Chapter 1. Introduction

The accurate estimation of velocity from reflection seismic data has long been a subject of interest to explorationists. Most commonly used velocity estimators are based on a layered media assumption. Because of this, their performance tends to degrade as the earth becomes non-layered. Here a method which allows accurate velocity estimates to be made from data recorded over a particular type of non-layered earth is presented.

Figure 1-1 indicates the two main ways in which the earth deviates from the usually assumed plane layers. One type of deviation occurs when velocity is constant or layered but the reflectors have arbitrary dip and curvature. Another occurs when the reflectors are planar but the velocity structure is arbitrary. The second class of structures tends to have the more drastic effect on velocity estimators. Although structures of the first class cause less drastic degradation of velocity estimates, there are situations where accommodation of their effects are of great importance. In this thesis we shall restrict our study of velocity estimation to data recorded over first class models.

Many of the difficulties associated with the estimation of velocity from seismic data recorded over non-horizontal reflectors can be traced to the fact that such data need not resemble, in detail, the earth structure over which they were recorded. (Diffraction and scattering are the major complicating factors.) Migration can be defined as an operation which suppresses diffraction and scattering effects by reorganizing the reflection data so that they resemble a reflectivity map of subsurface over which they were recorded. Because migration can be used to remove the phenomena which cause most of the velocity estimation difficulties in the earth models we are considering, velocity estimates made from migrated data should be superior to those made from unmigrated data. The main objective of this thesis is to show that this improvement does occur and that the practical problems associated with migrating data prior to the determination of true velocities can be overcome.

In this study we shall use wave equation methods to perform our migrations. We have chosen to use wave equation techniques (Claerbout and Doherty, 1972) rather than the ray techniques (Peterson and Walter, 1974) because there are some indications that practical implementations of the wave methods may produce results which are superior to those obtainable with ray techniques. However, our choice of a particular approach toward migration does not mean that velocity estimates can be improved only if that approach is used. As long as care is used in performing migrations, velocity estimates should have only a marginal dependence on the migration approach used.

In the following chapter some terminology and techniques often used in reflection seismic exploration are presented. There is also a brief description of some prevalent methods of velocity estimation. This chapter is intended as tutorial information for those not familiar with seismic exploration. Old hands, and doodlebuggers may wish to skip on to chapter 3.

In chapter 3 we begin a discussion of wave equation migration as it applies to wave fields generated by a single source. Although much of this material has been published previously it has been included here as an introduction to the problem of migrating data generated by many sources. Many of the assumptions and techniques developed in chapter 3 will be used extensively in the following chapters. A synthetic example has been included to illustrate wave equation migration and to show how the equations presented in chapter 3 extend the results of the previously published work.

In chapter 4 we tackle the many source problem which is essential to reflection seismic velocity estimation. We investigate the new characteristics of the migration equation associated with multiple sources. We find that if source-receiver directivity effects are ignored and small dip and moderate source-receiver offset assumptions are adopted, multiple source data can be migrated with equations no more complicated than those required for the single source problem.

In chapter 5 the equations and concepts developed in earlier chapters are applied to the velocity estimation problem. First we discuss, in some detail, the effects of reflector structure on velocity estimates. We then demonstrate that migration with the known velocity can accommodate these effects and allow accurate velocity estimation. Additionally, we show that satisfactory results can be obtained in the case where the correct migration velocity is not known. Finally, we apply the method to the problem of estimating velocity in regions where the earth has little or no structural continuity.