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Evidence of multiple late Bashkirian to early Moscovian (Pennsylvanian) fire events preserved in contemporaneous cave fills

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ABSTRACT

During a low sea level stand and wet climate phase at the end of the Mississippian, Lower Palaeozoic limestones at the northern edge of the Illinois Basin were karstified. The caves and fissures that formed were infilled subsequently with clastic sediments of Pennsylvanian age (late Bashkirian–early Moscovian (= Atokan, Duckmantian/Bolsovian, Westphalian B/C)). The earliest infills comprise organic-rich, almost coaly, sediments, while sands, silts and fine clays were deposited subsequently. The sediments are fossiliferous and contain abundant plant fragments, most notably cordaitalean and conifer remains. Many of the plants and megaspores are uncompressed and have undergone minimal thermal alteration. Charcoal occurs throughout the sedimentary infills but is most abundant in the later deposits, where conifer remains predominate. These conifers are currently amongst the oldest known from North America. The presence of cordaitalean remains in the earliest coaly infills is supported by the detection of specific fernane derivatives. The lipid extract of the cave fill sequence contains polyaromatic hydrocarbons (PAHs), such as pyrene, chrysene, benzo[ghi]perylene, and coronene, which distribution further attests to the importance of wildfire in preserving the plant remains.

1. Introduction

Cave fills, together with associated fissure fills are seldom described in the pre-Cenozoic fossil record yet they may preserve a wealth of palaeontological data (Harris, 1957, 1958; Leary, 1977, 1981; Whiteside and Marshall, 2008; Hartkopf-Fröder et al., 2008). This may include diverse vertebrate assemblages (Marshall and Whiteside, 1980; Wells et al., 1984; Archer et al., 1989; Whiteside and Marshall, 2008) through to unusual plant assemblages (Harris, 1957; Leary, 1974, 1977; Leary and Pfefferkorn, 1977; Hartkopf-Fröder et al., 2008), depending on the nature of the sedimentary fill. In addition, such deposits may yield charred plants, indicative of wildfires across the land surface (Harris, 1958; Hartkopf-Fröder et al., 2008).

Here we report on a system of well-preserved caves and cave fills within Ordovician limestones of north-central Illinois, U.S.A. These cave fills contain Early–Middle Pennsylvanian age sediments with abundant charred plant remains. Reports on the geology of the palaeokarst can be found in Plotnick et al. (2008a,b, in press), while Glasspool et al. (2009) reported on the ultrastructure of some of the uncharred lycopsid megaspores.

The most common plants found in the charred assemblages are considered to represent conifer fragments. Many of the earliest conifers have been reported preserved as charcoal (Scott, 1974; Scott and Chaloner, 1983; Winston, 1983) and are often fragmentary in nature and may have been transported from better drained uplands or extrabasinal areas (Scott and Chaloner, 1983; Winston, 1983; Lyons and Darrah, 1989; DiMichele et al., 2005). To date the oldest reported North American conifers are all of Middle or Late Pennsylvanian (= late Westphalian–Stephanian) age (Table 1) and include specimens ranging geographically from the Paradox Basin of Colorado to the Maritimes Basin of Nova Scotia (Rothwell et al., 1977; Lyons and Darrah, 1989). Here we report on charred conifers from roughly the centre of this geographic range, the Illinois Basin, that marginally predate these records and confirm their occurrence in North America at least as far back as the Bashkerian–Moscovian (= North American Atokan stage, the European Duckmantian–Bolsovian or Westphalian B/C stages). These conifer and cordaitalean fragments also provide further evidence of Pennsylvanian age wildfires across equatorial Euramerica, where it appears that fires were common (Scott and Jones, 1994; Scott, 2000; Falcon-Lang, 2000; Scott and Glasspool, 2006).

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2. Geological setting and lithology

The palaeokarst and associated fill occur in the upper part of the Central Quarry in Central, Kendall County, Illinois (Sec. 28, T35N, R7E; N 41.47669 W 88.43788; Fig. 1). The host rocks for the palaeokarst are Upper Ordovician limestones of the Dunleith Formation, Galena Group (Willman and Kolata, 1978).

The locality lies about 10 km southwest of the Sandwich Fault Zone, which was active in the Late Mississippian–Early Pennsylvanian (Kolata et al., 1978). The presence of flat-lying stratigraphically lower rocks of the Platteville group in a quarry 0.5 km to the west indicates the presence of a fault near the western edge of the quarry (Kolata pers. com.), with the Central quarry being on the downthrown side. Structural evidence suggests that this fault and associated fracturing are related to the Sandwich Fault and may be responsible for the formation of the palaeokarst.

The palaeokarst is exposed in a 310 m long section along the south wall of the quarry (Fig. 2a). Nearly all of the preserved features are roofed by limestone, and represent preserved cave passages (Fig. 2b). There is one probable example of a sinkhole. The exposed caves range in size from a metre in width up to approximately 10 m high and 18 m across (Fig. 2b–e). Most are semi-elliptical, with rounded convex bottoms. Dissolution features, such as pendants and half-tubes, as well as the cross-sectional shape, indicate the caves developed originally as phreatic tubes and then grew upward by paragenesis (Plotnick et al., in press). This is a process by which the floor of the cave is protected from dissolution and moves upward by clastic sediment deposition while the roof continues to erode. As a result, emplacement of the fill and later stages of speleogenesis are contemporaneous.

Compaction has been minimal as the fills were deposited within roofed caves. The material is poorly indurated and disaggregates readily in water, so that exposed fills erode rapidly. The sediments are distinctly stratified, fine upwards and contain numerous organic-rich horizons with well-preserved palynomorph assemblages (both miospores and megaspores; Glasspool et al., 2009). We have identified five facies (Fig. 3) in the largest and best preserved of the cave fills (Fig. 2b, c). Facies A comprises a basal roof collapse limestone breccia; facies B consists of alternating layers of poorly sorted silt and sand with varying amounts of coaly shale (abundant charcoal); facies C is a massive sandstone with occasional coaly shale (charcoal present); facies D consists of poorly sorted siltstones with sand, clay and plant debris (abundant charcoal); facies E, the youngest, is a light grey fine clay (for details see: Plotnick et al., in press).

The other fills in the quarry preserve only part of the sequence observed in the largest fill. Many of the smaller caves are solely filled with grey clay (facies E) or with grey clay overlying siltstone (facies D and E) that occasionally yields charred plant fragments (Fig. 2d, e).

Table 1
Correlation of standard chronostratigraphy with North American and European Regional Stages (data from Gradstein et al., 2004; figure produced with TSCreator PRO (http://www.tscreator.org)).

Standard chronostratigraphy			Regional stages		
Period	Epoch	Stage	North America	Europe	
Carboniferous	Middle Pennsylvanian	Moscovian	Desmoinsian	Stephanian	Cantabrian
				Westphalian	(D) Asturian
			Atokan		(C) Bolsovian
	Early Pennsylvanian	Bashkirian			(B) Duckmantian
					(A) Langsettian
			Morrowan	Namurian	

Broken lines indicate uncertainty of correlation.

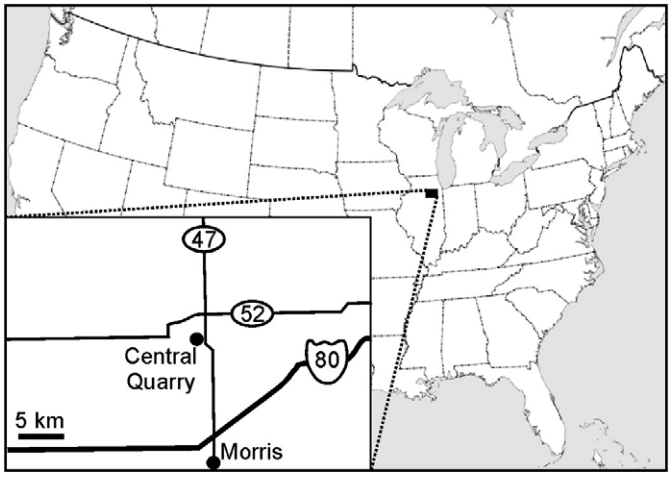

Fig. 1. Map of the U.S.A. Showing location of the Central Quarry, Illinois (inset).

2.1. Correlation of the fill and palaeokarst

An extensive review of the correlation of the fill is undertaken by Plotnick et al. (in press). However, the main points of this review are that:

1. Unusual euhedral overgrowths on the quartz grains of facies C are comparable with those of the Babylon Sandstone from the base of the Tradewater Formation (Wanless, 1939, 1957, 1962). In western Illinois, this unit usually forms the base of the Pennsylvanian sequence (Wanless, 1962). In northwestern Illinois, it is the first widespread unit above the sub-Absaroka unconformity (Leary and Trask, 1985). Peppers (1996) places the Babylon Sandstone at the top of the Westphalian B (= Atokan, late Bashkirian, Duckmantian).
2. Palynological analyses of both meso- and microfossil assemblages support correlation with the Tradewater Formation and the Atokan. While most are long ranging, many of the megaspores are considered particularly characteristic of Lower Pennsylvanian deposits (Winslow, 1959). *Valvisisporites sculptus* is known only from the Westphalian C (Bolsovian, early Moscovian, late Atokan, Glasspool et al., 2009). Overall, the miospore assemblage is similar to that described by Peppers (1996) for the *Torispora securis–Vestispora fenestrata* (SF) and *Radiizonates difformis* (RD) miospore zones, which are early–middle Moscovian (Middle to late Middle Atokan or late Duckmantian–Bolsovian; Westphalian B–C) in age.

We thus with good confidence correlate the fill to the Tradewater Formation. The palynology indicates an age of early–middle Moscovian (Atokan, Bolsovian, Westphalian C), though it is possible that the lower units may be as old as late Bashkirian–early Moscovian (Duckmantian, Westphalian B). Assuming the caves grew through paragenesis, they may also in part date from the same period, although speleogenesis may have certainly begun earlier.

This age is consistent with the regional stratigraphy. The nearest mapped Pennsylvanian rocks are 5 km to the south and assigned to the Tradewater Formation (Kolata, 2005). Regionally, to the south and west, basal Pennsylvanian sediments unconformably overlie rocks as old as Middle Ordovician (Howard, 1979).

3. Materials and methods

Samples were collected by REP, FK, ACS and IJG during multiple collecting trips. Initially loose samples from the top of the sequence were collected but on subsequent occasions samples were collected from measured sections. Samples were disaggregated in water and sieved. Organic residues were cleaned in HF and leaves were picked for SEM. Specimens were mounted on stubs for Scanning Electron