Some Thoughts on Looking for SP Conversions

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In this paper I will discuss a few ways of looking for SP (and possibly PS) converted waves in a seismic section. One method I will not be discussing is stacking at some sort of average PS velocity. Instead, I will be looking for ways of looking for SP waves in unstacked sections. SP waves in unstacked sections are not only more convincing than in stacked sections, but unstacked SP sections can also be subjected to such things as velocity analyses. A basic assumption is that our data is from a land seismic survey with a dynamite source and ordinary (as compared to three-component) geophones. The hope is that the dynamite source will produce S as well as P waves, and that even if the dynamite is no better than a Vibroseis at generating S waves, at least the source is below the weathering layer. If we can assume that some of these S waves will be converted to P waves on reflection, then three-component geophones are not really necessary for our purposes. They would be nice, however, for picking up PS conversions.

I will now discuss three possible methods of searching for SP conversions. I call them the Model-and-Subtract, the Velocity Filter, and the Motion-Filter methods. After discussing these three approaches, I will discuss the problem of imaging: how do you tell the SP waves from everything else you might see, and how do you convince other people that you aren't just imagining things?

Velocity Filters

This is perhaps the most straightforward method, and perhaps the one most likely to produce results. In this method, you apply some sort of velocity filter to the data in the hope of separating the lower-velocity SP and PS waves from the PP waves. The velocity filter could be applied either by performing a PP-velocity normal moveout, dip-filtering, and inverse NMOing the result, or by applying a time- and space-variable dip filter to the data. This approach has the advantage of being quick and simple. One disadvantage is that it would not work well in the presence of residual statics. I suppose,though, that the main reason I am not especially enthusiastic about this particular approach is that it does not seem very interesting. It might work, but it seems unlikely to provide any interesting results other than the SP conversions themselves.

Model and Subtract

The method that I am currently working on consists of least-squares fitting a PP-reflector model to the data, and then somehow subtracting the model from the data. What should be left are SP waves, PS waves, and any other sort of "noise" that doesn't fit the model. The model is based on the assumption that NMOed PP-reflector data can be considered to consist of several terms convolved together: $D_{sg} = S_s * G_g * Y_{\frac{s+g}{2}} * H_{\frac{s-g}{2}}$. Here D_{sg} corresponds to the data (the traces) in a shot-geophone coordinate system, while the S, G, Y, and H terms are functions of shot, geophone, midpoint, and offset respectively. The idea is to model a two-dimensional data space in terms of a group of one-dimensional vectors, using a least-squares best-fit criterion. It is based on Taner and Koehler's paper on surface-consistent statics removal (Taner, 1981).

So far, I have not succeeded in fitting real data to such a model. The model tends to go unstable after only one iteration, which may suggest that my model does not have enough constraints. Once I do have S, G, Y, and H terms that seems to fit, there is the problem of how to go about subtracting them from the data. Simple subtraction will probably not work too well, so I must come up with some sort of filtering scheme which will get rid of that data which fits the PP model. I have not yet done so.

There is an interesting difference between this scheme and schemes that try specifically to emphasize SP waves. While these other schemes emphasize only SP waves, the model-and-subtract approach filters out *only* PP waves. I like the latter approach for two reasons. First, by removing only the PP waves, it is possible that we will not only find the SP waves that we expect, but unexpected things as well. For instance, it might be interesting to look at diffractions from point scatterers. Second, filtering in *favor* of something sometimes has the tendency "to make noise look like signal" (to quote a note that Jon wrote on one of my rough drafts). Of course, it is also possible that the SP waves will be buried in noise even after the PP reflections are removed, necessitating a scheme that filters out everything except the SP waves that we expect to find.

The advantages, then, of this method are: it will throw away only PP waves, the problem itself seems more challenging, and it can (although I haven't mentioned this before) handle residual statics in the data. The main disadvantages are that it is untested, that there is no reason even to be sure that the data can successfully be fitted to a PP model, and that I haven't formulated very clearly the subtraction stage of the algorithm.

Motion Filtering

This approach is based on our experiences with movies of seismic data. While looking at common-shotpoint movies, we noted that various events seem to remain in the same common midpoint positions. This suggested that we are able to see horizontal variations in reflectivity. Now recall that the raypaths of SP conversions are not symmetrical -- that is, the angle of incidence does not equal the angle of reflection. As a result, y does not equal $(s+g)/2$, which means (if you think about it for a while) that horizontal variations in SP reflectivity would create "movement" in movies that would differ from the "movement" that is created by variations in PP reflectivity.

The point of all this is that we can create "motion filters" that will favor one type of motion over another. This can be done by using a sort of dip filter -- just as dip filters are usually applied to planes that show dip in time versus offset, for instance, this filter would be applied to a plane that showed "motion" in, say, offset as a function of shot number, at a constant value of time. (This explanation may seem a bit mystifying if you are not familiar with my article in SEP-28 (Sword, 1981) and my talk on SEP Tape 1.) We can either filter out motion associated with PP reflections, or filter in favor of motion associated with SP reflections.

There is a problem with this approach, however. This filter will filter the motion caused by variations in reflection coefficients (if that is indeed what causes the motion), but it will not filter any constant components of the reflection coefficient. Thus, if we try to filter out PP reflections, we will not get rid of any PP reflectors that do not vary greatly along their length, and if we try to filter in favor of SP reflections, we will only see SP reflectors which do vary along their lengths. The latter might be valuable, in that it might be convincing evidence that SP waves are indeed there, but it does not succeed in extracting all of the information that there is to be extracted. This approach does have one major advantage over the other two, however. Unlike the others, it is capable of distinguishing SP conversions from low-velocity PP multiples. Thus, while this method by itself is probably not very good for extracting SP waves, it would seem to be a useful approach to the problem of imaging -- that is, the problem of determining whether your claimed SP conversions actually are created by SP waves.

Imaging

As just mentioned, once we have something that we claim is an SP section, we must present some sort of evidence for our statement. An obvious check is whether the velocity of our alleged SP waves is significantly lower than that of PP waves. Unfortunately, our expected velocity would not be the S-wave velocity, but an average, more or less, of the P-wave and S-wave velocities, so that the velocity is not as effective a parameter as it would be in the case of SS waves. The main problem with a velocity analysis, however, is that it is not very effective at distinguishing SP conversions from low-velocity PP multiples that might be created in the weathering layer. If we are somehow certain that there are no PP multiples in our section, we can look for SP conversions based on the assumption that they will look more or less like lower-velocity multiples of PP reflectors. This approach would be especially effective in areas with dipping or undulating reflectors, where you could distinguish "multiples" (that is, SP conversions) from primaries.

Possibly the most effective approach, however, would be something similar to the motion-detector approach mentioned above, except that instead of some sort of filter, we use our eyes as the motion detector. Ideally, we would run some sort of movie on our AED terminal, and anything that wasn't stationary could be assumed to be associated with SP conversions. In what framework, then, would PP "motion" appear stationary while SP "motion" wouldn't? A good choice would seem to be a movie composed of NMOed common-offset sections. Almost by definition, common midpoints (data points) on PP reflectors would appear to be stationary. Common data points on SP conversions, on the other hand, would not. Actually, of course, common datapoints on a PP reflector will appear to move when the reflector is dipping, so that may throw the method off somewhat. However, there would seem to be at least some grounds for hoping that this method would make it possible to distinguish SP conversions from regular or multiple PP reflections. There is also, however, a possible reason for supposing that this method might not work. So far, we have assumed that the motion in movies is caused by variations in reflection coefficient along a layer. If, on the other hand, the motion is caused by something else, say diffraction from point scatterers, then this method might not work. Also, there are many other sources of spurious motion -- for instance, residual statics, and variations in attenuation in layers above the reflector of interest. If this method does work, however, it is possible that it will work not just on datasets where the SP conversions have been emphasized, but on unprocessed data sets as well. If this is the case, we might be able to use NMOed common offset movies of "raw" data to see if SP conversions are present in the first place, and if so, where.

Some Other Ideas

There are quite a few other ways of going about looking for SP conversions, using various characteristics that haven't been mentioned yet. For instance, if the S waves are created by a dynamite source, it seems reasonable to assume that they would have the same wavelength as the P waves that were also created. But since the S velocity is lower than the P velocity, the S waves would tend to have lower frequencies than the P waves. Thus, simple filtering might serve to bring out the S waves. Another characteristic may be observed, if we can assume that PS and SP conversions are recorded with about equal amplitudes. If these waves reflect from a dipping layer, a sort of splitting will be observed on common (non-zero) offset sections. The amount of splitting will vary with the offset, and thus should be observable on common-offset movies.

Strategy

Considering all of the above, it is possible to work out a more-or-less coherent strategy to follow in searching for SP conversions. First of all, we need to find a suitable data set. Once we have that and have removed static shifts, we should NMO the data and look at common offset movies to see what sort of things we can see. If there seems to be some hope that SP waves are present, we should then probably apply a velocity filter that discriminates against PP waves. Although I don't especially like that particular approach, it is not too difficult, fairly likely to succeed, and thus ought to be tried. Fitting data to a PP model is worthwhile, and could yield unexpected benefits, but it is a complex problem and might not succeed at all. Once we have something resembling an SP section, we can again image it using an NMOed common offset section movie (I am carefully avoiding specifying an NMO velocity), and see if anything likely turns up.

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REFERENCES

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