

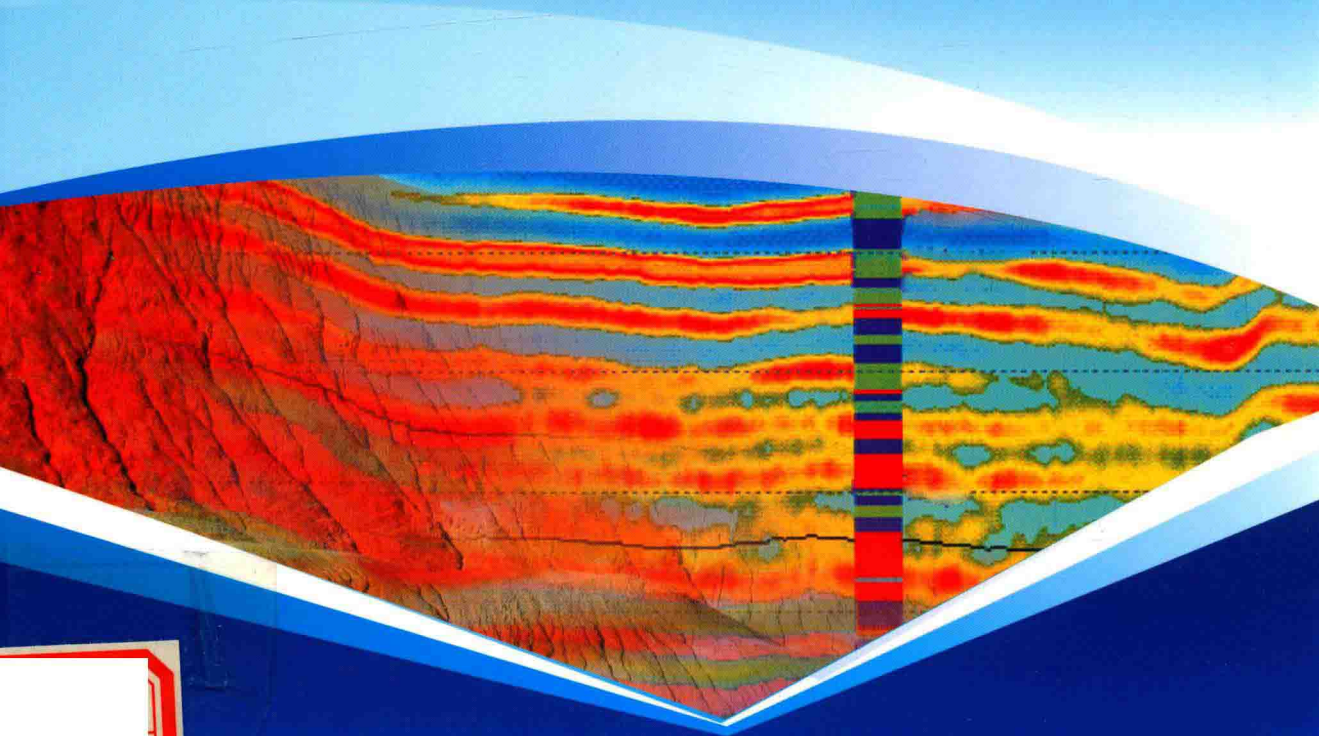


FUNDAMENTAL FOR
SEISMIC-GEOLOGIC INTERPRETATION

地震地质解释基础

(双语版)

王长城 徐国强 左银辉 ©主编



石油工业出版社

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内 容 提 要

本书以地震与地质紧密结合的研究思路为主线,从地震反射波的基本地质属性入手,详细阐述了地震子波、波阻抗与反射界面、显示极性、地震记录道与地震剖面等相关概念,重点介绍了人工合成地震记录的基本原理与制作方法、地震反射特征与地质特征的对应关系,并详细探讨了地震资料的纵向分辨率和空间分辨率,最后以波形分析的实例来说明“岩性地层—地震记录道—波形分析”的工作流程。

本书融入了编者多年的教学经验和科研成果,可为读者提供系统的地震解释基础知识以及相关的英文表达方式,可作为高等院校油气勘探相关专业的双语教材,也可供生产单位和科研院所从事地球物理勘探、地震资料综合解释的人员参考。

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序

能源是关系到世界各国经济发展、政治稳定的基石,石油更是被称为“黑色黄金”,事关国民经济的发展。地震勘探作为一种最成熟、最有效、低成本的油气勘探技术,得到了广泛应用,是一种寻找油气的关键技术。

地震资料解释是地震勘探技术的重要组成部分,它能直接提供勘探成果,是决定油气田开发战略的关键。目前,地震勘探新方法和新技术层出不穷,其透视地下油气的能力越来越强。地震资料解释技术已从对简单构造的解释转变为对复杂构造的解释、对地层的解释、对岩性的解释、对烃类的直接检测,能清楚真实地反映地下地质体的各种特征,已经能够描述地下数千米深度、小至 0.1km^2 的构造圈闭,可以透视厚仅2m砂体的空间展布,是寻找和描述地下油气藏的主要手段。

地震剖面上同相轴的形态特征,是地质体属性的反映。同相轴形态上的变化是地震资料解释的依据。一张经过精心处理的现代数字地震剖面,与地层构造剖面的形态特征非常接近,以至略懂地震和地质相关知识的人也能够从事地震资料解释。但是,同一张地震剖面,不同的人会得到不同的解释结果,即便是同一个人,在不同的时间、不同的条件下也可能作出不同的解释,这就是地震解释中的多解性。造成地震解释多解的原因很多,除地震资料品质、地质情况、井约束条件等客观原因外,大多数情况是人为的主观原因,是由于人们对地层构造背景、构造样式、岩相和沉积相缺乏深入了解,或者没有掌握合成地震记录、地震模型分析等关键技术,对地震与地质互通性概念掌握不好,将地震解释作为一种简单的相面解释所致。作为一名专业的地震解释工作者,首先要掌握地震勘探原理、构造地质学、岩石学、沉积相、岩相古地理、层序地层学等基础地质理论,还要掌握岩性地层—地震记录道和波形间互相转换的基础理论,通过系统学习地震构造解释、地震相分析的方法原理以及长期的工作实践,才能得到最为接近正确的、合理的地震解释结果。所以,地震资料解释并不是一项简单的技术工作,而是一项需要掌握相关理论才能从事的专业技术工作。没有掌握地震与地质相结合的研究思路及相关专业基础知识的地震解释人员,地震解

释通常是相面的、业余的,其地震解释是人为多解的。

成都理工大学的王长城、徐国强等同志,结合自身多年从事教学、科研工作的经验与成果,以地震与地质紧密结合的研究思路为特色,编著了《地震地质解释基础(双语版)》一书。该书对地震地质解释中的基础知识进行了系统的介绍,涵盖了地震地质解释的相关基本概念、人工合成地震记录的基本原理与制作方法、地震反射特征与地质特征的对应关系、地震资料的纵向分辨率和空间分辨率等。书中选取我国典型碎屑岩油气勘探开发实例,分析了不同岩石特征对应的地震波形特征,并以此为基础介绍了地震与地质紧密结合的研究思路以及“岩性地层—地震记录道—波形分析”的工作流程。该研究思路与工作流程已经直接指导和应用于部分国内外油气领域的勘探及开发实践,同时也为地震地质解释工作提供了思路和可借鉴的技术手段。

本书为双语版,详细介绍了地震资料解释的相关基础理论和技术方法,内容充实,语言严谨,是一部非常实用的地震资料解释领域的著作。我希望,它能够成为培养具有地质思维地震解释人员的有力工具,为油气勘探事业的发展发挥更大作用。

中国科学院院士

刘广润

2015年7月16日

前 言

地震勘探是一种具有高保真度、高分辨率、高精度,且探测深度大的地球物理勘探方法,是油气勘探的重要手段之一。近年来,随着油气需求的快速增长和计算机技术的进步,地震勘探新方法和新技术迅速发展,其识别地下油气的能力也越来越强,地震勘探技术已成为寻找和描述地下油气藏的主要手段。

地震资料解释是地震勘探方法的重要环节,是将地震数据体变成地质成果的过程。地震剖面作为地下地质体的反映,如何结合反射波的基本属性对地震剖面进行地质解释,是地震资料解释工作的关键。掌握基础的地震或地质知识的人员,能够对经过精心处理的、与地层构造剖面形态非常接近的地震资料进行简单的解释,但是,作为一名专业的地震解释工作者或想通过地震资料获取相关信息的地质工作者,不但应掌握地震勘探基本原理及相关地质理论,还应掌握岩性地层—地震记录道—波形之间互相转换的基础理论,才能得到与实际地质情况更为接近的合理地震解释成果,不仅做到“知其然”,而且做到“知其所以然”。

通过地震资料得到与实际地质情况更为接近的地震解释成果,就是要将地震与地质结合起来,弄清反射波属性变化所反映的地质因素。本书编者结合多年从事地震地层学、地震地质解释等方面的教学和科研工作的经验,建立了地震与地质相结合的研究思路,在运用地震资料解决地层、构造、沉积及油气地质问题方面独树一帜,完成了多项有关四川、渤海湾、南海等含油气盆地的国家级、省部级科研课题。结合科研成果,在成都理工大学开设了本科生课程“地震地下地质学”及研究生课程“地震地层学”“油气开发地球物理”,在教学过程中,遵循学生的认知规律,从学生对知识的理解情况,分析教学中存在的问题和改进方向,为本书的编写积累了大量经验。

本书分为两部分,第一部分为英文部分,第二部分为中文部分,每一部分分为5章并一一对应,可满足读者在学习专业知识的同时掌握相关的英文表达的需求。第1章详细介绍了地震资料采集处理基础、地震子波、波阻抗与反射系数、反射界面等基础知识。第2章主要介绍了地震记录道和地震剖面等相关概

念。第3章重点介绍了人工合成地震记录基本原理与制作方法,并进行了实例分析。第4章详细讨论了地震资料的纵向分辨率和空间分辨率。第5章以波形分析实例来说明“岩性地层—地震记录道—波形分析”的工作流程。本书系统地介绍了地震解释基础知识,在编写过程中始终贯彻地震与地质相结合的思路,能让读者更好地掌握地震与地质相联系的基础理论和方法,更好地为油气的勘探与开发服务。

本书吸收了成都理工大学徐国强教授2010年版“地震地下地质学”课程多媒体教材与徐怀大教授1990年版《地震地层学解释基础》的经典内容,同时,参考了国内外同行的相关著作和文献,并引用了他们的成果和论述,在此表示衷心的感谢。在本书的编写过程中,成都理工大学能源学院施泽进教授、宋荣彩副教授给予了大力支持和指导,中国石油经济技术研究院太科石油信息咨询服务公司对英文稿件进行了审校与修订,在此一并表示感谢。特别要感谢刘宝珺院士在百忙之中为本书作序。

本书由课题组共同完成,由王长城、徐国强、左银辉任主编。课题组先后多次经过讨论,对章节安排、撰写内容、图表规范等进行了明确和统一。其中,第1章由徐国强、王长城完成;第2章由王长城、张小兵完成;第3章由王长城、吴昌荣完成;第4章由王长城、徐国强完成;第5章由徐国强、左银辉完成。李文杰、孙意博、高福坤、杜萌、杨海欧等博士、硕士研究生参与了本书的文献调研、图件清绘、资料整理、文字校对等方面工作。全书的统稿工作由王长城、徐国强负责完成。

由于编者水平有限,书中错误和不当之处在所难免,热忱欢迎广大专家和读者给予批评、指教。

编者

2015年7月

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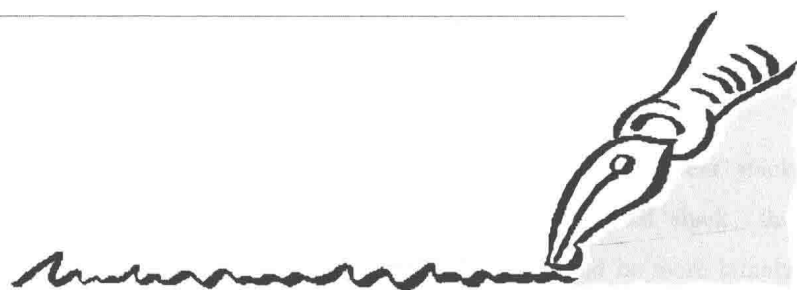
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英文篇



Chapter 1 Seismic Fundamentals



1.1 Seismic Data Acquisition and Processing

Seismic reflection profile can be obtained by seismic prospecting. Although there are still some technical problems in seismic prospecting in mountain, desert and complex tectonic zone for the moment, seismic prospecting has become a widely used mature technology. Multiple coverage technology like common mid-point (CMP) or common depth-point (CDP) is usually adopted in seismic prospecting, as shown in Figure 1.1.

By means of field geophone array operation and indoor sort demultiplex, different stack velocity is selected to conduct normal moveout correction; after having conducted stack, the multifold reflection wave is obtained (Figures 1.1 and 1.2), whose signal would be more largely strengthened than that picked up by single geophone, and simultaneously, the noise can be suppressed and the signal to noise ratio (SNR) can be enhanced. Seismic profile can also be obtained by many other processing procedures like migration and zero-phase processing, and relevant contents refer to *Principles and Methods of Seismic Prospecting* (He Qiaodeng 1986).

As shown in Figure 1.3, the seismic data acquisition and processing procedure can be briefly described as follows: when the seismic wavelet (one pulse wave) reaches the point O of a reflector, it would result in a reflection wave, which is received by the geophone and seismic record 1 is obtained. If multiple excitation and receiving are conducted in horizontal direction, by means of various processing, stacking and migration, a series of seismic records of different points of the reflector can be formed. The axial line composed of identical reflection wave phases of the same reflector is called line ups (event), whose fluctuation shape reflects the tectonic form of the reflector.

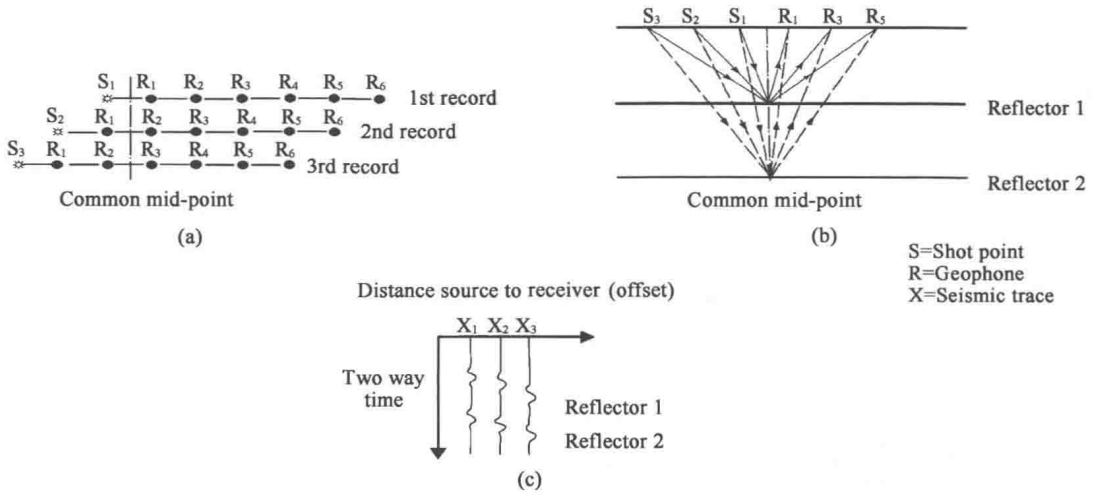


Figure 1.1 Common mid-point reflection waves (Badley, 1983)

(a) Geophone array of shot point and receiver. The shot and detection for the 1st, 2nd and 3rd time are actually on the same line, with receivers arrayed in equal interval; while shooting for the 2nd and 3rd time, the shot point shifts an interval leftwards each time, therefore, the same row of receivers in vertical direction are in the same position in field operation. (b) As for the common mid-point (CMP) shown in the Figure, there are two common depth-points (CDP) on the two subsurface reflectors, by means of which, while shooting at S_1 , seismic wave is received by R_1 , at S_2 , received by R_3 , and at S_3 , received by R_5 . (c) The seismic record of R_1 at the time of 1st shooting, of R_3 at the time of 2nd shooting and of R_5 at the time of 3rd shooting are the reflection waves coming from the same common mid-point, therefore, they can be extracted from the geophone array, and then recombined together, this is called demultiplex. The

reflection waves of reflectors 1 and 2 constitute 2 T-X curves

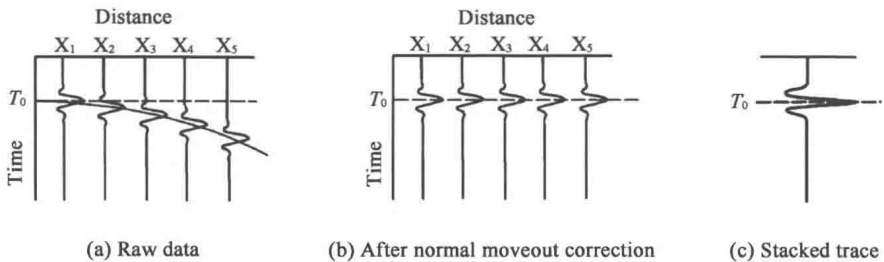


Figure 1.2 Stack of common mid-point reflection waves (Badley, 1983)

(a) Reflection waves coming from the common depth-point (CDP) constitute a T-X curve. (b) By means of normal moveout correction to T-X curve, the reflection waves coming from the common depth-point are corrected to T_0 time, i. e., the zero offset two way time from surface to common depth-point. (c) After the reflection waves coming from the common depth-point (CDP) having been corrected to T_0 time and stacked, the reflected signal is strengthened, and the number of signals taken part in stack is the seismic fold

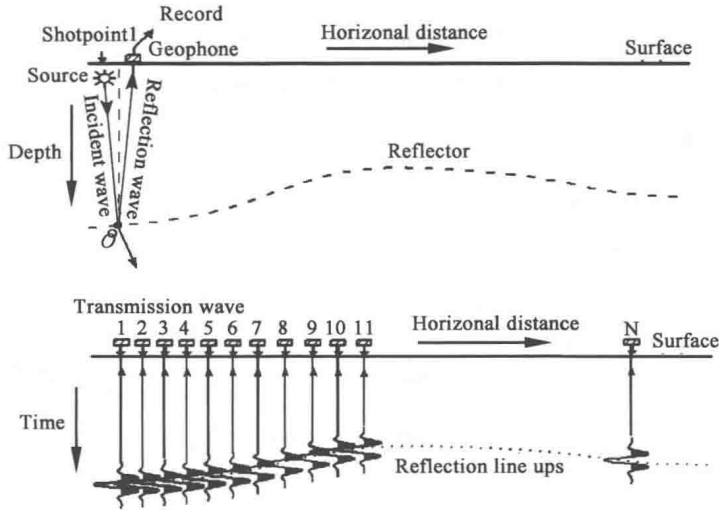


Figure 1.3 Reflector and reflection waves (modified from Anstey, 1982)

As shown in Figure 1.3, the prerequisite for generating seismic reflection wave lies in reflector and seismic source, i. e. , acoustic impedance boundary and seismic wavelet.

1.2 Seismic Wavelet

The seismic pulse wave excited by field shot, gravity hammer or air gun is called seismic wavelet. Seismic wavelet consists of two basic types: minimum phase wavelet and zero-phase wavelet; the former is the true field seismic pulse wave, while the latter is a theoretical wavelet.

The extreme point of seismic wave vibration is called phase, which is used to describe the shape and time position of reflection wave. The time span between two adjacent phases is called cycle, which is used to represent the time span of reflection wave. The reciprocal of cycle is called frequency, in unit of Hz, which is used to represent the number of vibrations per second. The distance from peak or trough extreme point to balance point is called amplitude, which is used to represent the strength of reflection wave. The range of all occurrence frequencies in the seismic wavelet is called bandwidth, which is used to judge the capacity for seismic wave to distinguish the geologic body (Figure 1.4).

1.2.1 Minimum Phase Wavelet

The seismic pulse wave excited by field shot, gravity hammer or air gun is generally characterized by: starting from the reflector, the energy mainly concentrates on the head of the

wavelet, while the energy (amplitude) in the middle and at tail weakens gradually, and this is a kind of asymmetric seismic wavelet. In seismic interpretation, the 1st phase, i. e., the minimum phase is taken as the phase corresponded by the reflector; therefore, it is termed minimum phase wavelet (Figure 1.4).

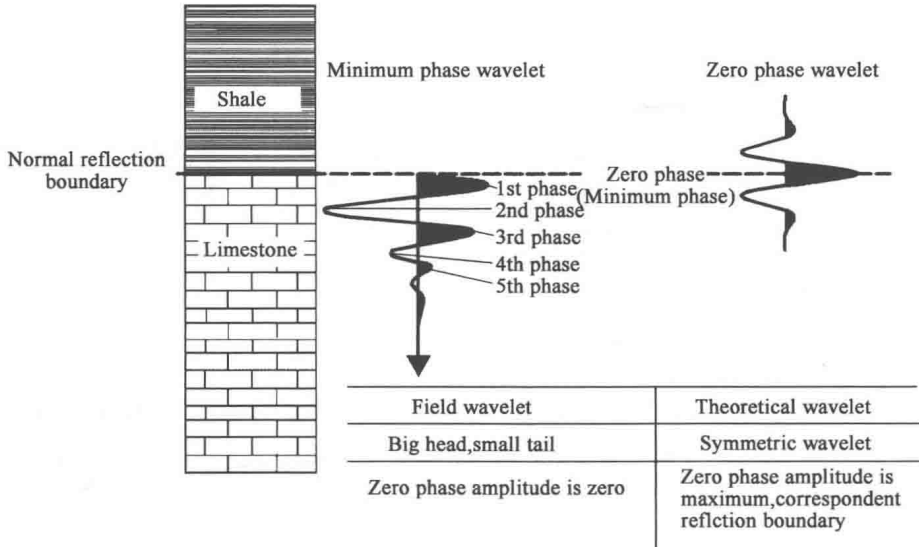


Figure 1.4 Minimum phase wavelet and zero-phase wavelet

1.2.2 Zero-phase Wavelet

Zero-phase wavelet is a kind of symmetric theoretical wavelet. The point of peak amplitude value corresponds to the reflector, i. e., at the point of zero phase, the amplitude is the maximum, the energy is the strongest, and it is a symmetric wavelet by taking the zero phase as a symmetric axis (Figure 1.4). For instance, Ricker wavelet; the zero-phase wavelet designed by Ricker is a mathematical function in which when the phase is zero, the amplitude value is the maximum ($A = 1.0$, $\omega = 0$), and the amplitude contracts with the increase of absolute value of the phase, i. e.,

$$b(t) = [1 - 2(\pi f_p t)^2] e^{-(\pi f_p t)^2} \quad (1.1)$$

Where, f_p is peak frequency, and t is time.

Zero-phase wavelet is a theoretical wavelet, requires the rock particle to start vibration before the incident wave reaches the reflector, and the vibration of particle to reach the maximum when the incident wave front reaches the reflector, which is enigmatical in geophysics.

The biggest difference between minimum phase wavelet and zero-phase wavelet lies in that the former is a true seismic pulse in nature, while the latter is a contrived and theoretically tenable