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Evaluating the extent to which wildfire history can be interpreted from inertinite distribution in coal pillars: An example from the Late Permian, Kuznetsk Basin, Russia

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ABSTRACT

Inertinite (charcoal) distributions in two randomly sampled *in situ* coal pillars (seams 78 and 88) from the Late Permian Kuznetsk Basin, Siberia, were analysed using petrographic techniques to determine palaeowildfire histories (fire occurrence, type and return interval). *In situ* coal pillars are judged to be essential for this type of research as they retain information on the original inertinite distribution and maceral clast size ranges which can never be obtained from the crushed coals typically used for petrographic analysis.

The seams represent an ombrotrophic mire (seam 78) and mire with mire lake (seam 88) depositional settings but both environments show the same pattern of fire history. Charcoal is present in all lithotype units in both pillars. Both pillars contain episodic charcoal horizons representing local surface fires within the peat-forming environment, interspersed with frequent regional background fire events (as shown by small scattered inertinite).

This paper presents an approach to calculating fire return intervals (FRI) in these coal pillars by removing the thickness of less compactable charcoal horizons before calculating original duration of peat formation. This is achieved by using a range of peat accumulation rates and peat to coal compaction ratios. Resultant mean FRI ranges from 7 years (extremes 0.5 to 143 years), for a lithotype unit containing 4 horizons, to 70 years (extremes 5 to 1550 years), for a lithotype unit with 2 horizons. The mid-range values both suggest shorter fire return intervals than seen in modern peat-forming environments.

1. Introduction

Wildfire is an important element of the Earth System (Bowman et al., 2009) not only in the modern record but since at least the Late Silurian (Glasspool et al., 2004; Scott, 2000). Charcoal produced during wildfires may be less biodegradable (Ascough et al., 2011) than uncharred material and therefore more likely to be preserved in the fossil record (Scott, 2010). We consider that all inertinite is charcoal (Bustin and Guo, 1999; Glasspool and Scott, 2010; Scott, 2010; Scott and Glasspool, 2007) though Hower et al. (2011) argue that some macrinite may have been formed through the activity of fungi and bacteria.

Inertinite contents in Permian coals vary from 3.9% to 83% but the overall mean value is high, 44% for the Early Permian (280 Ma) and 38.9% for the Changhsingian (all mineral matter free (mmf) basis) suggesting more frequent, widespread wildfire events which is hypothesised to be related to modelled high atmospheric oxygen levels during the Permian (Glasspool and Scott, 2010). These values are much higher than peats formed under present atmospheric oxygen levels (mean inertinite of 4.3%) (Glasspool and Scott, 2010).

Inertinite distribution in coal can be used to interpret detailed palaeowildfire history at a local scale. There are three wildfire types; surface, crown and ground fires (as summarised by Davis, 1959; Pyne et al., 1996; Scott, 1989a). Horizons of macroscopic (>1 mm *sensu* Scott, 2010) fusinite and semifusinite are likely to represent local surface fires within the peat-forming environment, with limited transport history (Blackford, 2000; Clark, 1988; Clark and Royall, 1995; Tinner et al., 1998; Tolonen, 1983) whereas scattered microscopic charcoal (<180 μm, but often <20 μm) represents a windborne size fraction from regional fire events within 20–100 km of the fire source (Clark et al., 1998; Collinson et al., 2007; Conedara et al., 2009; Lynch et al., 2004; Ohlson and Tryterud, 2000; Peters and Higuera, 2007; Pitkänen et al., 1999). However, certain conditions, such as severe convection in high intensity crown fires and favourable topography, can sometimes carry centimetre sized charcoal particles several kilometres (Pisaric, 2002; Tinner et al., 2006).

In this paper we present comparative petrographic data from two Late Permian *in situ* coal pillars (seams 78 and 88) from the Kuznetsk

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Basin, Siberia. Previous petrographic work (Pakh and Artser, 2003) reported that seam 78 had the highest inertinite content but this was only based on crushed samples representing a bulk seam sample. Unlike crushed coals, *in situ* coal pillars retain the original spatial and temporal context of inertinite distribution and will therefore enable interpretation of local scale, Late Permian wildfire history.

2. Materials and methods

2.1. Sampling locality

The Kuznetsk Basin is located in South Western Siberia and has an area of 26,000 km^2 (Evtushenko et al., 1975) (Fig.1A). Basin fill consists of 5 km of Permian non-marine siliciclastics and high volatile bituminous coals, grouped into three facies associations; fluvial channel-belt, overbank and floodplain/floodplain pond with extensive, long lived, mire environments on the floodplain (Davies et al., 2010).

Seams 78 and 88 are part of the Tailuganskaya Formation (Fig. 1B) which contains the thickest and most economic seams in the Kuznetsk Basin. Based on crushed coal industry data, seam 78 also has the highest inertinite content of the sequence (Evtushenko et al., 1975; Pakh and Artser, 2003).

Two *in situ* coal pillars were randomly sampled from two open cast mines (not named by request of the mine owners) that both exploit bituminous coals from the Late Permian. Seams were often in excess of 10 m thick (Fig. 2A) and coal pillar size in relation to total seam thickness is demonstrated in Fig. 2B(i), Fig. 2B(ii) (seam 78) and 2C (seam 88). It is outside the scope of this paper to analyse the entire seams, therefore for this study random samples were taken from accessible locations in each seam.

2.2. Dating the Permian sequence

The terrestrial Permian sequence is dated by traditional Russian correlation using a biostratigraphic framework which incorporates floral, ostracode, conchostracan, bivalve and charophyte assemblages (Mogutcheva and Krugovykh, 2009). The Latest Permian has been dated by Ar–Ar age determination of two basalt flows (250.3 ± 0.7 Ma and 250.7 ± 0.6 Ma) (Davies et al., 2010; Reichow et al., 2009). The basalt flows are above the latest coal seams (Davies et al., 2010) therefore the seams in this study must be older than the basalt flows.

2.3. Study methods

In situ coal pillars were removed from the coal seam face (Fig. 2B(ii); Fig. 2C) and wrapped tightly in aluminium foil to retain integrity and orientation. They were then transported in bubble wrap to prevent breakage.

The two coal pillars were embedded in plaster of Paris to retain integrity during cutting. The pillar was then cut in half. One half was embedded in polyester resin (1% hardener to 99% resin), cut into blocks of manageable size, milled and polished.

Petrographic analysis was undertaken on polished blocks, under oil using a Leica DM 2500 P reflectance microscope using a ×20 objective. Representative colour photographs (2560 × 1920 pixel resolution) were taken using a 5 megapixel camera attached to the reflectance microscope and Prog-Res Capture Pro 2.7 software. Images were taken using the same lamp setting to ensure consistency and have not been post-processed in any way.

There is currently no standardised methodology for petrographic analysis of *in situ* coal pillars (Stach, 1982) although, approaches to

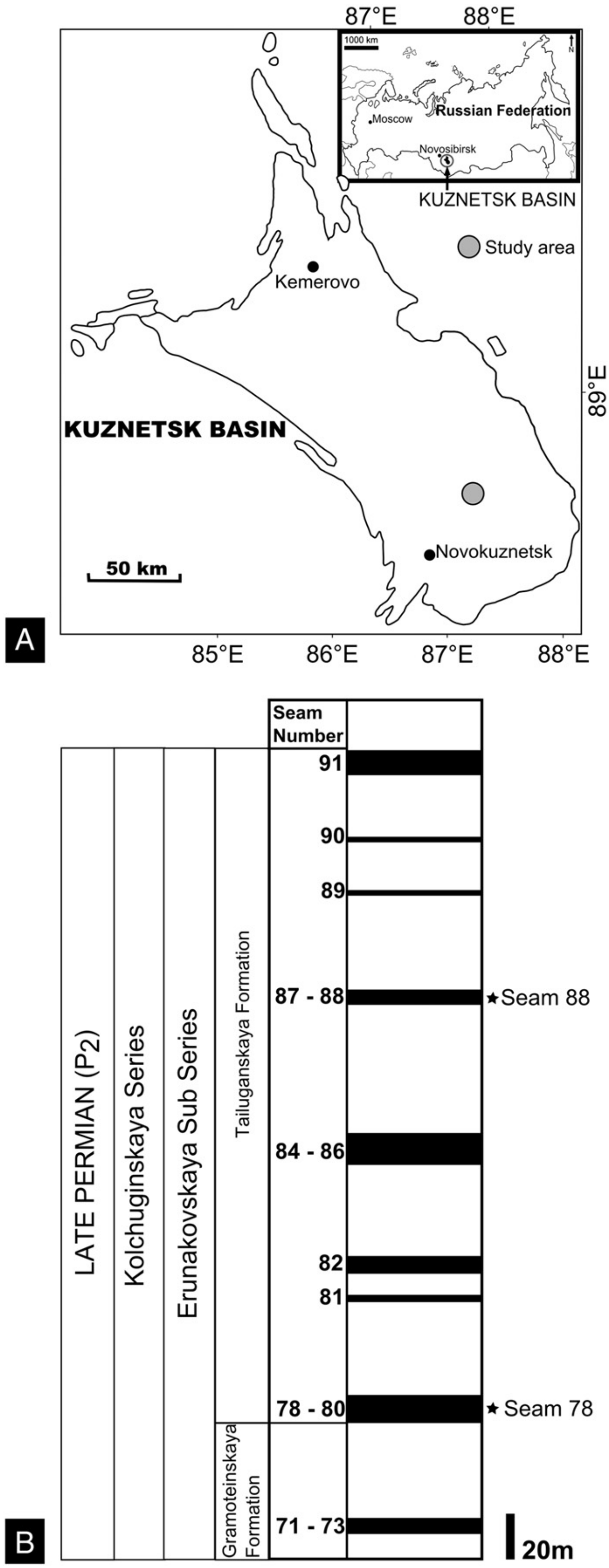

Fig. 1. A = Outline map of the Kuznetsk Basin showing the study area (after Pakh and Artser, 2003) with a small inset map showing the geographical context of the Kuznetsk Basin in Russia (after Walker, 2000). B = Schematic representation of relative coal seam and inter bed thicknesses obtained from borehole data from one of the open cast mines. The seams studied are marked with an asterisk (redrawn from Siberian mine company copy).