

OPTICAL CHARACTERISTICS OF AMORPHOUS KEROGENS AND THE HYDROCARBON-GENERATING POTENTIAL OF SOURCE ROCKS

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ABSTRACT

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Four recurring types of amorphous kerogen are optically identified in petroleum source rock samples and are related to hydrocarbon-generating potential (defined here as geochemically interpreted oil-prone or gas-prone). At this time a genetic classification is not possible. The different amorphous kerogen types are distinguished on the basis of microscopic textural differences: Type A — chunky compact masses with mottled network or weak polygonal textures; Type B — very small, dense, elongate, oval, or rounded individual grains; Type C — clumps with granular, fragmented or globular textures; Type D — thin, platy, or rectangular individual grains. Geochemically defined oil-prone samples generally contain Types A and/or D separately or combined; geochemically defined gas-prone samples rarely contain Type A and vary in amounts of Types B, C, and/or D.

The samples in this study contain dominantly one of the four types of amorphous kerogen, so the geochemical analyses of the whole rock or bulk concentrated kerogen samples are assumed to be analyses of the dominant amorphous type. The samples were chemically analyzed by several techniques to determine the oil- or gas-generating potential. The establishment of relations between specific optical and chemical properties of kerogen types can make visual kerogen analyses more meaningful in predicting the hydrocarbon generation potential of source rocks.

INTRODUCTION

It is widely accepted that organic material deposited within sediments may react (with time, temperature, pressure, and other parameters) to form hydrocarbons. The analysis of that organic matter can provide valuable clues to the history of possible hydrocarbon generation. The term 'kerogen' is used throughout this paper in the petrographic sense (Durand, 1980) because the concentrated organic material was not solvent-extracted (see Sample Preparation section). By visually studying kerogen, we can observe the various kinds of organic matter that were incorporated into a rock,

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the abundances of these kinds of organic matter, the level of maturation or thermal history of the rock, and possibly some clues to the environment of deposition (Staplin, 1969). Visual kerogen analyses are commonly done by microscopically examining, in transmitted light, strewn, smear, or palynological slides (see Sample Preparation section). The visually determined proportions of different kerogen types can be used in conjunction with geochemical analyses (total organic carbon, pyrolysis-gas chromatography, elemental, vitrinite reflectance, etc.) to better interpret the generating potential of source rocks. But, in order to make visual data more meaningful in these interpretations, it is necessary to understand the possible geochemical contribution of each kind of kerogen to the hydrocarbon-generating potential. Visual data can be obtained more quickly and cheaply than chemical data. It is hoped that, with more reliable visual data, more samples per well or region can be visually characterized with fewer chemical analyses needed for cross checks.

The customary description of kerogens is by one of two methods. One approach is the chemical (elemental) method such as that of Tissot et al. (1974) which discriminates kerogens into three types on the basis of atomic hydrogen to carbon (H/C) and oxygen to carbon ratios (O/C). Generalized assumptions of origins are made about these types, but few visual descriptions are given. The other approach is the optical method developed by palynologists which attempts to describe and relate kerogen to specific biological origins with little or no chemical analysis (Masran and Pocock, 1981). Two major groups of kerogen particles can be easily distinguished with an optical microscope: those with definite shapes or structures, often very similar to modern plant tissues; and those without distinct shapes or structures, which cannot be related to modern tissues or the structured kerogens. The shapeless particles have traditionally been given the name amorphous kerogen.

Combaz (1964, 1974, 1975), Staplin (1969), Burgess (1974), Robert (1981), and several others worked out different nomenclature schemes combining palynological and coal petrographical terms for the visual description of recurring kerogen types. These classifications became generalized by most workers into four categories: woody, herbaceous, coaly, and amorphous. These categories are frequently not specific enough to help characterize the hydrocarbon-generating potential of a source rock because they include several different kinds of organic particles in one generalized category, thereby masking many details. For example, the 'herbaceous' category often includes spores, pollens, leaf cuticle, algae, and membranous material. Each of these constituents may have a unique influence on the hydrocarbon-generating potential, so each should be identified separately and not 'lumped' together. Similarly, the 'amorphous' category contains different kinds of amorphous material which may be optically and chemically distinguished (Thompson and Dembicki, 1984).

The amorphous kerogen problem

In source rocks, amorphous kerogens usually occur more often and in greater quantities than structured kerogens. Tissot and Welte (1978), Massoud and Kinghorn (1985), and other workers have noticed the predominance of amorphous kerogen compared to structured material in most source rocks. In the Conoco Geochemical Data Base, approximately 60% of the samples with visual kerogen data contain 50% or more amorphous kerogen. The geochemical interpretations for these amorphous-rich samples vary from oil to gas to no hydrocarbon potential. Therefore, the single amorphous label has very little use for source predictions.

Chemical analyses of amorphous kerogen, with no optical descriptions, do not clarify the issue. Tissot (1984) states the accepted generalization about amorphous kerogen, "it is commonly considered to be dominantly algal in origin and thus equated with Type II or Type I kerogen. For this reason, 'amorphous' kerogen is considered to have a good source potential for generating oil." However, Tissot (1984) continues with the statement that "systematic elemental analysis performed on a set of amorphous kerogens from various origins has shown that, although some of them belong to Type II, the chemical composition of the amorphous kerogen may spread over the entire Van Krevelen diagram" (atomic O/C versus H/C).

Several authors have visually noted more than one kind of amorphous kerogen in source rocks. The work of Combaz (1980), Masran and Pocock (1981), and Venkatachala (1981) contain descriptions of different types of amorphous kerogen based on color (grey, yellow, etc.) and texture (granular, spongy, flaky, etc.). However, these authors attempt to relate the different amorphous kerogens to specific biological origins and/or physical-chemical degradation processes. Van Gijzel (1982) describes three kinds of amorphous kerogen (amorphinite A, B, C) on the basis of fluorescence color differences and relates them to general origins and probable hydrocarbon-generating potential. Batten (1983) attempts to describe amorphous kerogens by appearance in transmitted light but adds interpretations of origin.

Some workers have tried to understand the optical-chemical relationship of amorphous kerogen. Powell et al. (1982) attempted to optically distinguish hydrogen-rich and hydrogen-poor amorphous kerogen in source rock samples characterized by geochemical analyses (extraction, pristane/phytane, atomic H/C). They were unable to show a correlation because the genetic description (algal/microbial or terrestrial) and the quantity of the amorphous material do not sufficiently distinguish the different kinds of amorphous kerogen. Masran (1984) correlated only total organic carbon to the dominance of "marine-derived amorphous matter". Massoud and Kinghorn (1985) describe "four different constituents of the amorphous organic matter" with different hydrocarbon-generating potentials on the basis of

various geochemical analyses. Mukhopadhyay et al. (1985) correlate Rock-Eval pyrolysis hydrogen index to three optically different amorphous kerogen types. The nomenclature reflects an attempt to genetically classify the different amorphous kerogens.

The origin of amorphous material

The assumption is often made that the structured kerogen particles in a sample are related to the amorphous material (Staplin, 1969). While this is possible, of course, it must be kept in mind that once amorphous kerogen is formed, it is very difficult to determine its origin by optical and/or chemical techniques. Figure 1 suggests some of the varied origins of amorphous kerogens and illustrates why it is difficult to relate amorphous material to structured particles. The structured kerogen particles should be regarded as "fossil" or relict indicators of some possible kinds of organic input. Our work suggests that amorphous kerogens are predominant in oil and gas source rocks and that structured kerogens may not be present in large enough quantities in most source rocks to account for the major generation of hydrocarbons.

Many workers (Staplin, 1969; Durand, 1980; Robert, 1981, etc.) speculate that some amorphous kerogen originated from organic oozes, colloidal solutions, gels, precipitates, and sapropels derived from organic debris, bacteria, fecal pellets, etc., which have putrefied near the sediment-water interface (Fig. 1). This kind of amorphous kerogen has no optically observable relation to any of the structured kerogens. Staplin (1969) believed that the amount of this material trapped in sediments was "probably small" and therefore not a significant source of hydrocarbons; however, available

THE ORIGINS OF AMORPHOUS KEROGENS

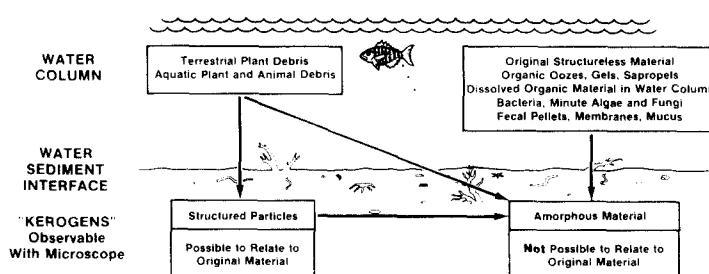


Fig. 1. Some of the possible origins of amorphous kerogens: physically/chemically degraded plant and animal debris; physically/chemically degraded structured kerogens; and original structureless material. Once amorphous kerogen is formed, it is very difficult, both optically and chemically, to identify the original source. The different kinds of optically recognizable amorphous kerogens are most likely related to different depositional environments and/or states of preservation.

data suggests the opposite. Some amorphous kerogens may be similar to the lipoid substances or liptodetrinite described by Teichmüller and Ottenjann (1977) and Creaney (1980); however, all amorphous kerogens (immature to mature range) do not fluoresce when viewed with near ultraviolet light. The natural occurrence of abundant amorphous material is supported by studies of modern continental margin sediments. Reimers (1982) describes this recent amorphous material as having very few recognizable structures. The realization that original amorphous organic material may become amorphous kerogen means that, rather than trying to describe amorphous kerogen in terms of what it came from, more attention should be given to describing (both optically and chemically) the amorphous kerogens as they now exist. It may be possible that the different amorphous kerogens are related to different depositional environments and/or states of preservation; further work is needed to substantiate this idea.

METHODS OF STUDY

This work combines information from both organic geochemical analyses and petrographic observations. We selected a study set of 75 samples of shale source rocks from nine different locations (wells) ranging in geological age from Silurian to Miocene (Table 1). These samples were chosen because: (1) they all contain 80 percent or more amorphous kerogen as determined by standard visual estimate; (2) they are from gas or oil source rocks which are not overmature (equivalent to vitrinite reflectance less than 1.1%, spore/pollen color less than three on the 1969 Staplin scale); and (3) they are not obviously contaminated (caved or reworked kerogens, drilling mud additives, oil staining, etc.). The samples were optically studied with the knowledge of which were oil-prone and which gas-prone in order to find differences and/or similarities among the amorphous kerogens.

Sample preparation (visual kerogen strewn slides)

It is necessary to concentrate the organic matter of a rock to prepare visual kerogen slides. Approximately 10 grams of washed and dried core or cuttings samples are crushed to +40 -20 mesh. The crushed sample is placed in a flask to which 10% HCl (hydrochloric acid) is added. Then concentrated (37%) HCl is added and the flask is placed on a shaking hot plate for six hours. The acid is poured off, distilled water added to the flask, and it stands overnight. The water is poured off and a mixture of concentrated HCl and 52% HF (hydrofluoric acid) is added to the flask which is agitated for six hours. The acid mixture is then poured off, distilled water added to the flask, and it is allowed to stand overnight. The water is decanted and HF is added to the flask which stands for six hours. After the HF is poured off, the flask is filled with distilled water to stand overnight. The samples are rinsed one more time with concentrated HCl and then distilled

water. The water is poured off, and the sample is transferred into a test tube which is then filled with distilled water. The test tube is centrifuged for five minutes at 2,000 rpm. The contents of the test tube are rinsed with distilled water, then acetone, then twice again with distilled water.

TABLE 1

Geochemically interpreted hydrocarbon-generating potential, location, age, depth, and dominant amorphous kerogen types of the studied source rocks*

Well	Location	Age	Depth (m)	Type
<i>Oil-prone samples</i>				
1	Anadarko Basin, OK, U.S.A. (Woodford Shale)	Mississippian—Devonian	2,564 2,578 2,581	A A A
2	Tunisia	Silurian	1,926 1,979* 1,986 1,995 2,041* 2,106 2,114* 2,116* 2,124* 2,125* 2,132* 2,139 2,166 2,182* 2,196 2,226 2,398*	B A A A A A A A & C A & C A & C B & C C A D D A A
3	Nile Delta, Egypt	Oligocene—Cretaceous	3,270 3,300 3,360 3,420 3,480 3,630 3,750 3,810 3,840 3,930 3,990	D D D D D A A A D & B D D
4	North Sea, offshore U.K. (Kimmeridgian Shale)	Upper Jurassic	3,492 3,508 3,553 3,599 3,614 3,630 3,736	A & C C A A C D & A B & C

Table 1 (continued)

Well	Location	Age	Depth (m)	Type
5	Santa Barbara Basin, CA, U.S.A. (Monterey Shale)	Miocene	2,410	A
			2,519	A
			2,593	A
			2,647	A
			2,693	A
			2,721	A
			2,794	A
			2,830	A
			2,922	A
<i>Gas-prone samples</i>				
3	Nile Delta, Egypt	Miocene	2,790	D
			2,850	D
4	North Sea, offshore U.K.	Cretaceous	2,959	C
			3,020	C
			3,020	C
			3,080	C
			3,080	C
			3,172	C
			3,203	C & B
			3,233	C
			3,264	C
			3,355	C
			3,370	C
6	Offshore Taiwan	Miocene	2,020	D
			2,500	C
7	Western Desert, Egypt	Tertiary—Cretaceous	552	C
			576	C
			600	B
			660	D
			690	D
			756	D
8	Barents Sea, offshore Norway	Upper Cretaceous	780*	B
			835*	B
			1,180*	B
			1,240*	B
9	Santa Barbara Basin, CA, U.S.A.	Oligocene	378	A & B
			442	A & B
			570	D

Canned-cuttings samples except where depth is followed by an asterisk (), indicating sidewall core samples.

The sample and water in the test tube are thoroughly mixed using a vortex mixer. A long, narrow eyedropper or pipette is used to withdraw a small amount of sample from the middle of the test tube (hopefully representative of both the heavy and light constituents). One drop of sample plus two drops of distilled water and one drop of polyvinyl alcohol are mixed together and evenly spread out on a cover glass. The cover glass is dried overnight and attached to a glass slide using a small quantity of mounting medium.

Organic geochemistry

The geochemical interpretations 'oil-prone' and 'gas-prone' (Table 1) were made using the total organic carbon, extractable C₁₅₊ hydrocarbon and light hydrocarbon data (ppm C₁-C₄ and C₅-C₇ for canned cuttings samples only) shown in Table 2.

Several of the samples are from geochemically 'well-known' source rocks (for example, the Woodford, Kimmeridgian, and Monterey shales). Pyrolysis-gas chromatography data, from a Conoco-constructed instrument (Dembicki et al., 1983) were also used in making these interpretations. The kerogen pyrolysate chromatograms were evaluated both quantitatively (percent C₁-C₅, percent C₅-C₁₀, percent C₁₀₊, etc.) and qualitatively noting, for example, the presence or absence of certain aromatic compounds, the shape of the chromatographic envelope, etc. (Dembicki et al., 1983; Horsfield, 1984). Elemental analyses for carbon, hydrogen, nitrogen, and oxygen were made on 20 "mineral-free" kerogen concentrates, but even after heavy liquid separation, the kerogen concentrates contained too much "ash" or mineral matter to yield useful elemental data. Infrared spectra, shown in Fig. 2, were obtained for sixteen kerogen concentrates (mixed in KBr pellets). Qualitatively, the presence or absence of the aliphatic structures helped to confirm the oil-prone or gas-prone nature of the four amorphous kerogen types.

The interpretation of organic geochemical data from different laboratories is difficult due to the lack of standardized sample preparation, instrumentation, measuring techniques, and good calibration standards (Dembicki, 1984). It is not the intention of this paper to explain how source rock samples are evaluated for hydrocarbon-generating potential. The emphasis of this paper is to illustrate that the optical properties of amorphous kerogen can be related to the interpreted oil- or gas-prone nature of the samples.

Organic petrography

The visual kerogen strewn slides were studied using a petrographic microscope equipped with transmitted light and incident (reflected) white and blue light. The same field of view was observed with several lighting conditions. A total magnification of 400X with oil immersion was used.

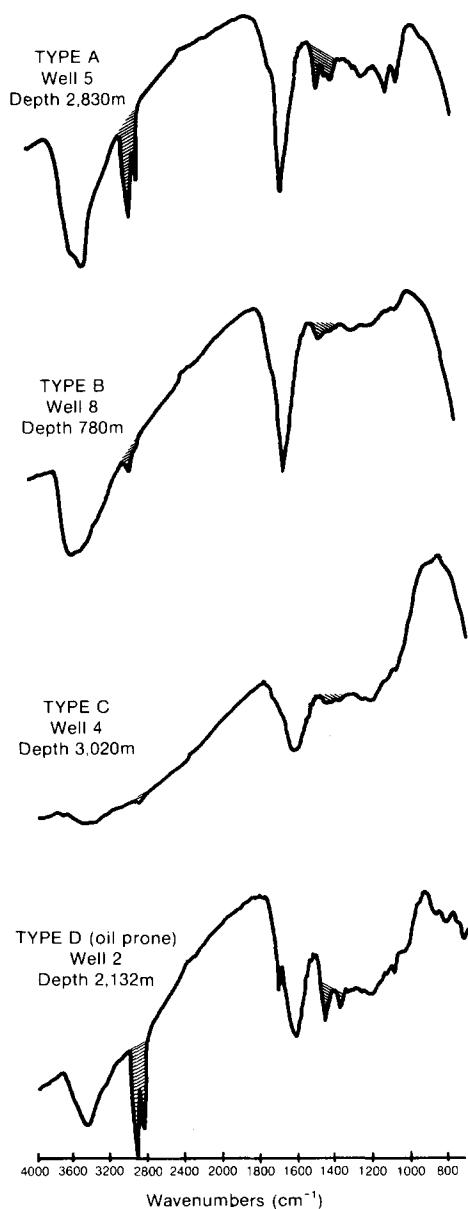


Fig. 2. Typical infrared spectra (transmittance) of the four amorphous kerogen types. The stippled areas indicate the aliphatic ($\text{CH}_2\text{-CH}_3$) structures at approximately $2,920 \text{ cm}^{-1}$, $2,850 \text{ cm}^{-1}$, $1,450 \text{ cm}^{-1}$, and $1,380 \text{ cm}^{-1}$ (Tissot and Welte, 1978) which are stronger bands in the samples interpreted to be oil-prone.

TABLE 2

Organic geochemical data for studied source rocks

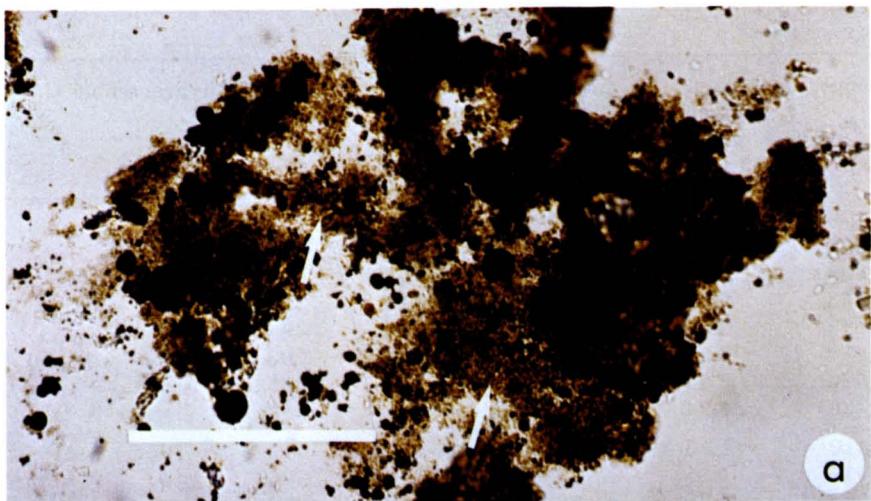
Well	Depth (m)	Total organic carbon (wt.%)	Light hydrocarbons*		Extracted hydrocarbons C ₁₅₊ (ppm)
			C ₁ —C ₄ (ppm)	C ₅ —C ₇ (ppm)	
1	2,564	1.92	473,450	64,470	1,763
1	2,578	3.35	1,240,983	72,543	2,175
1	2,581	1.70	174,277	4,855	1,883
2	1,926	0.60	42,061	30,005	494
2	1,979	1.12	—	—	933
2	1,986	1.83	277,402	102,859	1,231
2	1,995	1.70	212,350	91,665	1,185
2	2,041	0.94	—	—	720
2	2,106	0.51	197,861	74,537	95
2	2,114	1.97	—	—	1,692
2	2,116	5.32	—	—	1,758
2	2,124	4.70	—	—	1,891
2	2,125	6.04	—	—	2,117
2	2,132	10.60	—	—	2,501
2	2,139	19.10	959,708	1,074	1,940
2	2,166	1.17	154,944	32,977	441
2	2,182	0.54	—	—	582
2	2,196	1.03	68,022	25,900	376
2	2,226	0.50	93,509	31,141	282
2	2,398	0.71	—	—	1,183
3	2,790	0.50	774	183	168
3	2,850	0.61	994	296	377
3	3,270	0.90	6,241	9,019	181
3	3,300	0.80	3,878	6,351	234
3	3,360	0.72	901	2,609	286
3	3,420	0.66	7,416	11,497	608
3	3,480	0.72	1,390	4,496	565
3	3,630	0.97	4,715	8,785	358
3	3,750	0.89	5,409	11,996	372
3	3,810	0.86	13,356	20,285	400
3	3,840	0.78	12,187	13,879	307
3	3,930	0.63	13,476	14,280	182
3	3,990	0.63	4,651	10,540	229
4	2,959	0.33	2,198	66	53
4	3,020	0.36	6,867	199	63
4	3,020	0.35	883	24	81
4	3,080	0.34	2,611	89	50
4	3,080	0.35	3,683	94	79
4	3,172	0.38	1,267	226	207
4	3,203	0.41	2,747	279	197
4	3,233	0.50	4,612	399	240
4	3,264	0.52	6,293	98	267
4	3,355	0.61	4,282	251	422

Table 2 (continued)

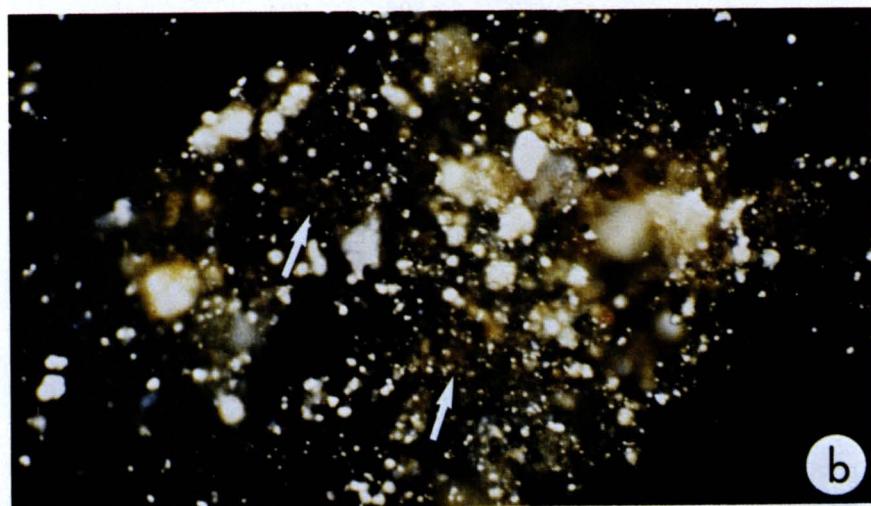
Well	Depth (m)	Total organic carbon (wt.%)	Light hydrocarbons*		Extracted hydrocarbons C ₁₅₊ (ppm)
			C ₁ —C ₄ (ppm)	C ₅ —C ₇ (ppm)	
4	3,870	0.50	3,796	1,207	243
4	3,492	3.44	88,087	3,970	600
4	3,508	3.70	90,343	10,193	1,047
4	3,553	2.41	81,108	24,774	722
4	3,599	2.67	56,042	29,166	494
4	3,614	3.29	71,789	40,545	703
4	3,630	3.93	77,841	54,419	1,385
4	3,736	4.24	92,434	7,724	432
5	2,410	1.13	8,372	17,490	413
5	2,519	1.35	27,573	38,098	586
5	2,593	1.68	28,146	41,086	983
5	2,647	1.50	12,462	19,396	904
5	2,693	1.71	31,913	39,829	280
5	2,721	1.40	29,604	39,594	149
5	2,794	1.29	25,777	39,990	228
5	2,830	1.43	40,477	46,304	268
5	2,922	1.05	22,092	25,673	297
6	2,020	0.56	—	—	399
6	2,500	0.61	—	—	186
7	552	0.51	247	22	32
7	576	0.75	252	26	27
7	600	1.09	200	24	180
7	660	0.93	170	31	84
7	690	1.06	240	25	83
7	756	0.71	291	31	60
8	780	0.78	—	—	0
8	835	1.17	—	—	38
8	1,180	1.30	—	—	92
8	1,240	1.57	—	—	88
9	378	1.53	—	—	29
9	442	1.28	—	—	11
9	570	0.79	—	—	32

*ppm expressed as vol./vol.

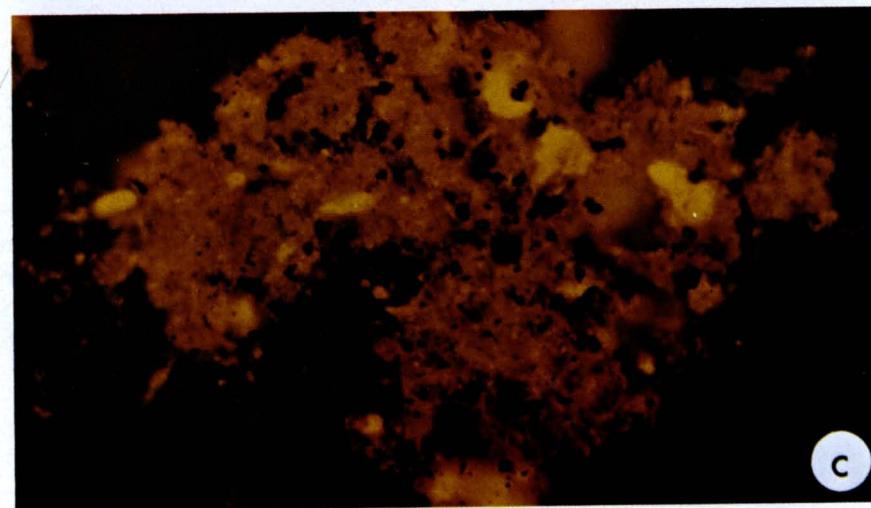
Blue light observations were made using a mercury vapor lamp, a 450–490-nm excitation filter, a 510-nm reflector (dichroic mirror), and a 529-nm barrier filter. Numerous photomicrographs were taken of each sample to help recognize recurring textures or kinds of amorphous kerogens. Letters of the alphabet (Table 3) were used to label the different types of amorphous kerogen which repeatedly occur in the set of samples.



a



b



c

The following descriptions of the four kinds of amorphous kerogens are to go with Figs. 3 through 6 and are summarized in Table 3.

Type A amorphous kerogen is distinguished by a mottled, interconnected network or weakly polygonal type of texture (Fig. 3). It usually occurs in large, chunky compact masses (300–400 microns across) but can also be observed in smaller fragments. In transmitted light (Fig. 3a), Type A is

TABLE 3

Optical descriptions of amorphous kerogen types shown in Figs. 3–6

Type	Texture ¹	TL ²	RL ³	FL ⁴
A	chunky compact masses (approximately 20–300 microns) with weak polygonal, mottled, interconnected network textures	red-brown	brown to grey	patches or flecks of yellow to yellow-grey to none
B	small, dense, elongate, oval to rounded individual grains (approximately 10–20 microns)	dark brown to black	brown to grey	none
C	dense clumps (approximately 50–300 microns) with granular, fragmented or globular textures	dark brown	grey	none
D	thin, rectangular or platy individual grains (approximately 10 microns)	light brown	brownish-grey	some yellow patches or flecks to none

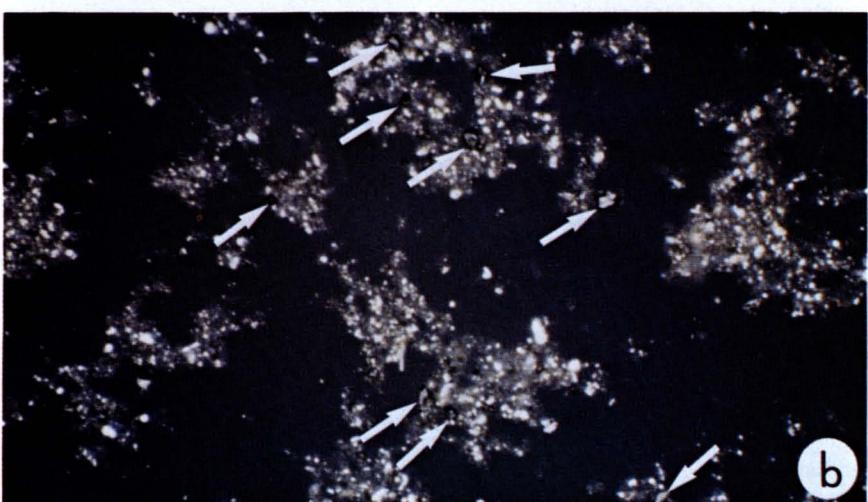
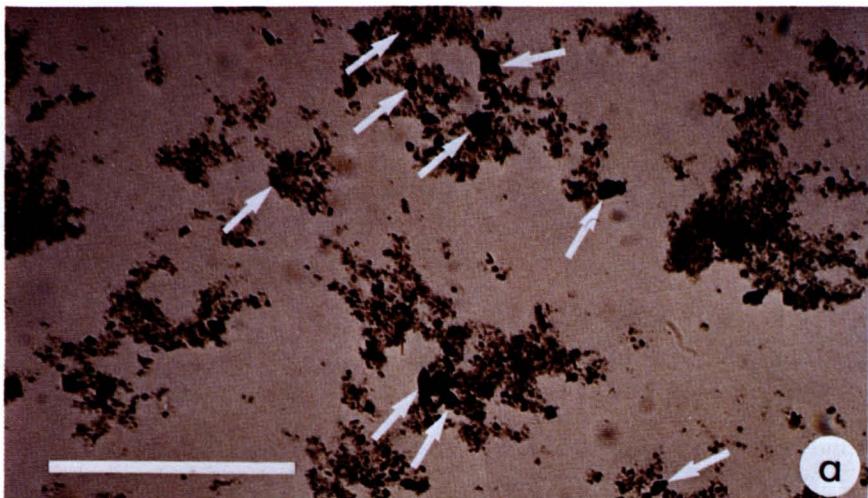
¹ Textural descriptions derived from viewing the sample with all three microscope lighting conditions with 400 \times magnification, oil immersion.

² Transmitted light.

³ Reflected light.

⁴ "Fluorescence light" or incident blue light.

Fig. 3. Type A amorphous kerogen (description in text and Table 3), three photomicrographs of the same sample field of view with different microscope illumination, oil immersion, scale is 100 microns. Sample from Well 5. Depth 2,519 m (Table 1).
 (a) Transmitted light (arrows) shows the weakly polygonal, mottled, or interconnected network type of texture in the chunky masses of organic material.
 (b) Incident white light allows for the distinction of sulfide mineral grains (white) from the brownish-grey organic material (arrows).
 (c) Incident blue light fluorescence highlights most of the organic material, showing patches of yellow color and some more textural details. Notice that some areas are brighter yellow than others, possibly due to thickness or composition differences. Not all the white sulfide grains shown in (b) are black, possibly due to a thin fluorescing layer of amorphous kerogen covering these grains.



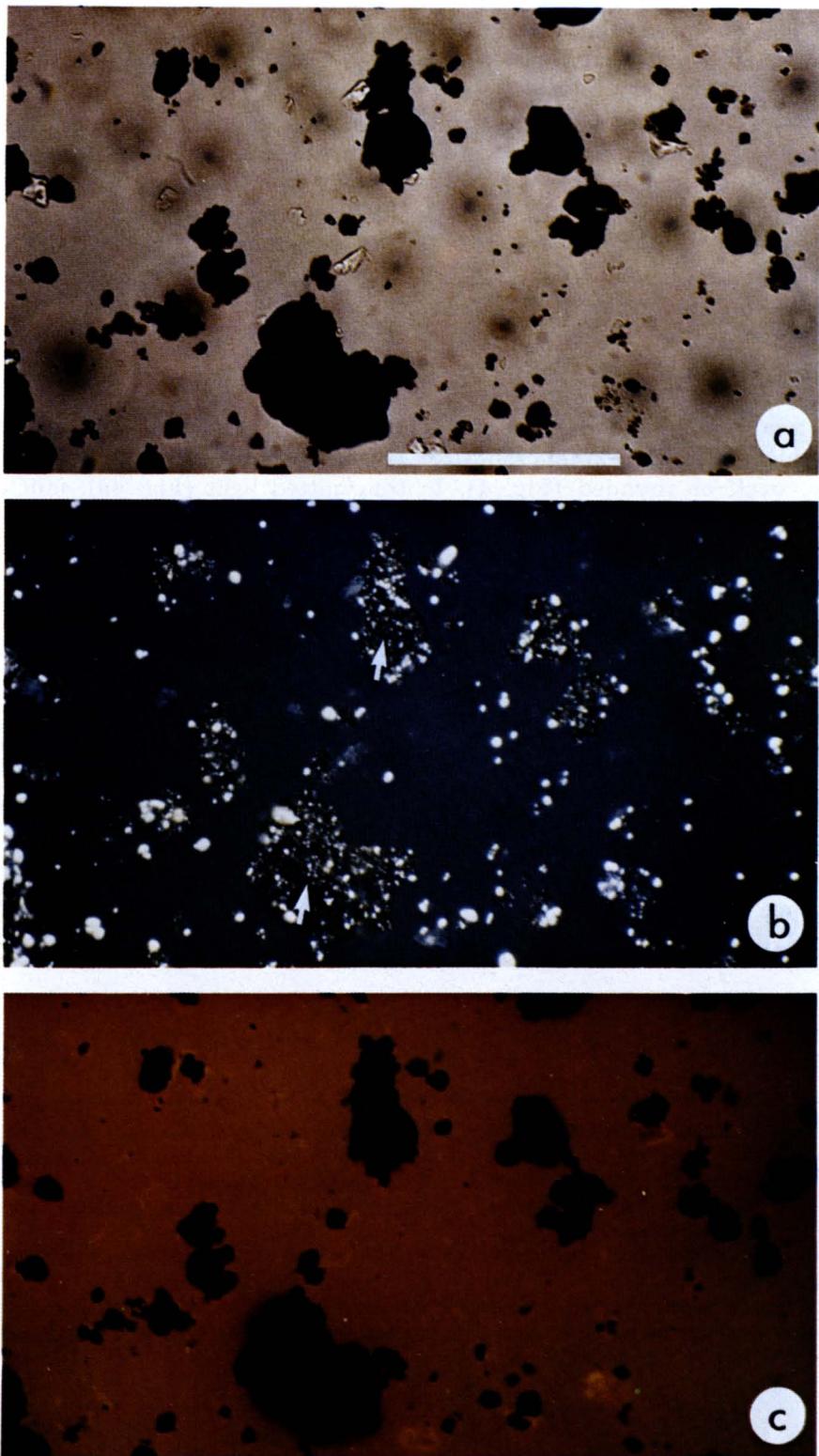
usually reddish-brown, but thicker masses can be darker brown. Sulfide mineral grains are often inside the masses giving them a black color in transmitted light. Viewing the same area of the sample with crossed polarizers shows the amount of birefringent mineral grains mixed with the kerogen. In this study set, there are very few mineral grains associated with Type A amorphous kerogen, other than the sulfides which can be seen with incident white light. With incident white light (Fig. 3b), the organic material is more brown than grey. Type A amorphous kerogen often exhibits a bright yellow color (Fig. 3c) when viewed with incident blue light. However, gradations of fluorescence among Type A amorphous kerogens are noted: shades of yellow to grey patches or flecks in nonfluorescing masses, and masses with no fluorescence at all.

Type B amorphous kerogen appears in finer, more particulate debris, but the organic grains (10–20-micron size) themselves are individual, dense, elongate, oval, or rounded (Fig. 4). In transmitted light (Fig. 4a), much of the fine-grained brown to black debris consists of tiny mineral grains (including sulfides) which are distinct with crossed polarizers or incident white light. The organic grains are usually medium grey when viewed with incident white light (Fig. 4b), although some may appear brownish-grey. Type B does not fluoresce (Fig. 4c). These grains may resemble 'vitrinite', but positive identification is difficult in strewn slides.

Type C amorphous kerogen is similar to Type B except it occurs in clumps (Fig. 5) which have globular to granular or fragmented textures. These clumps range in size from approximately 50 to 300 microns. Transmitted light (Fig. 5a) shows these clumps to be dark brown, although abundant sulfide grains may make them look black. With incident white light (Fig. 5b), these clumps are greyish-brown to medium grey. Type C displays no fluorescence (Fig. 5c).

Fig. 4. Type B amorphous kerogen (description in text and Table 3), three photomicrographs of the same field of view with different microscope illumination, oil immersion, scale is 100 microns. Sample from Well 8. Depth 1,240 m (Table 1).

- In transmitted light the organic grains appear as very dark brown, small, dense, oval to irregular shapes (arrows).
- Incident white light shows the many fine sulfide mineral grains (white) and the grey organic grains (arrows).
- The Type B amorphous kerogen grains do not fluoresce (arrows). The glints of yellow color are from mineral or mounting medium contaminants and/or small pieces of structured kerogens.



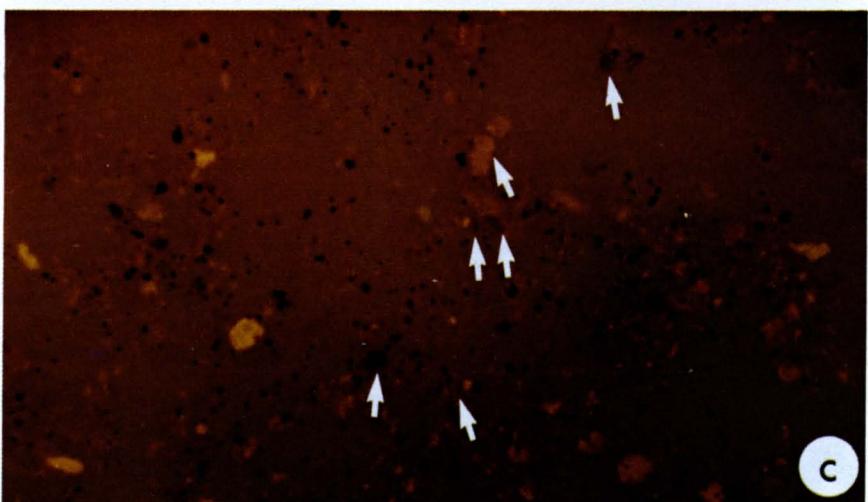
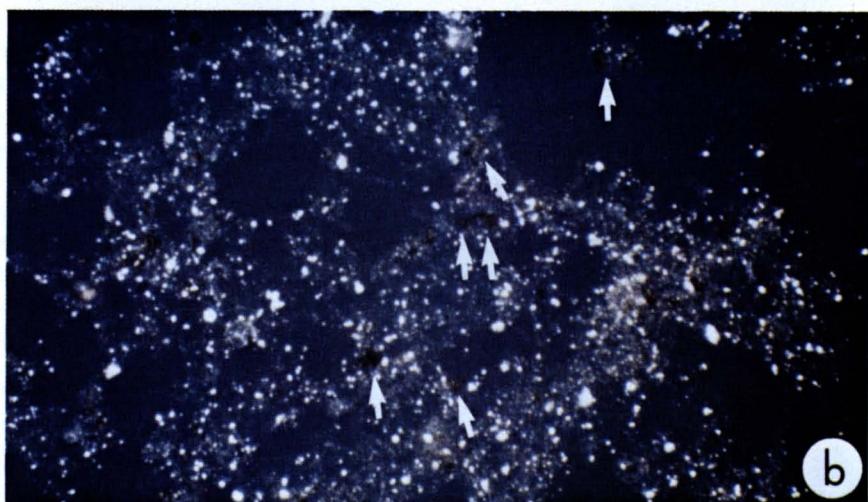
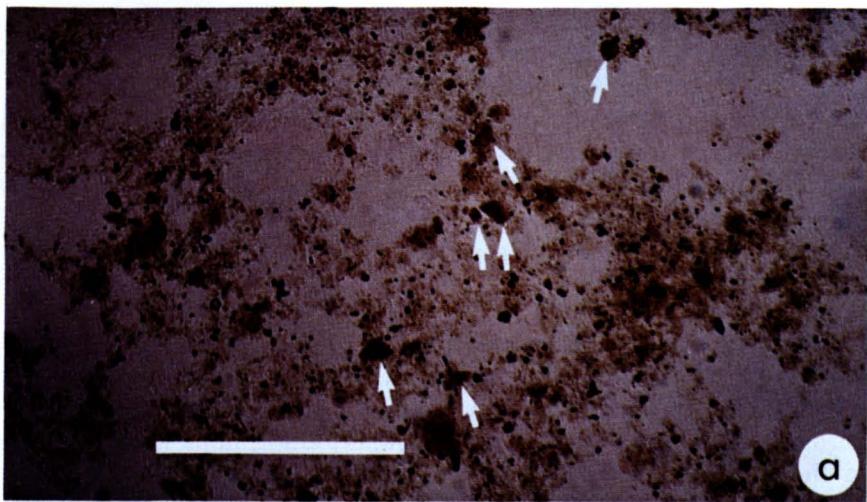
Type D amorphous kerogens are very small, thin, rectangular, or platy individual grains (Fig. 6), usually light brown in transmitted light (Fig. 6a). These grains are about ten microns in size. Often mineral grains are intermixed and careful observation between lighting conditions is necessary to discern the organic particles. These organic grains have a very dull brownish-grey reflectivity (Fig. 6b). Some Type D grains fluoresce with yellow patches or flecks, and some do not fluoresce at all (Fig. 6c).

Optical-chemical relationships

Since one of the four kinds of amorphous kerogen is usually very abundant in a sample, the geochemical characteristics (oil- or gas-prone) determined on the bulk sample is probably representative of the dominant amorphous kerogen type. Table 1 lists the dominant amorphous kerogen types found in the study set of samples according to the bulk sample oil- or gas-proneness. It is obvious that Type A amorphous kerogen is always oil-prone, only two gas-prone samples contain Type A in combination with Type B. Twenty-one of the gas-prone samples contain amorphous Types B and/or C, while only eleven of the oil-prone samples contain these types. From this limited study set, it appears that Types B and C are gas-prone kerogens. Almost an equal number of both gas- and oil-prone samples contain amorphous Type D. The fluorescent particles occur in both the oil-prone and gas-prone Type D amorphous kerogens. Type D is optically distinct from the other dominantly oil-prone (Type A) or gas-prone (Types B and C) amorphous types and does indicate the existence of possible hydrocarbons. Geochemical analyses are necessary to determine the hydrocarbon generation potential of samples containing Type D amorphous kerogen.

Fig. 5. Type C amorphous kerogen (description in text and Table 3), three photomicrographs of the same field of view with different illumination, oil immersion, scale is 100 microns. Well 4-Cretaceous. Depth 3,355 m (Table 1).

- (a) Transmitted light shows the organic grains to be red-brown to dark-brown dense globular clumps.
- (b) In reflected white light, some small sulfide mineral grains (white) can be seen inside the grey organic clumps with granular or fragmented textures (arrows).
- (c) Type C amorphous kerogens do not fluoresce and are seen as black clumps when viewed with incident blue light illumination.



CONCLUSIONS

The most important conclusion from this work is establishment of useful visual kerogen observations which can aid in the prediction of the hydrocarbon-generating potential of source rocks. The correlation of optically distinct amorphous kerogen types to the geochemically defined hydrocarbon-generating potentials (oil-prone, gas-prone) of source rocks is suggested in this study. Careful petrographic descriptions, using transmitted, incident white and blue light, are critical to recognizing the textural differences among the amorphous kerogen types. It is necessary to acknowledge the varied origin of amorphous organic material (oozes, gel, sapropels, etc.) in order to realize that amorphous kerogens cannot be characterized in relation to specific biological origins, such as algae or terrestrial plants.

If chemical traits (such as oil-proneness or gas-proneness) can be determined for each kind of optically recognizable kerogen, then visual analyses can play a very important role in the exploration for hydrocarbons. The sort of optical-chemical correlations suggested here should also be carried out for structured kerogens in hydrocarbon source rocks. In addition to the four kinds of amorphous kerogen documented in this study, there may be more optically identifiable types, such as those that may correlate with no hydrocarbon-generating potential. We feel that these amorphous kerogen types can be correlated to elemental (H/C, O/C) data as well as other geochemical parameters. The final nomenclature for the different amorphous kerogen types should describe the optical-chemical properties rather than imply specific biological origins. With additional study, it may also be possible to relate the various kinds of amorphous kerogens to specific environments of deposition such as the organic facies (oxic, sub-oxic, anoxic) described by Demaison and Moore (1980) and Massoud and Kinghorn (1985). The combination of optical and chemical techniques produces a very powerful method for understanding the hydrocarbon-generating potential and origins of source rocks. We hope the ideas presented here will lead to further classification of kerogen using combined optical and chemical techniques.

Fig. 6. Type D amorphous kerogen (description in text and Table 3), three photomicrographs of the same field of view with different illumination, oil immersion, scale is 100 microns. Well 3-Oligocene. Depth 3,270 m (Table 1).

- (a) In transmitted light, individual Type D particles (arrows) appear light brown, small, thin, rectangular, or platy. Many of the very fine fragments in this field are mineral grains which are birefringent when viewed with crossed polarizers.
- (b) Incident white light shows many fine sulfide particles (white) and the brownish-grey (arrows) Type D amorphous grains.
- (c) Incident blue light illumination shows the mixture of brightly fluorescing Type D grains and ones with little or no fluorescence (arrows). The fluorescence properties of Type D amorphous kerogens vary from sample to sample.

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