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番禺低隆起—白云凹陷北坡第三系储层 次生孔隙形成机理分析^①

郝乐伟^{1 2} 王琪^{1 2} 廖朋^{1 2} 唐俊^{1 2} 张功成³

(1. 中国科学院油气资源研究重点实验室 兰州 730000; 2. 中国科学院研究生院 北京 100049; 3. 中国海洋石油研究中心 北京 100027)

摘要 根据砂岩薄片、铸体薄片、扫描电镜的分析,研究区内发育大量的粒间和粒内溶蚀孔。在大量实测物性参数统计分析的基础上,发现了白云凹陷第三系储层存在两个次生孔隙发育带,主要分布在2 750~3 500 m和4 100~4 600 m两个深度段。通过同位素示踪的方法,证实了形成次生孔隙的原因主要是有机质成熟时释放的有机酸和成岩过程中有机质脱羧作用产生的CO₂形成的酸性水对长石、含长石火山岩屑、早期碳酸盐胶结物和生物化石等的溶解。影响次生孔隙的地质因素还有烃源岩的分布和类型、沉积相内砂体的分布和砂岩类型、构造活动产生的断裂。另外次生孔隙还受控于烃源岩成熟时间与断层、砂体和古构造脊组成的输导体系之间的匹配关系。综合各种地质因素分析后,将有机酸形成的次生孔隙模式概括为“生、运、匹、溶”,该模式对研究区优质储层的预测具有一定的指导意义。

关键词 白云凹陷 次生孔隙 有机酸 包裹体 输导体系 优质储层

第一作者简介 郝乐伟 男 1985年出生 博士研究生 储层沉积学 E-mail: haolewei66@163.com

通讯作者 王琪 E-mail: qiwang@lzb.ac.cn

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随着石油勘探向深部发展,深部储层高孔隙的发育日益成为石油地质工作者备受关注的问题。深部异常高孔隙可由早期烃类的注入或浅部发育流体超压等多种因素造成^[1],也可以由次生孔隙形成^[2,3]。其中形成次生孔隙的因素很多,包括大汽水、地表淋滤水的淋滤作用,有机质成熟演化中产生的有机酸的溶蚀作用^[4~7],黏土矿物转化产生酸性水的溶蚀作用^[8]等。储层次生孔隙的形成及保存机制是一个复杂的过程,既与微观组分有关,又与宏观地质作用相关,其研究不仅要考虑古气候条件、原始沉积相带、成岩环境的地温、压力条件和流体介质条件的影响,还要考虑多期构造变动对沉积及成岩作用的影响^[9,10]。前人已对珠江口盆地白云凹陷—番禺地隆起第三系的成藏组合、沉积体系和成岩作用做了大量的研究,但对该地区储层物性的变化规律及影响因素缺乏综合研究,对储层孔隙演化规律了解甚微。次生孔隙的形成机制及控制因素得到合理解释与否,直接影响着含油气盆地碎屑岩储层质量预测模式的建立,严重影响着对储层的客观评价。本文通过同位素地球化学、有机地球化学结合沉积学的方法,对制约研究区次生

孔隙发育的因素做了系统的探讨。

1 地质概况

珠江口盆地位于中国南海北部,华南大陆的南缘,呈北东—南西向展布,是中国近海含油气盆地中一个重要的盆地。该盆地东西长约800 km,南北宽100~300 km,面积约17.8×10⁴ km²。盆地的演化在中—新生代经历了裂前、裂谷、沉降和断块升降4个阶段^[11]。盆地可分珠一、珠二、珠三等3个拗陷和北部断阶、神狐暗沙隆起、东沙隆起、南部隆起及番禺低隆起8个二级构造单。番禺低隆起和白云凹陷位于珠江口盆地中、南部地区,二者相邻,分属于盆地的中央隆起带和珠二拗陷(图1)。白云凹陷是珠江口盆地面积最大、第三系沉积厚度最大的拗陷,最大沉积厚度超过10 km。番禺低隆起和白云凹陷的第三系自下而上发育有文昌组、恩平组、珠海组、珠江组、韩江组、粤海组、万山组,其中珠海组、珠江组和韩江组是主要的油气储层,发育的古近系文昌组、恩平组烃源岩,是该区主要的油气来源^[12]。

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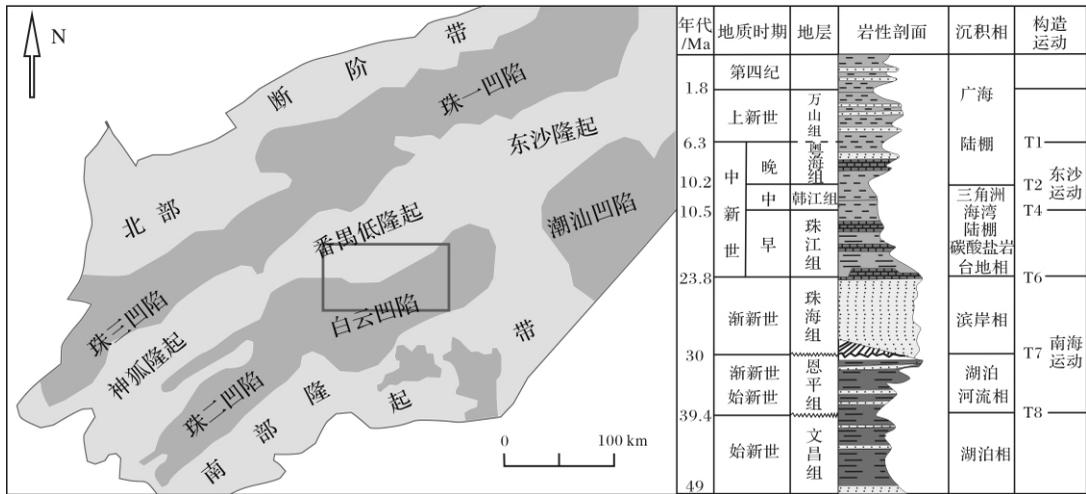


图 1 白云凹陷构造位置示意图和地层结构图(据王福国^[13] 2004, 修改)

Fig. 1 Tectonic location and sequence stratigraphic division of Baiyun sag(modified from Wang Fuguo , et al. 2004)

2 次生孔隙类型及演化特征

根据对研究区实际孔隙度数据与埋深的关系,孔隙度在 2 000 m 时偏离了理论孔隙度的变化曲线,这种偏离一直延续到 5 000 m。不考虑次生孔隙发育和早期碳酸盐胶结,孔隙度和承载压力之间是存在良好的线性关系的,按照理论推断孔隙纵向演化可以划分为 3 段:①高孔锐减段;②稳定下降段;③缓慢减缩段。理论孔隙度演化是逐渐降低的,不会出现回返^[14,15]。从孔隙度曲线的变化上可以说次生孔隙在研究区较为发育,在各个层位几乎都存在,但孔隙明显回升的层段主要分布在 2 750 ~ 3 500 m 和 4 100 ~ 4 600 m 两个区间(图 2):第一区间,此带是此间矿物颗粒和碳酸盐胶结物发生了溶蚀,粒间溶孔和粒内溶孔大量形成,次生孔隙开始大量发育,孔隙在本期具有一个明显的增大过程,属混合孔隙发育带。主要是由于烃源岩中有机酸的注入,形成酸性成岩环境产生大量溶蚀孔,从而形成了次生孔隙发育带。珠海组主体位于此带,此带以粒间溶孔 + 粒内溶孔 + 粒间孔组合为主。第二区间,随着埋深和成岩作用的加深,有机酸逐渐被消耗,酸性环境降低逐渐向碱性环境过渡。由于主要烃源层已先期进入成熟阶段,珠江组下段和珠海组的砂岩表现出早期溶解作用的成岩特点,早先形成的部分次生孔隙被其后的硅质增生所缩小,使深部难以保存大规模的孔隙回升现象。此带孔隙度和渗透率的相关性比较差(图 3),主要由于此带多为粒内溶孔,多见火山岩屑溶孔。珠海组下部、恩平组主体位于此带,以粒内溶孔 + 粒间溶孔 + 粒间孔组合为主。

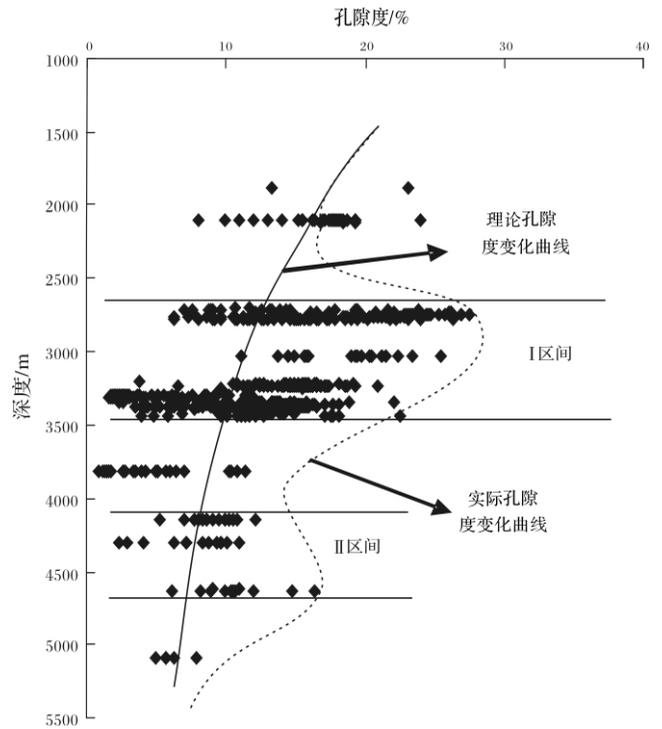


图 2 孔隙度随深度的变化

Fig. 2 The variation of porosity with depth

3 次生孔隙形成的条件与主控因素

在本地区酸性流体的溶蚀作用是次生孔隙产生的主要原因,蒙脱石等黏土矿物的脱水形成酸性流体对原生孔隙保存和次生孔隙的演化仅起到辅助作用。前人研究早就指出本区酸性流体在孔隙演化上起了重要意义^[15,16]。

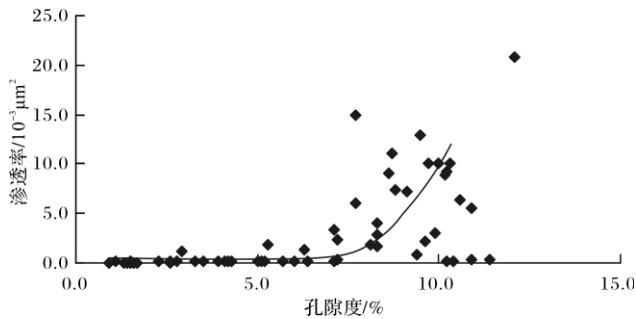


图3 第二区间孔隙度和渗透率相关性

Fig. 3 Relationship between porosity and permeability in the second interval

本次通过研究区内碎屑岩的氧、碳同位素进一步证实了前人的认识和研究成果。研究区内碎屑岩中 $\delta^{13}\text{C}$ 值变化在 $-11.8\text{‰} \sim -3.4\text{‰}$ 之间, $\delta^{18}\text{O}$ 为 $-17.8\text{‰} \sim 2.4\text{‰}$ (表1)。由于大气水中溶解 CO_2 的

$\delta^{13}\text{C}$ 值为 -7‰ ,湖相原生碳酸盐的 $\delta^{13}\text{C}$ 值为 $-2\text{‰} \sim 6\text{‰}$ ^[17]。Irwin的研究表明^[18]有机酸 $\delta^{13}\text{C}$ 值为 -20‰ , $\delta^{18}\text{O}$ 值为 $-3.5\text{‰} \sim -7\text{‰}$ 。由上面各种成因碳酸盐同位素特征值的对比可见,仅仅由沉积时保存的孔隙水是不能形成如此低的 $\delta^{13}\text{C}$ 值。在深埋过程中干酪根热脱羧形成有机酸并加入碳酸盐胶结物而致。这样,依据同位素资料就可以确定白云凹陷碎屑岩储层次生孔隙的成因主要是有机酸的溶蚀作用。

另外,通过对大量薄片观察,发现长石颗粒与岩屑颗粒被强烈溶蚀(图4a),有的仅剩残骸(图4b),可以说明是酸性比较强的酸性流体所致,而蒙脱石等黏土矿物产生的酸性水或有机质过成熟产生的 CO_2 难以产生这样的溶蚀效应。同时,恩平组、珠海组、珠江组等多个层段溶蚀的普遍性也说明了酸性流体的产出量大。如此酸性强、体积大的酸性流体,与本地区的烃源岩类型和分布密切相关。

表1 碳、氧同位素分析数据

Table 1 The data of carbon and oxygen isotopic composition of carbonate cements

序号	井位	层位	$\delta^{13}\text{C}_{\text{PDB}}/\text{‰}$	$\delta^{18}\text{O}_{\text{PDB}}/\text{‰}$	序号	井位	层位	$\delta^{13}\text{C}_{\text{PDB}}/\text{‰}$	$\delta^{18}\text{O}_{\text{PDB}}/\text{‰}$
1	LH19-2-5D	韩江组	-3.7	-10.5	30	PY33-1-1	珠海组	-10	-15.8
2	LH19-2-5D	珠江组	-4.5	-10.2	31	PY33-1-1	珠海组	-5.9	-12.7
3	LH19-2-5D	珠江组	-3.8	-10.4	32	PY33-1-1	珠海组	-5.9	-13.3
4	PY27-1-1	珠海组	-5.3	-12.4	33	PY33-1-1	珠海组	-4.5	-9.1
5	PY27-1-1	珠海组	-4.7	-12.8	34	PY33-1-1	珠海组	-5.4	-11.9
6	PY27-1-1	珠海组	-4.6	-11.5	35	PY33-1-1	珠海组	-6.2	-8.9
7	PY27-1-1	珠海组	-5.7	-11.6	36	PY33-1-1	珠海组	-7.4	-6.8
8	PY27-1-1	珠海组	-5.4	-13.5	37	PY33-1-1	珠海组	-5.7	-13
9	PY27-1-1	珠海组	-5.9	-12.2	38	PY33-1-1	珠海组	-7.7	-15.5
10	PY27-1-1	珠海组	-4.8	-12.5	39	PY33-1-1	珠海组	-3.4	-11.4
11	PY27-1-1	珠海组	-5.3	-11	40	PY33-1-1	珠海组	-5.4	-11.9
12	PY27-1-1	珠海组	-9.7	-4	41	PY33-1-1	珠海组	-6.7	-13.1
13	PY27-1-1	珠海组	-10.4	-12.3	42	PY33-1-1	恩平组	-7.6	-14.5
14	PY27-1-1	珠海组	-6.3	2.7	43	PY33-1-1	恩平组	-10.7	-17.7
15	PY27-1-1	珠海组	-9.7	-11.6	44	PY33-1-1	恩平组	-8.4	-14.6
16	PY27-1-1	珠海组	-5.1	-13.8	45	PY34-1-2	珠江组	-7.6	-12.2
17	PY27-1-1	珠海组	-8.9	-13.7	46	PY34-1-2	珠江组	-6.5	-13.4
18	PY27-1-1	珠海组	-11.2	-9.6	47	PY34-1-2	珠江组	-6.1	-12.1
19	PY27-1-1	文昌组	-14.1	-15.8	48	PY34-1-2	珠江组	-6.2	-11.2
20	PY27-2-1	珠海组	-7.2	-11	49	PY34-1-2	珠江组	-6.8	-12.1
21	PY27-2-1	珠海组	-6.3	-13.1	50	PY34-1-2	珠江组	-6	-13
22	PY27-2-1	珠海组	-7.2	-11.4	51	PY34-1-2	珠江组	-5.7	-14.1
23	PY27-2-1	珠海组	-6.6	-12.9	52	PY34-1-2	珠江组	-5.5	-14.9
24	PY27-2-1	珠海组	-7.6	-17.8	53	PY34-1-3	珠江组	-4	-11.9
25	PY27-2-1	恩平组	-8.1	-18.1	54	PY34-1-3	珠江组	-4.8	-13.8
26	PY27-2-1	恩平组	-10.9	-17	55	PY34-1-3	珠江组	-4.8	-13.9
27	PY27-2-1	文昌组	-7.6	-18.2	56	PY34-1-3	珠江组	-4.1	-12.4
28	PY27-2-1	文昌组	-7.2	-18.4	57	LW3-1-1	珠海组	-11.8	-11.3
29	PY27-2-1	文昌组	-8.1	-18	58	LW3-1-1	珠海组	-4.7	-9.2

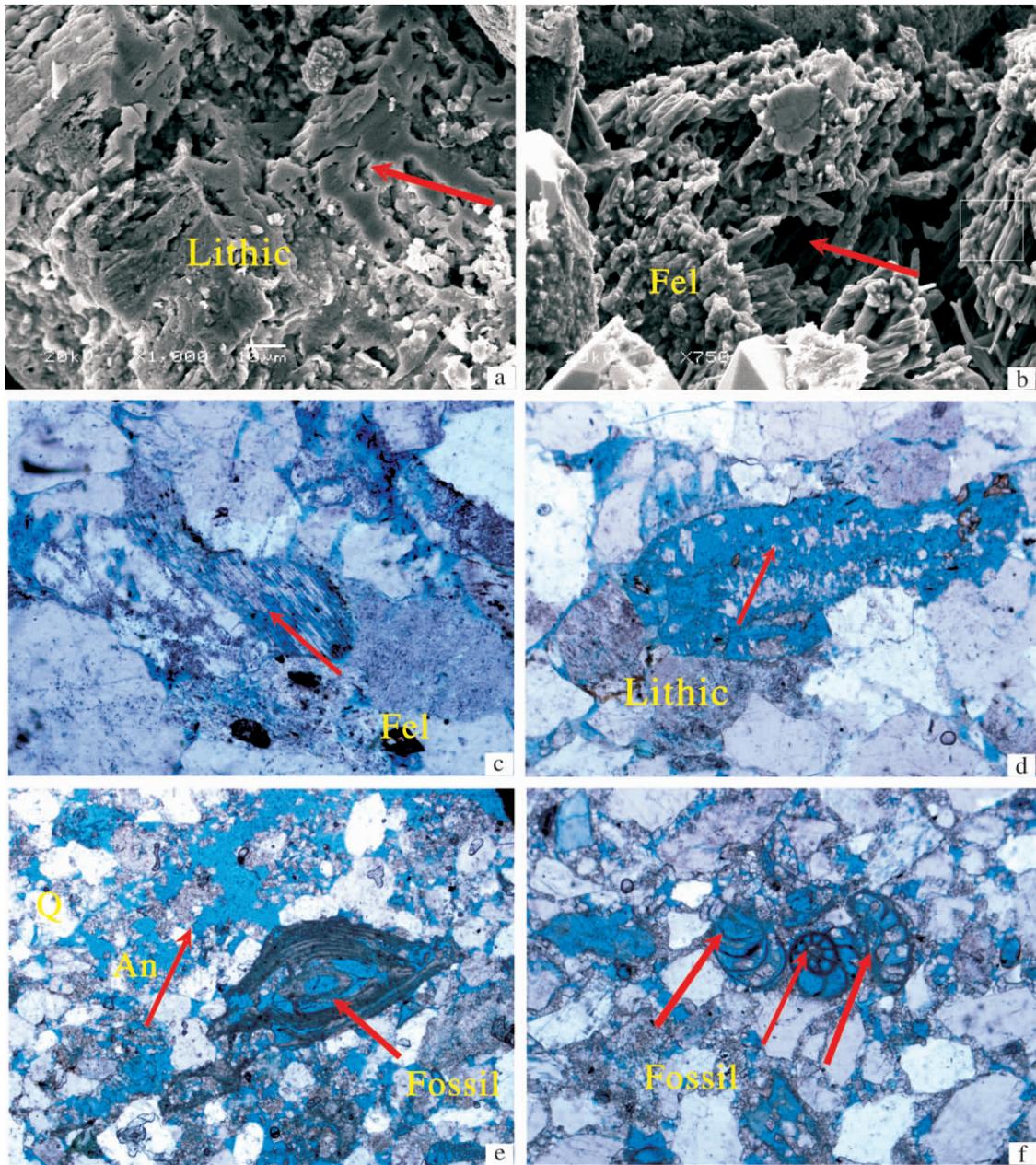


图 4 研究区典型的溶蚀现象

a. LW3-1-1-3 SEM β 136.00 m 岩屑颗粒表面发生强烈溶蚀形成溶蚀孔分布特征; b. LW3-1-1-11 SEM β 191.00 m 长石颗粒发生强烈溶蚀形成溶蚀残骸; c. PY34-1-2-15($\times 100$) (3 386.00 m N_1^{1z}) 岩屑石英细砂岩中中长石沿解理缝溶蚀; d. PY33-1-1-21($\times 50$) (4 299.85 m E_3^{ep}) 强压实岩屑细砂岩中火山岩屑粒间溶孔; e. PY33-1-1-14 ($\times 25$) 3 438.20 m E_3^{zh} 粒间白云石胶结物溶蚀及生物化石内部选择性溶蚀现象; f. PY33-1-1-14($\times 50$) (3 438.20 m E_3^{zh}) 弱压实钙质岩屑中—细砂岩中生物化石体腔孔

Fig. 4 Typical dissolution events in the study area

3.1 丰富的可溶物质

已有的研究表明,次生孔隙主要由骨架颗粒溶解形成,长石等铝硅酸盐是最为常见的易溶骨架颗粒,很多砂岩中次生孔隙的形成都是长石等铝硅酸盐溶解的结果^[19]。通过铸体薄片观察发现溶蚀现象有铝硅酸

盐溶蚀、石英颗粒边缘溶蚀和碳酸盐胶结物溶蚀三种情况,其中以碳酸盐胶结物溶蚀形成的次生孔隙对储层的贡献最大。镜下可以观察到大量的碳酸盐胶结物的溶蚀现象,甚至胶结物全部溶蚀后,表现出颗粒间以点一线接触的中—弱压实假象。通过岩石薄片和扫描

电镜的观察,发现在研究区碎屑岩储层中不缺乏可溶组分,主要有以下3类可溶蚀组分:

(1) 长石碎屑颗粒

含量一般,主要为钾长石、微斜长石和少量酸性斜长石,变化在2%~5%之间,主要沿颗粒解理缝发生溶蚀(图4c)。

(2) 含长石的火山岩屑

含量较高,变化在5%~30%之间,是被溶蚀的主要成分,多形成粒内溶孔(图4d)。

(3) 早期碳酸盐胶结物和生物化石

胶结物含量较高,变化在5%~30%之间,溶蚀较强,其中有孔虫化石发生选择性溶蚀(图4e),可形成体腔孔、铸模孔等(图4f)。

凡是岩屑含量较高的砂岩由于强烈的压实作用,造成许多岩屑被压实变形挤入孔隙之中形成了假杂基,堵塞原始粒间孔,造成原生孔隙保存较少,酸性水难以进入产生溶蚀作用,因而次生孔隙不发育。而成分较纯的石英砂岩其次生孔隙都很发育^[20]。研究区第三系主要储层砂岩成分和结构成熟度都较高。珠江组为石英砂岩和岩屑质石英砂岩,其次为长石质石英砂岩;珠海组为石英砂岩,其次为岩屑质石英砂岩(图5)。因此,研究区的储层非常有利于有机酸的进入形成次生孔隙度。

3.2 活跃的烃源岩

烃源岩是一种富含有机质、水和多种无机矿物的沉积体。Surdam等^[21]认为,有机酸主要生成于烃类开始大量生成之前。但经过后来学者做的实验表明,有机酸的生成过程似乎可以持续到整个烃类生成过程。陈传平等^[22]和曾斌辉等^[23]的实验研究结果表明在300℃条件下,干酪根热解可以大量生成有机酸。Barth等^[24]研究表明,在热解温度范围内最高温度为350℃都有有机酸的产出,且产率随温度的升高而增加。袁佩芳等^[25]对济阳坳陷古近系烃源岩的热解实验结果表明,至450℃都有有机酸的生成。因此在干酪根成熟过程中,一直存在着有机酸的生成,可以伴随整个烃类生成过程。珠江口盆地存在始新统文昌组、始新统一渐新统恩平组、上渐新统珠海组和下中新统珠江组4套烃源岩。文昌组和恩平组为已证实的有效烃源岩。文昌组烃源岩在白云凹陷分布面积达1900 km²,厚度最大达3000 m;恩平组烃源岩在白云凹陷分布面积达2860 km²,厚度最大达2300 m^[26]。并且文昌组已进入成熟、过成熟阶段, R_o 最大达3.0%,恩平组烃源岩进入成熟阶段, R_o 值为1.0%~1.5%^[27]。近期研究成果表

明,白云凹陷钻遇珠海组泥岩 TOC 值大多介于1.10%~1.15%,属于中等烃源岩;珠江组泥岩绝大部分样品 TOC 值小于0.6%,属于差烃源岩。珠江组 R_o 值为0.30%~0.43%,处于未成熟阶段;珠海组 R_o 值为0.43%~0.53%,处于低成熟阶段^[28]。由此可知,研究区主要烃源岩均进入产酸、产油和产气阶段,可以为油气储层溶蚀作用提供大量酸性流体。

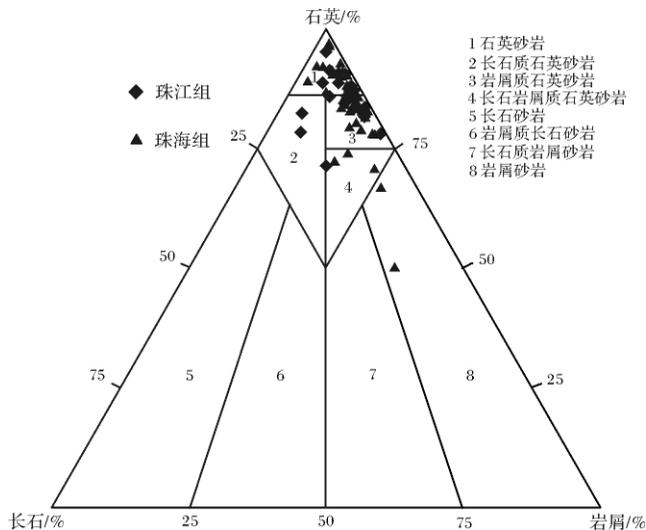


图5 研究区砂岩类型三角图

Fig. 5 Ternary diagram of sandstone types in the study area

前人的研究表明文昌组有机质类型以II型为主,部分为I型;恩平组有机质类型为II型,且以II₂型或偏III型为主^[29]。珠江组和珠海组有机质类型主要为II_B型。由此可知,珠江口盆地4套烃源岩中有机质类型以I和II型为主(图6)。模拟试验结果表明,在干酪根成熟过程中,一直存在着有机酸的生成,可以持续整个烃类生成过程。于酪根的类型对有机酸的产出具有明显的控制作用,III型干酪根烃源岩的生成量都明显地低于I型和II型干酪根^[25]。而研究区4套烃源岩中有机质类型以I和II型为主,因此研究区的烃源岩非常适合产酸,具有很强的产酸能力。

3.3 有利的输导体系

输导体系包括连通砂体、断层、裂隙、不整合面。断层对油气的垂向输导使油气沿断面从下向上垂向运移,并连通不同的砂体输导层,不整合面等进行侧向运移。干酪根成熟过程中,有机酸先期产生量大,但可持续整个生烃过程中,因此有机酸的排出稍早于或者和油气一同排出。一般流体的运移总是沿着先期流体形成的路径运移,油气的运移应是沿着先期有机酸运移的路径运移,因此油气的运移路径可以作为有机酸运

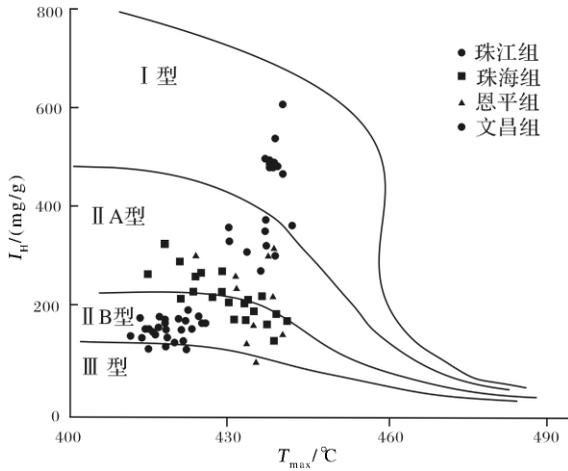


图 6 珠江口盆地烃源岩有机质类型分布 (据朱俊章等 2008 修改)

Fig. 6 The types of organic matter in source rock of Pearl River Mouth basin (modified from Zhu Junzhang, et al, 2008)

移路径的证据。研究区内研究区油气主要输导层为 T5、T4 ~ T3、T3 ~ T2 三个层位。在这些层位中广泛发育有三角洲、滨海砂体、浊积扇和盆底扇等砂体, 这些砂体为有机酸的侧向运移提供了侧向通道。番禺低隆起—白云凹陷北坡广泛发育第三系同沉积反向断层, 断层延伸的距离相对较远, 垂向沟通性好, 构成了白云凹陷主要烃源岩产生的有机酸往番禺低隆起上运移的纵向输导体系^[29, 30]。在番禺低隆起—白云凹陷北坡发育断层和砂体相互配置, 架起了烃源岩与储层之间的桥梁, 使得有机酸源源不断的从下部地层往浅部储集层运移。

流体包裹体是流体活动的直接证据, 它直接记录了流体活动期次、温度范围和压力条件。根据前人对流体包裹体的分析, 番禺低隆起珠江和珠海组砂岩储层中发育两期油、两期天然气充注。第一期和第二期以原油充注为主, 温度范围 89.1 ~ 132.3°C, 大致发生在 12.8 ~ 5.8 Ma; 第三期和第四期以气态烃充注为主, 温度范 129.8 ~ 171.3°C, 大致发生在 5.8 Ma 至今^[31, 32]。在这四次油气充注时白云凹陷北坡和番禺地隆起, 均有断层的活动和砂体的存在(图 7), 有机酸注入储层时具有非常好的匹配关系, 砂体输导层与断层相互切割, 为油气长距离侧向运移提供了输导通道。陈红汉等对各期次有机流体包裹体检测平面分布特征表明, 第一期流体充注是以 SW—NE 一个方向充注; 第二、第三和第四期均为 SW—NE 和 SE—NW 两个方向充注(图 8)。通过从有机流体包裹体的分布, 可知有

机酸进入番禺地隆起后, 沿着古构造脊运动, 沿途溶蚀储层形成次生孔隙发育带。

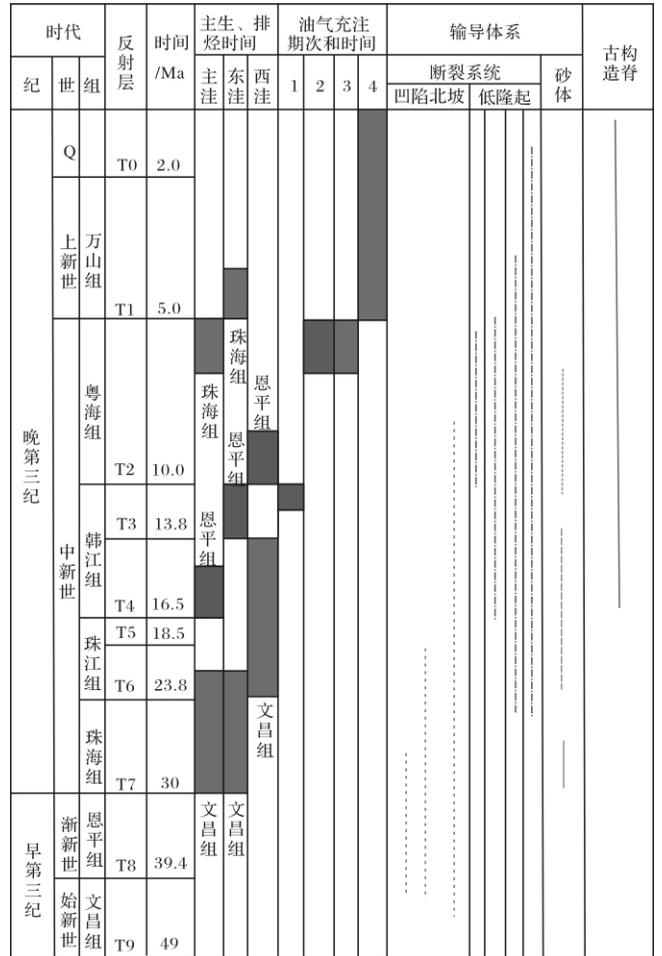


图 7 番禺低隆起—白云凹陷北坡油气演化与输导体系匹配关系(据王斌 2007 修改)

Fig. 7 Oil-gas evolution matching relation with migration system in Panyu low uplift to north slope of Baiyun Sag (modified from Wang Bin, 2007)

4 有机酸形成次生孔隙模式

丰富的可溶物质、活跃的烃源岩、有利的输导体系以及良好的匹配关系是白云凹陷—番禺地隆起形成次生孔隙发育带有利的地质因素。次生孔隙的形成是一个系统的地质过程, 盆地热流、构造演化、沉积作用、成岩作用、流体性质及运移等诸多方面均与次生孔隙度的形成和保存相关。在探讨白云凹陷—番禺地隆起系统形成次生孔隙主控因素基础上, 结合本区各种地质要素, 可以归纳出有机酸形成次生孔隙模式(图 9)。研究区 4 套烃源岩生成有机酸沿断层、砂体和古构造脊形成的输导体系运移至储层进行溶蚀形成次生孔隙

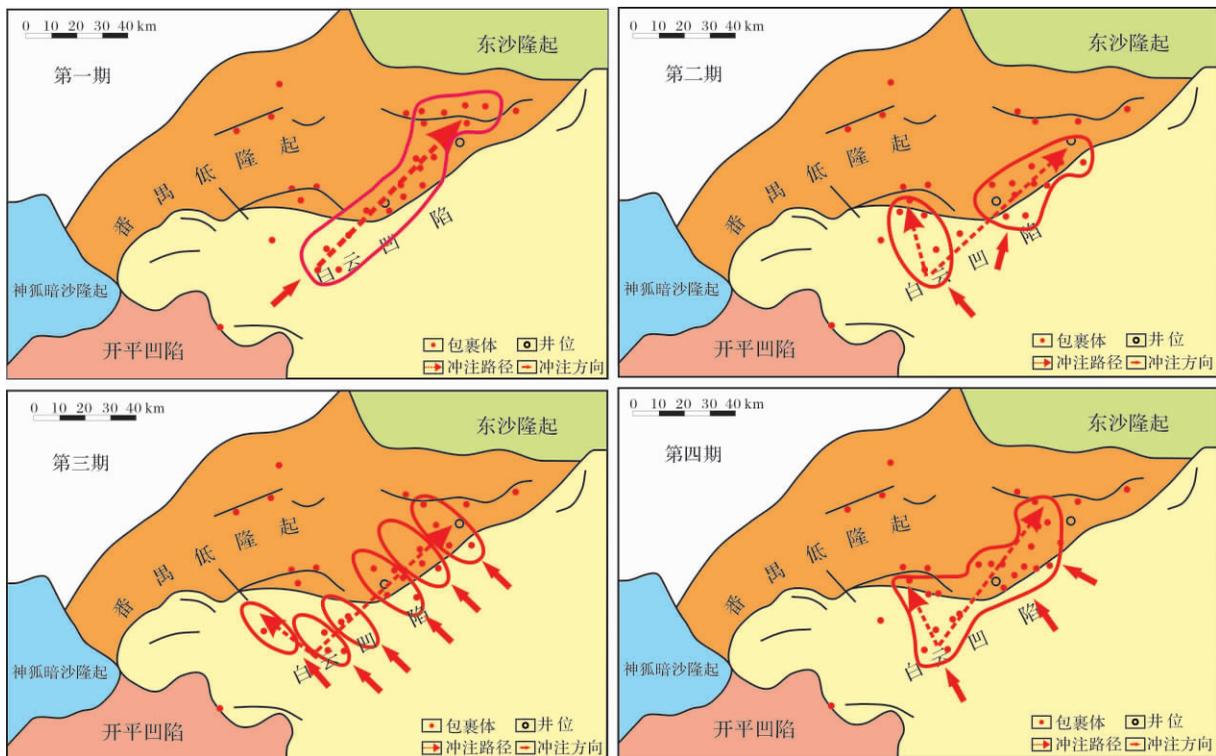


图8 四期有机流体包裹体平面分布特征指示的流体运移方向(据陈红汉等 2004, 修改)

Fig. 8 Planar distribution of fluid inclusion in four times showing the pathway of fluid migration
(modified from Chen Honghan, et al, 2004)

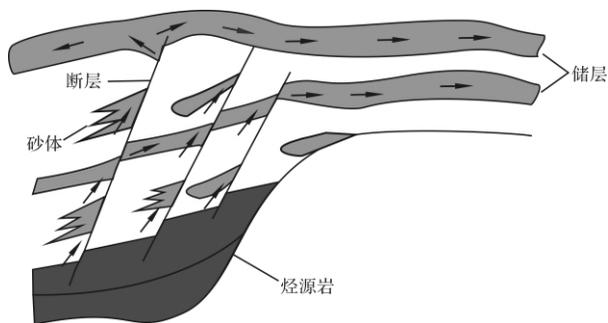


图9 有机酸形成次生孔隙模式

Fig. 9 Forming model of secondary porosity
caused by organic acid

发育带,且在此过程中烃源岩成熟排烃时间与断层形成时间要匹配。只有这样有机酸才有可能从烃源岩中排出进入到溶蚀层。即“生、运、匹、溶”模式。

5 结论

(1) 研究区第三系碎屑岩储层内含有两个次生孔隙发育带即:2 750 ~ 3 500 m 和 4 100 ~ 4 600 m。发育带内含有大量溶蚀孔,以粒间溶孔 + 粒内溶孔 + 粒间孔组合为主。

(2) 研究区碎屑岩储层中砂岩成分和结构成熟度都较高,利于有机酸的进入。且储层中含有大量可溶蚀组分:长石颗粒,含长石的火山岩屑,早期碳酸盐胶结物和生物化石等具备形成次生孔隙的物质基础。白云凹陷4套烃源岩有机质丰度、类型和成熟度特征均有利于连续产酸,为形成大量次生孔隙提供了丰富的酸性流体介质。白云凹陷内的烃源岩产生的酸性流体可沿北斜坡上的由断层和扇三角洲、三角州和浊积扇砂体构成的输导体系从西南向西北运移,进入番禺低隆起后,主要沿构造脊向北东方向运移,并沿途溶蚀储层形成次生孔隙发育带。其有机酸形成次生孔隙模式可概括为“生、运、匹、溶”。

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Forming Mechanism of Secondary Porosity in Tertiary Reservoirs in Panyu Low Uplift and North Slope of Baiyun Sag

HAO Le-wei^{1,2} WANG Qi^{1,2} LIAO Peng^{1,2} TANG Jun^{1,2} ZHANG Gong-cheng³

(1. Key Laboratory of Petroleum Resources Research, Chinese Academy of Sciences, Lanzhou 730000;

2. Graduate University of Chinese Academy of Sciences, Beijing 100049;

3. Research Center, CNOOC, Beijing 100027)

Abstract As the world's deep water oil and gas exploration continue to strengthen, the deep-water basin has increasingly become the new areas to gain growth in oil and gas reserves. The deep-sea oil and gas exploration has developed the inevitable challenges. Therefore, to make related research about the deep exploration and development in particular characteristic of the reservoir is a necessary requirement to find deep water oil and gas and also the direction of ocean exploration. Pearl River Mouth Basin is a major basin in China's offshore oil and gas basins with low level of exploration and the lacking comprehensive research on the variation law and influencing factors of reservoir properties. Deep reservoir with high porosity has been increasingly developed the concern problem with oil exploration performing to deep zone by petroleum geologists. The formation mechanism and controlling factors of the secondary porosity are reasonably explained or not, which directly impacts on the establishment of oil and gas basin clastic reservoir quality prediction model and serious impact on the objective evaluation of the reservoir. In this paper, the constraints of the factors of the secondary porosity in the study area are discussed systemically by isotope geochemistry, organic geochemistry methods combined with sedimentology. The study area contains a large number of grains and grain dissolution pore, according to sandstone sheet, cast thin sections, scanning electron microscopy analysis. Based on reservoir property data, two secondary porosity zones can be found in the Tertiary reservoirs, Baiyun Sag, mainly in the 2 750 ~ 3 800 m and 3 500 ~ 4 600 m. Mineral grains and carbonate cement are dissolved forming large of intergranular dissolution pores and dissolution

pores. By isotope tracing method, it is found that the formation of secondary porosity is caused by the organic acid. Organic maturity and acidic water in which CO_2 is released by decarboxylation of organic matter in the process of diagenesis were the main reason. The feldspar particles, containing feldspar volcanic debris, early carbonate cements and fossils in the reservoir are dissolved by organic acid. The distribution of oxygen and carbon isotope of clastic rocks in the study area is that the value of $\delta^{13}\text{C}$ changes in between -11.8‰ and -3.4‰ and $\delta^{18}\text{O}$ value changes in between -17.8‰ and 2.4‰ . If ^{13}C in carbonate cements is only from the depositional pore water, $\delta^{13}\text{C}$ value can not be so low. So, organic acids from kerogen decarboxylation must join in the process of the formation carbonate cements in the deep burial. Affecting the secondary porosity of the geological factors include the distribution and types of hydrocarbon source rocks, sandbodies distribution in the sedimentary facies and sandstone types, fracture resulting from tectonic activity. In Pearl River Mouth Basin, there are 4 sets of hydrocarbon source rocks including the Eocene Wenchang Formation, the Eocene-oligocene Enping Formation, upper the Oligocene Zhuhai Formation and under the Miocene Zhujiang Formation. As the types of organic matter are mainly I and II in these 4 sets of hydrocarbon source rocks, the research area's hydrocarbon source rocks are suitable to produce the acid and have strong ability to produce the sour fluid. Wenchang source rocks in which the value of R_o is up to 3.0% has been in mature or even over mature. Enping source rocks has entered the mature stage, $R_o = 1.0\%$ to 1.5%. The R_o value of Zhuhai source rocks is 0.43% ~ 0.53%. The main hydrocarbon source rocks enter the stage of producing sour fluid, which can provide the massive acidic fluid for dissolving the oil gas reservoir. The reservoir clastic rocks are mainly the silicarenite and the debris silicarenite which have the high constitute and structure maturity. Therefore, it is advantageous that the organic acid enters the reservoir to form the secondary pores. The development of faults and sandstone layer which act as the bridge between source rocks and reservoir to make a steady stream of organic acids migrating from the lower strata to shallow reservoirs in the Panyu lower uplift - Baiyun Sag North Slope. In addition, secondary porosity is also controlled by the matching hydrocarbon source rock maturity time with migration pathway system which includes faults, sand body and ancient structural ridge. When the organic acids migrate into the study area, there are the active faults and sands which can provide the long-distance lateral migration of oil and gas. Formation of secondary porosity is a systematically geological processes. Its formation and preservation are relevant to many aspects such as basin heat flow, tectonic evolution, sedimentation, diagenesis, fluid nature, and fluid migration and so on. After comprehensively analyzing various geological factors, the model which describes the organic acids forming secondary porosity can be summed up as "production, transportation, matching, and dissolution." Only the geological factors matching with each other can the secondary porosity be produced. These cognitions have good guidance for predicting high-quality reservoir in the studied area.

Key words Baiyun Sag; secondary pores; organic acid; inclusion; migration pathway system; high-quality reservoir