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渝东北城口地区 Y1 井页岩有机地球化学特征及勘探前景

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摘要: 基于钻井资料,以总有机碳(TOC)、干酪根显微组分、等效镜质体反射率(R_o)及碳同位素等测试数据系统分析了渝东北城口地区 Y1 井五峰组—龙马溪组页岩的有机地球化学特征,利用页岩流体包裹体的显微特征、均一温度及激光拉曼数据深入分析了 Y1 井页岩气成藏特征。结果表明:Y1 井上奥陶统五峰组—下志留统龙马溪组炭质页岩发育,TOC 含量 $>2\%$ 的富含有机质页岩厚度达 83 m,干酪根类型以 I 型干酪根为主,处于湿气生烃阶段。页岩裂缝脉体中大量烃包裹体和富含甲烷气体的含烃盐水包裹体证实城口地区五峰组—龙马溪组页岩发生了充足页岩气供给,具有高均一温度、高盐度的伴生盐水包裹体表明城口地区页岩气成藏时期的保存条件良好。这些 Y1 井页岩有机地球化学特征研究成果揭示了城口地区下古生界具备良好的页岩气勘探前景。

关键词: 城口地区; 五峰组—龙马溪组; 流体包裹体; 有机地球化学特征; 页岩气勘探前景

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渝东北地区位于四川盆地东北缘大巴山冲断带内,受多期构造活动改造,褶皱和断裂极为发育,地层倾角大,地质构造复杂^[1-2]。目前,经过大量油气勘探,渝东北区页岩气勘探取得一定成果,区内部分探井已经获得页岩气显示,如巫溪 2 井(中石油部署的资料井)五峰组—龙马溪组页岩现场解吸含气量 $2\sim3\text{ m}^3/\text{t}^{[3]}$,CT1 井(国投重庆页岩气公司部署的探井)下寒武统水井沱组页岩现场解吸含气量 $2.2\sim3.3\text{ m}^3/\text{t}^{[4]}$ 。当前关于渝东北区页岩气的研究成果主要为页岩气区构造演化与保存条件^[1-2,5]、页岩地球化学特征^[6-7]、页岩储层特征^[8-11]、页岩气成藏条件与成藏模式^[3,12-16]及页岩气资源评价^[7,12]等,主要从页岩有机地球化学特征、页岩储层及区域构造特征剖析页岩气成藏,而关于页岩气成藏时页岩储层内部的地球化学特征、成藏温度及成藏流体成分研究甚少。

流体包裹体在油气成藏研究中应用广泛,较精细地刻画了油气成藏时间、成藏温度、成藏流体等成藏信息^[17-18],但在页岩气成藏中研究甚少。实际勘探研究表明,页岩储层的裂缝通常被方解石、重晶石、石英等充填物充填,形成裂缝充填脉体。此类裂缝充填物形成过程中通常会捕获地质流体形成流体包裹体,是记录页岩地质演化重要的地质产物。欧光习(2014)^[19]、高键等(2015)^[20]、尚长健等(2016)^[21]、李双建等(2016)^[22]、张敏等(2017)^[23]通过页岩中的流体包裹体剖析页岩气成藏时地温、压力及成藏流体成分,为页岩气成藏深入开辟了新的研究途径。本文以渝东北城口地区 Y1 井为研究对象,通过系统采样,进行了大量的页岩有机地球化学测试,其中包括总有机碳(TOC)、干酪根显微组分、碳同位素、等效镜质体反射率(R_o)测试等,并引

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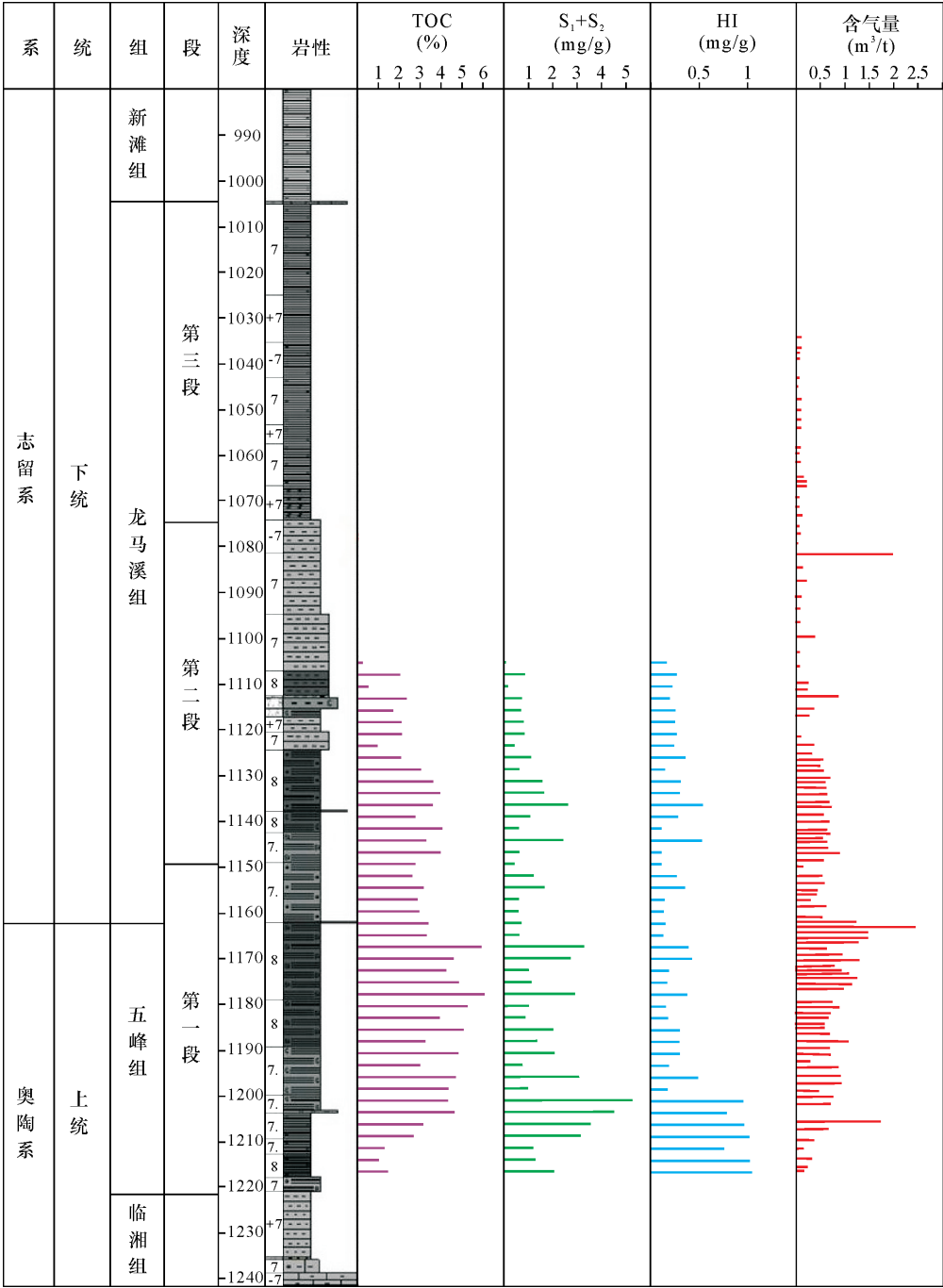


图 2 Y1 井五峰组—龙马溪组页岩段有机地球化学剖面

Fig.2 The organic geochemical profiles of shale of Well Y1 in Chengkou area

5% 之间,占样品总数的 48%;TOC 含量 >5% 的样品占 9%。整体上五峰组黑色页岩样品的 TOC 含量较龙马溪组稍高,五峰组的 TOC 含量平均为 3.75%,龙马溪组为 2.66%。参考焦石坝页岩气区、渝东北巫溪 2 井等志留系页岩气富集区地球化学特征,城口区五峰组—龙马溪组炭质页岩富含有机质,TOC 含量 >2% 的富含有机质页岩累积厚度可达 83 m,具有良好的供烃基础。

2.3 页岩干酪根显微组分特征

干酪根镜测试结果表明,干酪根显微组分主要为腐泥无定形组(图 3),其含量为 89% ~ 92%,类镜质组含量为 8% ~ 11%,干酪根类型指数 TI 分布于 80 ~ 83 之间,指示五峰组—龙马溪组炭质页岩为 I 型干酪根。干酪根的 $\delta^{13}C$ 值在 -26.9‰ ~ -31.1‰ 之间,平均值为 -29.7‰,具有腐泥型干酪根特征。

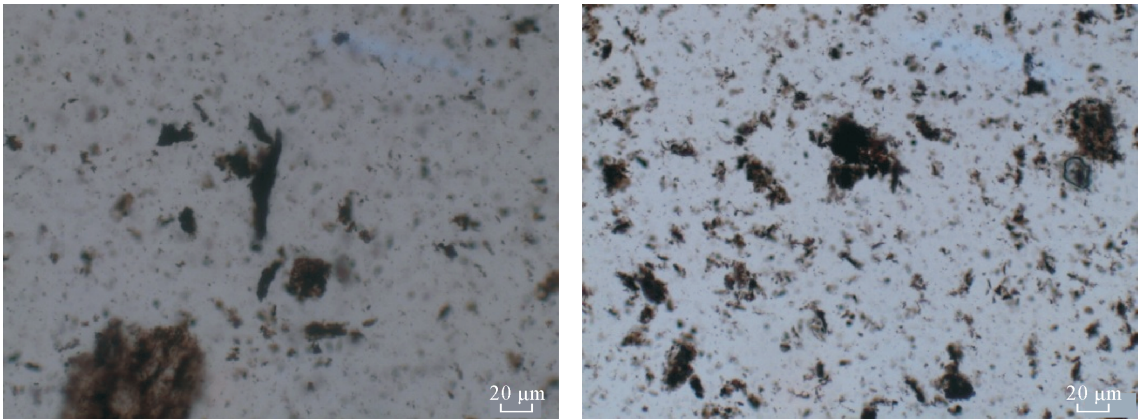


图3 Y1井五峰组—龙马溪组炭质页岩干酪根显微组分
Fig.3 The Kerogen macerals of shale in Well Y1

2.4 页岩等效镜质体反射率及碳同位素特征

基于样品的全岩沥青随机反射率数值,据 Jacob (1989)^[24]提出的 $R_o = 0.618R_b + 0.4$ 干酪根热演化成熟度换算公式,Y1井五峰组—龙马溪组炭质页岩的 R_o 值在 1.31% ~ 1.47% 之间,平均 1.40%,处于高成熟阶段。根据现场采集的 3 个页岩气样品的碳同位素显示,甲烷、乙烷、丙烷的碳同位素值分布正常,未发生倒转现象(图 4),表明 Y1 井区五峰组—龙马溪组炭质页岩进入高成熟度阶段早期,未形成大量原油裂解气,与成熟度 R_o 相符合,仍具有一定生烃潜力。

2.5 Y1 井页岩与国内外相关区域页岩主要地质特点的比较

与北美页岩气田对比(表 1),Y1 井五峰组—龙马溪组页岩的有机质丰度比 Barnett 及 Lewis 页岩^[25-26]高,有机质成熟度相近,均处于成熟阶段。但与渝东地区其他页岩气井如焦页 1 井^[26-28]、巫溪 2 井^[3,16]相比(表 1),除了热成熟度较低外,页岩的脆性矿物含量、有机碳、物性等特征均相近,类比表明渝东北城口地区五峰组—龙马溪组页岩气具备良好的页岩气成藏条件。Y1 井的现场页岩解吸气含量相比巫溪 2 井、焦页 1 井低,可能受地质因素和钻测井及试气等技术综合影响。

表 1 Y1 井及国内外页岩主要地质特点对比

Table 1 A comparison of main geological parameters of shale containing natural gas in Well Y1 of China and USA

盆地/井	页岩名称	厚度(%)	TOC(%)	R_o (%)	脆性矿物含量(%)	孔隙度(%)	含气量(%)
福特沃斯	Barnett	61~91	1.0~4.5	1.0~1.4	35~50	4.0~6.0/5	8.50~9.91
圣胡安	Lewis	152~579	0.45~2.5	1.6~1.88	50~75	3.0~55.0	0.3~1.3
焦页 1	五峰组—龙马溪组	35~45	3.5	2.2~3.06	50.9~80.3	1.17~7.98	0.89~5.19
巫溪 2 井	五峰组—龙马溪组	89.8	2.52	2.28~2.76	34.9~71.9	—	0.17~8.39
Y1 井	五峰组—龙马溪组	83	2.0~5.0	1.31~1.47	11.0~62.4	0.88~2.60	0.028~2.414

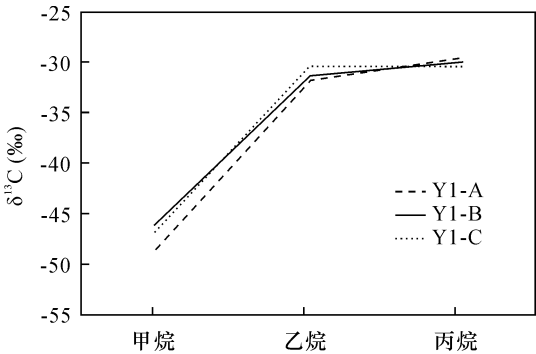


图4 Y1井五峰组—龙马溪组页岩气烷烃碳同位素分布特征
Fig.4 The characteristics of carbon isotope distribution in alkane of shale gas of Well Y1

3 Y1 井页岩气成藏流体证据

3.1 流体包裹体显微特征

Y1 井钻遇页岩气为上奥陶统五峰组一下志留统龙马溪组炭质页岩,该井采集 8 块岩心样品,岩性主要为炭质页岩,少部分含有硅质。岩心样品观察表明,Y1 井页岩裂缝较为发育,多数为高角度裂缝,部分裂缝被重晶石、方解石及少量石英等胶结物充填,形成裂缝充填脉体(图 5)。Y1 井五峰组—龙马溪组页岩的裂缝充填脉体中发育大量的烃类流体包裹体,呈群体定向分布、串珠状分布(图 6)。

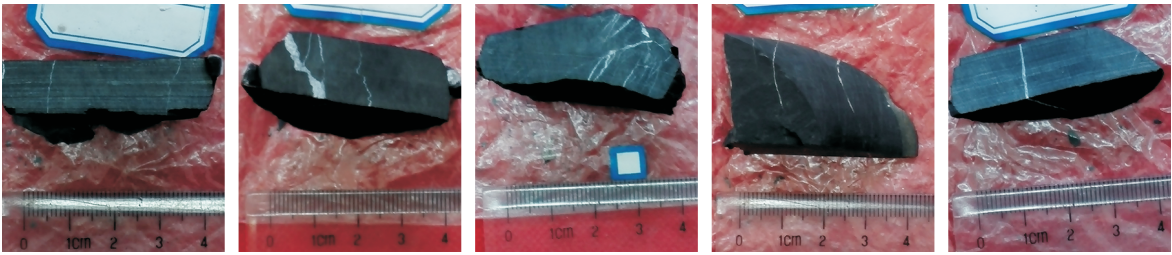


图 5 Y1 井页岩样品及脉体发育特征
Fig.5 The crack of shale filled by veins in Well Y1

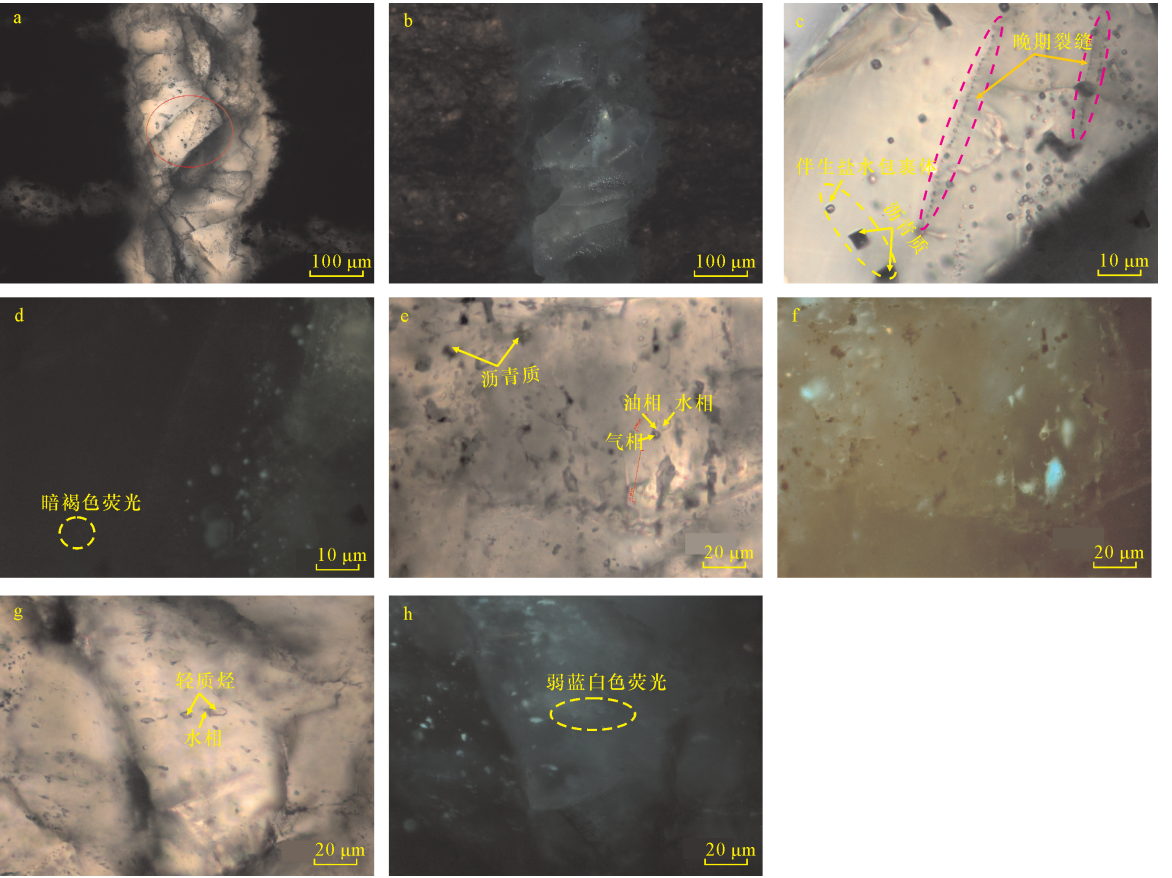


图 6 Y1 井五峰组—龙马溪组页岩流体包裹体显微特征
Fig.6 The microscopic characteristics of fluid inclusions in shale, Upper Ordovician Wufeng Formation—Lower Silurian Longmaxi Formation of Well Y1

根据本次 8 块样品的薄片镜下观察数据表明,重晶石和方解石中的流体包裹体十分发育,包裹体类型主要为气液相盐水包裹体(图 6c)、气液相含烃盐水包裹体(图 6e)、气液相烃包裹体(图 6e)、液相盐水-烃包裹体(图 6g)、纯液相烃包裹体(图 6c)及沥青包裹体(图 6e),总体上以烃类包裹体为主。液相烃包裹体多呈圆形、四边形,较大的烃包裹体多数为不规则;气液相盐水包裹体发育较少,多呈椭圆形、圆矩形。包裹体大小分布范围为 3 ~ 25 μm,液相烃包裹体大小以 3 ~ 8 μm 为主,共生气液相盐水

包裹体约 3 μm(图 6c)。包裹体内的气液比值多数为 10% ~ 20%(图 6c,e,g)。绝大多数气液相烃包裹体、液相烃包裹体均能够发荧光,主要为黄绿色、蓝白色,其荧光颜色反映出热成熟度与五峰组—龙马溪组页岩的成熟度相当。

根据流体包裹体发育特征及荧光特征,认为 Y1 井存在三期烃类流体包裹体。第一期,流体包裹体主要为含重质油的烃包裹体,发育在方解石的晶面上(图 6c),数量较少,发暗褐色荧光(图 6d),应属于生烃早期的大分子烃类充注形成。第二期,主要

为矿物的解理缝和愈合缝中呈带状、串珠状等定向分布群生烃类包裹体,个体较大,单偏光下多为透明状(图6c,e),荧光颜色主要为黄绿色(图6d,f),应属于“液态窗”阶段(成熟阶段)大量液态烃运移捕获而成。第三期,主要为透明状轻质烃包裹体(图6g),轻质烃部分能够发弱蓝白色荧光,应属于湿气阶段轻质烃运聚形成。

3.2 流体包裹体均一温度与成分特征

由于本区页岩裂缝脉体中盐水包裹体个体小、数量少,能够用于测温的伴生盐水包裹体较少。根据测试数据(图7)显示,伴生盐水包裹体的均一温度为140~180℃,含烃盐水包裹体的均一温度为103~109℃,烃包裹体均一温度相比伴生盐水包裹体均一温度低。盐水包裹体冰点值一般在-6.2~-10℃,盐度为9.47%~14.57%,表明流体包裹体捕获时本区油气运移聚集过程处于埋藏较深及保存条件好的状态。

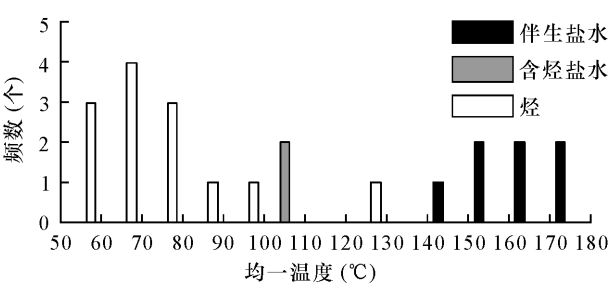


图7 Y1井五峰组—龙马溪组页岩流体包裹体均一温度分布特征

Fig. 7 The characteristics of homogenization temperature distribution of fluid inclusions of shale in Well Y1

根据含硅质页岩中流体包裹体的激光拉曼测试数据显示,石英胶结物捕获的流体包裹体中,烃类成分有沥青质和甲烷气体(图8)。由此表明,渝东北区Y1井中五峰组—龙马溪组页岩曾产生一定数量的天然气。结合流体包裹体显微特征,Y1井区五峰组—龙马溪组炭质页岩达到湿气阶段早期,但未出现大规模原油裂解气,与成熟度 R_o 值相符合。

4 结论

Y1井勘探研究证实,渝东北城口地区五峰组—龙马溪组发育富含有机质页岩。干酪根镜检、等效镜质体反射率(R_o)等地球化学参数表明,Y1井区五峰组—龙马溪组页岩生烃演化处于高成熟阶段早期,具有良好的页岩气成藏条件。流体包裹体显微特征证实,城口地区五峰组—龙马溪组页岩存在三期烃类流体包裹体,在地质历史时期曾发生大规模生烃。晚期的轻质烃包裹体和激光拉曼测试数据表明渝东北城口区五峰组—龙马溪组发生了页岩气供烃,页岩气成藏温度为150~170℃,处于深埋藏和连续烃类充注过程。Y1井富含有机质页岩段的现场解吸气气量低并非是页岩本身性质导致的,具体原因有待深入研究。

研究表明,城口地区下古生界五峰组—龙马溪组具有良好的页岩气勘探潜力,尤其是在盖层发育较厚、断层发育较少且页岩热演化成熟度达到湿气阶段生气高峰期的区域,如城口东南部地区,开展勘探工作更为有利。

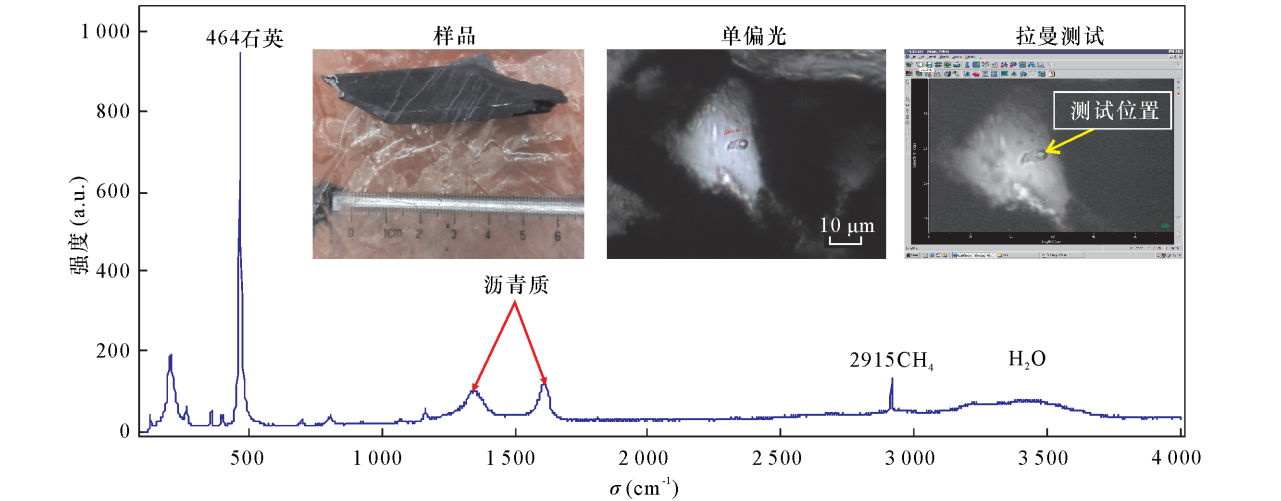


图8 Y1井页岩流体包裹体分布特征与激光拉曼谱图特征

Fig. 8 Distribution characteristics and laser Raman spectra of fluid inclusions of shale in Well Y1

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Organic Geochemical Characteristics of the Shale from Y1 Well in Chengkou Area of Northeastern Chongqing and Exploration Prospects

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Highlights

- The fluid inclusion was introduced to study the organic geochemical characteristics of shale formations of Y1 Well.
- On the basis of the fluid inclusion characteristics, it is confirmed that large-scale hydrocarbon generation has occurred in shale beneath the region where Y1 Well is located.
- The comprehensive analysis demonstrates that the Lower Paleozoic Formation in the Chengkou area possesses great exploration potential for shale gas.

Abstract: A study has been conducted based on the drilling data and geochemical data from the Y1 Well in Chengkou of Northeastern Chongqing, including total organic carbon (TOC), kerogen microcomponent, equivalent vitrinite reflectance (R_o) and carbon isotope composition, which are the organic geochemistry characteristics of Wufeng—Longmaxi Formation shale. The characteristics of shale gas accumulation were determined by analyzing the microstructure, homogenization temperature and laser Raman data of fluid inclusions in the shale. Results show that carbonaceous shale is well developed in Upper Ordovician Wufeng Formation and Lower Silurian Longmaxi Formation in the Y1 Well. Organic-rich shale (TOC > 2%) has a thickness up to 83 m. The kerogen type of the samples is mainly Type I, belonging to the moisture hydrocarbon generation stage. Numerous hydrocarbon inclusions and hydrocarbon-rich brine inclusions with methane gas in the fractured veins of shale indicate that the shale of Wufeng Formation—Longmaxi Formation in the Chengkou area has been supplied with sufficient shale gas. The associated brine inclusions with high homogenization temperature and high salinity indicate good preservation conditions during the shale gas accumulation period in the Chengkou area. The exploration results of the Y1 Well reveal good exploration prospects for shale gas in the lower Paleozoic strata in the Chengkou area.

Key words: Chengkou area; Wufeng—Longmaxi Formation; fluid inclusions; organic geochemistry characteristics; exploration prospects of shale gas