Introduction to Vitrinite Reflectance as a Thermal Maturity Indicator*

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Abstract

Thermal maturity is one of the most important parameters used in the evaluation of gas-shale and shale-oil plays. Vitrinite reflectance (VRo) is a commonly used thermal maturity indicator. Many operators use the vitrinite-reflectance value without knowing what it is or how it is derived. Conventional wisdom of the Barnett Shale gas play in the Fort Worth Basin indicates the highest gas rates occur at >1.4% VRo. Knowledge of the oil and condensate windows is essential for liquid hydrocarbon production. This presentation answers the questions: what is vitrinite; what is vitrinite reflectance; how is vitrinite reflectance measured; what are some sources of error; and how does one tell good data from bad data?

References


Bostick, N.H., 1979, Microscopic measurement of the level of catagenesis of solid organic matter in sedimentary rocks to aid exploration for petroleum and to determine former burial temperatures -- a review, in P.A. Scholle, and P.R. Schlager, (eds.), Aspects of Diagenesis: SEPM Special Publication 26, p. 17-43.


Ece, O.I., 1989, Organic maturation and paleoceanographic/paleogeographic implications of the Desmoinesian cyclothemic Excello


Introduction to Vitrinite Reflectance as a Thermal Maturity Indicator

Brian J. Cardott
Oklahoma Geological Survey
Goals of Presentation: Answer the following questions

- What is vitrinite?
- What is vitrinite reflectance?
- How is vitrinite reflectance measured?
- What are some sources of error?
- How do you tell good data from bad data?
Dispersed Organic Matter (DOM) in Shale

- **ROCK**
  - **MINERAL MATTER (99%)**
  - **ORGANIC MATTER (1%)**
  - **BITUMENS (10%)**
    - soluble organic matter
    - [also pyrobitumens which are insoluble]
  - **KEROGEN (90%)**
    - insoluble organic matter

Barker, 1979, p. 39
## Organic Matter Classifications

<table>
<thead>
<tr>
<th>MACERAL GROUP (Teichmuller and Ottenjann)</th>
<th>PHYTOCLAST GROUP (Bostick)</th>
<th>PHYTOCLAST GROUP (Massoud and Kinghorn)</th>
<th>KEROGEN TYPE (Tissot and Welte; Harwood)</th>
<th>PALYNOLOGICAL KEROGEN (Hunt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liptinite (Exinite)</td>
<td>Algal bodies</td>
<td>Keroginite</td>
<td>I</td>
<td>Algal</td>
</tr>
<tr>
<td></td>
<td>Floccules and Groundmass</td>
<td></td>
<td></td>
<td>Amorphous</td>
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<td></td>
<td>Liptinite</td>
<td>Liptinite</td>
<td>II</td>
<td>Herbaceous</td>
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<tr>
<td>Vitrinite</td>
<td>Low-gray Vitrinite</td>
<td>Vitrinite</td>
<td>III</td>
<td>Woody</td>
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<tr>
<td>Inertinite</td>
<td>High-gray Vitrinite and Fusinite</td>
<td>Inertinite</td>
<td>IV</td>
<td>Coaly</td>
</tr>
</tbody>
</table>

Taylor and others, 1998, p. 242-243
MACERAL
(from Latin: “macerare”, to soften)
Stopes, 1935

“Macerals are **organic** substances, or **optically homogeneous** aggregates of organic substances, possessing distinctive physical and chemical properties, and occurring naturally in the sedimentary, metamorphic, and igneous materials of the earth”

Spackman, 1958
# Microscopic Organic Composition
(Maceral Classification)

<table>
<thead>
<tr>
<th>MACERAL GROUP</th>
<th>ORIGIN</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITRINITE</td>
<td>Cell wall material or woody tissue of plants.</td>
<td>Intermediate</td>
</tr>
<tr>
<td>LIPTINITE (EXINITE)</td>
<td>Waxy and resinous parts of plants (spores, cuticles, wound resin)</td>
<td>Lowest</td>
</tr>
<tr>
<td>INERTINITE</td>
<td>Plant material strongly altered and degraded in peat stage of coal formation.</td>
<td>Highest</td>
</tr>
</tbody>
</table>

Crelling and Dutcher, 1980
Vitrinite occurs in post Silurian-age rocks.
# Vitrinite Maceral Classification

<table>
<thead>
<tr>
<th>VITRINITE GROUP (ICCP, 1982)</th>
<th>VITRINITE GROUP (ICCP, 1994)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maceral</td>
<td>Maceral</td>
</tr>
<tr>
<td>Submaceral</td>
<td>Maceral subgroup</td>
</tr>
<tr>
<td>Telinite</td>
<td>Telovitrinite</td>
</tr>
<tr>
<td>Telinite 1</td>
<td>Telinite</td>
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<tr>
<td>Telinite 2</td>
<td></td>
</tr>
<tr>
<td>Collinite</td>
<td>Telocollinite</td>
</tr>
<tr>
<td>Desmocollinite</td>
<td>Collotelinite</td>
</tr>
<tr>
<td>Corpocollinite</td>
<td>Collopetrinite</td>
</tr>
<tr>
<td>Gelocollinite</td>
<td>Vitrodetrinite</td>
</tr>
<tr>
<td>Vitrodetrinite(^1)</td>
<td>Gelovitrinite</td>
</tr>
<tr>
<td></td>
<td>Gelinete</td>
</tr>
</tbody>
</table>

\(^1\) Vitrudetrinite is incorporated in the detrovitrinite subgroup (ICCP, 1994)

Potter and others (1998) and ICCP (1998)
International Committee for Coal and Organic Petrology (ICCP)
Classification of Dispersed Organic Matter (DOM) (draft)
[used in visual kerogen analysis]

<table>
<thead>
<tr>
<th>MACERAL GROUP</th>
<th>MACERAL³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitrinite</td>
<td>Telnite</td>
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<tr>
<td></td>
<td>Collotelinite</td>
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<tr>
<td></td>
<td>Vitrodetrinite</td>
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<td>Collodetrinite</td>
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<td>Gelinite</td>
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<td></td>
<td>Corpogelinite</td>
</tr>
<tr>
<td>Liptinite</td>
<td>Alginithe</td>
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<tr>
<td></td>
<td>Bituminite/Amorphinithe</td>
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<tr>
<td></td>
<td>Liptodetrinite</td>
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<td>Sporinite</td>
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<td>Cutinithe</td>
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<td>Suberinithe</td>
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<td>Resinite</td>
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<tr>
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<td>Chlorophyllinite</td>
</tr>
<tr>
<td>Inertinite</td>
<td>Fusinithe</td>
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<tr>
<td></td>
<td>Semifusinithe</td>
</tr>
<tr>
<td></td>
<td>Funginithe</td>
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<td>Macrinithe</td>
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<tr>
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<td>Micrinithe</td>
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<td>Inertodetrinite</td>
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<tr>
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<td>Graptolite</td>
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<tr>
<td></td>
<td>Chitinozoa</td>
</tr>
<tr>
<td></td>
<td>Foram liners</td>
</tr>
<tr>
<td>Secondary Products</td>
<td>Bitumen</td>
</tr>
<tr>
<td></td>
<td>Pyrobitumen</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
</tr>
</tbody>
</table>
The amount of sample needed depends on the sample and how it will be analyzed.

**COAL**: 30 grams

**SHALE** (whole rock vs. kerogen concentrate; organic-rich vs. organic lean):

30 to 500 grams
Specimen holders for polishing pellets

Coal (or solid hydrocarbon) crushed-particle pellet

Pellet protective caps

Glass standard pellet

Whole-rock pellet

Kerogen plug pellet

Lucite blank pellet
Whole-rock or kerogen concentrate pellets are prepared using epoxy and allowed to cure over night;

Pellets are polished and placed in a desiccator over night to remove moisture.
Coal in Reflected White Light

Collodetrinite

Pseudovitrinite
(Collotelinite)

500X, field width 140 µ
**Vitrinite Reflectance** is used to determine coal rank and shale thermal maturity.
RANK refers to the physical and chemical changes that occur to organic matter as it is affected by increasing temperature and time.

[LIGNITE → SUBBITUMINOUS → BITUMINOUS (High Volatile; Medium Volatile; Low Volatile) → ANTHRACITE (Semianthracite; Anthracite; Meta-anthracite)]
COAL RANK FROM PROXIMATE ANALYSIS

Averitt, 1975
Vitrinite Reflectance (%Ro) is a measurement of the percentage of light reflected off the vitrinite maceral at 500X magnification in oil immersion.
Bustin and others, 1985, p. 118

Diagram showing the relationship between vitrinite volatile matter and vitrinite reflectance (Rmax). The diagram includes markers for medium volatile bituminous, low-volatile bituminous, semianthracite, and anthracite.
American Society for Testing and Materials

Designation: D 2798 – 91

Standard Test Method for Microscopical Determination of the Reflectance of Vitrinite in a Polished Specimen of Coal

ASTM, 1994

This standard is issued under the fixed designation D7708; the number immediately following the designation indicates the year of
original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A
superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the microscopical determination of the reflectance measured in oil of polished surfaces of
vitrinite dispersed in sedimentary rocks. This test method can also be used to determine the reflectance of macerals other than
vitrinite dispersed in sedimentary rocks.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this
standard.

1.3 This standard does not purport to address all of the
safety concerns, if any, associated with its use. It is the
responsibility of the user of this standard to establish appro-
priate safety and health practices and determine the applic-
ability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:
D121 Terminology of Coal and Coke
D388 Classification of Coals by Rank
D2797 Practice for Preparing Coal Samples for Microscopical
Analysis by Reflected Light
D2798 Test Method for Microscopical Determination of the
Vitrinite Reflectance of Coal

3. Terminology

3.1 Definitions—For definitions of terms, refer to Terminology D121.

3.2 Abbreviations:
3.2.1 \( R_f \) — mean random reflectance measured in oil.
Other organizations may use other abbreviations for mean
random reflectance.

3.3 Definitions of Terms Specific to This Standard:
3.3.1 alginite, \( n \) — a lipinitic maceral occurring in structured
m Morologies, talcinitic, and unstructured morphologies. La-
malginitic.

3.3.2 bituminite, \( n \) — an amorphous primary lipinitic maceral
with low reflectance, occasionally characterized by colored
internal reflections and weak orange-brown fluorescence, de-
erived from bacterial biomass and the bacterial decomposition
of algal material and faunal plankton. Bituminite is equivalent
to the amorphous organic matter recognized in SI 3 slides of
concentrated kerogen (I).

3.3.2.1 Discussion—Bituminite may be distinguished from
vitrinite by lower reflectance, as well as higher fluorescence
intensity if fluorescence is present in vitrinite. Bituminite has
poorly-defined wavy boundaries and may be speckled or
unevenly colored whereas vitrinite has distinct boundaries and
is blockier and evenly colored. The occurrence of bituminite in
association with lamalginite and micrinite is common. Rock
type, thermal maturity, and geologic occurrence can be used to
interpret the potential presence of bituminite; for example,
bituminite may be expected to occur in lacustrine or marine
settings. It is less commonly present in fluvial or similar
proximal depositional environments, where vitrinite may be
expected to occur in greater abundance.

3.3.3 chitinozoan, \( n \) — a group of fish-shaped, sometimes
ornamented marine microfossils of presumed metazoan origin
which are composed of "pseudochitin" proteinic material and
which occur individually or in chains. Chitinozoan cell walls
are thin, opaque to translucent, and range from dark gray to
white in reflected white light similar to vitrinite. Chitinozoans
are common in Ordovician to Devonian marine shales.

3.3.4 conodont, \( n \) — the phosphatic, tooth-like remains
of marine vertebrate worm-like animals present from the Can-
brian through Triassic, composed predominantly of apatite
with subordinate amounts of organic matter. Conodont mor-
phology is variable, but often well-defined denticles and blades
are preserved. In reflected white light examination conodonts
range from pale yellow to light brown to dark brown and to
black.

3.3.5 fuxinite, \( n \) — an inertinite maceral distinguished prin-
cipally by the preservation of some feature(s) of the plant cell
wall structure, high relief, and reflectance substantially higher
than first cycle vitrinite in the same sample. When less than
Coalification Curves

Stach and others, 1982
Physical, Chemical, and Molecular Changes of Vitrinite

Taylor and others, 1998
Reflectance Indicatrix

Taylor and others, 1998
Dispersed Vitrinite

Importance of vitrinite texture quality

500X, field width 140 μ
<table>
<thead>
<tr>
<th>PETROGRAPHER</th>
<th>VRo</th>
<th>SAMPLE IDENTIFICATION</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>nonpolarized light</td>
</tr>
<tr>
<td>DATE</td>
<td></td>
<td>PEPELLET NUMBER</td>
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<tr>
<td>V</td>
<td>PV</td>
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</tr>
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<td>0.60</td>
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<tr>
<td>0.57</td>
<td>0.87</td>
<td>1.22</td>
</tr>
</tbody>
</table>

**Precision to 0.01%**
WOODFORD SHALE, ARBUCKLE MOUNTAINS
VITRINITE REFLECTANCE HISTOGRAM

OPL 385
$R_0 = 0.53\%$
n = 75
S.D. = 0.01
Maximum Vitrinite Reflectance of Coal Stringer from Woodford Shale Core

R_{max} = 1.78\%

n = 100
PROPERLY IDENTIFIED VITRINITE
- Primary
- Recycled
- Caving
- Mud additives
- Subtypes vary Ro (<0.5)

FACTORS AFFECTING ACCURATE Ro MEASUREMENT
- Rough textured vitrinite
  - Weathered
  - Partially dissolved (pitted)
  - Fractured
- Oxidized vitrinite
- Inclusions
  - Pyrite
  - Bitumen
  - Other macerals
- Oily vitrinite
- Natural coking
- Too few readings (<20)

MATERIAL WHICH MAY LOOK LIKE VITRINITE
- Solid bitumen (several types)
- Pseudovitrinite
- Semifusinite

Modified from Dow and O’Connor, 1982
Vitrinite-like organic matter
Vitrinite subtypes
Inertinite macerals
Solid bitumen (several types)
Graptolites
Vitrinite Subtypes

Pseudovitrinite
(Collotelinite)

Colloidetrinite

500X, field width 140 μ
Inertinite Macerals

Fusinite

Semifusinite

200X, field width 320 μ
Genetic Bitumen Classification

- **Pre-Oil Solid Bitumen**: early-generation products of rich source rocks, probably extruded from their sources as a very viscous fluid, and migrated the minimum distance necessary to reach fractures and voids in the rock. [Kerogen → Bitumen → Oil]

- **Post-Oil Solid Bitumen**: products of the alteration of a once-liquid crude oil, generated and migrated from a conventional oil source rock, and subsequently degraded. [solid residue of primary oil migration]

Curiale (1986)
Two Common Pre-Oil Bitumen Optical Forms Based on Landis and Castaño (1994)
[regression equation is based on homogenous form]
Vitrinite-Like Organic Matter
Solid Hydrocarbons (Bitumen)

0.85% BRo

500X, field width 140 μ
Use of pre-oil solid bitumen as **thermal maturity indicator** following “solid hydrocarbon” reflectance to vitrinite reflectance equivalent regression equation of Landis and Castaño (1994)

\[ \text{VRE} = \frac{\text{BRo} + 0.41}{1.09} \]

For additional references visit [http://www.tsop.org/refs/bitref.htm](http://www.tsop.org/refs/bitref.htm)
Vitrinite-Like Organic Matter

Graptolites

For additional references visit http://www.tsop.org/refs/zooclast.htm
Cardott and Kidwai, 1991

500X, field width 140 μ
VITRINITE-REFLECTANCE ANALYSIS

SOURCES OF ERROR

- Samples
- Equipment
Samples are Everything
(Garbage In = Garbage Out)
SAMPLES

- SAMPLE TYPE
- LITHOLOGY
- SAMPLE HANDLING
- ORGANIC MATTER
SAMPLES

- **SAMPLE TYPE** (core, outcrop, well cuttings)
- **LITHOLOGY** (coal, shale, siltstone, sandstone)
- **SAMPLE HANDLING** (oil-based drilling mud, kerogen isolation, oxidation, heating)
- **ORGANIC MATTER** (quantity, quality, size, type, thermal maturity, reflectance suppression/enhancement)
CORE >> OUTCROP > WELL CUTTINGS
(Weathering) (Caving)

(Recycled Vitrinite)

(Vitrinite - Like Organic Matter)
Drilling Mud
Additive
Caving Contamination
Oil-Based Mud
EXPLANATION

Bitumen

Vitrinite

Reflectance value used to characterize level of diagenesis

High-gray group

Borehole cavings
Weathered Coal

Lo and Cardott, 1994

500X, field width 140 μ

For additional references visit http://www.tsop.org/refs/weath.htm
Weathered Shale

Cardott, 1994

500X, field width 140 μ
SAMPLES

- **SAMPLE TYPE** (core, outcrop, well cuttings)
- **LITHOLOGY** (coal, shale, siltstone, sandstone)
- **SAMPLE HANDLING** (oil-based drilling mud, kerogen isolation, oxidation, heating)
- **ORGANIC MATTER** (quantity, quality, size, type, thermal maturity, reflectance suppression/enhancement)
Reflectance of the coal seam with which each sample is compared.

Fields of data for each lithology: sandstones — ; argillites — ; limestones — .

Bostick and Foster, 1975
SAMPLES

- **SAMPLE TYPE** (core, outcrop, well cuttings)
- **LITHOLOGY** (coal, shale, siltstone, sandstone)
- **SAMPLE HANDLING** (oil-based drilling mud, kerogen isolation, oxidation, heating)
- **ORGANIC MATTER** (quantity, quality, size, type, thermal maturity, reflectance suppression/enhancement)
SAMPLES

- **SAMPLE TYPE** (core, outcrop, well cuttings)
- **LITHOLOGY** (coal, shale, siltstone, sandstone)
- **SAMPLE HANDLING** (oil-based drilling mud, kerogen isolation, oxidation, heating)
- **ORGANIC MATTER** (quantity, quality, size, type, thermal maturity, reflectance suppression/enhancement)
ORGANIC MATTER ERRORS

- Quantity (minimum of 20) (Barker and Pawlewicz, 1993)
- Quality (e.g., pitted vitrinite) (ICCP)
- Size (larger than measuring spot, >10 microns)
- Type (vitrinite-like organic matter)
- Thermal maturity (anisotropy, >1% VRo)
- Reflectance suppression/enhancement (e.g., alginate; oxidizing environment)
Pitted Vitrinite

0.47% Ro

500X, field width 140 μ
Pitted Vitrinite

1.04% VRo
(sample is 1.23% VRo)

500X, field width 140 μ
Reflectance Suppression

For additional references visit
http://www.tsop.org/refs/supro.htm

from:

modified after:
Summary of How to Tell Good Data from Bad Data

- **Number of Measurements** (minimum of 20)
- **Reflectance Histogram**
  (shape of distribution and spread of values)
- **Photomicrographs**
  (quality and size of clasts; surrounding minerals [kerogen concentrate vs. whole-rock]; correct identification of low-gray [primary] vitrinite vs high-gray [recycled] vitrinite or inertinite)
Example of Poor Interpretation from Core Sample

\begin{align*}
\text{NUMBER OF READINGS} & \quad \begin{array}{cc}
\text{MIN. REF.} & .041 \\
\text{MAX. REF.} & 2.15 \\
\text{MEAN REF.} & 1.18 \\
\text{Std. Dev.} & \pm 0.465 \\
6725 \text{ Feet} & \\
\end{array} \\
\text{READINGS} & : 110
\end{align*}
Another Example of Poor Interpretation (used to calibrate a new thermal maturity indicator)

Abdelmalak and others, 2012
EQUIPMENT

- **POLISHING EQUIPMENT** (quality of polish; relief-free, scratch-free surface)
- **GLASS STANDARDS/CALIBRATION** (Ro range; immersion-oil contamination; air bubbles)
- **MICROSCOPE/PHOTOMETER** (quality of photometer/optics; stability to 0.01% Ro; frequency of calibration)
Importance of petrographic qualitative thermal maturity indicators to check accuracy of vitrinite-reflectance value:

- **Fluorescence** of liptinite macerals (e.g., algae): fluorescence changes from green, greenish-yellow, yellow, orange with increasing thermal maturity before it is extinguished (0.9-1.0% VRo for Tasmanites)
- Vitrinite Reflectance Equivalent from bitumen reflectance values.
Vitrinite is a coal maceral derived from wood.

Vitrinite reflectance is a measurement of the percentage of light reflected from the vitrinite maceral.

Vitrinite reflectance value is an average of many measurements.

**Disadvantages**
Vitrinite reflectance cannot tell you whether or not a rock generated oil or gas

**Limitations**
Post Silurian-age rocks

Dependent on sample quality, size, and contamination
http://www.tsop.org

The Society for Organic Petrology

TSOP - Beijing

TSOP - Halifax 2011 Meeting

TSOP is...

A Society for scientists and engineers involved with coal petrology, kerogen petrology, organic geochemistry and related disciplines. We have over 200 members in 30 countries. If you are part of the organic petrology community, we invite you to join TSOP.

Website includes Members-Only section

TSOP Members! Set up your account in our members-only section (with the user ID which you received in e-mail) to check your membership data, use the new Membership Directory, and more. Members don't need an account to pay dues online.

Help develop this new TSOP web site

Volunteers are wanted, for example to work with image galleries, administer sections on links, the calendar, and others. Please contact the webmaster.

Ask An Organic Petrologist

Have a question about organic petrology? See this new feature to ask a TSOP expert for the answer to your question.

TSOP receives 501(c)(3) status

We incorporated as a non-profit in the state of Virginia, USA, in 2008. Following application in June, 2009, the US Internal Revenue Service granted recognition of 501(c)(3) tax-exempt status on February 9, 2010. See the article on page 6 of the March Newsletter.

Other organizations of organic petrologists include ICCP and CSCOP.

Elsevier's International Journal of Coal Geology publishes the proceedings of TSOP Annual Meetings.

TSOP is a Member Society of AGI (publishers of Earth, formerly Geotimes; see editorial statement), and an AAGB Associated Society.
Selected References on Organic Petrology

Introduction

These bibliographic references have been compiled as a TSOP project, and organic petrologists have found the references to be useful in their work. The publications should be available at university or geological research center libraries. They are not available from TSOP, except for those listed on our Publications page, or as part of the TSOP Newsletter.

To view a category of references on this web site, choose from the list of individual topics.

Additional reference citations for inclusion in this project may be submitted to webmaster@tsop.org. Please state which of the categories would include them.

ENDNOTE Library:

Bob Cluff and others at The Discovery Group have formatted all 2200 TSOP references (from the 2007 update) on the topics listed at the left into an EndNote® X1 library. Download it here: TSOP_references_2007.ent

Updates to that file may be downloaded here (for EndNote® X2 and higher):

TSOP_references_2005_update.ent (2005 and 2009)
EndNote users can use its update process to add the contents of the 2009 update to the 2007 file. If comments or additional references have been placed in the 2007 file, this process will preserve them in the resulting file.

Journal styles for EndNote may be downloaded here:
International Journal of Coal Geology style
Please submit requests for other journal style files to webmaster@tsop.org

references last updated December 2011
Please submit suggested additions to webmaster@tsop.org
References Cited


Bostick, N.H., 1979, Microscopic measurement of the level of catagenesis of solid organic matter in sedimentary rocks to aid exploration for petroleum and to determine former burial temperatures -- a review, in P.A. Scholle, and P.R. Schluger, eds., Aspects of Diagenesis: S.E.P.M. Special Publication 26, p. 17-43.


