Geophysical Corner April, 1998

Normal Moveout An Effect, Process

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by the AAPG Geophysical Integration Committee. This month's column is the first of a two-part series on "Moveout: What Is It, and What's Normal About It?")

By CHRISTOPHER L. LINER

Petroleum seismology is, and always has been, changing very quickly.

You might have heard whispers about exotic topics like crosswell tomography, wavelet transforms, cluster analysis, texture segmentation impedance inversion, geostatistical estimation, etc.

So why in this high-tech age is someone writing about something as ancient as normal moveout?

The answer involves the importance of understanding fundamental concepts, the natural lead-in that normal moveout provides to the juicier topic of dip moveout (to be covered here next month), and a chance to do it without any equations.

Normal moveout has two meanings – it is both:

☐ A seismic effect.
☐ A seismic processing step.

By itself, the term "moveout" goes back to the earliest days of reflection seismology in the 1910s. In those days a seismic shot consisted of a source (dynamite) sending waves into the earth to bounce around and return to a few geophones. The data were preserved as wiggly lines (traces) on a rotating drum of paper, or as dark lines on a photographic record.

The human eye is wonderfully adept at seeing patterns and relationships in very confusing data, e.g. recognizing a face across a crowded room full of strangers. Early seismic records were like that – lots of noise, not much signal. But the signals were there, and skilled interpreters could recognize them.

Some of these signal events came in straight lines across the traces; others formed curves. But whatever the shape, each kind of signal showed a delay from trace to trace as we move away from the source – and thus was known as moveout.

A Normal Example

A shot record is the collection of seismic traces generated when one source shoots into many receivers, as shown in Figure 1.

In this example, the upper black

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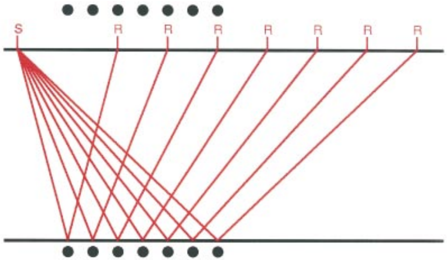
Figure 1 – A shot record showing source, receivers, rays, reflection points and midpoints. The increase of travel time with offset (source-receiver distance) is the normal moveout effect.



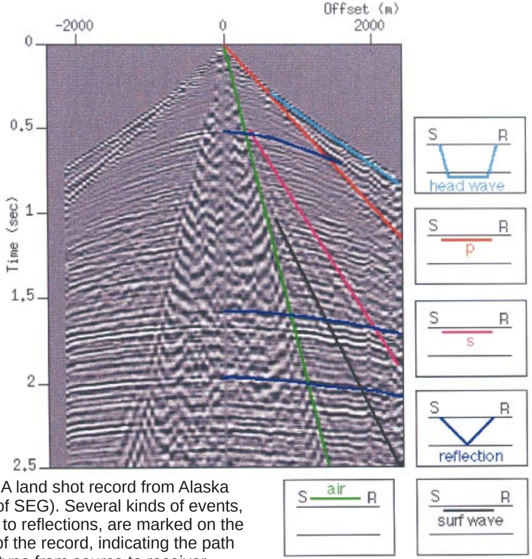


Figure 2 – A land shot record from Alaska (courtesy of SEG). Several kinds of events, in addition to reflections, are marked on the right side of the record, indicating the path and wave type from source to receiver.

Graphics courtesy of Christopher Liner

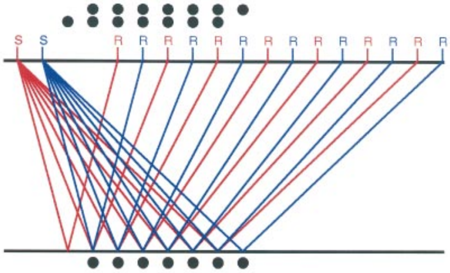


Figure 3 – A seismic line is acquired by rolling the shot and receivers a certain distance forward. This gives more than one ;trace with the same midpoint.

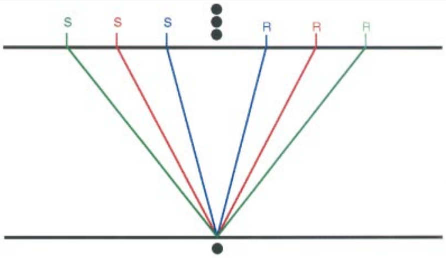


Figure 4 – All the traces that live at the same CMP location will be processed together as a family. Ultimately, they will be added (stacked) to make one stack trace that lives at this location. The process of Normal MoveOut (NMO) helps prepare the traces before they are added together.

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line is the acquisition surface and the lower one is the reflector. Dots below the reflector show subsurface reflection points. Halfway between the source and a receiver is a point on the ground called the midpoint. These are shown as black dots above the acquisition surface.

Where there is no dip, the midpoint is directly above the reflection point. As the offset (source to receiver distance) increases, so does the travel time from source to receiver.

This characteristic delay of reflection times with increasing offset is called normal moveout.

In Figure 2 (page 26), reflections can be seen in real data along with other kinds of events.

There are receivers on both sides of the shot in this case. The right side has been marked-up to identify different kinds of events – direct arrivals (p-wave, s-wave, air wave, surface wave), head waves and (a few) reflections. The left side is uninterpreted.

The reflection events have a hyperbolic shape characteristic of normal moveout.

Making the Earth Flat

So now we know something about normal moveout, the effect.

What about normal moveout, the process?

For this we will use the acronym NMO (Normal MoveOut) since for most people this term implies the process, not the effect.

What is NMO? The short answer is: A seismic processing step whereby reflection events are flattened in a common midpoint gather in preparation for stacking.

(If this makes sense then you can move along to the next article. Otherwise, read on.)

A seismic line is generated by “rolling” the shot and receivers forward a certain distance and firing again. As shown in above Figure 3, this generates a second shot record which partially overlaps the first.

Note that six of the seven reflection points from the blue shot were also reflection points for the red shot. This occurs by design and is called Common MidPoint (CMP) shooting.

As the shots roll along there will be many source-receiver pairs with the same CMP location, and the CMP fold is the total number of traces that live at any given CMP.

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CMP fold can vary from as few as six (low-fold land 3-D) up to several hundred (2-D marine).

The reason for gathering multifold data is that we get redundant information about the reflection point down in the earth, and this redundancy can be used to reduce noise and create a more reliable image. Our goal is to eventually process all these traces as a family and add them together (CMP stack) to make one trace that lives at this CMP location.

NMO is aimed at removing the hyperbolic curvature in reflection events. Basically, it is removing the effect of offset. If this is done properly then the reflection should come in at the same time for all offsets (since we have removed any travel time delay due to offset).

In short, reflection events should be flat after NMO.

Figure 5 shows the data after NMO processing (and air wave removal). In this case, we see the events are pretty well flattened by NMO, but there are a couple of interesting areas.

The blue box shows some disturbing behavior along a flattened reflection. This has nothing at all to do with NMO, but is related to lateral changes in the near surface layers (termed a static problem).

The red box shows what NMO does to the direct arrivals. Since these were linear and not hyperbolic, NMO has not flattened them. Also, note how fat (not flat) these events look after NMO. This is because NMO actually operates by stretching the trace – and the shallower something is the more it stretches.

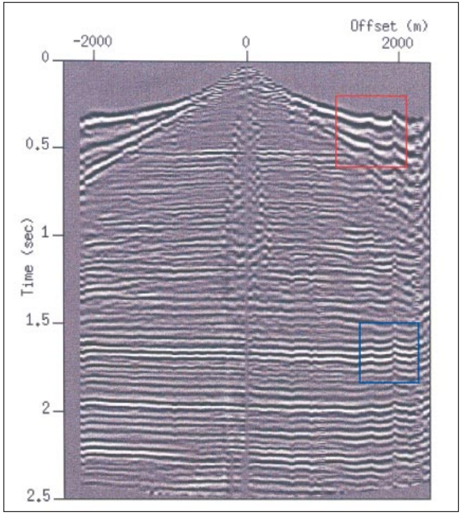

Figure 5 – Data from Figure 2 after Normal MoveOut processing (and air wave removal). The blue box highlights static problems; the red box shows stretched direct arrivals and head waves. Reflection events are flat (more or less).

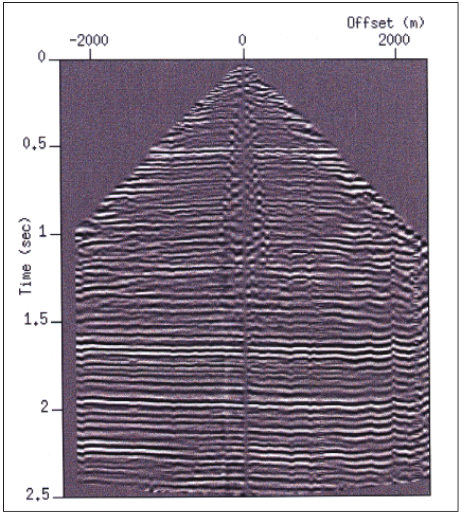

Figure 6 – Data after NMO with a 25 percent stretch mute. Note that the nasty events in the red box of Figure 5 have been removed.

Since our goal is to eventually flatten all these traces and add them together to make one trace, keeping this kind of stuff would wipe out shallow reflections. It needs to go.

We get rid of these events by muting – which is nothing more than replacing the offending data with zeros. We could do this by hand, but a seismic line may contain many thousands of CMP gathers.

It turns out we can let NMO itself do the muting for us. The idea is to keep track of how much stretch NMO is doing to the trace. The stretch changes down the trace – biggest at the top, smallest at the bottom. So the idea of an NMO stretch mute is to set a limit on how much stretch we are going to allow.

If the stretch gets bigger than our limit, then the data values are replaced by zeros in that part of the trace. Figure 6 shows the result of allowing a 25 percent stretch in the NMO process.

What About Dips?

At this point more than one astute reader is saying, “Yeah, yeah, you

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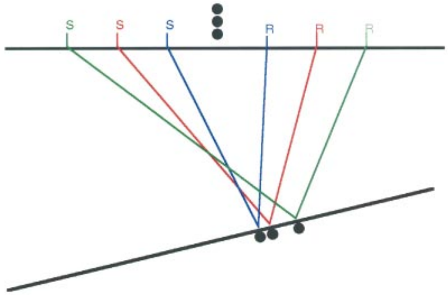

Figure 7 – When the reflector is dipping, midpoints are not vertically above reflection points. Compare Figure 4. NMO can handle this case, but breaks down when multiple dips are present in the subsurface.

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academic types are all alike – ignoring the real world. What about dipping beds?"

Figure 7 gives a hint of things to come.

The basic problem is that when the bed dips, midpoints are not vertically above reflection points. Furthermore, the reflection points become unevenly spaced along the reflector.

The fact is that NMO has a constant dip assumption built in. If every bed were dipping at the same angle, say 23 degrees, it turns out we could do NMO just fine. The real problem comes where there are many dips in the subsurface. In this case, NMO acts like a dip filter – preferentially passing some dip the processor chooses while suppressing others.

This was particularly notorious in places like the Gulf of Mexico, where gently dipping beds often meet steep salt domes. You could do NMO in such a way as to get a good image of one or the other, but not both.

This was the situation up until about 1981 or 1982. Then something new came on the scene. It was called – you guessed it – dip moveout.

That is our next article.

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Geophysical Corner May, 1998

Dip MoveOut Just Isn't 'Normal'

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by the AAPG Geophysical Integration Committee. This month's column is the second of a two-part series on "DMO – The Other MoveOut.")

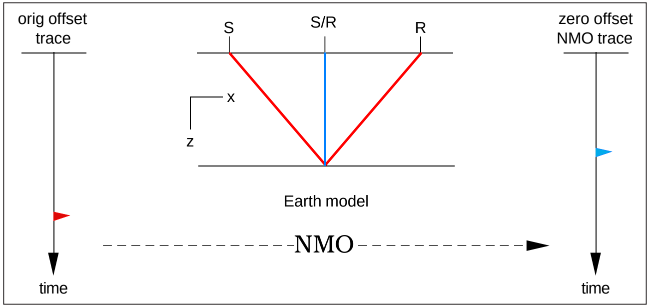

Figure 1. Normal MoveOut (NMO) is a process applied to pre-stack data. Here the effect is shown on a single trace with one reflection event (left). NMO assumes the reflection comes from a horizontal interface in the earth (center). Using a velocity function supplied by the processor, NMO adjusts the original time (red) to that which would have been observed at the midpoint, marked S/R. The blue path is two-way time down and back, which must be less than the red path time. So NMO's job is to move the reflection event up the trace (right). Note NMO operates on one trace at a time, which makes it inexpensive.

Graphics courtesy of Christopher L. Liner

By CHRISTOPHER L. LINER

You can talk about Normal MoveOut (NMO) all day long without mentioning migration – but Dip MoveOut (DMO) is another matter.

In fact, DMO started out with the cumbersome-but-descriptive name "pre-stack partial migration." That was in 1979, but at least two years earlier there was a DMO processing product on the market. It was named DEVILISH, an acronym for "dipping event velocity inequality licked."

You think I am making this up, but it's true.

Before moving on, I should say something about name-dropping. Unlike NMO, the development of DMO is very recent. The people involved are still alive and kicking.

We owe a debt of gratitude for their hard work and ingenuity, but if I mention one name I will have to mention them all. So we will deal here with the concepts and not the names.

We will attempt to understand what DMO is and does, not create a historical who's who.

* * *

Now, back to business.

In the field, a source and receiver are located, say, 3,000 meters apart (the offset) and a trace is recorded. This is pre-stack data.

From last month's article, we know that NMO lives to remove offset from pre-stack data. In the computer, we adjust this trace to simulate one that would have been recorded with no effect at a point half-way between the source and receiver (the midpoint).

This new trace is a zero-offset trace, and adding (stacking) all such traces that live at this midpoint yields a stack trace.

All the stack traces plotted side-by-side form the stack section, which is raw material for post-stack migration processing.

Figure 1 illustrates the NMO idea.

On the left is a field trace with some arbitrary offset and one reflection event. NMO assumes the reflection comes from a horizontal interface as shown in the middle figure.

This is an important and restrictive assumption.

The NMO correction adjusts observed travel time (red path) to midpoint zero-offset travel time (blue path). So after NMO, the event is moved up in time. Technically, we are changing time coordinate from raw time, t, to NMO time, t_n.

* * *

But what if the interface is not horizontal?

It's tempting to think that the reflector could be anywhere and still be consistent with the observed travel time. But this is not the case.

Let's say the original travel time

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is 1.0 second, and we know the velocity is 3,000 m/s. The total distance traveled has got to be 3,000 meters. So all valid reflector positions have one thing in common: The total distance from source to reflection point to receiver is constant, namely 3,000 meters.

Thinking back to Geometry 101, this is just the definition of an ellipse with the source and receiver at each focus.

Figure 2 shows such an ellipse.

Remember the goal is to remove offset and thus create a zero-offset section. NMO gives one of many possibilities, DMO gives all the rest. In Figure 2, some of the possible original travel paths are shown (red), along with the single travel path after NMO (blue) and the many travel paths after DMO (green).

From Figure 1 we saw that NMO is a process that takes one trace in and gives one trace out. DMO is different. One trace into DMO generates many traces out – all of which live between the original source and receiver locations. This is illustrated in figure 2 (lower) and figure 3 (page 66).

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Let's consider figure 3.

We have a panel of data containing only two spikes of amplitude on one trace (left panel). The other traces are there, but empty.

NMO moves the spike up on the same trace (middle panel). DMO then throws the spike out along a curve, which lives between the source and receiver (right panel). This is sometimes called the DMO smile. Since it comes from a spike or impulse on the input data, it is also called the DMO impulse response.

Now here is some magic. By creating the DMO smile, all possible dips are handled simultaneously. We do not need to know what the dip is in the earth – by processing all traces with DMO the actual reflections will emerge because they are tangent, at some point, to DMO smiles.

Also, DMO does not depend on the velocity, so long as the velocity is constant.

While not strictly true, this is one of the things that got everyone initially excited about DMO. And its weak dependence on velocity is one reason it is still so widely used.

Anyway, it is unlike NMO and migration, which always need velocity information, and are quite sensitive to it. Another big selling point is that NMO+DMO, rather than NMO alone, passes *all* dips into the stack section.

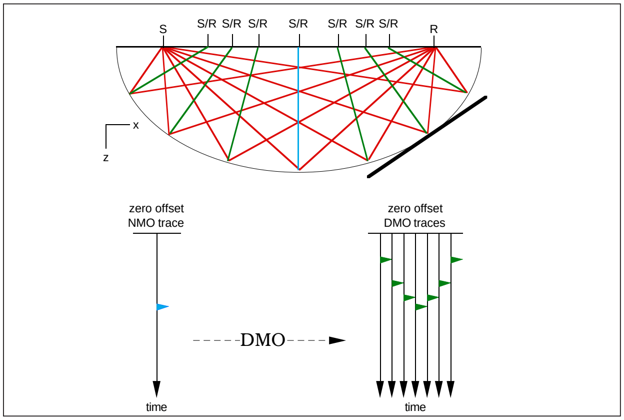
This gives more raw material for migration to work with in creating a final migrated image.

Since DMO spreads things out across traces, it is much more expensive than NMO, which only shifts things up on one trace. Even so, NMO+DMO is still cheaper than pre-stack migration.

Figure 4 (page 66) gives some representative run times for these, and other, processes.

See **DMO**, next page

Figure 2. Dip MoveOut (DMO) is a process that is applied after NMO. Since NMO assumes the reflection comes from a horizontal bed, it is picking up only one of many possibilities. For one trace with one reflection event, all possible travel paths have the same length – that is, the distance from source to reflection point to receiver is a constant. The geometrical shape with this property is an ellipse (upper). Some of the original path possibilities are shown in red. NMO reduces travel time based on a horizontal reflector (blue path), while DMO does all the other cases (green). So the action of DMO (lower) is to take the NMO'd event (blue) and broadcast it across several nearby traces (green). Since DMO operates on several traces, it is expensive.



DMO

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So here is the bottom line. If structure and velocity variation are not too nasty in an area, we can get away with a traditional processing sequence:

NMO + DMO + Stack + PostStackMigration.

In this equation, "+" means "followed by."

However, if things get really tough down there (e.g., subsalt), this sequence breaks down and fails to give a good image. In this case we are compelled to do one grand process called pre-stack migration.

In fact, DMO was originally invented to complete the following equality under mild subsurface conditions:

PreStackMigration = NMO + ? + Stack + PostStackMigration.

The "?" turned out to be DMO – and is used world-wide every day.

(Editor's note: Liner is associate professor of geosciences at the University of Tulsa. He may be contacted via e-mail at cll@utulsa.edu, or http://douze.utulsa.edu/~cll/ChrisLiner.html)

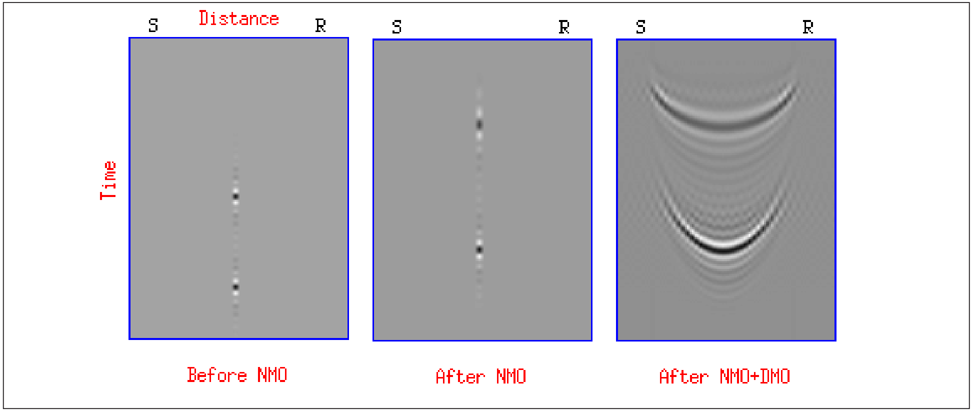

Figure 3. This numerical example illustrates the effect of NMO and DMO on a trace with two spikes, or reflection events. The spikes are shown on the left surrounded by a bunch of zero traces. The source and receiver location are denoted by S and R, respectively. NMO shifts the spikes up in time, but only on the same trace (middle). DMO throws the NMO'd spike amplitude out along a curve to handle all possible dips. This curve is called the DMO smile, or DMO ellipse, or DMO impulse response. Notice the DMO smile only lives between the original source and receiver positions.

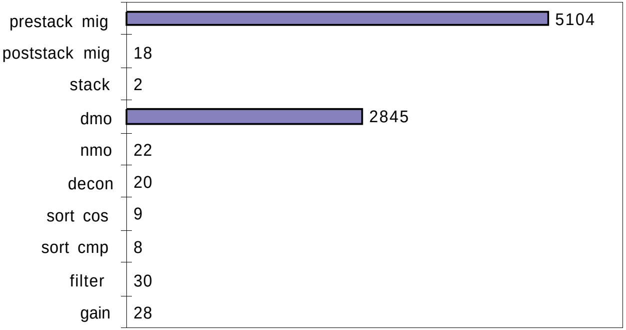

Figure 4. This chart illustrates processing time in seconds for a small sample data set. The relative times are important, not the size of the data set or kind of machine used. Starting from the bottom, the processes represent (in order) a more-or-less standard processing flow. By far the most expensive item here is DMO. But if we run pre-stack migration instead, it is even more expensive. Basically, the pre-stack migration replaces NMO, DMO, stack and post-stack migration. Due to the cost, pre-stack migration is a method to be used only when required by strong lateral velocity variations and/or extreme structure.