HHF. Bon. 1.1D
great project
not in shelf

Detailed analysis of R/V CONRAD [RC3005] Seismic data from the Hudson River
John Diebold

The Multichannel seismic [MCS] data shot by R/V CONRAD in the Hudson river during three days in the spring of 1989 was intended to image deep crustal reflectors. Therefore, the experimental design included parameters [particularly, minimum source-receiver offset] that precluded direct observation of shallow crustal and sedimentary structure. Single channel seismic [SCS] reflection data were also collected during this survey, and this study was intended to include the processing and interpretation of this data set. Unfortunately, the minimum source-receiver offset in the SCS acquisition geometry was too large to allow imaging of the shallow sedimentary structure in the Hudson River. These sediments have thicknesses varying between zero and about 300 meters, beneath a water layer whose average depth is about 40 feet. A more fruitful approach was the analysis of refracted and reflected arrivals in the MCS data, when they were viewed in the form of shotpoint and common midpoint [CDP] gathers.

Apparent fault at CDP 5080

A "tear" is seen in the surface-generated low frequency ringing at the top of the stacked CDP section near CDP 5080. Ray tracing modeling of first arrivals produces results that do not indicate a major change in the thickness of the sediments at this point (though there is a small basement high at shotpoint 3680, which corresponds to CDP 5080). A reasonable deduction is that this "tear" reflects an abrupt change in properties of the bedrock at this point (which might be expected in the case of a dike, for example) though by itself, this feature of the stacked CDP section is weak evidence.

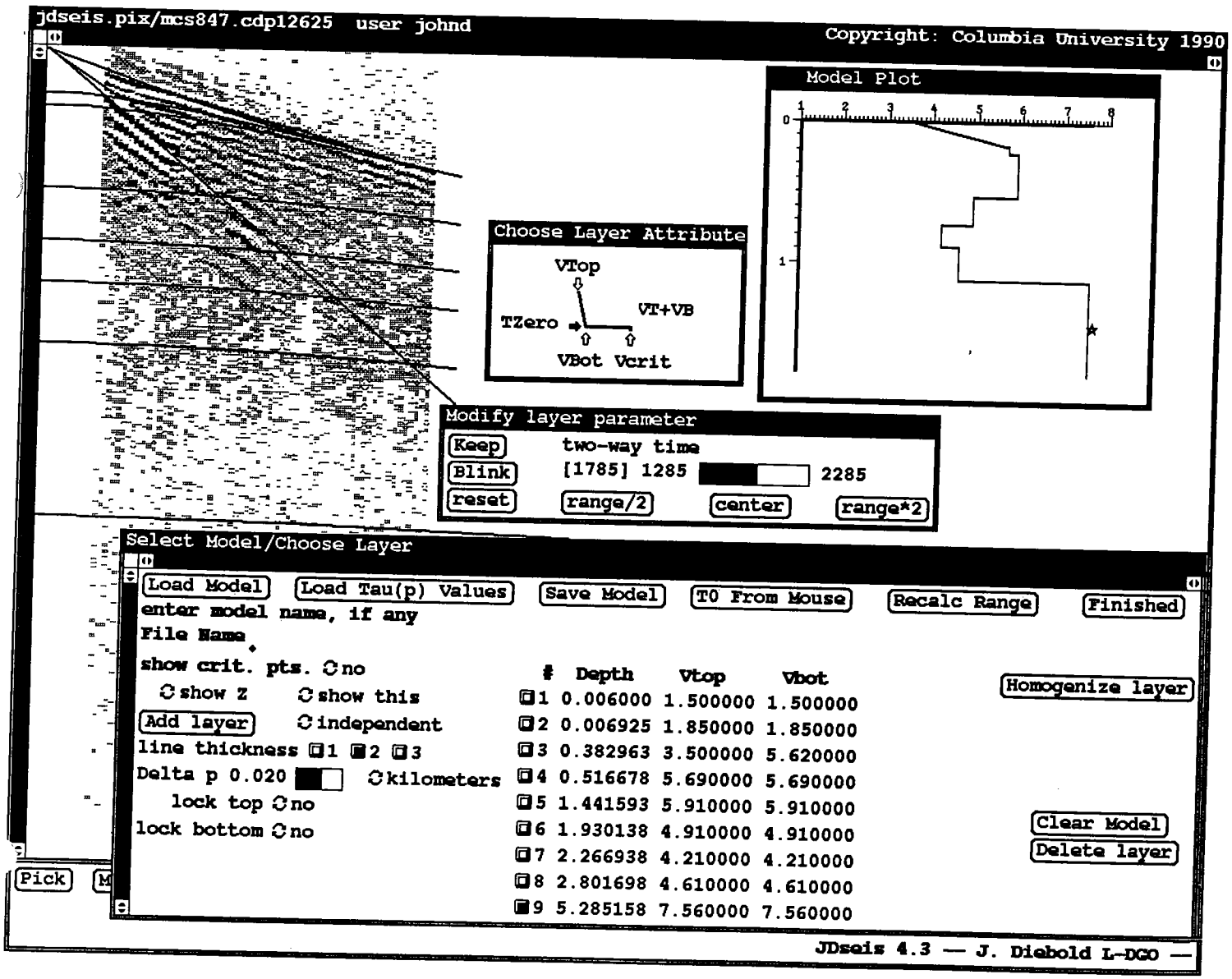
Two other phenomena indicate that some tectonic disturbance is present at this location, however. First, there is a consistent "pullup" in first arrivals of the shot gathers. This is a tightly localized time shift of about 25 milliseconds, which moves through the data from shot to shot, remaining in the physical location corresponding to CDP 5080. Since these arrivals are not included in the CDP stack, they are not themselves responsible for the displacement in the shallow arrivals. The exact source of this pullup is still a mystery. Several possibilities may be considered, however. If a downward kink had formed in the streamer, it would be expected that this would shorten the raypaths of the first arrivals, thus reducing the traveltime, and that the kink would tend to propagate backward as the streamer moved through the water. Howver, to account for the observed deviation in traveltime, this kink would have to have an amplitude in excess of 35 meters, which is at least three times the water depth at this point. The traveltime deviation must therefore result from a localized contrast in sound velocity within the earth. The PDR records do indicate a small high that seems to penetrate the sediment cover at this point. This feature is not well resolved in the bathymetric record, but the end of the streamer seems to have snagged it, contributing to the noisy quality of the data in this area. The vertical extent of a supposed body of contrasting velocity is related to the traveltime deviation (0.025 second) and the magnitude of velocity contrast by the simple equation

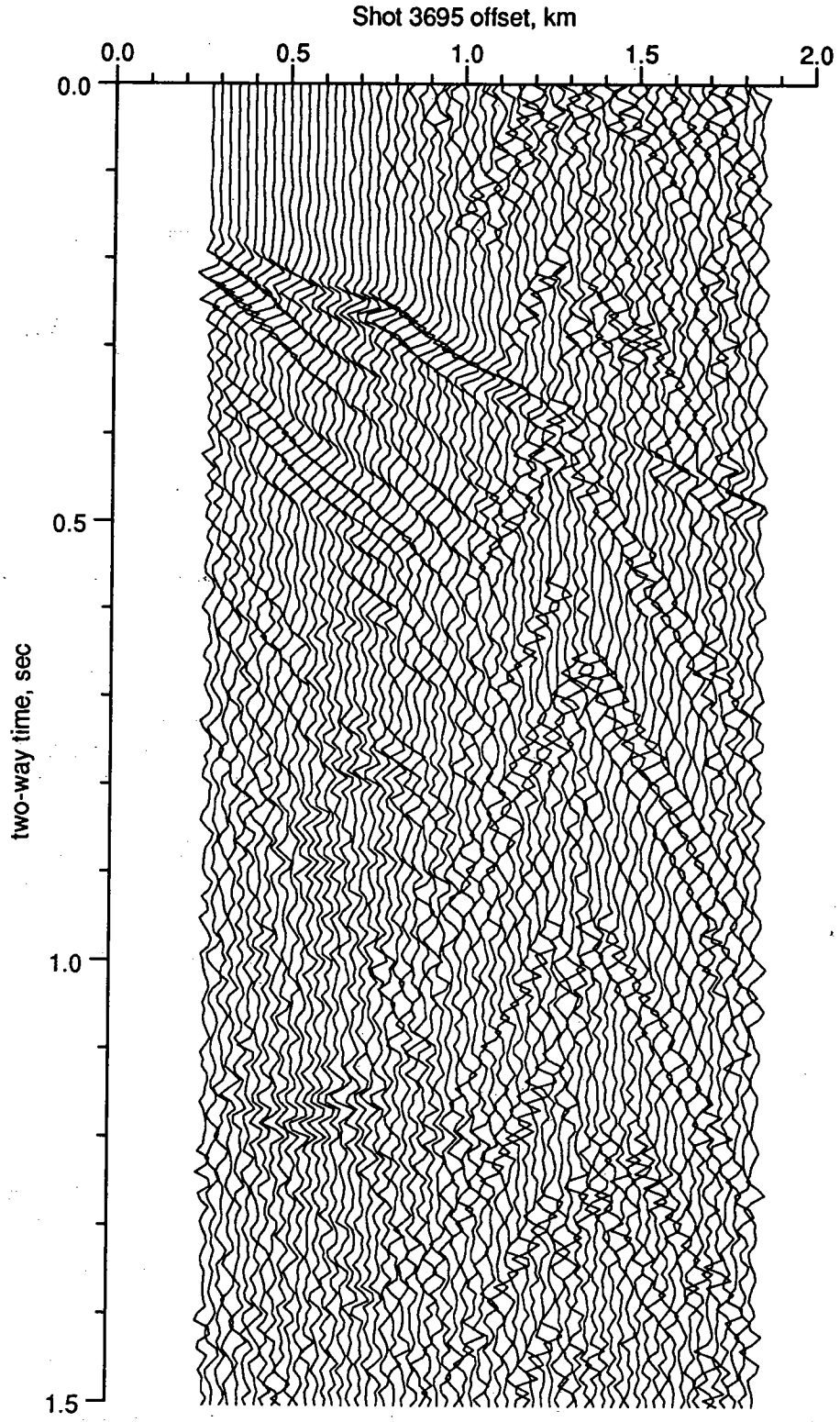
$$DZ = DT * DV$$

For example, a dike of igneous material with velocity 5.5 km/sec intruding into country rock with velocity 3.0 km/sec would have to be 62.5 meters high to produce the 25 millisecond

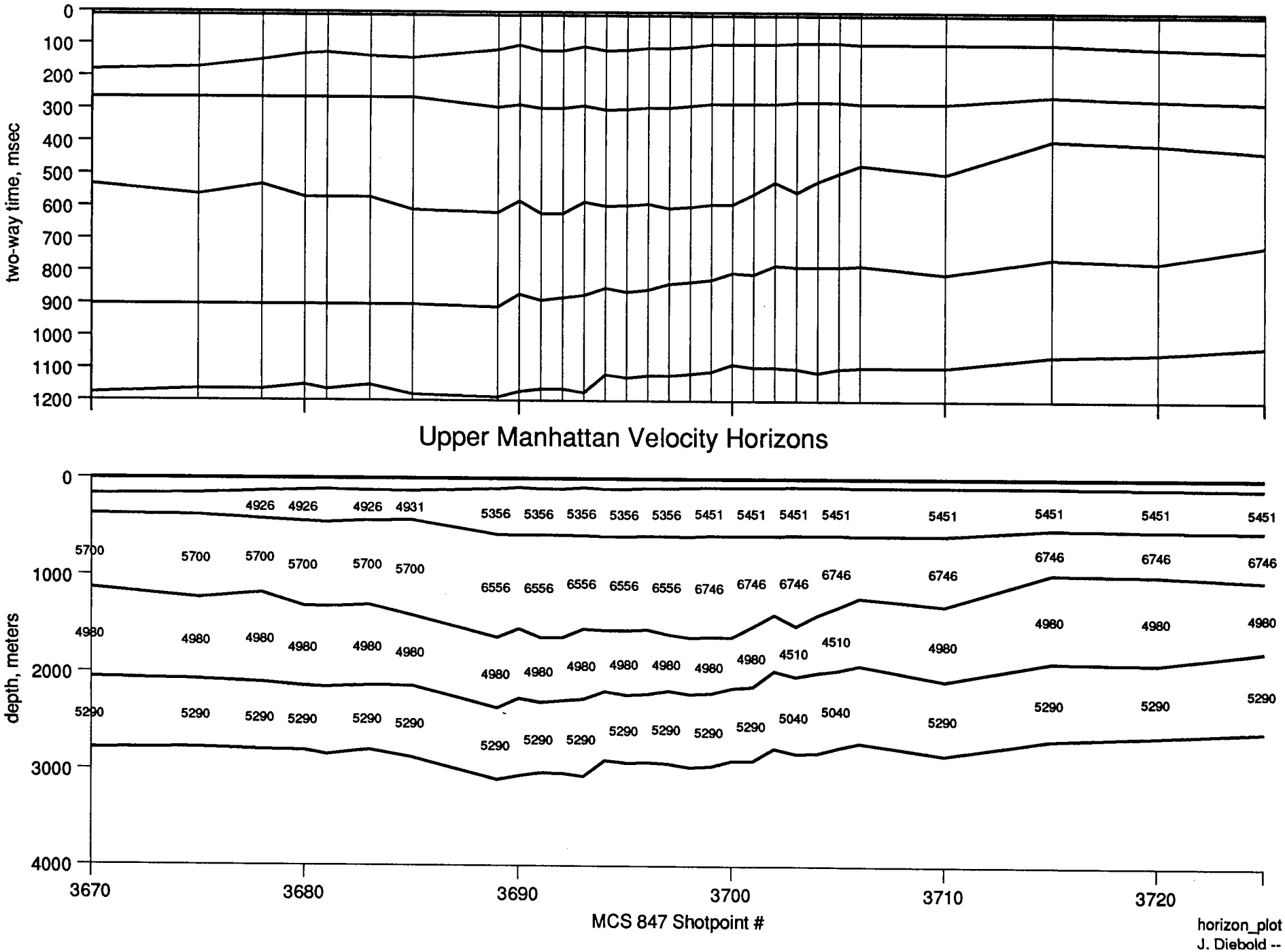
Interactive raytracing of Hudson river MCS data

Interactive raytracing, using a graphics workstation, was used to derive velocity-depth functions for dozens of CDP and shotpoint gathers from MCS line 847, shot by R/V CONRAD up the Hudson River.





A disturbance in first arrivals is seen in gathers near Dykeman Street. In this shot gather, the effect is maximum at an offset of 0.75 meters.


two-way time, msec
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Upper Manhattan Velocity Horizons
depth, meters
0
1000
2000
3000
4000
4926 4926 4926 4931 5356 5356 5356 5356 5356 5451 5451 5451 5451 5451 5451 5451 5451
5700 5700 5700 5700 5700 5700
6556 6556 6556 6556 6556 6746 6746 6746 6746 6746 6746 6746 6746
4980 4980 4980 4980 4980 4980
4980 4980 4980 4980 4980 4980 4980 4510 4510 4980 4980 4980 4980
5290 5290 5290 5290 5290 5290
5290 5290 5290 5290 5290 5290 5290 5040 5040 5290 5290 5290 5290
3670
3680
3690
3700
3710
3720
MCS 847 Shotpoint #
horizon_plot
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deviation. Futher examination of the apparent high point in the PDR record (and verification of its existence, which is not certain) might give us some kind of clue as to the origin of such a contrasting body, since there's little in the seismic data to indicate what it might be.

A third feature of the seismic section that indicates a disruption at this point is the offset in the reflectors seen at 1.1 seconds. It is apparent in the shot gathers that this offset is real, and that it is not caused by the traveltime pullup discussed above.

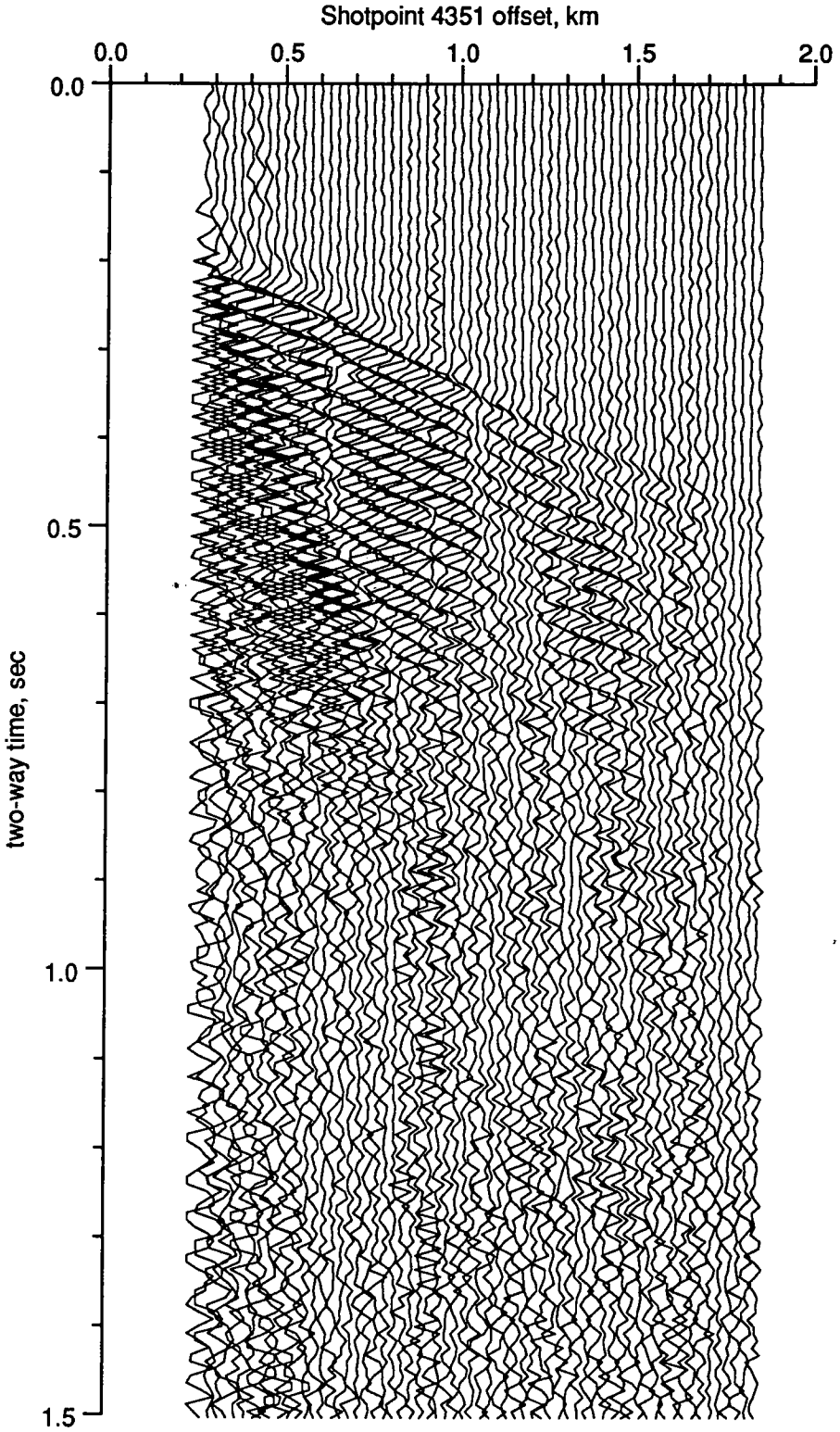
Unexplained feature near Dobbs Ferry

At about 41.0181 degrees North, 73.8862 degrees West, a similar, but less pronounced feature is seen in the shot gathers. It is interesting that at exactly this point, the echo sounder records show an odd feature; it may well be a cable crossing (this has not yet been verified). In this case, the seismic artifact may be a result of the cable's electric field, though this is doubtful.

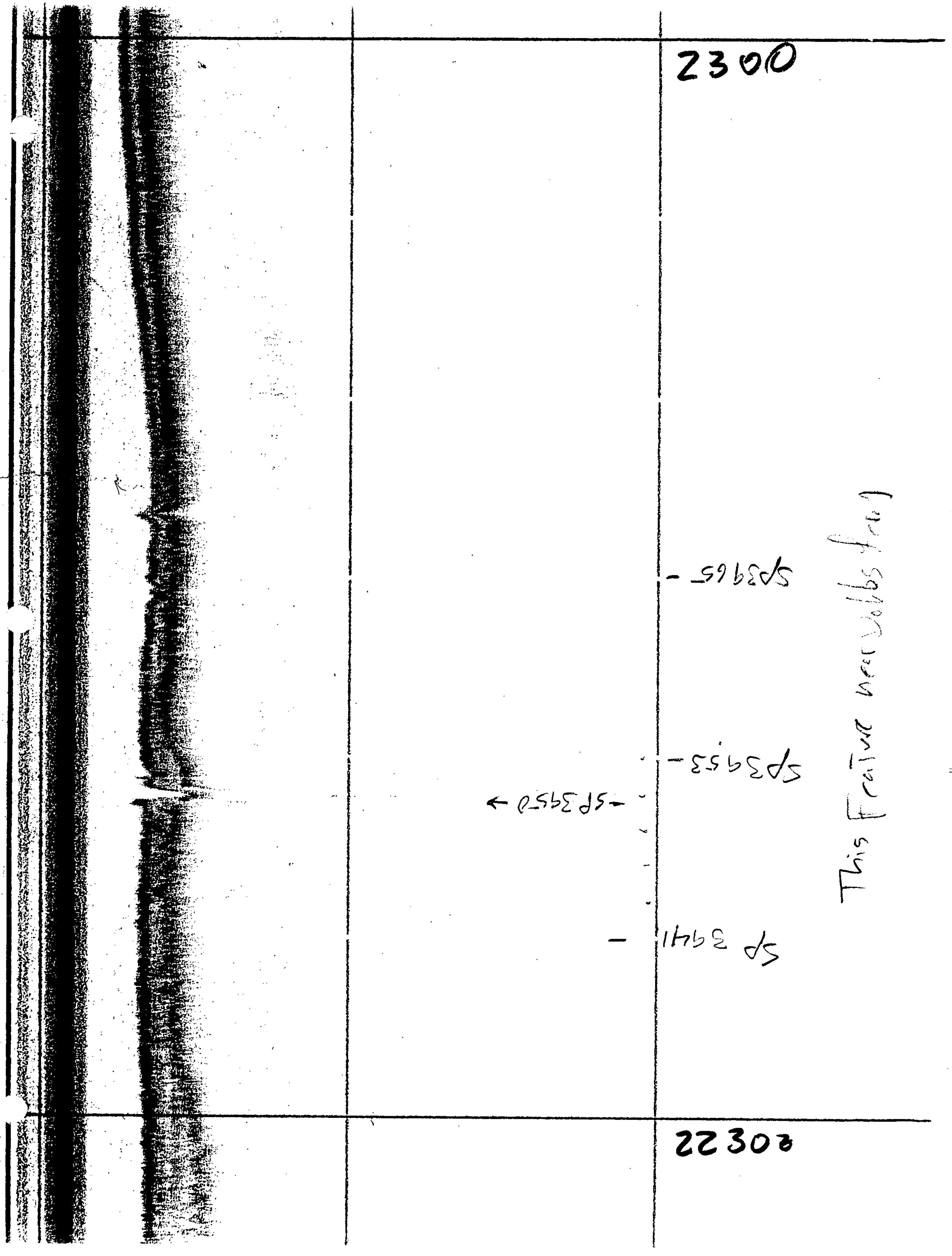
Velocity Interpretation - Lower Hudson Valley

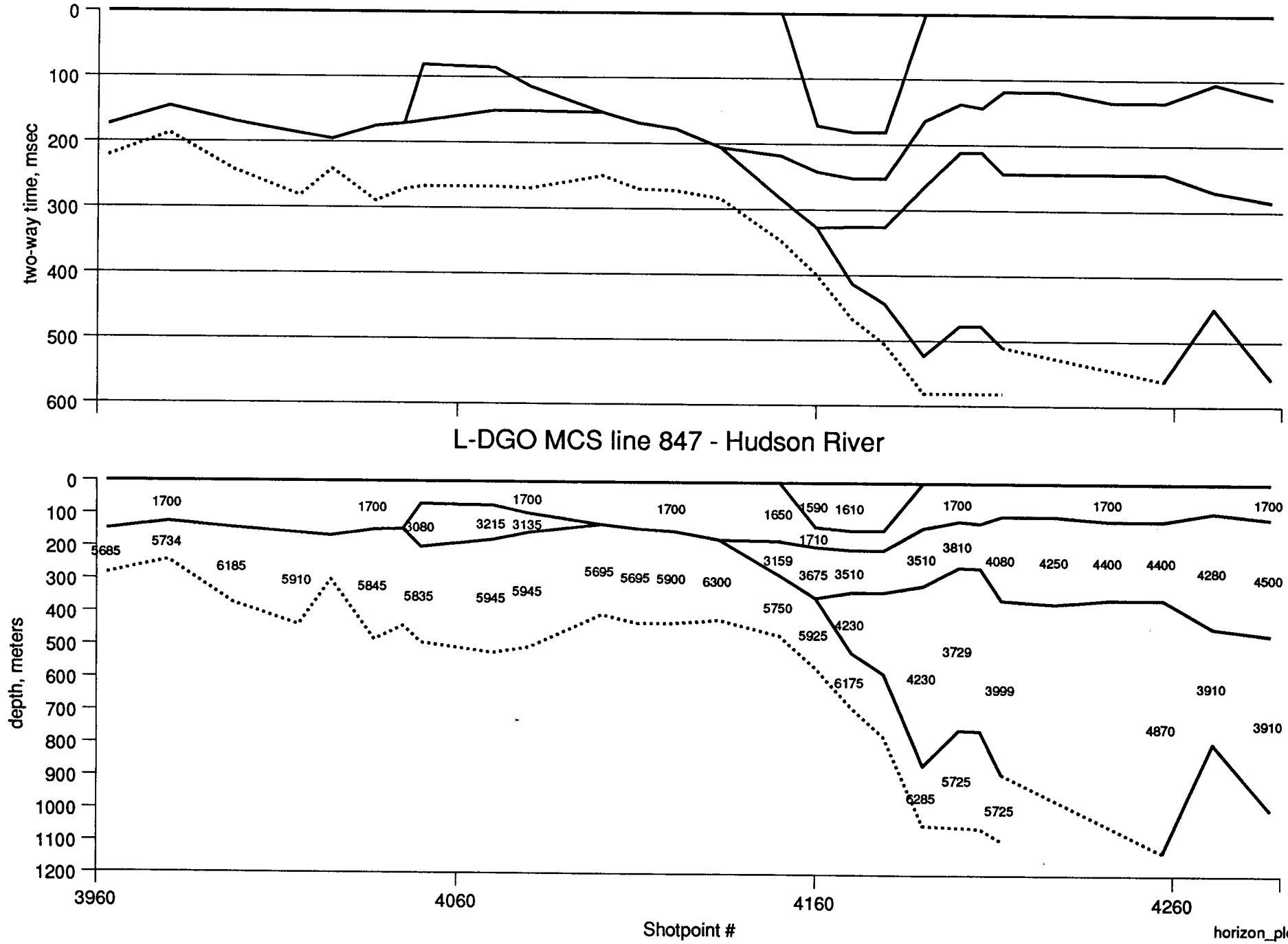
Thirty shot gathers from multichannel line 847 were analyzed by 1-D raytracing. The 64 seismic traces in each shot gather range between 300m and 1850m in offset. The 10-airgun source array and hydrophone receiver array were towed at mid-level in the water column, and the most consistent velocity results were obtained when the water column was neglected. An upper sediment velocity of 1700 m/sec was assumed, this value taken from the results of Worzel & Drake, 1959, who had access to borings made during the survey for the Tappan Zee bridge. In general, the shallowest arrivals used in the velocity analysis were modeled as refracted ["diving"] rays, turned upwards by rocks or sediment having a velocity gradient whose steepness could be determined from the arrivals' change in slope across the array. The thickness of the assumed upper sediment layer was roughly determined by the adjustments required to give proper traveltimes at the refracted arrivals' near offsets. To the South, the velocities of the early arrivals correspond to continental crustal rocks. In two areas (MCS 847 CDP's 6100 and 6400), the appearance of the early arrivals changed, and it was apparent that thicker amounts of slower material were present. It is entirely possible that shallow, low-velocity strata are present elsewhere, and that they could not be detected with this data set. To the North of CDP 6300, a deeper reflection was often seen, indicating the presence of rocks with more or less homogeneous velocities, lying above the crustal rocks. In the area of the North Haverstraw channel (CDP's 6550 - 6700), reverberation prevented the detection of deep arrivals. Their possible continuation is shown as a dotted line.

To display these results in graphic form, the velocity gradient models were converted to homogeneous velocity models, and plotted using software usually used for displaying structure sections obtained from horizons seen in multichannel seismic lines. Annotations show the average velocity in each layer, and the dotted bottom "horizon" is simply an indication of the maximum depth sampled by the arrivals used in the analysis.



A small disturbance in first arrivals is seen in gathers near Dobb's Ferry. In this case, the effect is seen at an offset of 0.65 meters.


2300
SP3965
SP3953
SP3950
SP 3941
This Feature near
22302


two-way time, msec
0
100
200
300
400
500
600
L-DGO MCS line 847 - Hudson River
depth, meters
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1700
1700
1700
1700
1650
1590
1610
1700
1700
1700
5685
5734
3080
3215
3135
1710
6185
5910
5845
5835
5945
5945
5695
5695
5900
6300
3159
3675
3510
3510
3810
4080
4250
4400
4400
4280
4500
5750
4230
5925
3729
6175
4230
3999
3910
4870
3910
5725
6285
5725
3960
4060
4160
4260
Shotpoint #
horizon_plot
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Apparent fault at CDP 6980

An examination of successive shot gathers indicates that a fault was crossed at shotpoint 4342, which coincides with CDP 6980, or shotpoint 4341, located at 41.2674 degrees North, 73.9639 degrees West. This feature is evidenced in the shot gathers as a zone showing a loss in amplitude over six or seven traces [150 - 175 meters] and a slight offset in traveltime. Velocity modelling of the CDP gathers on either side of this proposed fault shows a slight vertical offset; probably between five and ten meters, with the high side to the north. Therefore, most of the traveltime offset is due to low velocities within the fault zone itself. Low velocities within the fault zone may also explain the observation that almost no signal was detected for the three shots (4340, 4341, and 4342) located over the fault itself. A tabular low velocity zone would tend to "capture" the sound waves and channel them downwards, with little propagation into the adjoining, unfaulted, higher velocity rock.

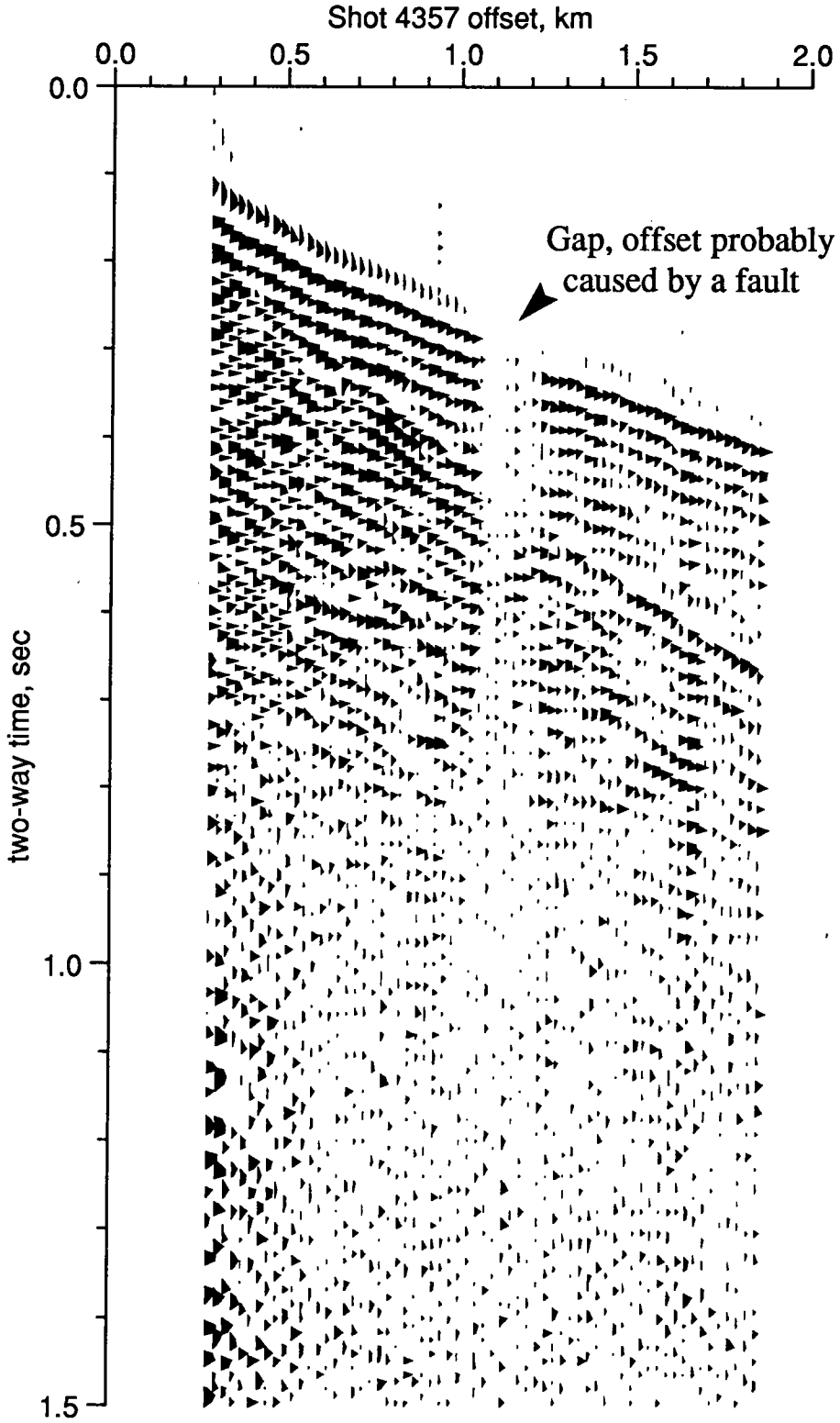
Given the direction of the ship track at this point (40 degrees), the relatively narrow appearance of this zone in the shot gathers indicated that it could not be the Ramapo fault, which is more or less parallel to the river at that point. The New York State Geological map shows no fault at this location or in the area with a northwesterly trend. Recent field mapping by workers at Lamont, however, has defined a set of faults with this trend. It appears that the course of the Hudson between Peekskill and the Bear Mountain Bridge is controlled by the best-defined member of this set. That fault is quite clearly shown by the Simulation Systems, inc. side looking airborne radar (SAR) mosaic of the Mid Atlantic region.

Examination of the depth sounder records from this area shows a graben-like structure in the highly reflective sediments though to be glacial till and gravels. This trough is about 4-5 meters thick, and is filled with recent, postglacial sediments, which are soft and practically transparent to the 12KHZ waves transmitted by the echo sounder. The relative ease with which these recent sediments are penetrated is probably why this location was selected as the crossing point for a pipeline. The position and relatively large extent of this depression indicate that it is more likely related to motion on the Ramapo fault system than on the newly observed Northwesterly trending system.

The Taconic Overthrust Klippe

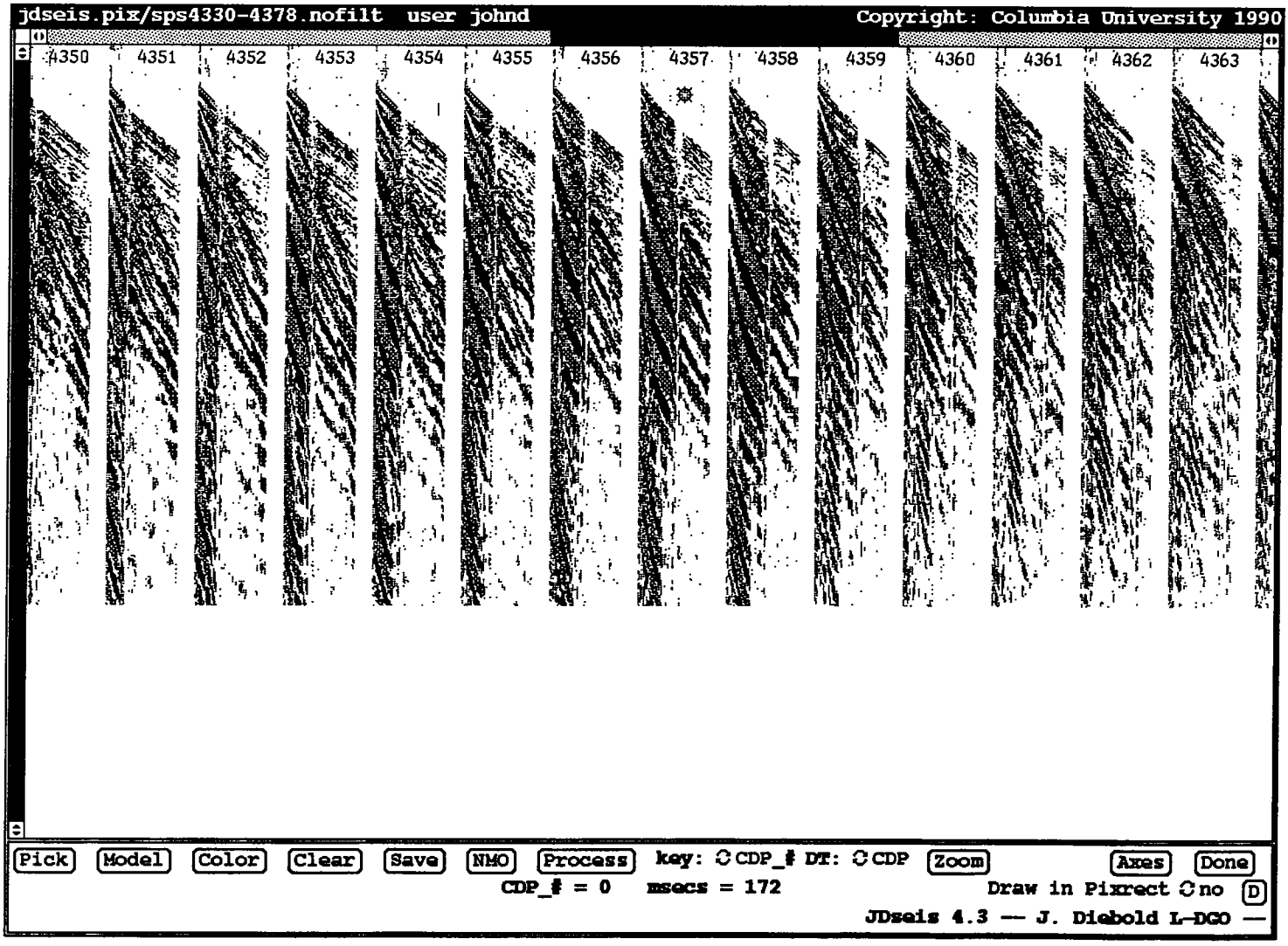
North of Catskill, two strong reflectors are seen in the CDP section with two-way times of 1.5 - 1 .0 seconds (a depth of approximately 3.5 km). These reflectors correspond to the cambrian shelf edge sedimentary strata that are exposed at the surface much farther west. Several faults can be seen in these horizons, and a study of the original shot gathers was made to determine if these faults had any surface expression.

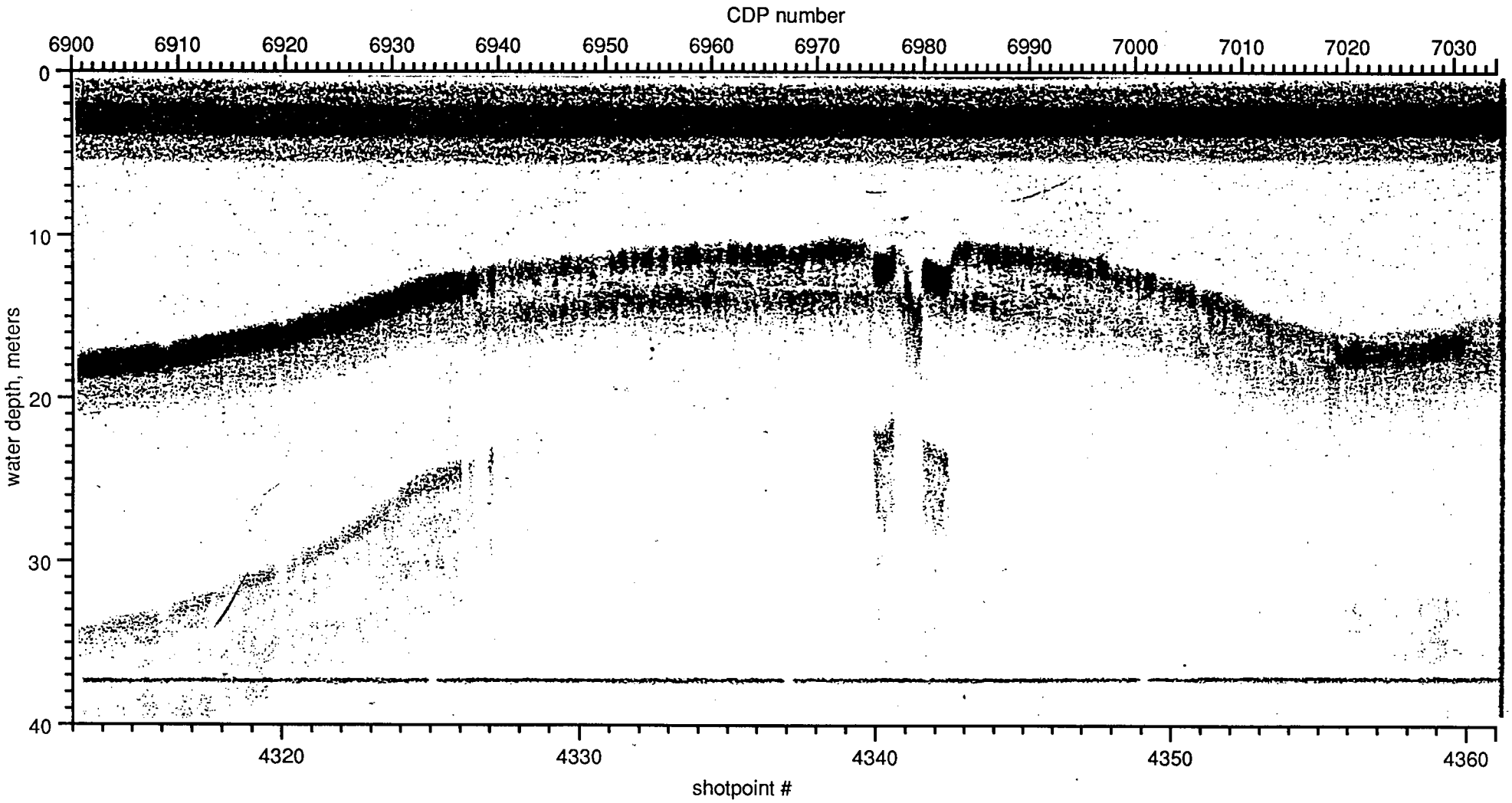
In this case, animation was used to facilitate the process of searching for the discontinuities in first arrivals that should correspond to faults. Four hundred shot gathers were loaded into the computer memory and flashed successively on the screen. Discontinuities and changes in basement depth can be seen to flow by as the seismic experiment is "recreated," but with a time factor speedup of 200x. Many discontinuities could be seen, but all of them correlated to

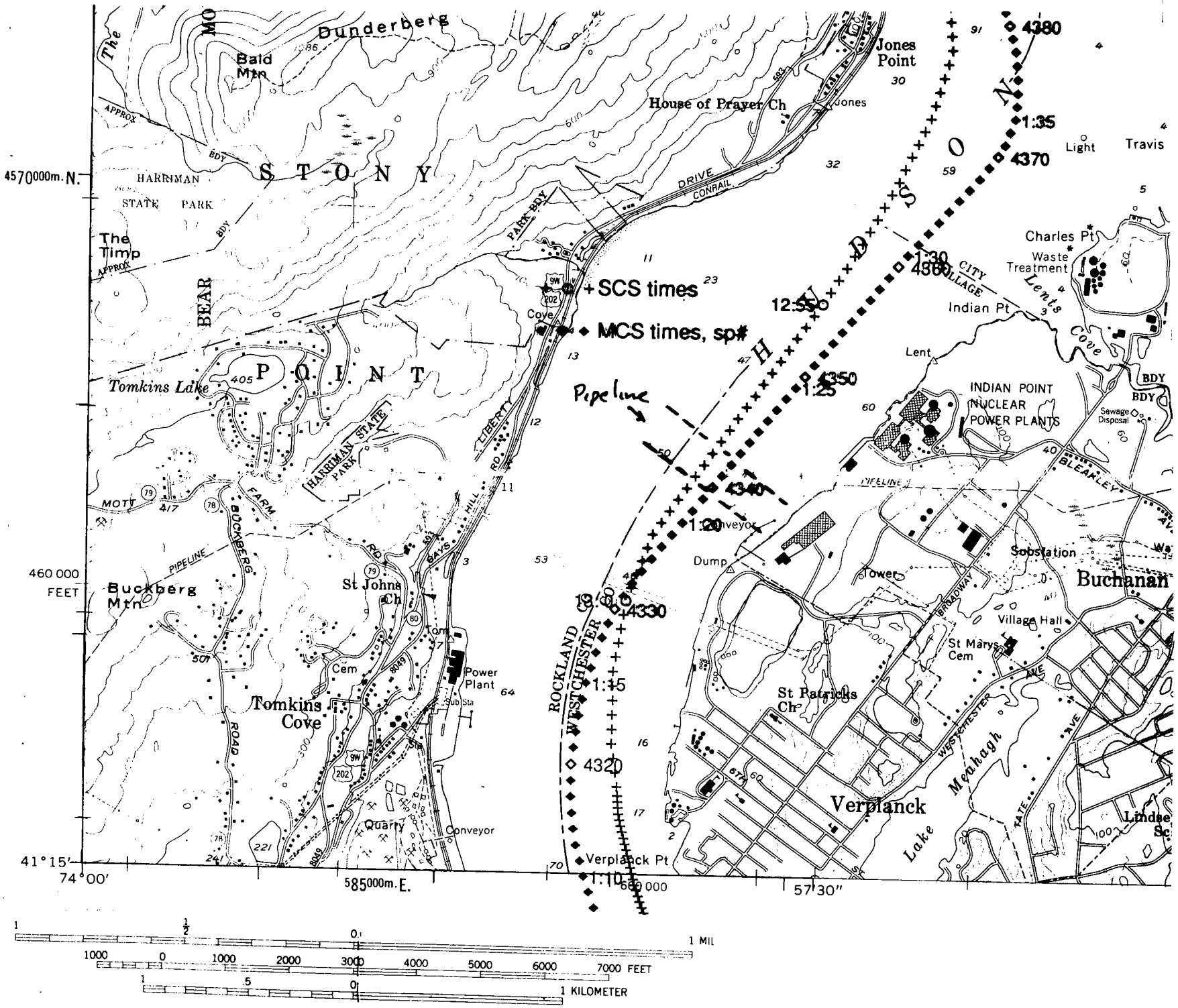

Shot 4357 offset, km
0.0
0.5
1.0
1.5
2.0
0.0
0.5
1.0
1.5
two-way time, sec
Gap, offset probably
caused by a fault

Apparent fault at MCS 847 Shotpoint 4341

In each successive shot gather, the "washed out" zone, apparently caused by poor seismic propagation through the fault zone, moves through the data. Since these first arrivals sample depths from 100 to 300 meters, whatever is causing the effect extends at least as deep.




CDP number
6900
6910
6920
6930
6940
6950
6960
6970
6980
6990
7000
7010
7020
7030
0
10
20
30
40
water depth, meters
4320
4330
4340
4350
4360
shotpoint #


+SCS times
◆ MCS times, sp#
Pipe line
4380
1:35
4370
1:30
4360
12:55
1:25
4350
4340
1:20
4330
1:15
4320
1:10
Jones Point
House of Prayer Ch
Jones
Light
Travis
Charles Pt
Waste Treatment
Indian Pt
Lent
Lents Cove
INDIAN POINT NUCLEAR POWER PLANTS
Sewage Disposal
Substation
Dump
Conveyor
Tower
Buchanan
Village Hall
St Marys Cem
St Patricks Ch
Verplanck
Lake Meahagh
Verplanck Pt
Dunderberg
Bald Mtn
The Timp
HARRIMAN STATE PARK
BEAR POINT
Tomkins Lake
Buckberg Mtn
St Johns Ch
Tomkins Cove
Power Plant
Sub Sta
Quarry
Cem
Tom
PIPELINE
CONRAIL
DRIVE
PARK BDY
BDY
APPROX
ROCKLAND
WESTCHESTER
4570000m. N.
460 000 FEET
41°15'
74°00'
585000m. E.
680 000
57'30"
1 MIL
7000 FEET
1 KILOMETER

crossings of the various sheets of the Taconic klippe which is intersected by the river between Catskill and Albany.

Assuming a simple model of a slow, homogeneous layer (the water and sediments) overlying a crustal layer with a strong velocity gradient, the traveltime of the earliest seismic arrival at the first trace in the seismic streamer is controlled primarily by the depth of the upper, "homogeneous" layer. This time was determined for each of the four hundred shot gathers used in the animation, and plotted here. The overthrusts are first encountered near CDP 11800, and continue until approximately the location of CDP 12675. The most outstanding feature in this plot is a depression extending from CDP 11860 to CDP 12040. This correlates with a large body of glacial till, which appears on the NY State geological map.

Minimum basement arrival time