TOMOGRAPHIC DETERMINATION OF INTERVAL VELOCITIES FROM REFLECTION SEISMIC DATA: THE METHOD OF CONTROLLED DIRECTIONAL RECEPTION

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Abstract

Tomography in the context of reflection seismology can be defined as the use of measured traveltime data to determine rock velocities. I propose a method of tomographic inversion that uses not only reflected-wave traveltimes, measured between source points and receiver points, but that uses ray parameters as well. The ray parameters (essentially, the angles of travel of the waves) are measured at the source and the receiver. A consequence of this approach is that reflecting interfaces (horizons) are only assumed to be locally continuous, and horizon positions are not determined during the process of inverting for interval velocity.

I am able to use a fully-automated computer program to pick the traveltime and ray-parameter data. This automated picking technique has been developed in the USSR as an aspect of the method of Controlled Directional Reception (CDR). The picked data are used to construct migrated images of seismic reflectors. These data can be filtered on the basis of velocity and dip to remove multiples and spurious picks.

I invert the picked data by means of an iterative ray-tracing technique to find the interval-velocity model that minimizes a non-linear least-squares objective function. This objective function is based on the mismatch between the actual paths of rays in the ground, as determined from the picked data, and the computed paths of rays in the velocity model. A penalty term is included in the objective function, to discourage sharp variations in the velocity model.

This tomographic method has given good results when I have used it to invert synthetic data and data from a marine reflection seismic survey.

...Почерк у [генерал-майора КГБ] Константинова был четкий и быстрый. Он, однако, предпочитал — особенно в последние годы — не писать, а сразу же печатать на портативной машинке, ибо слово напечатанное резко отличается от слова написанного. Более того, когда Константинов подготовил свою диссертацию к изданию (тема была открытой — «Политические маневры гитлеровской Германии накануне мятежа Франко»), он, к вящему своему удивлению, заметил, что страница, напечатанная на машинке, невероятно отличается от набранной в типографии — словно бы два совершенно разных текста. Он тогда подумал, что мера ответственности человека за мысль — а высшее выявление мысли это строка, набранная в типографии,— в значительной степени зависит от того, на какой бумаге и каким шрифтом набрано: куда ни крути, форма — это уже содержание.
(Юлиан Семенов, *ТАСС уполномочен заявить...*)

...[KGB Major-General] Konstantinov's handwriting was quick and precise. He, however, preferred—especially in recent years—not to write by hand, but to type directly on a portable typewriter, since the typed word differs sharply from the handwritten one. Moreover, when Konstantinov had prepared his dissertation for publication (the theme was an open one: "Political maneuvers of Hitler's Germany on the eve of Franco's revolt"), he, to his own great surprise, had discovered that a typewritten page differs by an amazing amount from one that has been typeset—almost as if they were two completely different texts. He came to realize that the extent of a person's accountability for his ideas (and the highest manifestation of ideas is the typeset page) to a significant degree depends on what sort of paper and what sort of typeface is used. There's no avoiding it: form is already substance.
(Yulian Semyonov, *TASS is Authorized to Announce...*)

Preface

The method of Controlled Directional Reception (CDR) was first developed by Frank Rieber in the 1930's (Rieber, 1936). This method, in its most elementary form, consisted of carrying out slant stacks (linear stacks along lines of different slope) (Schultz and Claerbout, 1978) over a short range of offsets. Rieber called the resulting slant-stacked traces sonograms. Although Rieber was an American, his method did not receive a great deal of attention in the United States. It was, however, extensively developed over the course of the next five decades in the Soviet Union, under the name CDR. Dr. L.A. Riabinkin (1910–1985) was the Soviet scientist most responsible for this development (Hermont, 1979); he always gave Rieber due credit for the original idea behind CDR.

As seismic recording technology and processing techniques grew more sophisticated, so too did the CDR method. The most recent Soviet contributions to CDR take advantage both of computerization and of the dense coverage afforded by modern recording methods. Despite these refinements, Soviet geophysicists have not been able to take advantage of the full power of CDR, because they have difficulty gaining access to adequate computer facilities.

I became interested in the CDR method during a 9-month stay in 1983–84 at the Gubkin Oil and Gas Institute in Moscow, where Dr. Riabinkin's laboratory is located. Upon return to Stanford, I developed the method of CDR tomographic velocity inversion, which I shall describe here.

Owing to differences in computer technology, some of the methods I describe in this thesis are dissimilar to those that are used in the Soviet Union. I make no real attempt to describe present-day Soviet CDR techniques, except as they have been incorporated into my own approach.

Acknowledgments

This thesis would not have been possible without the guidance of Professor Jon Claerbout. He encouraged me to try out my ideas, no matter how wild, and he always emphasized the importance of eventually applying these ideas to field data. He provided me with the perfect combination of freedom to explore, and guidance. The financial support for my work came from the Stanford Exploration Project (SEP), which Jon heads. I only wish that I had enough room to thank individually the forty companies and organizations that sponsor the Stanford Exploration Project.

Much of this thesis is based on work done by researchers in the Soviet Union. I had the opportunity to observe this work at first hand for nine months, thanks to the sponsorship of the International Research and Exchanges Board (IREX). I must also thank the Gubkin Institute of Oil and Gas in Moscow, which provided me with support while I was in Moscow. Boris Zavalishin of the Gubkin Institute was particularly helpful, and many of his comments found a place in this thesis. I also thank Charlotte Derksen, the Head Librarian of the Stanford Earth Sciences library. Thanks to her efforts, Stanford has an excellent collection of Soviet geophysical literature.

Kiyoshi Yomogida carefully read two drafts of this thesis, and pointed out many unclear and ambiguous usages. Paul Fowler spent a great deal of time reformatting a British Petroleum data set to make it easy to use. Without his generosity in sharing these reformatted data with me, my thesis might not have contained any field examples. Will Gray shared his wisdom and experience regarding the pitfalls of processing field data. Pat Bartz, the SEP Project Coordinator, is the reason why the other SEP graduate students and I could concentrate our energies on research, instead of on paperwork and administration. I would also like to thank Jeff Thorson, Ivan Pšenčík, Rick Ottolini, and Dan Rothman for helpful discussions and ideas.

Most of all, I would like to thank my parents. Their patience, love, and support over many long years are what truly made this thesis possible.

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