Interpretation with the overlay program

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ABSTRACT

The Yilmaz/Cumro field profiles were culled for interesting examples of reflection seismology using the "Overlay" program reported in the previous SEP report.

INTRODUCTION

In SEP report 50 in a paper entitled "Hyperbola overlay program development: a personal engagement" I described a computer program that I had written for interactive normal moveout and overlay of hyperbolic and other templates on seismic data. That paper was an account of my experience computerizing the interactive overlays. This paper shows how the program was used to interpret field data—mostly the Yilmaz [1983] profiles. Many of the profiles have an attractive "textbook" quality. Many of the interpretations illustrate central features of reflection seismology. It gives me considerable pleasure to bring these results to you. The thirty-one figures constitute the body of this paper.

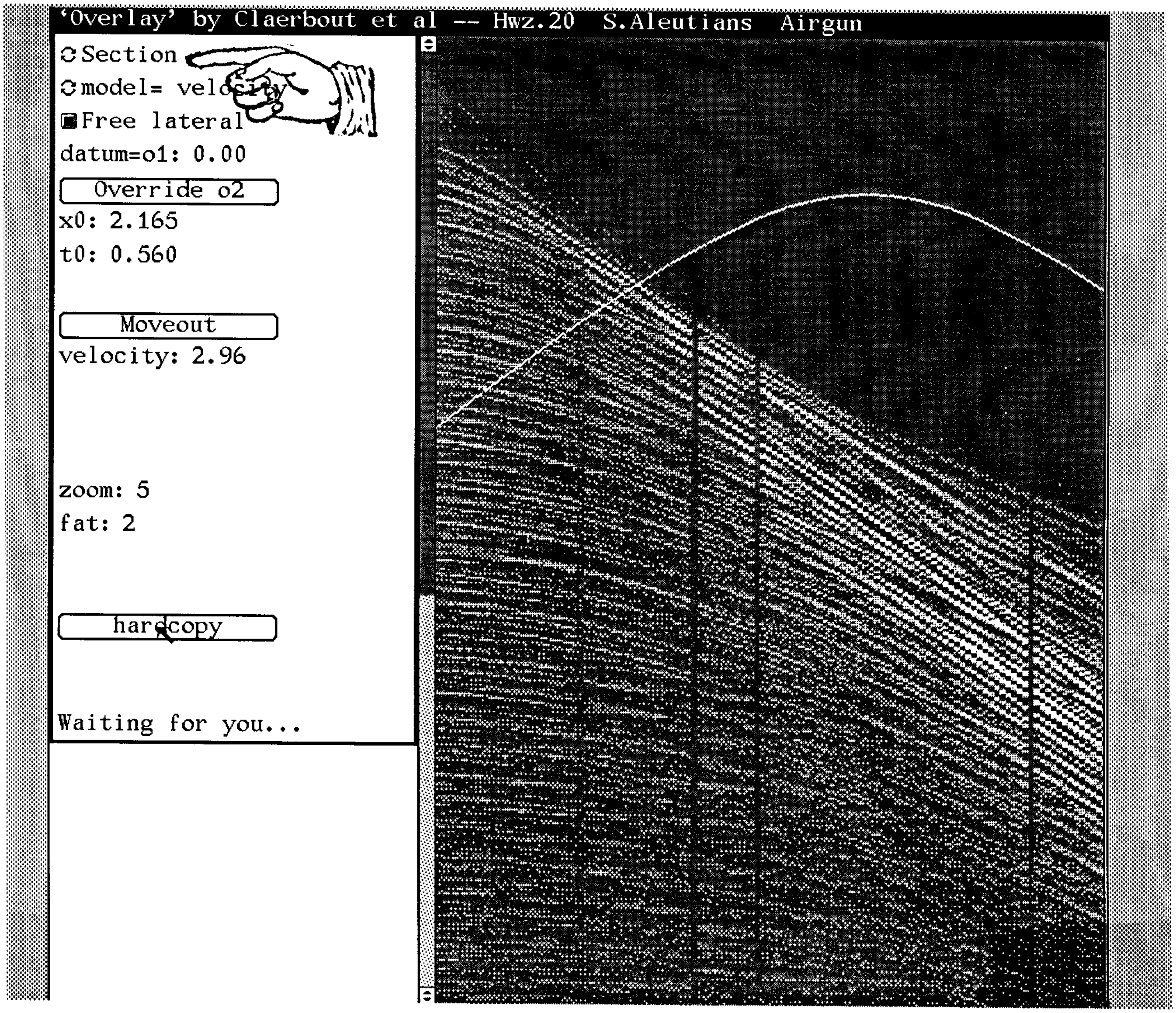
ACKNOWLEDGEMENT

I am grateful to Richard Ottolini and to Steve Cole without whose work I would have been unable to bring you these results in report form. Steve Cole developed various dithering algorithms (this report) and Rick Ottolini integrated them into an overall program for preparing the hardcopy from the variable brightness screen.

REFERENCES

Yilmaz, O., and Cumro, D., 1983, Worldwide Assortment of Field Seismic Records, released by Western Geophysical Company of America, Houston

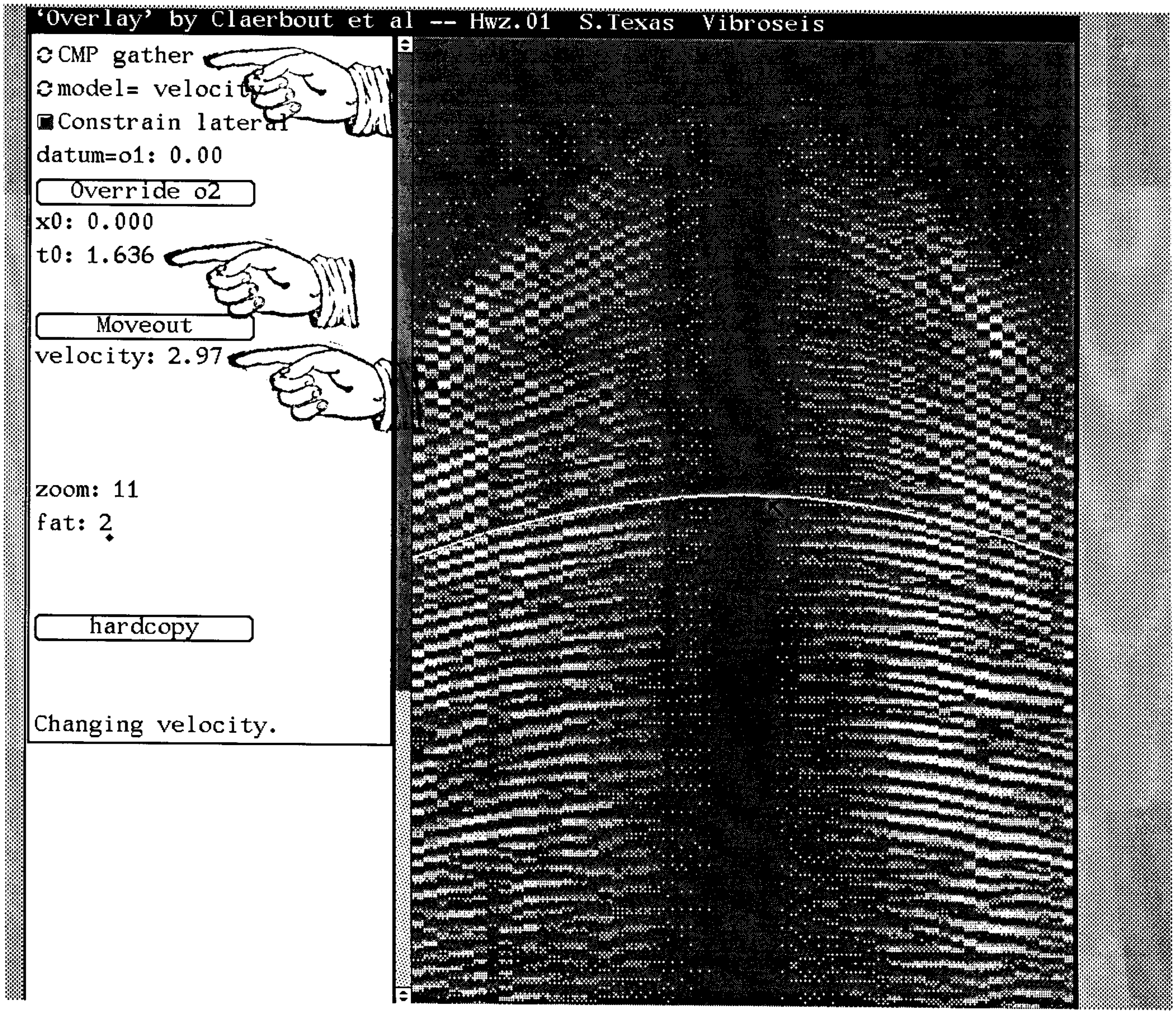
Claerbout, J., 1986, Hyperbola overlay program development: a personal engagement, SEP–50


'Overlay' by Claerbout et al -- Hwz.20 S.Aleutians Airgun

○ Section
○ model= velocity
■ Free lateral
datum=o1: 0.00
x0: 2.165
t0: 0.560
velocity: 2.96
zoom: 5
fat: 2

Waiting for you...

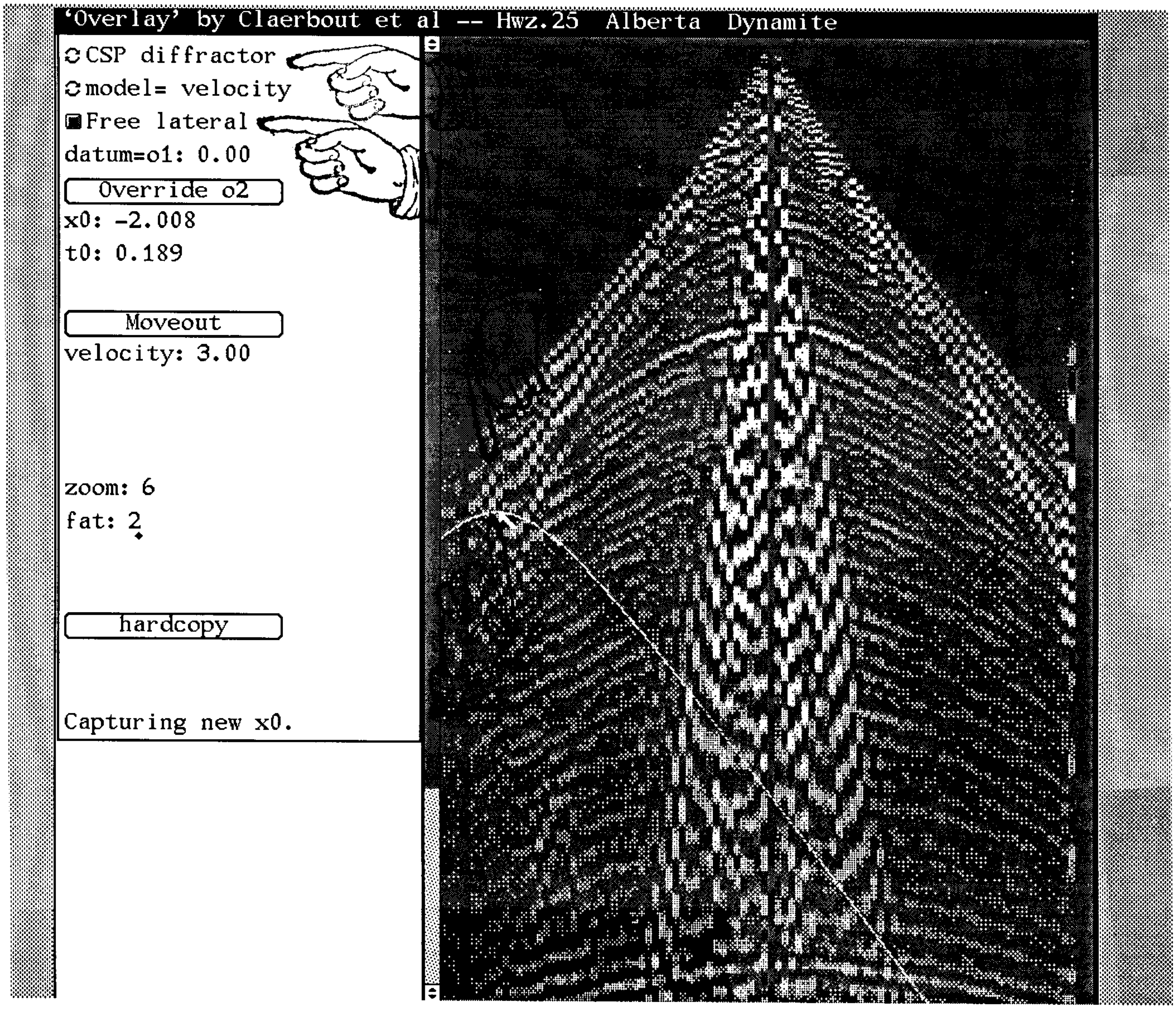
FIG. 1. The data set is a marine *profile* (common shot). The superposed hyperbolic overlay was designed for a seismic *section* (a hand points to a panel choice of "Section") so the hyperbolic overlay does not align with the data. Moving a "mouse" allows the operator to move the hyperbola and adjust its velocity. The overlay is white on the page but colored on the screen. The marine profile is "dithered" on the paper but much more clearly shown on the screen by variable intensity. All data sets in this study were gained by t^2 before display.



'Overlay' by Claerbout et al -- Hwz.01 S.Texas Vibroseis

○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 1.636
velocity: 2.97
zoom: 11
fat: 2
Changing velocity.

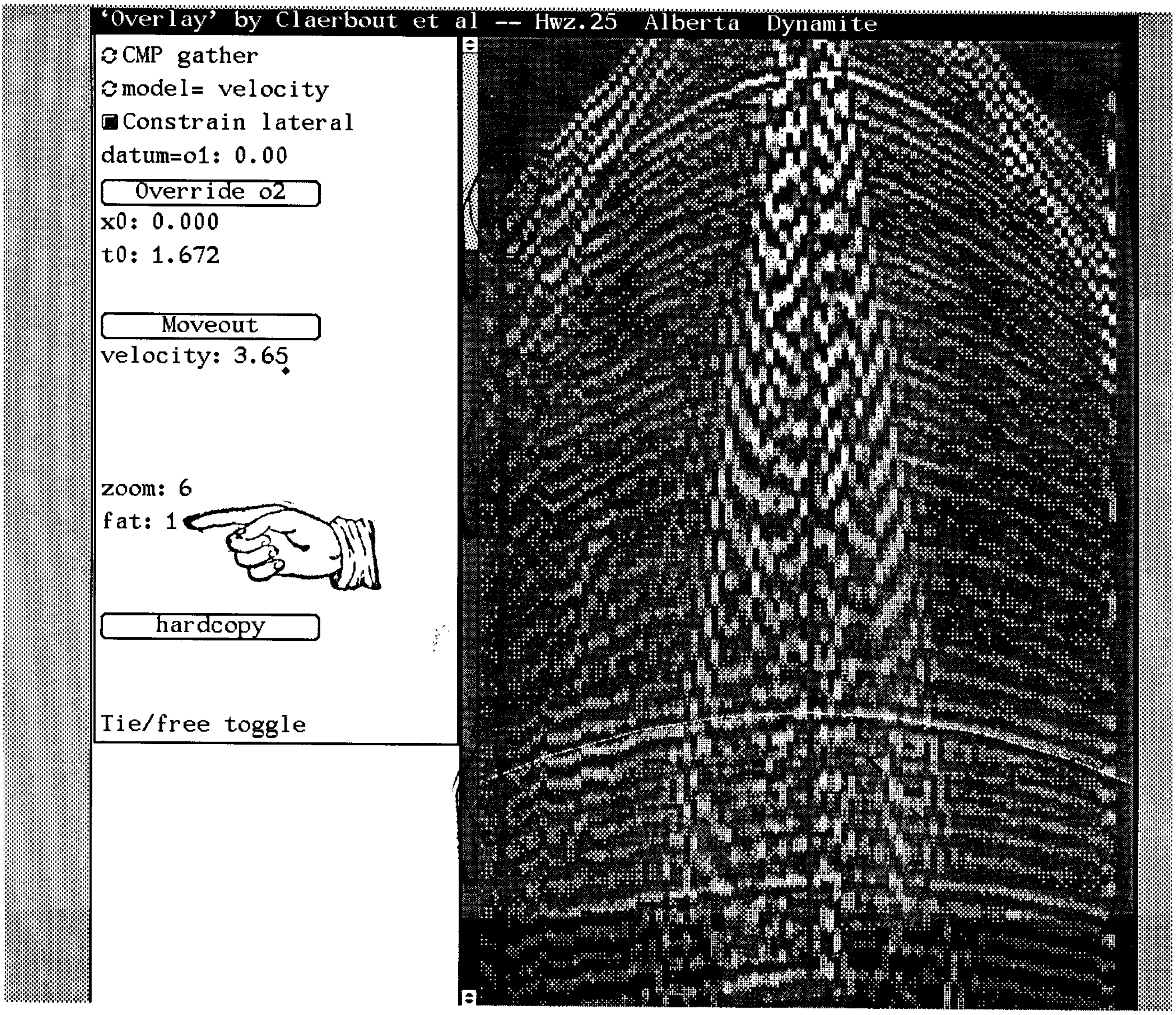
FIG. 2. A hyperbolic overlay designed for a common-midpoint (CMP) gather (see hand) overlies a split-spread land profile (common shot). The data is displayed without axes but you can read from the control panel the time of the hyperbola top (see hand) and the velocity of the hyperbola (see hand). Since the CMP hyperbola does a good job of matching the data, the earth dip must be small here.



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○CSP diffractor
○model= velocity
■Free lateral
datum=o1: 0.00
x0: -2.008
t0: 0.189
velocity: 3.00
zoom: 6
fat: 2
Capturing new x0.

FIG. 3. The black frame header bar at the top of the page identifies the data as "Hwz.25" which is our local designation for Yilmaz-Cumro field profile number 25. The overlay is a hyperbola with parameters for a near-surface diffractor on a Common Shot Profile (CSP) (see hand). The apex of the hyperbola is beneath a marked static disturbance, but no diffraction is apparent on the data itself. The depth of the hypothetical diffractor scales with the time difference between the hypothetical first arrival and the apex of the hyperbola. Notice the apex is sharp corresponding to a shallow depth interval (between hands). In this example the velocity 3.0 has been chosen so that the hypothetical first arrival is later than the actual arrival. A pushbutton "Free lateral" (see hand) will change the state to "Constrain lateral" in which subsequent overlays are constrained to pass through surface location x0= -2.008km.



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

↻ CMP gather

↻ model= velocity

■ Constrain lateral

datum=o1: 0.00

x0: 0.000

t0: 1.672

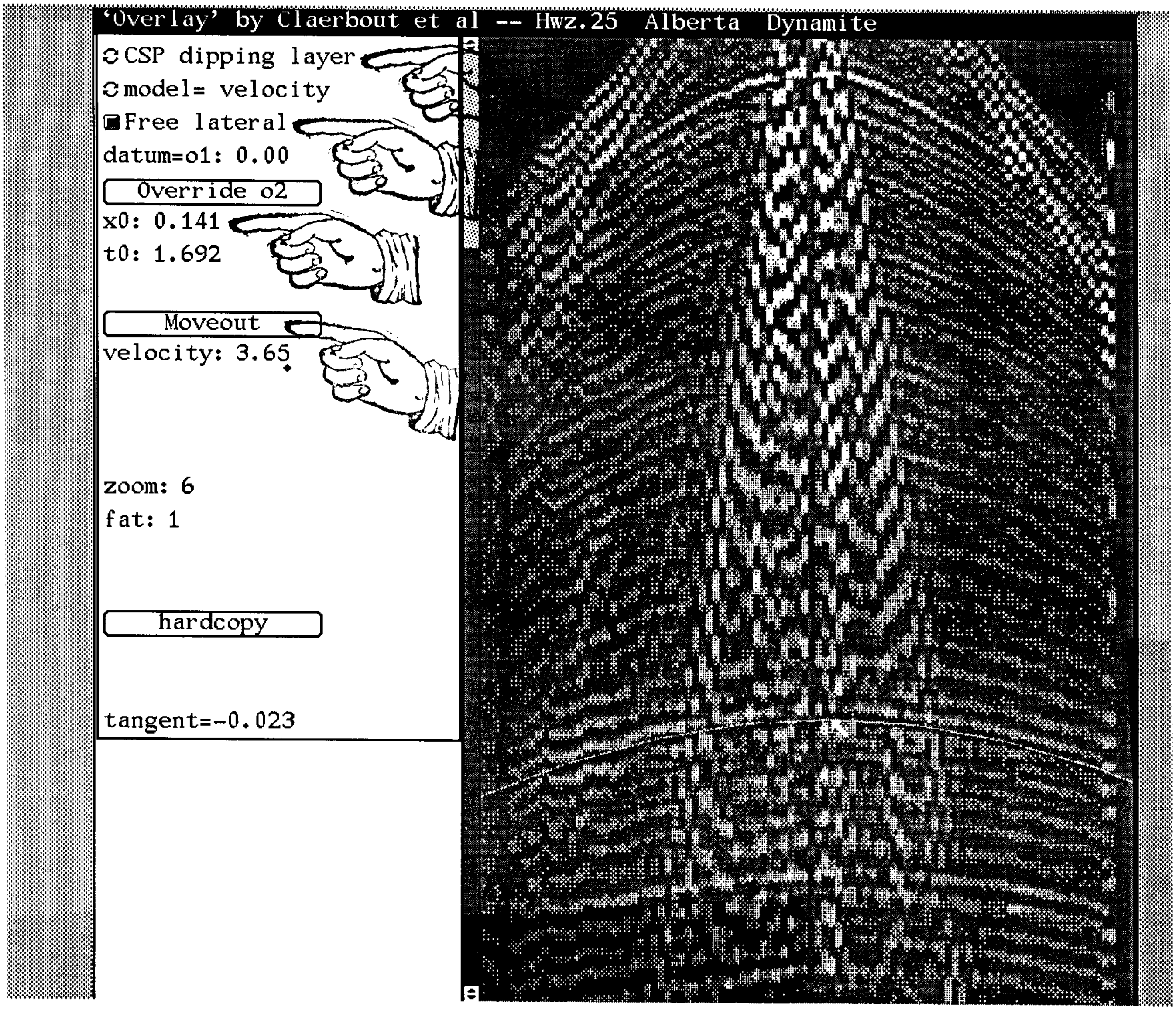
velocity: 3.65

zoom: 6

fat: 1

Tie/free toggle

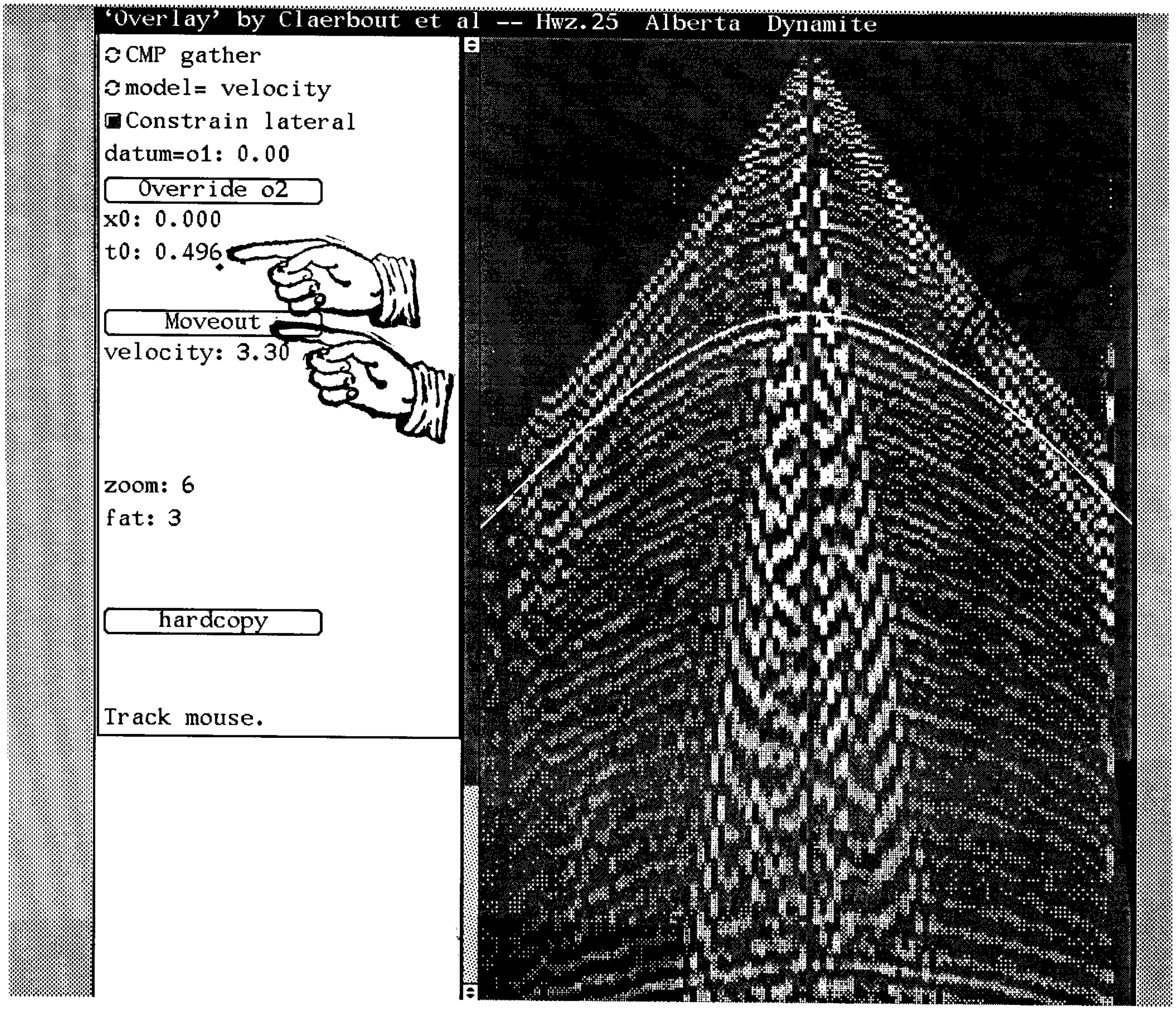
FIG. 4. The same profile has been scrolled downward (hands on vertical scrollbar) and a CMP hyperbola laid over a strong arrival. I forgot to thicken the hyperbola (hand pointing to "fat: 1") for visibility on the paper display. The hyperbola doesn't fit very well because a CMP hyperbola must go through zero offset but the earth evidently has a slight dip here.



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○CSP dipping layer
○model= velocity
■Free lateral
datum=o1: 0.00
x0: 0.141
t0: 1.692
velocity: 3.65
zoom: 6
fat: 1
tangent=-0.023

FIG. 5. The overlay has been changed to a dipping-layer (see hand) hyperbola. After the overlay has been positioned, various facts besides the velocity can be read from the panel. The earliest arrival is shifted 141 meters (see hand) from the shot. The apparent dip-angle tangent is -0.023 (see hand), that is, 23 meters altitude per kilometer. A pushbutton "Free lateral" (see hand) will change the state to "Constrain lateral" in which subsequent overlays are constrained to have apexes located at the same dip, i.e. moving the mouse will change t0 but keep x0/t0 constant.



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○ CMP gather

○ model= velocity

■ Constrain lateral

datum=o1: 0.00

x0: 0.000

t0: 0.496

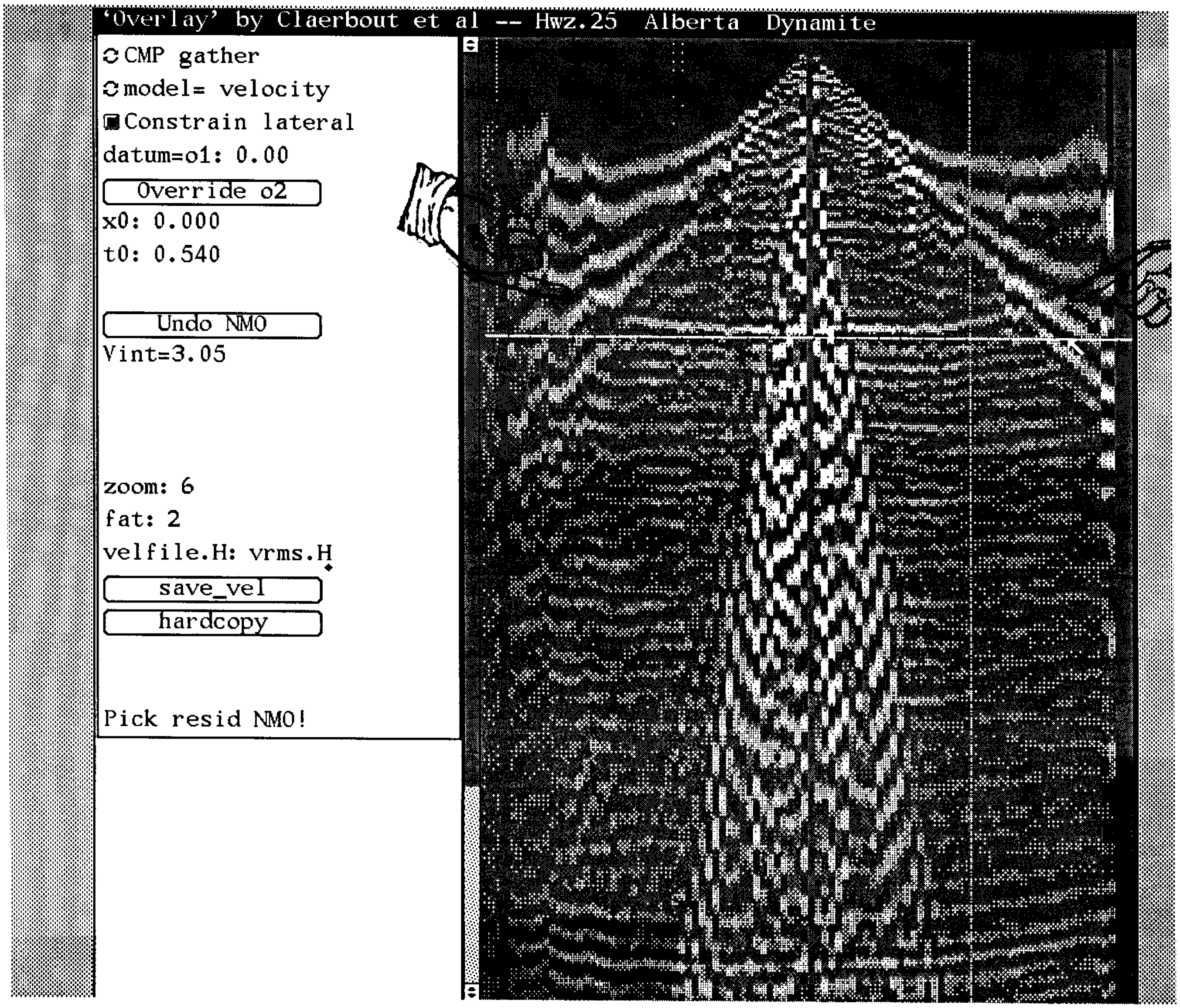
velocity: 3.30

zoom: 6

fat: 3

Track mouse.

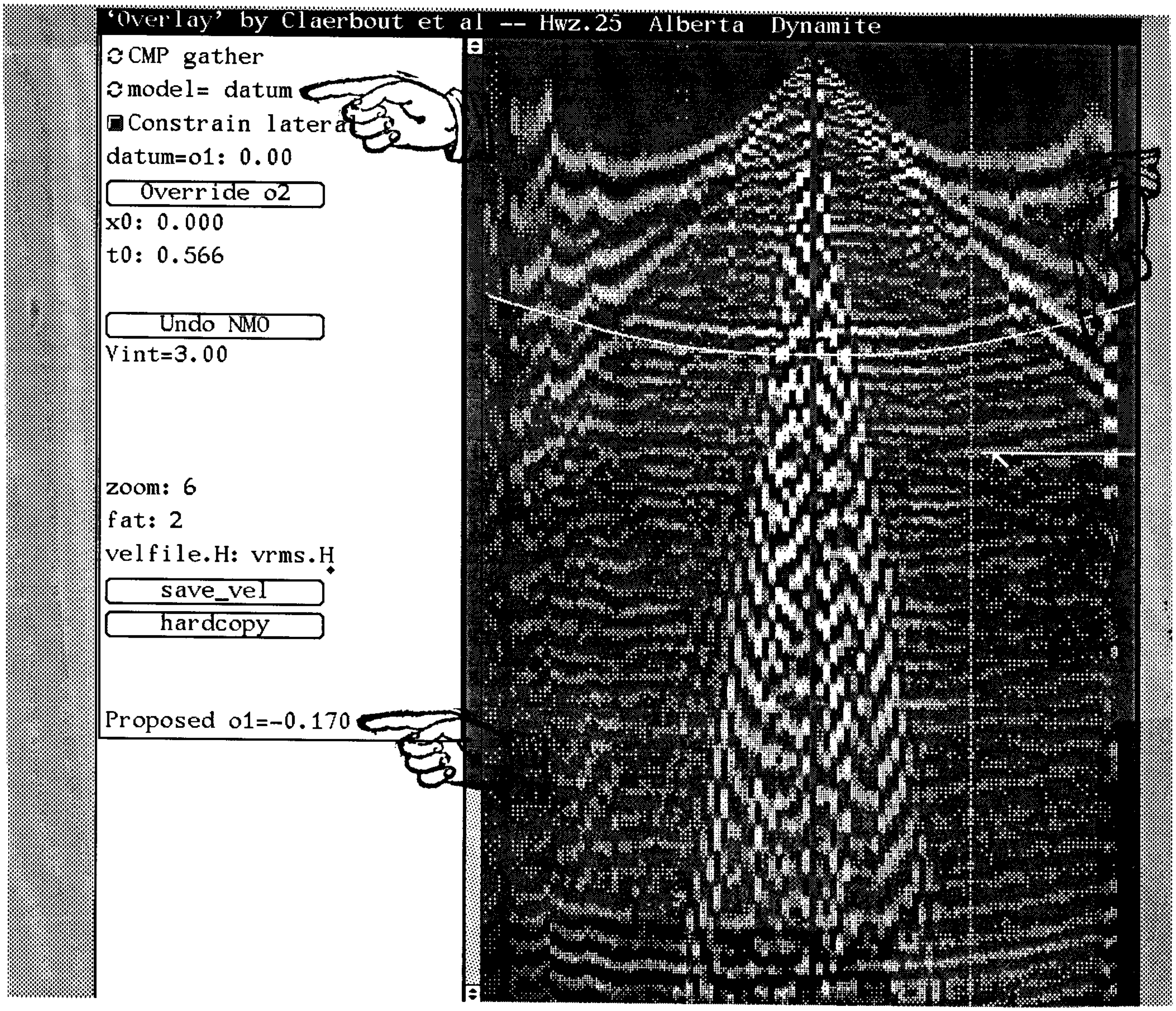
FIG. 6. A strong reflection is seen at about a half second (see hand) travel time. On the screen I use a slim colored hyperbola on the arrival itself, but on this page I placed a thick hyperbola just before it. The overlay does not match the data because the arrival is ***nonhyperbolic*** . This fact is more evident on the screen than on this page. Best confirmation here is around midrange (see hand) where the hyperbola is further above the arrival than at near and far offsets. To make the next display, I changed the velocity to 3.05 and pressed the "Moveout" button (see hand).



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.540
Vint=3.05
zoom: 6
fat: 2
velfile.H: vrms.H
Pick resid NMO!

FIG. 7. After normal moveout the departure of the overlay (now a horizontal line) from the event becomes more evident. The velocity 3.05 of the moveout was chosen to match near zero offset. At wide offsets the event is early (see hands). Since the data comes from Canada, perhaps this anomaly is properly called a "hockey stick."



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○ CMP gather

○ model= datum

■ Constrain latera

datum=o1: 0.00

x0: 0.000

t0: 0.566

Vint=3.00

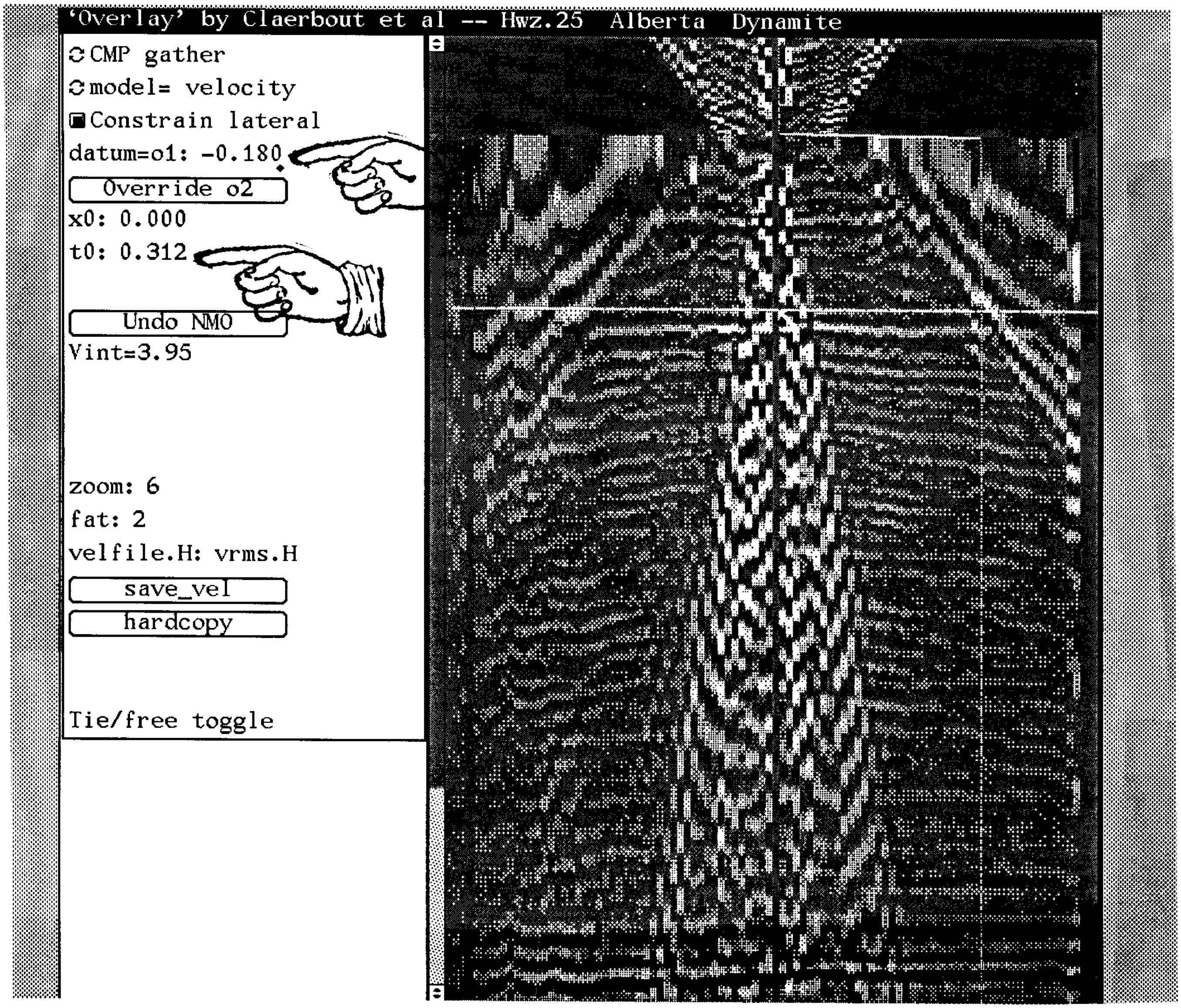
zoom: 6

fat: 2

velfile.H: vrms.H

Proposed o1=-0.170

FIG. 8. The overlay "model=datum" (hand on panel) allows changing the datum (time origin) by dragging the mouse. This overlay definition also readjusts the velocity at the same time the datum is changed to maintain constant curvature at zero offset. The overlay you see here after moveout has zero curvature at zero offset. Curvature at wider offset is the fourth order nonhyperbolicity of datum shift. The curve shown is one I selected having "Proposed o1= −.170s" (see hand) which is a proposed time for the first point on the seismogram. It means the first 170ms of the data may be discarded. Graphically this interval is the vertical separation between the overlay and a tiny white arrow and horizontal segment (see gap between hands).



'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○ CMP gather

○ model= velocity

☒ Constrain lateral

datum=o1: -0.180

x0: 0.000

t0: 0.312

Vint=3.95

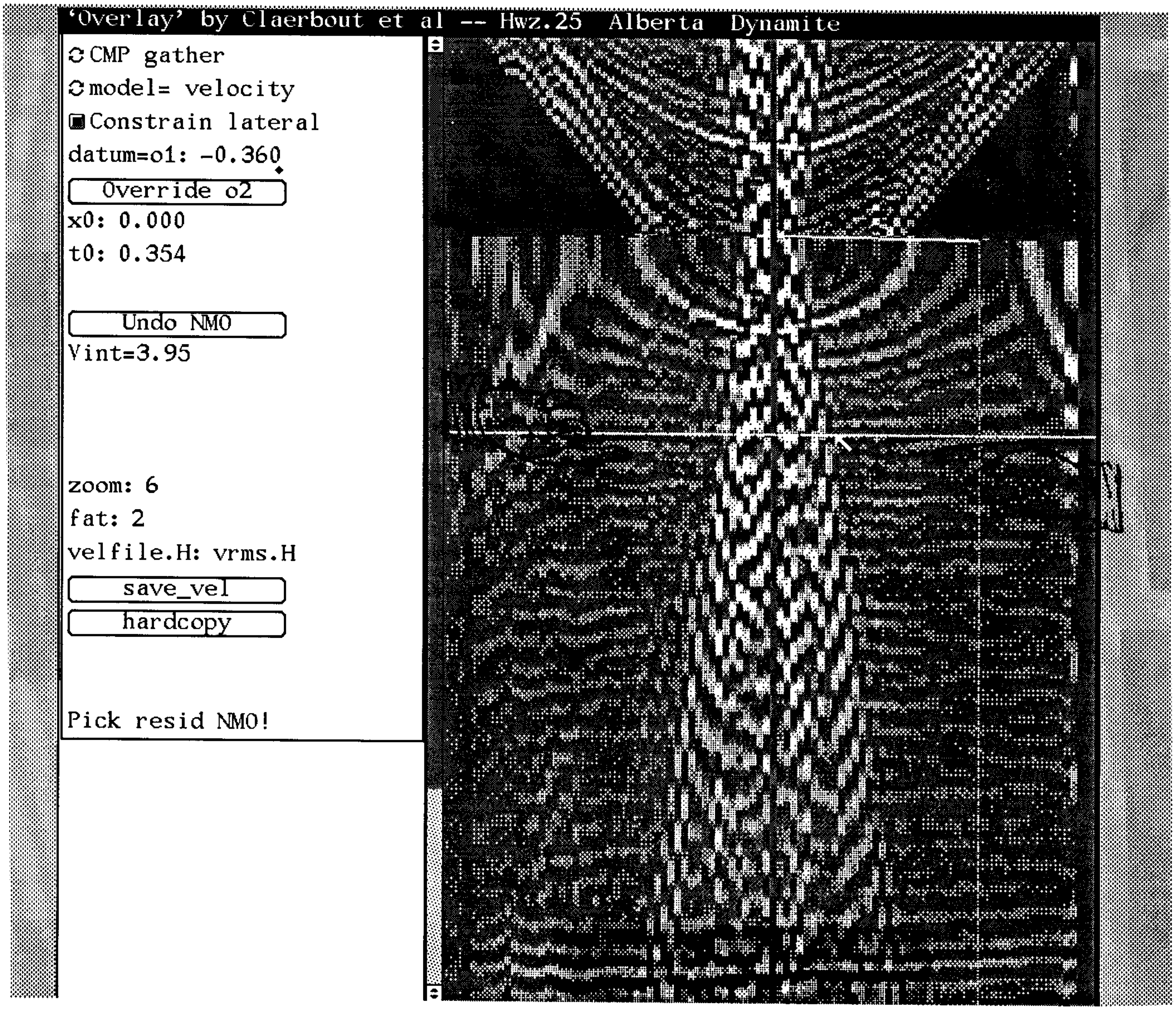
zoom: 6

fat: 2

velfile.H: vrms.H

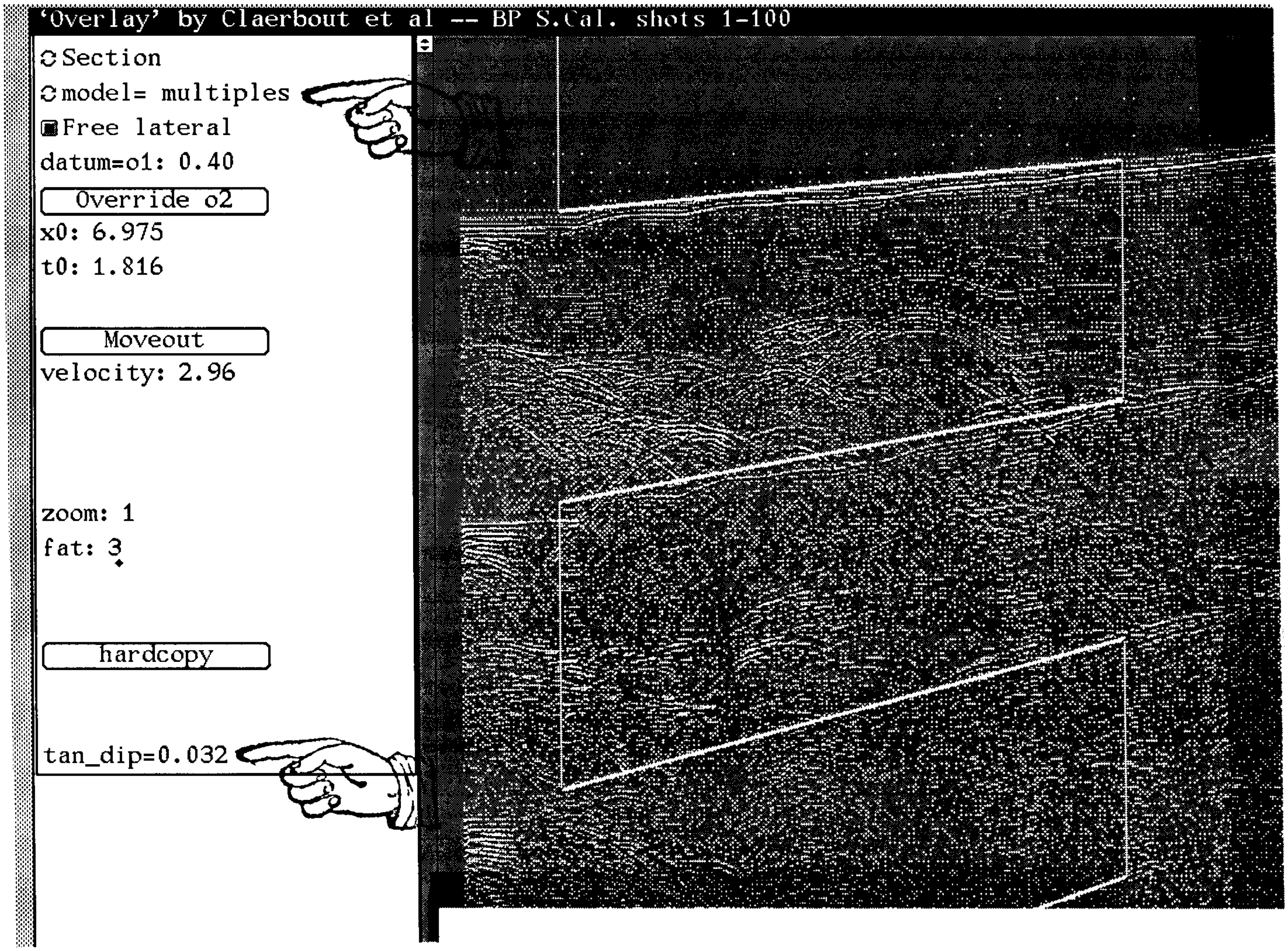
Tie/free toggle

FIG. 9. Entering (typing) the proposed value of datum into the control panel (see hand) invokes moveout with the new datum. Observe the top inch or so of the display is now meaningless. Perhaps the NMO program should be revised to put zeros here. The horizontal overlay is positioned at the onset of a strong arrival. It is the same event as before but observe that t0 (see hand) is now earlier. Although the overlay equations are exact, I readjusted the datum value to −180ms based on the revised display. The arrival has been substantially flattened, but a laterally variable residual remains, probably statics. Curiously, the deepest arrival shown is now flattened too, so with the new datum, one constant velocity flattens both the shallow and the deep events. Greater values of datum would imply an unlikely velocity model (decreasing with depth) to flatten both shallow and deep events. Events 100-300ms below the overlay are frowning (later at wide offset). This implies a lower velocity, evidently they are surface peglegs in shallow layers.


'Overlay' by Claerbout et al -- Hwz.25 Alberta Dynamite

○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: -0.360
x0: 0.000
t0: 0.354
Vint=3.95
zoom: 6
fat: 2
velfile.H: vrms.H
Pick resid NMO!

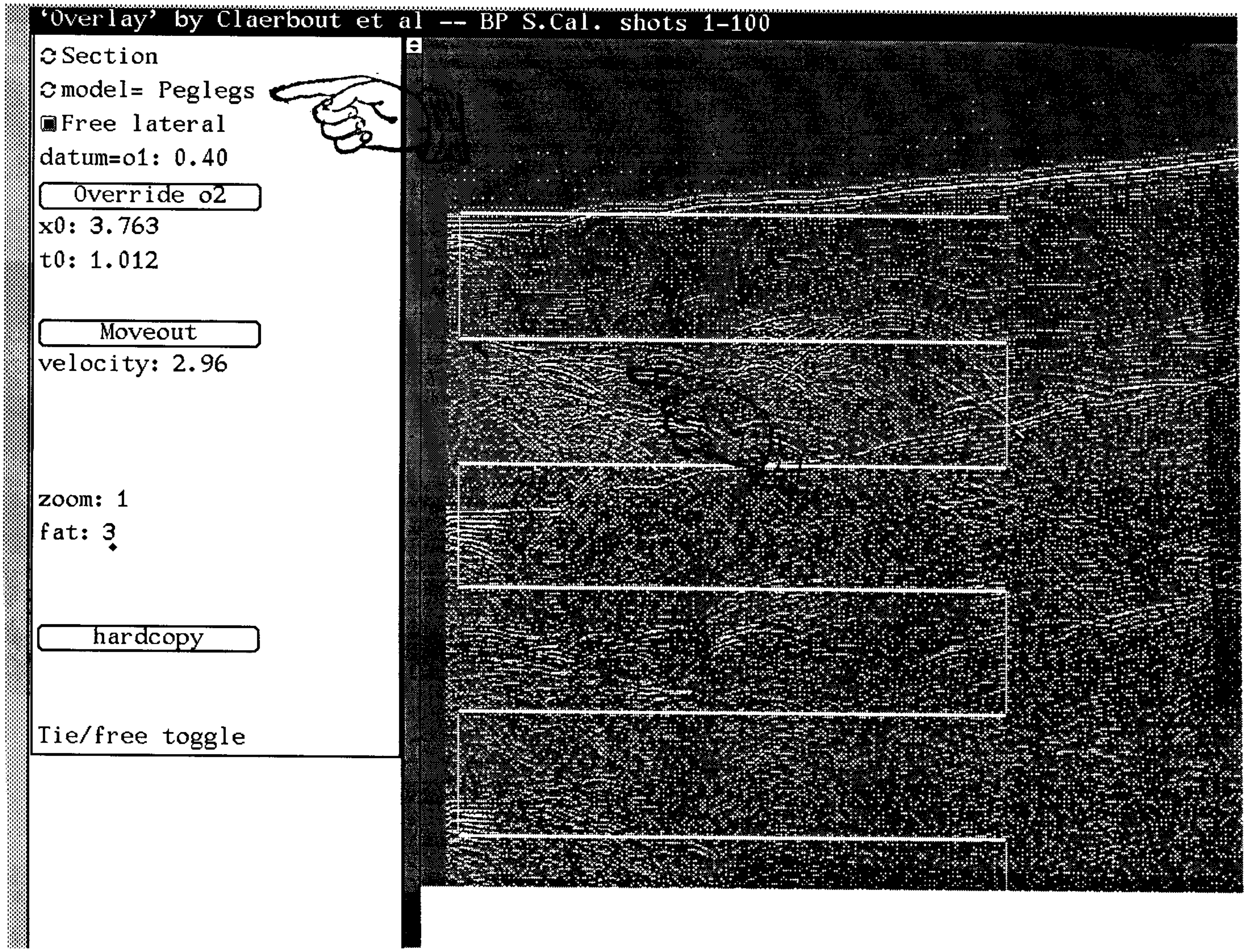
FIG. 10. To test the idea that the frowning events on the previous figure were peglegs in the weathered layer, I doubled the datum to 360ms. Observe the meaningless zone at the top of the profile is now twice as wide. Events that were frowning on the previous figure, now lie flattened under the overlay confirming the idea. Doubling the datum hypothesizes zero velocity in the weathered layers. But the idea that the surface peglegs come from the base of the weathered layer as marine peglegs come from the sea bottom is not confirmed by the timing of the events themselves. The weathered layer is more complicated than the hypothetical "zero velocity water layer."



'Overlay' by Claerbout et al -- BP S.Cal. shots 1-100

○Section
○model= multiples
■Free lateral
datum=o1: 0.40
x0: 6.975
t0: 1.816
velocity: 2.96
zoom: 1
fat: 3
tan_dip=0.032

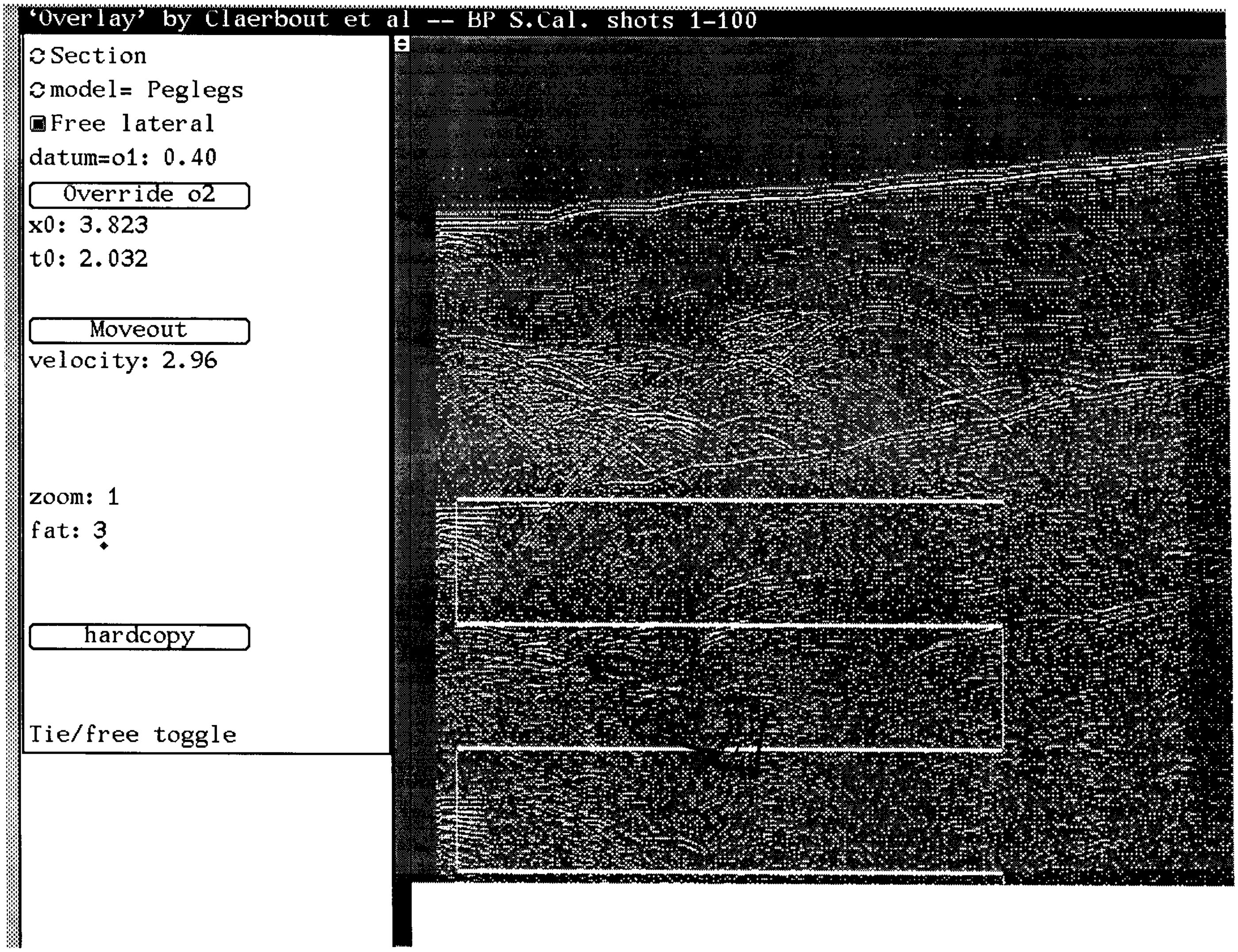
FIG. 11. A zero-offset section from British Petroleum being studied by Paul Fowler demonstrates an overlay for simple multiples. The program operator uses the mouse to adjust the location of a ladder-like overlay. Dragging the mouse stretches or shrinks the ladder and squeezes it laterally for the dipping seafloor. The dip of the primary may be read (see hand) from the control panel. It is 30 meters altitude per kilometer of traverse. (For me that is about second gear on a five speed bicycle.)



'Overlay' by Claerbout et al -- BP S.Cal. shots 1-100

○ Section
○ model= Peglegs
■ Free lateral
datum=o1: 0.40
x0: 3.763
t0: 1.012
velocity: 2.96
zoom: 1
fat: 3
Tie/free toggle

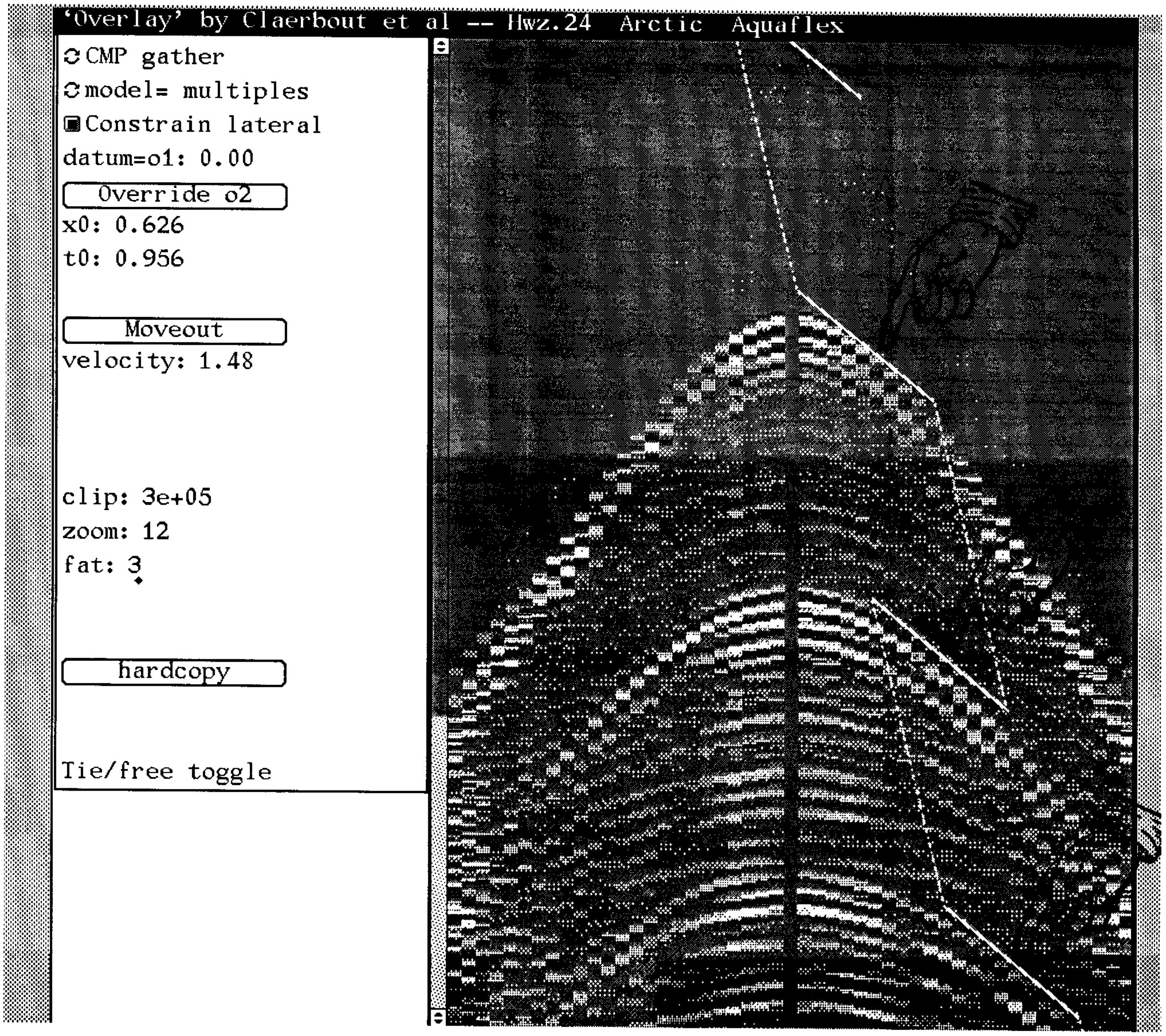
FIG. 12. I moved an overlay for water layer peglegs (see hand) to the ocean floor and then I stretched its top step down to a jumble of hyperbolic events. Previously I found these hyperbolics to have a slightly higher velocity than water, thereby casting doubt on the idea that they might be water layer sidescatter. If they are primaries they may have visible water-bottom peglegs.



'Overlay' by Claerbout et al -- BP S.Cal. shots 1-100

↻ Section
↻ model= Peglegs
■ Free lateral
datum=o1: 0.40
x0: 3.823
t0: 2.032
velocity: 2.96
zoom: 1
fat: 3
Tie/free toggle

FIG. 13. I moved the pegleg overlay down and the bottom of its top step (see hand) confirms the presence and timing of hyperbolic peglegs.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

CMP gather

model= multiples

■ Constrain lateral

datum=o1: 0.00

x0: 0.626

t0: 0.956

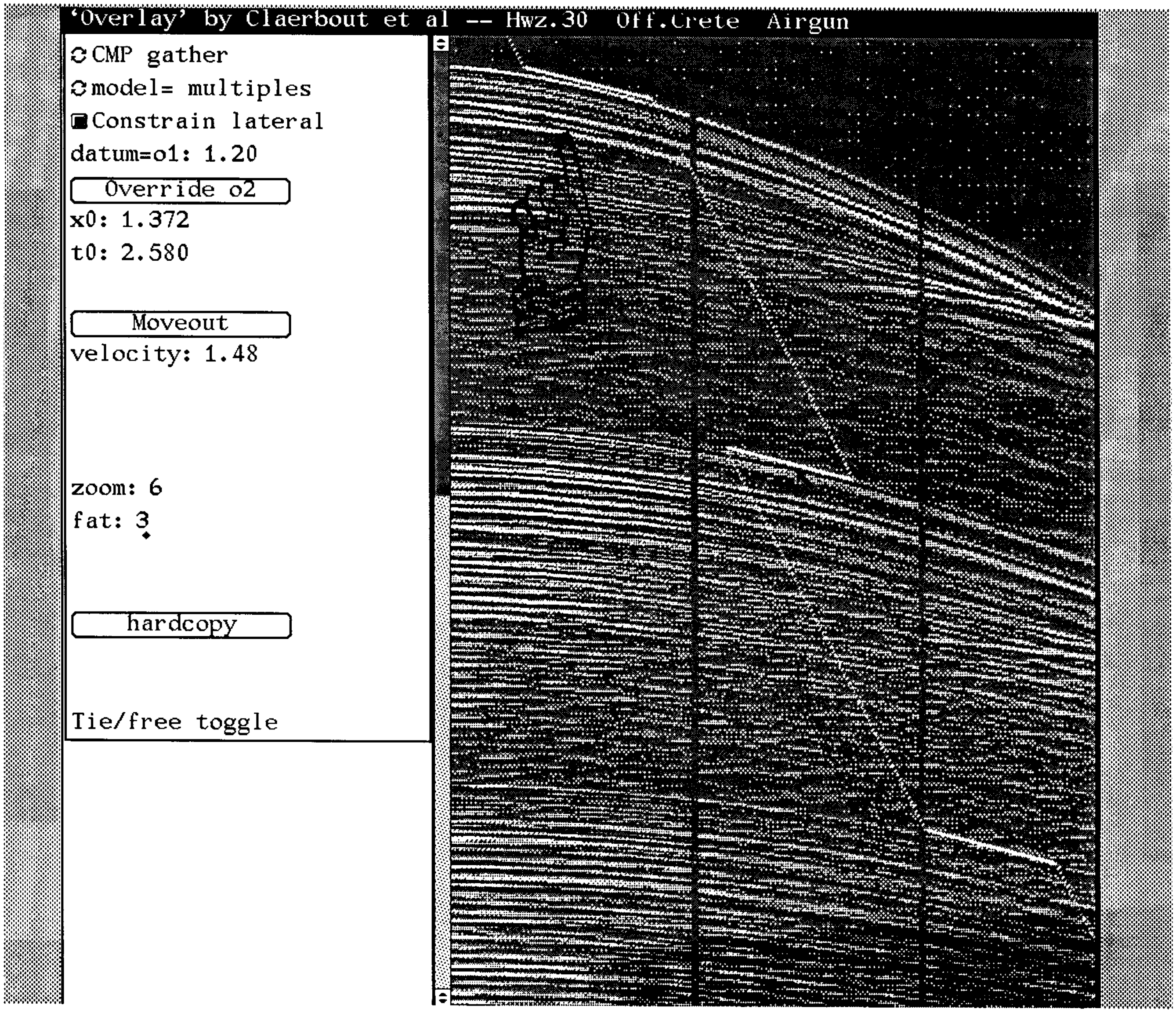
velocity: 1.48

clip: 3e+05

zoom: 12

fat: 3

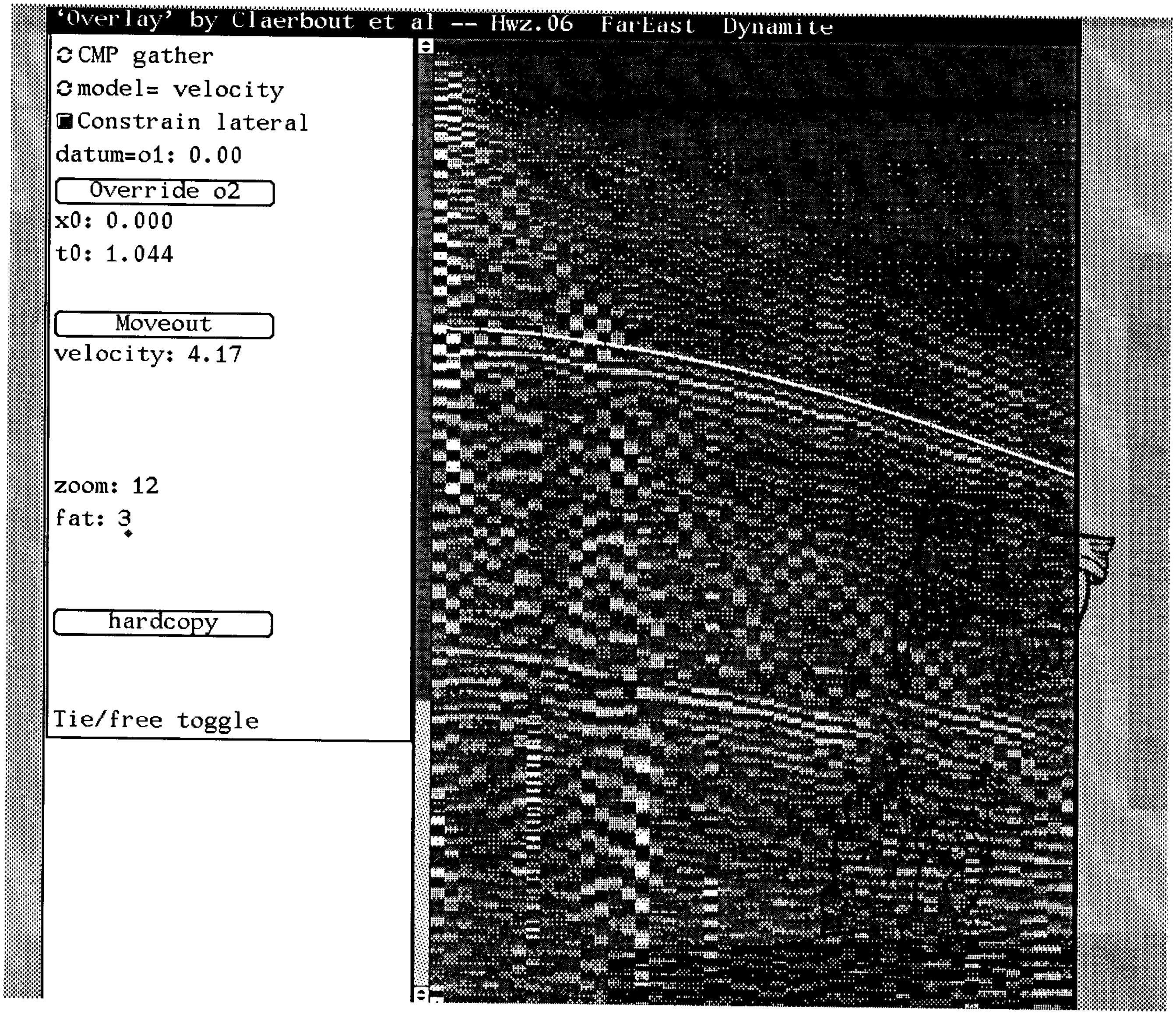
FIG. 14. A multiple reflection overlay designed for a common midpoint gather was laid on a field profile (common shot). Three short line segments (see hands) are parallel and uniformly separated. Their midpoints are also uniformly separated. Their slopes are determined by the equation $v^2 = (x/t)dx/dt$ which is the differential form of a hyperbola. The velocity is water velocity. Moving the mouse left and right causes the overlay to "swing" left and right changing its shape to track the multiples. Here is a question for you: Is this data land or marine? The multiples appear to be water bottom multiples, but who ever heard of a ship pushing a recording cable in front of it?



'Overlay' by Claerbout et al -- Hwz.30 Off.Crete Airgun

○CMP gather
○model= multiples
■Constrain lateral
datum=o1: 1.20
x0: 1.372
t0: 2.580
velocity: 1.48
zoom: 6
fat: 3
Tie/free toggle

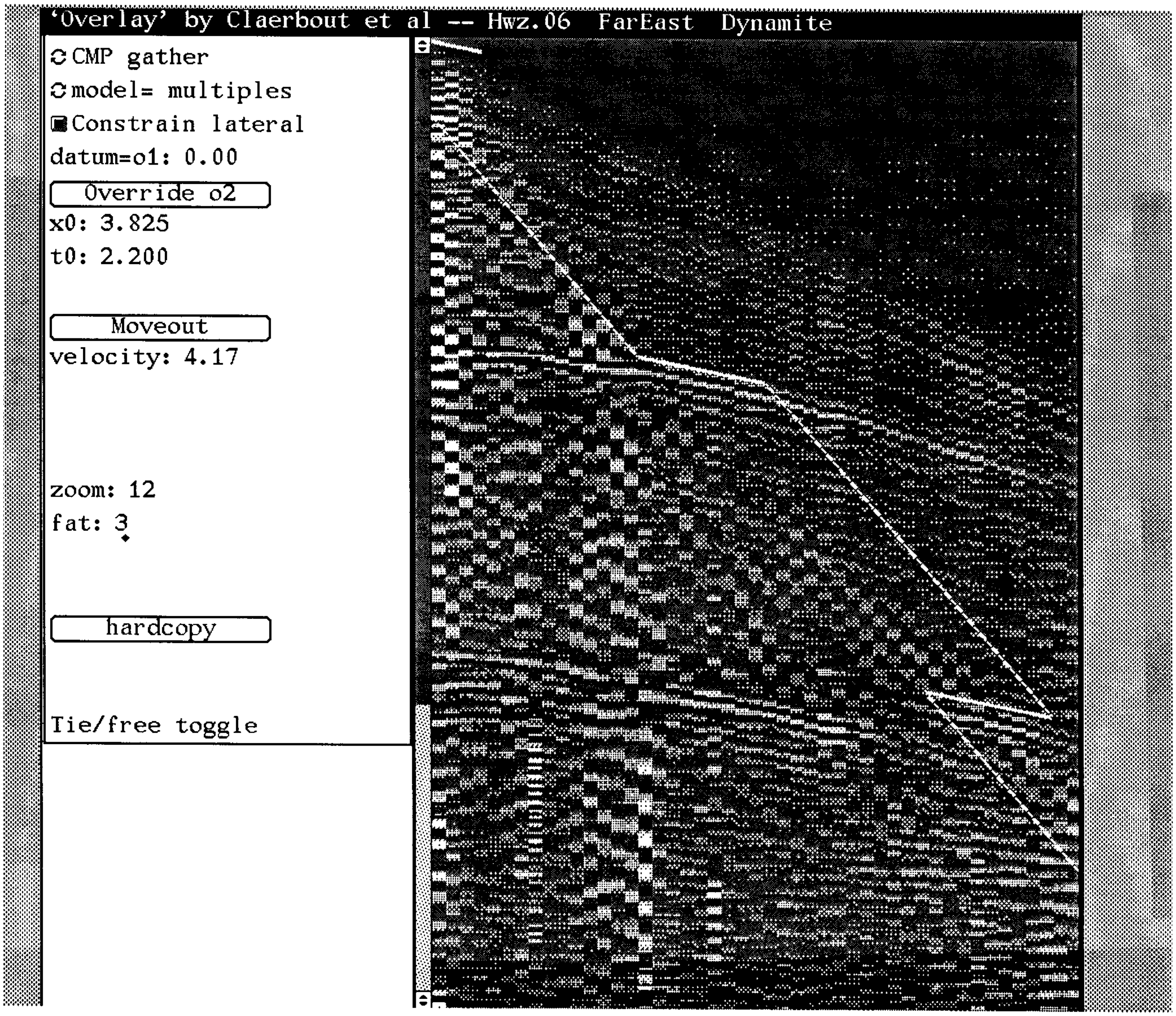
FIG. 15. This is the same multiple reflection overlay on a different profile. The alternating polarity of the multiples is clear (as it was on the previous figure). There is a mud layer whose base (see hand) becomes relatively stronger with each order of sea floor reflection. This illustrates that simple multiple strengths c^n are weaker than pegleg strengths nc^n where n is the order and c is the sea floor reflector strength. (I'll remind you that the data was gained by t^2 and I'll add that amplitudes were compressed slightly by raising to the .7 power.)



'Overlay' by Claerbout et al -- Hwz.06 FarEast Dynamite

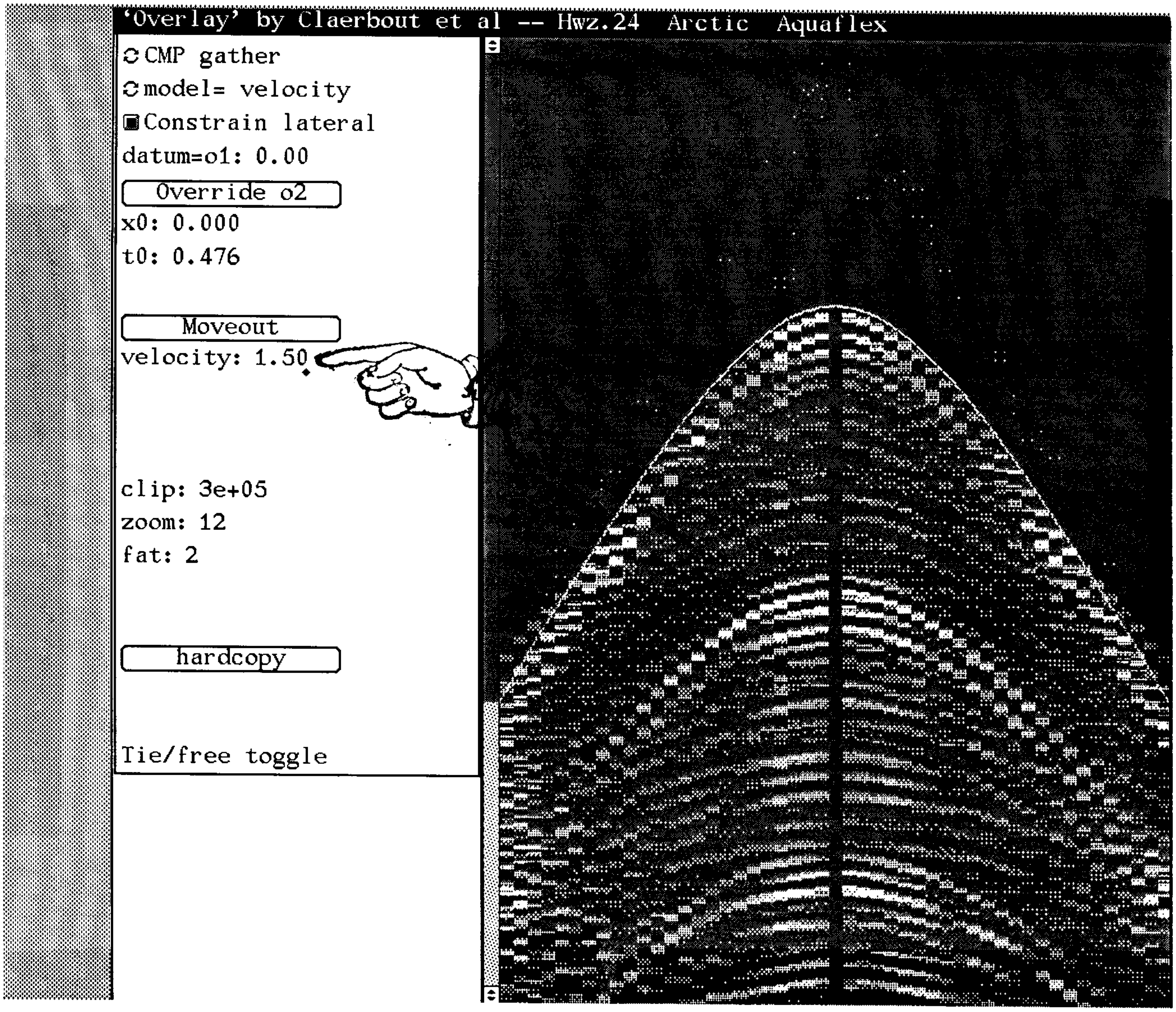
○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 1.044
velocity: 4.17
zoom: 12
fat: 3

FIG. 16. On this profile we see a strong event at about 1s with a velocity of about 4.17km/s. Further down the time axis about 2s we see another event, this one broken by a fault (with fault throw shown by the gap between the hands). Experimentation with hyperbolic overlays (not shown) on the 2s event leads to puzzlement about velocity. How do you interpret this event?



○ CMP gather
○ model= multiples
■ Constrain lateral
datum=o1: 0.00
x0: 3.825
t0: 2.200
velocity: 4.17
zoom: 12
fat: 3

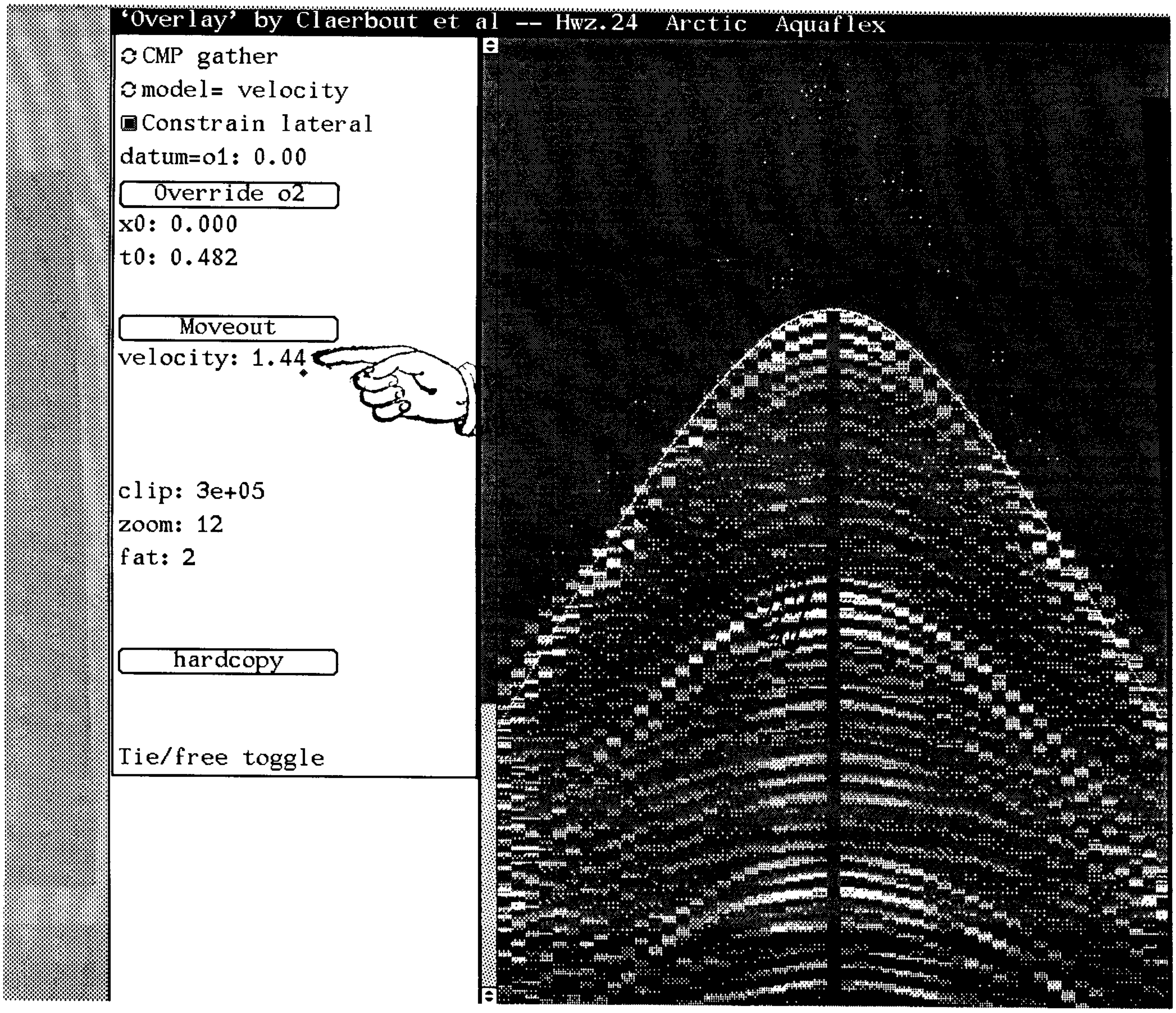
FIG. 17. Trying the multiple overlay leaves no doubt that the 2s event is a multiple reflection. But what about the "fault" on the multiple that does not appear on the primary? On the primary, the "fault" corresponds to a slight depression, evidently enough to cause focusing. I have been looking at migrations and diffractions for many years now, but I cannot explain the detailed shape of the primary and the multiple as a two dimensional scalar wave phenomenon. Another strange thing is a kind of bifurcation with offset of both the primary and the multiple. Is it anisotropy? Or is it just an unconformity?



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

datum=o1: 0.00
x0: 0.000
t0: 0.476
velocity: 1.50
clip: 3e+05
zoom: 12
fat: 2

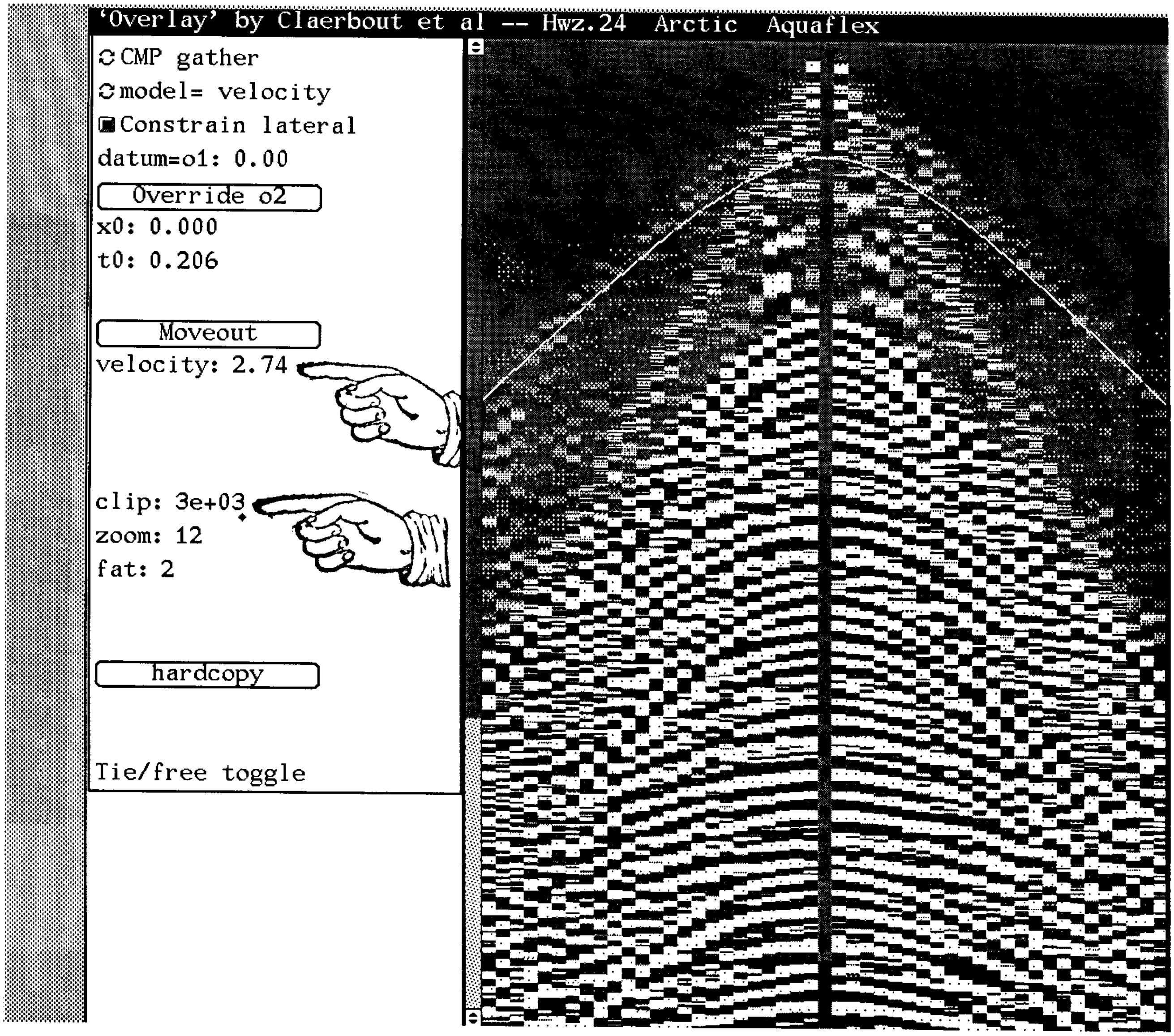
FIG. 18. A hyperbola overlain on a water bottom reflection. How accurately can we measure the water velocity? For best accuracy we should go to a wide offset but stay away from the head waves on the furthest several traces. For an ***upper bound*** on velocity we lay the hyperbola on the "outside" edge of the traces. The panel (see hand) shows a velocity of 1.5 km/s.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.482
velocity: 1.44
clip: 3e+05
zoom: 12
fat: 2
Tie/free toggle

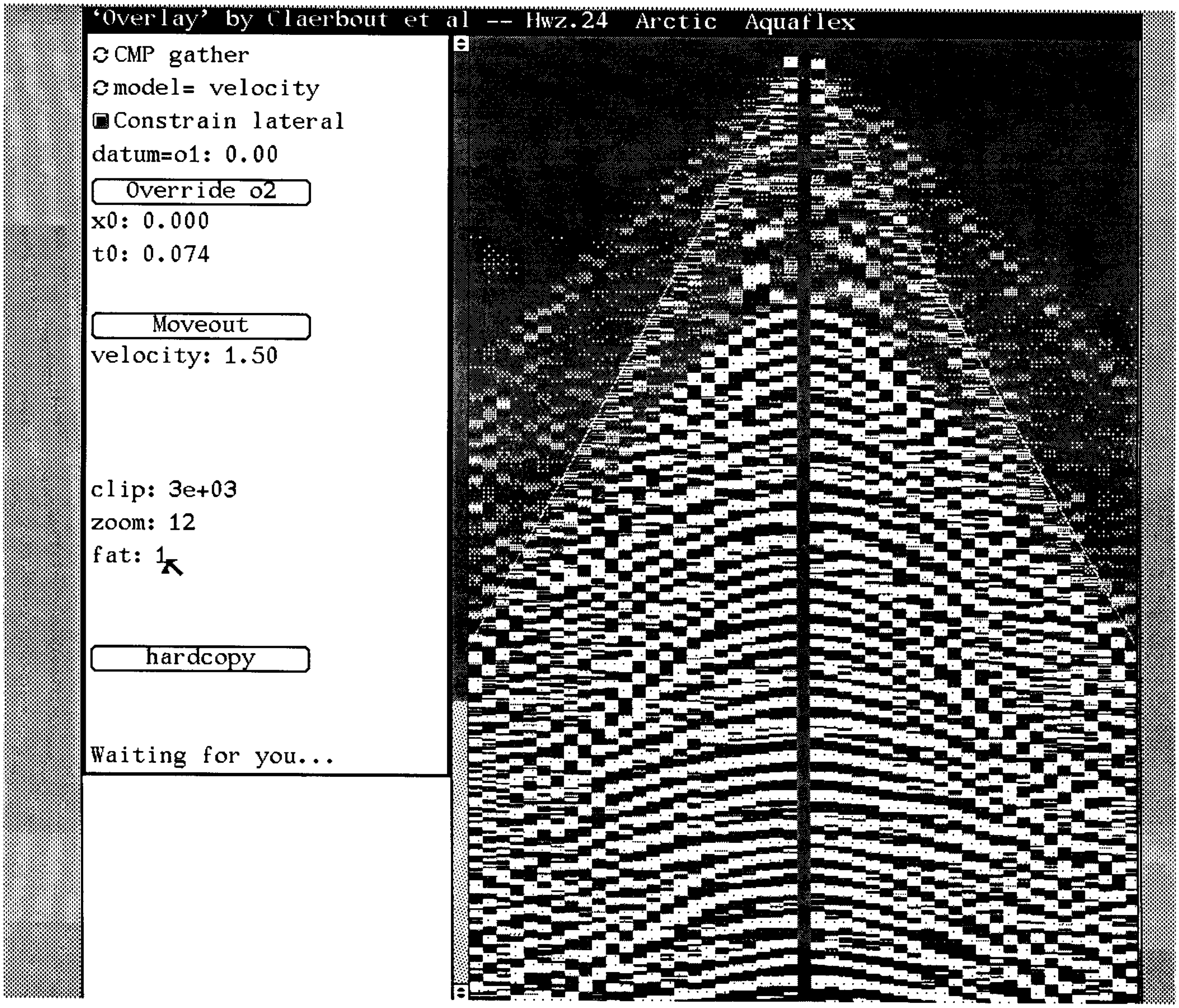
FIG. 19. For a *lower bound* on the velocity we lay the hyperbola on the "inside" edge of the traces. The panel (see hand) shows a velocity of 1.44 km/s. I have considerable confidence in a water velocity of 1.47-1.48s. With other experimental arrangements the speed of sound in water can be measured much more accurately. But the velocity of deeper sedimentary events can hardly be measured more accurately than by these manual methods. The accuracy of our water velocity measurement, one part in 150, is hardly ever attained by reflections from deeper layers. (Head waves are another matter). Why are the "speckles" in the water layer organized radially from the shot?



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
☒ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.206
velocity: 2.74
clip: 3e+03
zoom: 12
fat: 2
Tie/free toggle

FIG. 20. To see events in the water layer better we edit the clip (see hand) on the control panel to intensify the signal by a factor of a hundred compared to the previous figure. We change the clip from 3×10^5 to 3×10^3. Many arrivals are evident in the water layer. This is the profile (Hwz.24) seen earlier where the question arose how marine data could be recorded split spread. Now we see a direct wave with a velocity of 2.74 km/s (see hand) adding further question to how it can be marine data. The paradox is resolved by noticing the word "Arctic" in the black frame header bar. It must be data recorded on ice over deep water. If you are inclined towards interpretation, you might guess that the bottom of the ice layer is 20ms or so above the overlay.

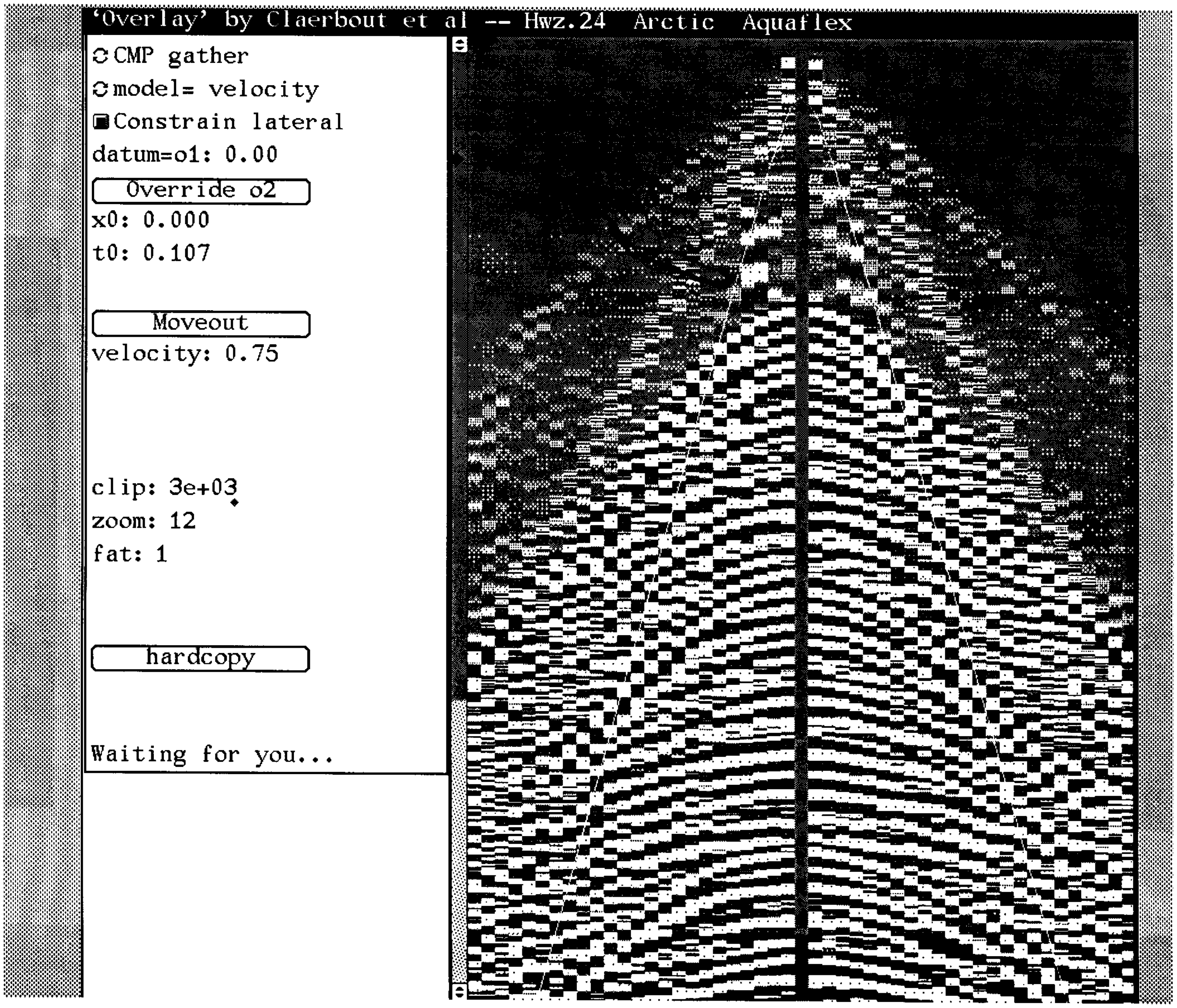


'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
■ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.074
velocity: 1.50
clip: 3e+03
zoom: 12
fat: 1

Waiting for you...

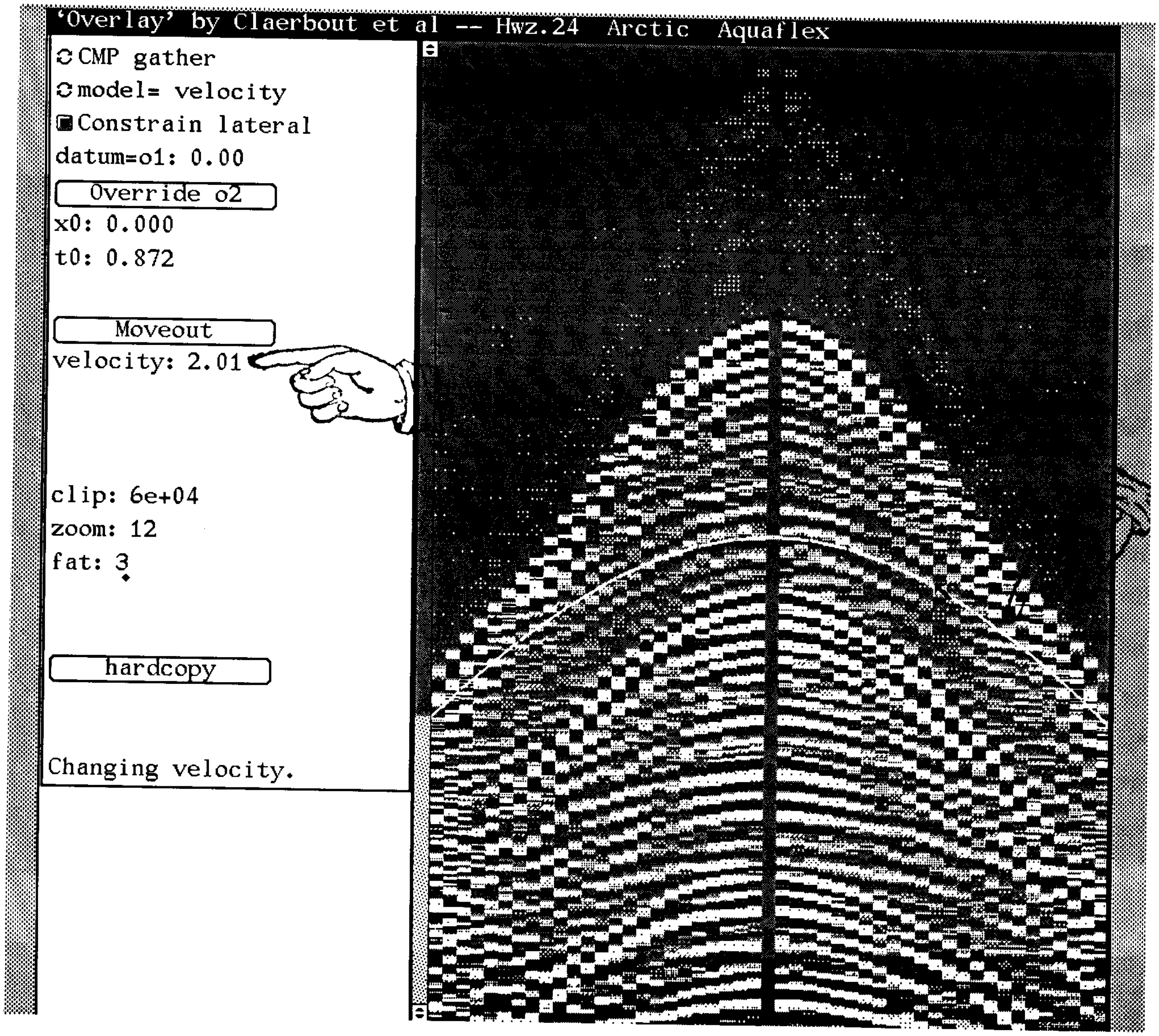
FIG. 21. Changing the hyperbola velocity to water velocity marks an uncharacteristic water wave. It is the highest frequency on the whole profile, as we expect. But the water wave is strangely incoherent from trace to trace. This incoherence probably results from the irregularity of the bottom of the ice pack.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
☑ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.107
velocity: 0.75
clip: 3e+03
zoom: 12
fat: 1
Waiting for you...

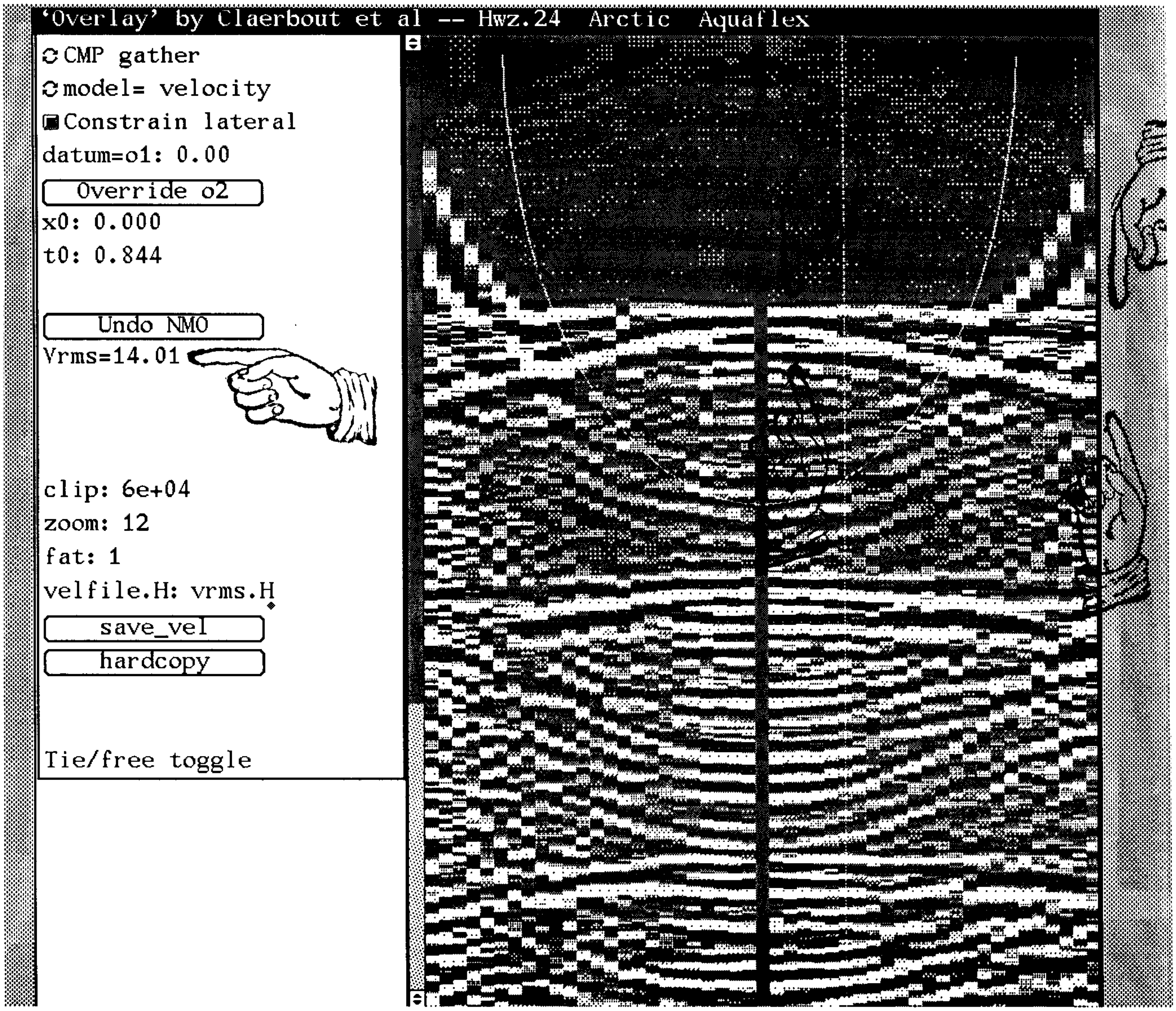
FIG. 22. In sedimentary rocks the shear wave typically travels at half the speed of the pressure wave. Likewise, the shear wave frequencies are typically lower than pressure waves by a factor of two. Here the overlay velocity was cut from 1.5km/s of water to .75km/s. Notice that the overlay clearly marks the onset of a low frequency wave. Is this wave the shear wave of ice? Or is it a Rayleigh wave? Or is it some kind of plate wave of the ice whose velocity depends on the thickness of the ice pack and is only accidentally equal half the water velocity?



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
● Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.872
velocity: 2.01
clip: 6e+04
zoom: 12
fat: 3
Changing velocity.

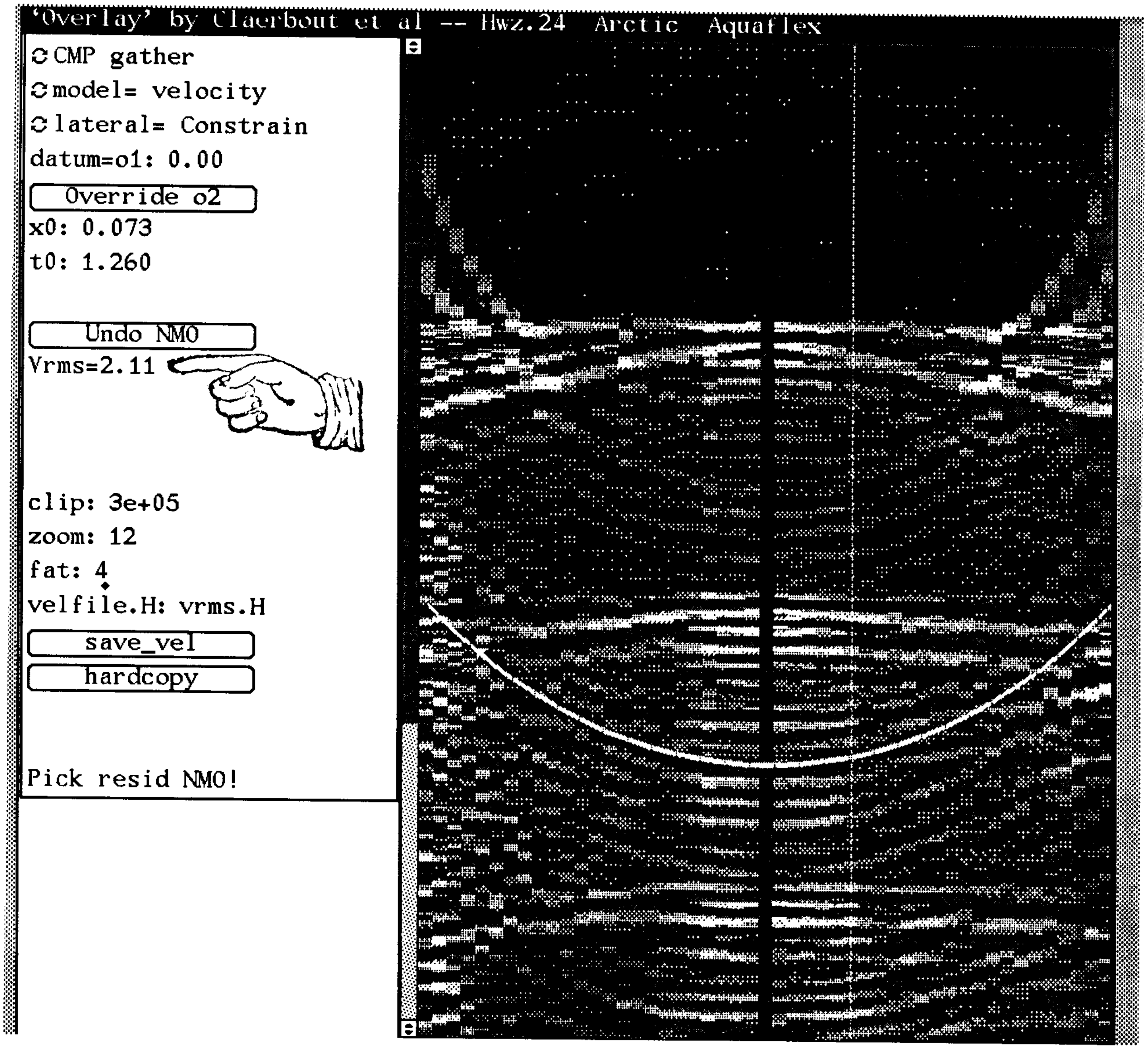
FIG. 23. Returning to a typical clip value the hyperbolic overlay is superposed on a sedimentary primary of velocity 2km/s (see hand). This velocity is the the so-called RMS velocity, an average of all the velocities in the propagation path from the surface, first the 1.5km/s water layer and then a sedimentary layer that must be faster than 2km/s.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

CMP gather
model= velocity
☑ Constrain lateral
datum=o1: 0.00
x0: 0.000
t0: 0.844
Vrms=14.01
clip: 6e+04
zoom: 12
fat: 1
velfile.H: vrms.H
Tie/free toggle

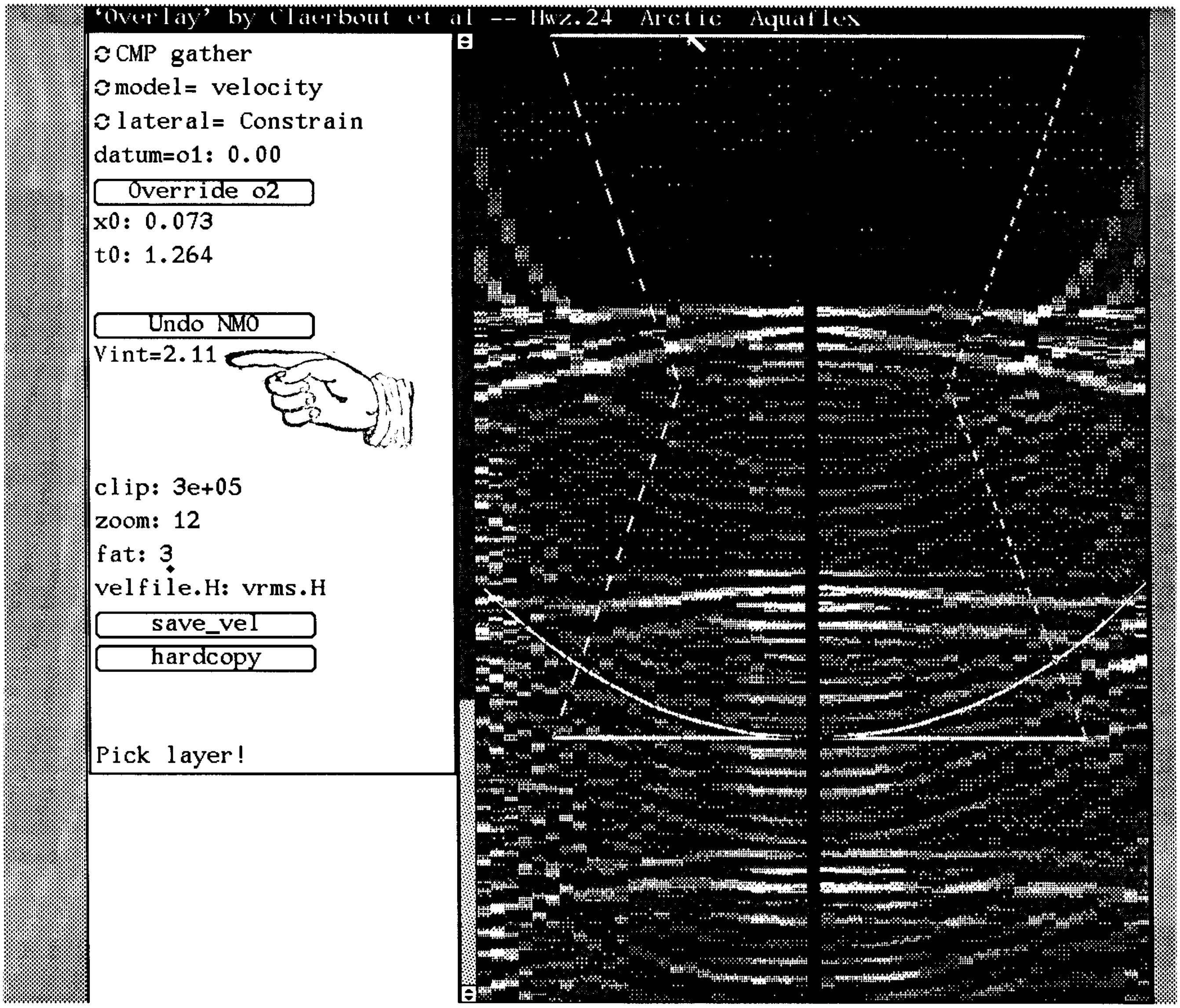
FIG. 24. From the previous figure, the velocity was set to water velocity and the "Moveout" button (see hand) was pressed. About five to ten seconds later this panel appeared. The water bottom arrival is now flattened. Because of "NMO stretch" we see the water bottom wave packet broaden out with offset (hands). A proper debubbling preprocess would have greatly reduced the broadening. The head waves pop up out of the water bottom. The overlay is the ellipse required for residual velocity analysis. It doesn't fit the data and the panel shows (see hand) that it implies the unrealistic RMS velocity of 14km/s.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

○ CMP gather
○ model= velocity
○ lateral= Constrain
datum=o1: 0.00
x0: 0.073
t0: 1.260
Vrms=2.11
clip: 3e+05
zoom: 12
fat: 4
velfile.H: vrms.H
Pick resid NMO!

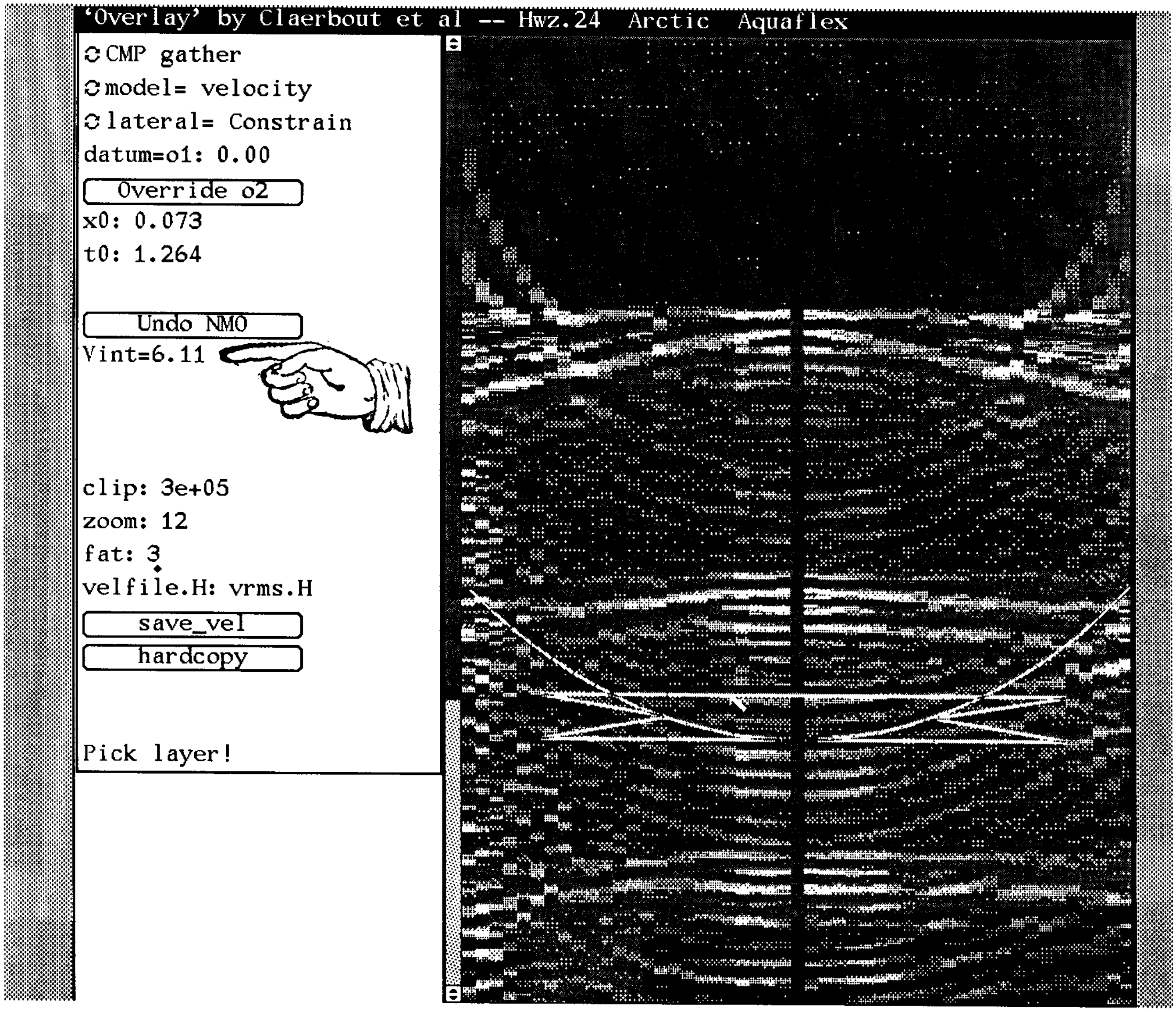
FIG. 25. The ellipse has been moved to a better velocity and now fits the data. The RMS velocity of 2.11 (see hand) must be distributed between the water layer and the deeper layers.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

```
CMP gather
model= velocity
lateral= Constrain
datum=o1: 0.00
x0: 0.073
t0: 1.264
Vint=2.11
clip: 3e+05
zoom: 12
fat: 3
velfile.H: vrms.H
Pick layer!
```

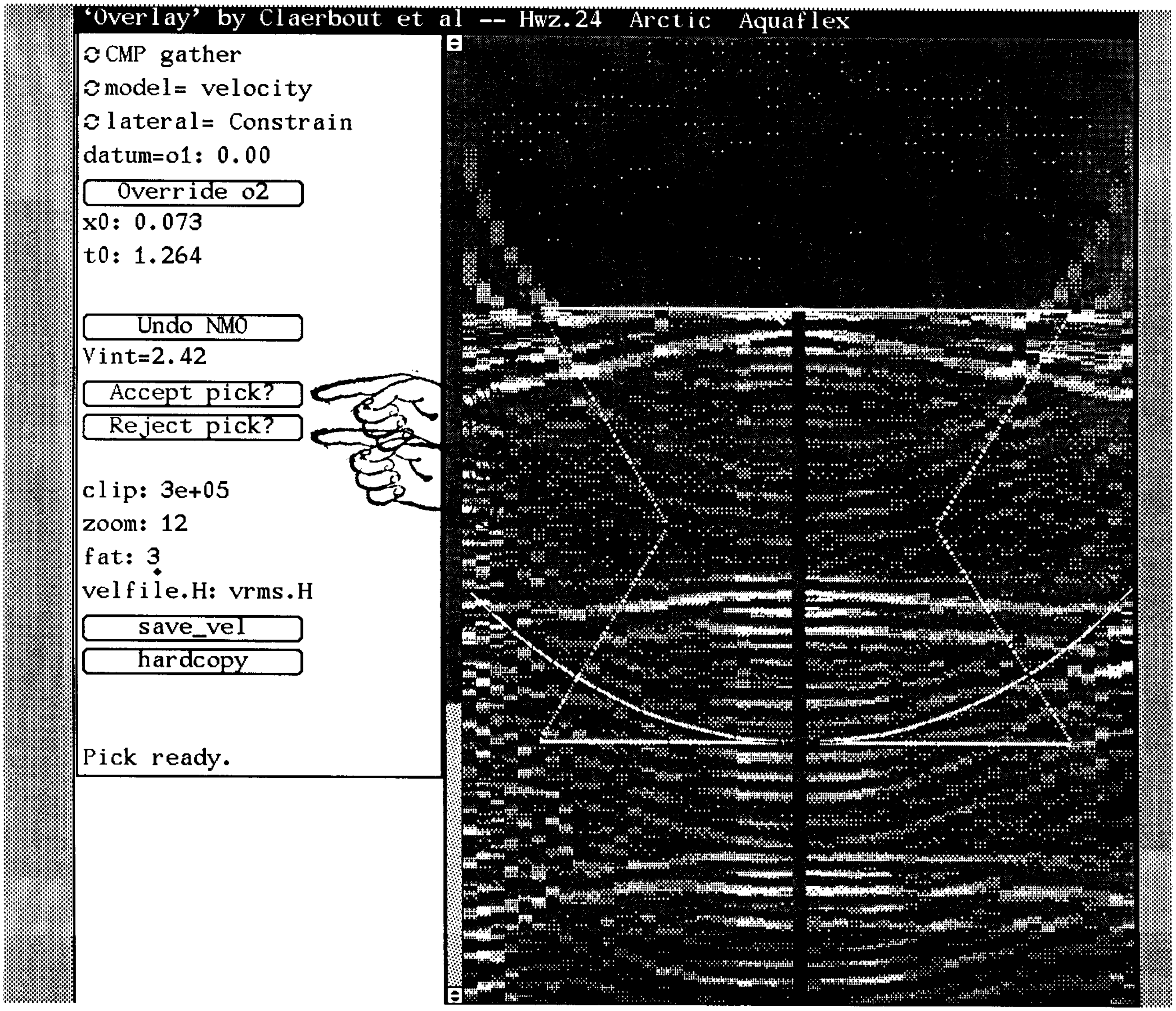
FIG. 26. An hourglass-shaped overlay means the program has entered a mode where a layer thickness is to be chosen. Setting the top of the hourglass to the top of the screen denotes a thick layer going all the way up to the surface with a layer velocity (see hand) the same as the previously noted RMS velocity.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

CMP gather
model= velocity
lateral= Constrain
datum=o1: 0.00
x0: 0.073
t0: 1.264
Vint=6.11
clip: 3e+05
zoom: 12
fat: 3
velfile.H: vrms.H
Pick layer!

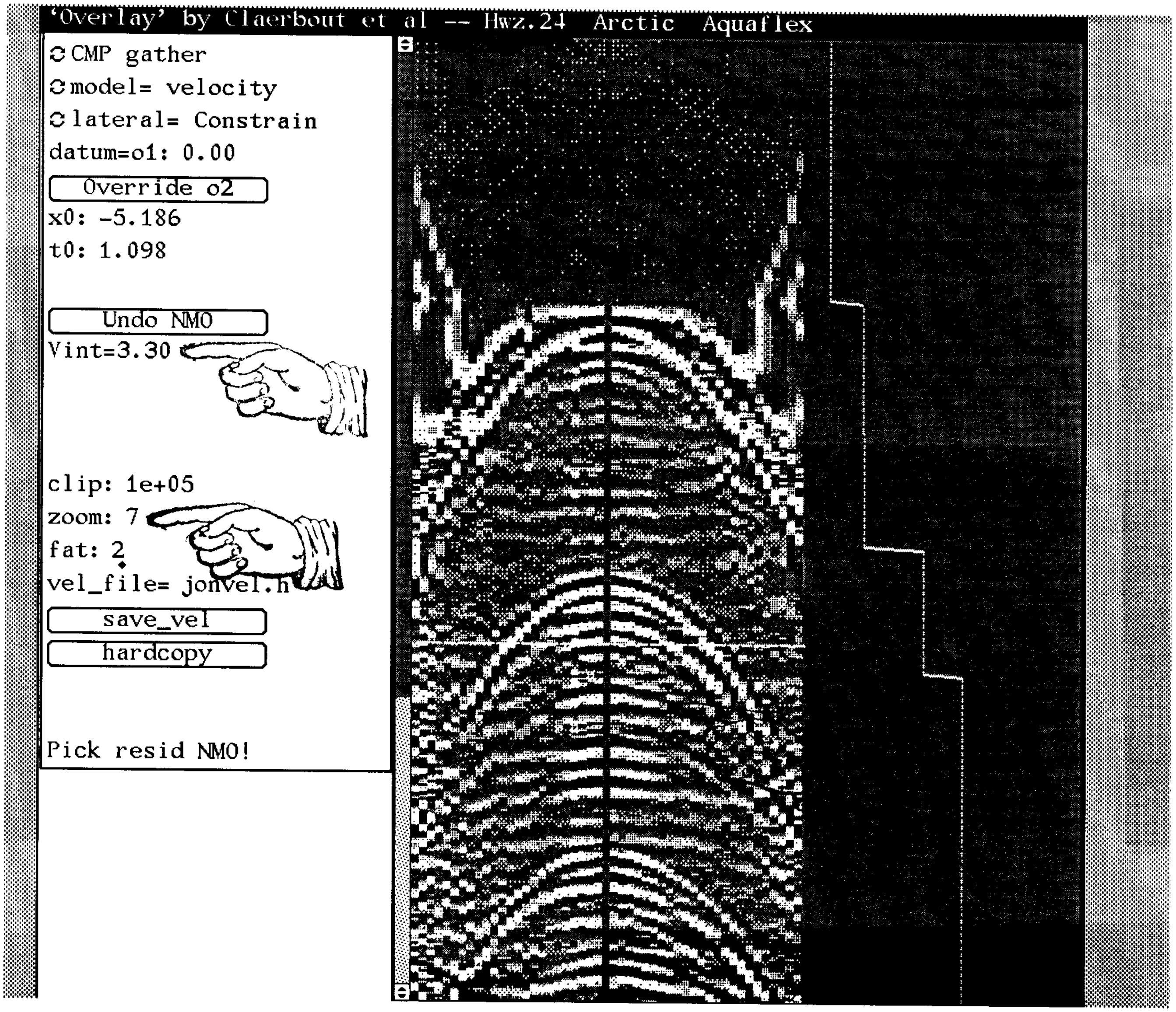
FIG. 27. The top of the hourglass has been pushed down (with the mouse) to denote a much thinner layer. The hourglass-shaped overlay is now about a centimeter high on the page. From the panel (see hand) we see that an interval velocity of 6.12km/s is required in this thin layer to fit the RMS velocity of the ellipse.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

CMP gather
model= velocity
lateral= Constrain
datum=o1: 0.00
x0: 0.073
t0: 1.264
Vint=2.42
clip: 3e+05
zoom: 12
fat: 3
velfile.H: vrms.H
Pick ready.

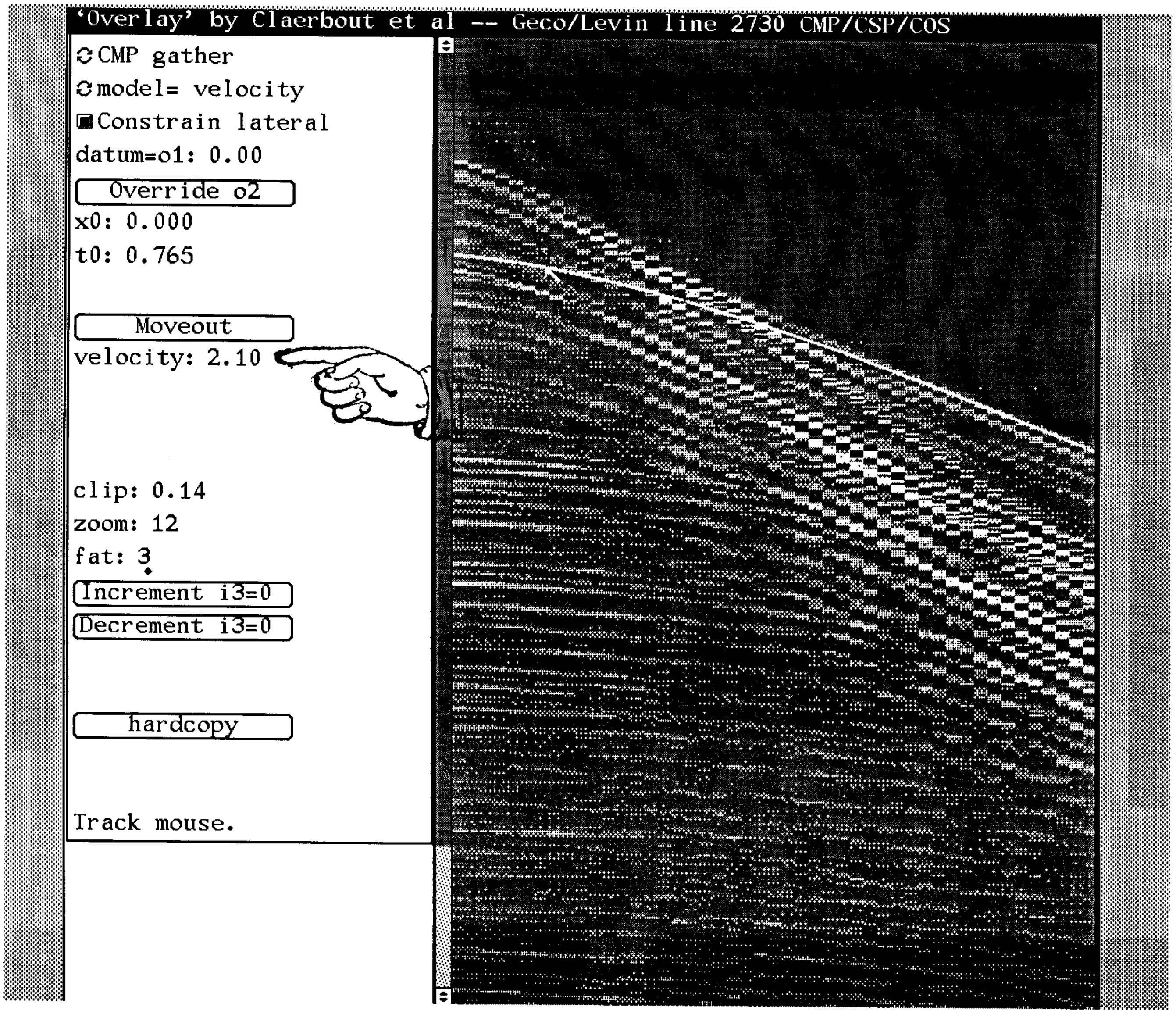
FIG. 28. The hourglass overlay now shows the most realistic location for the layer top—at the water bottom. Releasing the mouse causes two buttons to appear on the control panel (see hands) to indicate that a hypothetical velocity model has been completed, and it is the operators choice to reject it and start over, or to accept it and have moveout performed with the new velocity model.



'Overlay' by Claerbout et al -- Hwz.24 Arctic Aquaflex

↻ CMP gather
↻ model= velocity
↻ lateral= Constrain
datum=o1: 0.00
x0: -5.186
t0: 1.098
Vint=3.30
clip: 1e+05
zoom: 7
fat: 2
vel_file= jonvel.h
Pick resid NMO!

FIG. 29. Iterative operations of the kind described on the previous figures lead to the development of a model for interval velocity versus vertical travel time. I find I like to decrease the horizontal zoom (see hand) as the model building proceeds, and I often turn off the lights in the room and readjust the clip. It is pleasing that the velocity function is increasing with depth but a little below the deepest pick you can see some frowning events (hands), which are evidently peglegs. The velocity profile is shown as a steep "staircase" function. The interval velocity of the step near the small black arrow (see hand) can be read off the control panel to be 3.30km/s (see hand). The profile can be output to the file system for later use with the pushbutton "save_vel" (see hand).



'Overlay' by Claerbout et al -- Geco/Levin line 2730 CMP/CSP/COS

↻ CMP gather

↻ model= velocity

■ Constrain lateral

datum=o1: 0.00

x0: 0.000

t0: 0.765

velocity: 2.10

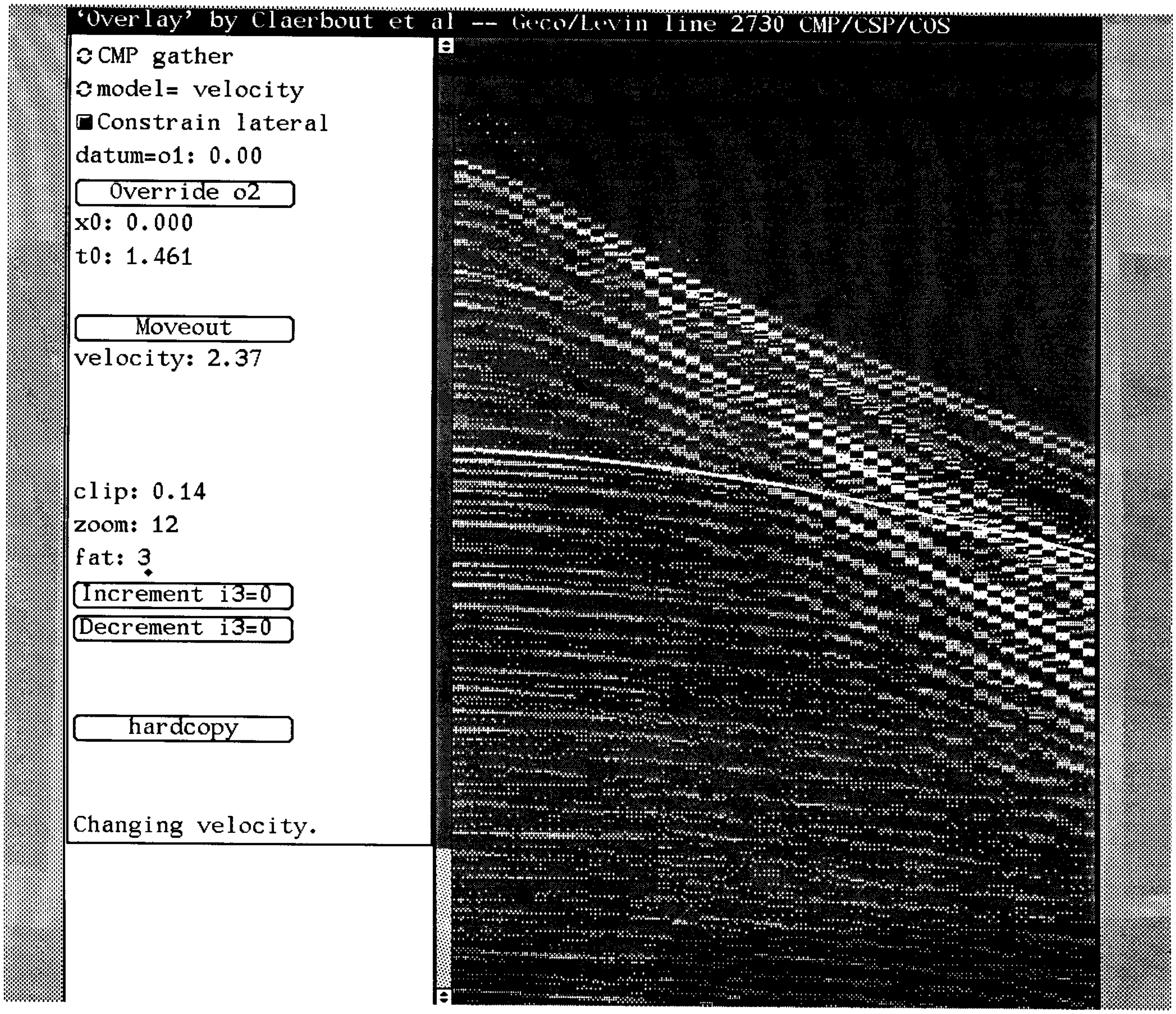
clip: 0.14

zoom: 12

fat: 3

Track mouse.

FIG. 30. A marine profile from GECO used by Stew Levin. The overlay matches a head wave with velocity 2.10 (see hand). No reflections can be seen with this velocity and despite substantial effort I was forced to conclude that head waves can contain extremely clear velocity information that is completely invisible in the reflections.



'Overlay' by Claerbout et al -- Geco/Levin line 2730 CMP/CSP/COS

↻ CMP gather

↻ model= velocity

☑ Constrain lateral

datum=o1: 0.00

x0: 0.000

t0: 1.461

velocity: 2.37

clip: 0.14

zoom: 12

fat: 3

Changing velocity.

FIG. 31. The overlay marks the ***only primary reflection*** after the water bottom. Other events are easily shown by velocity and timing to be multiples. So for velocity analysis we have one head wave and one reflection. Construction of a reasonable velocity model for this profile requires a technique that integrates reflection and head wave information. My overlay program is not yet capable of it.