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# 鄂尔多斯盆地彭阳地区洛河组砂岩褪色蚀变特征及对铀成矿流体的指示作用

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**提要:【研究目的】**红层含铀岩系褪色蚀变与还原蚀变作用密切相关, 褪色蚀变特征及其成因流体分析对深入认识铀成矿流体和成矿机理具有重要意义。**【研究方法】**基于彭阳地区洛河组砂岩褪色蚀变现象及其与铀异常的密切关系, 通过岩心编录、元素地球化学测试、高分辨率电镜扫描、电子探针分析、岩心 XRF 荧光及红外光谱扫描等手段, 开展洛河组砂岩沉积特征和褪色蚀变特征分析。**【研究结果】**洛河组不同颜色砂岩碎屑含量高, 且成分以石英为主, 具有典型沙漠相与风成沉积特点; 洛河组典型褪色蚀变砂岩一般具有铀矿物、黄铁矿及石膏富集而三价铁氧化物含量低的特点, 且铀与硫元素含量明显较高。**【结论】**洛河组砂岩主体形成于氧化条件的风成沉积, 其颜色、$Fe_2O_3$/FeO、Th/U 及 Cu/Zn 反映了随砂岩褪色程度增强, 环境发生了由氧化向还原状态的转变; 洛河组褪色蚀变与铀矿成矿作用在空间、矿物组合及氧化还原状态的一致性暗示了二者成因与同一还原性流体有关。

**关　键　词:** 砂岩型铀矿; 褪色蚀变; 矿产勘查工程; 洛河组; 彭阳地区; 鄂尔多斯盆地

**创　新　点:** 利用多手段刻画了彭阳地区洛河组砂岩褪色蚀变与铀成矿作用在空间和矿物学上在多尺度的匹配关系, 对比了不同褪色程度砂岩的氧化还原指标, 判断褪色蚀变及铀成矿作用受同一还原性流体改造, 对建立识别铀成矿流体标志具有创新意义。

**中图分类号:** P619.14　**文献标志码:** A　**文章编号:** 1000−3657(2024)05−1455−14

# Alteration characteristics and implication to uranium metallogenetic fluids of faded sandstones in Luohe Formation, Pengyang area, Ordos Basin

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**Abstract:** This paper is the result of mineral exploration engineering.

**[Objective]** The faded alteration of uranium−bearing rock series in the redbed is closely related to reductive alteration, and the analysis of the characteristics of faded alteration and its genetic fluid is of great significance for understanding the uranium ore−forming fluids and ore−forming mechanism. **[Methods]** This study is based on analyzing the sedimentary characteristics and faded alteration characteristics of sandstones in Luohe Formation by means of core logging, element geochemical test, electron microscope scanning, electron probe analysis, XRF scanning and core infrared spectrum scanning. **[Results]** The sandstones in the Luohe Formation are basically formed in aeolian sedimentary with oxidation conditions mineral assemblages enriched in uranium minerals, pyrite and gypsum but little trivalent iron oxides, and uranium and sulfur elements show obvious migration. Then, the redox state of sandstone and the correlation between uranium mineralization and faded alteration were discussed. **[Conclusions]** The main body of Luohe Formation sandstone was formed in aeolian deposits under oxidation conditions, and its color, $Fe_2O_3$/FeO, Th/U and Cu/Zn reflect that the environment has been changed from oxidation to reduction with the increase of sandstone faded degree. The characteristics of the consistency between faded alteration and uranium mineralization in Luohe Formation in space, mineral association and redox state suggest that their genesis is related to the same reducing fluid.

**Key words:** sandstone type uranium deposit; faded alteration; mineral exploration engineering; Luohe Formation; Pengyang area; Ordos Basin

**Highlights:** The multi−scale matching relationship between the faded alteration and uranium mineralization of the Luohe Formation sandstone in the Pengyang area was described by using multiple methods, and the redox indexes of the sandstones with different fading degrees were compared. The genesis of uranium mineralization and faded alteration is mainly reformed by reducing fluid by the same reducing fluid. This realization has an indicative effect on the fluid which has innovative significance for establishing and identifying metallogenic fluids of uranium.

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## 1 引 言

砂岩型铀矿除了在常见的灰色地层中分布(Jin et al., 2020; Yu et al., 2021; 金若时和滕雪明, 2022; 文思博等, 2023),在红层中也逐渐被发现(秦明宽和赵瑞全, 2000; 刘德长等, 2011; 方维萱等, 2017; 苗培森等, 2020; Miao et al., 2020; 刘正义等, 2021)。红层中铀成矿流体研究也逐渐成为热点研究领域,针对含铀岩系褪色蚀变砂岩的铀成矿流体研究(Nameroff et al., 2004; 田时丰, 2005; Penney, 2012; Samolczyk et al., 2012; 吴柏林等, 2015; Owen et al., 2016; 方维萱等, 2017; Song et al., 2019; 司庆红等, 2020)对于完善铀成矿理论和指导找矿具有重要意义。前人从岩石中沿微裂隙褪色和强烈铁染的蚀变现象和地球化学角度对塔里木盆地中紫红色铁质碎屑岩类的褪色化−变色化蚀变作用(方维萱等, 2017)、巴什布拉克铀矿床铀矿化特征及成矿机理(刘正义等, 2021)等红层褪色蚀变砂岩开展大量研究,发现红层中沥青、油气等还原性蚀变作用将大量 $Fe^{3+}$还原为 $Fe^{2+}$,同时对铀矿床的形成也具有重要作用,并认识到褪色蚀变岩石的矿物组合及元素组成特征对识别红层铀成矿相关流体至关重要。

近年来,学者对鄂尔多斯盆地西南部彭阳地区洛河组的沉积环境(乔大伟等, 2020; 张天福等, 2020)、蚀变矿物(朱强等, 2019, 2022; Si et al., 2021)及铀矿化特征(胡妍等, 2020; 赵华雷等, 2020; Zhao et al., 2021)开展了一系列研究并取得了重要进展。然而,目前对洛河组砂岩蚀变特征的研究还有不足,尤其褪色蚀变特征的研究还很薄弱,这在很大程度上限制了对褪色蚀变砂岩氧化还原状态、铀矿化相关流体及流体蚀变作用的深入认识,进而影响研究区洛河组流体蚀变规律和铀成矿机理的进一步研究。本文以彭阳地区洛河组砂岩为研究对象,运用岩石学、矿物学与元素地球化学相结合的方法,开展洛河组砂岩原生沉积条件和褪色蚀变特征的研究,在此基础上分析褪色蚀变氧化还原状态,并针对褪色蚀变对铀矿化相关流体的指示意义和流体蚀变作用进行探讨,以加深对洛河组砂岩褪色蚀变规律及铀成矿机理的认识。

## 2 地质概况

彭阳地区构造位置处于鄂尔多斯盆地天环坳陷(图 1a),西临六盘山,东侧毗邻长庆油田,西部断裂较发育。自盆地形成以来,彭阳地区自下而上主要沉积了三叠系、侏罗系、白垩系、新近系和第四系,其中主要含铀岩系洛河组为风成沉积的红色地

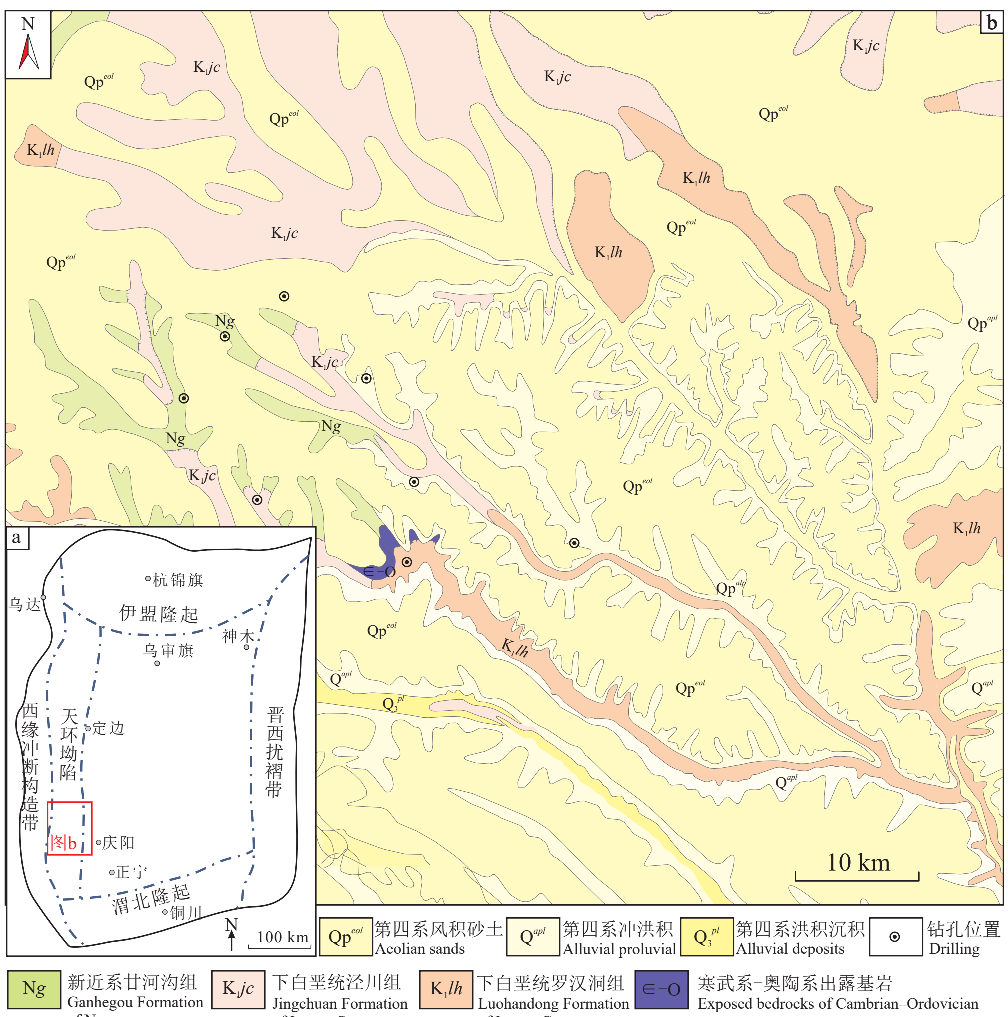


图 1 鄂尔多斯盆地西南部彭阳地区构造纲要图

a—彭阳地区构造位置图; b—采样钻孔位置及研究区地质图

Fig.1 Structure outline map of Pengyang area, Southwestern Ordos Basin

a–Structural location diagram of Pengyang area; b–Sampling borehole location and geological map of study area

层(乔大伟等, 2020)。洛河组厚度 100~380 m,发育大型高角度交错层理、平行层理以及波状层理,下部岩性以黄色、灰色粗—中砂岩为主,上部发育多套红色砂砾岩沉积(图 2)。铀矿(化)层段多位于洛河组下段,具有明显褪色特征(Miao et al., 2020; Si et al., 2021)。

## 3　实验与研究方法

本次研究在鄂尔多斯盆地西南部彭阳地区采集 Z1、Z2、Z3 和 Z4 共 4 个钻孔(位置见图 1b)的 51 件不同颜色的洛河组砂岩样品(包括 19 件黄色—红色样品和 32 件灰色—灰白色样品)进行主量元素 X 衍射荧光光谱分析。主量元素测试结果主要用以判断洛河组原生砂岩类型。

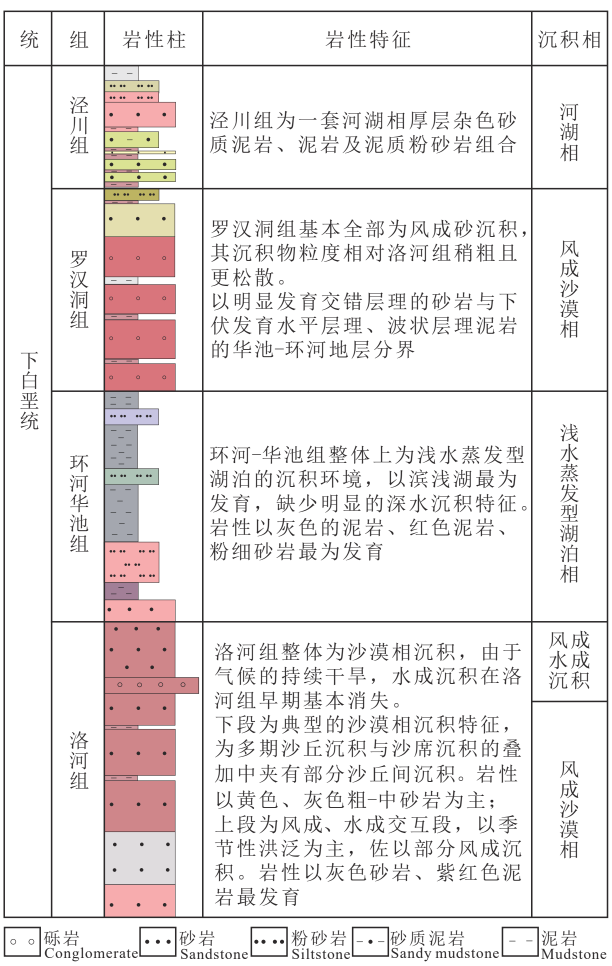


图 2　鄂尔多斯盆地西南部彭阳地区地层综合柱状图(据乔大伟, 2020 修改)

Fig.2　Comprehensive histogram of stratigraphic structure in Pengyang area, Southwestern Ordos Basin (modified from Qiao Dawei et al., 2020)

在对洛河组砂岩原生条件认识的基础上,选择典型钻孔 D1 孔开展洛河组褪色蚀变观察与分类,并采集褪色蚀变程度高的砂岩样品进行电镜扫描与电子探针分析,并利用手持荧光光谱仪对洛河组中褪色蚀变砂岩段进行元素扫描工作。

## 4　洛河组砂岩原生条件

沙漠相是早白垩世鄂尔多斯盆地中最具特色的沉积相类型,沙丘砂岩干净而无杂质,石英、长石含量较高,含较少云母片和黏土矿物;沉积构造以交错层理、平行层理、小型轻度翘曲、倒转褶曲等多类型层理和准同生变形构造发育为特征,其中交错层理是白垩系洛河组和罗汉洞组沙丘最典型的沉积构造(张忠义, 2005; 谢渊等, 2005; 杨友运, 2006; 朱欣然等, 2018)。彭阳地区洛河组砂岩以红色—浅红色及黄色—绿灰色砂岩为主,呈厚—巨厚层状,以细—中粒结构为主,并发育高角度砂波层理(图 3a、b、c)。洛河组砂岩碎屑含量占 70%~95% 以上,分选中等—好,磨圆度为次圆—圆状。碎屑物主要成分为石英、长石、岩屑(图 3d);填隙物的主要成分为钙质和铁质,钙质为方解石微晶,主要呈孔隙式胶结(胡妍等, 2020),且石英颗粒表面以常见碟形坑、新月形风蚀坑(图 3e)及毛玻璃化等机械成因结构(乔大伟等, 2020; 张天福等, 2020)。此外,彭阳地区洛河组视电阻率、密度、自然电位等测井曲线一般呈低幅度、平直光滑的箱状形态,代表了沙丘沉积的特性(张天福等, 2020)。

从彭阳地区洛河组砂岩主量元素含量和 $Al_2O_3$–$SiO_2$ 图解(刘晓雪等, 2016)可以看出,洛河组不同颜色砂岩的矿物成分主要以石英为主(图 4a、b)。这与前人总结出的鄂尔多斯盆地西南部沙漠相特征是相符的。

为了进一步确定洛河组褪色砂岩是否保留了原生沉积的特点,本次以岩石成分变异系数(ICW)为指标评价不同颜色砂岩遭受化学风化作用的程度及差别(式 1)。成分变异系数(ICW)常用于估计碎屑岩的原始成分变化程度,判断碎屑岩是代表第一次沉积的沉积物还是源于再循环的沉积物或沉积物经历强烈风化作用(Harnois, 1988; 张学敏和岳琼申, 2018)。

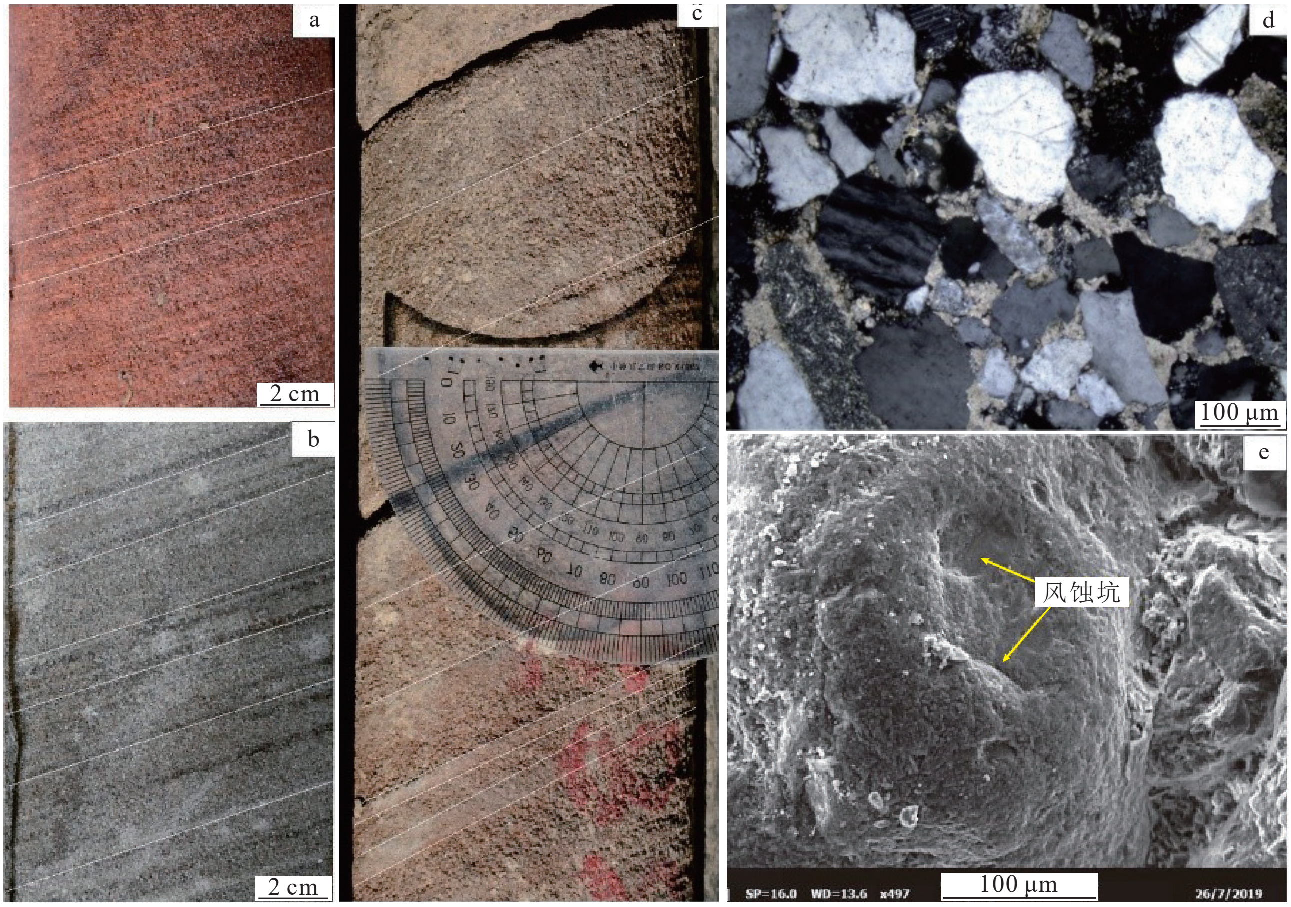


图 3 洛河组岩石沉积特征(据张天福等, 2020 修改)

a—红色砂岩中砂波层理; b—灰色砂岩中砂波层理; c—黄色—浅红色砂岩中砂波层理; d—砂岩中矿物颗粒的接触关系; e—电镜下石英颗粒风蚀坑

Fig.3 Characteristics of rock sedimentary in Luohe Formation (modified from Zhang Tianfu et al., 2020)

a–Sand wave bedding in red sandstone; b–Sand wave bedding in gray sandstone; c–Sand wave bedding in yellow–light red sandstone; d–Contact relationship of mineral particles in sandstone; e–Quartz particles wind erosion pit under electron microscope

$$ICW=(Fe_2O_3+Na_2O+K_2O+CaO+MgO+MnO+TiO_2)/Al_2O_3 \quad (1)$$

成分变异系数 ICW 值大于 1, 表明它们含有很少的黏土矿物, 反映样品在活动的构造带首次沉积; 若样品含大量黏土矿物则 ICW 值小于 1, 表明沉积物质经历了再循环或是经历了强烈的化学风化作用。研究区洛河组 51 件砂岩样品 ICW 总体在 0.90~3.06, 平均为 1.49。其中, 32 件灰色—灰白色砂岩样品 ICW 介于 0.90~3.06, 平均为 1.54; 19 件黄色—红色砂岩样品 ICW 介于 0.96~2.48, 平均为 1.41。ICW 小于 1 的样品共有 2 件(灰色砂岩和浅红色砂岩各 1 件), 其余均大于 1。反映洛河组砂岩遭受化学风化程度不大, 且不同颜色砂岩的化学风化程度差别也不明显, 也说明洛河组不同颜色砂岩均主要为风成沉积的产物。

彭阳地区洛河组砂岩主要形成于白垩纪时期的风成沉积环境, 而白垩纪地质历史中表现出的是一种极端的温室气候, 在大洋中表现出红层沉积富氧作用和黑色页岩沉积的缺氧事件(王成善和胡修棉, 2005; 张振国等, 2017), 而呈氧化态的赤矿物是红层的主要致色矿物(张振国等, 2013; 姜莲婷等, 2019), 红色应是洛河组砂岩在原生氧化条件下沉积的颜色。

## 5 洛河组砂岩褪色蚀变特征

### 5.1 褪色蚀变程度与类型

本次研究根据保留原生色调的程度, 将砂岩分为呈浅红—黄色的低褪色程度蚀变砂岩和呈灰

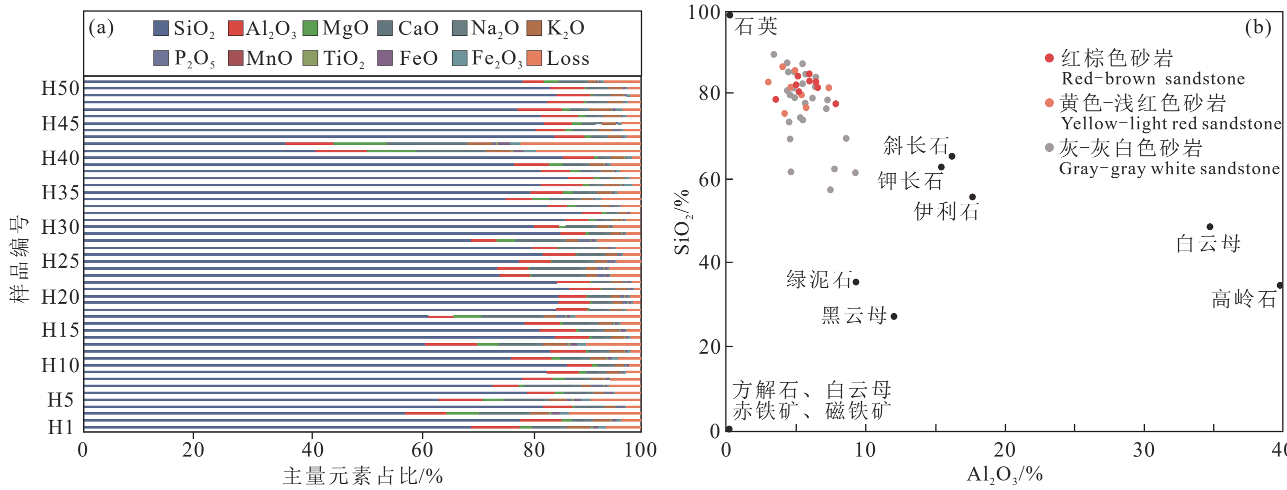


图 4 洛河组砂岩主量元素分布特征图

a—砂岩样品主量元素含量条形图; b—不同颜色砂岩样品的 $Al_2O_3$–$SiO_2$ 矿物图解

Fig.4 Distribution characteristics of major elements of sandstones in the Luohe Formation

a–Bar diagram of major element contents in sandstone samples; b–Schematic diagram of $Al_2O_3$–$SiO_2$ of sandstone samples in different color

白—灰色的高褪色程度蚀变砂岩。通过岩心编录与蚀变观察，发现不同褪色蚀变程度的砂岩颜色呈现不同颜色，砂岩颜色序列随着褪色程度由低至高大致表现为红棕色、浅红色、浅黄色、黄绿色、灰绿色及灰色。

根据褪色蚀变产状和其他蚀变伴生特点，大致将褪色蚀变类型划分为 5 种类型：含有机浸染的褪色蚀变、顺层的条带状褪色蚀变、伴有黄铁矿化的褪色蚀变、不规则斑状褪色蚀变及垂向脉状褪色蚀变(图 5)。

## 5.2 褪色蚀变带矿物组合特征

通过扫描电子显微镜观察与电子探针分析，发现洛河组褪色砂岩具有较多的铀矿物、磷灰石、黄铁矿及方解石、少量蒙脱石黏土矿物及绿泥石(图 6)，铀矿物多与黄铁矿呈星点状或团块状共生(图 6d、e、f)。

在此认识的基础上，针对 D1 孔洛河组蚀变带进行岩性组合、电阻率、放射性异常及红外光谱特征的综合对比(图 7)，发现洛河组褪色蚀变带(尤其是典型褪色砂岩段)的砂岩褪色蚀变程度与电阻

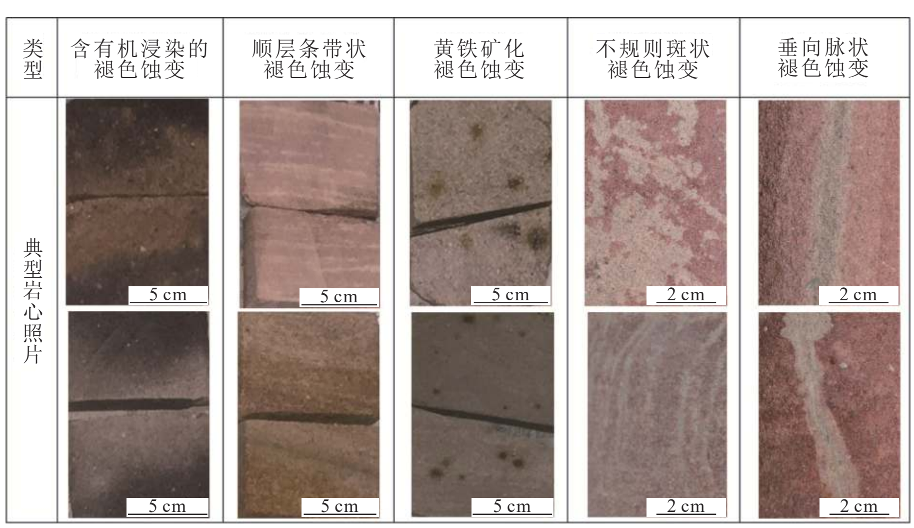


图 5 彭阳地区洛河组褪色蚀变砂岩蚀变特征

Fig.5 Alteration characteristics of fading altered sandstones in Luohe Formation, Pengyang area

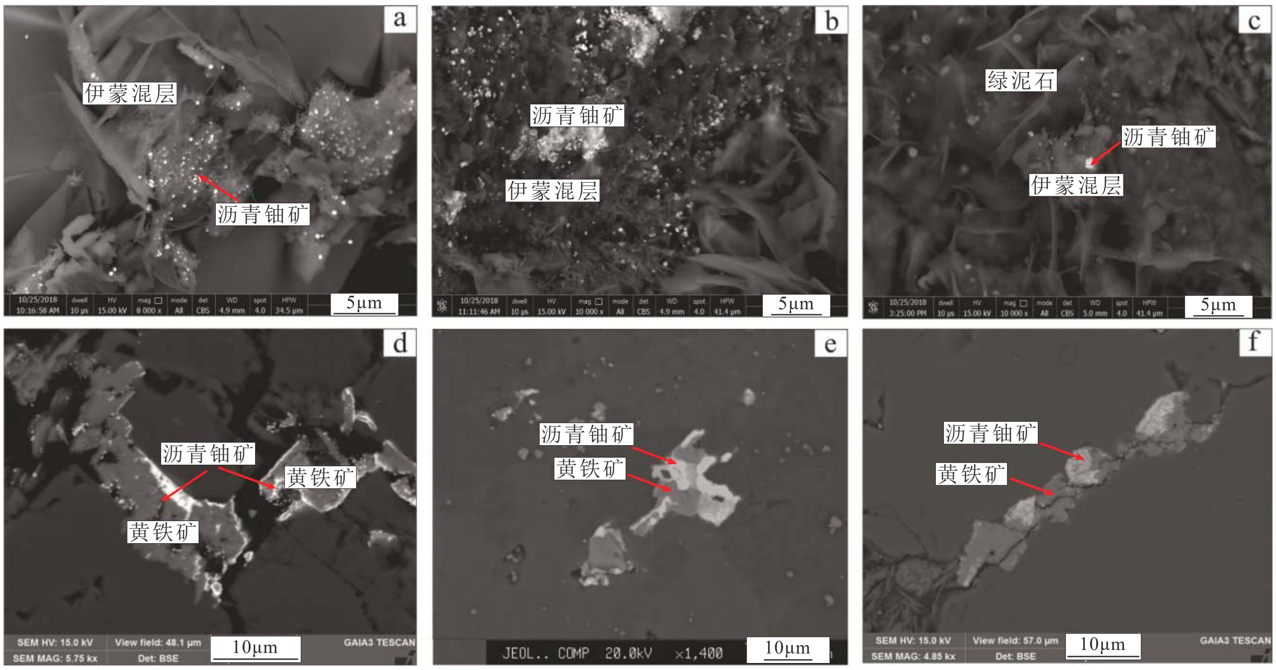


图 6 彭阳地区洛河组褪色砂岩中矿物共伴生关系的微观图像
a、b、c—沥青铀矿与黏土矿物; d、e、f—沥青铀矿与黄铁矿
Fig.6 Microscopic image of symbiosis minerals in faded sandstones, Luohe Formation, Pengyang area
a, b, c–Pitchblende and clay minerals; d, e, f–Pitchblende and pyrite

率、铀矿化程度、石膏及碳酸盐含量总体呈正相关关系，表现为如下特点：①洛河组孔渗性较高层段的砂岩往往发生褪色蚀变；②铀矿化增强；③三价铁氧化物消褪；④局部石膏含量有所增加。

### 5.3 洛河组蚀变砂岩的元素组成特征

本次研究通过 XRF 荧光光谱扫描对 D1 孔洛河组典型褪色砂岩(图 7)进行元素含量的分析。基于褪色砂岩具有三价铁氧化物减少而黄铁矿、石膏、黏土矿物增加的特点，重点研究了硫、铁、铀等元素的组成。褪色蚀变程度较高的砂岩中硫和铀元素的含量明显增高(图 8)，反映砂岩中铀及硫元素在砂岩蚀变过程中存在迁移。不同褪色蚀变程度砂岩的铁元素含量总体稳定或变化幅度较小，可能因流体中这些元素在蚀变过程中发生的迁移作用较小，在一定程度上也代表了砂岩原始沉积的元素组成特征。

## 6 讨　论

### 6.1 洛河组褪色蚀变砂岩的氧化还原状态

通过对研究区洛河组岩心红外光谱扫描和电镜扫描已证实洛河组砂岩褪色蚀变含铁矿物具有如下规律：随着褪色蚀变程度的增强，洛河组砂岩三价铁氧化物呈明显减少而黄铁矿化蚀变增强的总体特征。另外，褪色程度高的灰白—灰色砂岩 $Fe_2O_3/FeO$ 比值明显低于褪色程度低的浅红—黄色砂岩(图 9)，而不同褪色程度的蚀变砂岩铁元素的含量相差不大(图 8)。从矿物组合和元素组成的角度均反映了洛河组砂岩的褪色蚀变实质是发生了铁元素由三价到二价的转化，说明砂岩褪色蚀变主要受到环境由氧化向还原转变的影响。

由于钍和铀在还原条件下地球化学性质相似而在氧化状态下差别很大，即铀和钍在还原条件下均不易溶解而在氧化状态下铀相对易溶，Th/U 值>1 往往反映沉积物处于氧化环境状态(吴朝东等, 1999; 罗婷婷和周立发, 2013; 王善博等, 2018; 司庆红等, 2021)。另外，Cu/Zn 值越小代表环境中含氧度越低，则沉积物所处环境的还原程度越高(Dypvik and Harris, 2001; 张昭丰等, 2020)。本次研究将 Th/U 值和 Cu/Zn 值作为褪色蚀变砂岩所处环境氧化还原状态的判断指标。从洛河组不同程度褪色蚀变砂岩(图 7)的 Th/U 值和 Cu/Zn 值氧化还原指标(图 10)可看出，随着岩石颜色发生从浅红色

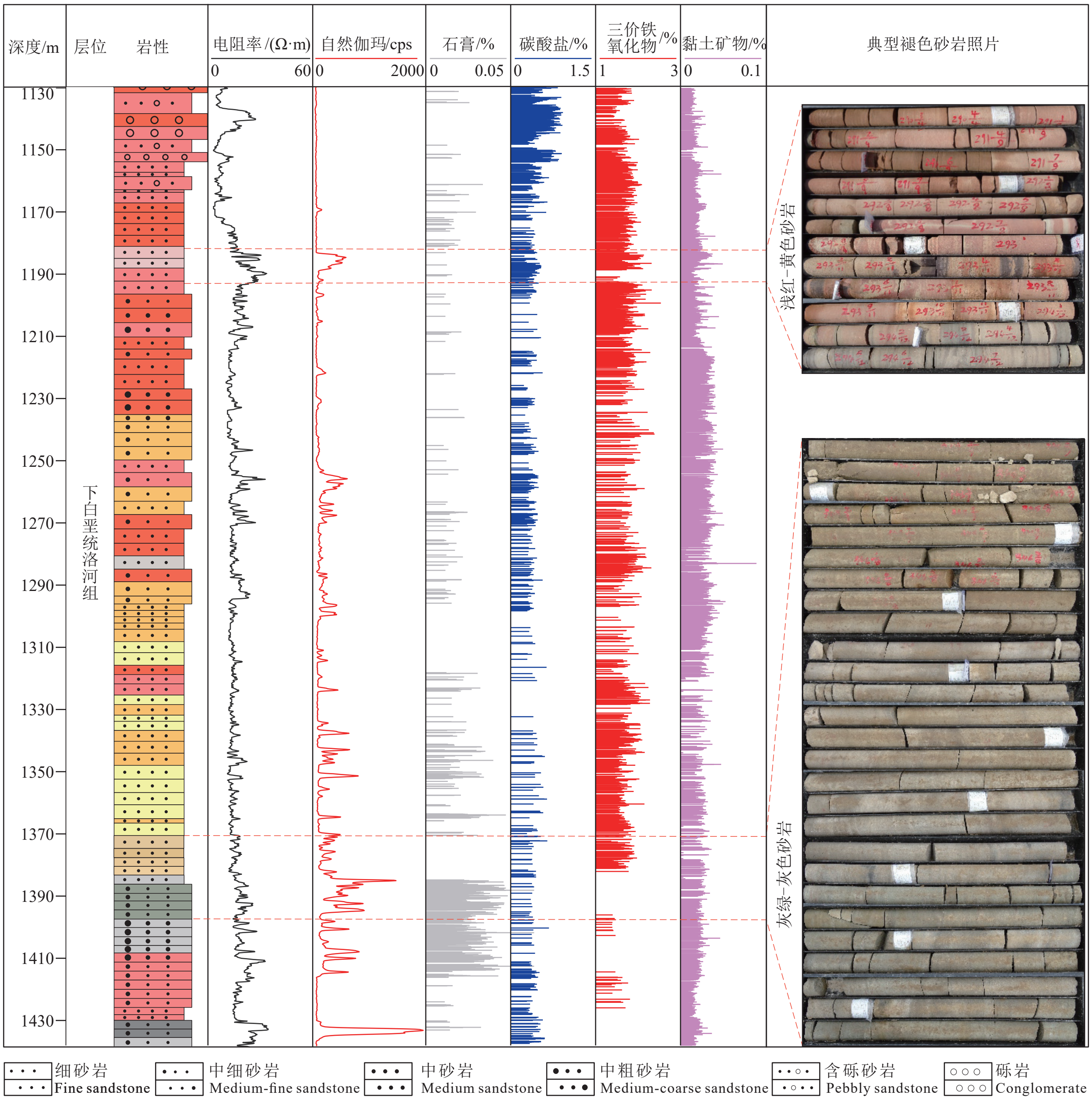


图 7 彭阳地区 D1 孔洛河组典型蚀变砂岩红外光谱表征的矿物组合特征

Fig.7 Characteristics of mineral assemblages characterized by infrared spectroscopy of typical altered sandstones in Luohe Formation of Well D1, Pengyang area

到黄绿色（图 10a）、从浅黄色到灰色的褪色蚀变（图 10b），砂岩总体呈氧化向还原环境的变化特点。

## 6.2 褪色蚀变与铀矿化相关流体的指示

洛河组褪色蚀变砂岩的氧化还原指标也反映环境发生了氧化向还原状态的转变，而洛河组本身地层中缺少沉积形成的炭屑、黄铁矿等还原介质，说明砂岩经历还原流体的改造作用。砂岩型铀矿成矿作用在不同程度上都反映了成矿流体氧化–还原反应是铀成矿的必要条件（Adams and Smith, 1981; Walton et al.,1981; 夏毓亮等, 2003; 贾立城和刘武生, 2012; 吴柏林等, 2015; 侯惠群等, 2016; Jin et al., 2016, 2018; 冯晓曦等, 2019; 程银行等, 2024; 安国堡等, 2024），砂岩型铀矿的成矿过程受到含氧含铀流体和还原介质流体的双重控制已成为国内

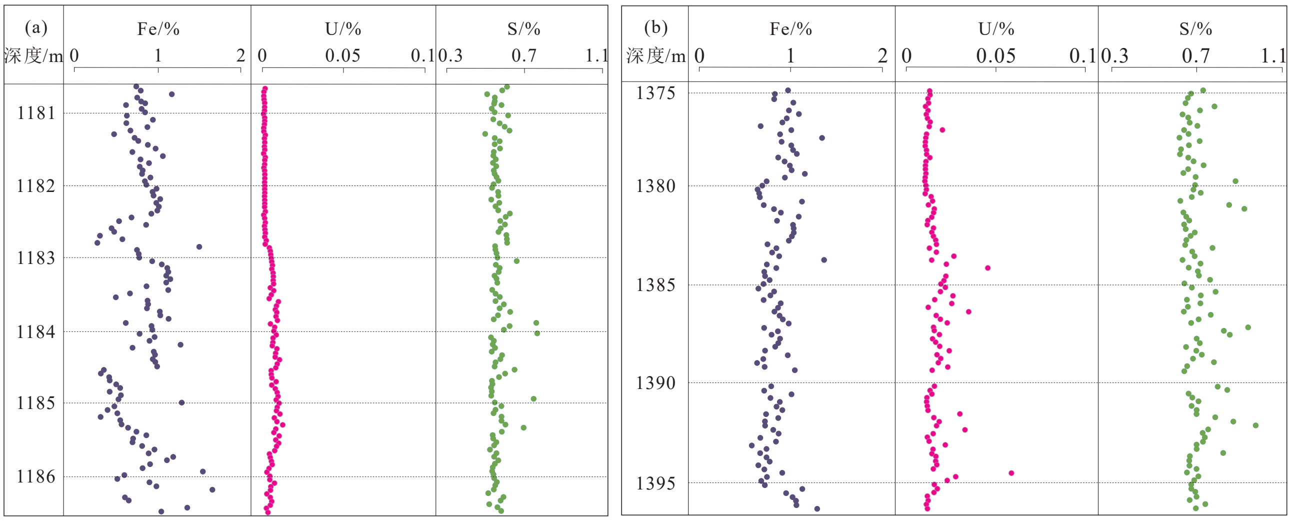

图 8 彭阳地区洛河组褪色蚀变砂岩典型元素地球化学柱状图
a—浅红—黄绿色褪色砂岩元素地球化学图; b—灰绿—灰色褪色砂岩元素地球化学图
Fig.8 Geochemical histogram of typical element in the faded sandstones, Luohe Formation, Pengyang area
a–Geochemical histogram of typical element in light red or yellow−green sandstones; b–Geochemical histogram of typical element in gray green−gray sandstones

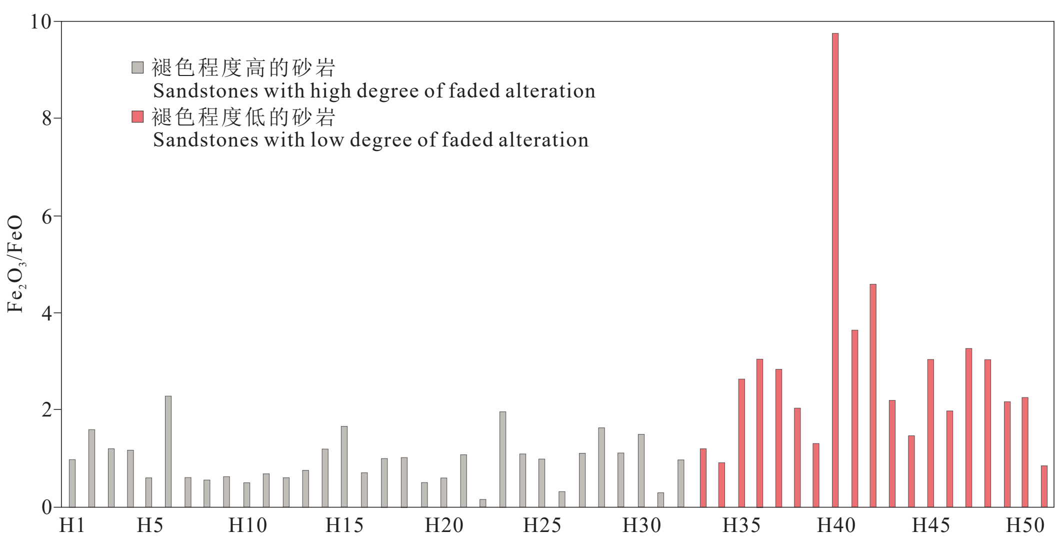


图 9 彭阳地区洛河组褪色砂岩不同价态铁氧化物相对含量直方图
Fig.9 Histogram of the relative content of iron oxides in different valence states of the faded sandstones, Luohe Formation, Pengyang area

外学者的共识。洛河组砂岩铀矿化蚀变除了受原生环境和含氧流体的影响,必然也与还原改造作用有关。

通过分析彭阳地区洛河组砂岩褪色蚀变与铀矿化蚀变的空间位置关系,不难发现洛河组铀成矿作用通常发生在褪色砂岩中,呈灰白—浅灰色的褪色砂岩铀矿化程度往往较高,呈浅红—浅黄色的褪色砂岩铀矿化程度一般较低。从矿物组合及元素组成角度来看,铀矿化蚀变与褪色蚀变砂岩具有黄铁矿化蚀变增强(图 6)、三价铁氧化物明显减少(图 7)以及偏还原的环境特点(图 9, 图 10)。此外,在表生条件下,黏土矿物带负电荷很容易吸附带正电荷和水解能力弱的铀酰离子(朱强等, 2020),可能是洛河组砂岩褪色往往伴有一定程度的黏土矿物富集现象的主要原因。从洛河组褪色蚀变与铀成矿作用在空间分布、矿物组合及氧化环境状态的匹

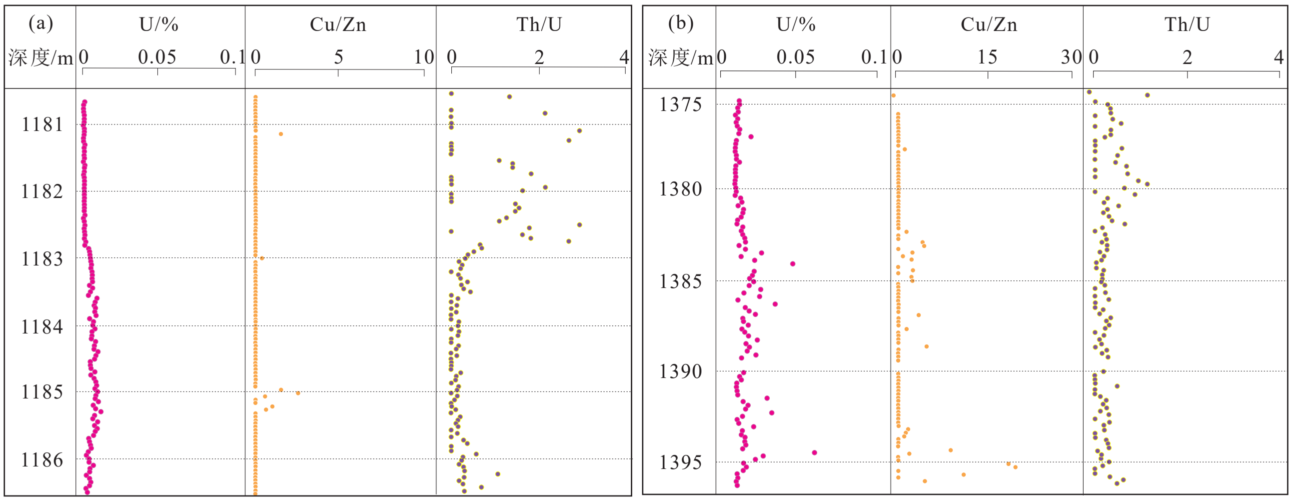


图 10 彭阳地区 D1 孔洛河组典型褪色蚀变砂岩的元素氧化还原指标及铀元素富集关系图

a—呈浅红—黄绿色褪色砂岩的氧化–还原指标; b—呈浅黄—灰绿色褪色砂岩的氧化–还原指标

Fig.10 Relationship between elemental redox indexes and uranium enrichment of typical faded altered sandstones in Luohe Formation of Well D1, Pengyang area

a–The redox index in light red or yellow green sandstone; b–The redox index in light yellow or gray green sandstone

配关系，推断二者可能受到同一或相似还原流体的改造作用。

前人研究发现，还原介质除了煤屑和黄铁矿外，$H_2$、$CH_4$、$H_2S$、CO 等气体还原剂也是有效的还原剂(赵凤民和沈才卿, 1986; 吴柏林等, 2014)。由于彭阳地区洛河组形成于原生环境，自身地层中缺少有机质，其还原介质应主要为外部流体。值得注意的是，彭阳地区洛河组褪色砂岩中发现有沿断裂及裂隙贯入的深层还原性流体改造痕迹和沥青残留(赵华雷等, 2020; Si et al., 2021)。除了烃类物质，在深层也有发现还原性硫化氢气体的报道(崔建军等, 2010; 陈亮, 2014)。当承载着沥青、硫化氢等还原性物质的流体进入洛河组中，由于沥青和硫化氢具有较强的还原性(刘正义和秦明宽, 2007; 刘正义等, 2021)，可作为 $UO_2^{2+}$的主要还原剂，同时原生氧化的红色砂岩中三价铁氧化物亦可被还原为二价铁，岩石发生褪色现象。沥青的还原反应如式(2)(刘正义和秦明宽, 2007; 刘正义等, 2021)所示，$C_{28}H_{44}O$ 为含烃流体中沥青物质化学式。

$$(C_{28}H_{44}O)_x + 3H_2O = (C_{28}H_{44}O)_x(OH)^{2-}{}_2 + 3H^+ + e^- \quad (2)$$

$H_2S$ 自身也具有还原性，在一定条件下使 $UO_2^{2+}$ 迅速还原。另外，离解产生的 $S^{2-}$与 $Fe^{2+}$结合形成黄铁矿。如式(3)和式(4)所示(李盛富和张蕴, 2004)。这与洛河组褪色砂岩中具有沥青铀矿与黄铁矿富集的特点是吻合的。

$$UO_2^{2+} + H_2S \rightarrow UO_2 + S + 2H^+ \quad (3)$$

$$H_2S + Fe^{2+} \rightarrow FeS + 2H^+ \quad (4)$$

彭阳地区含铀岩系以风成沉积环境为主，地层自身缺乏有机质。洛河组砂岩中这种富含烃类物质和硫化氢的深层流体可能是洛河组主要还原性流体，对砂岩褪色及铀成矿作用具有重要贡献。

## 7 结 论

(1)含铀岩系洛河组中砂岩具有明显的砂波层理，成分以石英为主，具有风成沉积特点；洛河组中不同颜色砂岩风化程度相似，并未显示沉积过程中有明显差别，均为干旱缺氧条件下风成沉积的产物。

(2)洛河组砂岩褪色蚀变多呈有机浸染、顺层条带状、伴有黄铁矿化、不规则斑状或和垂向脉状，褪色蚀变程度较高的砂岩往往具有铀矿化增强、三价铁氧化物含量减少及石膏含量增加的特点，铀及硫元素含量也有明显的变化。

(3)随着岩石发生浅红色—黄绿色—浅黄色—灰色的褪色蚀变，洛河组砂岩的环境状态总体呈自氧化态向还原态的转变特点。褪色蚀变与铀

成矿在空间分布、矿物元素组合及氧化还原状态上具有一致的变化特征,暗示二者可能受到同一或相似还原流体的影响。

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