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Identification of alginite and bituminite in rocks other than coal. 2006, 2009, and 2011 round robin exercises of the ICCP Identification of Dispersed Organic Matter Working Group

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ABSTRACT

The paper presents results of round robin exercises on photomicrograph-based identification of dispersed organic matter in source rocks that represent a range of marine and lacustrine deposits from worldwide localities and cover a range of thermal maturities. The round robin exercises were conducted by the Identification of Dispersed Organic Matter Working Group (IDOM WG) of the International Committee for Coal and Organic Petrology (ICCP). The round robin exercises aimed to (1) assess the applicability of the established ICCP definitions of bituminite, (2) identify deficiencies and improve the existing nomenclatures, and (3) provide a basis for the revision of the bituminite and alginite definitions in the ICCP Handbook (Taylor et al., 1998). Three round robin exercises performed in 2006, 2009 and 2011 involved 18 participants from research laboratories at universities and within government and industry. Participants were asked to identify macerals on the basis of existing definitions in 129 photomicrographs taken in incident white light and fluorescent mode and also in fluorescence light mode at prolonged (15 min) blue light irradiation. The results indicate that the definition of telalginite permits its positive and satisfactory agreement among the participants. In contrast, the descriptive characteristics of lamalginite referring to film-like appearance (filamentous) and lack of inner or outer structure are insufficient and inadequate to enable an unequivocal discrimination between it and telalginite. Furthermore, based on the amorphous nature of bituminite and lack of adherence to its established description and character (Taylor et al., 1998), the highest discrepancies were observed in its identification. Differentiation of bituminite from a fluorescent groundmass and in some cases from lamalginite proved to be particularly challenging. The findings of these round robin exercises are useful for improving the identification of sedimentary organic matter

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in source rocks and may be an important foundation for the modification of the ICCP definitions of alginite and bituminite.

1. Introduction

Over the past years, the International Committee for Coal and Organic Petrology (ICCP) has established standard maceral nomenclatures with corresponding definitions, as well as classifications based on optical microscopic methods. The ICCP also implemented several microscopy techniques applied in interlaboratory studies and round robin exercises carried out at research institutes, universities, and both national and international companies (e.g., Taylor et al., 1998; ICCP, 1998, 2001; Kwiecińska and Petersen, 2004; Sýkorová et al., 2005). The aim of the established ICCP system of maceral nomenclatures and definitions is to improve comparability, reproducibility, and consistency between research and industrial studies to (1) evaluate and assess maceral composition at maceral group and maceral type level, (2) characterise organic facies and depositional environments in coals and sedimentary rocks other than coal, and (3) estimate the proportion of oil-prone macerals in source rocks. The ICCP nomenclatures and definitions are recognized by international institutes such as the ISO (International Organization for Standardization) and by national standards organizations such as the German Institute for Standardization (DIN), American Society for Testing and Materials (ASTM international), and the Australian Standard Institute (ASI).

In addition to maceral definitions for the huminite, vitrinite and inertinite groups, the ICCP has also provided standardized descriptions and characteristics for the definitions of bituminite macerals of the liptinite group (Taylor et al., 1998).

Alginite in rocks other than coal has been subdivided into telalginite and lamalginite on the basis of its morphology. The term "telalginite" was proposed by Cook et al. (1982), replacing the former term "alginite A" of Hutton et al. (1980). Telalginite is defined as an algal body (both colonial and unicellular) occurring in distinctive lenses or flattened discs of elliptical, spherical, or circular shape. Major genera are *Botryococcus-type* algae (species *Reinschia and Pila*), *Tasmanites* algae, *Gloeocapsomorpha prisca* algae, Acritarchs, and Dinoflagellates. Tasmanitid cysts, representing planktonic solitary algae that are similar in morphological appearance to *Tasmanites*, occur from the Cambrian to the present. Lamalginite, formerly alginite B (Hutton et al., 1980), was introduced to describe finely banded, filamentous, lamellar alginite that was intimately interbedded with mineral matter, often forming a network structure. Lamalginite represents lamellar benthic or pelagic algae, occurring as isolated films typically < 0.005 mm (mm) thick and generally < 0.08 mm in lateral extent (thickness to length ratio of < 0.5); these films can coalesce to form thicker stripes. Sometimes, depending on the section, lamalginite can be distinguished at generic level and some of the components included in lamalginite are acritarchs, dinoflagellates, Cyanophyceae, Leiospheres and *Pediastrum*, although some of them may have transitional properties between telalginite and lamalginite.

Bituminite bears a special importance to marine and lacustrine source rocks, especially in oil shales in conventional and unconventional hydrocarbon systems. Bituminite occurring in association with secondary organic matter such as solid bitumen and oil may indicate hydrocarbon generation in sedimentary basins (Powell et al., 1982). Most of the dispersed organic matter in oil shales, as observed under incident light microscopy, is defined as amorphous (i.e., lacking definite shape or form). To denote its amorphous character, Teichmüller (1971) introduced the name "bituminite" to describe the amorphous dispersed organic matter occurring in petroleum source rocks. The term "bituminite" was also used by Teichmüller (1974) and Teichmüller and Ottenjann (1977) to describe amorphous organic matter in coals and source rocks. Subsequently, ICCP adopted the term "bituminite" and defined it for brown coals (Taylor et al., 1998) and for rocks other than coal (Taylor et al., 1998). Because bituminite in rocks other than coal is a product of multiple organic materials from different origins that are subjected to alteration and degradation, its morphology (from streaks, elongated lenses, "Schlieren" in vertical sections and tabular masses to equidimensional particles of varying shapes in horizontal sections), optical (reflectance, fluorescence) and chemical (hydrogen content, hydrogen to carbon (H/C) ratio) properties vary widely (Taylor et al., 1998; Pickel, et al., 2017). Also, changes during thermal maturation exert a significant influence on bituminite morphology, as well as on its optical (reflectance, fluorescence) and chemical properties (hydrogen content, H/C ratio). Therefore, a number of different types of bituminite are recognized in rocks other than coal; e.g., bituminite type I, II and III of Teichmüller and Ottenjann (1977); amorphinite A, B, and C of van Gijzel (1981) and Hetényi et al. (2003); and sapropelinite I, II, and III of Mukhopadhyay et al. (1985a,b). The different types of identified bituminite do not result from different terminological preferences of organic petrographers but instead indicate distinct variations in the heterogeneity of bituminite in individual source rocks and claystones.

From 2000 to 2015, the most often cited definitions of bituminite in rocks other than coal were those of Teichmüller and Ottenjann (1977) and Taylor et al. (1998), followed by Teichmüller (1974), irrespective of location and lithology (Table 1). The bituminite terminology used in these three studies encompassed various descriptions including (1) small lenses or irregular stripes, fine laminations, elongate strands, fine spheroidal particles, discrete, elongate, finely dispersed, flocculent form, lamellar masses, irregular flakes; (2) isolated spheres; and (3) porous, laminated, granular or patchy populations and grainy unstructured liptinite masses. Bituminite was also observed to occur in a groundmass. It is amorphous (lacking discrete form or shape), or "structureless". On the other hand, the term "structureless" is factually incorrect when applied to bituminite macerals because bituminite macerals display an internal structure or specific internal arrangement such as a granular appearance or fluidal character (Taylor et al., 1998).

The origin of bituminite in rocks other than coal is not conclusively established, but it is generally considered to be a degradation product (Taylor et al., 1998). The degrading agent ranges from bacterial to physiochemical. In marine- to lacustrine-dominated settings with predominantly anoxic conditions, bituminite presumably originated from degraded algae, zoo- and phytoplankton, zoobenthos, bacterial biomass, coccolith organisms, bodies of higher-level animals (fish, crayfish, etc.), or algal mats. In terrestrial environments, bituminite presumably originated from degraded humic matter (plant humus), (Koch, 1997; Taylor et al., 1998; Nowak, 2007). The established optical properties for bituminite (reflectance, fluorescence, fluorescence alteration upon prolonged irradiation) are limited to stages of low maturation of up to 0.7% mean random vitrinite reflectance (% VRr). At higher thermal maturity, fluorescence alteration no longer occurs (Robert, 1981).

The established definitions of bituminite and alginite in coal and rocks other than coal (Stach et al., 1982; Taylor et al., 1998) attempted to reconcile different previously existing nomenclatures for alginite and bituminite. However, based on previous interlaboratory exercises within the ICCP Isolation Working Group (1988–1998), the need for a modification of ICCP-established alginite and bituminite definitions has been recognized. As a result, a new ICCP Working Group on Identification of Dispersed Organic Matter (IDOM WG) was established within the ICCP Commission II "Geological Applications of Coal and Organic Petrology" at the 2005 ICCP Meeting in Patras, Greece. The IDOM WG began its activity in 2006 at the 58th ICCP Meeting in Bandung,

Table 1
Overview of the applied bituminite definitions in peer-reviewed publications from 2001 to 2016.

Reference	Bituminite type	Description/distinguishing features	Formation/age	Location	Lithology	Maturity	Reference(s) for bituminite description
Joachimski et al., 2001	Bituminite	Irregular flakes or as isolated spheres with diameters of 1–3 mm	Multiple formations, Devonian	Poland	Black marls and limestone	Immature	Stasiuk, 1993; Taylor et al., 1998
Schieber, 2001	Bituminite	Unstructured, amorphous dark streaks with brownish fluorescence	Multiple formations, Upper Devonian	Illinois Basin, Indiana, Kentucky, Tennessee, USA	Black marine shale	Immature	Teichmüller and Ottenjann, 1977; Taylor et al., 1998; Boussafir et al., 1995
Crosdale et al., 2002	Bituminite III	Non-fluorescent, optically similar to mineral matter	Multiple formations, Tertiary	Eastern Russia	Coals	Immature	Taylor et al., 1998
Kolonic et al., 2002	Bituminite II	Fluorescent lenses of variable size lacking a well-defined shape to relate to biological precursors	Multiple formations, Cretaceous	Southwestern Morocco	Marine black shale	Immature	Teichmüller and Ottenjann, 1977
Ran et al., 2003	Bituminite	Amorphous, yellowish green to yellow and brownish fluorescence	Not applicable	Ontario, Canada	Unconsolidated aquifer sediments	Early oil window	None
Rimmer et al., 2004	Bituminite	Dark, non-fluorescing or brown-fluorescing wispy matrix associated with clay	New Albany and Sunbury Shales, Devonian to Mississippian	Kentucky, USA	Black marine shale	Immature	Largeau et al., 1990; Boussafir et al., 1995; others
Singh and Singh, 2004	Bituminite	Streaky, fine granular substance of brown to dark brown colour, weakly fluorescent in orangish-brown to brown	Multiple formations, Permian	India	Coal	Not described	Stach et al., 1982; Teichmüller, 1989; Taylor et al., 1998
Hackley et al., 2005	Bituminite	"Groundmass", not described	Multiple formations, Tertiary	Venezuela	Coal	Immature to early oil window	None
Li et al., 2006	Matrix bituminite	Not described	Multiple formations, Paleogene	Kamchatka coastal margin, Russia	Lacustrine mudstone, shale and coal	Immature to early oil window	None
Ross and Bustin, 2006	Matrix bituminite	Brown/green streaks which define bedding	Gordondale Mbr., Jurassic	British Columbia, Canada	Marine marlstone and mudstone	Not described	Teichmüller, 1986; Robl et al., 1992
Botz et al., 2007	Bituminite	Small lenses or irregular brown stripes with weak brown-yellow fluorescence	Not applicable, modern	Red Sea	Sediments	Immature	Stach et al., 1982
Křibek et al., 2007	Bituminite	Porous, laminated, granular or patchy populations	Niutitang Fm., Lower Cambrian	Southern China	Marine black shale	Overmature	Teichmüller, 1974; Teichmüller and Ottenjann, 1977; Teichmüller et al., 1979; Teichmüller, 1989; Taylor et al., 1991, 1998; others
Nowak, 2007	Brown fluorescing black bituminite and grayish brown to grey fluorescing dark grey bituminite	Grainy unstructured liptinite mass, in thin bands and lenses	Anthracosia Shale, Carboniferous to Permian, Kupferschiefer Shale, Permian	Southwestern Poland	Lacustrine (Anthracosia), marine (Kupferschiefer)	Oil window	Teichmüller, 1974; Teichmüller and Ottenjann, 1977
Boucsein and Stein, 2009	Bituminite I (from algae biodegradation) and bituminite III (from humic acids)	Lenses and fine laminations with little to no fluorescence	Not applicable, Upper Cretaceous to Eocene	Lomonsov Ridge, central Artic Ocean	Sediments	Immature	Taylor et al., 1998
Fatimah and Ward, 2009	Bituminite	Fine spheroidal particles with orange-brown fluorescence	Sangkarewang Fm., Eocene to Oligocene	West Sumatra, Indonesia	Lacustrine shale	Immature	None
Ross and Bustin, 2009	Matrix bituminite	Not described	Gordondale Mbr., Jurassic	British Columbia, Canada	Not described	Early oil window to overmature	Stach et al., 1982; Teichmüller, 1986
Sýkorová et al., 2009	Bituminite	Not described	not applicable	Prague, Czech Republic	Fluvial sediments	Immature	None
Wójcik-Tabol and Ślączka, 2009	Bituminite	not described	Multiple formations, Albian-Turonian	Outer Carpathians, Poland	Marine shales	Not described	For citation of ICCP, 1993, refer to Wójcik-Tabol and Ślączka, 2009
Eble, 2012	Bituminite	Elongate strands of dark-reflecting material with ropy surface texture, variable fluorescence	Carbondale Fm., Pennsylvanian	Kentucky, USA	Transgressive marine shales	Early oil window	Teichmüller, 1974; Taylor et al., 1991
Fishman et al., 2012	Bituminite to mineral-bituminous groundmass	Discrete, elongate, lamellar masses with fairly well-defined boundaries and wavy or crinkly texture and variable fluorescence	Kimmeridge Clay Fm., Jurassic	Offshore United Kingdom	Clay-rich marine mudstone	Immature	Teichmüller and Ottenjann, 1977

(continued on next page)

Table 1 *(continued)*

Reference	Bituminite type	Description/distinguishing features	Formation/age	Location	Lithology	Maturity	Reference(s) for bituminite description
Havelcová et al., 2012	Bituminite	Groundmass originating from bacterial decomposition of algae with accumulated microbial biomass	Multiple formations, Tertiary	Czech Republic	Coal	Immature	Taylor et al., 1998
Tao et al., 2012	Bituminite to mineral-bituminous groundmass	Finely dispersed, flocculent, or in streaky form, occurring as a groundmass, variable fluorescence	Lucaogou Fm., Permian	Junggar Basin, China	Oil shale	Immature	Teichmüller, 1974; Teichmüller and Ottenjann, 1977; others
Blandón and Gorin, 2013	Bituminite	Not described	Amagá Fm., Late Paleocene to Oligocene	Colombia	Coal	Immature	For citation of ICCP, 1971, refer to Blandón and Gorin, 2013
Farhaduzzaman et al., 2013	Bituminite	Not described	Gondwana Group, Permian	Bangladesh	Coals, carbargillites, and mudstones	Early oil window	For citation of ICCP, 1963, refer to Farhaduzzaman et al., 2013
Wan Hasiah et al., 2013	Bituminite	Not described	Multiple formations, Tertiary	Labuan Island, Indonesia	Coals	Immature to peak oil window	None
Araujo et al., 2014	Bituminite	Amorphous organic matter intimately mixed with mineral matter	Huron Member, Ohio Shale, Upper Devonian	Appalachian Basin, USA	Marine shale	Immature to early oil window	None
Choung et al., 2014	Bituminite	Dark grey to orange-brown amorphous organic matter of marine origin,	Not applicable	New York, USA	Unconsolidated aquifer/aquitard sediments	Immature	Taylor et al., 1998
Gorbanenko and Ligouis, 2014	Bituminite I to VI	Various	Posidonia Shale, Lower Toarcian (Jurassic)	Lower Saxony Basin, Germany	Marine shale	Early oil window to overmature	Teichmüller, 1974; Teichmüller and Ottenjann, 1977; Teichmüller, 1989
Geršlová et al., 2015	Bituminite	Fine-grained to amorphous organic matter with dark orange to brown fluorescence	Mikulov Marls, Jurassic	Czech Republic	Dark grey, organic-rich marl	Immature to oil window	Hutton, 1987; Taylor et al., 1998
Gorbanenko and Ligouis, 2015	Bituminite I to VI	Various	Posidonia Shale, lower Toarcian (Jurassic)	Lower Saxony Basin, Germany; West Netherlands Basin, The Netherlands	Marine shale	Immature to early oil window	Teichmüller and Ottenjann, 1977; Gorbanenko and Ligouis, 2014
Juliao et al., 2015	Bituminite	Low intensity yellow-orange fluorescence	La Luna Fm., Upper Cretaceous	Middle Magdalena Basin, Colombia	Marine limestone and calcareous shale	Oil window	None
Kus, 2015	Bituminite	Weakly pale yellow to dark orange fluorescence and strong positive alteration in fluorescence intensity; gradual transition of both bituminite stingers into bituminous groundmass; bituminite changes its appearance from irregular stringers and filaments into amorphous and granular matrix;	Miocene, Quaternary	Alasehir Basin, Manisa Province, Aegean region of Turkey	Oil shale	Oil window	Teichmüller and Ottenjann, 1977; Stach et al., 1982; Stasiuk, 1993
Hackley et al., 2016	Bituminite	Brightly fluorescent groundmass	Lucaogou Fm., Permian	Santanghu Basin, China	Lacustrine mudrock	Early oil window	None
Hackley and SanFilipo, 2016	Bituminite	Brightly fluorescent, amorphous, finely disseminated and degraded, occurring as mineral coatings and in mineral interstices	Suzak Fm. equivalent, Eocene	North-central Afghanistan	Bituminous marl	Immature	None
Hackley and Cardott, 2016	Bituminite	Amorphous organic matter occurring in a continuum from organic-rich (lamalginite) to mineral-rich (mineral bituminous groundmass)	Multiple formations, Ordovician to Miocene	North America	Various	Various	Stasiuk et al., 2002
Synnott et al., 2016	Bituminite	Low reflectance lens of irregular shape, reddish to dark brown fluorescence	Second White Specks Fm., Upper Cretaceous	Western Canada Sedimentary Basin, Alberta Canada	Calcareous, organic-rich mudstone/shale	Immature	Teichmüller and Ottenjann, 1977; Taylor et al., 1998

FM – Formation; Mbr. – Member.

Indonesia. The goals of the WG were to (1) examine the applicability of the existing ICCP maceral definitions (e.g., bituminite and alginite as classified in the TSOP-ICCP classification of dispersed organic matter in sedimentary rocks and isolated organic matter) and (2) further constrain their definitions on the basis of the existing ICCP bituminite definitions of Stach et al. (1982) and the ICCP bituminite definitions found in Taylor et al. (1998). To date, research activities within the IDOM WG have included three round robin exercises (between 2006 and 2011) carried out solely on photomicrographs prepared from kerogen concentrates (2006) and rock pellets (2009, 2011).

2. Round robin exercises

The following three round robin exercises analysed 129 photomicrographs in incident white light or fluorescent light induced by blue light illumination; some photomicrographs were provided in fluorescence light at prolonged (15 min) blue light irradiation. The analysed photomicrographs of liptinite-rich source rocks covered immature to mature stages of thermal maturity:

(1) 2006 round robin exercise: 11 photomicrographs from the following 5 localities (Table 2) were examined by 16 participants: 1. Cretaceous (Turonian) marlstone from the Second Specks Formation in the St. Marthes mine, Saskatchewan, Canada; 2. Cretaceous oil shale from the Bucomazi Formation in the Lukami 2 × well, Zaire; 3. Pennsylvanian coaly shale from the Indiana paper coal, Parke County, Indiana, USA; 4. Permian oil shale from an unnamed tasmanite, Tasmania, Australia; 5. Upper Devonian to Lower Mississippian black shale from the Woodford Formation, Murray County, Oklahoma, USA.

(2) 2009 round robin exercise: 46 photomicrographs from the following 5 localities (Table 3) were examined by 13 participants: 1. Cretaceous (Eocene) bituminous shale from the Messel Formation in Darmstadt, federal State Hesse, Germany; 2. Middle Cretaceous (Early Oligocene) bituminous shale from the Fischschiefer Formation in Oberrheingraben, Federal State Baden- Württemberg, Germany; 3. Oil shale of an unknown stratigraphic age and formation from China; 4. Upper Cretaceous siltstone from the Chonta Formation in Quebrada Espirene, Rio Nusiniscate, Madre de Dios, Rio Inambari, Peru; 5. Teriary (Oligocene) oil shale from the Pozo Formation in Amazonas and San Martin, Faja Subandina, Peru; Upper Cretaceous oil shale from the Cachiyacu Formation in Maquia oil field, Ucayali Basin, Peru; 6. Lower Cretaceous (Eocene) oil shales from the Green River Shale Formation in Utah, Uintah Basin, Uintah County, USA and from Rifle/Craig, Piceance Creek, Colorado Piceance Basin, Green River, USA; 7. Upper Cretaceous oil shale from the Muwaqqar Chalk Marl Formation in Central Jordan; 8. Lower Cretaceous (middle to upper Eocene) oil shales from the Rundle Formation in The Narrows Graben, Kerosen Creek Seam, Australia; 9. Rock sample of an unknown stratigraphic age and formation from Brazil, Municipio Camamu, Bahia; 10. Lower Jurassic (Lias epsilon) oil shale from the Posidonia Shale Formation in Dotternhausen, Schwäbische Alb, Baden- Württemberg, Germany; 11. Rock sample of an unknown stratigraphic age and formation in Nördlingen, Germany; 12. Precambrian oil shale from an unknown formation in Nawabi Kas, Salt Range, Punjab, Pakistan; 13. Carboniferous (Pennsylvanian) black shale from the Burning Star No. 4 seam in Cutler, Perry County, Illinois, USA; 14. Upper Cretaceous (Miocene) oil shale of an unknown formation in Demirci Area, Demirci oil shale field, Turkey.

(3) 2011 round robin exercise: 72 photomicrographs from 8 different localities (Table 4) were examined by 9 participants. All samples were from the Posidonia Shale Formation in the Lower Saxony Basin, Lower Saxony, Germany.

The objective of all three round robin exercises was to identify macerals of the liptinite group by following the instructions included within each of the exercises. The specific instructions for each exercise are included below.

The 2006 round robin exercise included the following directions: (1) identify macerals (amorphinite/bituminite, liptodetrinite, and alginite) in photomicrographs of kerogen concentrates on basis of the TSOP-ICCP DOM Classification; (2) indicate your level of confidence by choosing 10%, 30%, 50%, 70%, or 90%; and (3) distinguish and identify features that are characteristic of the maceral.

The 2009 round robin exercise included the following directions: (1) identify bituminite and alginite macerals or their types in photomicrographs of rock pellets on the basis of the ICCP and non-ICCP definitions of bituminite and alginite found in Taylor et al. (1998) and Stach et al. (1982); (2) indicate problems in making a confident identification of alginite and bituminite macerals or their types (e.g., bituminite type II of Teichmüller and Ottenjahn (1977)); and (3) state the reason for why the identification could not be made confidently.

The 2011 round robin exercise included the following directions: (1) identify bituminite or its types in photomicrographs of rock pellets on the basis of the ICCP and non-ICCP bituminite definitions found in Taylor et al. (1998) and Stach et al. (1982); (2) indicate problems in making a confident identification of bituminite or its types; and (3) state the reason why the identification could not be made confidently.

The task definitions in the questionnaire sets for the 2006, 2009, and 2011 round robin exercises differed because a different preparation method was used each time. In 2006 kerogen concentrates were used and in 2009 and 2011, rock pellets were used.

3. Samples and methods

The five kerogen concentrates for the 2006 round robin exercise were prepared at different laboratories. The Turonian marlstone was supplied by Wolfgang Kalkreuth (Geological Survey of Canada) and was prepared at Dow Geochemical Services Inc., The Woodlands, Texas, USA, from clastic rocks. Siliciclastic sediments were processed using HCl to dissolve carbonates and HF for silicate digestion. The residual, unfloated organic matter was washed with H_2O and dried at room temperature. The Cretaceous shale sample from Zaire, the Late

Table 2
Relevant characteristics of the samples analysed in the 2006 IDOM round robin exercise including vitrinite reflectance data, lithology, and stratigraphic units.

Sample ID	VRr	SD	N	Location	Stratigraphic unit	Lithology
ICCP IOM 95–1	0.52	NA	NA	St. Marthes Mine, Saskatchewan, Canada	Second Specks Formation, Turonian, Upper Cretaceous	Marlstone
DOM Atlas	NA	NA	NA	Lukami-2 × well, Salt Basin, Zaire	Bucomazi Formation, Lower Cretaceous	Oil shale
DOM Atlas	0.42	NA	NA	Parke County, Indiana, USA	Indiana Paper Coal, Pennsylvanian, Upper Carboniferous	Coaly shale
DOM Atlas	NA	NA	NA	Tasmania, Australia	Permian-Carboniferous	Oil shale
Sample PR-1 (ICCP IOM 89–1)	0.43	0.14	50	Murray County, Oklahoma, USA	Woodford Formation, Upper Devonian-Lower Carboniferous (Mississippian)	Black shale

ID - identity; IOM - Isolation of Organic Matter Working Group; DOM - dispersed organic matter; PR - sample abbreviation; VRr - mean random vitrinite reflectance (%); SD - standard deviation; N - number of measurements; NA - not available.

Table 3
Relevant characteristics of the samples analysed in the 2009 IDOM round robin exercise including vitrinite reflectance data, lithology, and stratigraphic units.

Sample ID	VRr	SD	N	Location	Stratigraphic unit	Lithology
K14728	NA	NA	NA	Pit Fossil Site, Darmstadt, Federal State Hesse, Germany	Messel Shale, Eocene, Cretaceous	Bituminous shale
K704	0.32	0.03	25	Pit Fossil Site, Darmstadt, Federal state Hesse, Germany	Messel Shale, Eocene, Cretaceous	Bituminous shale
0810736	0.29	0.05	27	Oberrheingraben, Federal State Baden-Württemberg, Germany	Early Oligocene (Rupelian), Middle Cretaceous	Bituminous shale
K14929	0.33	0.04	4	China	NA	Oil shale
K10198	0,60	0.08	9	Quebrada Espirene, Rio Nusiniscate, Madre de Dios, Rio Inambari, Peru,	Chonta Formation, Upper Cretaceous	Siltstone
K8438	NA	NA	NA	Amazonas and San Martin, Faja Subandina, Peru	Pozo Formation, Oligocene, Tertiary	Oil shale
K9812	0.43	0.02	8	Maquia oil field, Ucayali Basin, Peru	Cachiyacu Formation, Upper Cretaceous	Oil shale
K7563	0.32	NA	NA	Utah, Uintah, Basin, Uintah County, USA,	Green River Shale Formation, Eocene, Lower Cretaceous	Oil shale
K8089	0.31	NA	50	Rifle/Craig, Piceance Creek, Colorado, Piceance Basin, Green River, USA,	Green River Shale Formation, Eocene, Lower Cretaceous	Oil shale
K2070	0,45	NA	32	Central Jordan	Lajjun Oil Shale, Belqua Group, Muwaqqar Chalk Marl Formation, Upper Cretaceous (Maastrichtian)/Lower Tertiary (Danian)	Oil shale
K11328	NA	NA	NA	The Narrows Graben, Kerosen Creek Seam, Australia	Rundle Formation, upper Eocene, Lower Cretaceous	Oil shale
K10570	0.39	0.02	13	The Narrows Graben, Kerosen Creek Seam, Australia	Rundle Formation, upper Eocene, Lower Cretaceous	Oil shale
K1360	0.25	NA	50	Brasil, Municipio Camamu, Bahia	NA	Oil shale
K11327	NA	NA	NA	The Narrows Graben, Kerosen Creek Seam, Australia	Rundle Formation, upper Eocene, Lower Cretaceous	Oil shale
K697	NA	NA	NA	Dotternhausen, Schwäbische Alb, Baden-Württemberg, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K4484	0.20	NA	NA	Nördlingen, Germany	NA	Oil shale
K13466	0.37	0.03	40	Nawabi Kas, Salt Range, Punjab, Pakistan	Precambrian	Oil shale
K8882	0.35	0.08	46	Cutler, Perry County, Illinois, USA	Burning Star No.4 seam, Pennsylvanian, Carboniferous	Black shale
K10597	0.28	NA	1	Demirci Area, Demirci oil shale field, Turkey	Miocene, Upper Cretaceous	Oil shale

NA: not available (either not measured or no huminite/vitrinite particles present in the sample); ID – Identity; VRr - mean random vitrinite reflectance (%); SD - standard deviation; N - number of measurements; NA - not available;

Table 4
Relevant characteristics of the samples analysed in the 2011 IDOM round robin exercise including vitrinite reflectance data, lithology, and stratigraphic units.

Sample ID	VRr	SD	N	Location	Stratigraphic unit	Lithology
K55	0.54	0.05	30	Winsen an der Aller, Lower Saxony, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K65	0.25	0.05	30	Lingen, Lower Saxony, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K66	0.26	0.07	19	Goslar, Lower Saxony, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K2733	0,48	0.02	3	Groß Düngen, Lower Saxony, Germany	Posidonia Shale Formation, Lias alpha, Lower Jurassic	Oil shale
K2737	0.47	0.08	8	Gitter am Berge, Lower Saxony, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K2739	0.28	0.02	3	Salzgitter-Bad, Lower Saxony, Germany	Posidonia Shale Formation, Lias epsilon, Lower Jurassic	Oil shale
K2755	0.33	0.02	8	Bad Harzburg, Lower Saxony, Germany	Posidonia Shale Formation, Lias delta, Lower Jurassic	Oil shale
K2758	0.60	0.06	6	Markoldendorf, Lower Saxony, Germany	Posidonia Shale Formation, Lias alpha, Lower Jurassic	Oil shale

ID – Identity; VRr - Random vitrinite reflectance (%); SD - Standard deviation; N - Number of measurements.

Carboniferous (Pennsylvanian) coaly shale, the Permian tasmanite oil, the Upper Devonian to Lower Mississippian black shale were supplied by various ICCP members and prepared by them following the procedure of acid maceration with density separation recommended by Taylor et al. (1998). All above kerogen concentrates were prepared according to international standards (Taylor et al., 1998).

Photomicrographs for the 2006 round robin exercise were taken in 1995 by Ángeles G. Borrego (INCAR-CSIC, Spain) with 40 × and 25 × oil immersion objectives and were provided in 2005 by Maria Mastalerz (Indiana University, Bloomington, Indiana, USA).

Core and outcrop samples selected for the 2009 and 2011 round robin exercises were obtained from the whole rock and rock pellet collection at the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany. To ensure the applicability of the samples to a narrow range of thermal maturity values, depositional environments, and appropriate maceral assemblages, samples were selected if (1) their vitrinite reflectance was 0.8% VRr or less, (2) they represented marine or lacustrine depositional environments, and (3) they contained intact and non-weathered alginite and bituminite macerals. Details of location, thermal maturity, and stratigraphy for each sample are presented in Tables 2 through 4. Rock samples were dried at 30 °C, crushed, and sieved to 1 mm grain size aliquots. They were then embedded and impregnated in an epoxy resin mixture, ground, and polished in water immersion, following guidelines summarized in DIN 22020-2 (1998–08) and Taylor et al. (1998).

3.1. Analytical procedure

The 2006, 2009, and 2011 round robin exercises were performed on photomicrographs. Photomicrographs used in the 2006 round robin exercise were taken in non-polarized light at magnifications of 250 × to 400 × under different incident-light microscopes equipped with a microphotometer photomultiplier. For analyses in blue light fluorescence and UV fluorescence excitation filters (365 to 420 nm (nm)), dichroic mirrors (400–420) and suppression (barrier) filters (420–470) were used. Photomicrographs used in the 2009 and 2011 exercises were acquired in non-polarized light, at magnifications of 500 × and 1000 × and room temperature of 23 °C ± 1 °C using a Leica DMRX incident-light microscope equipped with a MPV Compact 2 microphotometer photomultiplier tube (PMT), halogen lamp (12 V, 100 W), HBO® Lamp (103 W/2, 12 V), and Leica Oil P 50 ×/0.85 oil immersion objective. The filters used for analysis in blue light fluorescence were a Leica excitation filter BP 420–490, dichroic mirror RKP 510, and barrier filter LP 515. Photomicrographs taken in incident white light and blue light excitation used a Leica digital fluorescence camera DC300F at format of 1300 × 1030 pixels and were stored using Image Access Premium 09 imaging software. In the 2011 round robin exercise, photomicrographs with prolonged blue light irradiation (15 min) were acquired.

The different magnifications used in the 2006 and in the 2009 and 2011 round robin exercises reflect different optical microscope setups available at the petrographic laboratories. The lack of consistent magnification does not influence maceral identification.

The photomicrographs provided in the 2006 interlaboratory exercise were marked by a square outlining the maceral to be identified as opposed to unmarked photomicrographs used in the more recent 2009 and 2011 round robin exercises. The reason for using unmarked photomicrographs was to allow identification of macerals in a subjective manner with selection of recognized macerals left open to the participants.

A short description of the imaged samples with regards to maturity, locality, and stratigraphic age was enclosed in the introductory materials with the exercise. In addition, a questionnaire was provided for compilation by participant comments. The results submitted by participants were compiled for the purposes of overview and overall comparison and assessment. Furthermore, each of the participants received an individual participant's code.

4. Results

4.1. 2006 round robin exercise

4.1.1. General remarks

The conceptual preparation of the 2006 round robin exercise within the IDOM WG was based on previous work by Werner Hiltmann at the Federal institute of Geosciences and Natural Resources, Germany, and John R. Castaño at Shell Bellaire Lab in Houston, Texas, who noted difficulties in identification due to a lack of common nomenclature for organic matter observed in kerogen concentrates. A qualitative evaluation of the 2006 round robin exercise results revealed that a suitable scale bar and appropriate resolution of photomicrographs remained key factors in positive maceral identification. Participants with more years of experience in identifying macerals were most likely to positively identify the macerals (Fig. 1a, b) and indicated a higher level of confidence in doing so. The same observation applies to the second criterion, the level of confidence. An exception to this is the identification of amorphinite/bituminite in Fig. 1c, d, for which a weak confidence was evident.

4.1.2. Evaluation of the results

The following macerals and organic particles were recognized in the 2006 round robin exercise: alginite, bituminite, amorphinite, and liptodetrinite. The results from maceral identification indicated that different terminologies were applied to the same maceral. No separation of alginite into telalginite and lamalginite was undertaken. The identification of macerals was achieved solely in the case of solitary macerals characterised by clear outlines. A problem with differentiation and recognition of macerals from each other became evident in the following maceral pairs: alginite and liptodetrinite, alginite and amorphinite, and alginite and sporinite. Alginite was distinguished from liptodetrinite on the basis of its characteristics: spikes along edges characteristic of dinoflagellates, high fluorescence, irregular shape, and coccoidal Botryococcus-like form. Alginite (lamalginite) was distinguished from amorphinite on the basis of a filamentous or lamellar form for alginite and amorphous or irregular form for amorphinite. In this exercise, positive and unanimous identification was achieved only for alginite macerals marked by characteristic and unequivocal features, as in the case of Fig. 1b.

4.2. 2009 round robin exercise

4.2.1. General remarks

The 2009 round robin exercise within the IDOM WG was performed

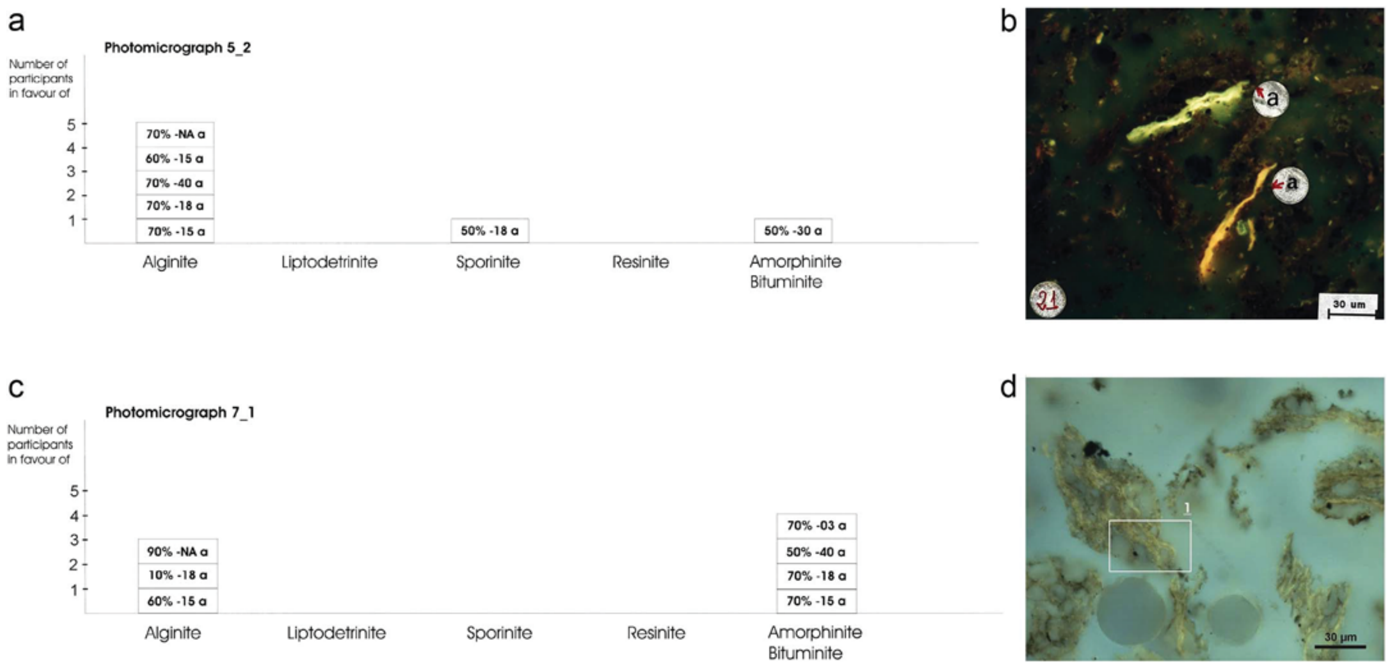

Fig. 1. a. Results of the 2006 round robin exercise performed in the ICCP IDOM Working Group for macerals marked in b. Most petrographers identified the marked macerals as alginite with a high confidence level of 60% or more. NA, no indication of years of experience in identification of dispersed organic matter; a, years of experience in identification of dispersed organic matter. b. Photomicrograph of pale to dark-yellow fluorescent alginite macerals in kerogen concentrate used in the 2006 round robin exercise. c. Results of the 2006 round robin exercise performed in the ICCP IDOM Working Group for the maceral marked in d. Petrographers identified the marked maceral either as alginite or amorphinite with a generally high confidence level of above 50%. d. Photomicrograph of pale-yellow fluorescent maceral in kerogen concentrate used in the 2006 round robin exercise. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

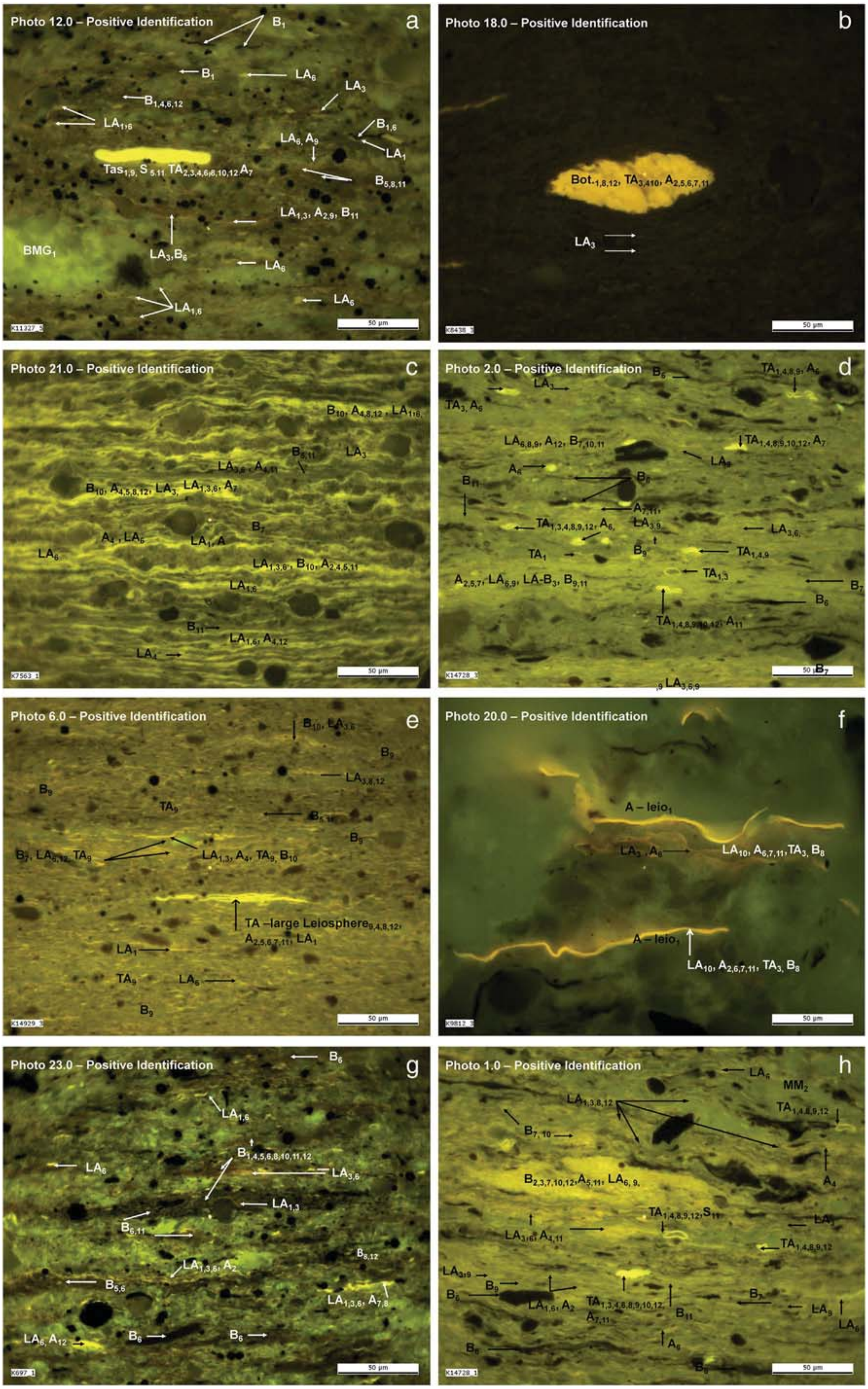

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Fig. 2. Photomicrographs of macerals identified in the 2009 round robin exercise performed in the ICCP IDOM Working Group. a, Photomicrograph of intensively yellow fluorescent *Tasmanite* algae enclosed in Lower Jurassic outcrop sample from Dotternhausen, Germany; A: alginite; B: bituminite; LA: lamalginite; S: spore; TA: telalginite; Tas: *Tasmanite*; BMG: bituminous groundmass. b, Photomicrograph of yellow fluorescent *Botryococcus* algae from an outcrop sample of the Pongo de Manseriche Gorge, in the Marañón Becken, Peru; A: alginite; Bot: *Botryococcus* Algae; TA: telalginite. c, Photomicrograph of yellow fluorescent lamalginite from the Eocene Green River Shale, Uintah County, Utah, USA; A: alginite; B: bituminite; LA: lamalginite. d, Photomicrograph of intensive green to yellow fluorescent telalginite and lamalginite from the Eocene Messel Formation collected at the Messel Pit Fossil Site, Hesse, Germany; A: alginite; B: bituminite; LA: lamalginite; TA: telalginite. e, Photomicrograph of intensive yellow fluorescent telalginite from a Tertiary oil shale sample from China; A: alginite; B: bituminite; LA: lamalginite; TA: telalginite. f, Photomicrograph of yellow to orange fluorescent telalginite and lamalginite from the Cretaceous Cachiyacu Formation collected from a well in the Maquia oil field, located in the Ucayali Basin, Peru; A: alginite; B: bituminite; LA: lamalginite; TA: telalginite. g, Photomicrograph of dark-brown fluorescent bituminite from the Lower Jurassic Posidonia Shale Formation collected from a quarry in Dotternhausen, Baden-Württemberg, Germany; A: alginite; B: bituminite; LA: lamalginite; TA: telalginite. h, Photomicrograph of intensive green to yellow fluorescent telalginite and lamalginite from the Eocene Messel Formation collected at the Messel Pit Fossil Site, Hesse, Germany; A: alginite; B: bituminite; LA: lamalginite; S: spore; TA: telalginite; MM: mineral matter. All photomicrographs were taken in fluorescence mode with oil immersion objective 50 ×; white numbering: identified particles correspond to bituminite. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

on photomicrographs acquired from whole rock pellets and the exercise focused on telalginite, lamalginite, and bituminite macerals.

4.2.2. Evaluation of the results

A positive identification of telalginite was achieved in the vast majority of cases (Fig. 2a, b). The reasons for positive identification was its occurrence in the form of discrete bodies with a clearly identifiably shape, size, and fluorescence that was distinct from the surrounding matrix. The distinct morphologies for given types of algae and characteristic arrangement of colonies also assisted in a positive identification. Only in a few cases were minor difficulties documented for alginite identification due to low fluorescence intensity (thus low contrast), followed by relatively small size (< 15 μm (μm) length and < 5 μm thickness) and filamentous character. Few participants confused alginite with cutinite and sporinite.

A positive identification of lamalginite was achieved only in a limited number of cases (Fig. 2c). The major reasons for positive identification included the following: (1) optically identifiable and recognisable lamellar structures, films, and fine bands; (2) isolated forms clearly distinguishable from one another and from the mineral groundmass; (3) lack of internal structure; and (4) weaker fluorescence intensity than telalginite (Fig. 2d). In the majority of cases, the positive identification of lamalginite was impeded due to the following reasons: (1) coalescence of isolated films to form thicker bands, stripes, and strands of uniform and homogenous appearance; (2) intimate interbedding with fluorescent mineral matter leading to an unclear shape and mottled appearance; (3) poorly bedded or laminated sections or sections parallel to bedding with anastomosing, diffuse appearance of isolated films and aggregates; and, (4) similarity to the description of bituminite I of Teichmüller and Ottenjann (1977) (Fig. 2e, f).

Positive identification of bituminite was sometimes possible. The following factors enabled a positive identification of bituminite: (1) fine granular texture (2) lack of characteristic lamalginite forms (e.g., thin and discontinuous lamellae < 5 μm in thickness, thin layers in sections parallel to bedding, botanical structure seldom present, greenish-yellow to orange at low rank, yellow to orange in the vitrinite reflectance range of 0.6% to 0.9% VRr and dull orange at higher ranks, higher fluorescence intensity, or their presence in minor amounts only); (3) homogenous appearance in the form of "Schlieren" (i.e., elongated lenses and vein-like streaks without intercalations and internal distortions); and, (4) fluorescence colour of bright yellow or orange, brown, or red in combination with the typical form of "Schlieren" (Fig. 2g). However, positive recognition of bituminite was inhibited in the majority of cases due to the following reasons: (1) similarity with the description of lamalginite, and specifically between the amorphous character of bituminite and the mottled, unclear forms of lamalginite; (2) interlamination of relatively weak fluorescent (pale green-yellow, dull orange to brown) bituminite with fluorescent groundmass; and (3) fine granular texture, if present, was not resolvable under 500 × magnification (Fig. 2h).

4.3. Round robin exercise 2011

4.3.1. General remarks

The 2011 round robin exercise was performed on photomicrographs acquired from whole rock pellets and focused solely on the identification of bituminite. Seventy-two photomicrographs in incident white light, in blue-light illumination at time (t) = 0 min (min), and in blue-light illumination at t = 15 min (i.e., prolonged fluorescence irradiation) were provided. The identification of bituminite was performed in both incident-white-light-based and blue-light-based photomicrographs, although the majority were made in blue-light-based photomicrographs. Most of the choices were made with high confidence except for a few cases (Fig. 3a). The most frequently used criteria to identify bituminite were (1) the relatively weak fluorescence and (2) its shape (as fine "Schlieren", threads, strands, bands, layers, lenses, flaser, and pods). Some participants reported difficulties in finding a "fine granular appearance", which is a typical identifying characteristic in the published ICCP definitions of bituminite (Taylor et al., 1998). Participants noted that difficulty in recognition was introduced by (1) the lack of criteria for identification of bituminite under 1000 × magnification, (2) diffuse borders or limits, (3) amorphous shape, and (4) close association with lamalginite.

4.3.2. Evaluation of the results

Slightly more than half of the identified bituminite in the photomicrographs corresponded to the ICCP definition of bituminite according to Taylor et al. (1998) (Fig. 3b, c). However, in a large number of cases, the identification of bituminite remained unsatisfactory. For example, several identified bituminite macerals did not correspond to (1) the criteria of colour in incident-white-light illumination, (2) the criteria of colour in blue-light illumination, and (3) the morphology outlined in Taylor et al. (1998). For example, instead of being dark brown, dark grey, or black in white-light illumination, the identified bituminites were pale red, red, or pale brown (Fig. 3d) or pale grey (Fig. 3e). The pale-yellow to yellow fluorescence of the incorrectly identified bituminite did not match the dark-brown to reddish fluorescence of the bituminite that had a measured low thermal maturity (VRr = 0.5% to 0.8%), (Fig. 3e,f). Also, some misidentified bituminite possessed a well-identified shape of an organic particle (Fig. 3g), or a bituminized vitrodetrinite. In some cases, misidentified bituminite corresponded to mineral components such as iron sulfide or fluorescent groundmass containing no bituminite. Furthermore, pale-yellow to olive-yellow fluorescent lamalginite identified as bituminite when examined under 500 × magnification actually contained a layered structure that was only discernable under 1000 × magnification. Bituminite was also embedded within the mineral groundmass, which prevented its identification.

In summary, the major reasons for the poor identification of bituminite were as follows: (1) poorly recognized optical properties led to misidentification (i.e., when observed in incident white light, a pale-grey to almost transparent colour was used to identify bituminite in thermally immature to oil-window mature rock samples instead of a dark brown, dark-grey, or almost black colour); (2) the "typically fine

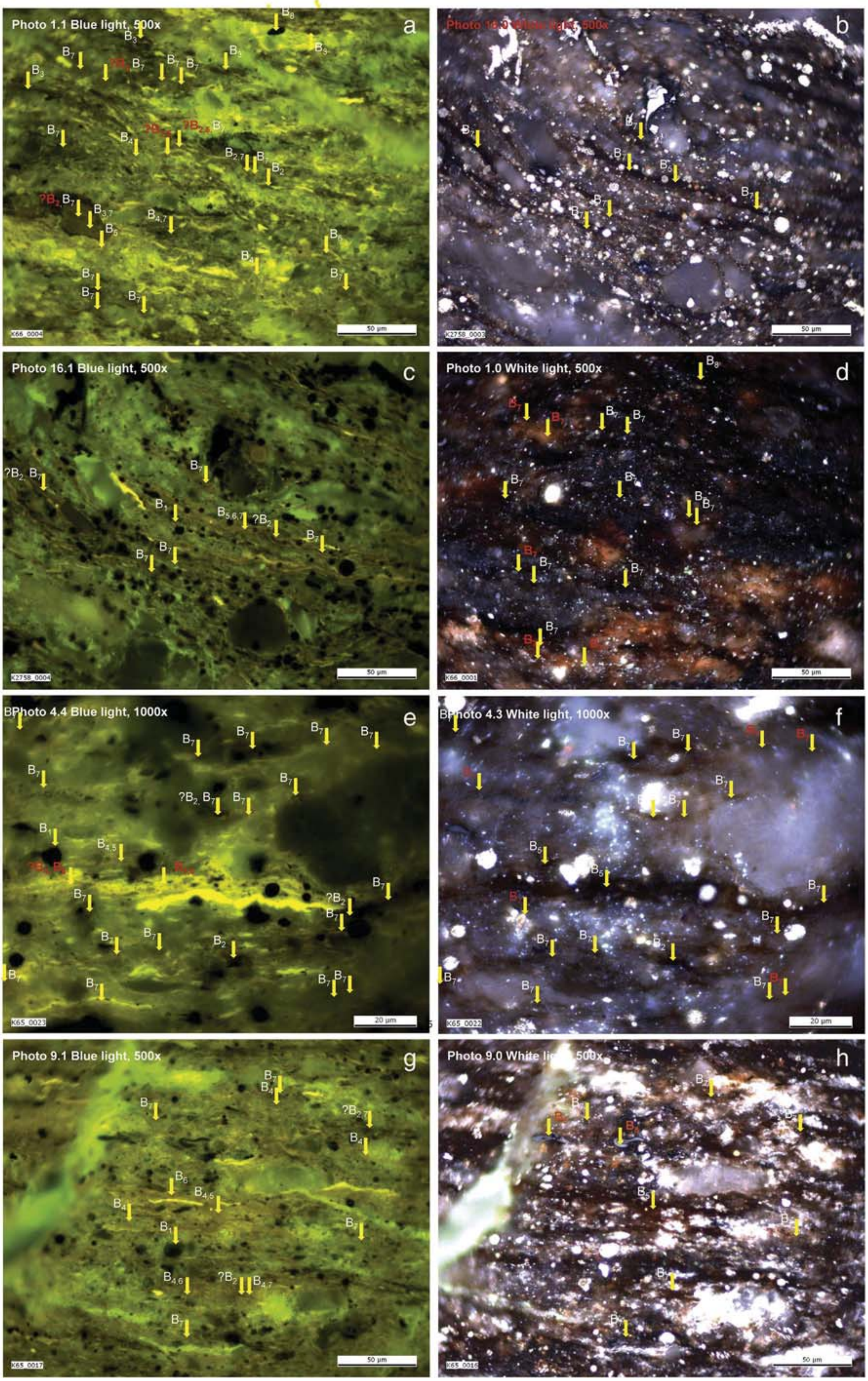

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Fig. 3. Photomicrographs of bituminite in the Lower Jurassic Posidonia Shale Formation, Germany, identified in the 2011 round robin exercise performed in the ICCP IDOM Working Group. All photomicrographs were taken with oil immersion objective 50 × or 100 ×. a, Photomicrograph of pale-brown to dark-brown fluorescent bituminite with pale-green to pale-yellow corroded algal remnants or liptodetrinite taken under incident blue-light illumination; B: bituminite;?B: possibly bituminite. b, Photomicrograph of dark-grey "Schlieren" of bituminite taken under incident white-light; B: bituminite; c, Photomicrograph of brown to dark-brown fluorescent bituminite with pale-green to pale-yellow corroded algal remnants or liptodetrinite taken under incident blue-light illumination; B: bituminite;?B: possibly bituminite. d, Photomicrograph of dark-grey "Schlieren" of bituminite taken under incident white light; B: bituminite. e, Photomicrograph of dark-grey "Schlieren" of bituminite taken under incident white light; B: bituminite; B: bituminite. f, Photomicrograph of brown to dark-brown fluorescent bituminite with pale-green to pale-yellow corroded algal remnants or liptodetrinite and of lamalginite taken under incident blue-light illumination; B: bituminite;?B: possibly bituminite. g, Photomicrograph of dark-grey "Schlieren" of bituminite taken under incident white light; numbering: participant's individual code; red marked numbering: identified particles do not correspond to bituminite; white numbering: identified particles correspond to bituminite. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

granular appearance" was taken as an obligatory condition for identification of the bituminite, possibly because the word of "typically" is found in the ICCP definition of bituminite; (3) particles of a definite shape (e.g., an iron sulfide, vitrodetrinite and even lamalginite) were identified as bituminite (i.e., there was clear confusion in the definition of bituminite having no definite form); and (4) altered lamalginite was misidentified as bituminite due to the graded transition from lamalginite to bituminite. The generally applied definition of bituminite as having a non-definite shape (amorphous) or being a structureless constituent appeared to be particularly confusing. A constituent of non-definite form takes the shape of whatever is holding it, clearly disagreeing with the ICCP derived "non-definite shape" definition where bituminite is variously described as stringers, irregular lenses, streaks, vein-like structures, thin layers, equidimensional particles of various shapes, or as a surrounding medium (substance). The meaning of "structureless" is understood as having no definite structure, arrangement, or organization; and lacking or devoid of a structure, i.e., homogenous. This again does not agree with the ICCP definition of morphology of bituminite where bituminite structure ranges from homogenous, streaky, fluidal, to finely granular (Taylor et al., 1998).

5. Discussion

5.1. General

One of the purposes of ICCP is to continuously modify and optimize existing nomenclatures and definitions of macerals examined in whole rock pellets in incident-white and blue-light illuminations. The IDOM WG, established in 2005, has attempted to address some of the shortcomings identified in the current ICCP and non-ICCP terminologies of alginite and bituminite (Stach et al., 1982; Taylor et al., 1998).

5.1.1. Alginite (telalginite and lamalginite)

Apart from the established ICCP terminology of alginite applied to coal (Taylor et al., 1998), other definitions and optical characteristics of alginite macerals in marine and lacustrine sedimentary rocks are outlined in Stach et al. (1982) and Taylor et al. (1998). The descriptions of alginite macerals may include, among others, their occurrences in the lower Toarcian Posidonia Shale (Teichmüller and Ottenjann, 1977) in Germany and in Australian oil shales (Hutton et al., 1980; Hutton, 1987).

Based on the evaluation of alginite identifications in the 2006 and 2009 round robin exercises, it is clear that the existing terminology of telalginite permits a satisfactory identification. In both exercises, the positive identification of alginite relied on a distinct appearance of discrete bodies, well differentiated from the surrounding mineral groundmass. The identification of telalginite was further enhanced by the presence of distinctive external and internal morphological and characteristics, such as (1) an external ornamentation with protrusions, spikes, fibers, and points; and (2) higher fluorescence intensities than other macerals. In a few cases where telalginite was lacking the above-mentioned characteristics and appeared to be filamentous or amorphous, petrographers experienced difficulty in differentiating between telalginite and lamalginite. The definition of the lamalginite maceral according to Stach et al. (1982) and Taylor et al. (1998) provides only a general description based solely on a summary of the observed features. As such, the above-mentioned lamellar or filamentous appearance of alginite did not permit its consistent identification as either telalginite or lamalginite. Moreover, the filamentous or lamellar optical appearance of organic matter in the 2006 round robin exercise caused difficulties when trying to differentiate between lamalginite and a maceral identified as amorphinite. A similar scenario appeared in the 2009 round robin exercise, where the coalescence of individual filamentous or lamellar algal bodies, intimate interbedding with mineral groundmass, diffuse appearance of isolated or aggregated lamellar algal bodies, and the similarity to bituminite I of Teichmüller and Ottenjann (1977) caused major identification problems of lamalginite. It appears that the descriptive characteristics of lamalginite as included in Stach et al. (1982) and Taylor et al. (1998) are insufficient to recognize this type of alginite with certainty in marine or lacustrine sedimentary rocks. The descriptive characteristics referring to a film-like appearance (filamentous) and a lack of structure (inner or outer) prevent an unequivocal discrimination between lamalginite and telalginite, bituminite I of Teichmüller and Ottenjann (1977), and mineral-bituminous groundmass.

5.2. Bituminite

The identifications of bituminite made during the 2011 round robin exercise were only partially satisfactory, pointing towards either a general lack of adherence to the established ICCP definition of bituminite (Taylor et al., 1998) or misapprehension, both of which reflect some deficiencies in the established bituminite definition and description. One major deficiency is that bituminite is regarded or described as being structureless or unstructured in its appearance (e.g., Obermajer et al., 1997; Nowak, 2007; Gorbanenko and Ligouis, 2014; Synnott et al., 2016). It is not clear whether this description refers to (1) the lack of a clear outline or a definite shape or form or, more importantly, to (2) the lack of an internal structure. According to the ICCP bituminite definition in Taylor et al. (1998), bituminite may display internal structure varying between homogenous to finely granular. Further, usage of the term "typically" should be avoided as it may imply a mandatory condition for the identified particle. Another deficiency in the existing ICCP-derived bituminite definition is that its pre-defined fine granular appearance, most likely derived from the description of bituminite III (Teichmüller and Ottenjann, 1977; Loh et al., 1986), is commonly perceived as a mandatory feature for identification of bituminite. However, the description of granular appearance refers to the internal structure of bituminite, which may be displayed in the examined samples but is certainly not compulsive. Bituminite macerals also are described as having irregular texture (e.g., Robl et al., 1987), which may be misleading as it can be used as a synonym to the term of structure. In general, texture refers to the size and shape of the consistent particles of a rock and also defines a specific type of alignment or orientation of components, inter- and overgrowths, and alternations of the particles. In addition, the term "optical texture" refers to the appearance of any surface under a polarized light. Therefore, the term "texture" should be used with great caution when describing the optical appearance of any amorphous organic matter under non-polarized light.

Yet another challenge to identifying bituminite is its similarity with banded lamalginite and its interlamination with mineral-bituminous groundmass "sensu stricto" as used in the ICCP definition of bituminite found in Taylor et al. (1998) for immature and mature source rocks. In the case of immature source rocks, the bituminite identified in the Posidonia Shale samples examined in the 2011 round robin exercise showed a clear genetic relationship with lamalginite, as established by Loh et al. (1986). In the case of mature source rocks, the identifications of both bituminite intimately interlaminated with mineral-bituminous groundmass and bituminite forming groundmass for other macerals and for minerals were specifically difficult because amorphous bituminite in the mineral-bituminous groundmass could not be appropriately identified in perpendicular or parallel sections under 500 × or 1000 × magnifications. Therefore, a clear and detailed description with suitable accompanying photomicrographs is required as a guide to help identify the unknown organic component as either bituminite or mineral-bituminous groundmass. This deficiency also reflects shortcomings in the established ICCP definition of mineral-bituminous groundmass in rocks other than coal (Taylor et al., 1998). Nonetheless, there are also limitations in the optical resolution of the incident-light microscopes, which can hinder confident identification.

6. Conclusions

An evaluation of photomicrograph-based identification of alginite and bituminite macerals in kerogen concentrates and whole rock samples was performed in three round robin exercises in 2006, 2009, and 2011, organized by the Identification of Dispersed Organic Matter Working Group of ICCP Commission II. The main conclusions derived from these exercises are as follows:

- The results revealed that, although well-structured telalginite with preserved outer-wall ornamentations was easily identified, major difficulties were encountered in recognizing and differentiating lamalginite and bituminite macerals when applying the established ICCP maceral terminologies and definitions.
- The largest scatter of results was for bituminite. In particular, major identification problems occurred when identifying transitions from (1) lamalginite to bituminite and (2) bituminite to mineral-bituminous groundmass. Thus, the established ICCP bituminite maceral definition (Taylor et al., 1998) requires a reconsideration with respect to the following aspects:

1. Clarification of the term "unstructured" in terms of lacking a definite shape or form as opposed to lacking internal structure.
2. The bituminite definition requires clarification of its established description in terms of morphological characteristics and should be accompanied with suitable photomicrograph examples. Usage of the term "typically" should be avoided.
3. A note on how to differentiate bituminite from other alginite macerals or mineral-bituminous groundmass is necessary.

- The descriptive characterisation of lamalginite in terms of being filamentous and lamellar is inadequate for the purpose of identification and systematic differentiation from telalginite. The established ICCP definition of alginite (Taylor et al., 1998) in terms of telalginite and lamalginite therefore requires a clear distinction between the following four forms of appearance: lamellar, filamentous, often finely banded lamalginite, and the mostly structured telalginite.

Acknowledgment

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