Chapter 3. Downward Continuation of Profiles

Introduction

Although profile data are not central to the velocity estimation problems we wish to deal with in this thesis, we will spend some effort to describe the profile problem in the hope that familiarity with profiles will make the somewhat more difficult problem of downward continuation of sections easier. Since profiles are generated with only one source, much observational experience and insight can be readily applied to them. This is not the case for sections. The fact that the wave field to be downward continued is generated by many separate sources often makes it difficult to apply insights gained from other wave phenomena to sections. Another reason for studying profiles as an introduction to downward continuation, is that profiles can be described with one less coordinate than sections.

Downward Continuation and Reflector Mapping

We shall begin with a discussion of what we mean by downward continuation and of why it is important. By downward continuation of seismic data we mean synthesizing data that would be recorded with buried receivers from the data recorded at the earth's surface. Figure 3-1 gives an indication of the desirability of downward continued data. The top frames show the hyperbolic nature of the data recorded with surface receivers over a point scatterer. The bottom frames show the reflections that would be recorded if the receivers were located at the depth of the scatterers instead of at the surface. (Note that we have excluded horizontally propagating waves.) A look at the buried receiver data shows that reflections are recorded only at the receiver positioned on the scatterer. Figure 3-1 illustrates the general statement that data recorded with buried receivers give a simpler picture of the subsurface than do data recorded at the surface.

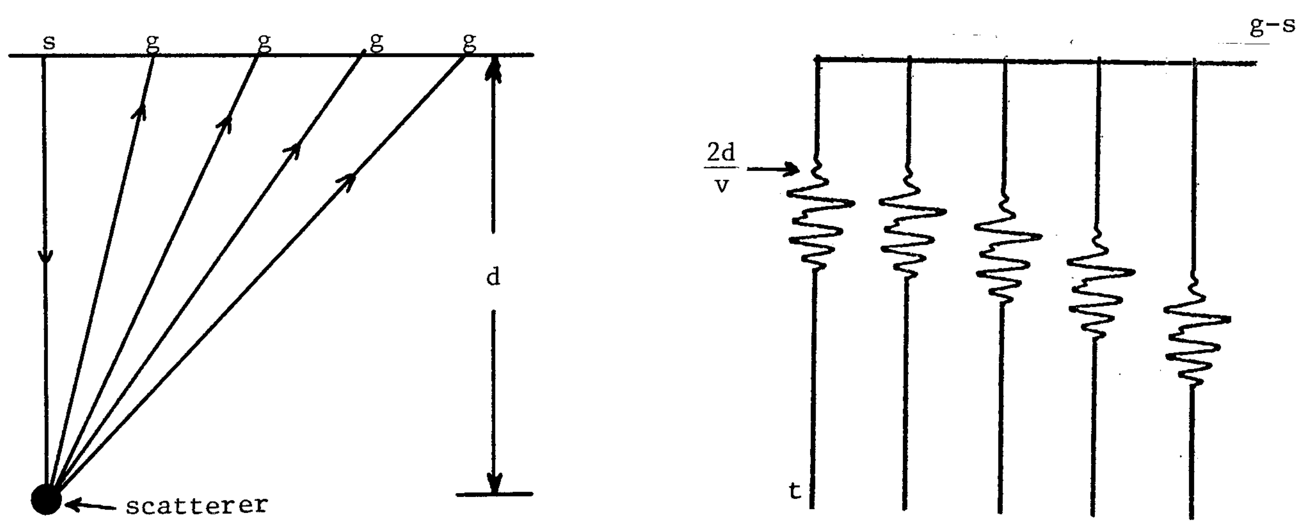

Figure 3-1a. Profile recorded over a point scatterer. The frame on the left shows the reflection paths. The right frame shows the data. Wave velocity, v , is constant.

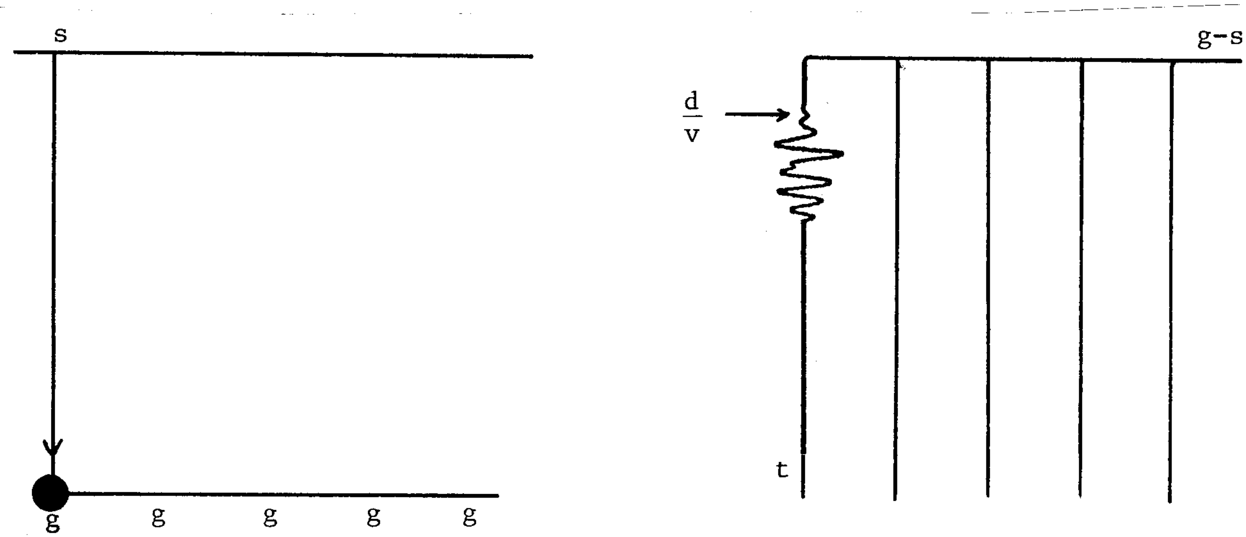

Figure 3-1b. Profile reflections from a point scatterer recorded with buried receivers. Since we exclude horizontally propagating waves reflections are received only at the geophone located at the point scatterer.

To describe the uses of downward continued data a bit more precisely we shall need to consider reflector mapping in general. The basic principle of reflector mapping is that reflectors exist at points in the earth where the first arrival of the downgoing wave is time coincident with an upcoming wave. In the absence of multiple reflections, this is the only principle needed to map subsurface reflectivity in a region of known velocity. Since data recorded with buried receivers are just the upcoming wave field at the receiver location, downward continued data contain almost all the information necessary to determine reflector geometry. The other information needed is the subsurface downgoing wave. Fortunately, in the absence of multiple reflections, synthesis of the downgoing wave is simple, since to first order it is independent of subsurface reflectivity. One does not err much in assuming that the downgoing wave of profiles can be modelled by a quasi-spherical wave expanding in the velocity structure of interest. Thus, one reason downward continuation is interesting and important to the geophysicist, is that in many cases, the ability to perform downward continuation is equivalent to the ability to map subsurface reflectivity.

The process of transforming seismic data into a map of subsurface reflectivity is usually called migration. The reflectivity maps are often called the migrated data. Although downward continuation has its most obvious application to the field of migration, in later chapters we show that it can be an important tool in velocity estimation.

A final topic we need to discuss in this section is the operator which we should use for downward continuation. The wave equation is the operator which governs propagation of the upcoming wave from the reflector to the surface receivers. Accordingly, we shall use this same operator, albeit time reversed, to propagate (downward continue) the upcoming wave from the surface back to the reflectors.

Moveout Correction

The process of reflector mapping we have described requires downward continuation of the upcoming wave and a determination of where the downgoing and upcoming wave are time coincident. Consider the case where the reflectors are plane layered and velocity is constant. If the downgoing wave is a vertically incident plane wave, the search for time coincidence is simple because neither the downgoing or upcoming wave depends on the horizontal coordinate. This simplicity is lost in the profile geometry because the downgoing wave is spherical. Its arrival time and the arrival time of the reflected wave at a particular receiver depend on both the vertical and the horizontal coordinate of that receiver.

Even if we ignore the question of time coincidence, figure 3-2 shows that downward continuation of profile data will probably be more difficult and expensive than continuation of the reflections generated by a plane wave source. For the constant velocity, flat reflector case, downward continuation of plane wave reflections amounts to simple laterally invariant time shifting. Profile wave field continuation requires hyperbolic time shifting and lateral repositioning of the data.

It would be a great advantage to be able to treat profile wave forms recorded over layered reflectors with the same ease as the wave fields generated by plane wave sources. One way of accomplishing this goal is to perform downward continuation and reflector mapping, in a coordinate system where the profile waveforms recorded over layered reflectors appear planar. To transform the data into these coordinates we shall need

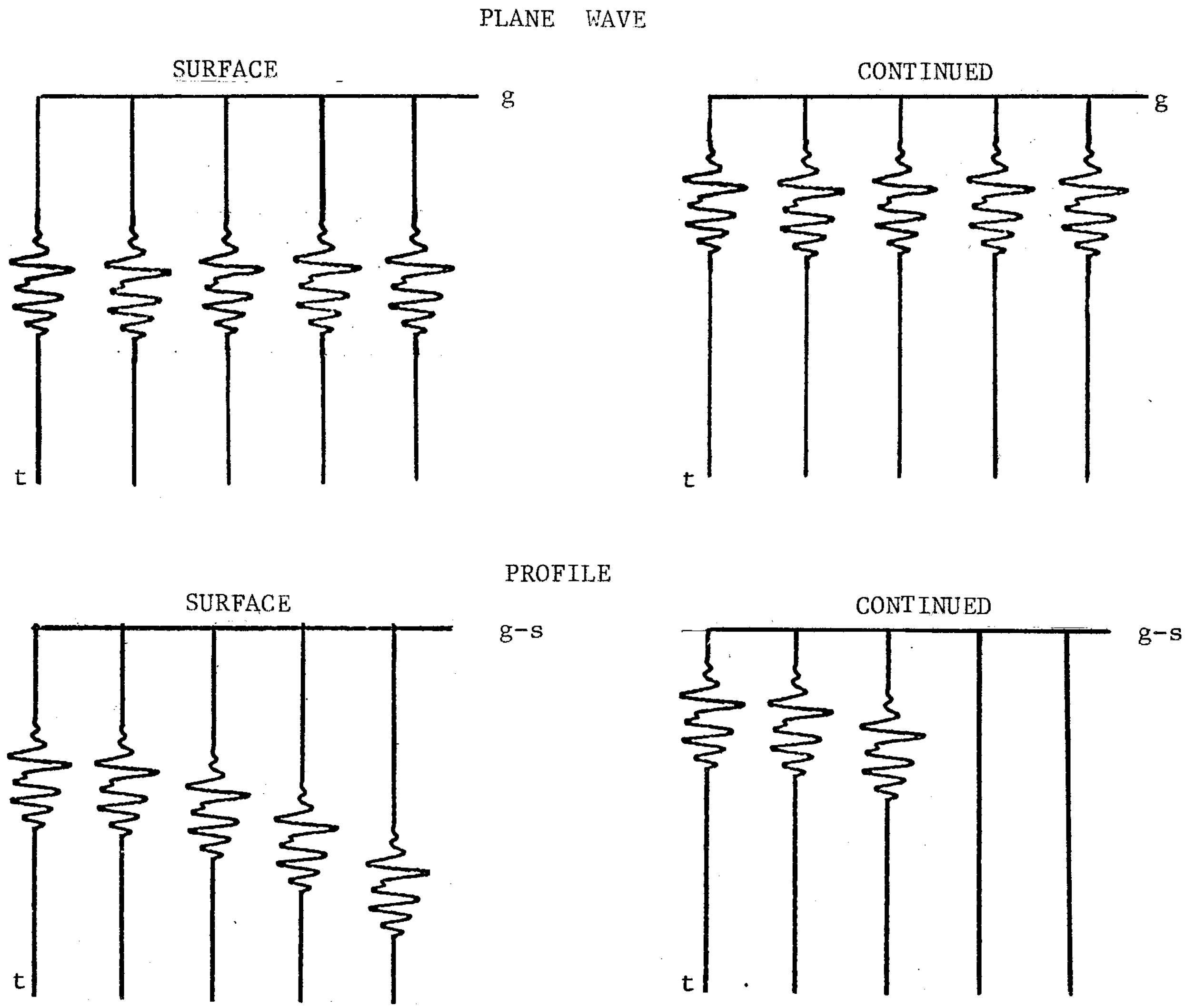

Figure 3-2. Profile and plane wave source data before and after continuation. The bottom frame shows an un-moveout corrected profile recorded over a horizontal reflector. The curvature of the downward continued data (right) is the result of the hyperbolic arrival times of the downgoing wave. The smaller horizontal extent of the downward continued data is due to the fact that reflection points of the surface data are at the midpoint of the surface shot and receiver. The top frame shows the data expected for a plane wave source. The downward continued data differ from the surface data only by a laterally invariant time shift. If moveout correction had been applied to the data of the lower frame they would have appeared exactly like the data of the top frame. Moveout correction requires that surface data be time shifted hyperbolically and that data recorded at each receiver be placed at the midpoint of the shot and that receiver.

equations which deform the hyperbolic arrival times of reflected spherical waves into horizontal lines. Another way of saying this, is that we need equations which correct for the differential travel time caused by non-zero shot receiver offset. Such transformations have long been used by explorationists. They are called normal moveout or or just moveout corrections. We adopt that terminology here. Data displayed in these hyperbolically deformed coordinates will be called moveout corrected data.

If the simplicity gained by using moveout corrected data was achieved only when the reflectors were horizontal, moveout correction would be of little value to us. However, moveout correction approximately corrects for the effects of shot receiver offset even when the reflectors are only approximately horizontal. Because of this, it is nearly always true that less work is required to downward continue moveout corrected data than raw data. This reduction is important to us because we shall use numerical methods to perform downward continuation. In general, the less work a numerical scheme must do, the more accurate and inexpensive it becomes.

In addition to reducing numerical-computational problems, the use of moveout corrected data also eases the determination of time coincidence of the upcoming and downgoing wave. To see this, consider a moveout corrected profile recorded over a curved or dipping reflector. Suppose each portion of these data was downward continued until the arrival time of the downward continued data corresponded to the vertical travel time associated with the receiver depth. In this case, the arrival time of the moveout corrected downgoing wave (the vertical travel time) would be the same as the travel time of the upcoming wave (the data). Thus, by our mapping principle the downward continued data would be a reflectivity map. By using moveout corrected data we replace the task of finding time coincidence of the upcoming and downgoing wave with the simpler task of insuring that the data are continued until their arrival time equals the vertical travel time associated with the receiver depth.

Because of the advantages associated with the use of moveout correction, any subsequent discussion of downward continuation in this thesis will always be in terms of moveout corrected data.

Coordinate System and Wave Equation

Once we decide to downward continue moveout corrected data, we are faced with the question of how the wave equation must be modified so that it is valid for wave fields modified by a moveout correction. To resolve this question we must consider in some detail what we mean by the wave equation and moveout correction.

We will consider the wave equation first. To a great extent the form and complexity of the wave equation depends on the materials in which one wishes to study wave propagation. More correctly, the form one uses does not depend on the materials, but instead on the assumptions about the materials (be they correct or not) one wishes to make. In this thesis we shall assume that the materials are such that wave propagation is adequately described by the scalar wave equation. We shall also assume that no shear wave can exist in the medium. In deriving continuation equations we shall also assume that any reflectors are independent of one horizontal coordinate and thus, we shall use a 2-dimensional wave equation.

The form of the wave equation also depends on the coordinate system in which it is expressed. Generally, we write the wave equation in a system directly relatable to physical space. In this discussion, we shall express it in a 2-dimensional cartesian coordinate system with g being the horizontal coordinate, z being the vertical coordinate with $+z$ down into the earth, and t being the time coordinate. To fix the system to the problems of interest we shall assume the receivers are distributed along the g axis and that the shot is located at $(g,z,t) = (s,0,0)$. With all these things in mind, we can write the wave equation which we assume governs our problem as

$$P_{gg} + P_{zz} = \frac{1}{\tilde{v}^2} P_{tt} + \delta(s-g,z,t) \qquad (3\text{-}1)$$

where P is a pressure and $\tilde{v}$ is the compressional wave velocity. We have used subscripts to denote partial derivatives. The delta function represents the source.

Now that we have the wave equation tied down, we will discuss moveout correction. As we have said previously, moveout correction is an operation designed to remove hyperbolic, source-receiver geometric effects from the data. An important property of this operation is that it is one-to-one. That is, each point on the field data (the upcoming wave recorded at the earth's surface) is mapped uniquely onto the moveout corrected profile. Because of this one to one property, moveout correction can be thought of as an invertible coordinate transformation from a set of field recording coordinates to a set of moveout corrected coordinates. We define these moveout corrected coordinates as follows: x is half the surface source receiver separation, d is a moveout corrected two-way travel time and r is the receiver depth. Using these definitions, and referring to Figure 3-3, we can express the normal moveout operation as

$$x = g/2\{ 1 + z/(v(t^2 - g^2/v^2)^{1/2})\} \qquad (3\text{-}2a)$$

$$d = (t^2 - g^2/v^2)^{1/2} + z/v \qquad (3\text{-}2b)$$

$$r = z \qquad (3\text{-}2c)$$

where v is a constant moveout correction velocity which need not be related to $\tilde{v}$, the velocity in the wave equation.

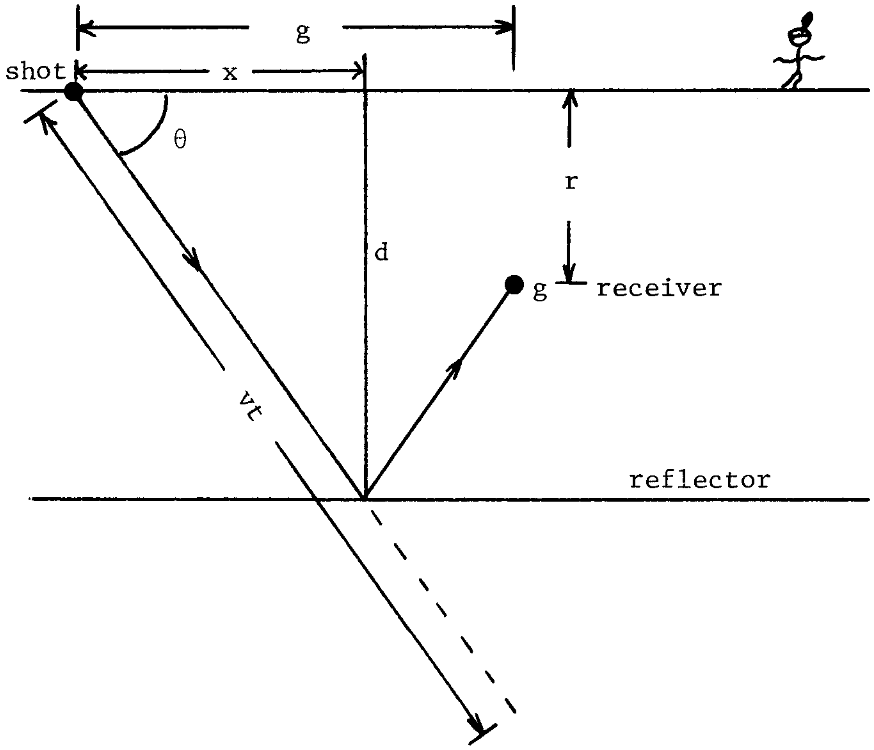

Figure 3-3. Geometry and coordinates for continuation of profiles.

These equations are an extension of the usual definition of normal moveout because they are depth dependent. For the moment, we will study the effects of moveout correction on surface data by setting $z = 0$. In this case we see that (3-2a) performs the operation of placing each trace at the midpoint of the shot and receiver. Equation (3-2b) performs the hyperbolic time shifts necessary to flatten reflections from plane layers.

The reason that we have explicitly included depth dependence is that we wish to describe moveout corrected data that are recorded at subsurface locations. Since x is usually thought of as the horizontal coordinate of the reflection point, and d as a measure of reflector depth, equations (3-2a) and (3-2b) include a z dependence such that for plane layer reflections, these quantities are constant along a ray path. This definition for d makes this type of moveout correction different than that discussed in the previous section, in that downward continuation in this coordinate system will cause no change in the arrival times of plane layer reflections which have been properly moveout corrected.

As we noted previously, transformation (3-2) is invertible; the inverse is

$$g = (d - r/v)\ 2x/d \tag{3-3a}$$

$$t = (d - r/v)\ (1 + 4x^2/v^2d^2)^{1/2} \tag{3-3b}$$

$$z = r \tag{3-3c}$$

Continuation Equation

Now that we have equations (3-1), (3-2), and (3-3), we return to the question of modification of the wave equation. Since moveout correction is a coordinate transformation expressed by (3-2) and (3-3), all we need to do to find the equation which governs moveout corrected data is to transform (3-1) into the moveout corrected coordinate frame.

As a first step we note that the wave fields are invariant under coordinate transformations. That's

$$Q(x,r,d) = P(g,z,t) \tag{3-4}$$

We have defined Q to be the wave field viewed in the moveout frame. Now we can transform the wave equation. Using the chain rule we have

$$
\begin{aligned}
P_t &= Q_x\, x_t + Q_r\, r_t + Q_d\, d_t \\
P_{tt} &= Q_{xx}\, x_t^2 + Q_{rr}\, r_t^2 + Q_{dd}\, d_t^2 + 2x_t\, d_t\, Q_{xd} + 2x_t\, r_t\, Q_{xr} \\
&\quad + 2\, r_t d_t\, Q_{rd} + x_{tt}\, Q_x + r_{tt}\, Q_r + d_{tt}\, Q_d \\
P_{zz} &= Q_{xx}\, x_z^2 + Q_{rr}\, r_z^2 + Q_{dd}\, d_z^2 + 2\, x_z\, d_z\, Q_{xd} + 2\, x_z\, r_z\, Q_{xr} \\
&\quad + 2\, r_z\, d_z\, Q_{dr} + x_{zz}\, Q_x + r_{zz}\, Q_r + d_{zz}\, Q_d \\
P_{gg} &= Q_{xx}\, x_g^2 + Q_{rr}\, r_g^2 + Q_{dd}\, d_g^2 + 2\, x_g\, d_g\, Q_{xd} + 2\, x_g\, r_g\, Q_{xr} \\
&\quad + 2\, r_g\, d_g\, Q_{dr} + x_{gg}\, Q_x + r_{gg}\, Q_r + d_{gg}\, Q_d
\end{aligned}
\tag{3-5}
$$

where x_g , x_t , x_z denote partial derivatives of the transform coordinates. Substitution of (3-5) into (3-1) gives a transformed wave equation for a source free region of the form:

$$
\begin{aligned}
& Q_{xx}\left(x_g^2 + x_z^2 - \frac{1}{\tilde{v}^2}\, x_t^2 \right) + Q_{rr}\left(r_g^2 + r_x^2 - \frac{1}{\tilde{v}^2} r_z^2\right) + Q_{dd}\left(d_g^2 + d_z^2 - \frac{1}{\tilde{v}^2}\, d_t^2 \right) \\
& + 2Q_{xd}\left(x_g d_g + x_z d_z - \frac{1}{\tilde{v}^2}\, x_t d_t \right) + 2\, Q_{xr}\left(x_g r_g + x_z r_z - \frac{1}{\tilde{v}^2}\, x_t r_t \right) \\
& + 2\, Q_{rd}\left(r_g d_g + r_z d_z - \frac{1}{\tilde{v}^2}\, r_t d_t \right) + Q_x\left(x_{gg} + x_{zz} - \frac{1}{\tilde{v}^2}\, x_{tt} \right) \\
& + Q_r\left(r_{gg} + r_{zz} - \frac{1}{\tilde{v}^2}\, r_{tt} \right) + Q_d\left(d_{gg} + d_{zz} - \frac{1}{\tilde{v}^2}\, d_{tt} \right) = 0
\end{aligned}
\tag{3-6}
$$

Computing the required frame derivatives we have

$$\frac{\partial r}{\partial(g,z,t)} = 0; \quad 1; \quad 0 \tag{3-7a}$$

$$\frac{\partial d}{\partial(g,z,t)} = -\frac{2x}{v^2 d}\ ; \quad \frac{1}{v}\ ; \quad \left(1 + \frac{4x^2}{v^2 d^2}\right)^{1/2} \tag{3-7b}$$

$$\frac{\partial x}{\partial(g,z,t)} = \frac{1}{2} + \frac{r}{2v(d-r/v)} + \frac{2x^2 r}{v^3 d^2 (d-r/v)}\ ; \quad \frac{x}{vd}\ ;$$

$$- \frac{rx(1+4x^2/v^2d^2)^{1/2}}{vd(d-z/v)} \tag{3-7c}$$

For the second partials we have

$$\frac{\partial^2 r}{\partial^2(g,z,t)} = 0\ ;\ 0\ ;\ 0 \tag{3-8a}$$

$$\frac{\partial^2 d}{\partial^2(g,z,t)} = -\frac{(1+4x^2/v^2d^2)}{v^2(d-r/v)}\ ; \quad 0\ ; \quad \frac{-4x^2}{v^2d^2(d-r/v)} \tag{3-8b}$$

$$\frac{\partial^2 x}{\partial^2(g,z,t)} = \frac{3rx}{v^3 d(d-r/v)^2} + \frac{12x^3 r}{d^3(d-r/v)^2 v^5}\ ; \quad 0\ ;$$

$$+ \frac{xr}{vd(d-r/v)^2}\left(2 + \frac{12x^2}{v^2d^2}\right) \tag{3-8c}$$

Substituting (3-7) and (3-8) into (3-6) gives

$$\frac{\left(1+\frac{4x^2}{v^2d^2}\right)}{(d-r/v)^2}\left\{\frac{d^2}{4}+\left(\frac{r^2}{v^2}\,\frac{x^2}{v^2d^2}\right)\left(1-\frac{v^2}{\tilde{v}^2}\right)\right\}Q_{xx}+Q_{rr}$$

$$+\;Q_{dd}\left(\frac{1}{v^2}\left(1+\frac{4x^2}{v^2d^2}\right)\left(1-\frac{\bar{v}^2}{\tilde{v}^2}\right)\right)-2Q_{xd}\left(\frac{2x}{vd}\,\frac{r\left(1+\frac{4x^2}{v^2d^2}\right)}{v^2(d-r/v)}\left(1-\frac{v^2}{\tilde{v}^2}\right)\right)$$

$$+\;\frac{2x}{vd}Q_{xr}+\frac{2}{v}Q_{rd} \tag{3-9}$$

$$+\;Q_x\left(\frac{3rx}{v^3d(d-r/v)^2}+\frac{12x^3r}{d^3(d-r/v)^2v^5}-\frac{1}{\tilde{v}^2}\left(\frac{xr}{vd(d-r/v)^2}\left(2+\frac{12x^2}{v^2d^2}\right)\right.\right.$$

$$+\;Q_d\left(-\frac{\left(1+\frac{4x^2}{v^2d^2}\right)}{v^2(d-r/v)}+\frac{1}{\tilde{v}^2}\,\frac{4x^2}{v^2d^2(d-r/v)}\right)=0$$

If we assume $\tilde{v} = v =$ constant equation (3-9) becomes

$$\frac{d^2\left(1+\frac{4x^2}{v^2d^2}\right)}{4(d-r/v)^2}Q_{xx}+Q_{rr}+\frac{2x}{vd}Q_{xr}+\frac{2}{v}Q_{rd}$$

$$-\;\frac{Q_d}{v^2(d-r/v)}\left(1+\frac{8x^2}{v^2d^2}\right)+Q_x\left(\frac{rx}{dv^3(d-r/v)^2}\right)=0 \tag{3-10}$$

Equation (3-10) is the transformed wave equation which controls the behavior of moveout corrected wave fields. Since the only assumption made in transforming the wave equation was the constant velocity assumption, equation (3-10) models all possible wave effects regardless of their relevance to the problem of interest. With an eye toward deleting terms which deal with phenomena not central to our application, we will discuss some of the terms in equation (3-10).

Consider the first order terms Q_x and Q_d . In the high frequency limit they are small compared to the remaining second order terms. We will delete both of these terms using the high frequency assumption that gradients of the wave field are more important than gradients of the coordinate system. While it is difficult to discern the wave phenomenon suppressed when the Q_x term is neglected, the effects of neglecting the Q_d term are fairly apparent. The Q_d term increases the amplitude of the wave field by an amount proportional to inverse travel time, but it has little or no effect on phase. Neglecting Q_d , therefore, is nearly equivalent to neglecting amplitude changes due to geometrical spreading.

The final term we consider is the Q_{rr} term. Unlike the first order terms, the importance of Q_{rr} is dependent on the earth models one wishes to be able to handle. If the earth is plane layered we expect the moveout corrected wave fields recorded at the earth's surface to be the same as those recorded at depth. Thus, for a plane layered earth we have $Q_r = Q_{rr} = 0$. Recall that moveout correction approximately models the behavior of reflections even when the earth is only approximately layered. Because of this, moveout corrected data recorded over a nearly layered earth will be only moderately dependent on receiver depth. In this case, since Q_r is small and $Q_r >> Q_{rr}$, one might neglect Q_{rr} in favor of Q_r . We shall adopt this small dip assumption and delete Q_{rr} from our downward continuation equation. Deleting Q_x , Q_d and Q_{rr} we get

$$\frac{x}{d} Q_{xr} + Q_{dr} = - \frac{v}{8} \frac{d^2}{(d-r/v)^2} \left(1 + \frac{4x^2}{v^2 d^2} \right) Q_{xx} \tag{3-11}$$

Comparison of this development with Claerbout 1970 and 1971 shows that deletion of Q_{rr} will yield an equation which models only upcoming waves. The earlier work also indicates that simply dropping Q_{rr} will limit the range of accuracy of the resulting equation to dips of less than 15°. Claerbout 1971b gives economical procedures for extending the range of accuracy of the continuation equation to include reflector dips up to 45°. Claerbout and Johnson 1971 and also Riley 1975 give computer algorithms which can be used, with some modifications, to solve equations like (3-11).

Using methods similar to those shown here, Claerbout and Doherty 1972 derived an equation for downward continuing profiles. Expressed in the coordinates used in this thesis, their equation (equation 49) is

$$\frac{x}{d} Q_{xr} + Q_{dr} = -\frac{v}{8} \left(\frac{d}{d-r/v} \right)^2 Q_{xx} \qquad (3\text{-}12)$$

The only difference between equations (3-11) and (3-12) is the lack of the $\frac{x^2}{v^2 d^2}$ dependence of the Q_{xx} coefficient in (3-12). We find that the absence of this dependence in the published equation seriously degrades its performance for large offset data. In the earlier work it was felt that the $\frac{x}{d} Q_{xr}$ term might be important because its coefficient was first order in x. Here we find that downward continued wave fields are only weakly dependent on this term.

To put these comments on a firmer ground, we shall consider an example. As before, we shall use the point scatterer as our investigative probe since it is the most general reflector. Figure 3-4 indicates the recording geometry for the point scatterer synthetic profile we will use. Figure 3-4 shows ray paths only for the shallowest point in the synthetic data. Taking the angle between the actual ray paths and

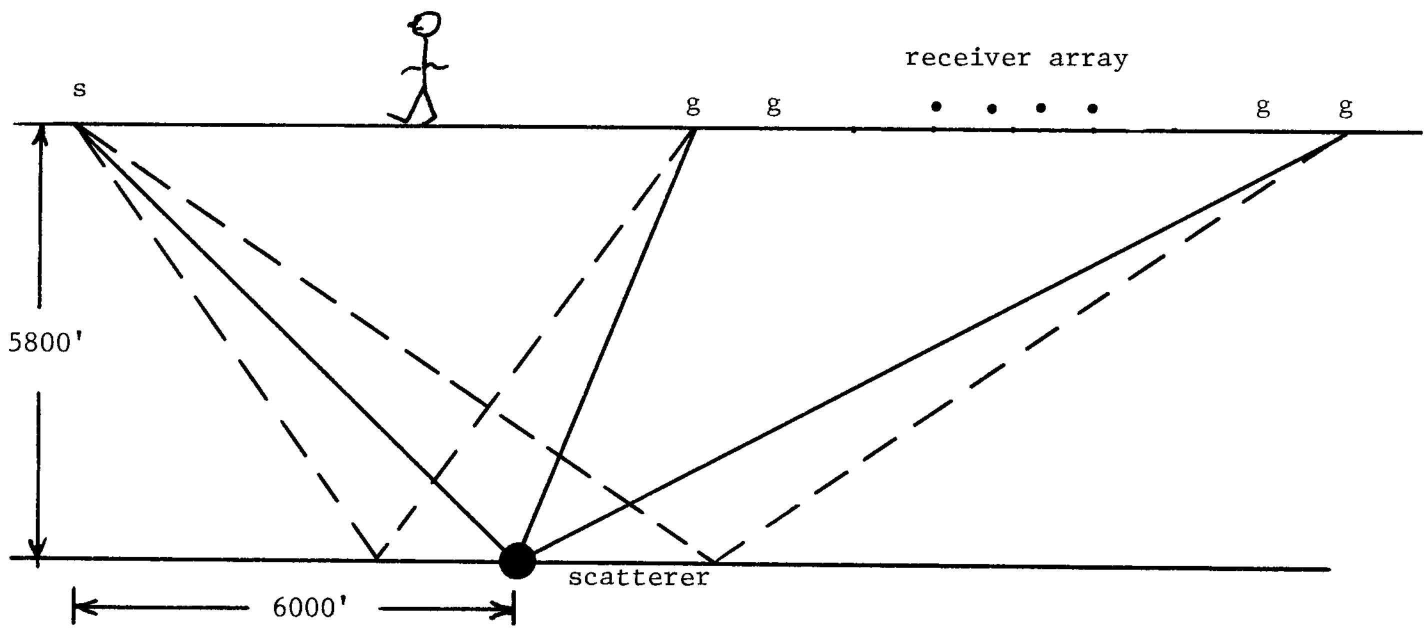

Figure 3-4. The recording geometry for the data of figure 3-5. Actual ray paths are shown with solid lines. The ray paths assumed in the moveout correction are dotted. The paths shown are to the nearest and farthest receivers. The shortest shot-receiver offset is 8260' , the longest is 16000' . Receiver spacing is 110' . The scatterer shown here causes the earliest arrivals shown in Figure 3-5.

the ray paths assumed in the moveout correction as a measure of dip, measurement on 3-4 shows that data recorded in that geometry fall within the 15° dip assumption made in dropping Q_{rr} . The top left frame of figure 3-5 illustrates the surface synthetic profile data after they have been moveout corrected according to equations (3-2) (the effects of geometrical spreading and wavelet stretching due to moveout correction have been suppressed). To a viewer familiar with the section geometry, the most remarkable characteristic of this frame is that the data are not symmetric about the scatterer position. A look at the transformation equations (3-2) shows that symmetry should only be expected when the scatterer is directly under the source. The fact that this asymmetry exists should alert us to the possibility that insights gained from experience with sections may have to be modified somewhat if they are to be valid for profiles.

Frame 3-5b shows the same data after migration with the zero order terms (in x) of equation (3-11). That is with

$$Q_{dr} = -\frac{v}{8}\left(\frac{d}{d-r/v}\right)^2 Q_{xx} \qquad (3\text{-}13)$$

An equivalent equation was used with much success on zero offset sections in the Claerbout-Doherty paper. Frame 3-5c shows the data migrated with the zero and second order terms from (3-11). That is with

$$Q_{dr} = -\frac{v}{8}\left(1 + \frac{4x^2}{v^2 d^2}\right)\left(\frac{d}{d-r/v}\right)^2 Q_{xx} \qquad (3\text{-}14)$$

Frame 3-5d shows the data migrated with all the terms in (3-11).

Fig. 3-5 Cont'd.

correction. Frame b shows the data of frame a after migration with equation (3-13). Frame c shows the same surface data after migration with equation (3-14). Frame d shows the same data after migration with equation (3-11). On the basis of these frames we can conclude that profiles can be migrated with good accuracy by an equation of the form

$$Q_{dr} = -\frac{v}{8}\left(1+\frac{4x^2}{v^2 d^2}\right)\left(\frac{d}{d-r/v}\right)^2 Q_{xx} \quad .$$

Since the aim of migration and downward continuation is to obtain a moveout corrected profile which is a reflectivity map, the migrated data of figure (3-5) should resemble point scatterers. Because we are dealing with waves, we expect a focus rather than a point. In general, the size of this focus will depend both on the predominate wave length of the source wavelet and on the angular bandwidth of the initial conditions.

Obviously, frames (c) and (d) are much better approximations to focuses than (b). However, frames (c) and (d) are very similar. On the basis of this observation, we conclude that the $\frac{x^2}{v^2 d^2} Q_{xx}$ term is required for migrating data of reasonable offset, while the $\frac{x}{d} Q_{xr}$ term is not. Note that the only noticeable effect of the Q_{xr} term is an almost undetectable increase in the asymmetry of the foci. Since we know that any estimate of the reflectivity of a point scatterer should be symmetric about the point scatterer, inclusion of Q_{xr} seems to move the data in the wrong direction. Part of the asymmetry of the migrated data is due to the asymmetric moveout function. However, this contribution is small since the foci are distributed over a narrow band in x and the moveout is essentially constant across this band. Most of the asymmetry results from the biased nature of the angular bandwidth of the initial conditions. Although the receivers in the array are distributed equally along the x axis, the angular bandwidth of the data is not. Since the angular bandwidth of the data is narrow for midpoints to the right of the scatterer, the focuses of 3-5 are wide on the right. The asymmetries in 3-5 occur because the appearance of the subsurface depends a great deal on the direction from which it is illuminated and the position from which it is viewed. The most familiar example of this kind of effect is the phases of the moon. Although illumination always comes from the same location, the relative position of the observer changes during the month and thus the appearance of the moon also changes during the month.

Because a multi-offset section is constructed from a large number of profiles, we can make some predictions concerning section continuation on the basis of our work with profiles. We should expect that first order terms like Q_x and Q_d will be unimportant because they deal with low order effects like geometrical spreading. Also, we should find that directional derivative terms like Q_{xr} will control source-receiver location directivity effects. The result of their inclusion in a continuation equation will probably be a minor asymmetry in the migrated data.