



# Development of web-based organic petrology photomicrograph atlases and internet resources for professionals and students



Brett J. Valentine\*, Eric A. Morrissey, Andy J. Park, Mark E. Reidy, Paul C. Hackley

U.S. Geological Survey, MS 956 National Center, Reston, VA, 20192, United States

## ARTICLE INFO

### Article history:

Received 2 February 2012

Received in revised form 25 September 2012

Accepted 27 September 2012

Available online 5 October 2012

### Keywords:

Photomicrograph atlas

Organic petrology

Macerals

Web atlas

Online tools

## ABSTRACT

With advances in web applications, organic petrography and other related disciplines are in need of updated online resources and educational tools to aid professionals and students in the identification and interpretation of macerals. The U.S. Geological Survey (USGS) Organic Petrology Laboratory along with USGS Eastern Energy Resources Science Center Information Technology staff have developed five web atlases containing images of organic matter in geologic materials: 1. an American Society for Testing and Materials (ASTM) Atlas, 2. an Organic Petrology Taxonomy for International Classification (OPTIC) of Coal Macerals Atlas, 3. an Interactive Gulf Coast Photomicrograph Web Atlas (I-Map), 4. an Organic Material in Shales Atlas (Shale), and 5. an interactive Blue/White/Ultraviolet (UV) Light Atlas (Light). Each web atlas contains images of macerals with associated sample and petrographic data collected by the USGS. These webpages will provide means to preserve and circulate petrographic data collected by the USGS for coal and shale samples from all over the world.

Published by Elsevier B.V.

## 1. Introduction

Textbooks, printed regional atlases, and compact disc compilations displaying coal macerals have been useful resources to aid organic petrology professionals and students in the identification and interpretation of macerals (e.g., Falcon and Snyman, 1986; International Committee for Coal and Organic Petrology, 2006; Martinec et al., 2005; Panaiteescu and Predeanu, 1999; Papp et al., 1998; Potter et al., 1998; Sen Gupta and Bardhan, 2005; Taylor et al., 1998; Yang et al., 1996). These traditional resources can be expensive to produce, and difficult to access. Some may use outdated nomenclatures, or have poor quality images. Today maceral descriptions with photomicrograph examples are being delivered over the internet in web atlases (e.g., Crelling, 2003; Dennen and Valentine, 2009; Indiana Geological Survey, 2011). Online atlases provide resources for students and the public on organic petrology and coal macerals; however, a sufficient number of photomicrographs are needed to fully express the range of variation that macerals can exhibit, along with supporting sample/petrographic data.

In 2009 the U.S. Geological Survey (USGS) Organic Petrology Laboratory (USGS-OPL) in Reston, Virginia, launched an online web atlas for metallurgical bituminous coals containing 140 photomicrographs (Gesserman et al., 2009) with macerals labeled according to the

American Society for Testing and Materials (ASTM) coal maceral classification criteria (ASTM, 2011a). Referred to herein as the ASTM Atlas, the labeled photomicrographs are divided into seven maceral groups and types. Web metrics data collected from October 13th, 2011, through December 13th, 2011, showed 160 visits to the USGS Organic Petrology Photomicrograph Atlas webpage from unique government, academic, private sector and public web users representing 25 different countries (Tables 1 and 2). The ASTM atlas had 106 visits over the same time period with the vitrinite gallery receiving the most views (Table 2). Even though the web metrics data cover a fairly short timeframe, they show that the atlas is being viewed by a wide audience of different user types from many locations.

Building upon the ASTM Atlas, the USGS Eastern Energy Resources Science Center (EERSC) staff has developed multiple petrographic web atlases (<http://energy.usgs.gov/Coal/OrganicPetrology/PhotomicrographAtlas.aspx>). These atlases provide tools and examples that aid in identifying organic matter in geologic material. This paper describes the content of the atlases and the methodology used to create them. The web atlases include:

1. Organic Petrology Taxonomy for International Classification (OPTIC) of Coal Macerals Atlas
2. Interactive Gulf Coast Photomicrograph Web Atlas (I-Map)
3. Organic Material in Shales Atlas (Shale)
4. Interactive Blue/White/Ultraviolet (UV) Light Atlas (Light).

Updates to the ASTM Atlas are also described herein.

\* Corresponding author. Tel.: +1 703 648 6480; fax: +1 703 648 6419.  
E-mail address: [bvalentine@usgs.gov](mailto:bvalentine@usgs.gov) (B.J. Valentine).

**Table 1**

Two month representation of the number of visits by types of web users to the USGS Organic Petrology Atlas Webpage. Data were collected from October 13th, 2011, to December 13th, 2011.

| Types of atlas web users | # of visits |
|--------------------------|-------------|
| Government               | 44          |
| University/school        | 12          |
| Private sector           | 11          |
| Public sector/other      | 93          |
| Total                    | 160         |

## 2. Methods

### 2.1. Laboratory procedures and equipment

Samples received by the USGS-OPL for petrographic analyses are prepared by grinding to pass 850  $\mu\text{m}$  (no. 20 mesh) or 1000  $\mu\text{m}$  (no. 16 mesh) sieves and mounting into a circular one inch mold with thermoplastic powder or epoxy resin medium. Sample pellets are then ground and polished to make a flat examination surface following protocols established by the ASTM Standard Practice D 2797: *Preparing Coal Samples for Microscopical Analysis by Reflected Light* (ASTM, 2011b). After sample preparation, USGS staff conducts an array of petrographic analyses during which photomicrographs are taken to document features found during examination. Images are captured using either a Leica DMRX microscope with a Leica DFC 480 digital camera or a Zeiss Axiolmager microscope with a Zeiss AxioCam MRc digital camera. Both microscopes are equipped with tungsten halogen (for white incident light) and tin halide (for blue light/UV fluorescence) light sources.

### 2.2. Image capture and processing

The USGS-OPL has been capturing digital photomicrographs of organic matter in coals, shales, and other geologic materials during routine petrographic analysis since 2002 and has amassed thousands of photomicrographs since that time. All photomicrographs were saved in Tagged Image File Format (TIFF) over multiple computers and servers. Atlas development began by collecting all of the digitally saved images and compiling a detailed inventory, which included descriptions of maceral types, illumination conditions (e.g., oil immersion, incident white light), sample origin, preparation, and collected petrographic data. This information was then used to generate metadata for each of the images found within the atlases (Table 3). Editing and labeling of images were completed using Adobe Photoshop™ and Illustrator™ software.

Except for images in the ASTM and Light Atlases, all photomicrographs contain macerals labeled according to classifications promulgated by the International Committee for Coal and Organic Petrology (ICCP; ICCP, 1998, 2001; Sýkorová et al., 2005) and, in the case of liptinite

macerals, classifications according to the textbook *Organic Petrology* by Taylor et al. (1998). The labeled macerals in the atlases were chosen because they meet the standards established by the ICCP or ASTM and range in quality from “textbook” examples to those that could span several different maceral types. By displaying some photomicrographs that are not prime maceral examples, users can view and interpret the variability that macerals can exhibit. Despite the fact that the definitions and standards for maceral identification promulgated by the ASTM and ICCP give practitioners the best guidance in the identification of macerals, the process can be subjective. The labeled macerals in the web atlases were identified by USGS-OPL staff following interpretation of the ASTM and ICCP definitions and standards. Maceral labels that contain a “?” indicate that the exact identification could not be labeled with 100% confidence; a short comment describing why the maceral was marked as questionable is included in the metadata. Users who find errors or have suggestions for improvement are encouraged to contact the USGS-OPL using contact information found in the metadata of each photomicrograph.

After labeling, image file sizes are reduced from a high resolution TIFF format (200 dpi) to a Portable Network Graphic (PNG) image format (75 dpi) for faster web viewing. Each labeled photomicrograph is reviewed by at least two staff members of the USGS-OPL to evaluate the maceral identifications and the information compiled within the metadata. During the image review process if there is a disagreement or uncertainty about a maceral identification, the label is changed or the description of the maceral is amended to provide clarification.

### 2.3. Webpage construction

Once photomicrographs have been formatted and labeled, and the metadata compiled, USGS-OPL staff passes all digital content to USGS EERSC Information Technology (IT) staff that creates the atlas and gallery webpages. An open source web content management system that contains a web site development framework (DotNetNuke) is utilized to quickly build and deploy feature-rich, interactive web sites and applications utilizing Microsoft.NET technology. A gallery module in DotNetNuke uploads and organizes photomicrographs into their individual galleries. Photomicrograph metadata is built using a Microsoft SQL database that creates and/or retrieves data from the photomicrograph inventory database. The metadata is hyperlinked to each image within the gallery module.

The final web product varies slightly depending on the atlas type, but ultimately the webpage of each photomicrograph gallery exhibits thumbnails for each image. By selecting a thumbnail, a high quality enlarged image in a gallery viewer window will open on the users' monitor. Users can expand the image, advance to other images within the gallery, enable a slideshow of images, view associated metadata, print or email the image, or use social networking tools such as Twitter™ or Facebook™ to share images and data.

Following USGS Fundamental Science Practices for peer review (USGS, 2011) and per the discretion of the USGS EERSC, two technical reviewers evaluate all webpages. Webpages are posted once they have received Bureau approval. All USGS Photomicrograph Atlases are provided on a provisional basis and are potentially subject to revision. The data are released on the condition that neither the USGS nor the United States Government may be held liable for any damages resulting from its authorized or unauthorized use.

## 3. Content

### 3.1. USGS Organic Petrology Atlas Webpage

Photomicrograph Atlas users are initially presented a ‘dashboard’ menu that allows them to navigate between the different atlases (Fig. 1). Web users can also navigate to background information

**Table 2**

Two month representation of the number of web user visits to the USGS Organic Petrology ASTM Photomicrograph Atlas by maceral type gallery. Data was collected from October 13th, 2011, to December 13th, 2011.

| ASTM Atlas photomicrograph galleries | # of visits |
|--------------------------------------|-------------|
| Vitrinite gallery                    | 37          |
| Sporinite gallery                    | 13          |
| Micrinite gallery                    | 13          |
| Cutinite gallery                     | 12          |
| Semifusinite gallery                 | 12          |
| Fusinite gallery                     | 10          |
| Inertodetrinite gallery              | 9           |
| Total                                | 106         |

**Table 3**  
List and description of USGS Organic Petrology Photomicrograph Atlas metadata.

| Attribute title        | Data description and format                                                                                                                                                                                             |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Photomicrograph        | Name of the photomicrograph.                                                                                                                                                                                            |
| File name              | File name of the photomicrograph with JPEG image hyperlink.                                                                                                                                                             |
| Title                  | Title of the photomicrograph listing the type of sample (e.g., lignite, subbituminous, shale) and the macerals labeled in the image.                                                                                    |
| Sample name            | Sample names are typically assigned by the collector of the sample.                                                                                                                                                     |
| Lab ID                 | A unique laboratory identification number for each sample that enters the USGS Organic Petrology. Lab IDs were first assigned in 2005. All samples prior to 2005 will have a Lab ID of 0.                               |
| Sample type            | Describes the type of sample collected (e.g., core, cutting, grab sample).                                                                                                                                              |
| Date taken             | Date the photomicrograph was taken in the USGS Organic Petrology Laboratory.                                                                                                                                            |
| Photographer           | Name(s) of the photographer who captured the image.                                                                                                                                                                     |
| Location               | The location of the USGS Organic Petrology Laboratory: U.S. Geological Survey, MS 956 National Center, Reston VA 20192                                                                                                  |
| Contact                | USGS Organic Petrology Laboratory staff member to contact if there are questions or to request additional information.                                                                                                  |
| Preparation            | Describes how the sample was prepared in the USGS Organic Petrology Laboratory prior to making sample briquette.                                                                                                        |
| URL                    | Uniform resource locator (URL) listing the internet address of the atlas or gallery that comprises the photomicrograph.                                                                                                 |
| Condition              | Describes the microscope conditions during image capture (e.g., white incident light under oil immersion, blue incident light under oil immersion).                                                                     |
| Collector              | The name of the person who collected the sample.                                                                                                                                                                        |
| Material               | Describes the sample rock type (e.g., coal, shale).                                                                                                                                                                     |
| Well/mine name         | The name of the well or mine from which the sample was collected.                                                                                                                                                       |
| Number of samples      | The number of unique samples recovered from the well or mine location (e.g., number of samples taken from different depths in a well).                                                                                  |
| Country                | The country of origin of the sample.                                                                                                                                                                                    |
| State                  | The state where the sample was collected.                                                                                                                                                                               |
| County                 | The county where the sample was collected.                                                                                                                                                                              |
| Latitude               | Sample collection decimal degree location values.                                                                                                                                                                       |
| Longitude              | Sample collection decimal degree location values.                                                                                                                                                                       |
| Lease                  | Sample collection well lease name.                                                                                                                                                                                      |
| API                    | American Petroleum Institute (API) number identifying well where the sample(s) were collected.                                                                                                                          |
| Top depth (ft)         | Depth to top of sampled section.                                                                                                                                                                                        |
| Bottom depth (ft)      | Depth to bottom of sampled section.                                                                                                                                                                                     |
| Basin                  | Describes the basin or region where the sample was taken (e.g., Gulf Coast, North Slope Alaska, Appalachian).                                                                                                           |
| Period                 | The geologic time period of the rock formation.                                                                                                                                                                         |
| Epoch                  | The geologic epoch of the rock formation.                                                                                                                                                                               |
| Age                    | The geologic age of the rock formation.                                                                                                                                                                                 |
| Group                  | The geologic group of the rock sample.                                                                                                                                                                                  |
| Formation              | The geologic formation of the rock sample.                                                                                                                                                                              |
| Member                 | The geologic member of the rock sample.                                                                                                                                                                                 |
| Vitrinite Ro, random   | Measurement of sample mean vitrinite reflectance. Be advised, some samples may not have been measured to ASTM standards. Use the metadata publications hyperlink (where available) to access more in-depth information. |
| Vitrinite Rmax         | Measurement of sample mean maximum vitrinite reflectance according to ASTM standards. Use the metadata publications hyperlink (where available) to access more in-depth information.                                    |
| Standard deviation     | Measure of the variability or diversity of the vitrinite reflectance measurements.                                                                                                                                      |
| Number of measurements | Number of vitrinite measurements collected from each sample.                                                                                                                                                            |
| Estimated rank         | Estimated coal rank based on ASTM D388 (ASTM, 2011d).                                                                                                                                                                   |
| Project                | The name of the research project for which the sample was collected.                                                                                                                                                    |
| Publication            | Hyperlink (where available) to online publications that contain additional information and data regarding the sample, location, or photomicrograph.                                                                     |
| Macerals               | A list of the macerals that have been labeled in the photomicrograph.                                                                                                                                                   |
| Mineral                | A list of minerals either labeled or present in the photomicrograph.                                                                                                                                                    |
| TOC                    | Total organic carbon (TOC) measurement in wt.%.                                                                                                                                                                         |

**Table 3** (continued)

| Attribute title | Data description and format                                                                                                                                                                                                                                    |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Comment         | Describes the photomicrograph by listing the labeled macerals found within the image and the light conditions in which it was taken. Comments may also describe questionable maceral identifications or why a particular maceral type was chosen over another. |

about each photomicrograph atlas including its purposes, related publications, citation preference for images, atlas contributors, and frequently asked questions (FAQ)/help within the About section of the dashboard (About; Fig. 1).

### 3.2. ASTM Atlas

The ASTM Atlas (ASTM; Fig. 1) has been available since 2009 (Gesserman et al., 2009) and contains 7 maceral type galleries showing images of metallurgical bituminous coals labeled according to the ASTM coal maceral classification criteria (ASTM, 2011a). For each maceral type gallery selection, users view a short description of the maceral based on the ASTM classification, with a gallery of thumbnail images. Selection of a thumbnail image opens a high quality enlarged image with options previously described (view metadata, print or email, share via social networking, or proceed to other images; Fig. 2).

### 3.3. OPTIC Atlas

The OPTIC Atlas (OPTIC; Fig. 1) was created to provide visual examples of macerals according to classifications established by the ICCP (ICCP, 1998, 2001; Šýkorová et al., 2005) and liptinite examples from Taylor et al. (1998). The atlas is divided into maceral groups, subgroups, and maceral type, with 25 maceral type galleries containing approximately 400 labeled images. Selection of a thumbnail in a maceral type gallery opens an enlarged image with tools previously described. Initial images for the OPTIC Atlas were taken from USGS-OPL investigations of lignite and subbituminous coals in the North Slope of Alaska and the Gulf Coast region, USA (Bailey, 2008; Hackley and Warwick, 2005; Hackley et al., 2006, 2007, 2011, 2012; Warwick et al., 2006). Most images were taken under oil immersion in white incident light and some were collected under a dry objective or oil immersion with blue light or UV fluorescence. A small portion of the images have been published in USGS or outside publications, but the majority has not been available until now. Once the ICCP approves a new classification standard for liptinite macerals, the atlas will be updated to comply with those standards. As part of planned updates to the OPTIC and other image atlases, the USGS-OPL and IT staff are developing user feedback tools.

### 3.4. Interactive Gulf Coast Petrographic Web Atlas (I-Map)

The interactive Gulf Coast Petrographic Web Atlas (I-Map; Fig. 1) allows users to select images and metadata based on sample location (e.g., core samples from a well, or channel/grab samples from a mine or outcrop) on an interactive map. Over 1100 photomicrographs of lignite and subbituminous coals from five states in the Gulf Coast have been collected by the USGS-OPL since 2002. The images were generated as part of the assessment of coal resources in the region (Warwick et al., 2011). Some of the petrographic data have been published (e.g., Hackley et al., 2007) but the majority of the images have not been available until now.

The I-Map was created with Adobe Flex using the Environmental Systems Research Institute (ESRI) Web Application Programming Interface (API; Fig. 3). The map contains basic navigation tools and the ability to change scale from regional to localized levels of detail. Users can conveniently sort and select sample data using the data table located below the map or filter locations by using the filter

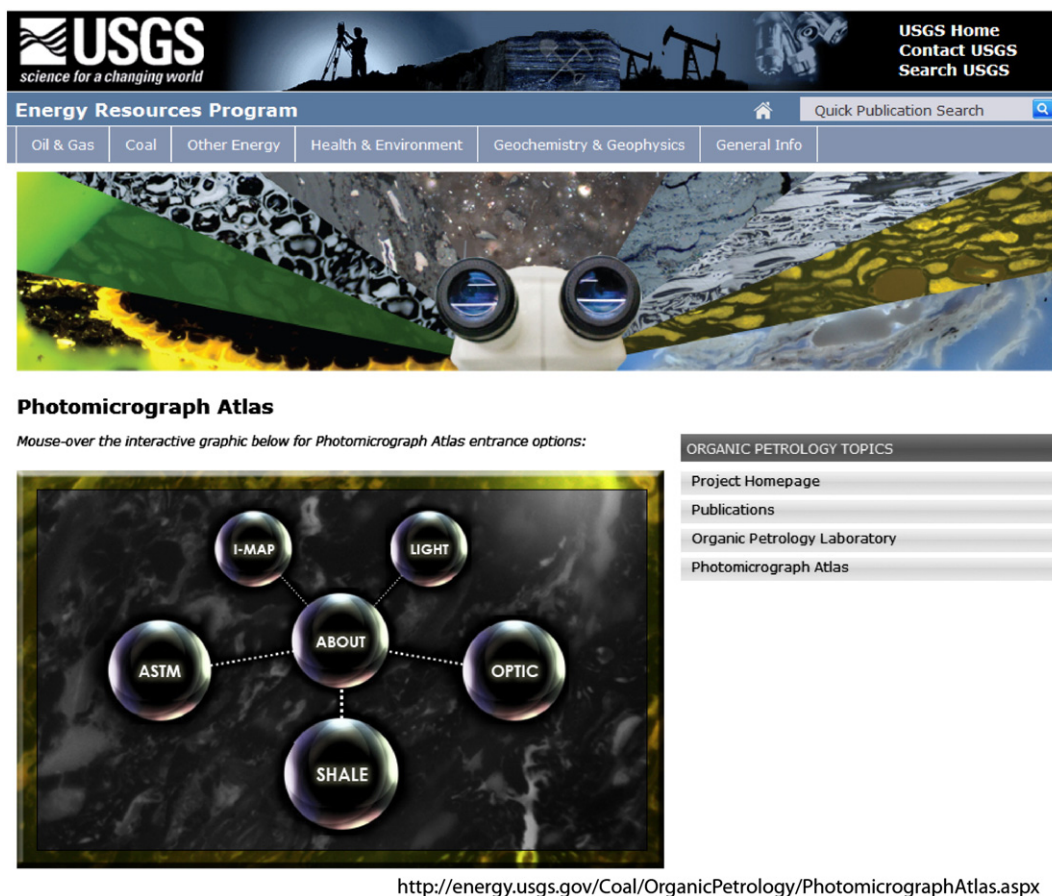


**Fig. 1.** Screen capture image of the USGS Organic Petrology Atlas Webpage with “dashboard” menu. Through the use of the “dashboard,” web users can view information about the atlas webpages (“About”) or navigate to one of the 5 petrographic atlases: ASTM Atlas (“ASTM”), OPTIC Atlas (“OPTIC”), Interactive Gulf Coast Photomicrograph Web Atlas (“I-Map”), an Organic Material in Shales Atlas (“Shale”), and an interactive Blue/White/Ultraviolet (UV) Light Atlas (“Light”).



**Fig. 2.** Screen capture image of the gallery viewer window displaying a photomicrograph taken in incident white light under oil immersion.

tool, which isolates locations based on geologic age, group/formation name, or rock type. Once a sample location is selected, users can view photomicrographs from that location, or link to sample information and associated petrographic data within the online USGS or other publications.

For each location, thumbnail images of all available photomicrographs are displayed. Locations that have multiple samples from different depths have images organized according to depth (in ft), with the shallowest samples first. Maceral identifications of huminite and inertinite in the I-Map were labeled based on the ICCP classifications (ICCP, 2001; Sýkorová et al., 2005) and liptinite based on Taylor et al. (1998).

Future plans for the I-Map Atlas include expansion to active organic petrography studies by the USGS-OPL on coal, shale, and other geologic materials from other parts of the U.S. and the world (e.g., Hackley and Martínez, 2007; Hackley et al., 2005, 2009, 2010). Expansion of the interactive map atlas will include historical data for samples collected since the 1970s (Deems and Hackley, 2012).

### 3.5. Organic Material in Shales Atlas (Shale)

The Organic Material in Shales Atlas (Shale; Fig. 1) contains labeled images organized by formation name. The Shales Atlas was designed to supplement ASTM D7708-11 *Standard test method for microscopical determination of the reflectance of vitrinite dispersed in sedimentary rocks* (ASTM, 2011c) and the images were collected for energy resource assessments (Hackley, 2012), as well as other projects (e.g., Suárez-Ruiz et al., 2012). Fine grain size and dispersion into the mineral matrix complicate the identification of organic materials in shale. This atlas

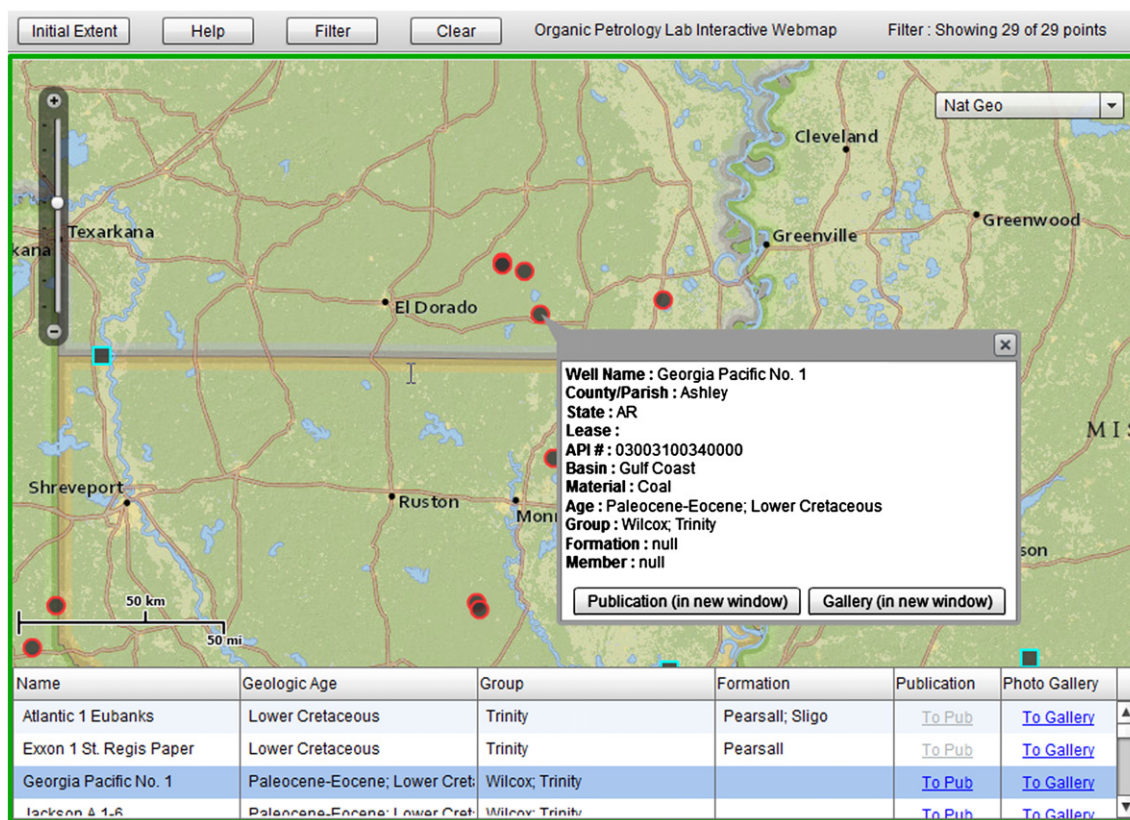


Fig. 3. Screen capture image of the Interactive Gulf Coast Petrographic Web Atlas (I-Map) interface.

aids in generic identification by providing access to the USGS-OPL analyzed shale sample data and publications. The same tools (print, email, social networking tools, hyperlinks to metadata) discussed in previous sections are available to users of the shale images.

### 3.6. Blue/White/UV Light Atlas (Light)

The Blue/White/UV Light Atlas (Light; Fig. 1) is designed for those users new to organic petrology or fluorescence microscopy by allowing users to interactively compare and contrast macerals in blue, white and UV light. This is accomplished with a scrolling tool bar that allows users to swipe (slide layers aside) between different types of illumination (Fig. 4). All available image sets are of the same field of view, taken using white light, blue light, and UV fluorescence, all under oil immersion. The photomicrographs used in the Light Atlas are from those compiled for the OPTIC and I-Map Atlases, except that the Light Atlas image sets do not contain maceral labels.

## 4. Conclusions

The enhanced USGS Organic Petrology Photomicrograph Atlas webpages are designed to supply resources and tools that aid in the identification of organic matter in geologic materials. The atlas website preserves and distributes petrographic data for coal and shale samples from around the world. The development of these webpage atlases is an evolving project that will continue to expand as new online tools and resources become available. The USGS welcomes feedback to ensure that the atlas webpages meet the needs of our customers.

## Acknowledgments

The authors of this paper would like to thank Laura R.H. Biewick (USGS), Lopo Vasconcelos and Deolinda Flores for their comments and edits during the review process. Any use of trade, product, or firm names herein is for descriptive purposes only and does not imply endorsement by the U.S. Government. This paper is dedicated to the memory of Alan Cook.

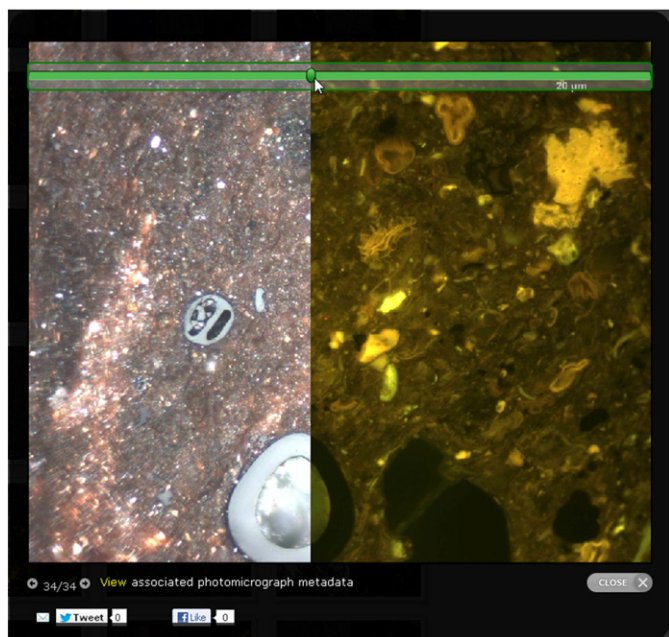


Fig. 4. Screen capture image of the gallery viewer window from the Blue/White/UV Light Atlas (Light). The example shows the field of view of a photomicrograph in incident white light (left hand side) and in incident blue light fluorescence (right hand side) both taken under oil immersion. Users can toggle with the scroll bar at the top of the image to adjust the field of view between white and blue light.

## References

- ASTM Standard D2799-11, 2011a. Standard Test Method for Microscopical Determination of the Maceral Composition of Coal. ASTM International, West Conshohocken, PA. <http://dx.doi.org/10.1520/D2799-11>. [www.astm.org](http://www.astm.org).
- ASTM Standard D2797/D2797M-11a, 2011b. Standard Practice for Preparing Coal Samples for Microscopical Analysis by Reflected Light. ASTM International, West Conshohocken, PA. <http://dx.doi.org/10.1520/D2797-D2797M-11A>. [www.astm.org](http://www.astm.org).
- ASTM Standard D7708-11, 2011c. Standard Test Method for Microscopical Determination of the Reflectance of Vitrinite Dispersed in Sedimentary Rocks. ASTM International, West Conshohocken, PA. <http://dx.doi.org/10.1520/D7708-11>. [www.astm.org](http://www.astm.org).
- ASTM Standard D388-11, 2011d. Standard Classification of Coals by Rank. ASTM International, West Conshohocken, PA. <http://dx.doi.org/10.1520/D0388-11>. [www.astm.org](http://www.astm.org).
- Bailey, 2008. Wainwright test well finds gas. *Petroleum News* 12 (44) 7 pp., <http://www.petroleumnews.com/pntruncate/516981573.shtml> (Accessed January 6, 2012).
- Crelling, J., 2003. Petrographic atlas of coals, cokes, chars, carbons, and graphites. Coal Research Center and Department of Geology, Southern Illinois University. web site at <http://mccoy.lib.siu.edu/projects/crelling2/atlas/>, (Accessed on January 10, 2012).
- Dennen, K.O., Valentine, B.J. (compilers), 2009. The USGS World Coal Quality Inventory – Archive of Coal Petrographic Analyses and Photomicrographs, v. 1.0. U.S. Geological Survey and University of Kentucky Center for Applied Energy Research, Digital Data Series. <http://energy.usgs.gov/Coal/AssessmentsandData/WorldCoalQualityInventory.aspx> (Accessed January 24, 2012).
- Deems, N.J., Hackley, P.C., 2012. Catalog of the United States coal pellet collection of the Organic Petrology Laboratory, Eastern Energy Resources Science Center, U.S. Geological Survey, Reston, Virginia. U.S. Geological Survey Open-File Report 2012-1151. 14 pp., <http://pubs.usgs.gov/of/2012/1151> (Accessed September 24, 2012).
- Falcon, R.M.S., Snyman, C.P., 1986. An introduction to coal petrography: atlas of petrographic constituents in the bituminous coals of southern Africa. Geological Society of South Africa Review Paper 2. 27 pp., 39 plates.
- Gesserman, R.M., Morrissey, E.A., Hackley, P.C., 2009. Petrographic web atlas for metallurgical bituminous coal macerals. Geological Society of America Abstracts with Programs, Portland, Oregon, October 18–21, 2009, v. 41, no. 7, p. 334. [http://gsa.confex.com/gsa/2009AM/finalprogram/abstract\\_159903.htm](http://gsa.confex.com/gsa/2009AM/finalprogram/abstract_159903.htm) (Accessed January 30, 2012).
- Hackley, P.C., 2012. Geological and geochemical characterization of the Lower Cretaceous Pearsall Formation, Maverick Basin, south Texas, USA: a future shale gas resource? *American Association of Petroleum Geologists Bulletin* 96, 1449–1489.
- Hackley, P.C., Warwick, P.D., Hook, R.W., Alimi, H., Mastalerz, M., Swanson, S.M., 2012. Organic geochemistry and petrology of subsurface Paleocene–Eocene Wilcox and Claiborne Group coal beds, Zavala County, Maverick Basin, Texas, USA. *Organic Geochemistry* 46, 137–153.
- Hackley, P.C., Guevara, E.H., Hentz, T.F., Hook, R.W., 2009. Thermal maturity and organic composition of Pennsylvanian coals and carbonaceous shales, north-central Texas: implications for coalbed gas potential. *International Journal of Coal Geology* 77, 294–309.
- Hackley, P.C., Martínez, M., 2007. Organic petrology of Paleocene Marcelina Formation coals, Paso Diablo mine, western Venezuela: tectonic controls on coal type. *International Journal of Coal Geology* 71, 505–526.
- Hackley, P.C., Ratchford, M.E., Warwick, P.D., 2006. Reflectance measurements of well cuttings from Ashley and Bradley Counties, Arkansas. U.S. Geological Survey Open-File Report 2006-1155. 29 p., <http://www.pubs.usgs.gov/of/2006/1155/> (Accessed January 6, 2012).
- Hackley, P.C., SanFilippo, J.R., Pacha Azizi, G., Davis, P.A., Starratt, S.W., 2010. Organic petrology of subbituminous carbonaceous shale samples from Chalāw, Kabul Province, Afghanistan: considerations for paleoenvironment and energy resource potential. *International Journal of Coal Geology* 81, 269–280.
- Hackley, P.C., Warwick, P.D., 2005. Organic petrography of coals from a coalbed methane test well, Ouachita Parish, Louisiana. USGS Open-File Report 2005-1134. 20 pp., <http://pubs.usgs.gov/of/2005/1134/> (Accessed January 6, 2012).
- Hackley, P.C., Warwick, P.D., Breland Jr., F.C., 2007. Organic petrology and coalbed gas content, Wilcox Group, northern Louisiana. *International Journal of Coal Geology* 71, 54–71.
- Hackley, P.C., Warwick, P.D., Gonzáles, E., 2005. Petrology, mineralogy, and geochemistry of mined coals, western Venezuela. *International Journal of Coal Geology* 63, 68–97.
- Hackley, P.C., Warwick, P.D., Thomas, R.E., Nichols, D.J., 2011. A review of the lignite resources of western Tennessee and the Jackson Purchase area, western Kentucky. In: Warwick, P.D., Karlsen, A.W., Merrill, M., Valentine, B.J. (Eds.), *Geologic assessment of coal in the Gulf of Mexico coastal Plain, USA: American Association of Petroleum Geologists Discovery Series No. 14/Studies in Geology No. 62*, pp. 326–347.
- ICCP, 1998. The new vitrinite classification (ICCP System 1994). *Fuel* 77, 349–358.
- ICCP, 2001. The new inertinite classification (ICCP System 1994). *Fuel* 80, 459–471.
- ICCP, 2006. Atlas of anthropogenic particles. Indiana Geological Survey Open-File Study 06-01. CD-ROM.
- Indiana Geological Survey, 2011. Indiana coal: macerals. Indiana Geological Survey. web site, <http://igs.indiana.edu/Coal/Macerals.cfm> (Accessed January 10, 2012).
- Martínez, P., Jirásek, J., Kožušnicková, A., Sivek, M. (Eds.), 2005. Atlas of Coal: The Czech Part of the Upper Silesian Basin. Anagram, Ostrava, 31 pp., CD-ROM.
- Panaiteanu, C., Predanu, G., 1999. Carbo-petrographic Atlas: Coals, Coke, Carbon Products. Editura Academiei Române, Bucuresti, România. ISBN: 973-27-0724-0. 264 pp.
- Papp, A.R., Hower, J.C., Peters, D.C., 1998. Atlas of coal geology. The Society for Organic Petrology and the American Association of Petroleum Geologists (AAPG) – Energy Minerals Division. AAPG Studies in Geology No. 45. CD-ROM.
- Potter, J., Stasiuk, L.D., Cameron, A.R. (Eds.), 1998. A petrographic atlas of Canadian coal macerals and dispersed organic matter. Canadian Society for Coal Science and Organic Petrology, Geological Survey of Canada (Calgary). Canada Centre for Mineral and Energy Technology. 105 pp.
- Sen Gupta, S., Bardhan, B., 2005. Petrographic atlas of Indian coal. Geological Survey of India Catalogue Series, 7. 150 pp.
- Sýkorová, I., Pickel, W., Christanis, K., Wolf, M., Taylor, G.H., Flores, D., 2005. Classification of huminite – ICCP System 1994. *International Journal of Coal Geology* 62, 85–106.
- Suárez-Ruiz, I., Flores, D., Mendonça Filho, J.G., Hackley, P.C., 2012. Review and update of the geological applications of organic petrology: part 1. *International Journal of Coal Geology* 99, 54–112.
- Taylor, G.H., Teichmüller, M., Davis, A., Diessel, C.F.K., Littke, R., Robert, P., 1998. Organic Petrology. Gerbrüder Borntraeger, Berlin. 704 pp.
- USGS, 2011. Fundamental science practices: peer review. U.S. Geological Survey Manual section 502.3. <http://www.usgs.gov/usgs-manual/500/502-3.html> (Accessed January 6, 2012).
- Warwick, P.D., Breland Jr., F.C., Hackley, P.C., Dulong, F.T., Nichols, D.J., Karlsen, A.W., Bustin, R.M., Barker, C.E., Willett, J.C., Trippi, M.H., 2006. Analytical results from samples collected during coal-bed methane exploration drilling in Caldwell Parish, Louisiana. U.S. Geological Survey Open-File Report 2006-1213. 520 pp. <http://pubs.usgs.gov/of/2006/1213/> (Accessed January 6, 2012).
- Warwick, P.D., Karlsen, A.K., Merrill, M., Valentine, B.J. (Eds.), 2011. Geologic assessment of coal in the Gulf of Mexico coastal Plain, USA: American Association of Petroleum Geologists Discovery Series No. 14/Studies in Geology No. 62. CD-ROM.
- Yang, Y., Zou, R., Shi, Z., Jiang, R. (Eds.), 1996. Atlas for Coal Petrography of China. China University of Mining and Technology Press, Beijing, China. ISBN: 7-81040-519-5. 321 pp.