谨以此书献给石油大学五十周年华诞

油气藏形成与勘探

YOUQICANG XINGCHENG YU KANTAN

石油大学石油天然气成藏机理

教育部重点实验室2001年科研成果文集

张一伟 主编

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内容提要

本书为石油大学石油天然气成藏机理教育部重点实验室2001年科研成果文集。书中汇集了油气运移和聚集动力学、烃源岩及油藏地球化学、圈闭形成与演化及预测方面的重要成果。

本书可供石油、天然气地质科研人员使用。

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《油气藏形成与勘探》
编　委　会

前　言

石油大学石油天然气成藏机理教育部重点实验室是教育部2000年10月批准成立的,它的主要任务是致力于研究中国复杂地质条件下油气成藏机理与分布规律,为有效勘探开发油气资源提供理论指导。

在教育部的领导下,在中国石油天然气集团公司科技局、中国石油化工股份公司勘探开发研究院、中国海洋石油总公司勘探开发研究中心以及大庆油田和胜利油田等会员单位的大力支持下,两年多来,石油天然气成藏机理教育部重点实验室紧紧围绕学术委员会所确定的油气运移和聚集动力学、烃源岩及油藏地球化学以及圈闭形成、演化及预测三个研究方向开展工作,取得了丰硕成果。

(1)完善了实验室的管理制度,成立了以依托单位主管领导为主任和相关职能部门为委员的实验室管理委员会,改善了实验室的工作环境,提高了工作效率。

(2)圆满完成了"九五"、"211"工程建设任务,建成了油藏地球化学实验室、构造物理模拟实验室、油气成藏机理物理模拟实验室和油气成藏机理数值模拟实验室四个校级实验室。2001年获得教育部"211"工程评审专家组的高度评价,认为石油大学已在油气成藏研究领域发展成为我国主要的实验基地、研究基地和人才培养基地。

(3)探索了会员合作制,并取得了初步成效,为实验室今后的长期稳定发展和保障基础理论研究的顺利进行积累了有益的经验。

(4)出色地完成了"九五"期间承担的两项研究经费在1000万元以上的研究项目:大、中型油气田成藏定量模式研究(中国石油天然气集团公司"九五"重大科技攻关项目);柴达木盆地石油地质综合研究与勘探目标选择(中国石油天然气股份有限公司"九五"重点科技攻关项目)。并获得了一批高水平的研究成果,其中三项获省部级科技成果一等奖,即:"大、中型油气田成藏定量模式研究"获中国石油天然气集团公司2002年技术创新一等奖,"塔里木盆地油气源与成藏研究"获教育部2002年科技进步一等奖,"柴达木盆地石油地质综合研究与选区评价"获2002年青海省科技进步一等奖;一项获省部级科技成果二等奖,即:"排烃门限理论研究与应用"获2002年北京市科技进步二等奖;两项获省部级科技成果三等奖,即:"塔里木盆地形成演化过程与复合含油气系统多旋回油气成藏动力学研究"和"柴达木盆地天然气资源评价与有利勘探区选择"获2001年北京市科技进步三等奖,为实验室的进一步发展奠定了坚实的基础。

(5)"十五"期间,争取到国家重点科技攻关项目"济阳坳陷下第三系沉积体系与油气运聚机理研究"和国家杰出青年基金项目"沉积盆地超压系统演化及成藏效应"等重大基础研究项目,实验室将继续围绕油气成藏机理深入开展工作,不断推动我国油气勘探理论的发展。

(6)开展了广泛的国内外学术交流。已与加拿大、美国、俄罗斯、日本、韩国、澳大利亚和德国等国家著名研究机构、大学和石油公司建立了联系并开展合作研究,互派博士后和留学生。实验室设立了开放研究基金,对全国开放。

今后石油天然气成藏机理教育部重点实验室将坚持油气成藏研究的学术方向,瞄准油气

勘探的重大理论问题，强化叠合盆地油气富集规律研究，依靠物理模拟揭示微观机理，借助现代技术实现宏观预测，加强国内外学术交流与合作，努力提高学术水平，走产学研相结合的发展道路，发挥团队精神，使实验室成为全国油气成藏机理研究、学术交流和人才培养的重要基地。

为了进一步推动全国油气成藏机理研究，全面反映石油大学石油天然气成藏机理教育部重点实验室的研究成果，我们决定每年公开出版一本科研成果文集。现在我们组织出版了《油气藏形成与勘探——石油大学石油天然气成藏机理教育部重点实验室 2001 年科研成果文集》和《油气藏形成与勘探——石油大学石油天然气成藏机理教育部重点实验室 2002 年科研成果文集》。这两部文集一方面展示了石油大学石油天然气成藏机理教育部重点实验室 2001 年和 2002 年在油气运移和聚集动力学、烃源岩及油藏地球化学和圈闭形成、演化及预测三个研究方向公开发表的主要成果，另一方面介绍了实验室两年来取得的主要科研成果、实验室的基本情况以及实验室研究骨干。在文集出版的过程中得到石油工业出版社周家尧、谭忠心等同志的大力支持。曾溅辉、翁庆萍等人付出了大量的劳动，在此表示衷心的感谢。由于水平有限，时间仓促，不妥之处，敬请指正。

石油大学石油天然气成藏机理教育部重点实验室主任

庞雄奇教授

2003 年 6 月

目　　录

油气运移和聚集动力学

烃源岩及油藏地球化学

圈闭形成、演化及预测

油气运移和聚集动力学

Influences of Deep Fluids on Organic Matter of Source Rocks from the Dongying Depression, East China❶

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Abstract Ten samples of source rocks from the Dongying depression were analysed by organic petrographic and geochemical methods in order to study the influences of deep fluids on organic matter of source rocks. The results indicate that the organic parameters show different variations under the influences of deep fluids. The extract yields increase in the samples from the strong fluid zone. The contents of saturated and aromatic hydrocarbon fractions are lower, whereas the contents of polar compound and asphalt fractions are higher in the samples from the strong fluid zone. The hydrogen from the deep fluids might react with organic matter, and resulted in the increase of the extract yields, or deep fluids as catalyses for hydrocarbon generation resulted in the increase of the extract yields. The maturity parameters decrease under the influences.

1 INTRODUCTION

The role of geofluids in petroleum formation has been studied for a long time (Mann and Mackenzie, 1990; Capuano, 1993; Parnell, 1994). As pass ways of fluids, faults have been noticed by many geologists (Hagen, 1988; Daling, 1998; Losh et al., 1999). Some reservoirs related with faults and volcanic activity (Jin Qing et al., 1999). According to references, the influences of deep fluids on organic matter may be in three different kinds: (1) increasing the maturity of organic matter by thermal activity; (2) reaction with organic matter; (3) as catalyses for hydrocarbon generation (Sun, 1998; Jin et al., 1999).

The purpose of this paper is to study the role of deep fluids in hydrocarbon formation. The deep fluids of this study mean the fluids from deep crust or upper mantle.

The Bohaiwan basin is a petroleum-bearing basin, and formed by Mesozoic-Cenozoic con-

❶ 原载《ENERGY EXPLORATION & EXPLOITATION》, 2001, 19(5)。

tinental rifts. Dongying depression belongs to the Bohaiwan basin, and is located in the north of Shandong Peninsula, the south seashore of Bohai. It was formed by two evolution stages. In early Tertiary, the tectonic active strongly and the depression sink quicken up. In the late Tertiary, the tectonic activity is slowdown. Although the entire strata of Cenozoic are observed in Dongying depression, the Lower Tertiary formation is the main source rock and reservoir.

Shengli oil field was found in April 1961 in the Bohaiwan basin. It is the second largest onshore oilfield in China. Dongying depression is the largest sub unit of the Shengli oil field. It began producing oil in 1961. The oil reserve is about 1.94 billion tons according to the 2000 annual report of Shengli oil company (unpublished data). Its annual oil production was about 13 million tons.

The previous study has proved that the deep fluids active strongly, and the CO_2 and he reservoirs have been found in this depression (Xu, 1996; Dai et al., 2000). Their isotopic and geochemical analyses indicate that the CO_2 and he are from deep crust and mantle. The second evidence for the activity of deep fluids is that abundant trace metals were determined in the crude oil. The Au content reaches 132 ppb in crude oil (Lin Qing et al., 1993), whereas a high Au content in around rock and the source rock has not been found. This phenomenon may indicate that the Au is from the deep crust by deep fluid activity. Au and other trace metals from the deep fluids may act as catalyze for hydrocarbon formation. Furthermore, magma and volcanic actives could be accompanied with deep fluids. They bring not only trace metals, but also heat energy to source rock. These heat energy may let the maturity increase of organic matter.

10 samples were taken from five drill cores in the Dongying depression. Six of them were taken from the source rock in the Daluhu reservoir near the Gaoqing – Pingnan fault, and this area is named as strong fluid zone in this study. Four of them were taken from the source rock in the Niuzhuang reservoir which is far from the fault, and this area is named as weak fluid zone. The weight of every sample is about one kilogram.

2 EXPERIMENTAL

2.1 Petrographic Analyses

The maceral composition was analyzed on polished blocks under reflected white light. Vitrinite reflectance was measured using a Leitz MPV3 reflected light microscope that is fitted with a halogen lamp. The reflectance was measured using a oil immusion objective (32x) under 546 nm filtter. The measurement was calibrated using a Leitz glass standard (R_{oil} = 0.889%).

2.2 Solvent extraction and liquid chromatography

Finely ground coal samples were extracted by Soxhlet – extract method for 24 h. Prior to GC – MS analysis, the extracts were separated into three fractions by column chromatography using pre – washed silica gel (70 – 230 mesh, 50(1 cm)). The alkanes were eluted with n – hexane, the aromatic hydrocarbons with dichloromethane and the polar compounds (heterocompounds) with methanol (40 ml of each solvent).

2.3 Organic Carbon Analysis

The total organic carbon (TOC) content was measured using a Leco CR – 12 carbon determinator. Carbonates were removed from the samples by prior treatment with concentrated hydrochloric acid.

2.4 GC and GC/MS analyses

The gas chromatographic (GC) analyses were carried out on a Varian – 3700 gas chromatography fitted with a silica capillary column 20m (0.2mm i.d.), temperature programmed from 80 to 320℃ at 4℃/min.

GC/MS analyses were performed on a Finnigan – Mat 4021C GC – MS. A fused silica capillary column 25m(0.18mm i.d.) coated with SE – 54 was used. The column temperature was programmed from 80 to 300℃ at 4℃/min and was held at 300℃ for 20 min. The ionizing voltage was 70eV and helium was used as carrier gas.

3 RESULTS AND DISCUSSION

3.1 Microscopic analysis

The maceral composition was analysed by microscope. The macerals are consist of bitumen, alginite, sporinite and vitrinite. The bitumens are migrabitumens and reach 40 – 50% of macerals. Alginite reaches 15 – 25% of macerals, the sporinite reaches 5 – 15%, and the vitrinite reaches 20 – 30% of macerals. Non – differences of the maceral composition were observed between the samples from the Niuzhuang and Daluhu reservoirs. The values of vitrinite reflectances vary from 0.72% to 0.74%, and are slightly higher in the samples from the Niuzhuang reservoir. The discrimination may be due to the different depth of the source rock (Table 1).

Table 1 Geochemical parameters

Bulk parameter								
Sample No	sample amounts		TOC(%)	Extr (mg/g TOC)	Alk(%)	Aro(%)	Het(%)	Asph(%)
strong fluid	6		1.8	131	41.98	8.26	39.41	9.7
weak fluid	4		1.88	115	45.3	12.21	34.69	7.8
Saturated hydrocarbon								
Sample No	Max – peak	C_{21-}/C_{22+}	$C_{(21+22)}/C_{(28+29)}$	Pr/Ph	Pr/nC_{17}	Ph/nC_{18}	CPI	OEP
strong fluid	"C23,C25"	0.65	1.87	1.32	0.61	0.52	1.15	1.2
weak fluid	"C17,C19"	1.06	1.67	1.18	0.43	0.38	1.22	1.1

continue

Bulk parameter								
Sample No	sample amounts		TOC(%)	Extr (mg/g TOC)	Alk(%)	Aro(%)	Het(%)	Asph(%)
Aromatic hydrocarbon								
Sample No	MPR	DPR	MPI	DPI	Rc(%)	Rr(%)		
strong fluid	0.67	0.26	0.52	0.54	0.712	0.725		
weak fluid	0.8	0.2	0.63	0.67	0.778	0.731		

MPR = 2 − MP/1 − MP; DPR = (DMP3 + DMP4)/(DMP5 + DMP6); MPI = 1.5(2 − MP + 1 − MP0/(P + 1 − MP + 9 − MP)

Rc = 0.6 * MPI 1 + 0.4; DPI = 4(DMP1 + DMP2 + DMP3 + DMP4)/(P + DMP5 + DMP6 + DMP7)

TOC = total organic mater, Extr = extract, Alk = n − alkanes, Aro = aromatics; Het = heteros compounds, Asph = asphalte

MPR = methylphenantherene ratio, DPR = dimethylphenantherene ratio, MPI = methylphenantherene index,

DPI = dimethylphenantherene index, Rr = vitrinite reflectance, Rc = caculated vitrinite reflectances.

Pr = pristane, Ph = phytane, P = phenanthrene, DMP = dimethylphenantherene.

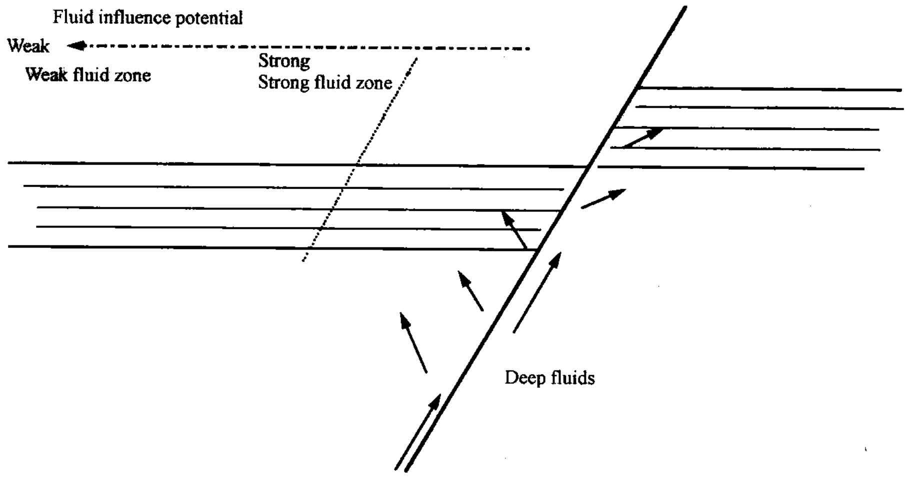

Fig. 1 Sketch map of sampling sites

One difference is observed in pyrite shapes. The most pyrites from the strong fluid zone show framboidal textures which are formed in the syngenesis (Sun, 1996). However, the most pyrites from the weak fluid zone do not have a framboidal texture and are present as crystals with sharp edges. The second type of pyrites is formed after the syngenesis (Sun, 1996).

3.2 Geochemical analysis

3.2.1 *Organic bulk parameters*

TOC contents are not only related to the depositional environments, but also related to fluid conditions in the diagenesis. It has been reported that the basin brines could deplete the TOC contents in the black shale from Germany and southwestern Poland (Sun, 1996; Sun and Püttmann, 2001).

The average TOC content of the samples from the strong fluid zone is 1.8%, and is 1.88 in the samples from the weak fluid zone. The differences of the TOC contents could be due to the influences of fluids which can with organic matter and result in a decrease of TOC contents (Sun, 1996). An alternative explanation may be a slight variation of the depositional facies. The extract yields in the samples from the strong fluid zone is 131 mg/g TOC, and is 115 mg/g TOC in the samples from the weak fluid zone. This distribution trend is reversing the TOC contents. The reason may be that some compounds or elements of deep fluids can catalyze the organic matter and form more hydrocarbons (Jin et al., 1999). The contents of saturated hydrocarbons are higher in the samples from the strong fluid zone, whereas the contents of aromatic hydrocarbons are lower in these samples. In the sample close the fault, the contents of polar compound fraction and asphalt are lower than in the weak fluid zone.

3.2.2 *Saturated hydrocarbon*

Two GC traces of the samples from the different zones are shown in Fig. 2. The intensities of the peaks are different. Eight parameters of saturated hydrocarbon were calculated from two group samples. They show different variation. The max – peaks occur in $nC_{23} - nC_{25}$ in the samples from the strong fluid zone, whereas they are present in $nC_{17} - nC_{19}$ in the samples from the weak fluid zone. In the sample of the strong fluid zone, the values of C_{21-}/C_{22+} and $(C_{21} + C_{22})/(C_{28} + C_{29})$ are higher than those in the weak fluid zone. The different distribution of the saturated hydrocarbon compounds may be due to the reaction of deep fluids and organic matter.

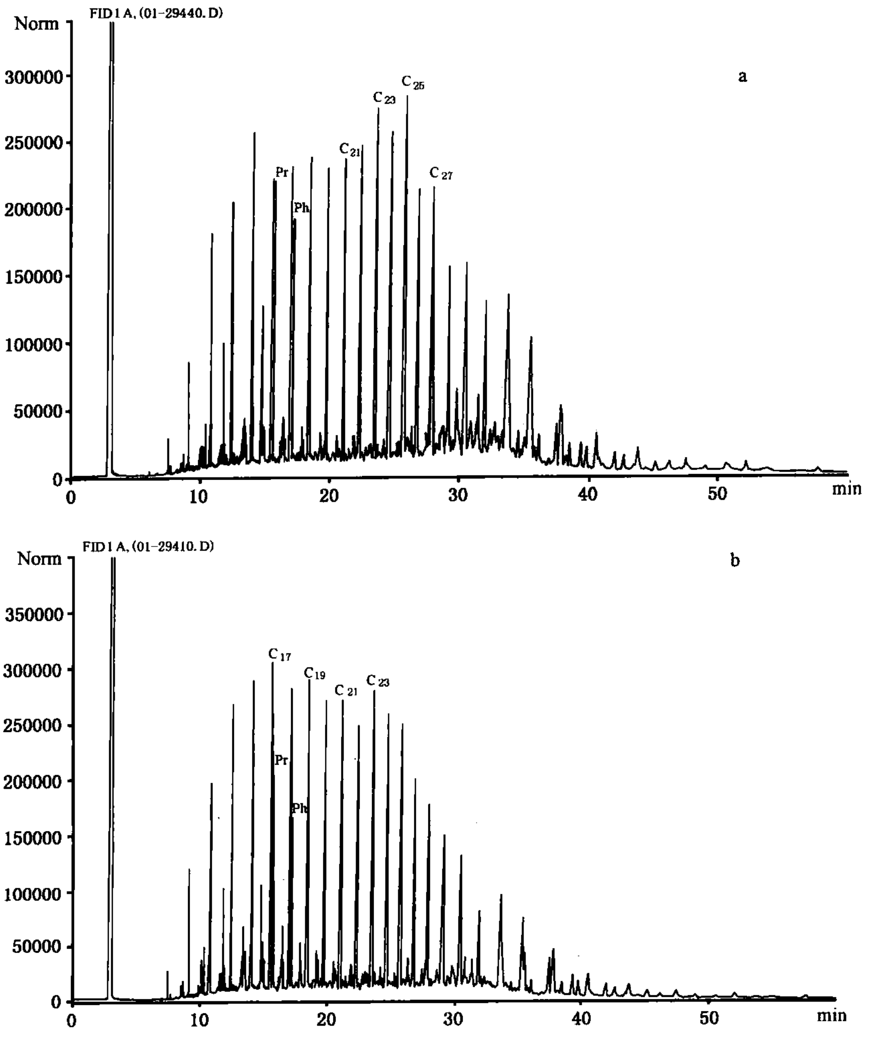

Fig. 2 GC traces of saturated hydrocarbons from the Dongying depression
(a) the samples is close to the Gaoqing – Pingnan fault;
(b) the sample is far from the fault

Pristane and phytane are the degradation results of chlorophyle side – chains (Brooks et al, 1969; Tissot and Welte, 1984). Pristane is formed in a relative oxic condition, whereas phytane is formed in a relative euxinic condition. Therefore, Pristane/phytane (Pr/Ph) ratio has been used as an environmental parameter (Tissot and Welte, 1984). The Pr/Ph ratio is 1.32 in the strong fluid zone, and 1.18 in the weak fluid zone. This may indicate that the deep fluids in the strong zone let the source rock become more euxinic.

Pristane/nC_{17} and phytane/nC_{18} are the maturity parameters and can also be influenced by diagenese invironments (Püttmann et al., 1994). Their values in the strong fluid zone reach 0.61 and 0.52, respectively, whereas they are only 0.43 and 0.38 in the weak fluid zone, respectively. CPI and OEP are also maturity parameters, and their values are also different in both zones, but their differences are small (Table 1). The variation of these parameters may indicate that the deep fluids let some compound contents increase, and result in the increase of these parameters.

3.2.3 *Aromatic hydrocarbon*

Two GC traces of aromatic hydrocarbon are shown in Fig. 3. Fig. 3 (a) is from the weak

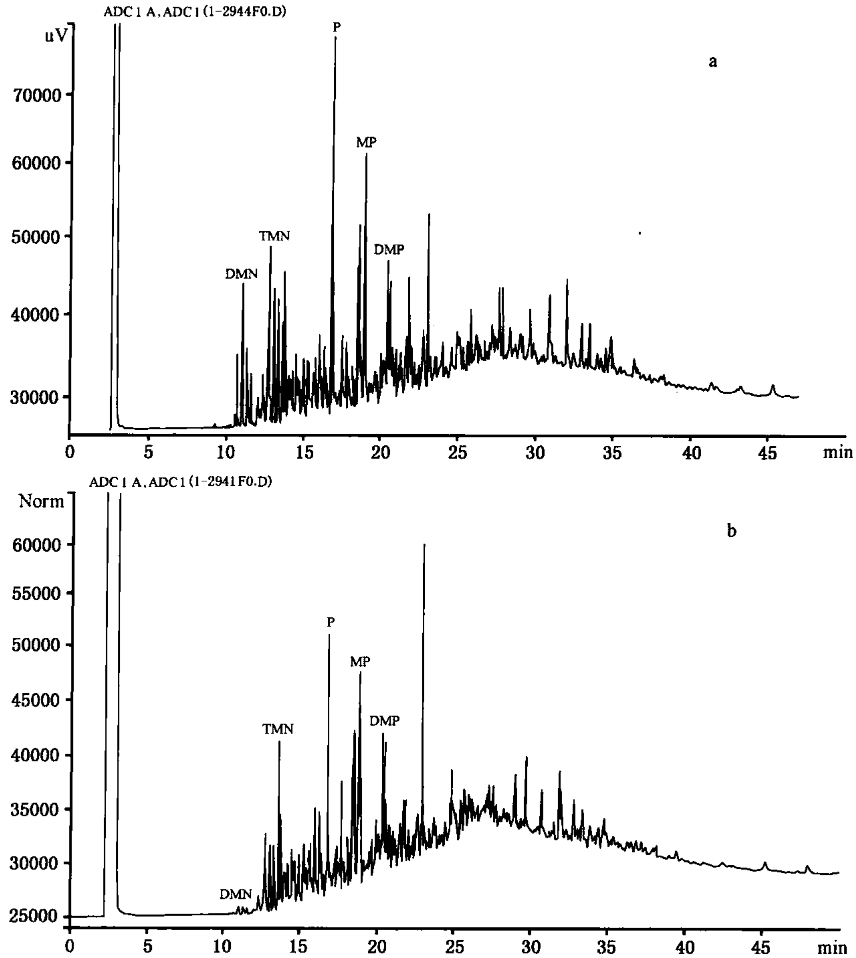

Fig. 3 GC traces of aromatic hydrocarbons from the Dongying depression
(a) the samples is close to the Gaoqing – Pingnan fault;
(b) the sample is far from the fault