复杂地区地震勘探实践

王西文　高建虎　刘伟方　胡自多　苏　勤　刘文卿　等著

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内 容 提 要

本书所研究的地震技术展示了其在寻找复杂油气藏的过程中良好的应用前景，为寻找大场面油气藏奠定了坚实的基础。全书共分6章，第1章为吐哈盆地山前带复杂构造地震成像方法研究及应用；第2章介绍了四川盆地高陡构造地震资料处理技术；第3章为塔里木盆地深度域成像攻关研究；第4章为塔里木盆地碳酸盐岩洞缝储层叠前成像与叠前预测技术研究；第5章为苏里格天环地区叠前成像研究；第6章为鄂尔多斯盆地苏里格气藏地震技术应用。

本书可供从事石油勘探的科技人员参考。

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前　言

随着油田勘探开发的需要，简单的、容易找到的油气藏已所剩无几。在此形势下，要保持储量、产量的持续稳定，只有向复杂构造地区发展，寻找新的油气藏，这是无法避免的事实。从勘探的思路上，地震勘探已经从构造勘探全面向岩性勘探转变，勘探目标从构造圈闭转向岩性圈闭。而在复杂地区，由于地表及地下地震地质条件非常复杂，地表类型多样，低降速带差异很大，地震反射信噪比低，分辨率低，反射同相轴连续性差，地震成像差，地震反射杂乱，断点不清晰，给地震采集和处理带来了较大难度。同时地下断层发育，也影响了地震资料品质，造成地震资料品质较差、处理难度大，主要在静校正、叠前去噪、速度分析及偏移成像等方面，处理成果不能满足圈闭描述和勘探目标选择与评价的需要。地下地层构造条件和储盖组合多样化，层位及地质解释存在推测和多解性，增加了勘探风险。因此，地震成像问题是制约复杂地区地震勘探的一个瓶颈。本书所研究的复杂地区地震成像方法对于落实复杂地区地质结构、提高地质认识具有非常重要的现实意义。

目前，制约复杂地区地震成像的难点主要表现在静校正问题严重、信噪比较低和地下地质体准确落实困难三个方面。从理论来讲，传统地震资料处理技术存在一系列缺陷，具体表现在这些技术所依据的假设条件与复杂区域的实际情况相距甚远，导致精度大幅度下降，甚至得出错误的结果和虚假的构造。每一种技术方法，在理论推导阶段，都需要一些假设条件，在此假设条件之下，该理论才能适用。地震资料处理技术也不例外，在技术设计之初，为了技术的可操作性，均有其相应的假设条件。当实际情况与这些假设条件相差不远时，这些技术方法的应用就可达到要求的精度。反之，其误差就相当大。因此单一的地震勘探方法不能解决全区的地质问题。地表高差大，低降速带纵向厚度、速度变化无常，表层模型结构复杂，野外低速带调查资料（微测井、小折射、岩性取样、地质露头）很难反映实际低降速带模型。目前成熟的地震勘探方法大多基于地表一致性假设，而复杂山地，近地表射线传播路径不满足垂直传播的假设，即使模型准确，常规的时移静校正也解决不了近地表对反射波的畸变问题；高速层速度横向变化大，起伏剧烈，基准面和替换速度的准确选取十分困难，会产生长波长剩余静校正问题，而基于反射波的自动统计剩余静校正方法不能解决长波长剩余静校正问题。针对以上难点和分析以往采用技术的缺点，本书从多方法、多域及叠前成像处理出发，进行技术创新，取得了成像精度的突破。关键的针对性处理技术主要包括：综合静校正技术、叠前多域逐级噪声压制技术和浮动面叠前深度偏移方法等。而在具体实现过程中，为了建立起准确的偏移速度模型，本书坚持贯彻处理、解释一体化的研究思路。

随着勘探力度的加大，需要在复杂地区开展叠前成像处理攻关研究，以提高地震资料处理质量，落实构造。从对复杂地区叠前深度偏移攻关的结果来看，叠前深度偏移是解决复杂构造成像和恢复地下真实构造形态的有效技术。本书经过精细速度模型建立、速度精度论证、偏移方法和偏移参数的攻关研究，其地震资料的品质得到了改善，构造高点落实，对复杂地区构造成像有很大的推动作用；叠前深度偏移处理后的目的层位波组特征清楚，构造成像合理。叠前深度偏移剖面比叠后时间偏移剖面、叠前时间偏移剖面在成像和构造归位等方面有很大的提高。通过精细的速度模型建立，叠前深度偏移剖面可以准确落实构造形态、刻

画构造细节。叠前深度偏移由于考虑了地震波传播过程中的折射项，并且在较好模型基础上进行反射波归位，消除了上覆地层速度异常对下伏地层的影响，得到了地下准确的构造形态。所以在理论上叠前深度偏移的效果要好于时间偏移。从本书研究内容中的实际处理情况来看，深度偏移在复杂构造成像和落实构造方面有很大的优势。

随着复杂油气藏的勘探开发日益成为研究的重点，复杂油气藏成为增储上产的重要领域。但是复杂油气藏的有效勘探开发技术依然滞后，特别是物探技术，严重制约这些油气藏的勘探开发。针对复杂地区的储层目标，本书开展了叠前储层预测研究工作，以机理的研究带动新技术和新方法的优选、集成和配套，通过岩石物理基础和物理模拟研究，明确复杂储层的地球物理响应特征，并在此基础上系统开展复杂储层的地震资料处理、解释和油藏描述方法研究。叠后地震技术对碳酸盐岩洞缝储层很难精细刻画，应用叠前地震技术可以提高预测有效储层分布及流体性质识别的精度。因此，针对复杂碳酸盐岩洞缝油气藏，本书以保真成像处理为基础，形成叠前地震资料的精细描述配套技术体系，为油气藏预探、评价井位优选提供技术依据。另外，常规叠后地震技术显然不能完全解决研究区的储层预测和流体检测的要求。而利用叠前地震信息（AVO分析和叠前地震反演、叠前地震属性等），不但能降低预测多解性，而且还可以得到直接反映地下岩层信息的资料，除了纵波阻抗外，还有横波阻抗，纵横波速度和密度等，由此可以计算所有弹性参数，为岩性和流体识别与预测提供了广阔的空间，是开展复杂储层描述的最有潜力的工具。

本书针对各种复杂地区不同地震资料特点与储层预测的要求，研究应用了不同的地震技术。叠前偏移技术的推广与应用，为复杂构造成像及特殊地质体的落实提供了技术保障。本书所涉及的应用过程突出精细，强化振幅保真度，确保目的层的信噪比、分辨率和准确成像。采用高保真、高信噪比、高分辨率和准确成像的“三高一准”处理，强化地表一致性全三维处理技术，注意保护低频，提高资料的信噪比，提高目的层段 CMP 道集和 CRP 道集的信噪比。在岩性油气藏勘探中，为了能有效识别岩性油气藏，通常要求对地震资料做提高分辨率处理，但过分强调高分辨率和高信噪比会使处理结果的保真度变差。因此，在地震技术的应用过程中，本书强调以保真为主，适当提高分辨率及信噪比。针对有利勘探区块，在地质目标和地质构造指导下进行目标精细处理。每一步关键处理环节，结合地质、钻井、测井资料，利用合成地震记录，对井旁地震道进行层位标定和对比，确保处理时振幅、频率、相位、波形的相对保持，严格控制处理质量，使地震资料的分辨率、信噪比逐步提高。本书在成果数据体上进行精细储层预测和资料解释，利用解释成果检测和评价地震资料的处理质量，对有利含油区和有利储层，根据需要重新进行目标精细处理，包括处理模块、关键参数的合理性进行定量分析，优化处理流程，提供符合地质特征的高保真地震资料，为高精度储层预测奠定良好基础。

多年来的勘探开发研究证实，技术的进步，再次证明了复杂地区的油气勘探大有可为。本书所研究的地震技术展示了其在寻找复杂油气藏的过程中良好的应用前景，为寻找大场面油气藏奠定了坚实的基础。全书共分 6 章，第 1 章为吐哈盆地山前带复杂构造地震成像方法研究及应用；第 2 章介绍了四川盆地高陡构造地震资料处理技术；第 3 章为塔里木盆地深度域成像攻关研究；第 4 章为塔里木盆地碳酸盐岩洞缝储层叠前成像与叠前预测技术研究；第 5 章为苏里格天环地区叠前成像研究；第 6 章为鄂尔多斯盆地苏里格气藏地震技术应用。

本书前言由王西文、马龙执笔；第 1 章由苏勤、吕彬、黄云峰、王宇超、王西文执笔；第 2 章由胡自多、王西文、邵喜春执笔；第 3 章由刘文卿、王小卫、袁刚执笔；第 4 章由王

西文、刘伟方、王小卫、田彦灿、吕磊、蒋春玲、刘卫华执笔；第5章由王西文、刘文卿、王宇超、张喜梅、刘秋良、张小美执笔；第6章由高建虎、王西文、董雪华、赵玉莲、陈启艳执笔。本书由王西文负责修改和统稿。

本书内容涉及的研究项目，得到了中国石油勘探与生产分公司、长庆油田分公司、塔里木油田分公司、西南油气田分公司、吐哈油田分公司的支持。在本书的编写过程中，得到了中国石油勘探开发研究院西北分院杨杰院长的支持与帮助。笔者在此一并表示衷心的感谢。

由于笔者水平所限，书中疏忽之处在所难免，敬请读者批评指正。

Preface

Along with the great progress of petroleum exploration and development, there aren't many simply and easily discovered reservoirs left. Under this situation, it is inevitable to find new reservoirs in the area with complicated structures for the purpose of reserve maintenance and production stabilization. In terms of exploration thinking, the seismic exploration has shifted from the structural exploration to the lithological exploration, and the exploration targets have changed from structural trap to lithological trap. However, in the complicated area, due to complex surface and underground seismic and geologic conditions, diverse surface types, great difference of low deceleration zone, low S/N ratio of seismic reflection, low resolution, poor continuity of reflection event, poor seismic imaging, chaotic seismic reflection, unclear fault point, the work of seismic data acquisition and processing are very difficult; meanwhile, the underground fault development also affects the seismic data quality, leading to poor data quality and difficult and data processing, mainly in terms of static correction, pre - stack de - noising, velocity analysis and migration imaging etc., and the processing results can't meet the demand of trap description and exploration target selection and evaluation. The diversity of underground structural conditions and reservoir - seal assemblage, as well as the speculation and ambiguity of horizontal and geologic interpretation, increases the exploration risk. Therefore, the seismic imaging is a bottleneck restricting seismic exploration in complex area. The seismic imaging method applied in the complex area in this book plays a practical significance to determine the geologic configuration and improve the geologic understanding in the complex area.

At present, the seismic imaging in the complex area is difficult because of serious static correction, low S/N ratio and difficult geologic body determination. Theoretically, there is a series of defects of traditional seismic data processing, which is because the hypothesis conditions of the technology are far away from the real conditions of complex area, resulting in great decline of precision and even wrong results and fictitious structures. In the theoretical induction phase, each technical method needs some hypothetical conditions under which the theory can be applied. There is no exception in terms of seismic data processing technology; during the initially technical design phase, for the sake of technical operability, there are corresponding hypothetical conditions. When the actual situation is close to the hypothetical conditions, the application of the technologies can meet the demand of precision. Otherwise, the error is substantial. Therefore, the single seismic exploration method can't tackle the geologic problems in the whole area. Due to great surface elevation difference, constantly changing of vertical thickness and velocity in the low deceleration zone and complex surface model configuration, the field low velocity zone data (microlog, short refraction, lithological sampling and geologic outcrop) is difficult to reflect the real deceleration zone model. At present, the mature seismic exploration methods are mostly based on the surface consistency hypothesis, yet in the complex mountain area, the travel path of near - surface ray can't meet the hypothesis of vertical propagation; even if the model is correct, the conventional time shift static correction can't tackle the reflection wave distortion caused by near surface either; in the high velocity zone, due to great change of the lateral velocity and sharp fluctuation, the accurate selection of datum and alternative velocity is difficult, leading to the residual static correction of long wavelength problem, but the residual static correction on the basis of wave automatic statistics cannot figure out the problem of residual static correction of long wavelength problem. Aiming at the above difficulties and the previous technical shortcomings, the book begins from the multi - method, multi - domain and pre - stack imaging processing, carries out technical innovation and gets breakthrough of imaging precision. The key processing technologies include: composite static correction technique, pre - stack multi - domain gradual noise suppression technique and floating plane pre - stack depth migration method. However, in the actual realization process, in order to establish accurate migration velocity model, the book insists on research thought of integrated processing and interpretation.

With the enhancement of exploration, it is required to carry out technical breakthrough research into the pre - stack imaging processing in the complex area in order to improve the seismic data processing quality and confirm the structure. In view of the research results of the pre - stack depth migration in the complex area, the pre - stack depth migration is an effective technology to realize the complex structure imaging and restore the real underground structural pattern. Through fine velocity model establishment, velocity precision demonstration, making breakthrough in migration method and migration parameter research, the seismic data quality is improved, and the structural high is confirmed, which has greatly improved the structure imaging in the complex area; after the pre - stack depth migration, the wave characteristics of target formation are clear, and the structure imaging is rational. The pre - stack depth migration profile can get better imaging and structure homing than post - stack time migration profile and pre - stack time migration profile. With the assistant of fine velocity model, the pre - stack depth migration profile can accurately confirm the structural pattern and depict the structure detail. As the pre - stack depth migration considers the refraction during the seismic wave transmission and carries out reflection wave homing on the basis of good model, the influence of velocity anomaly of overlying formation on the underlying formation is removed, thus acquiring the accurate underground structural pattern. Therefore, the effect of pre - stack depth migration is theoretically better than time migration. In view of the real processing in the book, the depth migration has great advantages in terms of complex structure imaging and structural confirmation.

As the exploration and development of complex reservoirs has increasingly become the research emphasis, the complex reservoirs turn into the important domain for increasing reserve and production. However, the effective exploration and development technologies of complex reservoir still lag behind, especially the geophysical technologies, which seriously restrict the exploration and development of these reservoirs. Aiming at the reservoir targets in the complex area, the book describes the pre - stack reservoir prediction in which the mechanism research drives the new technology and new method selection, integration and matching, makes the geophysical response characteristics of complex reservoirs clear on the basis of rock physics and physical simulation, and then conducts seismic data processing, interpretation and reservoir description method research of complex reservoirs. The post - stack seismic technologies are difficult to depict the carbonate fracture - cavern reservoir, but the pre - stack seismic technologies can improve the precision of predicting effective reservoir distribution and fluid property identification. Therefore, with regard to the complex carbonate fracture - cavern reservoir, the book is based on the fidelity imaging processing, forming the precise description matching technology system of pre - stack seismic data, which provides technical basis for reservoir prospect and evaluation of well location selection. Furthermore, the conventional post - stack seismic technology is apparently unable to meet the demand of reservoir prediction and fluid detection in the research area. However, the pre - stack seismic information (AVO analysis and pre - stack seismic inversion, pre - stack seismic attributes etc.) can not only reduce the prediction ambiguity but also can get the data directly reflecting the underground formation information, which includes P - wave impedance, S - wave impedance, P - wave and S - wave velocity and density, which can be used to calculate all the elastic parameters and provide wide space for rock and fluid identification and prediction; therefore, it is the most potential tool for complex reservoir description.

The book mainly aims at the different seismic data characteristics and demand of reservoir prediction in all kinds of complex areas and applies different seismic technologies. The introduction and application of pre - stack migration technology provides technical guarantee for the complex structure imaging and special geologic body confirmation. The involved application highlights precision, strengthens amplitude fidelity, ensures the S/N ratio and resolution of target formation, and gets accurate imaging. The " three highs and one accurate" processing, namely high fidelity, high S/N ratio, high resolution and accurate imaging, intensifies surface consistent full 3D processing technology, pays attention to low frequency protection, S/N ratio improvement of full data, and S/N ratio improvement of CMP gather and CRP gather in the target formations. In the lithological reservoir exploration, in order to effectively identify the lithological reservoir, it is usually required to conduct resolution improvement processing on the seismic data, but overemphasis on the high resolution and high S/N ratio will lead to poor fidelity of processing results. Therefore, during the application of seismic technology, the book mainly highlights the fidelity and properly improves the resolution and S/N ratio. In the favorable block, the precise target processing is carried out under the direction of geologic target and geologic structure. Each key processing link combines with the geologic, drilling and log data and uses the synthetic seismic record to conduct the horizontal calibration and correlation on the near - well seismic trace, thus ensuring the relative holding of amplitude, frequency, phase and waveform; strictly control the processing quality to gradually improve the seismic data resolution and S/N ratio. This book research carries out fine reservoir prediction and data interpretation on the resulting data volume, uses the interpretation achievements to detect and evaluate the seismic data processing quality; as to the favorable oil - bearing area and favorable reservoir, the target processing is refined as required, including quantitative analysis on the rationality of processing module and key parameter, and the optimization of processing flow provides the high fidelity seismic data suitable for geologic characteristics, which lays a good foundation for high precision reservoir prediction.

The exploration and development research for many years proves that the technical advancement is very important to the petroleum exploration in the complex areas. The seismic technologies studies in this book show the bright future of application in the complex reservoir exploration, which lays a sound foundation to discover large - scale reservoirs. The book includes six chapters, chapter 1 tells the seismic imaging method research and application of complex structures in the mountain front of Tuha Basin; chapter 2 introduces seismic data processing technology in the high - steep structure of Sichuan Basin; chapter 3 introduces the imaging research breakthrough in the depth domain in Tarim basin; chapter 4 introduces technical research of the pre - stack imaging and pre - stack prediction of carbonate fracture - cavern reservoir in the Tarim Basin; chapter 5 introduces the pre - stack imaging research in Tianhuan area, Sulige; chapter 6 introduces the seismic technology application of Sulige gas reservoirs in Ordos Basin.

The preface of the book is written by Wang Xi - wen and Ma Long; chapter 1 is written by Su Qin, Lv Bin, Huang Yun - feng, Wang Yu - chao and Wang Xi - wen; chapter 2 is written by Hu Zi - duo, Wang Xi - wen and Shao Xi - chun; chapter 3 is written by Liu Wen - qing, Wang Xiao - wei and Yuan Gang; chapter 4 is written by Wang Xi - wen, Liu Wei - fang, Wang Xiao - wei, Tian Yan - can, Lv Lei, Jiang Chun - ling and Liu Wei - hua; chapter 5 is written by Wang Xi - wen, Liu Wen - qing, Wang Yu - chao, Zhang Xi - mei, Liu Qiu - liang and Zhang Xiao - mei; chapter 6 is written by Gao Jian - hu, Wang Xi - wen, Dong Xue - hua, zhao Yu - lian and Chen Qi - yan. Wang Xi - wen is in charge of the revision and compilation of the whole book.

The research projects involved in the book are supported from PetroChina E & P Company, Changqing Oilfield Company, Tarim Oilfield Company, Southwest Oil & Gas Field Company and Tuha Oilfield Company. The compilation of the book also receives the support and help from Yang Jie, director of PetroChina Exploration&Development Research Institute (Northwest) . The author hereby expresses sincere appreciation to all.

Due to limited level, there must be some inevitable negligence in the book, please give praise and correction when reading.

目　录

Contents

1 吐哈盆地山前带复杂构造地震成像方法研究及应用

1.1 概述

1.1.1 吐哈盆地北部山前带勘探概况

吐哈盆地北部山前带地区位于吐哈盆地台北凹陷北部博格达山前，西起卡拉图，东至车轱泉，呈东西向展布，面积约6450km²。由西向东依次发育卡拉图、七泉湖、恰勒坎、核桃沟、鄯勒、红旗坎、金北、大步、车轱泉9个构造带（如图1.1.1所示）。该区紧临生烃洼陷，油源条件较好，成藏条件优越，存在亿吨级资源潜力；并且山前带勘探层系多，发育多套储盖组合，可以形成多套含油气组合，该带主要目的层古近系—中下侏罗统、二叠系、三叠系为北物源控制的扇三角洲及冲积扇沉积，储层发育，目前钻井已证实至少发育5套储盖组合，并在Esh、J_2q-J_2s、J_2x、J_1发现了油气藏，前侏罗系也发现油气显示，证实了该带是一个重要的复式油气聚集带，剩余圈闭较多，多期圈闭叠置发育；同时山前带存在多期构造运动，处于多期古构造的相对高部位，是油气运移、调整的优势指向区[1]。该区目前已成为吐哈油田增储上产的重要战场[1]。

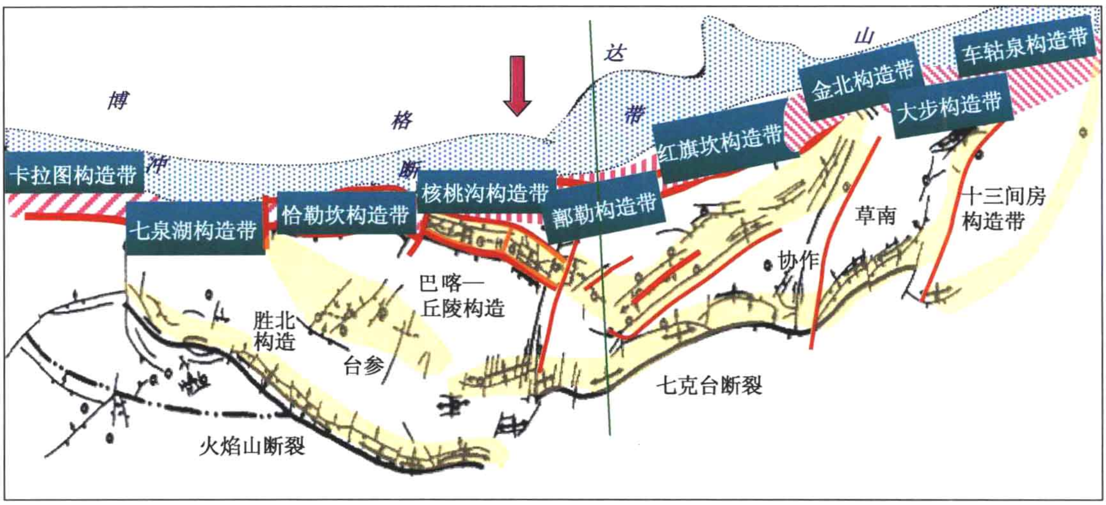

图1.1.1 吐哈盆地北部山前带构造分布特征示意图

但该地区地表及地下地震地质条件非常复杂，给地震采集和处理带来了较大难度。除鄯勒地区地震资料品质较好、基本能满足构造解释以外，其他地区资料地震反射信噪比低，分辨率低，反射同相轴连续性差。尤其是红旗坎、金北、阿克塔什、玉果局部区域地震成像差、地震反射杂乱、断点不清晰，不能满足精细落实地质结构、构造面貌和储层预测的需要。因此，地震成像问题是制约吐哈盆地北部山前带地震勘探的一个瓶颈，开展山前带复杂构造地震成像方法研究对于该区落实地质结构、提高地质认识具有非常重要的现实意义[2]。

1.1.2 地震成像难点分析

目前制约吐哈盆地北部山前带地震成像的难点主要集中在以下三个方面：