

STRUCTURAL INVESTIGATIONS OFF CHILE:
KIRCHHOFF PRESTACK DEPTH MIGRATION
VERSUS
FRESNEL VOLUME MIGRATION

STRUKTURELLE UNTERSUCHUNGEN VOR DER KÜSTE
CHILES:
KIRCHHOFF PRESTACK TIEFENMIGRATION
VERSUS
FRESNEL VOLUMEN MIGRATION

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FRIEDRICH NIETZSCHE (1844-1900)

Summary

Noise and artifacts often strongly influence the resolution of depth images obtained with standard migration algorithms. Those features can either be generated by several different natural conditions or they are man-made. In this thesis a new method of seismic imaging was applied to two marine data sets acquired during the CINCA experiment in 1995: The Fresnel Volume Migration. A comparison between the latter and Kirchhoff Prestack Depth Migration was performed to discuss the additional structural details extracted with the help of Fresnel Volume Migration.

Both Kirchhoff Prestack Depth Migration and Fresnel Volume migration require information about the velocity structure in the subsurface. Two velocity models were built, each based on different available information. One of them was constructed by extending an existing velocity field of the outer forearc (IFM-model), the other model contained seismic boundaries and average crustal velocities from wide-angle seismics (wide-angle model). Different velocity models resulted in different travel times and thus affected the migration results. Hence, the reliability of both model types was discussed with respect to the resulting images obtained from both migration techniques.

The depth sections obtained from migration with both velocity models showed significant differences which were analyzed and discussed. Increased migration smiles and an oversized image of the sedimentary layers indicated overmigration due to the use of too high velocities in the upper part of the oceanic crust when the velocity information from wide-angle seismic was used. On the other hand, a possible Moho reflection was found within these images, which is absent using the IFM-model. The lack of knowledge about the exact location of the transition zone from low to high velocities complicated the construction of the velocity field. Thus, in order to investigate the structures of the upper 1 km - 2 km of the oceanic crust, the use of the IFM-model was proposed. In contrast, the study of deeper features was done with the help of the wide-angle model.

Fresnel Volume Migration is based on the idea of restricting the migration operator in a form that the resulting image of a recorded event is limited to the volume in the

subsurface that physically contributes to the reflected signal. The Fresnel volumes were calculated using the paraxial ray method. The ray tracing algorithm required information about the emergence angles of the waves arriving at the receivers. A multichannel cross-correlation technique was used to estimate the horizontal slowness sections which comprise the necessary emergence angle information. A few tests with respect to the frequency dependence of the slowness algorithm indicated a quite better quality of the resulting images when a lower dominant frequency was used.

Regarding the Fresnel Volume Migration, several input parameters were studied with the aim to obtain the best images as well as to reduce the computing time. In order to find the best combination of parameters with respect to the latter aims, their influence on the ray tracing procedure and on the resulting images was analyzed. The best and most reliable input parameters were then used for Fresnel Volume Migration.

A method was developed to additionally reduce the computing time. The Fresnel Volume Migration results obtained with this method showed no significant differences compared to the images resulting from migration without this method.

The comparison of the Kirchhoff images with the corresponding Fresnel images of line SO104-07 and, respectively, of line SO104-13 showed a noticeable improvement of the images after Fresnel Volume Migration. A strong suppression of the migration artifacts due to the limitation of the migration operator was demonstrated as well as the reduction of the noise level within the resulting Fresnel images.

Thrust faults have been identified after Fresnel Volume Migration in a region where normal faulting due to plate bending was expected. The complex internal structure of the frontal prism at the trench was analyzed and discussed. Thereby, small eastward dipping normal faults were found on line SO104-07 but on line SO104-13 folds are located below the seafloor forming a sedimentary ridge at the deformation front. The intra-plate boundary itself was imaged down to approximately 12 km depth on both lines as well as a downward continuation of the ocean bottom structures underneath the continental slope. Plate parallel faults were observed and interpreted to mark the upper boundary of the subduction channel. In the case of a horst-continent collision, strong compressional forces may occur, possibly resulting in an eastward movement of parts of the overriding plate. The strong reflectivity of these faults was discussed to be the result of infiltration of fluids or material contrast or cataclastic fabric. The Fresnel images gave an excellent and detailed insight into the normal fault systems located between 104 km and 118 km along line SO104-07 and also between 90 km and 113 km along line SO104-13. Reflections below these normal faults suggested a detachment.

The application of the Fresnel Volume Migration method to the marine data sets enabled to visualize certain details of the subsurface within the investigation areas which are not observable in the Kirchhoff images.

Zusammenfassung

Das Auflösungsvermögen herkömmlicher Migrationsmethoden wird sehr häufig durch starkes Rauschen eingeschränkt. Auch können Artefakte, die in den resultierenden Tiefensektionen die abzubildenden Strukturen überlagern, eine Interpretation zusätzlich erschweren. Eine mögliche Ursache für das Auftreten dieser Phänomene liegt entweder in den natürlichen Gegebenheiten des zu untersuchenden Gebietes, sie können jedoch auch durch den Menschen verursacht sein. Die hier vorliegende Arbeit beschäftigte sich mit der Untersuchung und Implementierung eines neuen seismischen Abbildungsverfahrens, der Fresnel Volumen Migration. Mit dieser Methode wurden zwei Datensätze prozessiert, die 1995 während des CINCA Experiments aufgezeichnet wurden. Es wurde weiterhin ein Vergleich der Ergebnisse mit den entsprechenden Ergebnissen der Prestack Kirchhoff Tiefenmigration durchgeführt. Die mit Hilfe der Fresnel Volumen Migration zusätzlich herausgearbeiteten Strukturen wurden analysiert und diskutiert.

Beide Methoden benötigen als Eingabeparameter Informationen über die Geschwindigkeitsverteilung in der Tiefe. Zwei verschiedene Geschwindigkeitsmodelle wurden zur Prozessierung der Daten verwendet. Das eine wurde durch die Erweiterung eines bereits vorhandenen Modells gewonnen (IFM-Modell), das andere wurde unter Zuhilfenahme von Ergebnissen aus der Weitwinkelseismik modelliert (Weitwinkel-Modell). Da die Verwendung unterschiedlicher Geschwindigkeiten zur Laufzeitberechnung auch zu Abweichungen in den seismischen Abbildern führt wurden beide Modelle bezüglich der Ergebnisse geprüft.

Die Migrationsergebnisse für das jeweilige Geschwindigkeitsmodell wiesen deutliche Unterschiede auf. Diese Unterschiede wurden herausgearbeitet und diskutiert. Hinweise auf Übermigration durch zu hohe Geschwindigkeiten im Weitwinkel-Modell, lieferten vergrößerte Migrationsartefakte und eine zu mächtige Sedimentschicht in den Ergebnissen. Hier konnten jedoch schwache Reflektoren in einer Tiefe beobachtet werden, die der aus früheren Untersuchungen bekannten Tiefe der ozeanischen Mo-ho in dieser Gegend entspricht. Die Unkenntnis über die genaue räumliche Lage der Übergangszone von niedrigen zu hohen Geschwindigkeiten in der Tiefe erschwerte

die Modellierung erheblich. Aus den oben genannten Gründen wurde zur Untersuchung oberflächennaher Strukturen das IFM-Modell bevorzugt, während für tiefere Regionen das Weitwinkel-Modell für die Prozessierung der Daten vorgeschlagen wurde.

Die Fresnel Volumen Migration basiert auf der Idee, den Migrationsoperator so zu begrenzen, dass das resultierende Abbild eines gemessenen Signals auf ein Volumen in der Tiefe beschränkt wird, das physikalisch zum eigentlichen reflektierten Signal beisteuert. Zur Berechnung der Fresnel Volumen wurde die Methode des paraxialen Ray Tracing benutzt. Um Ray Tracing durchführen zu können ist die Kenntnis der Einfallsrichtung der Wellen an den Empfängern erforderlich. Eine Mehrspur-Kreuzkorrelation wurde durchgeführt um die horizontale Langsamkeit zu berechnen, die ihrerseits wiederum die notwendigen Winkelinformationen beinhaltet. Einige Tests wurden durchgeführt um die Frequenzabhängigkeit der Slowness-Bestimmungsmethode zu untersuchen. Dabei konnte eine leichte Verbesserung in den Ergebnissen für niedrigere dominante Frequenzen beobachtet werden.

Mit dem Ziel die bestmöglichen Ergebnisse zu erzielen und die Rechenzeit zu verkürzen wurden die verschiedenen Eingabeparameter für die Fresnel Volumen Migration untersucht. Dabei wurden hauptsächlich die Parameter getestet, die für das Ray Tracing notwendig waren. Die besten Werte wurden für die Fresnel Volumen Migration der CINCA Daten benutzt.

Neben der oben genannten Optimierung der Parameter wurde eine weitere Methode zur Verkürzung der Rechenzeit entwickelt. Die Tiefensektionen, die mit dieser Methode berechnet wurden unterschieden sich dabei nicht wesentlich von denen, die ohne diese Methode migriert wurden.

Der Vergleich zwischen Kirchhoff Prestack Tiefenmigration und Fresnel Migration der beiden Linien SO104-07 und SO104-13 zeige eine sehr deutliche Verbesserung der Abbilder zugunsten der Fresnel Volumen Migration. Durch die Beschränkung des Migrationsoperators konnten sowohl Migrationsartefakte unterdrückt als auch das Rauschen signifikant reduziert werden.

In den Ergebnissen aus der Fresnel Volumen Migration wurden in einigen Gegenden Überschiebungen identifiziert, die aufgrund der Plattenbiegung eigentlich ausschließlich durch Abschiebungen geprägt sein müssten. Die komplexe innere Struktur des Frontalkeils wurde analysiert und diskutiert. Hier wurden kleinere landwärts geneigte Abschiebungen im Norden beobachtet (Linie SO104-07), während im Süden (Linie SO104-13) Faltenstrukturen direkt unterhalb des Ozeanbodens ansässig sind. Letztere bilden eine kleine Erhöhung am Meeresboden an der Stelle, die mit der Deformationsfront in Zusammenhang gebracht wird. Die Oberkante der subduzierten Nazca Platte konnte bis in eine Tiefe von etwa 12 km dargestellt werden. Auf beiden

Linien zeigten sich subduzierte, horstähnliche Strukturen unterhalb des Kontinentalhanges. Störungen wurden gefunden, die sich parallel zur abtauchenden Platte bis in größere Tiefe erstrecken. Sie legen die obere Begrenzung des Subduktionskanals fest und könnten als Folge einer Horst-Kontinent Kollision entstanden sein. Die in solch einem Falle auftretenden Kompressionskräfte könnten für eine Ostwärtsbewegung einzelner Teile der angrenzenden kontinentalen Kruste verantwortlich gewesen sein. Ihre hohe Reflektivität erklärt sich möglicherweise durch Infiltration von Fluiden oder aber durch Materialkontrast. Exzellente Abbilder der Abschiebungen zwischen 104 km und 118 km (Linie SO104-07) und zwischen 90 km und 113 km (Linie SO104-13) konnten mit Hilfe der Fresnel Volumen Migration gewonnen werden. Auch ein zugehöriger Abscherhorizont war auf beiden Linien deutlich zu erkennen.

Die Fresnel Volumen Migration zweier Offshore-Datensätze ermöglichte es viele strukturelle Details des Untergrundes darzustellen, die in solch einer Qualität in den Kirchhoff Ergebnissen nicht zu beobachten waren.

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