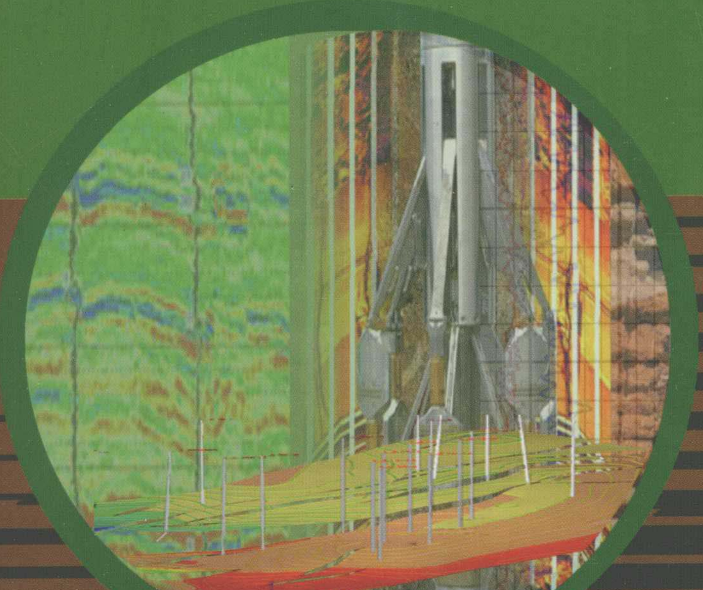
Progress in Geophysics and Information Technology

Xiao Lizhi et al.



Petroleum Industry Press

Progress in Geophysics and Information Technology

Xiao Lizhi et al.

Petroleum Industry Press

图书在版编目（CIP）数据

地球物理与信息技术研究进展 = Progress in Geophysics and Information Technology：英文/肖立志等编．—北京：石油工业出版社，2011. 12

ISBN 978-7-5021-8718-7

Ⅰ. 地…

Ⅱ. 肖…

Ⅲ. 信息技术-应用-地球物理勘探-研究-英文

Ⅳ. P631-39

中国版本图书馆 CIP 数据核字（2011）第 203486 号

出版发行：石油工业出版社

（北京安定门外安华里 2 区 1 号　100011）

网　址：www. petropub. com. cn

发行部：（010）64523620

经　销：全国新华书店

印　刷：北京晨旭印刷厂

2011 年 12 月第 1 版　2011 年 12 月第 1 次印刷

787×1092 毫米　开本：1/16　印张：71. 5

字数：2000 千字

定价：198. 00 元

（如出现印装质量问题，我社发行部负责调换）

Foreword

It gives me great pleasure to write this foreword for this book entitled "Progress in Geophysics and Information Technology". This volume is a collection of recent publications (2006 – 2010) by the faulty members and research associates and students of the School of Geophysics and Information Engineering at China University of Petroleum in Beijing (CUBP). The volume covers a spectrum of technical areas ranging from applied topics of Geophysical Exploration, Geophysical Well Logging, to more fundamental work in computer Science and Technology as well as Electronic Engineering and Automation.

I am truly impressed by the depth and breadth of the topics covered and the quality and impact of the wide range of internationally renowned and nationally leading journals where the CUBP papers have been published. In the area of geophysics for example, there is a rich variety of high quality and original research papers published in leading international journals to address a range of cutting – edge scientific challenges from wave propagation, seismic modeling anisotropy, rock physics to fracture modeling and prediction. In the area of Geophysical Well Logging, there are excellent papers on NMR, electrical and sonic methods and a wide range of applications in well – logging for formation evaluation and fluid typing. Under the topics of computer science and technology, a variety of algorithms has been investigated for improvement in efficiency and accuracy. Application of those methodologies covers numerical simulation, image processing, and many others beyond. Equally in the sections on Electronic Engineering and Automation, the readers can find advanced and emerging technologies that can be applied in a range of industry sectors from consumer electronics to petroleum exploration and production.

I commend the great efforts by my colleagues at CUPB for their excellent achievements in the past five years. Much of the work collected here has helped push forward the frontiers of knowledge and contributed to the technology development both internationally and in China. As a leading school in its own field in China, in my view CUBP's School of Geophysics and Information Engineering has made significant contribution in helping shape the direction and trend of Geophysics and Information Technology R&D in China. With the large number of research students associated with the research work collected here, the School has also made significant contributions to R&D and innovation by nurturing future research and technical talents.

Looking forward to the next 5 years, I am sure the school will go from strength to strength with increasing synergy and cross – fertilization of ideas between geophysics and information technology. I am also very pleased to see the momentum building up in the School to foster international collaborations and exchanges. Two noticeable examples are the recent successful hosting of the International Conference on MRI and joint topical conference on core analysis for unconventional resources, and the increasing number of industry scholarships offered to PhD students by international and national energy companies including Royal Dutch Shell. With this encouraging trend, I am sure we will see an increase of high-quality papers from the School and an increase in joint papers by the school faculty members, students and international research partners.

I congratulate the School of Geophysics and Information Engineering at China University of Petroleum in Beijing and the Dean Professor Xiao Lizhi for this tremendous achievement.

Dr. Dirk Smit

Chief Scientist in Geophysics & Vice President of
Exploration Technology at Royal Dutch Shell
Visiting Professor in Geophysics at China University of Petroleum

Preface

This book incorporates the main achievements in geophysical exploration, geophysical well logging, computer science and technology, electronic engineering and automation by people at the College of Geophysics and Information Engineering (GIE), China University of Petroleum (Beijing) in the past five years (2006 – 2010).

GIE currently has total 130 faculty members, which include 33 professors, 31 associate professors, 10 visiting professors, and 56 lecturers, research associates and technicians, with a number of high level research platforms, such as State Key Laboratory of Petroleum Resources and Prospecting, Beijing Key Laboratory of Earth Prospecting and Information Technology, CNPC Key Laboratory of Geophysical Exploration, etc.. Research projects conducted here are highly diverse, funded by multiple resources including major government research foundations of China, such as National Key Development Program for Basic Research (973 Projects), National High Technology Research and Development Program (863 Projects), and Natural Science Foundation, and industry research funds from CNPC, SINOPEC, CNOOC, and a number of oil fields.

The guideline for GIE in the next five years (2011 – 2015) can be summarized as "Excellence, Specialty, and Opening", in which Opening is of special significance. We will take constant effort to strengthen the related disciplines in GIE by utilizing both domestic and international resources. At present, we are keeping good interaction with many organizations such as Shell and Schlumberger; in the future, we will collaborate more profoundly with universities, enterprises, and research institutes from all over the global. In this way we can contribute more for geophysical and information science and technology.

We understand that our achievements are limited and the next five years will be crucial to us. Effective measures will be taken to gradually improve all aspects of GIE.

At the end, I wish to acknowledge the contribution and cooperation of all the authors for sharing their valuable accomplishments. I also thank the assistants in GIE during the compilation of this book. And special thanks to Dr. Dirk Smit for his time to proofread this book and write the foreword as an encouragement to GIE.

Dr. Xiao Lizhi

Cheung Kong Scholars, Professor and Dean
College of Geophysics and Information Engineering,
China University of Petroleum, Beijing

Contents

Geophysical Exploration

Geophysical Well Logging

Computer Science and Technology

Electronic Engineering and Automation

Geophysical Exploration

Physical modelling studies of 3 – D P – wave seismic for fracture detection❶

Wang Shangxu[1], Li Xiangyang[2], Qian Zhongping[2], Di Bangrang[1] and Wei Jianxin[1]

(1. CNPC Geophysical Key Lab oratory, China University of Petroleum, Beijing, China; 2. British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK)

Abstract: We have carried out two seismic physical experiments to acquire wide – azimuth P – wave 3 – D seismic data with a scaled down model (1 : 10000) and scaled – up frequencies (10000 : 1). Our aims are to verify the physical basis of using P – wave attributes for fracture detection, to understand the usage of these attributes and their merits, and to investigate the effects of acquisition geometry and structural variations on these attributes. The base model consists of a fractured layer sandwiched between two isotropic layers (Epoxylite). Inside the fractured layer there is a dome and a fault block for investigating the effects of structural variations. The two experiments were carried out using different acquisition geometries. The first experiment was conducted to maximize the data quality, with an offset – depth ratio of only 0.68 to the bottom of the fracture layer. For comparison, the second experiment was carried out to maximize the anisotropy effects, with the offset – depth ratio to the bottom of the fracture layer raised to 1.34. For each experiment, about 20km^2 of wide – azimuth 3 – D data were acquired with a P – wave source. The physical modelling confirms that the P – wave attributes (traveltime, amplitude and velocity) exhibit azimuthal variations diagnostic of fracture – induced anisotropy. For the first experiment with noise – free data, the amplitude from the top of the fracture layer yields the best results that agree with the physical model parameters and free of the acquisition footprint. The results from other attributes (traveltime, velocity, AVO gradient) are either contaminated by the structural imprint, or by the acquisition footprint due to the lack of offset coverage. For the second experiment, despite the interferences from multiples and other coherent noise, the traveltime attributes yield the best results; both the acquisition footprint and the structural imprint are reduced due to the increased offset coverage. However, the results from the amplitudes are affected by the noise and are less reliable. Analysis of the two experiments reveals that the offset – depth ratio to the target is a key parameter for the success of the P – wave techniques. Smaller offset – depth coverage may only be applicable to amplitude attributes with high quality data; whilst large offset coverage makes it possible to use traveltime attributes. A reliable estimation from traveltime attributes requires an offset – depth ratio of 1.0 or more.

Key words: anisotropy, fractures, physical modelling, 3 – D P wave

1 Introduction

Fractures play an important part in reservoir development and enhanced oil recovery in

❶ Geophys. J. Int., 2007, 168: 745 – 756.

tight formations of otherwise low permeability. The use of seismic anisotropy to detect natural fractures has been gradually gaining the acceptance of the hydrocarbon industry. The underlying physics for this technology comes from the equivalent medium theory for seismic-wave propagation in fractured media, which has been intensively studied by a range of authors (e. g. Hudson, 1981; Schoenberg & Douma, 1988; Liu et al. , 2000a; Chapman, 2003, amongst others). According to these theories, a medium containing vertically aligned fractures with scale length much less than the wavelength can be modelled by an equivalent azimuthally anisotropic medium for seismic wave propagation. Numerical modelling based on the equivalent medium theories reveals shear wave splitting and azimuthal variations in P-wave amplitude and traveltime as diagnostic features of the fractured medium.

Crampin (1981, 1985) was among the first in proposing the use of shear wave splitting for fracture characterization. Shear waves have been shown to be much more sensitive than P waves to detect fractures (Li, 1997). There are two main reasons: first shearwave splitting can be measured from a single ray path, secondly the polarization of the fast shear wave and time-delay between the fast and slow waves are directly measurements of the fracture orientation and density. In contrast, P-wave measurements are made from a range of different ray paths in both the azimuth and offset domains (Ruger, 1997; Li et al. , 2003). Furthermore, wide-azimuth 3-D P-wave data were not readily available in the 1980s. However, as the increasing use of wide-azimuth 3-D P-wave data in the late 1990s, coupled with the declining in shear wave acquisition, the use of P-wave seismic data for fracture detection became popular with the industry.

Over the past 10 years, there has been a continual increase in the use of 3-D P-wave data for fracture characterization. Both numerical modelling and case histories of fracture detection using P-wave seismic have been the subject of intensive study (e. g. Lynn et al. , 1996; Liu et al. , 2000b; Smith & McGarrity, 2001; Hall & Kendall, 2003; Wang & Li, 2006, amongst others). In comparison, the number of corresponding physical-modelling studies is much less (Luo & Evans, 2004), whilst physical modelling studies of shear wave splitting were well documented in the early 1990s (e. g. Ebrom et al. , 1990; Brown et al. , 1991; Cheadle et al. 1991; Slack et al. 1991; Gregovic et al. , 1992). Here, we fill this gap by presenting physical modelling studies of fracture detection using large-scale 3-D P-wave seismic data. In addition to an examination of the underlying physics, this study also investigates the effects of acquisition geometries and compares the use of different P-wave seismic attributes and different analysis techniques on controlled experiments for fracture detection.

2 The Physical Models

As shown in Fig. 1, the base model consists of three horizontal layers. The first and third layers are constructed from the same material (epoxylite) and are believed to be isotropic. The second layer is constructed from a special industrial material and is believed to be azimuthally anisotropic. The material is composed of epoxy-bonded fibre sheets, simulating

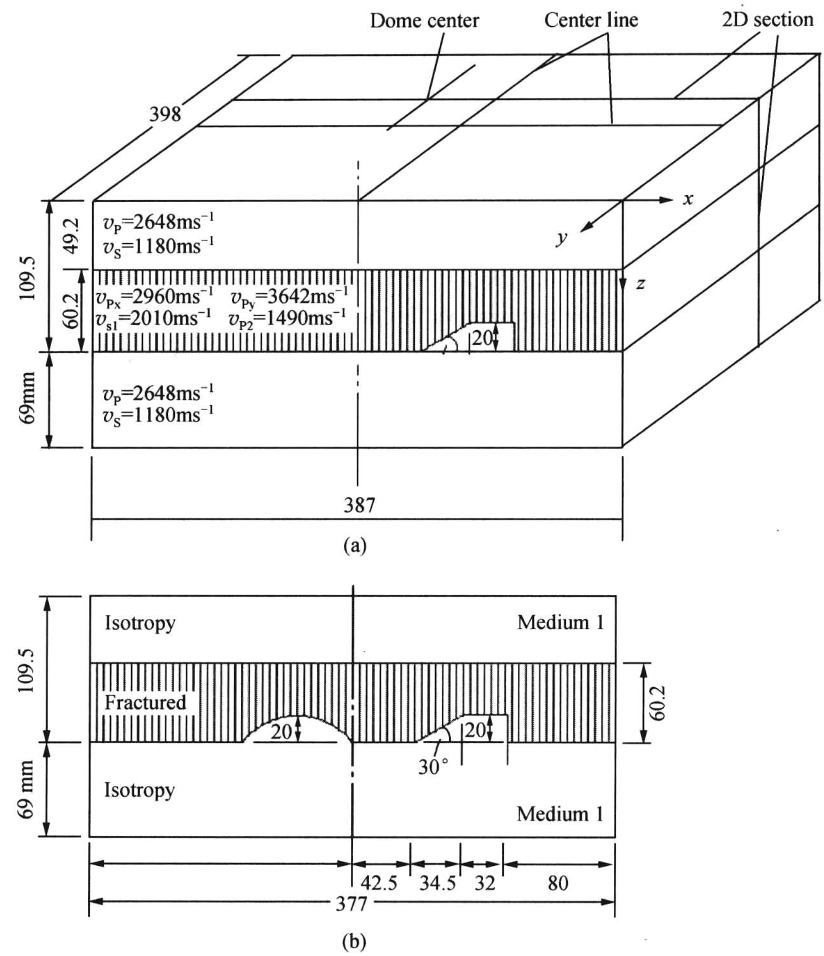


Figure 1 (a) The 3－D physical model, and (b) a 2－D section through the dome centre. The numbers that specify the dimensions are in millimetres, and the model is scaled down by 1 : 10000 with scale up frequencies of 10000 : 1. There is a dome and a fault block inside the fracture layer

vertical fractures. The layer is highly anisotropic with about 20 percent P－ and S－wave anisotropy, and fracture density around 0.2 (Fig. 1). The measured elastic parameters and the corresponding anisotropic parameters are shown in Table 1, which exhibits some weak orthorhombic symmetry. There are also two built－in geological features inside the fracture layer. One is a dome, and the other is a fault block, consisting of a normal and a vertical fault (Fig. 1). The model is constructed with a scale of 1 : 10000 for spatial dimensions and time measurements with a corresponding velocity scaling of 1 : 1.

Two models are derived from the base model for experiments simulating varying offset－depth ratios and acquisition geometries, as shown in Fig. 2. Model 1 [Fig. 2 (a)] consists of a very deep－water layer of 1470m on top of the base model in order to maximize the data quality, which ensures primary reflections from the base model free of multiple contaminations. The total thickness of the overburden above the fracture layer is 1962m, and the maximum offset – depth ratio is about 0. 9 to the top of the fracture layer, and about 0. 7 to the bottom of the fracture layer. Model 2 consists of a thin water layer of 10m and another isotropic layer of 430m on top of the base model [Fig. 2 (b)]. Model 2 is designed to maximize the anisotropic effects. The total thickness of the overburden in Model 2 is reduced to 932m, and the maximum offset – depth ratio is about 2. 2 to the top of the fracture layer, and about 1. 3 to the bottom of the fracture layer.

Table 1 The measured elastic constants (C_{ij}, in $10^9 Nm^{-2}$) and anisotropic parameters ε and γ for the fractured layer in Fig. 1 using the experimental method described in Cheadle et al. (1991). The material exhibits orthorhombic symmetry. The density of the material is 1. 45g · cm^{-3}. In defining the elastic constants, the axes of x, y and z are represented by indices 1, 2 and 3, respectively. ε and γ are defined as (Thomsen 1986): $\varepsilon=(C_{33}-C_{11})/(2C_{11})$ and $\gamma=(C_{44}-C_{66})/(2C_{66})$

C_{11}	C_{22}	C_{33}	C_{44}	C_{55}	C_{66}	C_{12}	C_{13}	C_{23}	ε	γ
12. 704	19. 233	22. 162	5. 858	3. 299	3. 219	7. 865	8. 199	9. 320	0. 372	0. 410

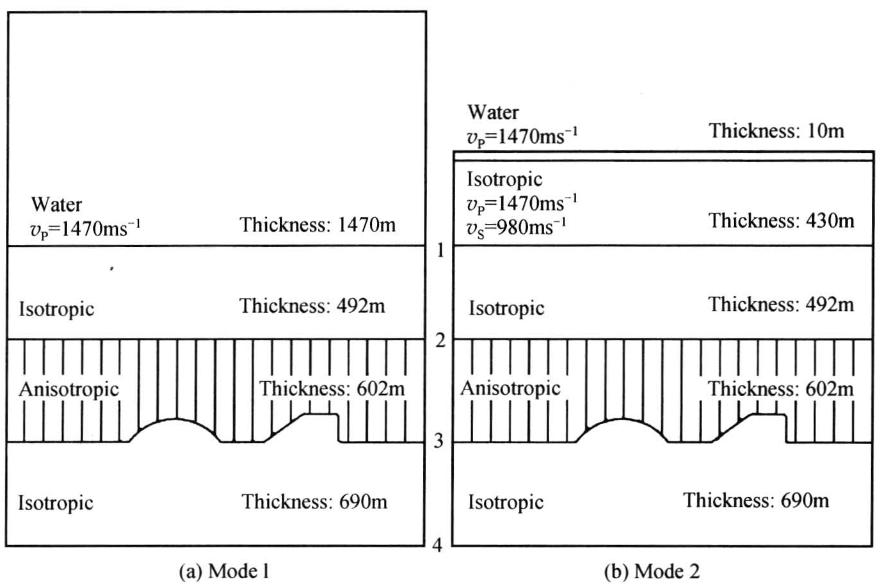


Figure 2 Section view of the two models derived from the base model in Fig. 1. Note that the base model forms the bottom three – layers in Models 1 and 2 and the corresponding properties are shown in Fig. 1 with a scaling of 1 : 10000. The numbers 1, 2, 3 and 4 indicate the main interfaces which are referred to in subsequent figures

3 Data Acquisition

3 – D data acquisition is conducted in a water tank. Fig. 3 shows the experimental set – up. The modelling system is shown Fig. 3 (a), consisting of an ultrasonic pulse source and receiver system, analogue/digital converter and motor – driven positioning system. The maximum movement in the x, y and z directions are 230cm × 230cm × 100cm, respectively, and