Springer Geology

Dexin Jiang
Eleanora Robbins
Yongdong Wang
Huiqiu Yang

Petrolipalynology

Science Press
Beijing

Springer

Dexin Jiang · Eleanora I. Robbins
Yongdong Wang · Huiqiu Yang

Petrolipalynology

Science Press
Beijing

Springer

Dexin Jiang
Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics
Chinese Academy of Sciences (Lanzhou Institute of Geology, CAS)
Lanzhou, Gansu
China

Eleanora I. Robbins
Department of Geological Sciences Adjunct Faculty
San Diego State University
San Diego, CA
USA

Yongdong Wang
Nanjing Institute of Geology and Palaeontology
Chinese Academy of Sciences
Nanjing, Jiangsu
China

Huiqiu Yang
Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics
Chinese Academy of Sciences (Lanzhou Institute of Geology, CAS)
Lanzhou, Gansu
China

ISSN 2197-9545 ISSN 2197-9553 (electronic)
Springer Geology
ISBN 978-3-662-47945-2 ISBN 978-3-662-47946-9 (eBook)
DOI 10.1007/978-3-662-47946-9

Jointly published with Science Press, Beijing
ISBN 978-7-03-045557-4 Science Press, Beijing

Library of Congress Control Number: 2015945126

Springer Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer-Verlag GmbH Berlin Heidelberg is part of Springer Science+Business Media (www.springer.com)

Springer Geology

More information about this series at http://www.springer.com/series/10172

Foreword 1

The authors and publishers of this English language revised translation of the Chinese publication *Palynology of Petroleum Source* are to be congratulated for re-introducing and reinvigorating a practical and fascinating aspect of palynology; namely the recovery of acid-resistant microfossils, or palynomorphs, from hydrocarbon fluids.

The technique has been applied from the 1930s in, *inter alia*, the UK, the Former Soviet Union, and Australia, but with the exception of work in China, seems now to be rarely used. With the essential requirement to avoid contamination, and the need for caution when handling hydrocarbons, results from this relatively simple technique can add to understanding the "plumbing" of sedimentary basins.

Acid-resistant plant microfossils (palynomorphs) are sedimentary particles, which also have the inherent ability to record geologic age, paleoenvironment and paleoclimate, and thermal history. Consequently, their recovery from transported crustal fluids has the capacity to contribute to understanding structural history, and fluid migration pathways and mechanisms. The authors note, for example, that plant microfossils are, for the most part, larger than pore throats of reservoir rocks—so what is the mechanism that allows their transport—through microfissures resulting from initial expulsion, or during dynamic dilation of faults (often evident from seismic sections)? Analysis of recovered plant microfossil assemblages may also contribute to understanding origins of associated geochemical biomarkers, which sometimes record contributions from organic matter from different geologic periods. Equally a comparison of the thermal maturity indices derived from biomarkers and from recovered palynomorphs may be useful for analysis of migration pathways.

This book is a *tour de force*. The authors provide detailed geological information from five "inland petroliferous basins": Tarim, Junggar, Turpin-Hami, Qaidam, and West Jiuquan; and three "coastal shelf basins": Liaohe, Beibu Gulf, and Zhujiang Mouth. It includes principal stratigraphic units, thickness, lithology, paleoenvironmental/tectonic setting, and age. This provides the context for understanding the formation of hydrocarbon source rocks, carrier rocks, and reservoirs rocks. As noted by the authors, recovered plant microfossils are derived from one or more of these three sedimentary rock types. Contemporaneous recycling of palynomorphs may complicate the picture—emphasizing that all information must considered in context. There

are 48 plates of photomicrographs (36 black and white and 12 color) of the almost 500 named species of spores and pollen recovered from oils from 28 oilfields studied. Using globally determined age ranges for these taxa, the authors show that the recovered assemblage is, respectively, of Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and Paleogene age. And from this information identify potential hydrocarbon source formations. This novel palynological information complements other basin assessment techniques, including geochemistry and structural analysis.

Although focussed on recovery of acid-resistant microfossils from hydrocarbons, this technique could be readily adapted to hydrological studies.

The book should be of great interest to explorationists, geochemists, and palynologists.

April 2015

Clinton Foster, Ph.D.
Chief Scientist
Geoscience Australia, Canberra
Adjunct Professor
School of Earth and Environment
The University of Western Australia

Foreword 2

Palynology has been an important discipline in paleontology and biostratigraphy, studying mainly fossil spores and pollen grains from reproductive organs of plants preserved in sedimentary rocks. The field has been an effective approach for better understanding of plant taxonomy, stratigraphic correlation, paleovegetation, and interpretation of paleoclimate and paleoecology. Previously, palynology was regarded as a branch of paleobotany, but now it has become such a useful tool and is often studied independent of plant megafossil remains, especially in geology for stratigraphic correlations and for assessing maturation of oil-rich strata. This monograph shows that fossil spores and pollen in crude oils are also useful indicators for determining petroleum source rocks, studying petroleum origin, migration and accumulation, and forecasting target strata for exploration.

Although palynology of petroleum sources has become accepted as a sub-discipline of palynology, there has been no special academic international monograph on this important subject. Petrolipalynology by Profs. D.X. Jiang, E.I. Robbins, Y.D. Wang, and H.Q. Yang, is the first academic monograph in a new field of interdisciplinary science between palynology and petroleum geology. It represents an achievement in this field and offers a new window for investigating fossil spores and pollen in crude oils from oil fields within ten petroliferous basins of China. In this unique monograph, the authors have defined petroleum sporo-pollen assemblages, introduced the method for extracting fossil spores and pollen from crude oil samples, and explained the approach based on oil source rock correlations for judging hydrocarbon source rocks. In addition, the character, geochronological and geographical distribution of petroleum source rocks in the inland, and coastal shelf petroliferous basins of China are expounded. Based on the ecological characteristics of the original plants that produced the spores and pollen extracted from crude oils, the authors assessed that deep lacustrine deposition under a warm or hot and wet climate was the most favorable condition for formation of petroleum source rocks. They also explained that spores and pollen in crude oils can provide information about passages, phases, directions, routes, and distances of petroleum migration.

This is a well-illustrated book with fossil spores and pollen having wide geographical ranges. It reveals important theoretical significance and practical significance in exploration and development of oil and gas fields. There is no doubt that the publication of this book by Springer will be greatly

conducive to international academic exchanges. I firmly believe that this book will have important reference value and serve as a useful scientific work in the fields of petroleum geology, paleontology, and stratigraphy for scientific research, teaching, and talent training.

February 2015

Ge Sun, Ph.D.
Professor, Vice President of Paleontological
Society of China
Dean of College of Palaeontology
Shenyang Normal University
Director, Palaeontological Museum of Liaoning

Foreword (Chinese Edition)

Palynology of Petroleum Source is an academic monograph based on the study on fossil spores and pollen in crude oils from several dozen oil fields within ten petroliferous basins of China. This unique work is the first monograph in this field. Based on more than 20 years of palynological datum accumulation, the authors have produced a book that will be used as both significant guidance for commercial petroleum exploration and undergraduate and graduate student textbook.

Within this monograph, a petroleum sporo-pollen assemblage is defined; an approach based on the oil source rock correlations of spores and pollen for judging potential source rocks is explained; and the character, geochronological, and geographical distribution of petroleum source rocks in the inland and coastal shelf petroliferous basins of China are expounded. The ecological characteristics of the original plants that produced the spores and pollen in crude oils indicate that deep lacustrine deposition under a warm or hot and wet climate is the most favorable for formation of petroleum source rocks. The authors explain that spores and pollen in crude oils can provide information about passages, phases, directions, routes, and distances of petroleum migration. A significant finding is that microfissures in source rocks are probably the features that allowed the primary migration of petroleum. According to fossil spores and pollen in crude oil, the authors demonstrate that petroleum in the igneous rock petroleum reservoir of the Beisantai Oil Field in the Junggar Basin originates from organic materials of the surrounding sedimentary rocks, thus adding supporting evidence for the organic petroleum origin theory.

Academicians in both geology and botany fields have spoken highly of the accomplishments of the study on spores and pollen in crude oils that lead to this monograph. The famous petroleum geologist Prof. Xia Zhu wrote "Research on palynology of petroleum sources has established a bridge of discipline infiltration between palynology and petroleum geology, opening up a new research field." Another renowned palynologist, Prof. Jen Hsü wrote "The work on spores and pollen in crude oils represents the advanced study of Chinese palynologists in this field." Scientists at home in China and abroad have paid attention to the study of palynomorphs in petroleum since the early 1980s. Fleet and others (1988) edited "Spores and pollen in oils as indicators of lacustrine source rocks" in **Lacustrine Petroleum Source Rocks**. Robbins (1990) edited "Palynological evidence for identification of

nonmarine petroleum source rocks, China" in **Palynology of Ore Deposits**. Jansonius and McGregor (1996) edited "Fossil pollen and spores in crude oil from an igneous reservoir" in **Palynology: Principles and Applications**. It is considered that these studies merit wider attention. Finally, "Mesozoic nonmarine petroleum source rocks determined by palynomorphs in the Tarim Basin, Xinjiang, northwestern China" was published by the British journal **Geological Magazine** (Jiang et al. 2008).

I sincerely hope that this monograph will be published as early as possible. I believe that this work will be helpful to petroleum exploration and will surely promote development of the discipline.

February 2012

Yongchang Xu
Professor
Lanzhou Center for Oil and Gas Resources
Institute of Geology and Geophysics
Chinese Academy of Sciences
(formerly the Lanzhou Institute of Geology
Chinese Academy of Sciences)
Director
State Key Laboratory of Gas Geochemistry

Preface

Scientists have paid attention to studies about palynomorphs in petroleum since the early 1980s. Traverse (1988) in his unique work **Paleopalynology** wrote "A number of studies have turned up the interesting fact that spores/pollen are capable of being swept along with migrating petroleum as it moves through porous sedimentary rocks." McGregor (1996) reviewed studies of palynomorphs in petroleum and considered that these studies merit wider attention, because the results and interpretations of researchers working on this subject have achieved credibility.

A Chinese monograph **Palynology of Petroleum Source** (in Chinese with English Summary) was published by Science Press in Beijing in 2013. Some palynologists and petroleum geologists suggest that English edition of the monograph should be published. This suggestion is supported by the leadership of Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences (formerly the Lanzhou Institute of Geology, Chinese Academy of Sciences).

Petrolipalynology is the English version of the Chinese monograph, with additions that advance **Palynology of Petroleum Source**. This book is the first English monograph in this field. The principles and methods for determining petroleum source rocks based on the fossil spores and pollen are explained, and the character and distribution of the petroleum source rocks in the inland petroliferous basins and the coastal shelf petroliferous basins of China are expounded within the monograph. In accordance with the study on palynomorphs in petroleum, the authors discuss how microfissures in source rocks should be the passages for primary migration of petroleum and then expound on the mechanisms of petroleum migration in detail. Based on more than 20 years of palynological data accumulation, the authors have produced a book of use to commercial petroleum exploration and undergraduate and graduate students alike. Just as Prof. Xia Zhu wrote "Research on palynology of petroleum sources has established a bridge of discipline infiltration between palynology and petroleum geology, opening up a new research field." In a word, Petrolipalynology is a seminal discipline with bright prospects.

This English monograph is written by Prof. Dexin Jiang (Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences), Dr. Eleanora I. Robbins (San Diego State University),

and Dr. Yongdong Wang (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences), with plates edited by Prof. Huiqiu Yang.

This project is supported by Lanzhou Center for Oil and Gas Resources and the Open Fund Program of the Key Laboratory of Petroleum Resources Research, Institute of Geology and Geophysics, Chinese Academy of Sciences, and the Key Laboratory Project of Gansu Province (Grant No. 1309RTSA041). This work was also jointly supported by State Key Programme of Basic Research of Ministry of Science and Technology, China (Grant No. 2012CB822003), the Innovation Project of CAS (Grant No. KZCX-2-YW-154), and the Team Program of Scientific Innovation and Interdisciplinary Cooperation of CAS.

The authors acknowledge academicians from the Chinese Academy of Sciences, Prof. Shu Sun, Prof. Ziyuan Ouyang, and Prof. Xu Chen for their encouragement and advice. The authors express their deep gratitude to Prof. Clinton Foster and Prof. Ge Sun for heartily writing Foreword for this book. Special thanks are due to the renowned palynological professor at the Pennsylvania State University, USA, Dr. Alfred Traverse for his encouragement and inestimable help. We are very grateful to Prof. Lianjie Guo, Prof. Yanqing Xia, Prof. Yongchang Xu, Prof. Junchao Wei, Prof. Xianbin Wang (Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences), Prof. Shu Ouyang (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences), and Prof. Mingcheng Li (China University of Geosciences) for their valuable advice and assistance. The authors also express hearty thanks to Mr. Feng Sun, Ms. Jiang Wei, Ms. Jine Du, Ms. Changyu Lai, Dr. Ning Tian, Dr. Chong Dong, Mr. Ping Wu, Mr. Zheng Shi, Ms. Yuxiao Dong, Ms. Liqin Li, and Ms. Xiaoqing Zhang for making their important contribution to this project.

February 2015

Dexin Jiang
Eleanora I. Robbins
Yongdong Wang

Preface (Chinese Edition)

As energy sources, oil and natural gas are very important for the development of national economies, especially China's. Coal of course is the foremost energy source used in China. The world's petroleum industry developed rapidly in the span between 1950 and 2000; it reached the height of development in the 1980s. Owing to the rapid development of petroleum exploration in the inland petroliferous basins of China, many new petroleum fields such as the Kekeya and the Yakela oil fields in the Tarim Basin, and the Huonan and the Beisantai oil fields in the Junggar Basin were discovered since the 1970s. The development of this petroleum industry offered an opportunity for science and technology to blaze new trails.

An apparatus for extraction of spores and pollen from crude oil samples was set up in the palynological laboratory in Lanzhou Institute of Geology, Academia Sinica, in 1965. Since then, abundant fossil spores, pollen, and algae have been extracted from more than 200 crude oil and natural gas samples associated with oil samples from the Jiuquan, Ordos, Junggar, Turpan, Tarim, Qaidam, Liaohe, Beibu Gulf, Sanshui, and Zhujiang Mouth basins. The initial findings of spores and pollen in crude oils were confirmed by renowned scientists, academicians of Chinese Academy of Sciences. The first appointed director of the original Institute of Geology, Academia Sinica, Prof. Defeng Hou said "Fossil spores and pollen found in crude oils can provide reliable information for judging and dating petroleum source beds, which can also offer evidence for the generation and migration of petroleum." The renowned sedimentologist Prof. Lianjun Ye said "Study on spores and pollen in crude oils serve the production of petroleum by means of palynology as a tool. It is a creative work and is proved to be effective." The renowned palynologist Prof. Jen Hsü said "Spores and pollen in crude oils can provide valuable evidence for petroleum origin and petroleum sources." The famous petroleum geologist Prof. Xia Zhu said "Research on palynology of petroleum sources has established a bridge of discipline infiltration between palynology and petroleum geology, opening up a new research field. The academic accomplishments will be possessed of important function of guidance to petroleum exploration." Thus, the study of spores and pollen in crude oils was listed in the National 1986 to 1990 and 1991 to 1995 Science and Technique Major Research Programs.

The present monograph is a summary of the palynological achievements in the National 1986 to 1990 Program "Geological theory and exploratory

technique of petroleum fields" and the National 1991 to 1995 Program "Petroleum resources of the Tarim Basin" as well as the Program of National Natural Science Foundation of China "Principles and methods of petroleum source rock identification by means of spores and pollen" (Grant No. R 850879). The character and distribution of petroleum source rocks in the inland petroliferous basins including the Tarim, Junggar, Turpan, Qaidam, and Jiuquan basins and the coastal shelf petroliferous basins including the Liaohe Basin of East China Sea and the Beibu Gulf and Zhujiang Mouth basins of South China Sea are expounded in this monograph. The work is based on the palynological data that have been accumulated for more than 20 years. The main achievements of this monograph are as follows:

1. The definition and classification of petroleum sporo-pollen assemblage are provided. An approach based on the oil source rock correlations of fossil spores and pollen species and color for judgment of petroleum source rocks is explained. By way of the application in eight petroliferous basins, the approach is proved to be effective.
2. The authors expound that microfissures in source rocks are the important passages for the primary migration of petroleum, allowing the passage of pollen and spores, and showing that fossil spores and pollen in crude oils are capable of dating petroleum source rocks.
3. The ecological characteristics of the original plants that shed the spores and pollen act as indicators of petroleum source rocks, thereby indicating that the lacustrine and swamp/marsh sedimentary environments under warm/hot and humid/wet climatic conditions are favorable for the formation of nonmarine petroleum source rocks.
4. Fossil spores and pollen in crude oils show reliable information about passages, phases, directions, routes, and distances of petroleum migration. Microfissures in source rocks formed by abnormal high pressure and undercompaction during the process of diagenesis are supported as the passageways for primary migration of petroleum. The passageways for secondary migration include connective pore spaces, bedding voids, joints, fissures, faults, and unconformities in the carrier bed and the reservoir bed. The phase state of primary migration includes the oil phase, gas phase, water-soluble phase, oil-soluble phase, gas-soluble phase, and diffusion phase. The phase state of secondary migration generally inherits the phase state of primary migration. The directions of petroleum migration are from low porosity and permeability rocks to high porosity and permeability rocks, following either vertical migration or lateral migration pathways. The routes of migration are from petroleum source beds to traps. The distances of migration are dependent on the distances between petroleum source beds and traps.
5. Ninety-six species of fossil spores and pollen referred to 52 genera were found in crude oil from an igneous petroleum reservoir in the East Junggar Depression. Igneous rocks cannot yield biological fossils; thus, the spores and pollen in crude oil must have been carried by oil, gas, and water from the surrounding sedimentary petroleum source rocks to the

igneous reservoir during petroleum migration. This discovery is convincing evidence for the organic petroleum origin theory.

6. One hundred and eighty-three species of fossil spores and pollen referred to 89 genera were found in crude oils from the Tarim Basin. The original plants of the spores and pollen are continental plants, which have their sources from the terrestrial environment. These spores and pollen bear witness to petroleum generation from the continental facies.
7. The results of the study on fossil spores and pollen in crude oils indicate that in China, the Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and Tertiary Systems of the inland petroliferous basins contain petroleum source rocks, and the Paleogene System of the coastal shelf petroliferous basins contains excellent petroleum source rocks. The spore/pollen exine colors indicate that these petroleum source rocks are mature.

In the course of the performance of the present project, the authors obtained encouragement, advice, and assistance from the leadership of Division of Earth Science of Academia Sinica, the leadership of Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences (the original Lanzhou Institute of Geology, Academia Sinica), Academician Shu Sun, Prof. Jindong Zhang, Prof. Yanqing Xia, Prof. Yongchang Xu, Prof. Difan Huang, Prof. Digang Liang, Prof. Zhuosheng He, and Prof. Kailin Dong. To the above leaders and specialists, the authors express their deep gratitude.

The Chinese monograph was written by Dexin Jiang, while the plates were edited by Huiqiu Yang. Mr. Feng Sun, Mr. Yongdong Wang, Ms. Jine Du, Ms. Changyu Lai, Mr. Ping Wu, and Mr. Zheng Shi, all of whom participated in this project.

The authors acknowledge the careful review of Prof. Junchao Wei. Special thanks are due to Ms. Jiang Wei for computer technical assistance. Appreciation is extended to Ms. Yuxiao Dong for her obtaining some necessary references in libraries.

January 2012 Dexin Jiang

Contents