Porosity in Shales of the Organic-Rich Kimmeridge Clay Formation (Upper Jurassic), Offshore United Kingdom*

Neil S. Fishman¹, Heather A. Lowers², Paul C. Hackley³, Ronald J. Hill⁴, Sven O. Egenhoff⁵

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Abstract

Petrographic, SEM, and RockEval pyrolysis analyses of organic-rich shale samples from 6 wells that penetrated the Upper Jurassic Kimmeridge Clay Formation (KCF), offshore United Kingdom, were performed to evaluate the nature (physical and chemical) of the organic material and to document changes in organic porosity as a function of increasing thermal maturity. The formation is at depths ranging from ~6,100 ft to ~15,300 ft (subsea). It is thermally immature to marginally mature in the shallowest core samples, where total organic carbon (TOC) contents are as high as 10 wt%, vitrinite reflectance (Ro) values are ~0.6%, and hydrogen indices (HI ) are high (>400 mg hydrocarbon/g rock). In contrast, it is thermally mature in the deepest core (Ro values ~1.2%), with high TOC contents (as much as 8 wt%) but low HI values (<30 mg hydrocarbon/g rock). In addition, the KCF has intermediate HI and Ro values in other core samples.

At least four distinct types of organic components were observed in petrographic and SEM analyses, which are, in decreasing abundance: 1) amorphous organic material admixed with clay platelets (as much as 20 μm long); 2) elongate (up to 300 μm) mat-like masses (micro-algal mat?) with small (<0.5 μm) quartz, feldspar, and clay entrained within it; 3) discrete particles (possibly alginate?); and 4) Tasmanites microfossils. Regardless of depth and thermal maturity, the following observations were made of porosity in shales of the KCF. On ion-milled surfaces, there are irregular-shaped micropores and nanopores (0.1-0.01 μm across) in some mat-like masses, whereas regularly shaped micropores (up to 1 μm across) are in the discrete organic particles. Other types of pores,
particularly interparticle (i.e., between illite flakes or platelets as well as between authigenic quartz euhedra), and intraparticle (i.e., between crystallites in framboidal pyrite) are also present and are noteworthy because they compose much of the observable porosity in the KCF shales.

No systematic increase in organic porosity was observed in any organic material within the KCF with increasing depth and thermal maturity. As such, organic porosity does not contribute significantly to overall pore volume in the KCF, even in organic-rich shales that are thermally mature. Therefore, the petroleum storage potential in the formation appears to reside largely within interparticle and intraparticle pores between or within inorganic components of the shales, respectively.

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Approach

- Characterize organic macerals (RockEval & petrography)
- Evaluate maceral distribution
- Observe organic pores (maceral type & maturity)
- Evaluate inorganic pores
Kimmeridge Clay Fm deposition

KCF depo during transgression that also saw connection Tethys & Arctic (Boreal) seas

Modified from Ziegler, 1990
Study area, Kimmeridge Clay Fm, UK

- **North Atlantic Ocean**
- **Scotland**
- **North Sea**
- **Northern Ireland**
- **Ireland**
- **England**
- **Wales**

**LOW MATURITY**
- ~6100' deep
- Ro = ~0.35 %
- HI = >400
- TOC < 10%
- Qtz = 27 wt%
- Clayave = 46 wt%
- K-sparave = 6 wt%

- **Scotland**
- **North Sea**
- **Northern Ireland**
- **Ireland**
- **England**
- **Wales**

**Wales**
- **Wales**

**KCF Ro**
- 0.6-0.8%
- 0.8-1.0%
- 1.0-1.2%
- 1.2-1.4%
- >1.4%
Study area, Kimmeridge Clay Fm, UK

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INTER. MATURITY
- ~9400' deep
- Ro = ~0.45 %
- HI = 200-500
- TOC < 7%
- Qtz = 37 wt%
- Clay = 40 wt%
- K-spar = 5.3 wt%

Wales

North Atlantic Ocean

Scotland

North Sea

Northern Ireland

England

Ireland

Wales

0 120 km

0 120 km
Study area, Kimmeridge Clay Fm, UK

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~15,600’ deep
Ro = ~1.2%
HI = <30
TOC up to 8%
Qtz = 27 wt%
Clayave = 59 wt%
K-sparave = 1 wt%
Maceral identification

RockEval—“gross” evaluation
Petrography—“fine” evaluation
RockEval data

HI vs OI
largely marine algal, but mixed
**RockEval data**

**HI vs OI**
largely marine algal, but mixed

**S₂ vs TOC**
Generatable HC greatest in **Core 1**, decreasing to **Core 3**
RockEval data

HI vs OI
largely marine algal, but mixed

S$_2$ vs TOC
Generatable HC greatest in
Core 1, decreasing to Core 3

HI vs $T_{max}$
Increasing maturity from
Core 1 to Core 3
Macerals (Type II & III)

Lamellar bituminite & alginite
Lamellar alginite & bituminite, Tasmanites
Vitrinite, Bituminite (Bituminous mineral groundmass)
Distribution of macerals

Where are macerals as a function of core location/depositional system?
Organic macerals, low & high mat. wells

Low maturity well
- Terrestrial$_{low}$
- Lamellar alginate$_{low}$
- Bituminous mineral groundmass$_{low}$

High maturity well
- Terrestrial$_{high}$
- Lamellar alginate$_{high}$
- Bituminous mineral groundmass$_{high}$
Maceral porosity

Similar macerals in KCF across study area (not same amnts)

Nature of porosity—function of maceral type

Nature of porosity—function of maturity
Pores—bituminous mineral groundmass

BMG, somewhat similar micro/nanopore shape & size, but pores not abundant in either low or high maturity well.
Pores in lamellar alginate

Low maturity well

High maturity well

Micro/nanopores at low and high maturity, no apparent difference in size or shape
Pores in Type III macerals

Low maturity well

High maturity well

Similar micropore shape & size, regardless of maturity
Evidence lacking systematic maturity-induced development Corg porosity

Now what?
Organic porosity preservation related to mineralogy?

- **Qtz**: Barnett, Woodford, Horn River
- **Clay**: Kimmeridge
- **Carb**: Haynesville, Niobrara
Organic porosity preservation related to mineralogy?

**Qtz**
- Barnett, Woodford, Horn River

**Clay**
- Kimmeridge

**Carb**
- Haynesville, Niobrara

Potentially strong, ‘rigid’ mineralogical framework
Organic porosity preservation related to mineralogy?

- Relatively weak, ductile mineralogical framework: Clay (Kimmeridge)
- Potentially strong, ‘rigid’ mineralogical framework: Carb (Haynesville, Niobrara)
- Quartz (Qtz): Barnett, Woodford, Horn River
What other role might mineralogy play?

Now what? Inorganic Porosity?
**Inorganic porosity**

- Illite: Low mat, interparticle
- Kaolinite: High mat, interparticle
- Framboidal pyrite: Low mat, intraparticle
- K-feldspar: Inter mat, intraparticle
- Dolomite: High mat, intraparticle
Inorganic porosity

- Pores (intra-interparticle), function of grain types (clays, K-spar, etc.)
- Inorganic porosity significance (2\textsuperscript{nd})
- Porosity potentially significant, function of bulk mineralogy
Conclusions, Kimmeridge Clay Fm., UK

- At least 3 types of organic macerals in KCF
  a) Bituminous mineral groundmass (Type II)
  b) Microbial mats—lam. al. & bit. (Type II)
  c) Terrestrial (Type III)

- Micro- & nanopores exist in all maceral types

- No clearly systematic increase in micro- or nanoporosity w/increasing maturity

- Inorganic porosity exists at all maturities & variability (mineralogy) is possible

- Inorganic porosity variability has potential for mineralogical control on porosity

- Lack of ‘rigid’ mineralogical fabric$\text{KCF}$ resulted in minimal organic porosity preservation
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U.S. Department of the Interior
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Evaluate maceral distribution

Observe organic pores (maceral type & maturity)

Evaluate inorganic pores
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- Quartz (Qtz)
  - Barnett, Woodford, Horn River
- Clay
  - Kimmeridge
- Carbonate (Carb)
  - Haynesville, Niobrara
Organic porosity preservation related to mineralogy?

- **Qtz**
  - Barnett, Woodford, Horn River
  - Potentially strong, ‘rigid’ mineralogical framework

- **Clay**
  - Kimmeridge

- **Carb**
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- **Clay** (Kimmeridge)
  - Relatively weak, ductile mineralogical framework
- **Carb** (Haynesville, Niobrara)

Diagram: A triangle with Qtz at the top, connected to Clay and Carb. Clay is a semi-circle at the bottom left, and Carb is a semi-circle at the bottom right.
What other role might mineralogy play?

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Inorganic porosity

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