Understanding Seismic Anisotropy in Exploration and Exploitation

The 2002 SEG/EAGE Distinguished Instructor Short Course

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Introduction

The subject of seismic anisotropy has a long history, but only recently has it come to be seen as a central feature of geophysics, as applied to the exploration for hydrocarbons, and to their exploitation. The reason for the long neglect of anisotropy is, of course, that isotropy is *simpler*. The equations are simpler, and the application of one's intuition is more direct. And, perhaps *because* of their simplicity, these basic, isotropic ideas have enabled the discovery most of the world's known hydrocarbons.

I am told, even, that hydrocarbons were found at one time by using the ideas of *acoustic* wave propagation! Improbable as it sounds, this myth does explain how very useful simple ideas can be, and what a strong hold they have upon the imagination.

However, in those ancient days, the success of exploration geophysics was a *lot* lower than it is today. Wildcat success-rates were as low as 10% in the 1950s, growing slowly to 25% by the 1970's, before exceeding 50% today. There are three basic reasons for our increased success-rates in the modern era:

- Better data, including more intense acquisition (*eg*. 3D, 4D), broader bandwidths, and new survey methodologies (*eg*. Ocean Bottom Seismics and vertical cables);
- Better ideas, including better algorithms for imaging, recognition of the information content in amplitudes, and fuller utilization of the vector nature of seismic waves;
- Better tools, including more powerful computers for number-crunching, and more intuitive workstation interfaces for aiding interpretation.

Seismic anisotropy has a role in each of these. As examples:

- longer source-receiver offsets, acquired for the purpose of greater AVO leverage, usually imply greater angles of incidence on reflectors, so that the angle-dependence of velocity is more evident in the resulting data.
- quantitative analysis of AVO obviously requires theory that recognizes the corresponding Velocity Variation with Offset, otherwise known as anisotropy.
- Very high-speed computers enable anisotropic migration, on a scale which would have been impracticable just a few years ago.

So, the time has come when seismic anisotropy should be a part of every geophysicist's expertise. This SEG/EAGE Short Course is designed to show you how to recognize the effects of anisotropy in your data, and to provide you with the intuitive concepts that you will need to analyze it. You will not be an expert, but you will have many of the basic tools needed to become an expert, through further study and working with your own data.

This is a course about *ideas*, not about the mastery of specific software tools. Many of these ideas find their most concise expression in the form of *equations*. So, you will see a lot of equations in the following pages. And, you will hear a lot of discussion about the *meaning* of these equations. <u>Do not be afraid</u>; we will simply be discussing ideas, and increasing your fundamental *understanding*.

In most cases, we will be making strategic approximations, seeking *insight* rather than numerical *accuracy*. The exact equations have been known for years, and it is straight-forward to program computers to solve them. But, finding the right parameters to feed into these equations requires insight and understanding of how anisotropy affects our data. Achieving this understanding is the goal of this course.

DISC 2002: Course Outline

1. Physical principles
2. P-waves (imaging)
3. P-waves (characterization)

   [Lunch]

4. S-waves
5. C-waves

Support Materials

In this process, you may have to "unlearn" many concepts that you already think you know, from your isotropic experience. More precisely, you will come to see that these concepts are only approximations to more subtle anisotropic concepts. Isotropy is just a simple special case of anisotropy (just as elasticity itself is a simple special case of continuum mechanics). So, you will continually struggle to interpret these deeper insights in the light of your isotropic intuition. Occasionally you will have that great "AHA!" moment, when you see the reason behind a fact that you had long observed. It should be fun.

This course is designed to answer the needs of members with a wide variety of different backgrounds, different mathematical sophistication, and different facility with English. The breadth of the audience inevitably means that some members will find the pace too slow at times, while others will find it too fast. This text is designed to help with this problem; it is closely keyed to the oral presentation, and designed to be <u>open in front of you</u> as you listen to the lectures. The figures are (almost) exactly those used in the lectures, and the page of text facing each figure augments the oral material. If you are already familiar with the oral argument, then the text may offer amplification that will be useful. The numbering of the text figures corresponds to the numbering of the figures used in the oral lecture (so that you may ask questions, referring to a particular figure by number). This numbering is not necessarily continuous, since some redundant figures are omitted from the text.

> There will often be indented text; this material is usually more advanced, and will not be addressed in the oral presentation.

There will often be white space on the text page, which will be useful for you for making your own notes, *in the book* (don't be shy about this!). Of course, most mathematical development is put into the **Appendices**.

There will be many specialized terms used in this text, and some specialized notation. If you miss the introduction of these terms and symbols, you might be able to find them in the **Glossar**y, or the **Notation** section.

These materials were put together for you through the collaboration of many individuals around the world. Their names are mentioned in context, and the literature references to their original work is listed in the **Annotated Bibliography**. In particular, I refer you to the much more complete textbooks by Tsvankin (2000) and Helbig (1994) which will fill in many of the holes which are necessary in this one-day course. Another excellent recent book by Macbeth (2001) provides a stronger focus on anisotropy as seen in the *VSP* context. A more mathematically intense book by Carcione (2001) puts anisotropy into context with other complications caused by other Real World rock properties.