International Journal of Coal Geology 98 (2012) 73–94

Contents lists available at SciVerse ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

Review article

Review and update of the applications of organic petrology: Part 2, geological and multidisciplinary applications

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ARTICLE INFO

Article history:
Received 13 October 2011
Received in revised form 9 March 2012
Accepted 9 March 2012
Available online 19 March 2012

Keywords:
Organic petrology
Organic matter
Coal
Coalification
Thermal maturity
Ore deposits
Ore genesis
Bitumen
Coal fires
Archeology
Forensics
Environmental pollution

ABSTRACT

The present paper is focused on organic petrology applied to unconventional and multidisciplinary investigations and is the second part of a two part review that describes the geological applications and uses of this branch of earth sciences. Therefore, this paper reviews the use of organic petrology in investigations of: (i) ore genesis when organic matter occurs associated with mineralization; (ii) the behavior of organic matter in coal fires (self-heating and self-combustion); (iii) environmental and anthropogenic impacts associated with the management and industrial utilization of coal; (iv) archeology and the nature and geographical provenance of objects of organic nature such as jet, amber, other artifacts and coal from archeological sites; and (v) forensic science connected with criminal behavior or disasters. This second part of the review outlines the most recent research and applications of organic petrology in those fields.

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0166-5162/$ – see front matter
doi:10.1016/j.coal.2012.03.005

1. Introduction

In a previous paper (Suárez-Ruiz et al., 2012) focused on geological applications of organic petrology two of the main fields of application were described: depositional paleoenvironments (including organic facies and geothermal history of basins), and fossil fuel exploration (source and reservoir rocks). These are the traditional fields in which organic petrology has been applied and developed. The present paper is a continuation of the previous, but in this case the discussion is focused on application of organic petrology to less well-known disciplines. The first section of this manuscript is dedicated to applications of organic petrology to ore genetical investigation examining cases when organic matter is associated with ore deposits. The second section gathers applications of organic petrology to multidisciplinary fields unrelated to geology but of increasing societal interest such as the coal fires (self-heating and self-combustion), environmental science, archeology, and forensics (including forensic geology). These later disciplines can be described as unconventional applications of organic petrology. The range of unconventional applications and the amount of published contributions have been growing in the last 15 years.

As indicated in the previous paper (part 1, Suárez-Ruiz et al., 2012), in this review (part 2), the application of organic petrology to coal utilization is not considered given that a monograph focused on this subject was recently published (Suárez-Ruiz and Crelling, 2008).

When organic petrology is applied to investigations of ore genesis and other unconventional fields the technique and optical microscopy approach is the same as that conventionally applied to the study of the coal or dispersed organic matter as was described in part 1. This approach includes: i) observations in incident light to determine the type, source, and physico-optical properties of organic matter; ii) analysis of the optical textures (isotropy/anisotropy) in order to establish mineral and organic matter paragenesis in ore deposits, or to establish an anthropogenic source of organic material; iii) analysis of the fluorescence properties of organic matter, and iv) quantitative petrographic determinations such as reflectance measurements which are an organic indicator of thermal evolution and can be used to establish paragenetic sequences in the case of ore deposits.

Observations in transmitted light (thin sections) are infrequently used in the study of organic matter in ore deposits. However, such observations may provide additional information regarding thermal maturity because the color of some organic components irreversibly changes from light yellow to black with increasing maturity. For example, Gize (1993) reported the potential for simple coloration studies to outline thermal anomalies associated with hydrothermal mineralization although such studies require detailed investigation and must be interpreted with caution. On the other hand, analysis of organic matter in transmitted light is a classic tool in forensic investigations, particularly in the use of palynological studies to diagnose organic components. In all ore-related and unconventional applications, organic microscopy studies normally are used in combination with geochemical analysis.

2. Applications of organic petrology

2.1. Ore genesis and organic matter

2.1.1. Introduction

The formation of an ore deposit necessarily requires that the concentration of metallic elements is above average crustal levels (Meyers et al., 1992). It is well-known that some ore deposits occur associated with organic matter and that some of these deposits are of economic interest. Therefore in the 1980s, Dean (1986) edited a book examining organic matter associated with ore deposits including study of processes involved in concentration and accumulation of metals by organisms, methods used in the study of organic matter, and focused case studies. Some associations are well-documented, for example the Kupferschiefer in Central Europe (*e.g.*, Heppenheimer et al., 1995; Sawlowicz et al., 2000) which hosts the Cu–Pb–Zn–S mineralization with noble metals (*e.g.*, Kucha, 1993), the organic matter (kerogen and bitumen) occurring with gold and uraninite in the Witwatersrand ore deposits in South Africa (Eakin and Gize, 1992; Mossman et al., 2008; Parnell, 2001; Spangenberg and Frimmel, 2001, among others), hydrocarbons associated with Carlin-Type disseminated gold deposits (mentioned in Gize, 1993), and bitumens associated with various Cu deposits in Chile (Cisternas and Hermosilla, 2006; Wilson, 2000; Wilson and Zentilli, 2006).

Nature of the involvement of organic matter in some aspects of ore formation (*e.g.*, Meyers et al., 1992; Mossman, 1999) varies from active participation in the emplacement of ore deposits to post-depositional alteration of organic matter unrelated to the ore forming process. According to Mossman (1999) mechanisms by which the organic matter may concentrate metals include metal accumulation in living organisms (biomineralization processes, not discussed herein), metal absorption, and organic matter facilitation of reduction reactions through electron donation. Organic matter interacts with metals due to their inherent reducing, acidic and chelating properties. Redox reactions are important mechanism in diagenetic and epigenetic ore-forming environments wherein organic matter acts as a reducing agent for example for soluble metal sulfates in the generation of metal-sulfide deposits and/or the reduction of soluble metal cations to the insoluble native element. In all cases organic matter becomes oxidized. Leventhal (1986) described the physico-chemical processes (mobilization, transportation, concentration, reduction and preservation) and the role of organic matter in ore deposits (Table 1). Disnar and Sureau (1990) reviewed relationships between organic matter and uranium, gold, zinc, lead and copper in large ore deposits with special reference to the Witwatersrand (South Africa), Blind River–Elliot Lake (Ontario, Canada), Pine Point (Northwestern Territories, Canada, see also Macqueen, 1986), Jumbo Mine (Kansas, USA), Mississippi Valley-type ore deposits, and the Kupfershiefer deposit. They discussed the occurrence and role of the organic matter in metallic ore concentration, concluding that the key to understanding processes of ore genesis was the identification of specific alteration traits of the organic materials and criteria of the redox processes participating in metal concentration.

In the last 30 years many researchers have tried to determine relationships between organic matter and ore deposits mainly using organic geochemistry techniques (TOC and CHNOS determinations, Rock-Eval Pyrolysis, GC–MS analysis, stable isotopes such as C, O, among others) including *e.g.*, Ben Hassen et al. (2009), Bostick and Clayton (1986), Brocks et al. (2003), Giordano (1985, 2000), Hatch et al. (1986), Ho et al. (1990), Ho and Mauk (1996), Kríbek (1989), Kettler et al. (1990), Kremenetsky and Maksimyuk (2006), Landais et al. (1990), Macqueen and Powell (1983), Gize (1986a), Spangemberg and Frimmel (2001), and Strmic Palinkas et al. (2009), among others. Others have recognized the potential of organic petrology applications in studies of metal concentration and have incorporated additional microscopy techniques such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) in combination with organic geochemical analysis to investigate the role of organic matter. Examples include the investigations of Aizawa (2000), Bechtel et al. (1998), Cortial et al. (1990), Cunningham et al. (2004), Eakin and Gize (1992), Forbes et al. (1988), Glikson et al. (2000a, b), Glikson and Taylor (2000), Golding et al. (2000), Hausen and Park (1986), Heppenheimer et al. (1995), Héroux et al. (2000), Hu et al. (1998), Jochum (2000), Mauk and Hieshima (1992), Meunier et al. (1990), Monson and Parnell (1992), Mossman et al. (1993a,b), Mossman et al. (2008), Parnell (1992, 1999, 2001),Parnell and McCready (2000), Pasava et