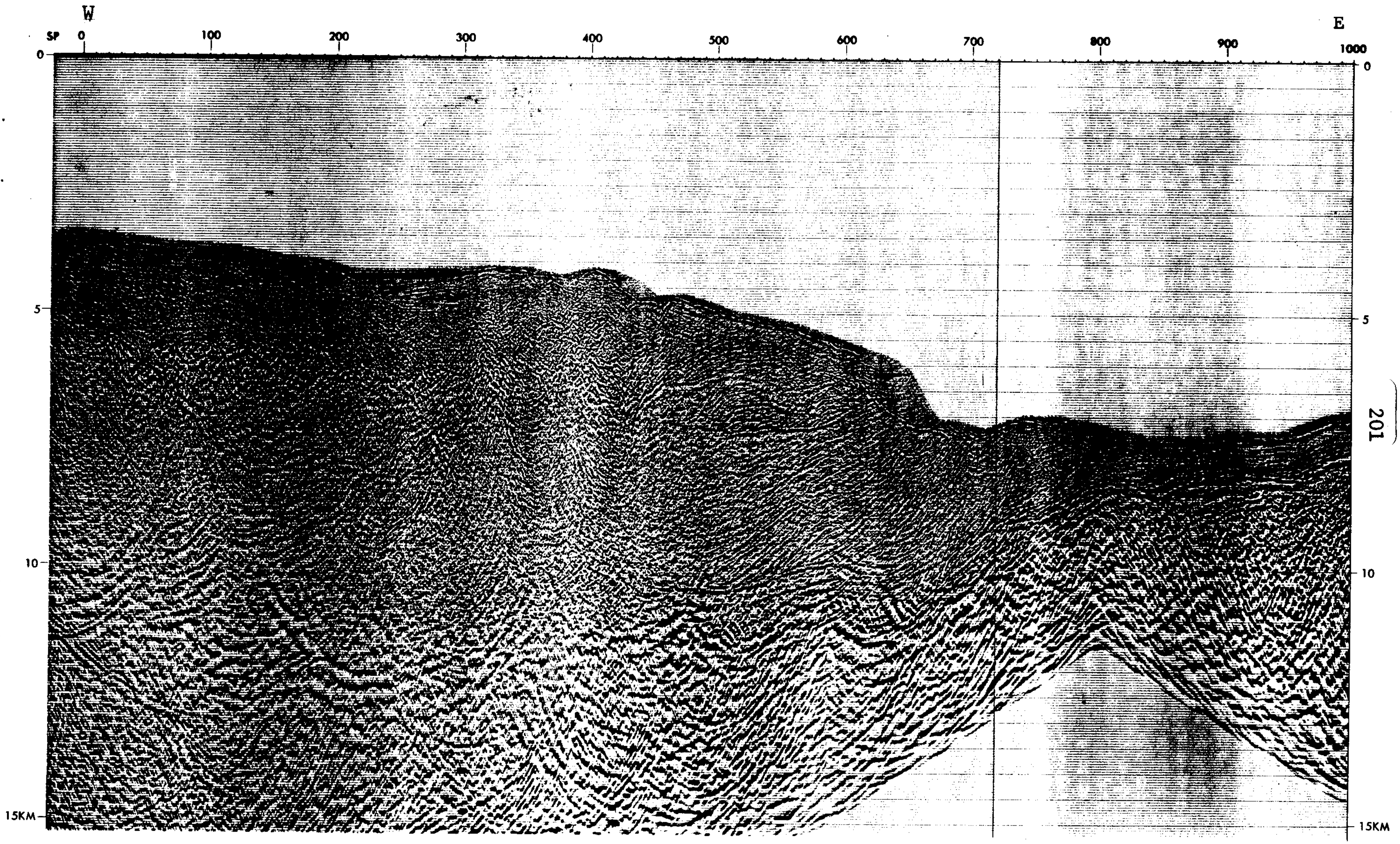
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Figure 6.

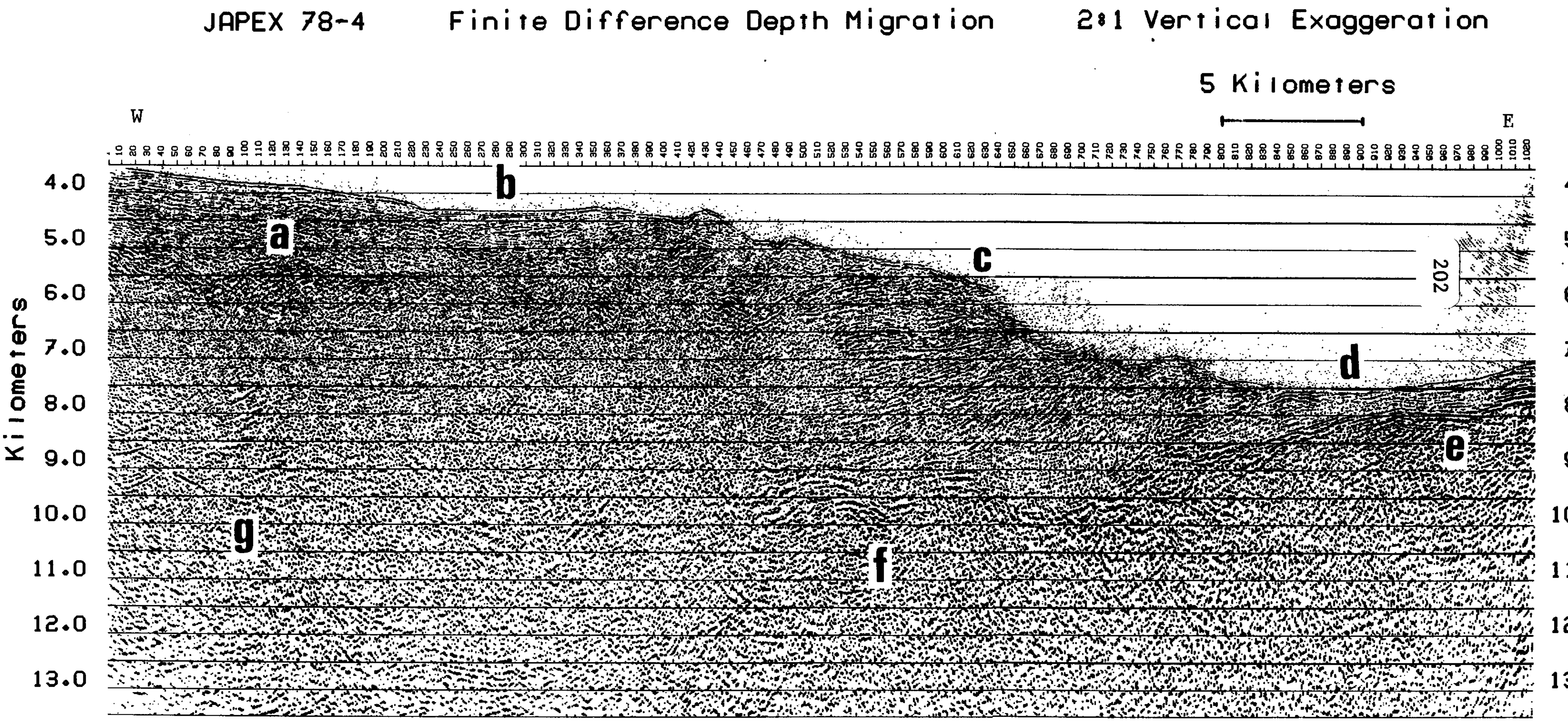
JAPEX 78-4
Finite Difference Depth Migration
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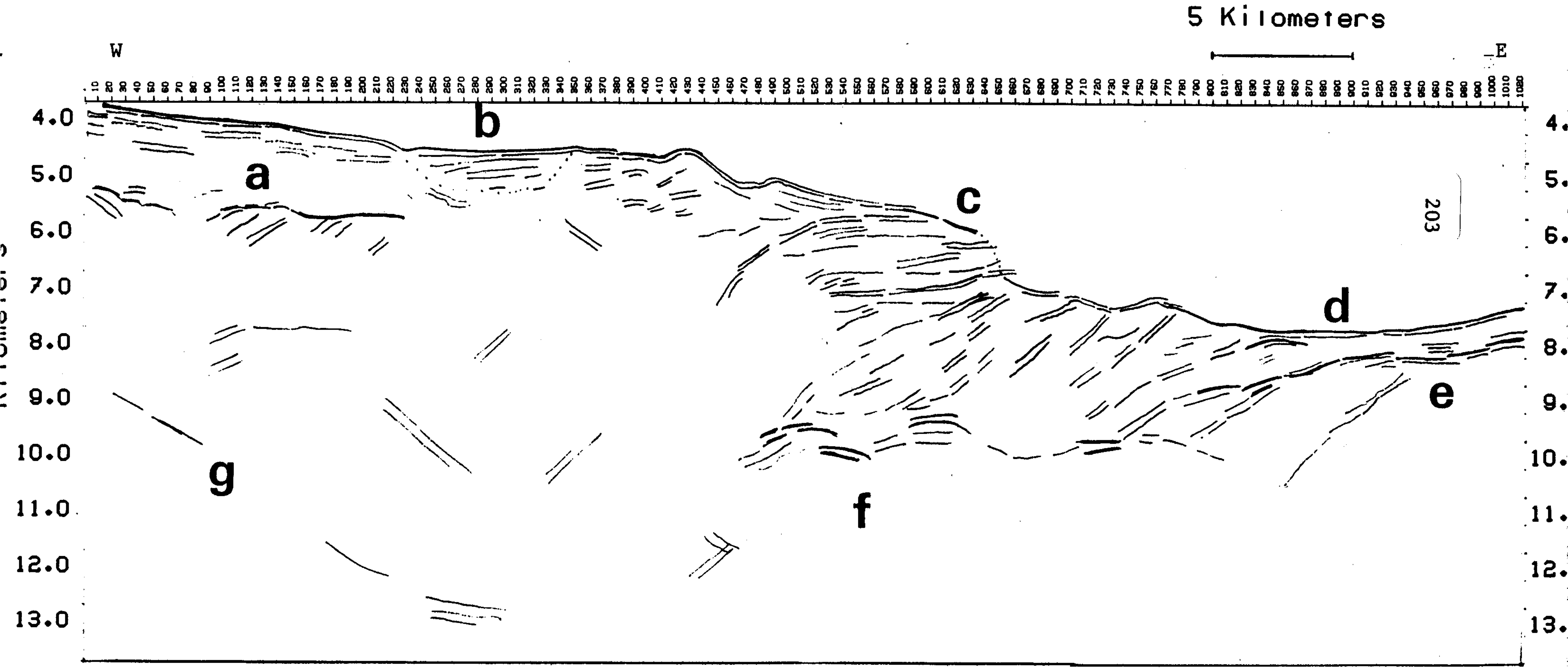
Figure 7.

JAPEX 78-4 Line Drawing of Migrated Section 2:1 Vertical Exaggeration



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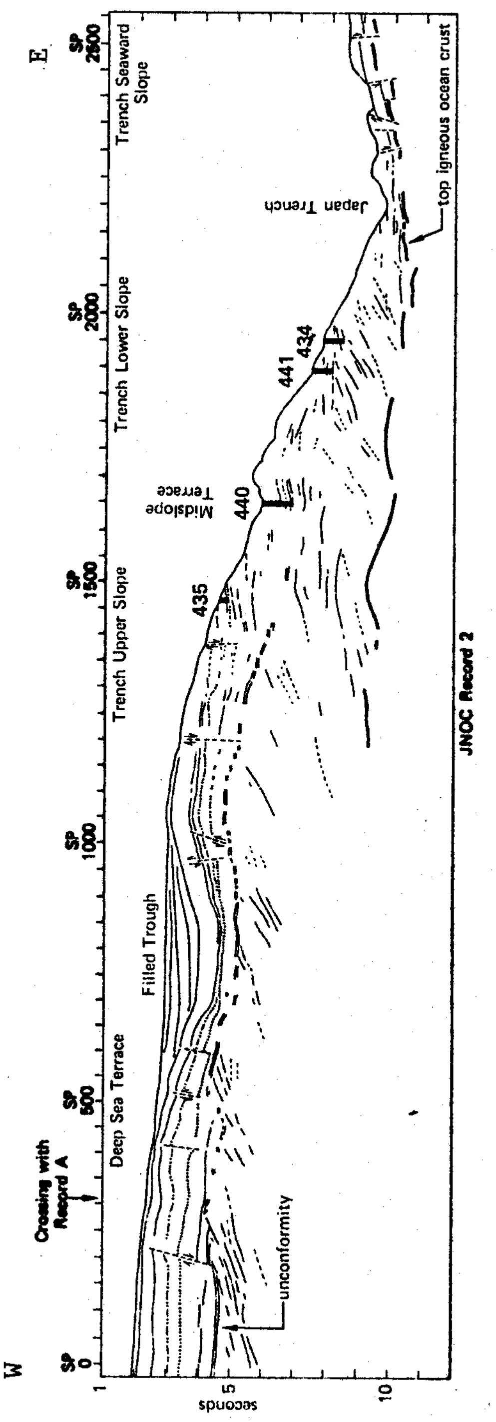
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Filled Trough
Trench Upper Slope
Trench Lower Slope
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Midslope Terrace
Japan Trench
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Figure 9.

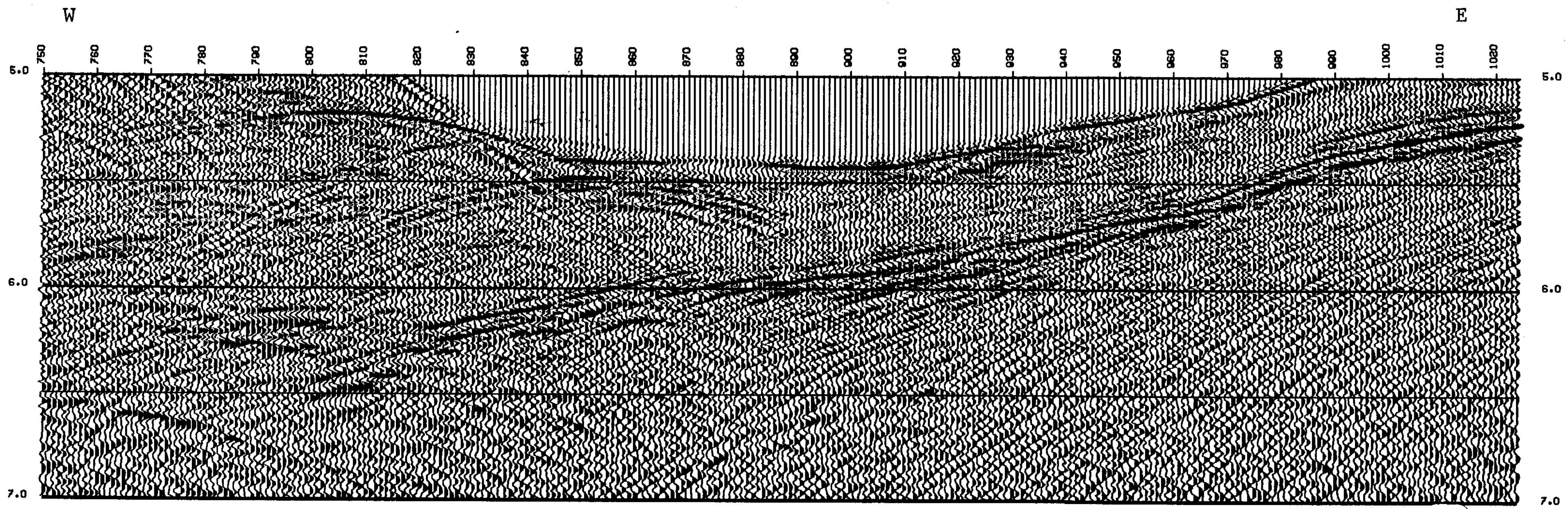
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Figure 10.

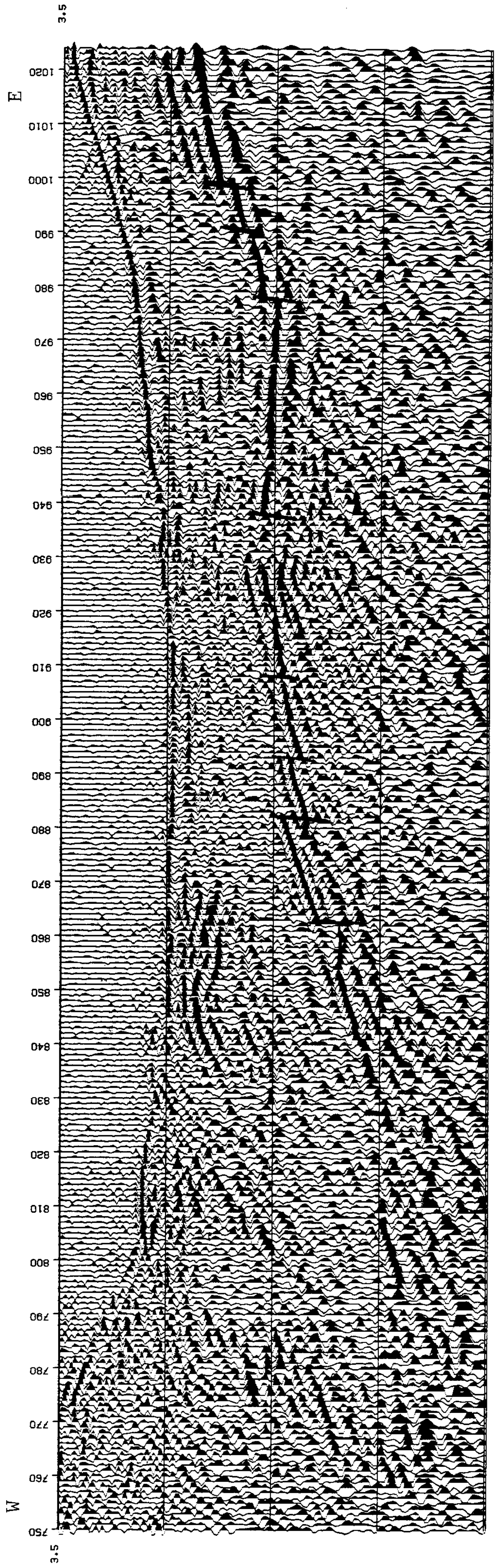
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Figure 11.

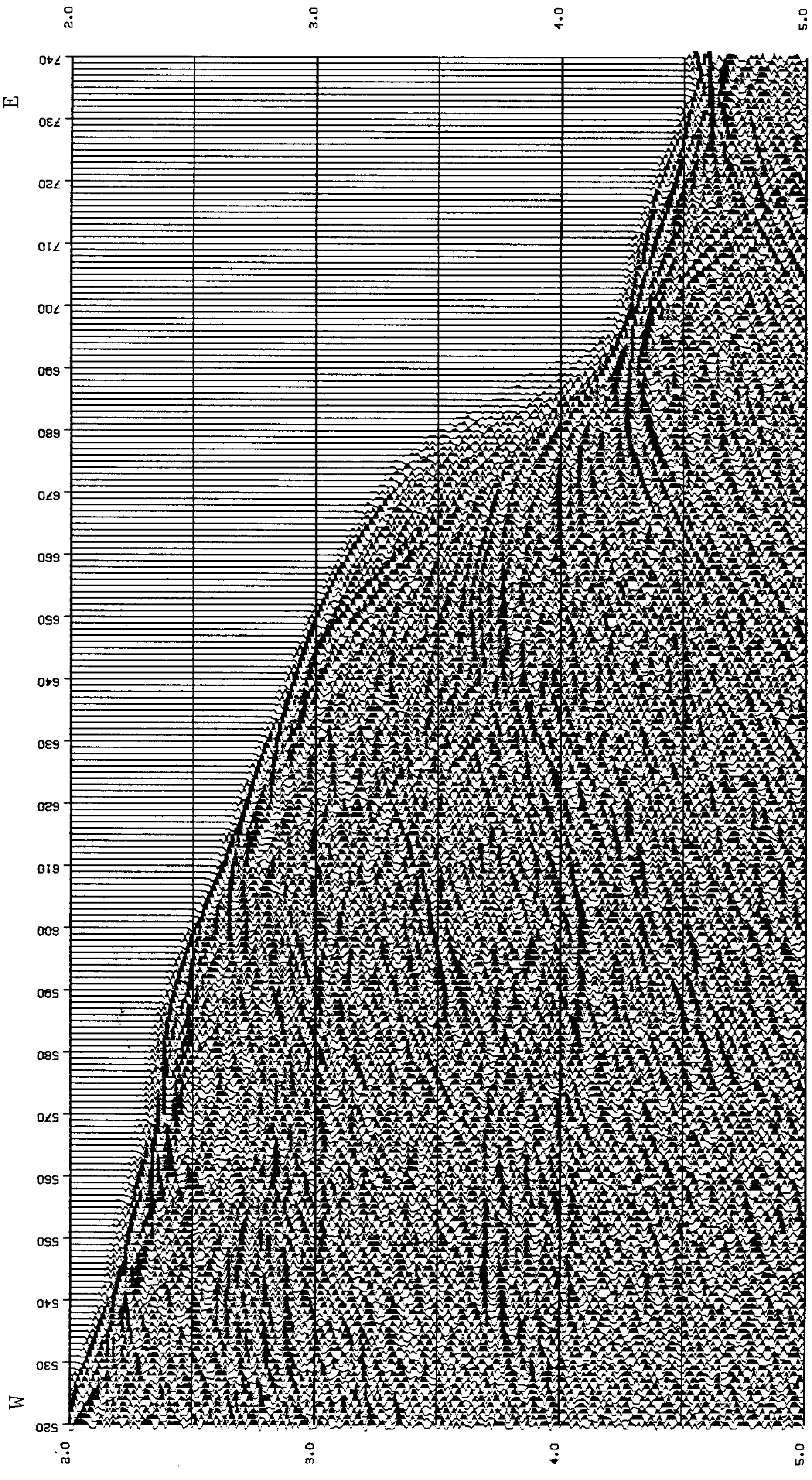
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Figure 12.

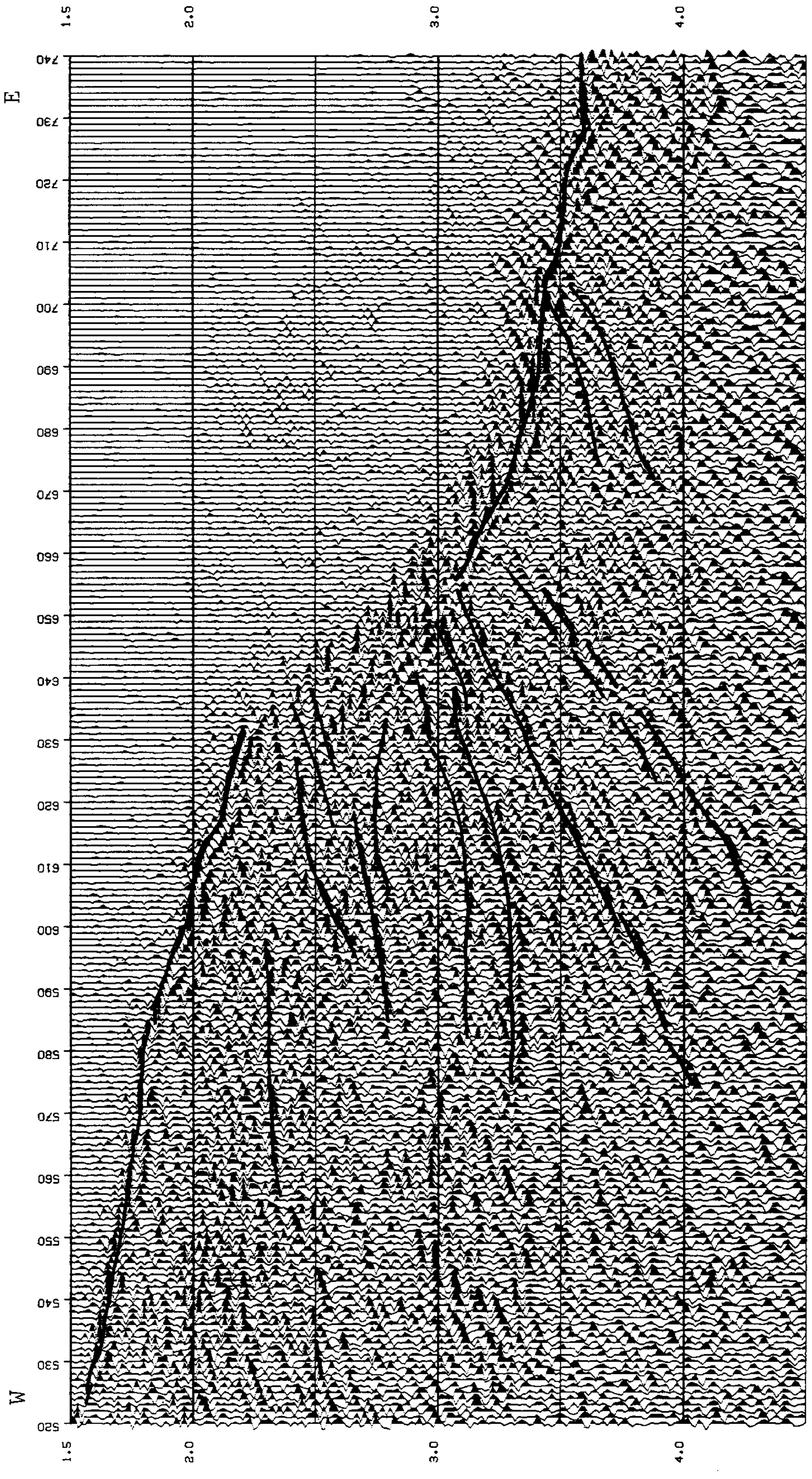
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Figure 13.