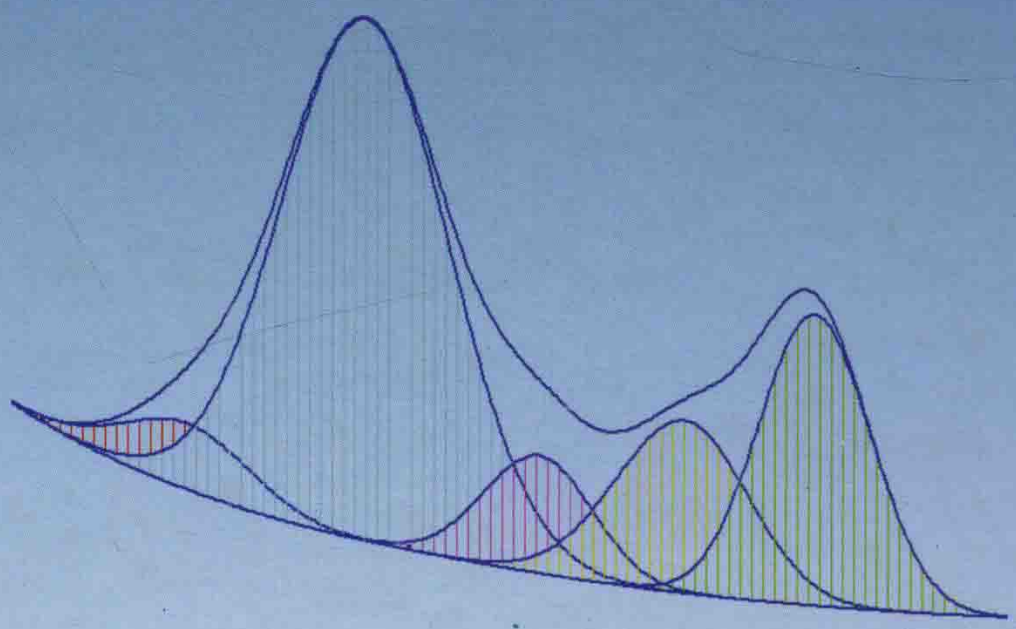
Geochronology of Authigenic Illite:
Principles, Methods and Applications

自生伊利石年代学研究
——理论、方法与实践

张有瑜　刘可禹　罗修泉　著



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内 容 简 介

本书以油气成藏史研究为主线，对自生伊利石年代学研究的理论、技术方法和实际应用进行全面系统介绍，全书分为四部分，即基础篇、技术篇、应用篇和讨论篇。基础篇和技术篇重点介绍自生伊利石的定义、分类、矿物学特征及其分离提纯方法，以及 K-Ar 法、Ar-Ar 法年龄测定技术；应用篇重点论述塔里木盆地、四川盆地自生伊利石年龄分布及其在成藏史研究中的应用，并对该项技术在泥页岩“哑层”和断层泥年龄测定方面的应用进行探索性研究；讨论篇主要对自生伊利石 K-Ar 法、Ar-Ar 法测年技术进行对比并对其应用前景进行深入探讨。

本书可供地质、石油天然气地质工作者，特别是油气成藏史研究人员、地质、石油院校师生阅读参考。

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序　一

随着油气勘探难度的进一步加大，油气成藏史研究的作用和意义进一步彰显。自生伊利石年龄测定可为成藏史研究提供重要的年代学信息。自生伊利石年龄测定与油气成藏史研究结合始于国外20世纪80年代，并在北海油气区获得较好应用效果，显示出较好发展前景。为了适应国内油气勘探形势需要和跟踪国际发展前沿，中国石油天然气股份有限公司勘探开发研究院于1996年开始筹建我国首个重点针对油气成藏研究的年龄同位素质谱实验室，即自生伊利石同位素年龄测定实验室。经过近二十年的努力，自生伊利石年代学实验室在理论、技术、方法和应用等方面取得了一系列重要收获。该书是该实验室主要研究人员张有瑜教授与刘可禹教授和罗修泉研究员十几年合作研究成果的集中体现，能够正式出版，感到很欣慰，并表示祝贺！

该书内容比较全面、系统，涵盖理论、技术和方法，也有实例和讨论，可读性、实用性都比较强，具有较高的学术价值。更为可喜的是，该书中的实验数据不仅多，而且全，具有较强的可追溯性，图文并茂，可查、可用。

油气成藏史研究需要综合多方面知识，多种技术手段相结合。相信该书的出版能够在加速推广自生伊利石年代学研究知识方面发挥重要作用，使从事油气勘探的广大工作者能够更系统、充分了解自生伊利石年代学理论、技术及其应用，互相促进、共同提高。

从该书的内容可以看出，作者强调新技术开发和油气勘探实践的紧密结合。对塔里木盆地、四川盆地、鄂尔多斯盆地的系统研究成果可能很具有启发意义。此外，自生伊利石测试样品分布范围广、盆地和层位多，也很有借鉴意义。当然，对于多期成藏，与其他成藏史研究技术手段的对比，以及在油气勘探实践中的作用等方面，还需要继续加强研究。

中国科学院院士 

2015年7月6日

序　二

Energy and hydrocarbons are important in today's society. Several geologic elements are necessary for hydrocarbons (oil or gas) to accumulate in sufficient quantities to be economically extracted. The petroleum systems approach is widely applied in petroleum exploration and relies on an understanding of various elements, including the nature of the source rock, generation and migration processes, reservoir rocks and seal/trap formation. Of fundamental importance is an understanding of the temporal evolution of the various elements of petroleum systems. One aspect that is often poorly constrained is the timing of petroleum migration and entrapment. This is a major obstacle for geoscientists when developing predictive hydrocarbon exploration models. K-Ar and Ar-Ar dating of authigenic illite offer opportunities to address these challenges.

Isotopic dating and geochemical studies of authigenic clay minerals are important tools to understand diagenetic and fluid flow histories for hydrocarbon exploration and reservoir management. Authigenic illite contains potassium and is therefore suitable for age determination using the K-Ar geochronometer. Dating of K-bearing illite minerals, using the K-Ar isotopic systems, offers the prospect of establishing the absolute timing of diagenetic events. These data are of fundamental importance and control points for understanding basin development, burial and thermal history, and the hydrocarbon system. Geochronology research such as that which Prof. Zhang conducts is extremely useful to the petroleum industry. I would like to congratulate the Science Press (China) for this special publication on Geochronology of Authigenic Illite —Principles, Methods and Applications by Professor Zhang focusing on his lifetime research contributions to illite age dating.

Prof. Zhang has been working since 1998 on authigenic illite dating which is a highly specialized field and only carried out in a few labs around the world. The PetroChina RIPED authigenic illite age dating facility is the only operational and dedicated facility of this kind in China providing reliable illite age data based on an integrated and holistic sample characterization, sample disintegration, clay separation and subsequent age dating. The key word here is reliable; many facilities are capable of measuring a K-Ar age but only a few scientists take the care to prepare and characterize the material in such a manner that the resulting data are meaningful. The RIPED illite age dating facility is one of only a very few facilities which is capable to obtain reliable

K-Ar age data, based on the detailed understanding of the special sample preparation and characterization requirements prior to age dating. In brief, the radiogenic isotope systematics of sedimentary rocks are complex due to the intimate mixture of minerals of different origins such as detrital phases, potentially from a variety of sources, as well as authigenic minerals. Consequently, it is often difficult to unambiguously interpret measured ages. Special sample preparation techniques involving freeze thaw disaggregation to avoid over crushing and extensive size separation to reduce the amount of detrital phases can address these issues and were implemented in the RIPED facility under Prof. Zhang's guidance. The validity and importance of the assumptions involved in K-Ar dating of authigenic illite (e. g. contamination, closed system behaviour, excess Ar) must be carefully addressed and the sample material characterized using a wide range of tools comprising X-ray diffraction, secondary electron microscopy, particle granulometry and transmission electron microscopy to name a few. I have been aware of Prof. Zhang's work on K-Ar dating of diagenetic events for a number of years, beginning in the early 2000's with his work on using K-Ar dating of diagenetic illite to constrain the timing of hydrocarbon migration in Tarim Basin sandstone reservoirs. I have spent more than 20 years studying diagenesis of sandstone reservoirs as a petroleum research geochemist, and one of the key issues to reduce exploration risk is to determine the timing of diagenetic events and how these relate to petroleum migration and trapping. The generated data are particularly valuable for helping to define, on a play scale, how the basin is interconnected in time. Exploration for oil and gas is a high risk task. Typically, an exploration well will cost between $ 20 to 50 or more million US dollars, yet the rate of success is around 5% to 15 %. One of the key focuses in the oil/gas industry is to develop and apply new technologies such as integrated authigenic illite age dating to lower that risk.

The research output of the RIPED illite age dating facility under Prof. Zhang's guidance has been exceptional with more than 600 investigated samples by the K-Ar and $^{40}Ar/^{39}Ar$ dating methods comprising surface and deep drill core samples from over 20 investigated stratigraphic reservoir units covering most geological ages from the Silurian to the Neogene of over 20 sedimentary basins and oil and gas fields in China. The Tarim Basin is a key study area of Prof Zhang with further main studies focusing on the Sichuan Basin and Ordos Basin. His scientific output involves publications in journals such as AAPG, Acta Petrolei Sinica, Petroleum Exploration and Development, Earth Science Frontiers etc., numerous abstracts and confidential industry reports. The compiled book with 16 chapters contains a comprehensive introduction (Part 1) to the potential and difficulties of authigenic illite age dating, methods and techniques (Part 2), applications (Part 3) and a general discussion (Part 4) as well as an up-to-date complete reference list. This

unique book summarizing the research of Prof. Zhang should be of wide spread interest to the Chinese petroleum geoscience community and students interested in this topic.

Horst Zwingmann
Kyoto, Japan
Aug. 2015

Horst Zwingmann

Prof. Zwingmann has a background in geochronology and low temperature geochemistry. He studied geology at Göttingen University, Germany and obtained a PhD in geochemistry from the Université Louis Pasteur, Strasbourg, France in 1995. He joined the Commonwealth Scientific and Industrial Research Organization, Australia and remained with CSIRO until 2015. Since 2009 he has been an associate professor at the University of Western Australia, Perth, Australia. In 2015 he was appointed Professor of Geotectonics at Kyoto University, Japan. His research interests focus on characterization and dating of brittle fault zones, diagenetic processes and very low temperature geochemical processes.

前　言

时光如梭，从1998年开始创建油气储层自生伊利石Ar同位素年代实验室至今，转眼已经度过了17个春秋。如果从1996年中国石油勘探开发研究院实验中心提交《建立年龄同位素质谱实验室报告》算起，已近20载。

17年来，在院、实验中心领导的关心和鼓励下，笔者相继建立了K-Ar法、Ar-Ar法同位素年龄测定和自生伊利石分离提纯实验室，开发了砂岩样品制冷-加热循环解离（简称冷冻）和自生伊利石分离提纯微孔滤膜真空抽滤（简称真空抽滤）等特色技术，并对国内主要含油气盆地或地区（油气田）的主要储层进行了自生伊利石年龄测定，层位从古生代志留系、泥盆系、石炭系、二叠系，到中生代三叠系、侏罗系、白垩系，到新生代古近系、新近系，并重点对塔里木盆地、四川盆地、鄂尔多斯盆地进行了系统研究，从理论、方法、技术到应用均取得了一系列重要认识。经历了艰辛与困惑，也收获了成功与欢乐。

为了推广自生伊利石年代学研究知识，让有志于自生伊利石年代学研究的同行不再是“从零起步”，同时也为了让他们能在已有成果的基础上再攀高峰，在国内外挚友的鼓励和帮助下，终成此书。

之所以冠名为《自生伊利石年代学研究——理论、方法与实践》，其目的在于阐明“为什么要这样做”、“如何做”和“怎样做”，强调“实用”和“适用”，这可以理解为本书的宗旨和特色。

自生伊利石是分布非常广泛的一种黏土矿物。自生伊利石年龄测定，特别是自生伊利石K-Ar法年龄测定与油气成藏史研究始于国外20世纪80年代（Aronson and Burtner，1983[①]；Lee et al.，1985[②]），或更早，可以说这是一项引进的技术。但国外主要是针对北海地区或北海油气区，层位主要是二叠系赤底群下莱曼组风成砂岩和中侏罗统布伦特群河流相砂岩，层位少，样品数量也相对较少。迄今为止，即便是国外也还没有自生伊利石年代学方面的专著出版，大多只是作为相关专著中的一章或几章、一节或几节，如Weaver（1989[③]）；Emery和Robinson（1993[④]）；Clauer和Chaudhuri（1995[⑤]）；Stille和

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① Aronson J L, Burtner R L. 1983. K-Ar dating of illitic clays in Jurassic Nugget sandstone and timing of petroleum migration in Wyoming Overthrust Belt (abstract). AAPG Bulletin, 67:414

② Lee M, Aronson J L, Savin S M. 1985. K-Ar dating of time of gas emplacement in Rotliegendes sandstone, Netherlands. AAPG Bulletin, 69(9):1381-1385

③ Weaver C E. 1989. Clays, Muds, and Shales. Developments in Sedimentology. Amsterdam-Oxford-New York-Tokyo: Elsevier

④ Emery D, Robinson A. 1993. Inorganic geochemistry — applications to petroleum geology. Oxford: Blackwell Scientific Publications

⑤ Clauer N, Chaudhuri S. 1995. Clays in Crustal Environments-Isotope Dating and Tracing. Berlin Heidelberg New York: Springer-Verlag

Shields(1997[①])；Meunier 和 Velde(2004[②])等。我们有自己的独特的发展、方法、技术和特点(样品多、层位多、自生伊利石类型多、特征全)。

回顾 17 年来的发展与进步，有 3 位良师益友至关重要。首先是罗修泉研究员。稀有气体质谱仪，也称静态真空质谱仪，属于高真空(10^{-8}～10^{-10} torr[③])、高灵敏度、高分辨率的大型精密仪器。在罗老师的带领下，很快便创建了高水平 Ar 同位素年代实验室(MM5400 静态真空质谱仪)并投入运营，“填补了国内石油系统 40 年来没有年龄同位素实验室的空白”，并且实验室充满石油(地质)特色。其次是 Horst Zwingmann 博士[澳大利亚联邦科学和工业研究院(CSIRO)教授，现为日本京都大学教授]和刘可禹博士(中国石油勘探开发研究院教授、澳大利亚新南威尔士大学客座教授、柯廷大学和 CSIRO 客座研究员，“中国国家千人计划”学者)。Horst Zwingmann 博士和刘可禹博士的帮助是全方位的，从仪器设备到实验技术，从英文写作到国际最新进展。

全书共 4 篇(基础篇、技术篇、应用篇、讨论篇)16 章。首先是基础篇，共 2 章，主要讨论“什么是自生伊利石”、“如何鉴定自生伊利石”和“怎样分离提纯自生伊利石”。其次是技术篇，共 5 章，重点介绍实验室的特色技术，如“冷冻”技术、“真空抽滤”技术，以及静态真空质谱仪技术、K-Ar 年龄测定技术、Ar-Ar 年龄测定技术，尤其是 K-Ar 技术和 Ar-Ar 技术，在兼顾体系和完整的基础上，重点突出石油(地质)特色，其核心内容如稀释剂分装、IAA(伊利石年龄分析)技术，以及自生伊利石 Ar-Ar 法问题等都是笔者重点推出的研究成果，许多内容可能在其他公开出版物中很难找到，如稀释剂分装、关于自生伊利石 Ar-Ar 法问题的全面系统论述等。然后是应用篇，共 7 章，分 3 个方面，其中关于在成藏史研究方面的应用，是本书的核心内容，属于十几年来公开发表成果，但都做了较大修改，增加了新的数据、新的认识和新的研究成果，并不是简单的再版，而是赋予了新内容，反映了当前的研究水平；不讨论泥页岩“哑地层定年”和“断层泥定年”，就不能冠以“自生伊利石年代学研究”，或至少是不全面的，第十三、十四章分别介绍了在这两个方面的初步探索，遗憾的是工作区或研究目的层不是十分理想，所以没有收到较好的应用效果，但这并不影响其价值和意义，因为我们强调的是方法和思路，此外，提供一些实实在在的年龄数据资料以及经验与教训也是非常有意义的。最后是讨论篇，共 2 章，不讨论自生伊利石 Ar-Ar 法，同样也不能称为“自生伊利石年代学研究”，因为这方面内容非常重要。自生伊利石 Ar-Ar 法可以说是一个“壁垒”或“雷区”，不仅实验难、周期长、费用高，而且问题多、争议多。如果仅仅怀着美好的期望，稍有不慎，就可能会陷入“误解”、“误用”。之所以会出现这样的问题，实测数据少、研究实例少、分析讨论少、普及知识少等，可能是主要原因。在对国内 5 个含油气盆地或地区 8 个层位(S、D、C、P、T、J、K、E)不同典型自生伊利石进行未真空封装 Ar-Ar 法年龄测定的基础上，分别以苏里格气田二叠系砂岩和塔里木志留系

① Stille P, Shields G. 1997. Radiogenic Isotope Geochemistry of Sedimentary and Aquatic Systems. Berlin Heidelberg: Springer-Verlag.

② Meunier A, Velde B. 2004. Illite-Origins, Evolution and Metamorphism. Berlin Heidelberg New York: Springer-Verlag.

③ 1torr=133.322Pa。

沥青砂岩储层为例，全面系统地论述了自生伊利石 Ar-Ar 法问题及其与自生伊利石 K-Ar 法的技术对比和应用前景。增加“附录”部分的目的就是为了把我们所获得的具有较强代表性的自生伊利石年龄数据，包括 K-Ar 年龄、Ar-Ar 年龄、Ar-Ar 阶段升温数据和 Ar-Ar 年龄谱等，全部系统、完整地奉献给广大读者，其中很大一部分是在本书正文中没有机会详细列出或没有披露的，能为读者所用乃最大心愿！

全书由张有瑜、刘可禹、罗修泉执笔，罗修泉、刘可禹审校，最后由张有瑜统稿并定稿。为了填补数据空白（地区上的或层位上的）、为了数据的连续性、系统性以及可对比性（如 K-Ar、Ar-Ar 年龄对比等），本书及历年发表的论文中分别引用了国内同行学者的部分数据资料（SEM、XRD、K-Ar 年龄），如高岗、傅国有、罗小平、罗忠、刘四兵、马玉杰、任战利、苏劲、孙玉梅、王红军、王延斌、许怀先、于志超、张水昌、张忠民等。这些数据都是由笔者实验室完成的，具有较好的一致性和可比性。对于他们的协作和帮助，在此表示诚挚的谢意！

感谢中国科学院院士贾承造教授和日本京都大学 Horst Zwingmann 教授在百忙中为本书作序！

感谢中国石油勘探开发研究院领导、石油地质实验研究中心主任张水昌教授、前主任张大江教授，以及实验中心其他领导的支持和帮助！感谢提高石油采收率国家重点实验室、中国石油天然气集团公司盆地构造与油气成藏重点实验室的支持和帮助！感谢石油地质研究所陶士振教授、CSIRO Andrew Todd 博士的支持和帮助！感谢实验中心林西生、朱德升、游建昌、魏宝和、郑永平等有关同志所给予的支持和帮助！

对笔者而言，自生伊利石年代学研究同样也是一个新领域，充满着创新和挑战。书中不当、不妥之处在所难免，敬请读者批评指正。

潜心研究自生伊利石近 20 载，可谓魂牵梦萦、朝思暮想，特赋诗一首，以述情怀，并敬请鉴赏！

张有瑜

2015 年 7 月 1 日

报时鸟

——自生伊利石赞

亘古砂岩报时鸟，
飘逸洒脱忠职守。
静观油气滚滚来，
默记心头在何时。
待到学人欲知晓，
浴火焚身报准期。
喜看油浪腾华夏，
乐闻气流进万家。

甲午年（贰零壹肆）
六月二十日凌晨四时五十分
于北京

Preface

It has been 17 years since the establishment of the Petroleum Reservoir Authigenic Illite Argon Isotope Labaoratory, also known as the Authigenic Illite Geochronology Lab (AIG Lab) in the Research Institute of Petroleum Exploration and Development (RIPED) in 1998. Over the past 17 years, under the guidance of several RIPED presidents and directors of the Petroleum Geology Research and Laboratory Center, the AIG Lab has developed a series of unique methods or techniques including the repetitive freezing and thawing sandstone sample disaggregation technique (the freezing technique), and the vacuum filtrating device and technique to separate authigenic illite with microporous membrane (the vacuum filtrating technique). The AIG Lab has conducted numerous dating of petroleum reservoirs in major Chinese petroliferous basins and/or oil fields of a wide range of ages from the Palaeozoic to the Cenozoic periods including Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Eogene and Neogene. The Lab has conducted systematic geochronological studies of hydrocarbon charge in the Tarim Basin, Sichuan Basin and Ordos Basin. It is pleased to see that over the past 17 years the AIG Lab has achieved a number of milestones in technique development and field applications of dating petroleum reservoir charge timing and has provided some critical geochronological information for understanding petroleum charge history in various basins.

This book intends to provide readers who are interested in authigenic illite geochronology some background knowledge and our hard-earned experience in the field of authigenic illite dating so they would not need to start from scratch and avoid some pitfalls.

Entitled 'Geochronology of Authigenic Illite—Principles, Methods, and Applications', the book intends to tell the readers on 'what is authigenic illite dating', 'why we need to date', 'how to date' and 'how to interpret the dating results'. We particularly want to emphasize practical and appropriate ways of conducting authigenic illite dating and interpreting the results.

Authigenic illite is a commonly occurring clay mineral in sedimentary basins. Authigenic illite geochronology, especially the use of authigenic illite K-Ar to date hydrocarbon charge timing, started in the 1980s abroad (Aronson and Burtner, 1983①;

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① Aronson J L, Burtner R L. 1983. K-Ar dating of illitic clays in Jurassic Nugget sandstone and timing of petroleum migration in Wyoming Overthrust Belt (abstract). AAPG Bulletin. 67: 414.

Lee et al., 1985[①]) and was introduced to China subsequently in the 1990s. However, the application of the authigenic illite dating of hydrocarbon charge timing abroad primarily confined to the North Sea oilfields on limited reservoir intervals including the well documented Permian Rotliegend Group aeolian sandstone (the Lower Leman Sandstone), and the Middle Jurassic Brent Group fluvial sandstone reservoirs with limited dating samples. So far there have been no dedicated books on authigenic illite geochronology published in China and abroad, except for some individual chapters or sections embedded in books dealing with other themes, e. g. Weaver(1989[②]); Emery and Robinson(1993[③]); Clauer and Chaudhuri(1995[④]); Stille and Shields(1997[⑤]); Meunier and Velde(2004[⑥]). Since its introduction to China and especially over the past decade, authigenic illite geochronology has been further developed and applied to a wide range of basins and reservoir intervals in China.

Over the past 17 years, the research and development of the AIG Lab has been benefited from three key people. Firstly and foremostly, is Prof. Xiuquan Luo, a very experienced expert on the high-sensitivity, high-resolution, and high vacuum (10^{-8} ~ 10^{-10} torr) noble gas mass spectrometer. Under his guidance and technical assistance, the AIG Lab has mastered the MM5400 static vacuum mass spectrometer and established a world-class Ar isotope geochronology laboratory in PetroChina. Dr Horst Zwingmann (now with Kyoto University) and Dr Keyu Liu (now with RIPED and Curtin University), both of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) previously have been in close collaboration with the AIG Lab since 2003. Their contributions are multifaceted including instrumentation, technique development, field application and publications.

The book consists of four sections (Fundamentals, Techniques, Applications and Discussion) and 16 chapters. The Section on the "Fundamentals" comprises two chapters primarily dealing with "features of authigenic illites", "how to identify authigenic illites" and "how to obtain pure authigenic illites". The Section of the

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① Lee M, Aronson J L, Savin S M. 1985. K-Ar dating of time of gas emplacement in Rotliegendes sandstone, Netherlands. AAPG Bulletin. 69(9): 1381-1385.

② Weaver C E. 1989. Clays, Muds, and Shales. Developments in Sedimentology 44. Amsterdam-Oxford-New York-Tokyo: Elsevier.

③ Emery D, Robinson A. 1993. Inorganic Geochemistry—Applications to Petroleum Geology. Oxford: Blackwell Scientific Publications.

④ Clauer N, Chaudhuri S. 1995. Clays in Crustal Environments-Isotope Dating and Tracing. Berlin Heidelberg New York: Springer-Verlag.

⑤ Stille P, Shields G. 1997. Radiogenic Isotope Geochemistry of Sedimentary and Aquatic Systems. Berlin Heidelberg: Springer-Verlag.

⑥ Meunier A, Velde B. 2004. Illite-Origins, Evolution and Metamorphism. Berlin Heidelberg New York: Springer-Verlag.

"Techniques" comprises five chapters dealing with unique techniques developed by the AIG Lab including the "freezing technique", the "vacuum filtrating technique", and also the "Static vacuum mass spectrophotometer", K-Ar and Ar-Ar dating techniques, respectively. Aimed with providing a systematic workflow we especially focused on the petroleum geological application aspects including spike (^{38}Ar) splitting, illite age analysis (IAA) and issues around authigenic illite Ar-Ar dating, which might not be easily found in the literature nowadays. The section on "Applications" comprises seven chapters covering three key aspects. Investigation of hydrocarbon charge is the principal component of the section and the entire book. The section contains several published papers by the authors over the past decade. However, the chapters are not simple reproduction of the published work but have been updated with new data, analysis and interpretation. Chapter 13 and 14 discuss some pilot work on the "barren-bed dating" and "fault gauge dating". Unfortunately those pilot studies are not very successful due to a number of factors, mostly not ideal geological settings. Nonetheless, they offer readers some hard-learned lessons on authigenic illite dating applicability in those areas. The Section on "Discussion" presents the authigenic illite Ar-Ar dating method in two chapters. Authigenic illite Ar-Ar dating is regarded as a "mine field" or "unresolved barrier" in the field of authigenic illite geochronology as it involves a long and difficult procedure and is also a costly and controversial method. Without a good understanding of various factors affecting the authigenic illite Ar-Ar ages, the method can easily be misused or abused. This is mainly caused by very limited data so far available and the lack of well investigated case studies and open discussion on the issue. By using the unencapsulated method, we have analyzed a variety of authigenic illite samples from five petroliferous basins and eight stratigraphic intervals (S, D, C, P, T, J, K and E) in China. We systematically addressed the issues relating to the authigenic illite Ar-Ar dating method and its potential applications using examples from the Sulige giant gas field in the Ordos Basin and the Silurian bituminous sandstone in the Tarim Basin. The inclusion of an Appendix section aims to provide readers with some typical authigenic illite dating results including K-Ar ages, Ar-Ar ages, and Ar-Ar age spectra, some of which are not discussed elsewhere in the book. We hope readers may find the data useful to their work.

The book is primarily written by Youyu Zhang with contribution from Keyu Liu and Xiuquan Luo. In addition to our own research work and data, for completeness of covering more regions and stratigraphic intervals, and for technique's comparison (e. g. K-Ar vs Ar-Ar), the book also makes use of some data (e. g. SEM, XRD, K-Ar ages) of other colleagues including Gang Gao, Guoyou Fu, Xiaoping Luo, Zhong Luo, Sibing Liu, Yujie Ma, Zhanli Ren, Jin Su, Yumei Sun, Hongjun Wang, Yanbin Wang, Huaixian Xu, Zhichao Yu, Shuichang Zhang, Zhongmin Zhang, et al. All those data

were analyzed in the AIG Lab by the authors using the same procedure and can thus be compared.

We are grateful to Prof. Chengzao Jia, Academician of Chinese Academy of Sciences, and Prof. Horst Zwingmann of Kyoto University for their review and endorsement of the publication of this book.

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Even after years of research in the field, authigenic illite geochronology is still a new research field for us and is full of new challenges. It is anticipated that some inadequacy and omissions are present throughout the book. We welcome comments and suggestions from the readers.

Youyu Zhang
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