SEP Goes to the Movies

Chuck Sword

Movies on the AED

Recently the Stanford Exploration Project purchased an AED 512 color graphics display terminal. As described by Ottolini in *Color Graphics Terminals at SEP* (this report), this particular terminal is able to display movies by means of a combination of zoom and pan commands. This capability, combined with the terminal's ability to display variable-density seismic sections, makes it possible for us to see easily changes in successive groupings of data. For instance, we can detect similarities and differences between successive common shot gathers that would be very difficult to notice on conventionally-plotted seismic sections. In effect, by making data into movies, we are adding a new dimension to the display -- motion. In this paper I will describe some of the movies we have made so far, and what we think we have learned from them. The illustrations included with this article, of course, will not give much of an idea of what the movies actually look like, but they will make it possible to point out certain features that we have noticed.

So far, we have made movies of common shot gathers, synthetic common-shot gathers, NMOed common-shot gathers, isotime panels (I will describe the meaning of this term later in this report), and CDP gathers. We don't yet understand everything that we have seen, but it has become clear that we are now able to see information (that is, signal) in what previously might have been considered noise.

Common shot movies

The first data set that we made into a movie was a set of common shot gathers taken over the Flemish Cap. As it happens, this is the data set that I will be using thoughout this paper. When plotted on paper in the ordinary manner, this data does not appear unusual in any way. However, when we turn the data into a movie, it is possible to see motion.

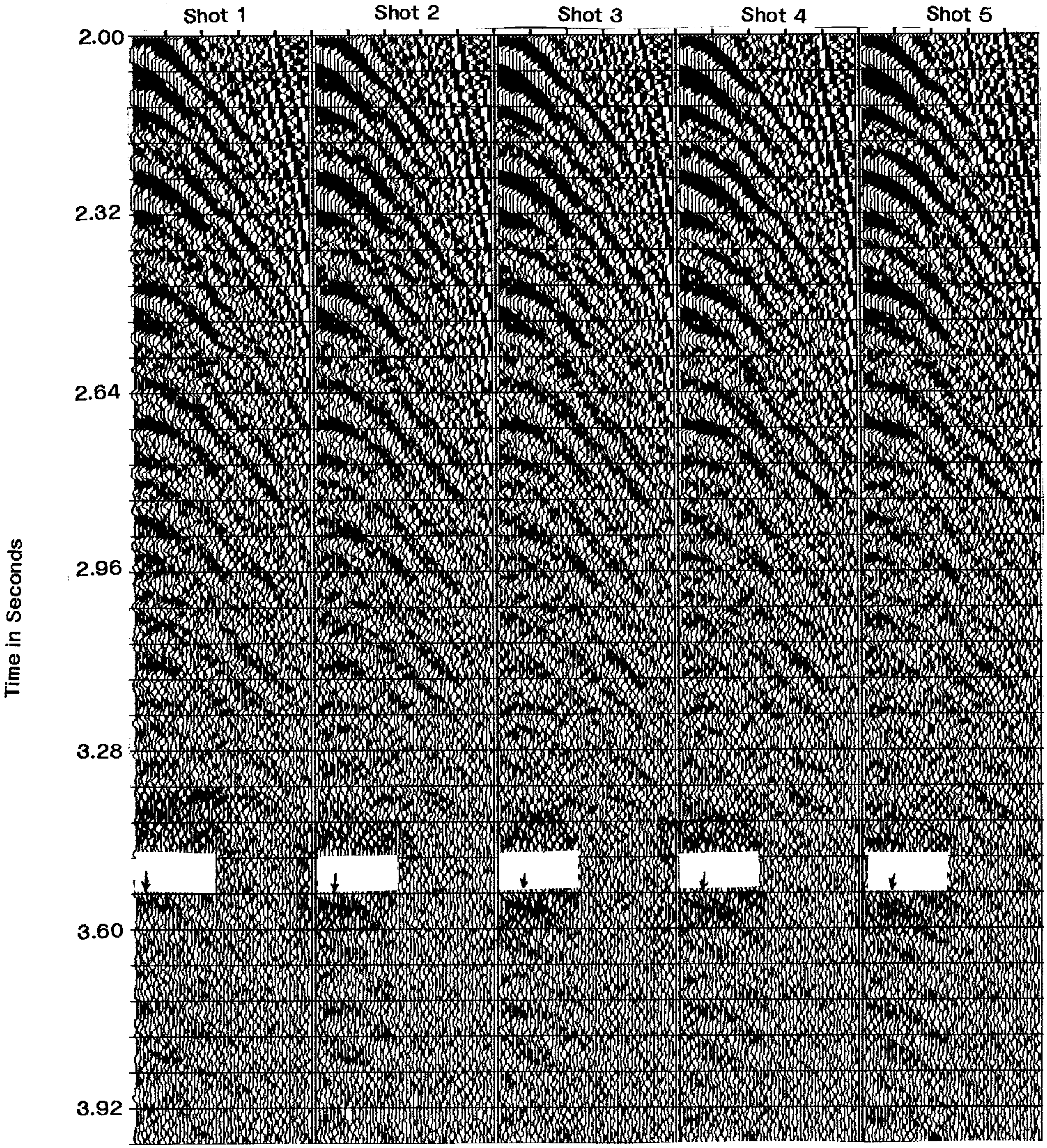


FIG. 1. (First half) Series of marine common shot gathers collected over the Flemish Cap area. Shotpoints were 25 m apart, while geophones were 50 m apart, with 48 geophones on the cable. In this illustration, time goes from 2.0 sec to 3.920 sec.

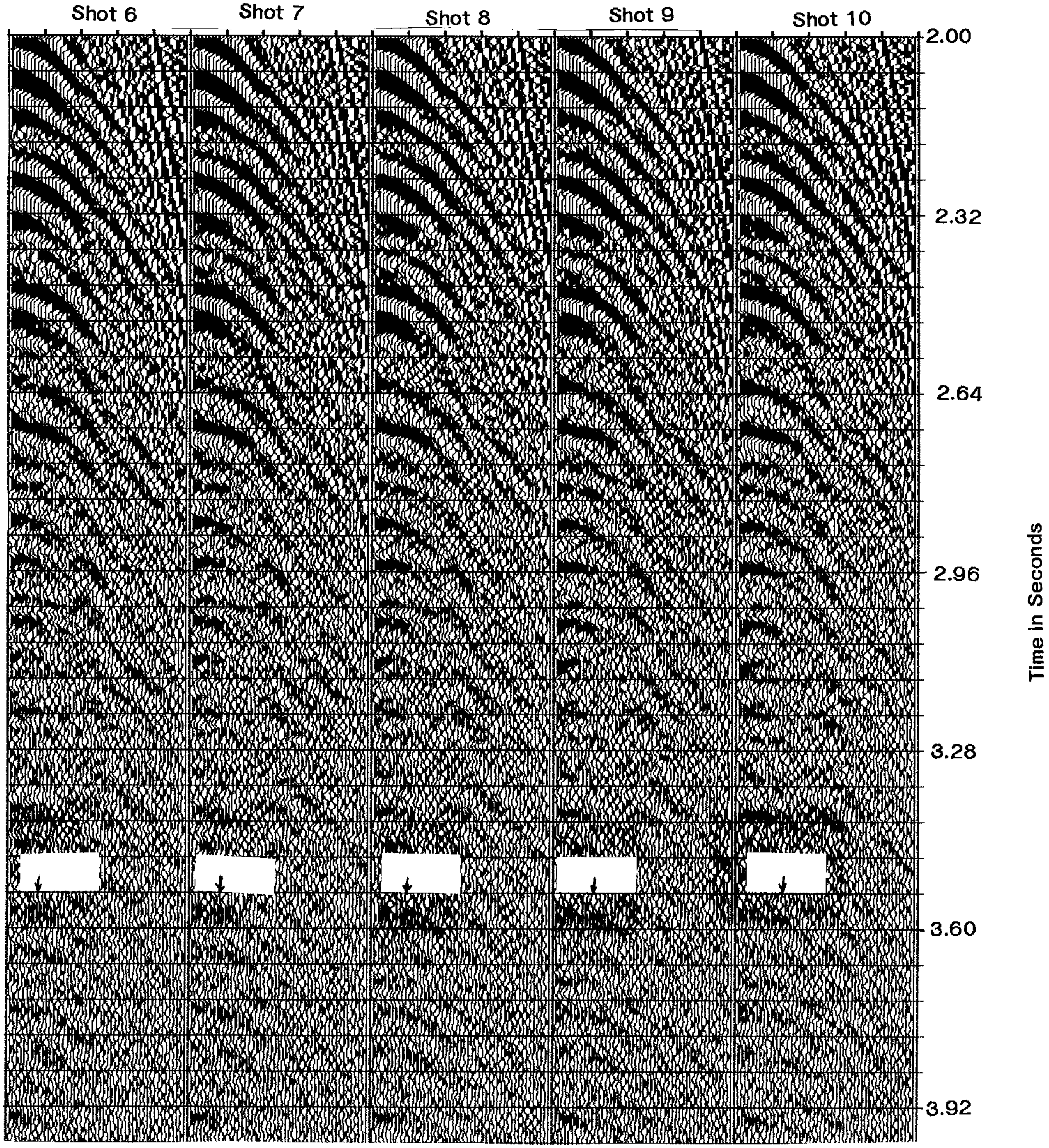


FIG. 1. (Second half) White markers show the "movement" of a particular event.

In Figure 1 I have attempted to show some of this motion. It is, in the first place, very difficult to see what is moving, even when the data is being shown in the form of a movie. The nearest analogy I have is that of watching clouds that are being blown by the wind: you can see that the clouds are moving, but since the clouds themselves are changing as they move along, you can't easily pick out a particular cloud and measure its velocity. Since in this report I can only show movies in the form of a series of still frames, it is not only difficult to see motion, but it is especially difficult to distinguish regular, constant-speed motion from random frame-to-frame fluctuations.

The impression of motion in this particular data set is quite striking. It is noticeable at every offset for nearly all values of time. It is, unfortunately, not so obvious when the movie is displayed as it must be in this report, one frame after another. In any case, the immediate question is, "What is moving?" We don't know the complete answer, but at this point we have some ideas. For instance, we have reason to think that the motion is connected in some way with the geology of the sub-surface reflectors (rather than, say, the geology of layers lying between the reflectors and the surface, or the noise of nearby ships).

The major evidence for this assertion is the speed at which things seem to move as we run the movie. Although it is very difficult to follow any one event as it moves across the screen, we are able to get an idea of the average speed. This speed turns out to be about one geophone per panel. Each panel represents one shotpoint, the shotpoints are 25 m apart, and the geophones are 50 m apart. Putting this all together, we can see (in Fig. 2, for instance) that our "moving" events are actually stationary with respect to the reflectors; it is the ship that is moving.

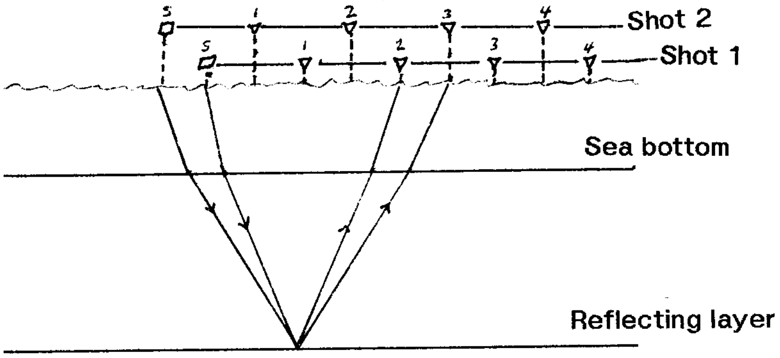


FIG. 2. Geometry of data collection for a distance between shots of 50 m, and a distance between geophones of 25 m. In this case, for successive shots, successive geophones image the same sub-surface formation.

Isotime movies

Before continuing our analysis, it might be worthwhile to look at the evidence provided by another type of movie. We call this new type an *isotime* movie. First we collect all the data that arrived precisely at a given time, say at $t = 3.024$ seconds. This data is then plotted as in Fig. 3, according to its shotpoint and offset. Then we look at all the data from $t = 3.028$ seconds, and so on. The easiest way to get data into this form is to take common shot data and transpose it.

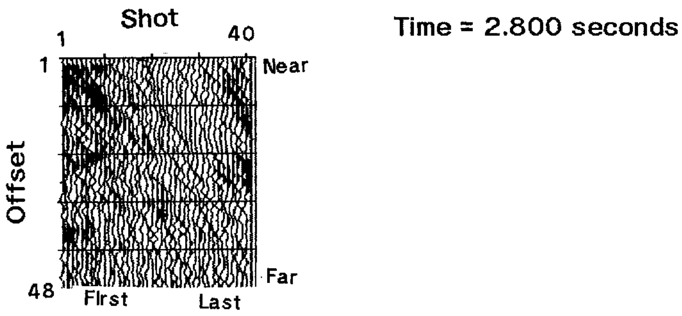


FIG. 3. A typical isotime panel, showing how amplitudes for all shotpoints and offsets can be plotted for a given time.

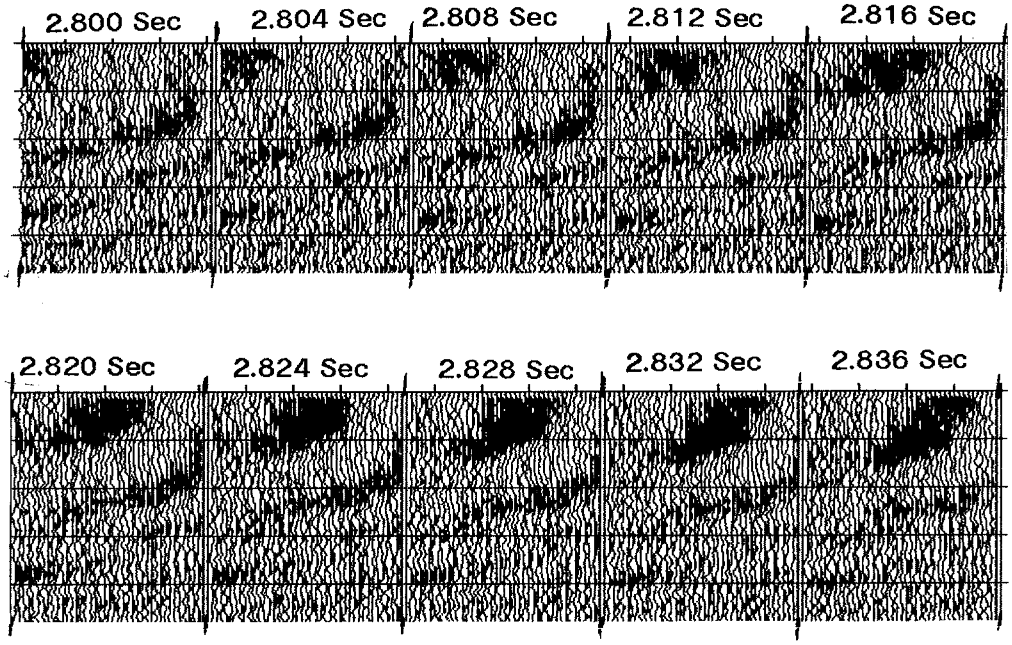


FIG. 4. Isotime panels. Each panel shows the amplitudes for all shotpoints and offsets at a given time.

Fig. 4 shows what this sort of data looks like. Looking from one frame to the next, it is very easy to see motion: the more-or-less-horizontal bars are moving vertically downwards. It should be fairly clear that we are seeing the legs of reflection hyperbolas, and the reason that they move downwards is that any given leg will have a greater offset at greater travel-times. In Fig. 4, however, the bands are not completely horizontal. I will leave it to readers to convince themselves that non-horizontal bands indicate the presence of dipping reflectors. Try it. This sort of mental exercise will make it easier to understand what follows.

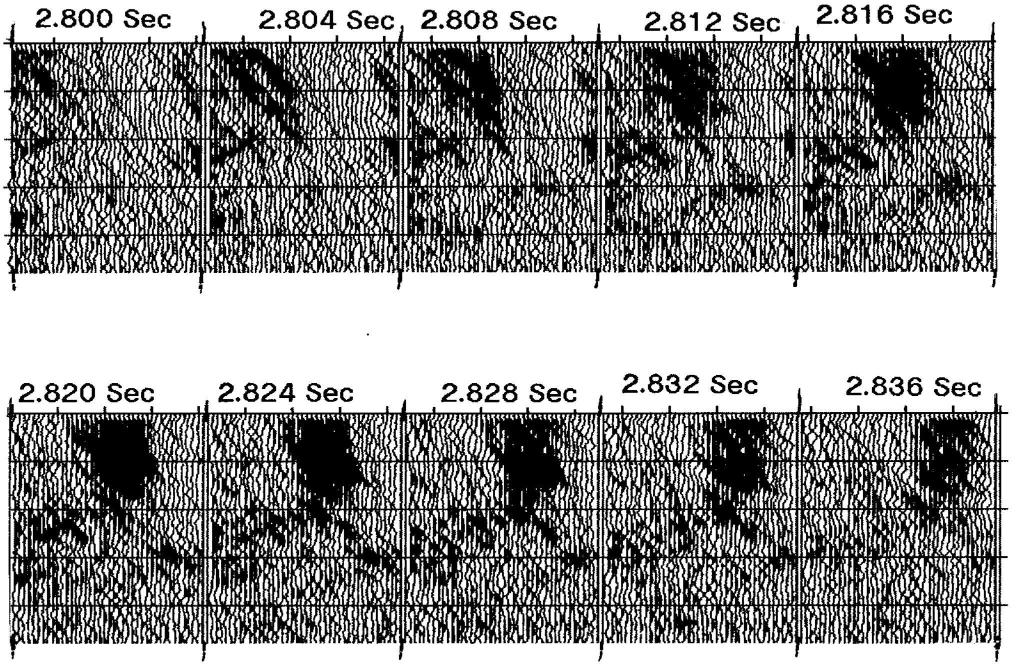


FIG. 5. Isotime section of NMO-corrected data. Time ranges from 2.8 to 2.836 seconds.

Now let us apply some normal moveout to our gathers and turn them into isotime sections. Fig. 5 shows the result of doing this. The most obvious feature in Fig. 5 is the black blob that travels from the upper left to the upper right of the section. (That is, it travels from the near-offset, early-shot corner to the near-offset, later-shot corner). The most interesting features, though, are not nearly as easy to see. They are the little streaks that go from upper left to lower right across the sections. These streaks, I believe, give us our clearest glimpse of whatever is moving on the common shot gathers. In effect, these diagonal streaks help create the impression of motion.

In order to see how diagonal streaks can translate into motion, it is necessary to look at the geometry of isotime sections in a little more detail. Fig. 6 shows a cube of data. It is oriented in such a way that looking at the top face you see an isotime section, looking at the front face you see a common shot gather, and looking at the right-hand face you see a common offset gather. It may seem a bit confusing to have shotpoint and offset, rather that shotpoint and geophone point, as two coordinates of the cube, but that is the way that marine data is conventionally acquired. It should now be clear how the two types of movies that we have looked at so far interrelate. The common shotpoint movie is simply made by looking at the front face, peeling it off, looking at the face behind it, and so on. The isotime movie is made by peeling off the top layers, one after another.

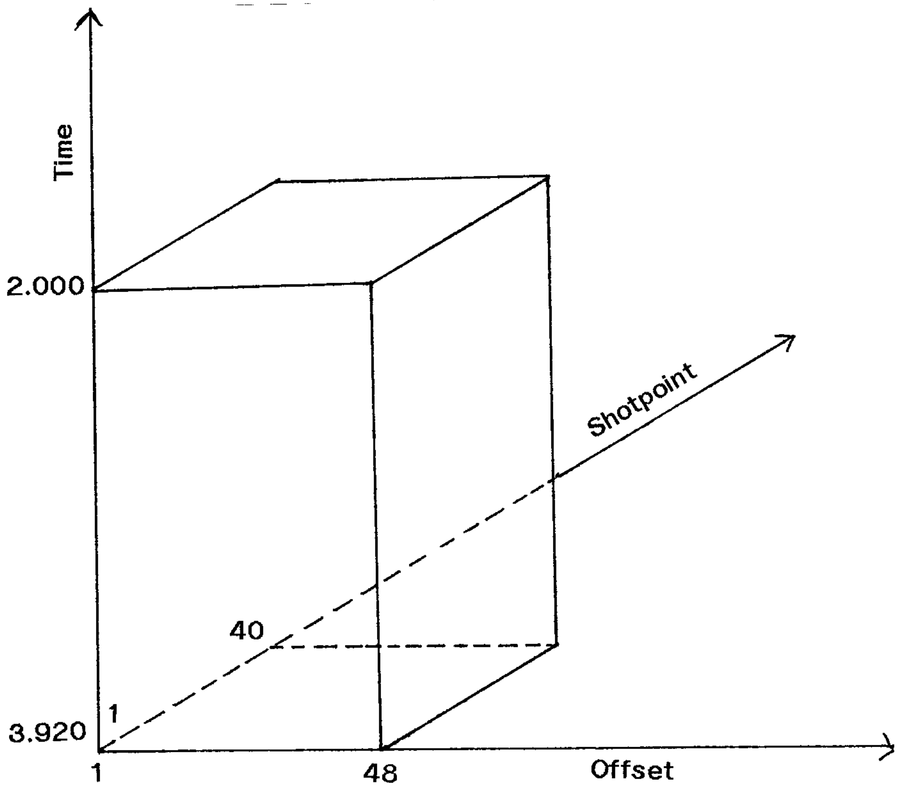


FIG. 6. A data cube. Field data from marine surveys can easily be put into this form. From the front it looks like a common shot gather, from the side it looks like a common offset gather, and from the top it looks like an isotime section.

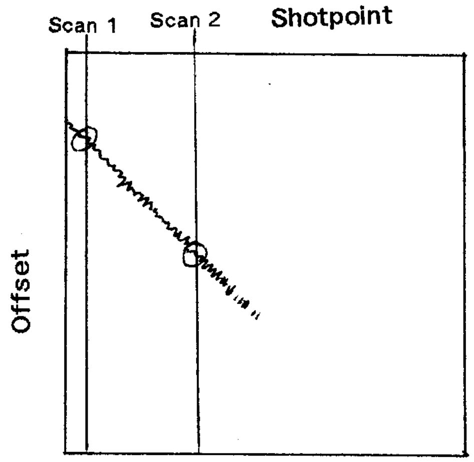


FIG. 7. A typical isotime section. The diagonal line represents a typical streak, while vertical lines represent how the section would be "scanned" in the process of producing a common shotpoint movie.

Keeping in mind the geometry of the cube, it is now possible to consider the case of our diagonal streaks. Let us look at the case of a single isotime section, as shown in Fig. 7, as it is being "scanned" to form part of a common shotpoint movie. The scan starts as a vertical line at the left side of the isotime section. Referring back to the cube, it is clear that this "vertical" line is horizontal from the point of view of a common shotpoint movie. At this point, the streak intersects the scanning line at a near offset. At a later point in the common shotpoint movie, the scanning line is now further towards the left, and the streak intersects the line at a farther offset. Thus, what looks like a diagonal line on an individual isotime section, turns into a moving point in a common shotpoint movie.

These diagonal streaks, then, cause motion when we view the data cube in the form of a movie of common shotpoint sections. In fact, these streaks may be the best way we have of objectively measuring this motion, and their presence raises some interesting questions. For instance: streaks that run at a 45° angle clearly represent lines of common midpoints, which means that each of these 45° streaks can be connected with some stationary feature on some reflector. However, streaks at angles differing from 45° have sometimes been observed. What do these represent?

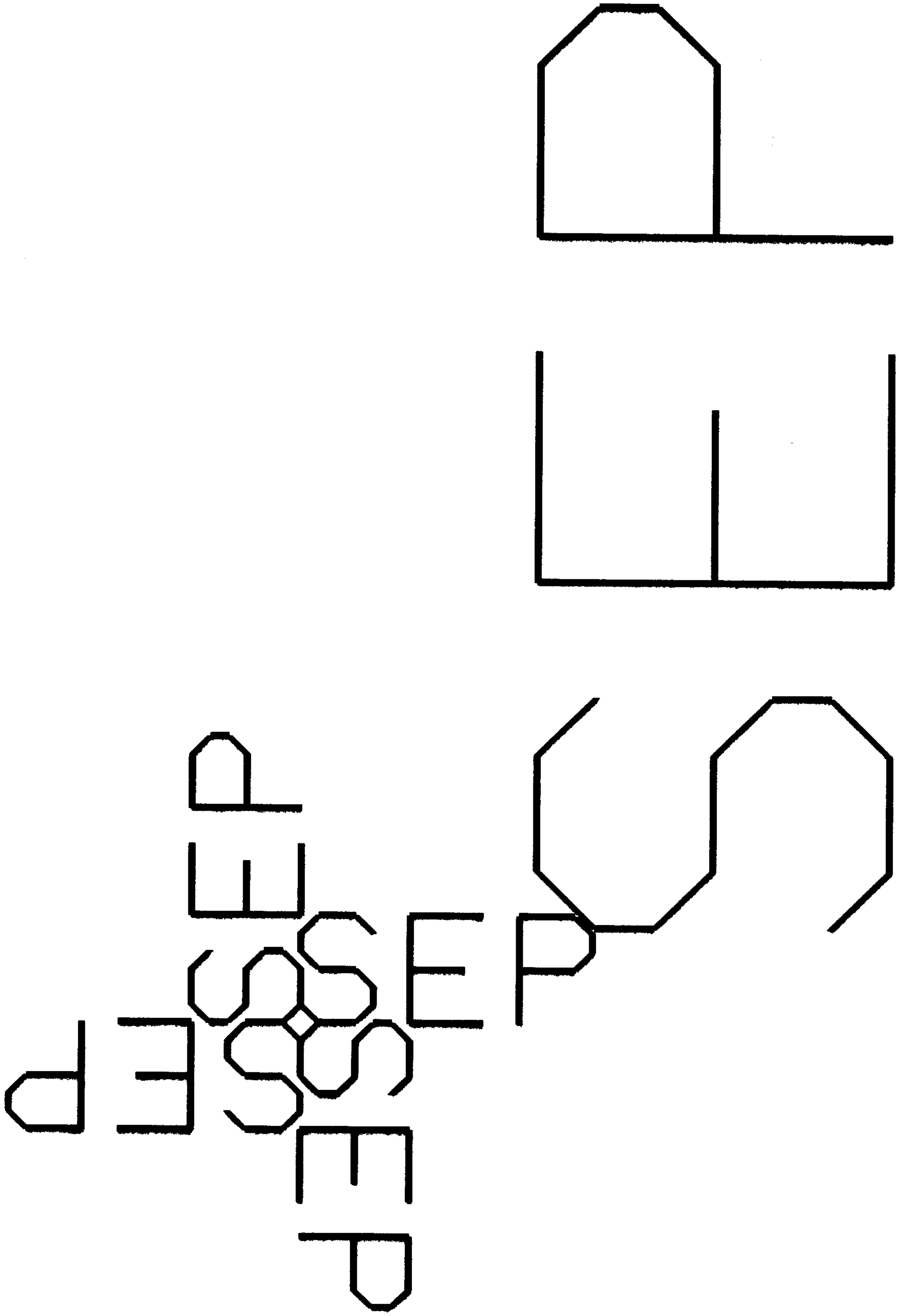
Analysis

We have looked at various manifestations of the motion that we see in common shotpoint movies, but we have not yet really answered the question of what is doing the moving. However, we now have quite a few clues. At this point it appears that the motion is somehow associated with various irregularities in the subsurface reflectors. What sort of irregularities are these? The most obvious irregularities are variations in depth or coefficient of reflection. However, while not ruling these out, it appears that something else may be involved. After all, if these irregularities explain everything, why is the motion so elusive? In other words, why is it so difficult to point at what exactly is moving?

We don't yet (and may not ever) have a complete answer to any of these questions, but we have another clue. Let us look more carefully at one of the common shotpoint gathers that we saw previously in Fig. 1, as reproduced in Fig. 8. It is possible to see, without too much effort, what appear to be rather high-frequency diffraction hyperbolas. I believe that these hyperbolas are responsible, for the most part, for producing the diagonal streaks that we see on our isotime sections. The reason for this belief is that the streaks are very narrow, and thus seem to correspond to the high-frequency diffractions. Thus these diffractions, presumably caused by various reflector irregularities, are responsible for some of the motion that we see.

However, diffractions do not seem to be the sole cause of motion. Without including any supporting illustrations, since they would be virtually useless, I will merely state that we performed one more experiment on the data. Basically, I put a low-pass filter on the data to see what would happen when the diffraction hyperbolas were removed. Even after filtering, movement was still present, and in fact, it was easier to see what appeared to be movement caused by irregularities in depth and reflection coefficients.

In summary, then, we have looked at various types of movies made from the same data set. A preliminary analysis indicates that the apparent motion has several causes: irregularities in reflector depths, irregularities in coefficients of reflection, and diffraction hyperbolas caused by sub-surface irregularities.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