Direct Observation of Lateral Velocity Anomalies in Field Data

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Lateral velocity anomalies can be directly observed in unprocessed field data. Rays passing through these anomalies will be time shifted relative to nearby rays. These time shifts appear as amplitude or polarity changes. They also assume distinctive geometric patterns.

The Role of a Movie Machine

Time shifts are difficult to observe due to (1) noise and (2) inconvenience of manipulating field data. Past efforts have detected time shifts in an indirect way: power over time windows (Kjartansson), cross correlation (Kjartansson), and vrms velocity variations (Lynn, Rocca and Toldi). We have found interactive seismic data movies to be useful in observing time shifts. The eye has a powerful ability to see ordered patterns of movement (or stillness) against fluctuations of background noise in a seismic data movie. An interactive movie program allows us to slice through the data cube in various directions, magnify, change speed, and change contrast- all which help us to identify signals (Ottolini).

Time Shift Patterns of Velocity Anomalies

We analyze how time shift patterns appear in normal moved out seismic data. Normal moveout makes the data appear more uniform in the offset direction. Then it is easier to detect amplitude variations with a constant time slice of the data.

A velocity anomaly will affect some raypaths which reflect from interfaces below it. Two limiting cases are illustrative- a reflector at the level of the anomaly and far below the anomaly (figure 1). A constant background velocity will be assumed for simplification. Figure 2 shows what happens on a constant time slice for each case. In the case of a deep

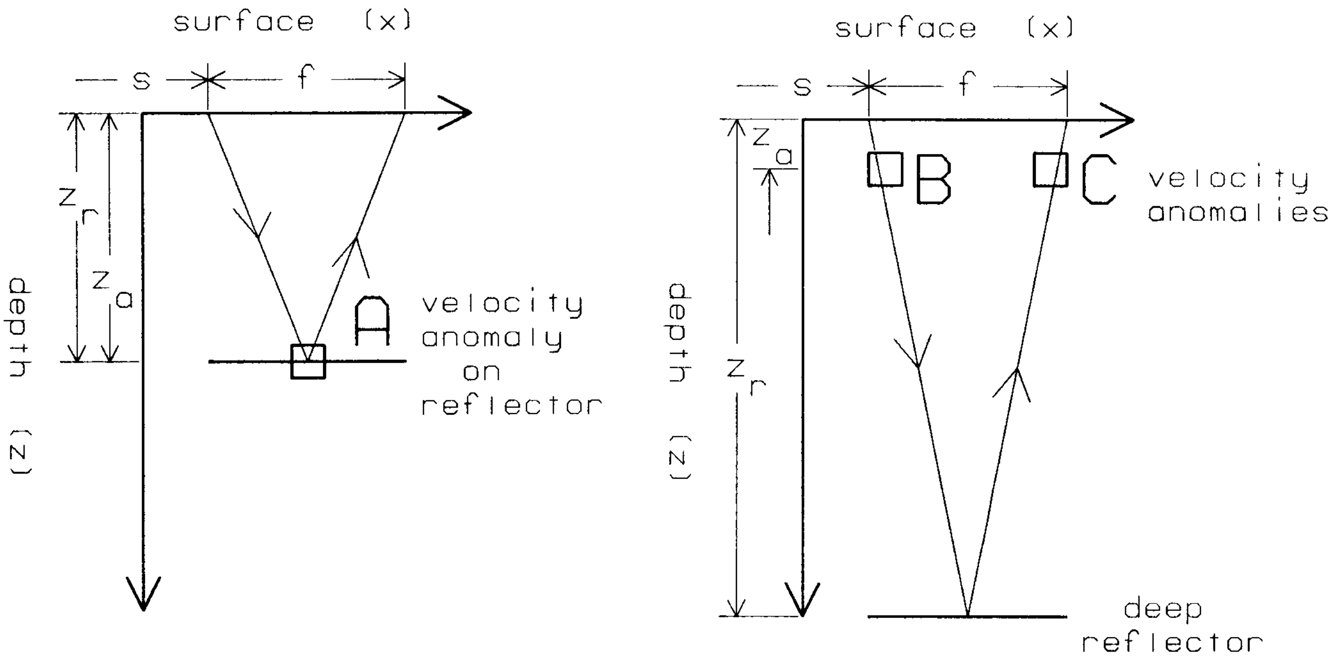

FIG. 1. On the left is the raypath through an anomalous velocity region (box) at the level of the reflector. Distance s is shot location, f is full offset, z_a is anomaly depth, and z_r is reflector depth.

On the right is the raypath through anomalous velocity region far above the reflector. This situation is equivalent to shot (B) and geophone (C) statics.

reflector, line B represents the shot over the anomaly. All geophones experience a time shift at the same location, so the pattern appears as a vertical line. Line C is the pattern when each geophone is over an anomaly. The shot location is changing for each geophone, so the line goes at 45 degrees. The deep reflector situation is equivalent to near surface statics. Pattern A is observed when the reflector lies just below the anomaly. Then the raypaths intersect the anomaly at the midpoint, which is a line midway between lines B and C.

Figure 3 shows figure 2 expanded out in time. The earliest time shift appears when the reflector is just below the anomaly. The pattern is a single line tracing midpoint. For long travel times, lines B and C form a "vee" pattern. The width of the vee is the shot-geophone offset. At intermediate times, there is a narrower vee pattern.

Figure 3 also shows what happens at constant offset. The bullet shape obeys the equation (from Rocca and Toldi)

$$w = f\left[\frac{z_r - z_a}{z_r}\right]$$

where w is the vee width, f is offset, z_r is reflector depth, and z_a is the anomaly depth.

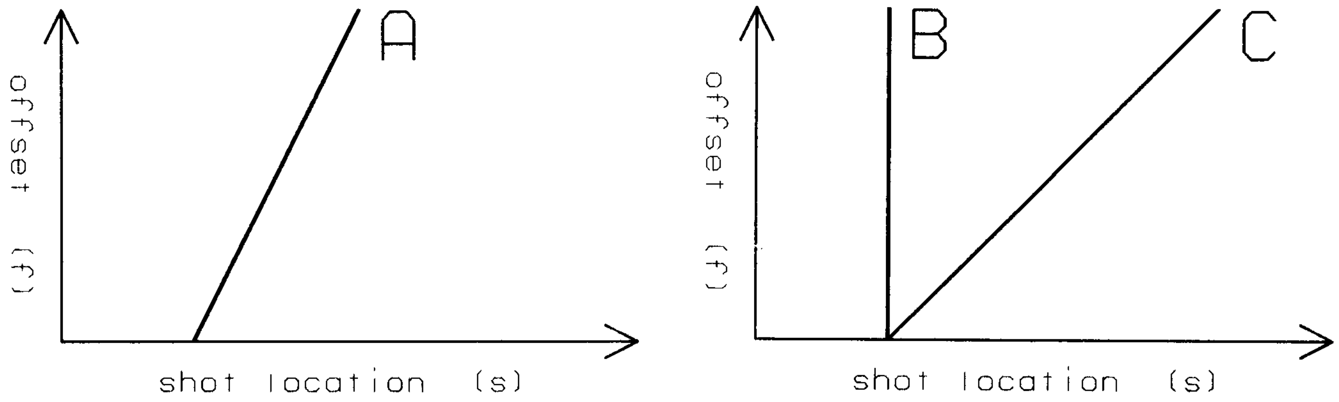

FIG. 2. On the left is the time shift pattern appearing in a NMO time slice. The velocity anomaly is at the depth of the reflector as shown in figure 1A. The line has a slope of 62.5 degrees and is the trajectory of common midpoint. In real data (figures 7 to 10) the time shift appears as an amplitude change or polarity reversal. Note that the vertical axis is *offset* instead of geophone location (not to be confused with statics diagrams).

On the right is the time shift "vee" pattern appearing when the velocity anomaly is far above the reflector, corresponding to figure 1B. The B limb is when the shot is above the anomaly, that is all the offsets at the same shot location or a vertical line. The C limb is when the geophone is above the anomaly, when the shot location changes or a 45 degree line. The width of the "vee" is the offset f.

Depth varying velocities and wide velocity anomalies can alter this bullet shape.

These time shift patterns are easiest to see in movies through constant normal moved out time slices. The time shift results in a change of color (representing amplitude or polarity) between adjacent recordings. The time shifts are less visible in movies of trace sections. They appear as small bumps in this case.

Time Slice Examples

We observed the time shift patterns of a lateral velocity anomaly in an offshore seismic dataset. The velocity anomaly appears as an opening vee as the movie goes through increasing time. Representative time slices appear in figure 4. It is hard to capture the opening "vee" pattern in noisy still frames, but it stands out dramatically during the course of a movie. A widening vee pattern also appears in the multiples.

The normal moveout correction (at 1500 m/s) was a bit too small. The result is that each time slice cuts through a couple polarity bands. This actually works to our advantage when we try to measure the dimensions of the velocity anomaly. These bands turn at the boundaries of the vee (see figures 4C and 4D). The width of this turn for the deep reflector

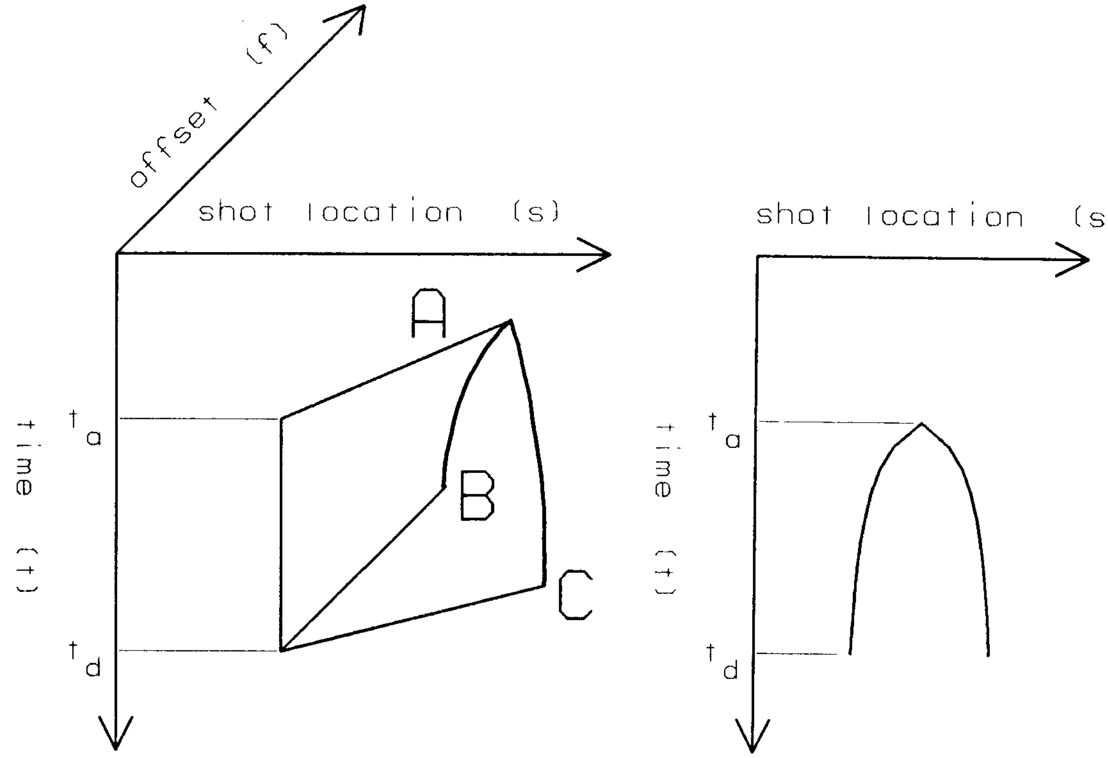

FIG. 3. The diagram on the left shows how the vee time shift pattern opens as time increases. Line A is for a reflector at the level of the anomaly, while lines B and C are from a reflector far below the anomaly.

The diagram on the right shows a constant offset cross section through the diagram on the left. It follows the equation given in the text.

(figure 4D) is about 350 meters. It takes two successive time slices (16 milliseconds) for bands to progress the width of the jag, so the time shift is about this large. The magnitude of the time shift is a product of its thickness and velocity pertubation. The direction of the jag indicates a positive time shift, or that the anomaly is a velocity decrease.

Figure 5 plots the width of the vee as a function of normal moved out time. It does not fit the bullet in figure 3 exactly, but the deviations are easy to explain. The flattened top is comparable to the width of the anomaly. The slope changes in the limbs are probably due to depth velocity variations.

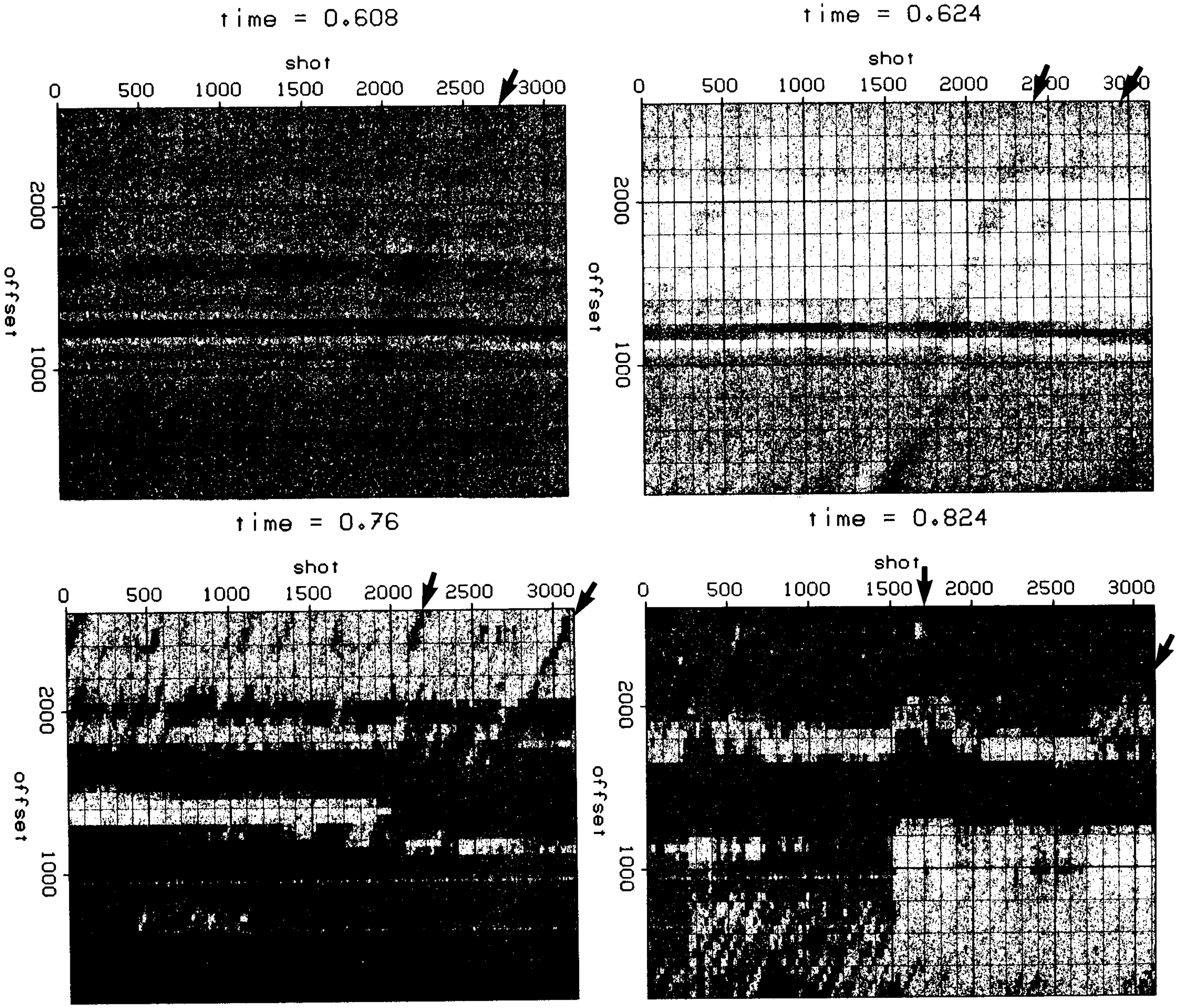

FIG. 4. Time slices through a normal moved out dataset. Upper left is at the travel time of the anomaly, so it appears as diagonal line. The next two frames show the vee widening. The last frame is approximately the static situation where the vee takes on the orientation of figure 3.

The opening vee is much more dramatic in a movie than seen here. The eye picks out the signal easier as motion. The CRT screen also has sharper contrast than ink plots.

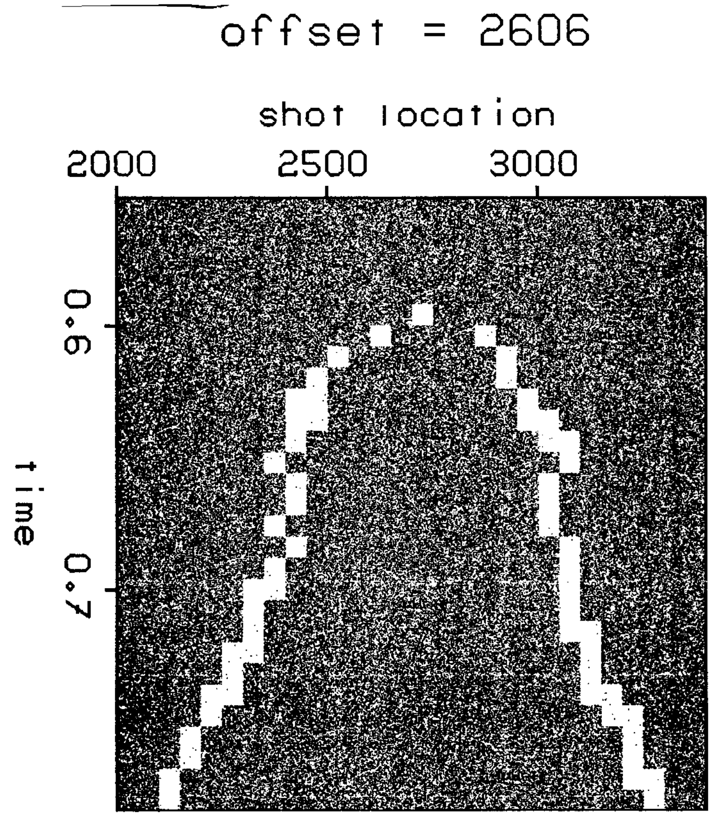

FIG. 5. Plot of vee width as a function of time. (These values were hand picked; this is not a constant offset section.) There are a couple of explanations why this shape deviates from the bullet of figure 3. One is that this is the flattened hyperbola of the constant offset section. However, from other views of the data it is definite that the vee's are made of time shifts and not diffractions. Alternatively, the anomaly in the time slices of figure 4 shows a significant width which is comparable to the width of the above curve. The limbs of this curve bend due to the raypath refraction of depth increasing velocity.

Trace Section Movies

The time section movies clearly indicate the location of the velocity anomaly. Armed with this information, we can then look for the time shift bumps on the shot profile and constant offset section movies. The moved out shot profile of figure 6 clearly shows that there is a depression of about 16 milliseconds in the seafloor reflection at the offsets where the vee is.

The constant offset movie also shows that there is a diffraction associated with the edges of the anomaly (figure 7). Of course, the diffraction is not causing the vee pattern in the time slice movie. It is not a time shift and cannot explain the polarity shift of the vee.

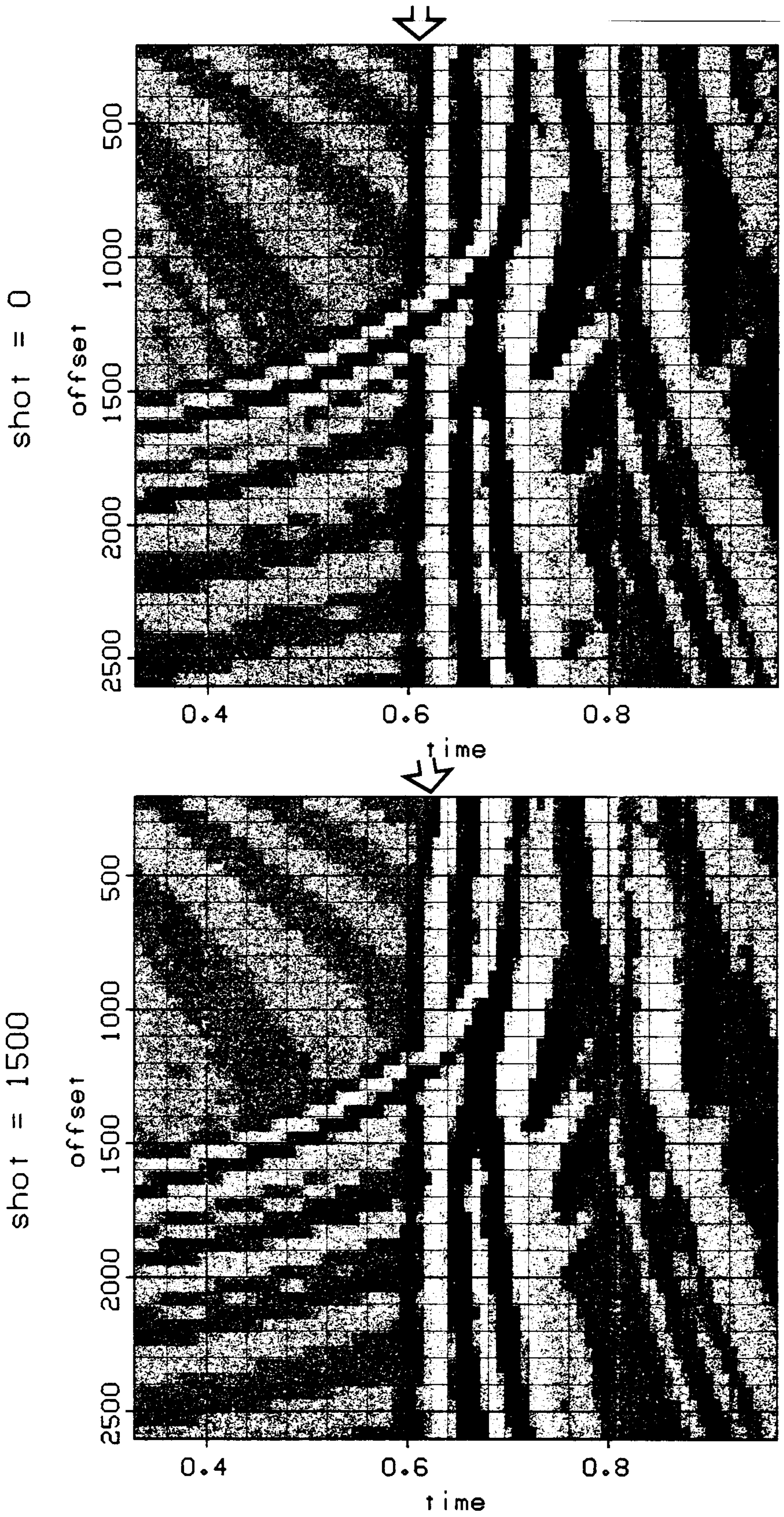

FIG. 6. The normal moved out shot profile at the left has a small depression at low offsets not present in the profile to the right. The top of the anomaly intersects at this offset, time, and shot location according to figure 4. The anomaly is much clearer when the dataset is animated.

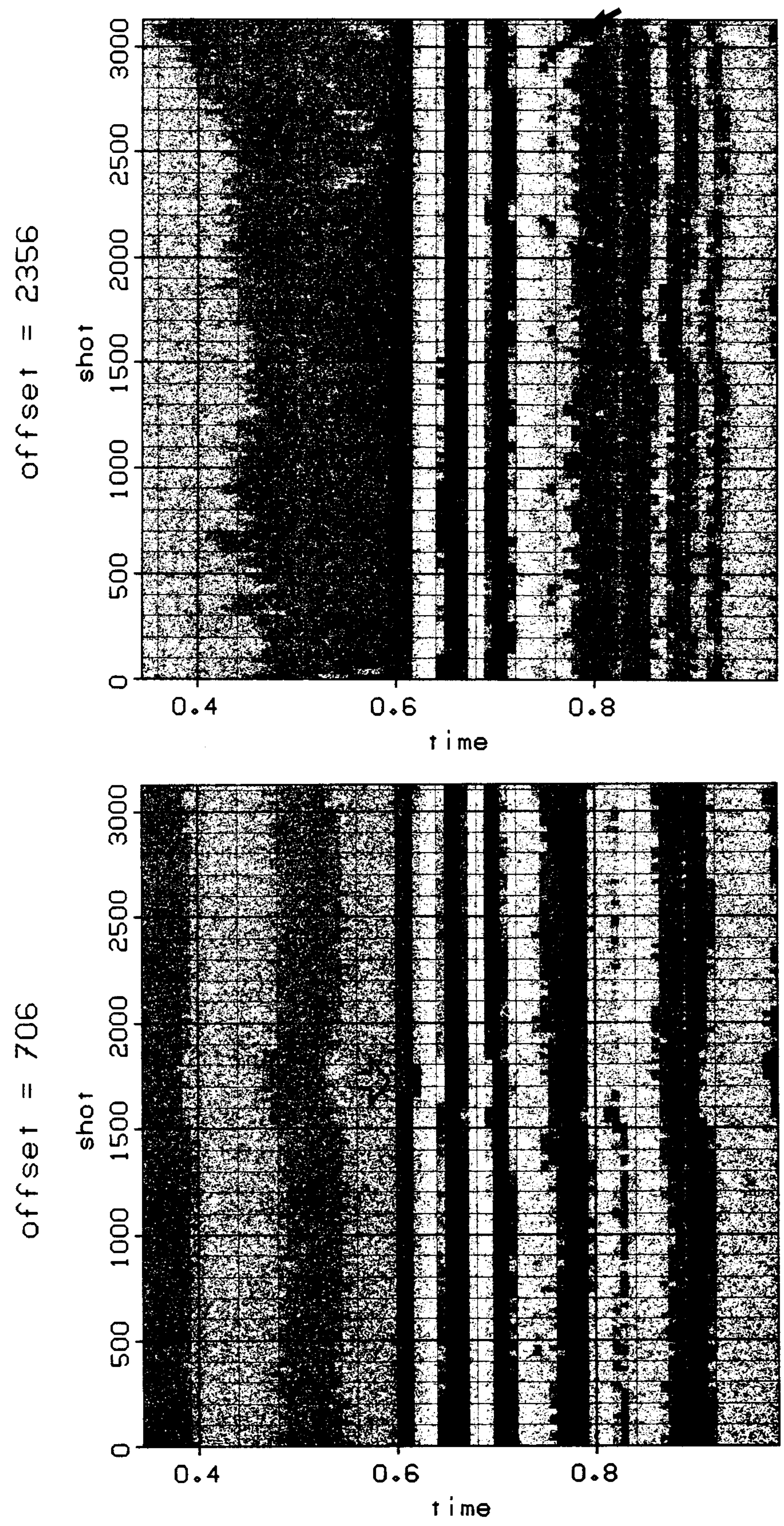

FIG. 7. Two constant offset sections through the anomaly. A negative time shift appears on the small offset figure (left) at .6 seconds and shot location 1700. A weak diffraction accompanies the time shift. In the wide offset figure to the right, a diffraction appears by the anomaly. As before, the signal is much clear in the course of a movie.

Conclusions

Lateral velocity anomalies appear as vee shaped amplitude variations in times slices of field data. Movies through such time slices enhance our ability to detect such phenomenon.

ACKNOWLEDGMENTS

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