



石油地质进展丛书 1

Advances in Petroleum Geology Series 1

有机地球化学和陆相生油

Organic Geochemistry and Origin of Oil
from Continental Deposits

中国石油学会石油地质委员会编

Edited by Petroleum Geology Institute of Chinese Petroleum Society

石油工业出版社
The Petroleum Industry Press

27855

石油地质进展丛书 1

有机地球化学和陆相生油

中国石油学会石油地质委员会编

石油工业出版社

内 容 提 要

本书选编了一九八四年五月在天津召开的全国第二届有机地球化学和陆相生油会议上交流的32篇论文。这些论文反映了近年来我国在有机地球化学，特别是陆相生油和石油勘探地球化学方面，有关实验技术和应用研究上的发展水平和所取得的最新进展。

本书的论题主要有：陆相生油理论综述；生物标志和芳烃的地球化学；干酪根的镜下观察、红外光谱、热解气相色谱和化学动力学；煤成气；油气运移和生油评价等。可供从事科研、教育和可燃矿产勘探的地质、地球化学研究人员和大专院校师生参考。

石油地质进展丛书 1
有机地球化学和陆相生油
中国石油学会石油地质委员会编

石油工业出版社出版
《北京安定门外外馆东后街甲 8 6 号》
北京顺义燕华营印刷厂印刷
新华书店北京发行所发行

787×1092毫米 16开本 20³/₄印张 1插页 504千字 印1—1,700

1986年6月北京第1版 1986年6月北京第1次印刷

书号：15037·2600 定价：4.30元

石油地质科学研究
要展望未来

康世恩

一九八五.三月

序

中国石油学会石油地质委员会自1979年成立以来,举办了多种形式的学术交流活动,不仅活跃了学术空气,而且对发展我国石油地质学理论和油气勘探工作起到了一定的促进作用。在各种专业学术会议上,交流和宣读了大量具有较高理论水平,并能够指导油气勘探工作的论文和科研报告。但由于石油地质委员会没有与其学术活动相适应的公开刊物,以及受到各方面条件的限制,只有极少量的论文得以出版,而更多的优秀论文和科研成果未能编纂成册,给科研、生产、教育部门的利用带来不便,实为可惜。

为了更好地促进学术交流,不断提高我国石油地质学术水平,推广科技成果,系统地积累各类学术资料,为油气勘探、科学研究和人材培养服务,石油地质委员会决定自1985年起编辑出版《石油地质进展丛书》,我们将选择各种专业学术会议上交流的具有较高理论水平和实际应用价值,并能代表国内外科学技术发展方向的论文和科研成果,按石油地质构造、地层古生物、沉积相与沉积环境、油气生成及有机地球化学、油气藏形成、资源评价以及地震测井、遥感技术、数学地质、实验技术等专题编纂成册,交石油工业出版社出版、发行。

中国石油学会名誉理事长康世恩同志为《石油地质进展丛书》题词:“石油地质科学研究要展望未来”,对编辑出版这套丛书寄予很大的希望和提出了很高的要求。我们将本着这一精神,努力探索,开拓石油地质学的新领域。我们将把《石油地质进展丛书》作为反映我国石油地质理论进展和油气勘探实践的窗口,并使之成为石油地质科学研究和生产实践之间的一座桥梁,起到指导油气勘探工作的作用。

在我国新的历史时期中,为实现四个现代化的宏伟目标,加速发展我国的石油工业,用先进的石油地质学理论、先进的油气勘探技术和方法,对我国油气资源进行全面的预测和评价,指出油气勘探方向和有利的油气富集区,是我会组织各种学术活动的宗旨,我们将遵循“百花齐放,百家争鸣”的方针,提倡不同学术观点的讨论,在《石油地质进展丛书》上刊载不同学派的科研成果和学术论文。欢迎广大石油学会会员和各有关部门及单位的石油地质科学工作者,积极发表独到的见解、观点和创造性的成果,为繁荣我国石油科技事业,为发展我国石油工业作出卓越的贡献。

中国石油学会石油地质委员会

1985年3月

Preface

Since the founding of the Petroleum Geological Institute of the Chinese Petroleum Society in 1979, different forms of academic activities have been organized to make provisions for its members to exchange their learnings which have not only created a lively academic atmosphere among the members but also acted as a catalyst in the development of petroleum geology both in theoretical research and in practical exploration. Large numbers of papers or findings have been presented to or read in the different symposiums which win the consensus of having fairly high theoretical level, capable of guiding field work. Due to the lack of a publication of its own and limited by many other factors, only a very few of the articles have been selected and published, leaving many of the equally outstanding papers aside, which is quite a big loss to the research, production as well as educational institutions.

As a way out, the Petroleum Geological Institute has decided to edit, starting from the year 1985, this publication called "Advances in Petroleum Geology Series", in order the better to promote academic exchanges, raise the level of petroleum geological science, propagate research results and accumulate, in a systematic manner, materials on different subjects for the use of explorationists, research workers and teaching personnel. The primary source of articles will be those from the symposiums organized by the Petroleum Geological Institute which are considered to be outstanding both in theoretical level and in practical value, and representative of the scientific achievements and trend of development of geological science at home and abroad. The subjects to be covered by the series will be: petroleum geological structures, stratigraphic paleontology, sedimentary facies and sedimentary environment, origin of oil and organic geochemistry, formation of oil and gas pools, appraisal of resources, as well as seismic survey, well logging, remote sensing technique, mathematical geology, experimental techniques etc. It is a specialized publication of open circulation, published in series by the Petroleum Industry Press.

In commemorating the first issue of "Advances in Petroleum Geology Series", Comrade Kang Shien, Honorary Chairman of the Board of Directors of the Chinese Petroleum Society, sends us his words of en-

couragement saying, "The research in petroleum geology should aim at forecasting the future". These words have placed a very high demand on the publication of the series. And in the spirit of these words, we should make efforts to explore and unremittingly to open up new areas for the development of petroleum industry, and through the publication of this series as a window to reflect our progress and as a bridge to link scientific research with production, guiding our way in the search of oil.

In this our new historical epoch, with the realization of four modernizations as our grand goal, we, as workers of the petroleum industry, must direct all our academic efforts toward speeding up the development of the industry through the introduction of advanced geological theories and application of advanced exploration techniques, so as to do well the work of resources forecasting and appraisal and of locating abundant oil and gas accumulations. We will stick to the policy of "letting a hundred flowers blossom and a hundred schools of thoughts contend". Discussion of different views and different schools of thought will be encouraged, and scientific treatises and academic papers from different schools will be accepted and published. Members of the Chinese Petroleum Society and petroleum geologists from related departments are welcome to make their contributions for a common cause--a flourishing petroleum science and a prosperous petroleum industry.

Petroleum Geological Institute

Chinese Petroleum Society

March, 1985

前 言

近年来,陆相生油理论和有机地球化学研究,在我国得到了迅速发展。不仅在实验技术方面装备了各种先进的仪器设备,同时也逐步形成了一支具有一定水平的实验和研究的技术队伍。为了总结交流经验,1984年4月30日至5月6日,中国石油学会石油地质委员会和中国岩石矿物地球化学学会沉积学会在天津联合召开了《第二届全国有机地球化学和陆相生油学术讨论会》。这次会议,收到178篇论文摘要,有93篇文章在会议上进行了交流,与会代表170人。这些论文比较全面地反映了近年来我国在有机地球化学特别是在石油地球化学和陆相生油研究领域中,科学技术发展的基本水平和所取得的许多重要成果。反映了我们在油区综合地球化学研究、生物标记化合物、干酪根提取研究技术、热解-气相色谱-质谱应用技术,以及实验模拟和成烃机理的化学动力学等方面所取得的进展。其中,关于生物标记又有一些新的化合物在陆相原油和地层中被发现,并且对生物标记和同位素参数应用的研究也更为深入。原油和生油岩中芳香烃的地球化学,在对比生油物质和有机质的热演化方面也有了可喜的收获;热解气相色谱进一步揭示干酪根的性质及成烃产物的特征,而其化学动力学的研究,则进一步向我们展示了陆相成烃的机理。其它,关于生油定量评价方法的探索,关于天然气地球化学研究等,也都有引人注目的进展。

这次会议还着重讨论了我国有关油气勘探和陆相生油理论研究中一些急待解决的地球化学问题以及今后学科的发展方向。其中,引人注意的是,对低成熟石油非干酪根成因的探讨,对生物标记等各项地球化学指标的可比性、有效性及成油门限的讨论,以及生油定量评价的原则和方法、煤成气的资源量等,都是这次会议上热烈讨论的课题。

这次会议表明,我国有机地球化学工作者的研究领域日益深广,正在努力开拓具有中国特色的陆相有机地球理论。

在这本论文集中,我们选编了这次会议的部分论文,共32篇。还有一些相当不错的文章,由于有关刊物的约稿在先,故没有选入。

这次论文的征集、审编工作,是在中国石油学会石油地质委员会主任田在艺的指导下,由论文编审组负责进行的。编审组的成员是:

组 长:黄第藩

副组长:傅家谟、卢松年、王书林

成 员:程志纯、黄汝昌、周光甲、贝 丰、张义纲、李晋超、尚慧芸、程克明、张大江
本书的编辑工作由《石油勘探与开发》编辑部负责完成。谨对上述同志致以谢忱。

编者

Editor's Words

Rapid strides have been made in the study of the origin of oil from continental deposits and organic geochemistry in recent years in this country. Laboratories equipped with modern instruments have been set up and a sizeable technical force with adequate research capabilities is in the process of building-up. To provide for an occasion of exchange of experiences and views, the "2nd National Symposium On The Origin of Oil From Continental Deposits And Organic Geochemistry" was convened in Tianjin on April 30, 1984, under the auspices of the Petroleum Geological Institute of the Chinese Petroleum Society, the Chinese Litho-Mineral Geochemical Society and the Sedimentology Society. 178 abstracts were received and 93 papers were read and discussed in the meeting attended totally by 170 representatives from all the interested circles. These papers reflect, in one way or another, the technical level we have reached and the major achievements we have made in the field of organic geochemical research, particularly in petroleum geochemical research in respect to the origin of oil from continental deposits. Advances in the comprehensive study of geochemistry, the study of biomarker compounds, the extraction of kerogen, the application of pyrolysis-GC-MS, and the laboratory simulation and study of chemical kinetics of transformation of organic matters into hydrocarbons are among the most outstanding. Of particular interest are the discovery of new biomarker compounds in crude oils of continental origin and the application of biomarkers and isotopic parameters for deep-going research; the use of geochemical characteristics of aromatics from crude oil and source rock in the correlation of source materials of oil and characterization of thermal evolution of organic matters which has achieved gratifying results; analytic study of pyrolytic gas chromatogram which has revealed more details about the structure and composition of the source materials for identification of source rocks; and the study of chemical kinetics which has shed more light on the mechanism of the transformation of organic matters of continental origin into hydrocarbons. Noticeable advances have also been reported in the exploration of a method of quantitative appraisal of hydrocarbon transformation and geochemical study of natural gas, etc.

Discussions in the 2nd symposium centered on some of the pressing

theoretical problems like the geochemistry of oil of continental origin, which is related to the exploration of oil and gas, as well as on the future trend of development of this discipline. To mention but a few, the question of the origin of non-kerogen oil of low maturity was discussed, together with the comparability and effectiveness of geochemical indexes as biomarkers etc. and the threshold depth or temperature for oil transformation; the principle and method of quantitative appraisal of oil generated and the amount of coal gas resources available were also subjects of heated discussion.

From this meeting, it may well be said that the organic geochemists of our country are expanding their domain of study, they are attempting to create an organic geochemical theory for non-marine oil.

In the present issue, we have only collected 32 articles from among those presented in the meeting, as prior commitment by authors to other magazines does not permit us to publish many of the equally good papers here much to our regret.

A group of specialists have been invited to review and finalize the papers under the guidance of Tien Zaiyi, Director of the Petroleum Geological Institute of the Chinese Petroleum Society. The group consists of the following:

Group Leader, Huang Difan

Assistants, Fu Jiamo, Lu Songnien, Wang Shulin

Members, Cheng Zhichun, Huang Ruchang, Bei Feng, Zhang Yigang,

Li Jinchao, Shang Huiyun, Cheng Keming, Zhang Dajiang

The Editorial Board of "Petroleum Exploration and Development" who are responsible for editing the present issue wish to express their thanks to the above comrades.

The Editor

目 录

陆相生油研究史略	黄第藩 (1)
石油地球化学中同位素研究	徐永昌 沈平 王先彬 (22)
甾、萜等生物标志化合物定量的初步研究	傅家谟 徐芬芳 J. R. 马克思威尔 梁狄刚 (29)
常用的甾烷、萜烷类生物标记物指标应用有效性探讨	周光甲 李树青 陈致林 宋一涛 (39)
芳香甾与甾烷及8,14-断-藿烷与藿烷的相关性和热演化规律	王忠然 马顺平 王俊林 刘淑珍 曾宪章 (52)
旬容坳陷藜烷及甾烷地球化学特征及油源对比	尚慧芸 徐伟民 阎霞 (61)
克拉玛依原油中的降解甾烷和藜烷	蒋助生 (72)
克拉玛依原油中的生物标记物及其地球化学意义	盛国英 周中毅 蒋助生 (83)
作为母源输入标志的几种分子化石	曾宪章 刘淑珍 马顺平 王俊林 王忠然 (94)
四环藿烷——8,14-开环藿烷和二环藜烷系列的鉴定及其地化意义	黄绍甫 (102)
原油、生油岩芳烃气相色谱特征及其地化应用的研究	程中第 (112)
华北地区生油岩和原油中的芳烃及其硫化物的地球化学	刘明先 潘正五 王忠然 张文龙 (123)
岩石芳烃中芘的高效液相色谱法测定	佟鼎勋 刘竞文 张微航 (132)
沉积岩中多环芳烃类化合物的同步荧光光谱分析及应用	邓穗明 (139)
总体荧光光谱及其在生油研究中的应用	李一敏 刘双卯 (147)
茂名和抚顺油页岩有机质的碳骨架结构	秦匡宗 劳永新 (154)
应用热解气相色谱法研究干酪根的类型及其演化特征	阎霞 黄第藩 李晋超 程中第 (163)
干酪根的热解 气相色谱分析及其应用	刘宝泉 于立正 蔡冰 (177)
干酪根热模拟成烃规律研究	盛志伟 葛修丽 (187)
一种松树花粉的地球化学特征	高瑞祺 (203)
我国陆相生油岩干酪根的红外光谱特征	杨志琼 唐琳仙 杨一峰 (211)
干酪根类型参数的相互关系及其意义	郭迪孝 王荣福 胡惕麟 陆美芝 (224)
苏北东台坳陷下第三系干酪根特征初析——兼论干酪根类型及成熟度的判别	高品文 卢松年 黄绍明 (229)
活性干酪根在不同分解百分数时的表观活化能及干酪根裂解热效应的测定	沈光球 刘文渊 宋心琦 程克明 (238)
陆相干酪根热降解动力学研究	王会祥 黄第藩 李晋超 (245)
沉积物的压实作用与烃类的初次运移	贝丰 王允诚 (257)
生油层定量评价方法研究	程克明 金伟明 何忠华 (265)

济阳坳陷实用烃产率曲线.....	王新洲 (273)
我国生油岩的 T_{max} 与 R_o 关系图版.....	邬立言 周光鑫 王立明 李杨 (281)
应用 DTA 热谱探讨松辽盆地南部白垩系青山口组干酪根的演化程度.....	王铮 (287)
煤成气型生物成因气及其成因的探讨.....	戴金星 宋岩 (297)
试论我国天然气中汞分布的几个特征.....	涂修元 吴学明 陶庆才 (305)

Contents

A review on studies of the origin of oil from continental deposits	Huang Difan (1)
Isotope study in petroleum geochemistry	Xu Yongchang, Shen Ping, Wang Xianbin (22)
Quantitative analysis of steranes, terpanes and other biomarkers	Fu Jiamo, Xu Fenfang, J. R. Markswell, Liang Digang (29)
Discussion on the effectiveness of application of terpanes and steranes as biomarker index	Zhou Guangjia, Li Shuqing, Chen Zhilin, Song Yitao (39)
Correlation of aromatic steranes with steranes and 8,14-seco-hopanes with hopanes, and their thermal evolution characteristics	Wang Zhongran, Ma Shunping, Wang Junlin, Liu Shuzhen, Zeng Xianzhang (52)
Geochemical characteristics of terpanes and steranes from Ju Rong depression and their bearing on oil/source rock correlation	Shang Huiyun, Xu Weimin, Yan Xia (61)
Degraded steranes and terpanes derived from Kelamay crude oils	Jiang Zhusheng (72)
Biomarker compounds in Kelamay crude oils and their geochemical significance	Sheng Guoying, Zhou Zhongyi, Jiang Zhusheng (83)
Molecular fossils as markers of oil origins	Zeng Xianzhang, Liu Shuzhen, Ma Shunping, Wang Junlin, Wang Zhongran (94)
Identification and geochemical significance of tetracyclic hopanes—8,14seco-hopanes and bicyclic terpane series	Huang Shaopu (102)
GC characteristics of aromatics from crude oils and source rocks and their application in geochemistry	Cheng Zhongdi (112)
Geochemical characteristics of aromatic hydrocarbons and their sulfides from source rocks and crude oils in the Huabei region	Liu Mingxian, Pan Zhengwu, Wang Zhongyan Zhang Wenlong (123)
HPLC Determination of perylene in aromatic hydrocarbons extracted from rocks	

.....Tong Dingxun, Liu Jingwen, Zhang Weihang (132)	
Synchronized fluorescence spectrography analysis of polycyclic aromatic compounds in sedimentary rocks.....Deng Suiming (139)	
Overall fluorescence spectrography and its application in the study of oil origin.....Li Yimin, Liu Shuangmao (147)	
Carbon frame work of organic matters in oil shales from Mao Ming and Fushun.....Qin Kuangzong, Lao Yongxin (154)	
Application of pyrolysis-GC method to the study of kerogen types and their evolution features.....	
.....Yan Xia, Huang Difan, Li Jinchao, Cheng Zhongdi (163)	
Pyrolysis-GC analysis of kerogen and its application.....	
.....Liu Baoquan, Yu Lizheng, Cai Bing (177)	
Study of hydrocarbon formation from kerogen by thermal simulation	
.....Sheng Zhiwei, Ge Xiuli (187)	
Geochemical characteristics of some pine pollens.....Gao Ruiqi (203)	
Infrared spectrography of kerogens from continental source rocks in China.....Yang Zhiqiong, Tang Linxian, Yang Yifeng (211)	
Inth relationship and significance of parameters of different types of kerogen.....	
.....Guo Dixiao, Wang Rongfu, Hu Tilin, Lu Meizhi (224)	
Preliminary study of the characteristics of kerogen from Tertiary sediments in Dong Tai depression in the Su Bei region— Discussion on types and maturity of kerogens.....	
.....Gao Pinwen, Lu Songnian, Huang Shaoming (229)	
Apparent activation energy of activated kerogen at different degradation percentage and determination of heat effect of cracking keragen.....	
Shen Guangqiu, Liu Wen yuan, Song Xinqi, Cheng Keming (238)	
Study on thermal degradation kinetics of continental kerogens	
.....Wang Huixiang, Huang Difan, Li Jinchao (245)	
Compaction of sediments and primary migration of hydrocarbons	
.....Bei Feng, Wang Yuncheng (257)	
Quantitative evaluation of source beds.....	
.....Cheng Keming, Jin Weiming, He Zhonghua (265)	
Practical hydrocarbon productivity curves for the Jiyang depression	
.....Wang Xinzhou (273)	
Plates showing the relationship between Tmax and Ro of source rocks in China.....	
.....Wu Liyan, Zhou Guangxin, Wang Liming, Li Yang (281)	
Discussion on the maturation of kerogen extracted from Cretaceous	

rocks in the Qingshankou Formation, south of the Songliao basin by DTA.....	Wang Zheng (287)
Discussion on biogas generated from coal measures and its origin	Dai Jinxing, Song Yan (297)
Discussion on the mercury distribution in natural gas in China	Tu Xiuyuan, Wu Xueming, Tao Qingcai (305)

陆相生油研究史略

黄 第 藩

(石油工业部石油勘探开发科学研究院)

据记载,“石油”(Petroleum)一词,在我国十一世纪(宋代)就出现了,是沈括(公元1031—1095年)在其著名的《梦溪笔谈》一书中提出的。在该书中,沈括对陕北延长一带的石油,有一段精彩的记述:“鄜延境内有石油,旧说高奴县出脂水,即此也,生于水际砂石,与泉水相杂惛惛而出”。并指出,“石油至多,生于地中无穷”。1907年,正是在这个地区建立了我国第一个陆相油田(延长油矿)。实际上,早在一千五百至二千多年以前,我国就有了关于陕北延长、甘肃酒泉(玉门)和南疆库车等地陆相油苗及其利用的记述。而有关陆相油气的开采及其油井、气井的记录,则早在十三世纪(元代,油,陕北)和十六世纪(明代,气,四川,1835年在自流井还打成了一口深达1001.4米的气井)就已经见诸于史料了^[1]。

从学科领域来看^[2,3],石油有机成因说是在同无机成因说的争论中发展成熟起来的,而在有机说本身又存在着陆相生油和唯海相生油之争。众所周知,世界上绝大部分油气田是产于海相地层中,因此在很长一段时期内(主要是五十年代以前),许多学者都怀疑或否定陆相沉积中油气生成的可能性,而把“所有的油田都和在海底形成的沉积岩相伴生”作为任何石油成因理论都必须满足的原则之一^[4-7,9-13]。甚至到1950年美国出版的《石油的实际资料 and 统计数字》中,仍然把中国同日本、澳大利亚和土耳其等国一起列入含油远景最差的国家^[14]。

中国是一个中、新生代陆相沉积盆地极为发育的国家^[8],又往往有强烈的块断作用和岩浆活动存在,因此上述陆相贫油的观点在对我国油气资源的估价上,曾集中反映出来,甚至一度影响了我国某些学者,使他们也持有类似的观点^[15,16]。

总之,陆相贫油,中国贫油,这代表了五十年代以前相当一部分学者对油气形成与分布的观点。在生产实践中,人们的观点往往会受到生产发展水平的限制,这是一种历史的局限性。五十年代以前,在世界石油工业约一个世纪的发展历程中,石油几乎都是从海相地层中生产出来的,而从典型陆相盆地中生产的石油极少。在海相地层中,人们已经积累了丰富的找油经验,而在陆相地层中的勘探实践甚少。并且由于中国地质构造背景、地质发展历史和石油地质条件的特殊性,当时人们持有陆相贫油、中国贫油的观点是可以理解的。

但是,在世界石油工业这一发展时期,有些学者注意到,陆相地层中的油气时有发现,其前景是值得重视的。其中主要有:

(1) 我国陕北的延长油田(1907),石油产于上三迭统延长统陆相地层中。

(2) 加拿大东部的石溪油田(1909),石油产自下石炭统淡水沥青页岩和砂岩中。

(3) 本世纪早期(1902—1936),在美国落基山区的格林河(Green River)和尤英塔(Uinta)等盆地中,石油(高含蜡)产自该区广布的下第三系富含有机质的湖相地层中,并且这里的沥青脉、沥青砂和油页岩早已闻名于世。据M.D.皮卡德(Picard)统计,

到1956年美国总计有21个油田, 169口油井从第三系陆相沉积中生产油气, 1955年的产油量约为21万吨, 累积约为110万吨^[17]。

(4) 我国甘肃玉门的老君庙油田(1939年5月), 石油产自第三系陆相红色地层中, 生油层为早白垩世的内陆湖相沉积。

(5) 我国新疆独山子油田(1938年), 其产层和生油层均为第三系陆相地层。

(6) 巴基斯坦波特瓦尔盆地的霍尔(Khaur, 1915)油田和杜里安(Dhulian)油田等, 石油产自下第三系的陆相地层中^[18]。

(7) 英格兰中部石炭系的油田(1938—1939, 现为英吉利盆地油气田群的陆上部分), 石油产自英国东中部煤田石炭系的煤系地层中。

(8) 南美哥伦比亚中马格德勒那盆地(Middle Magdalena Basin)第三系河湖相地层中的瓦利斯昆兹油田(1940, Velasquez field)。

(9) 澳大利亚昆士兰盆地的天然气井(1900, 1908, 1927, 1934), 有的产凝析油, 产层属陆相侏罗系, 含煤。1961年又发现了著名的莫尼油田(Moonie field)^[19]。

(10) 西起罗马尼亚(喀尔巴阡)经北高加索(格罗兹内)、土库曼直到费尔干纳盆地, 这是一个绵延4000公里的重要产油带, 开发很早, 且迄今仍不断有所发现。尽管石油主要产于海相地层, 但是高蜡油的分布(产层或油田)也相当普遍, 其成因引起某些学者的注意^[20, 21]。

(11) 1949年我国解放以后, 开展了大规模的石油勘探, 在五十年代大庆油田发现以前(1959年9月26日), 先后在柴达木、准噶尔、酒泉、四川等盆地中、新生界陆相地层中, 发现了一批油气田, 其中引人注目的有: 准噶尔盆地克拉玛依大油田(1955)、柴达木油区(1955, 第三系和侏罗系)和川中侏罗系油区(1958, 油主要产自侏罗系淡水介壳灰岩, 生油层为本身的黑色页岩), 还有酒泉盆地除老君庙油田外的新发现的油田等。至1959年底, 我国原油的年产水平已经从解放前的7万吨增长到276万吨, 天然气的年产水平从1117万立方米增长到4亿立方米以上^[21]。

以上实例, 有的尽管不能完全排除油气经垂直和侧向运移而来自下伏或旁侧海相地层的可能性(如哥伦比亚和巴基斯坦的油), 但大部分却是唯海相生油论无法作出科学解释的。在这样的事实面前, 人们不能不考虑湖相沉积生油的可能性及其油气资源的潜力了。

据我们了解, 最早涉及陆相生油的研究工作是从湖成淤泥的干馏试验开始的。1916年, 美国D.怀特(White)指出, 形成生油层的有机软泥, 既能在盐水中沉积, 也能在淡水中沉积。后来, 他在“论北美石油的产状”中进一步指出, 淡水软泥干馏获得的石油同海相沉积中获得的并无区别^[22]。1919—1925年, 苏联H.Д.泽林斯基(Зелинский)用巴尔喀什湖腐泥干馏(260—400℃)得到了含烃类的焦油, 包括汽油、煤油和柴油这些类似天然石油的产物(H.Д.Зелинский, 《Вопросы Происхождения Нефти》, 1941)。这些成果虽然是从实验室取得的, 但却能启发人们去思考湖相沉积生油的可能性。

下面我们将陆相石油成因理论的发展历史作一概述。以前, 我国徐永昌、石宝珩、安作相也曾先后就这一问题进行过阐述, 值得参考^[23, 24, 25]。

一、陆相生油理论的初创阶段(三十至四十年代)

现代, 我国最早的有关石油的专著是1937年谢家荣所著《石油》一书, 当时他已经注意