MIGRATION AND INTERPRETATION OF DEEP CRUSTAL SEISMIC REFLECTION DATA

A DISSERTATION

SUBMITTED TO THE DEPARTMENT OF GEOPHYSICS

AND THE COMMITTEE ON GRADUATE STUDIES

OF STANFORD UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

By
Heloise Bloxsom Lynn
December 1979

printed as Stanford Exploration Project Report No. 22

by permission of the author

ABSTRACT

COCORP, Consortium for Continental Reflection Profiling, has been gathering deep seismic reflection data in order to learn more about the nature of the continental crust. To wring the ***maximum*** amount of information from the seismic profiles, migration is absolutely necessary to collapse diffractions which obscure the underlying signal, to display dipping energy in its true spatial and temporal location, to remove the distortions caused by lateral velocity variation, and to improve the signal/noise ratio. Before geologic significance can be assigned to the migrated data, the limitations caused by recording and migrating procedures should be understood.

First, the dip limitations on migrated sections as imposed by recording geometry, line length and recording time, are analyzed. Then two migrated datasets are presented and interpreted: the Hardeman Cty., Tx., data, and the Wind River thrust, Wyo., data. We interpret the Hardeman Cty., Tx., data as showing part of a tabular epizonal batholith, underplated by gabbroic sills. The migrated Wind River, Wyo., data show the Wind River (WR) thrust continuing to at least 25 km and probably 32 km depth, thereby cutting three-fourths of the continental crust. The discovery of flattening of the WR thrust with depth, both in smaller-scale local branches and in the larger-scale flattening at 32 (or 25) km depth, provides a geometric model to explain: (1) the observed tilt of the WR Range and Basin, (2) the interpreted decrease of fault offset with depth, and (3) the lack of Moho offset indicated by the gravity data.

ACKNOWLEDGMENTS

A lot of people have had a hand in the migration and the geologic interpretation of the COCORP data. The three chapters are papers for publication, and I want to thank my friends, the coauthors, who worked with me. Prof. George Thompson gave continual support, interest, and valuable ideas throughout the entire project. Rick Ottolini provided most of the computer expertise for the papers. Lisa Kanter and Spencer Quam helped to shape the WR data interpretation. Swavek Deregowski spent a "sabbatical" with the Stanford Exploration Project, which was a time of profitable and exciting interaction.

Einar Kjartansson, Laura Gagnon, and the COCORP research seminar members all gave ideas, support, time, and effort, which is heartily appreciated. I thank Prof. Jon Claerbout for his interaction, help, and kindness; his research on migration provided the fundamental tool for this study, and his decision to expand the Stanford Exploration Project (SEP) hardware made possible this research. The SEP members produced and continue to produce new data processing tools which "data-types" like myself do not create, yet want to use. They also put up with the hundreds of computer hours spent doing those " d--- migration hog-jobs."

Walter Lynn, my husband, kept me associated with Stanford long enough to finish this thesis. While working on his own dissertation in the SEP, he wrote programs for me, explained obscurities, provided moral support, and made the long hours fly by being near. I thank him and my parents for their encouragement.

INTRODUCTION

The length of a seismic profile and the recording time available as input to migration govern simple, first order equations relating dip observable on migrated profiles to the spatial location of the reflector. This relationship is particularly important in COCORP seismic reflection profiles of the continental crust, commonly 50 to 200 km and 16 to 20 sec long. On migrated sections, a certain amount of the observed decrease of dip both with depth and with proximity to the edge of the section can be related to the size of the input; any ***further*** decrease in dip with depth may have geologic significance. Both seismic profile planners and interpreters are affected by the dip limitations. The inhomogeneity of the crystalline crust can be estimated by the number, length, and degree of dip of reflectors; however, interpreters of migrated data must not assign geologic significance to limitations caused by recording or migration procedures.

Focused seismic images of the continental crust were obtained when COCORP's three Hardeman, Texas, lines were migrated with a variable-velocity frequency-domain algorithm. The frequency-domain migration algorithm is fast, inexpensive, and suitable for the stratified media situation at Hardeman County. We adopt Hamilton and Myers' (1967) hypothesis that epizonal batholiths are tabular in shape, spread laterally at shallow (to ~ 10 km) depth, and may crystallize beneath their own volcanic ejecta, for our interpretation that part of a batholith has been sampled seismically in Hardeman County. Intra-basement layered reflectors from 1.42 to ~1.6 sec (~2.86-~3.4 km depth) may be rhyolitic lavas and ash-flow tuffs. At greater depth, where porosity in the volcanics is lost, the transition from rhyolitic to granitic rocks is seismically transparent (~1.6 to 2.8 sec, ~3.3-~7.1 km depth). Strong reflections at 2.8 sec and 3.8 sec (~7.1 and ~10.5 km depth) may be tabular mafic bodies ~800 m thick within the rhyolite/granite section and at the base of a tabular granitic pluton, respectively. The high-amplitude reflections are interpreted as occurrences of gabbroic underplating. The base of the ~7.5-km-thick silicic pluton is clearly defined by the deeper of the postulated gabbroic sills, such that there is ***not*** a gradual downward transition to sub-plutonic rocks. Under the silicic pluton, between 4 and 11 sec, are many short, shallowly dipping reflection segments; however, the observable dips at these depths are severely limited by the shortness of the lines. These reflections may represent deformed layers or fortuitously horizontal foliation on the order of the seismic wavelength in Precambrian schist and gneiss (migmatite, amphibolite). Our interpretation links the seismic data with the widespread silicic and mafic igneous rocks in the Texas and Oklahoma basement.

The migrated Wind River (WR), Wyoming, data show better, more focused images of the continental crust than ever previously published, and lead to new interpretations of Laramide deformation processes in the intermediate and lower crust. The data were migrated using a 45-degree ω-finite-difference depth migration. The algorithm allows velocity to vary laterally and with depth, contains the thin lens (or shifting) term, and correctly migrates energy in laterally varying media within the limits of a 2-D algorithm and 2-D dataset. The Laramide major structural features displayed in the migrated data are the Pacific Creek (PC) anticline and the WR thrust. The PC anticline is underlain by a thrust fault similar in geometry to the WR thrust. The base of the Green River Basin sediments has a seismically observed vertical offset of 600 m. The intra-basement PC thrust reflections are as conspicuous as the WR thrust reflections, yet the movement along the PC fault was 1/50th of that of the WR fault. The reflectivity of the PC fault is attributed to the change in seismic impedance of the fault zone constituents, rather than a change of rock types across the fault. The WR thrust fault is clearly seen to ~25 km depth, and can be interpreted to continue to ~32 km depth with an apparent dip of 30 degrees (assuming a N55E dip direction of the WR thrust). A vertical offset of 14 km and dip slip of 26 km is known from geologic evidence. Although the WR fault zone was interpreted as planar from time sections in previous papers, it is more accurately described as composed of many strands in a wide complex zone of deformation. The fault zone increases in thickness from a zone 1 km thick at 2 km depth (known from well *and* seismic data) to one at least 4 km thick at 16 km depth. The vertical offset of the fault zone decreases with depth, from 14 km at the surface, and (an interpreted) 6-8 km at 22 km depth, to a negligible amount at the base of the crust.

On the migrated sections, the dip segments of the fault reflection flatten at 6.6, 12, 18, 25, and 32 km depth. The reflections can be interpreted as thrust splays or as local slip zones; the reflectivity is probably due to the seismic impedance contrast provided by the fault zone. We explain the difference in offset with depth and the tilting of the WR Range and Basin by curvature and flattening of the fault zone at 25 km and 32 km depth, perhaps accompanied by multiple thrust splays which also decrease in dip with depth. The entire zone of deformation associated with the major WR thrust is at least 50 km in lateral extent.

TABLE OF CONTENTS