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The properties of Çan Basin coals (Çanakkale—Turkey): Spontaneous combustion and combustion by-products

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ABSTRACT

The goals of this study were to investigate the susceptibility of Çan Basin (Çanakkale—Turkey) coals to spontaneous combustion and to determine the composition of the gas produced from the coal during combustion. Coal properties were determined using burned and partly burned coal samples; gas samples were analyzed for their composition. The mineralogical variations of burning coals were also investigated. Our results indicated that the pyrite content of Çan Basin coals is a significant factor for promoting combustion in addition to rank and moisture. X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses indicated that the coal samples contained pyrite, quartz, cristobalite, tridymite, kaolinite, amorphous matter, and gypsum. Fumarolic minerals (sulfur blooming and ammonium chloride) forming on the surface of coal seams were monitored. Elements including beryllium, fluorine, scandium, vanadium, cobalt, nickel, copper, zinc, arsenic, selenium, zirconium, molybdenum, tungsten, mercury, tantalum, lead, and uranium were found to be higher in Çan coal samples than the world average. The concentration of arsenic (max. 3319.7 μg/g) was relatively high and is the major hazardous element in the region.

Gases emitted from coal-fire vents in Çan coalfields were found to consist of a complex mixture of hydrocarbons, greenhouse gases, and toxic concentrations of carbon monoxide (CO), hydrogen sulfide (H_2S), and benzene. Hydrocarbon concentrations ranged from 77 to 92%, and the dominant hydrocarbon gas was methane. Ethane (0.3 to 2.1%) and propane (0.2 to 1.4%) were also detected. Hazardous compounds such as 5-methyl-3-propyl-1,2-oxazole ($C_7H_{11}NO$), ethanediimidic acid, 1,2-dihydrazide ($C_2H_8N_6$), and 2,3-dihydrofuran (C_4H_6O); high concentrations of nitrogen (N_2) (max. 6.8%) and carbon dioxide (CO_2) (max. 18.2%); and low concentrations of carbon monoxide were also determined. Greenhouse gases (CO_2 and methane (CH_4)) from burning coal beds may contribute to climate change and alter ecosystems. Gas components including furan, H_2S, CO, carbon disulfide (CS_2), benzene etc., can be hazardous to human health, even in trace amounts. As a result, the uncontrolled release of pollutants from burning coal beds presents potential environmental and human health hazards.

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1. Introduction

Spontaneous combustion or the self-heating of coal can be defined as a naturally occurring process caused by the oxidation of coal. When coal mixes with air, the spontaneous combustion of coal followed by a coal fire may result. The term coal fire refers to a burning or smoldering coal seam, coal storage pile, or coal waste pile. According to the experimental studies of Banerjee (1985), the oxidation of coal occurs in four stages, as follows: 1) the physical adsorption of oxygen, resulting in a temperature increase; 2) chemical sorption (over 50 °C), producing oxygenated hydrocarbons or peroxy-complexes; 3) the decomposition of oxygenated hydrocarbons when the self-heating temperature is reached (over 70 °C), with the concurrent oxidation of unaltered coal matter; and 4) spontaneous combustion that may occur if all of the above processes result in temperatures higher than 150 °C, typically described as the ignition threshold. Factors affecting the spontaneous combustion of coal have been investigated (Donely and Taylor, 2012; Kaymakçı and Didari, 2002; Mohan, 1996; Stracher and Taylor, 2004). The spontaneous combustion of coal largely depends on either intrinsic or extrinsic factors (Kaymakçı and Didari, 2002). Intrinsic factors are largely associated with the nature of the coal, whereas extrinsic factors are related to atmospheric, geological, and mining conditions. A number of intrinsic factors impact spontaneous combustion, including the following: 1) the moisture and volatile matter content; 2) the particle size and available surface area; 3) the mineral matter type and the pyrite content (in particular); and 4) the coal rank and petrographic composition (coal type) (Donnely and Bell, 2012; Kaymakçı and Didari, 2002; Wang et al., 2003).

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Spontaneous combustion may occur during coal mining (opencast and underground), storage, waste disposal, and transportation (Pone et al., 2007), and causes serious and negative effects in relation to environmental and human health. As expected, the processes of oxidation and self-combustion can degrade the quality of coal (Donnely and Bell, 2012; Kuenzer et al., 2007; Pone et al., 2007; Querol et al., 2011; Ribeiro et al., 2010; Wang et al., 2003). Many environmental and health problems occur due to the mobilization of potentially toxic organic and inorganic components during coal combustion (Finkelman, 2004; Finkelman and Gross, 1999). Analytical research conducted in China, the USA, and India has revealed the presence of arsenic (As) and fluorine (F) in coal that impacts human health (Dai et al., 2005, 2012a; Finkelman, 2004; Stracher and Taylor, 2004).

During the coal combustion process pollutant emissions occur as a result of the thermal alteration (pyrolysis) of organic and mineral matter. Volatile components include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), hydrofluoric acid (HF), ammonia (NH_3), hydrochloric acid (HCl), *n*-alkanes, *n*-alkenes, sugars, alcohols, polynuclear aromatic hydrocarbons (PAHs), mercury (Hg), arsenic (As), lead (Pb), selenium (Se), etc. (Carras et al., 2009; Engle et al., 2011, 2012, 2013; Fabiańska et al., 2013; Finkelman, 2004; Hower et al., 2009, 2013; Ide and Orr, 2011; Li et al., 2014; Liu et al., 1998; Misz-Kennan and Fabiańska, 2011; O'Keefe et al., 2010, 2011; Pone et al., 2007; Stracher and Taylor, 2004; van Dijk et al., 2011; Zhao et al., 2008). Among the pollutants released during the spontaneous combustion of coal, sulfur (SO) and nitrogen oxides (NO) may lead to acid rain and to the formation of gases such as CO, CO_2, and CH_4 that play a role in the greenhouse effect (Carras et al., 2009; Finkelman, 2004; O'Keefe et al., 2010; Stracher and Taylor, 2004; Zhao et al., 2008).

Although Çan Basin coals have been investigated in various studies (Gürdal, 2008, 2011; Gürdal and Bozcu, 2011), this study is the first to examine the spontaneous combustion of Çan coals. We investigated intrinsic factors that impact spontaneous combustion susceptibility, changes in the organic and inorganic constituents of coal due to spontaneous heating, and the composition of gas formed by combustion.

2. Geological setting

The Early–Middle Miocene-aged Çan Basin is located in NW Anatolia (Turkey) (Fig. 1). Stratigraphical studies of the Çan Basin by Gürdal and Bozcu (2011) indicated that the Çan Basin mainly consists of volcanoclastics, fluviatile and lacustrine clastic sediments, and a lignite seam with an average thickness of 17 m. The general stratigraphy of the Çan Basin is provided in Fig. 2. The Çan Formation has an average thickness of between 60 and 270 m and contains heterogeneous lithologies such as conglomerate, sandstone, claystone, lignite, claystone with organic

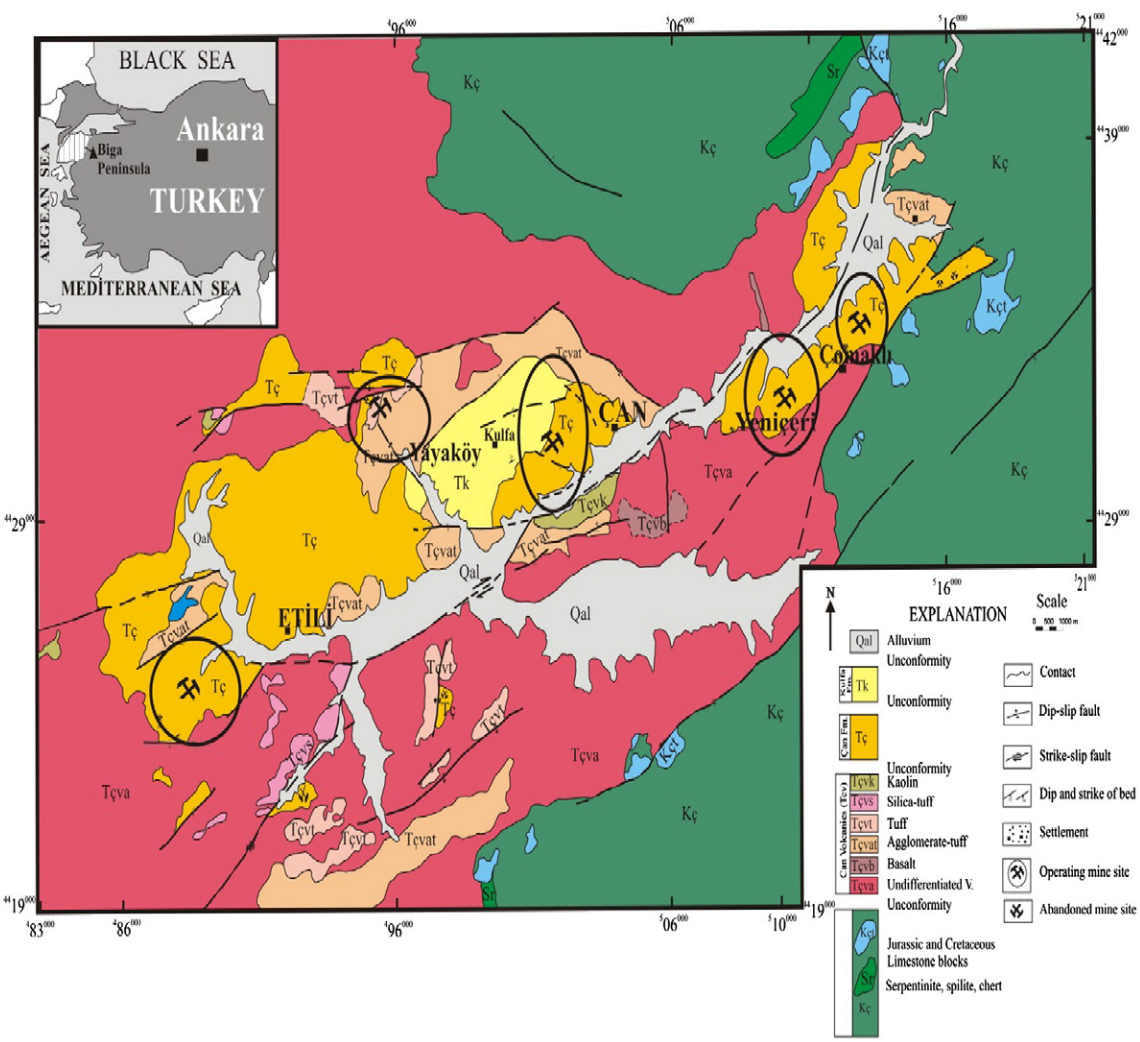

Fig. 1. A geological map of the Çan coalfield.
From Gürdal and Bozcu (2011).

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