

## **GC Seismic Velocities\***

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### **Background**

The realm of our seismic data typically has been horizontal distance and vertical time -- but now we are flooded with seismic data that is displayed in distance and depth. Seismic velocities originally came to us as a by-product of the process of stacking the data. By the geometry of the acquisition program we reference for this column, there was a large redundancy in the reflection information designed to produce many reflections off of the same subsurface point.

Figure 1 illustrates the very naïve assumption that source and receiver locations with the same mid-point would be reflected off of the same subsurface point. The stacking process consisted of correcting each reflection for "normal moveout" that was the direct result of two parameters. These are the source-to-receiver offset and the subsurface velocity. When all of the reflectors were perfectly aligned, the traces with a common midpoint could be summed to produce a stacked trace.

The source-to-receiver offset was known from the acquisition geometry, but the unknown quantity was the velocity. The method used here was to correct the reflection events with a large suite of velocities to determine the velocity that optimally aligned the reflection events. Having picked the optimal "alignment" velocities, the traces were appropriately corrected sample by sample and then stacked as shown in Figure 1.

It was, of course, recognized that in the presence of dipping reflectors, the traces contributing to the stack did not have a reflection point directly under their common midpoint. Having produced a stack of the corrected reflections, the composite trace had to be migrated -- that is, the stacked reflections had to be shifted in time and distance to their appropriate points of origin by poststack migration.

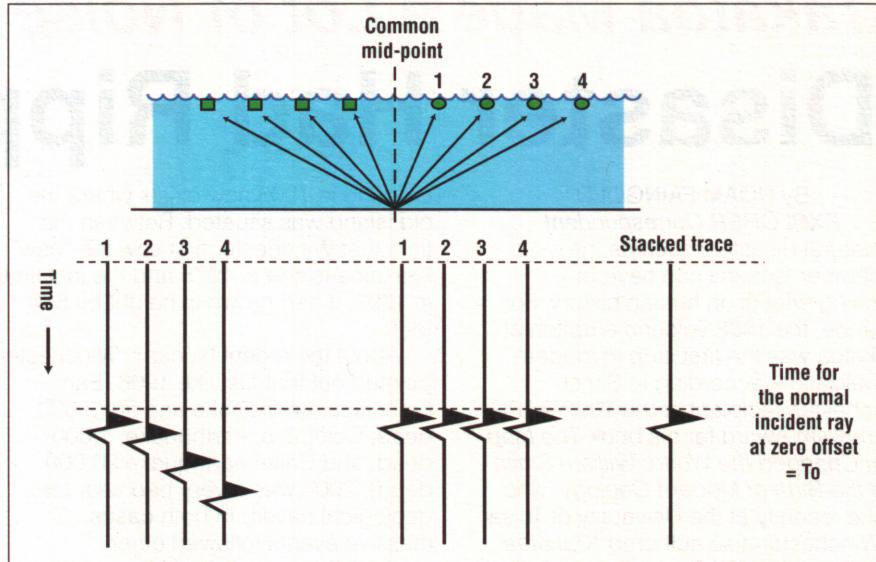


Figure 1. The old concept of stacking prior to migration.

### Moveout Equation and Stacking Velocities

The equation that relates the acquisition geometry (source-to-receiver offset, or SRO) to the subsurface velocities was given to us by C. Hewitt Dix and is called the Dix Moveout Equation. The geometry and the subsurface model related to the velocities are shown in Figure 2, along with the moveout equation. The equation compares the reflection arrival time (TT) of a reflection at an offset SRO with the reflection travel time (TO) at zero offset. The difference between these two times is the moveout correction applied to the reflection events for a trace at offset SRO.

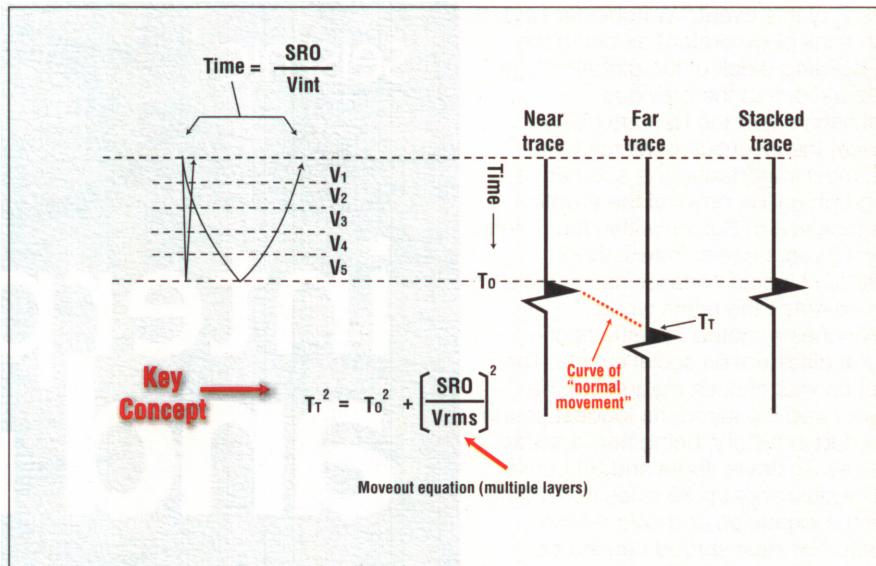
The velocity in this equation is a "time-weighted root-mean-square average" of all the individual velocity layers. For this reason, the stacking velocity is referred to as both Vstack and Vrms. These have become synonymous, even though the moveout equation stated in Figure 2 is actually an approximation.

The important work of C. Hewitt Dix gave us a second equation that is really the key to using stacking velocities for depth conversion. For any given velocity analysis location, optimal stacking velocities are picked for the major reflectors. The data set, therefore, consists of the reflection travel time at zero offset (TO) and the stacking velocity (Vrms) for each event. The interval (rock) velocity referred to as Vint, between any two layers for which TO and Vrms have been determined is given by:

$$V_{int}(i)^2 = \frac{V_{rms}(i)^2 T(i) - V_{rms}(i-1)^2 T(i-1)}{T(i) - T(i-1)}$$

If we can derive Vint from the TO -- Vrms pairs, a depth corresponding to each time can be easily calculated, thereby converting time reflection data to depth. The velocity appropriately used to convert reflection times to depth is a "time weighted average velocity," referred to as Vave. This is simply the travel distance divided by the travel time. Converting stacking velocities (Vrms) to average velocities is a process called "Dix correcting" the stacking velocities.

In the presence of a dipping reflector, simple geometry shows us that traces that have a common midpoint do not actually have a common reflection point, but the data was forced to stack by using anomalous stacking velocities and then migrated. This was the compromise that was practical with the computer power at hand.



**Figure 2. The moveout equation for a layered model.**

### Prestack Migration

When computer power ultimately allowed us to fix the problem of getting the reflections into the correct subsurface location prior to stack with prestack migration, we had to re-look at the velocity analysis process. Every trace prior to stacking has a unique source and receiver location. We do not know where any given reflection actually came from, but the trajectory of all the possible reflection points lies on an ellipse with the source and receiver locations at the two focus points.

The strategy here is to sweep every sample of every trace in the data set into all of its possible points of origin. When all of these "swept" traces are added together, constructive interference builds the image of the actual reflector locations. This is illustrated in Figure 3.

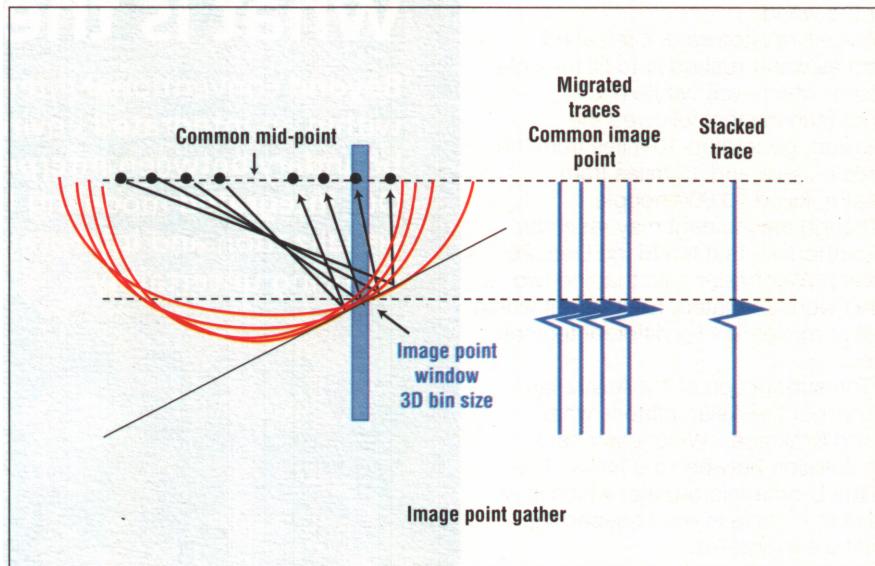
This process bypasses moveout correction -- and since the shape of every ellipse is a function of the velocities, where does this velocity information come from? The answer is the same as it was for the old method of stacking. We use the velocity that optimally aligns reflection events prior to stacking them.

Figure 3 shows the common midpoint traces that previously would have been corrected for moveout then stacked. Now they are migrated before stack to be in the correct location on the reflector. For this diagram, we have displayed the traces that have been migrated into a single bin location in a 3-D data cube. The moveout correction is implicit in the migration if the velocities are correct. The migrated traces prior to stack are inspected for their alignment -- that is, are they properly aligned to produce an optimal stack?. This is an iterative process in that we adjust the migration velocities to align the reflection events.

In the presence of a layered earth, the migration velocity is also a Vrms average of the layer velocities, so this amounts to the same choice as it did for moveout correction. Since the migration velocity is a Vrms average of the layer velocities, the Dix equation is still valid to convert the time image to depth. Recently, the product of prestack migration has been an image in depth. The driver for depth migration is a velocity model that once again is derived from the imaging process.

In either case, if we stack the data to produce stacking velocities, or migrate the data to produce migration velocities, there is a component of interpretation in that we choose the velocities that optimally align the reflection events. Both of these processes generate Vrms velocities that become the data base that we call “seismic velocities.”

The relationship between Vrms, Vint and Vave is shown in Figure 4.



**Figure 3. The new concept of migration before stacking.**

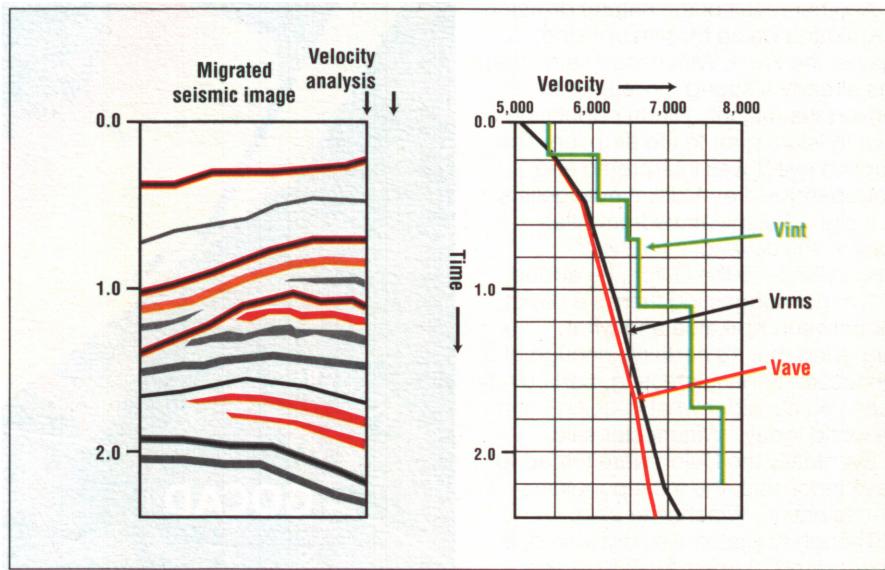


Figure 4. The suite of velocities derived from migrating the data.