Cretaceous Research (1995) **16**, 705–716

The stratigraphy and palaeontology of the Upper Weald Clay (Barremian) at Smokejacks Brickworks, Ockley, Surrey, England

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Received 1 December 1994 and accepted 28 April 1995

The stratigraphy of the Weald Clay of Surrey is summarized. The Hauterivian/Barremian boundary is shown to correspond closely to the Lower Weald Clay/Upper Weald Clay boundary, which lies at the base of BGS (British Geological Survey) Bed 3a and is close to the Ewhurst/Capel ostracod faunicycle boundary. Detailed sections of the sediments exposed in the pit at Smokejacks Brickworks are published for the first time. BGS Bed 5c is present at the top of the pit, which indicates that the sediments belong to the Upper Weald Clay and suggests an early Barremian age for this site. The pit has yielded a diverse non-marine fossil fauna and flora consisting of the remains of insects, crustacea, bivalves, dinosaurs (including *Baryonyx walkeri*), pterosaurs, crocodiles, sharks, bony fish, club mosses, horsetails, ferns, conifers and a primitive aquatic or marsh-dwelling herbaceous plant. The extinct lacewing family Brongniartiellidae is recorded from the Barremian for the first time. The sediments exposed in Smokejacks pit and their fossil content indicate a shallowing upwards sequence, documenting a change from a lacustrine/lagoonal to a fluvial/mudplain environment.

KEY WORDS: Wealden; Weald Clay; Barremian; England; dinosaurs; fossil insects; fossil plants.

1. Introduction

Smokejacks Brickworks (National Grid Reference TQ 113 373) is situated 4 km southwest of the village of Ockley, Surrey and 10 km north-northwest of the town of Horsham in southeast England (Figure 1). It has one of the largest working brickpits in the Weald, but no complete detailed section has been published previously. The site exposes 23 m of silty clay and sandstone beds belonging to the Weald Clay, which was deposited in a non-marine lacustrine/lagoonal/mudplain environment (Allen, 1981, 1990). The brickworks is famous for the discovery, in 1983, of a new species of theropod dinosaur, *Baryonyx walkeri* Charig & Milner.

2. Stratigraphy

The precise stratigraphical position of the section exposed at Smokejacks Brickworks, particularly its age, has been unclear owing to some misinterpretation of the position of lithostratigraphical and chronostratigraphical boundaries

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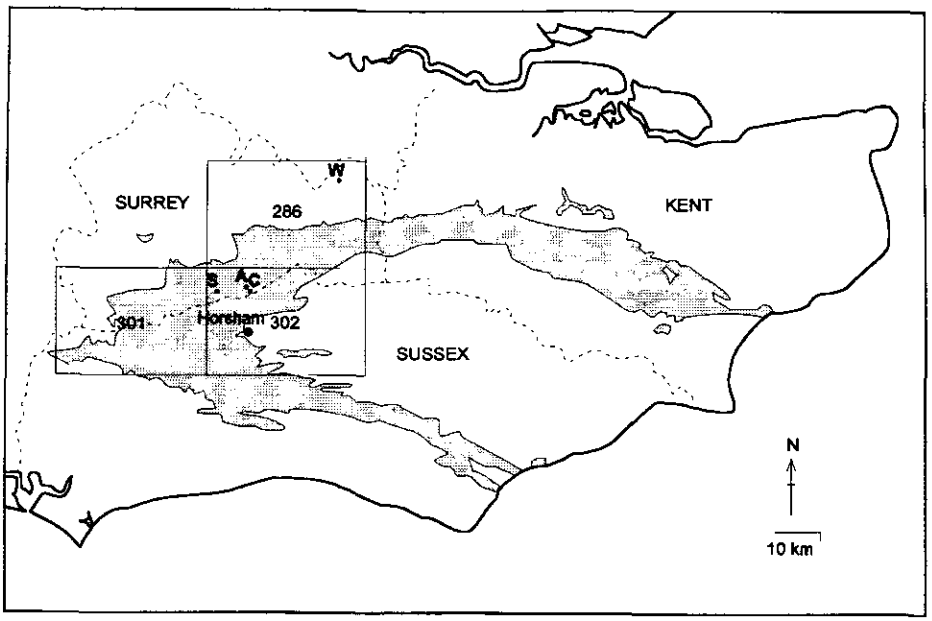

Figure 1. *Map of south-east England showing the outcrop of the Weald Clay (stippled), county boundaries (dashed), the areas covered by BGS maps 286, 301 and 302, and the geographical position of Smokejacks Brickworks (S) and other localities mentioned in the text (A = Auclaye Brickworks, C = Clockhouse Brickworks, W = Warlingham Borehole).*

within the Weald Clay. It has been suggested (e.g., Jarzembowski, 1991a) that the section exposed in the pit lies within the Upper Weald Clay and is early Barremian in age. This is tested below.

Lithostratigraphy

The Weald Clay forms a low lying, C-shaped outcrop in the Weald (Figure 1) and reaches a maximum thickness of about 700m. It lies above the Upper Tunbridge Wells Sand and below the Atherfield Clay. Thurrell *et al.* (1968) introduced a scheme, modified from Topley (1875), in which every mapped sandstone and limestone bed in the Weald Clay was given a number. A modified version of this, for Surrey only, is given in Figure 2 (excluding information from British Geological Survey (BGS) Sheet 286 as this area has not been adequately mapped). Allen (1976) gave names to many of these beds. Worssam (1978) recognized two major cyclic units in the Weald Clay, referred to as lower and upper divisions, which culminated in brackish-marine facies. He gave the boundary between the two divisions as the base of Topley's bed 5 and later (Worssam, *op. cit.*, p. 9) indicated that this is equivalent to the base of BGS Bed 3a. Some workers (e.g., Allen & Wimbledon, 1991) have wrongly assumed that Topley's bed 5 is the same as BGS bed 5. Thurrell *et al.* (1968, p. 25) indicated that it is equivalent to BGS beds 3 and 5 beyond the northern limit (in Sussex) of bed 4.

The Smokejacks Brickworks pit is shown on BGS Sheet 302 (Horsham) to cut through sandstone Bed 5c (the Alford Sand of Allen), which therefore places it within the Upper Weald Clay (see Figure 2). During 1991–94 we measured the sections that are shown in Figure 3. Figure 4 shows the approximate size of the

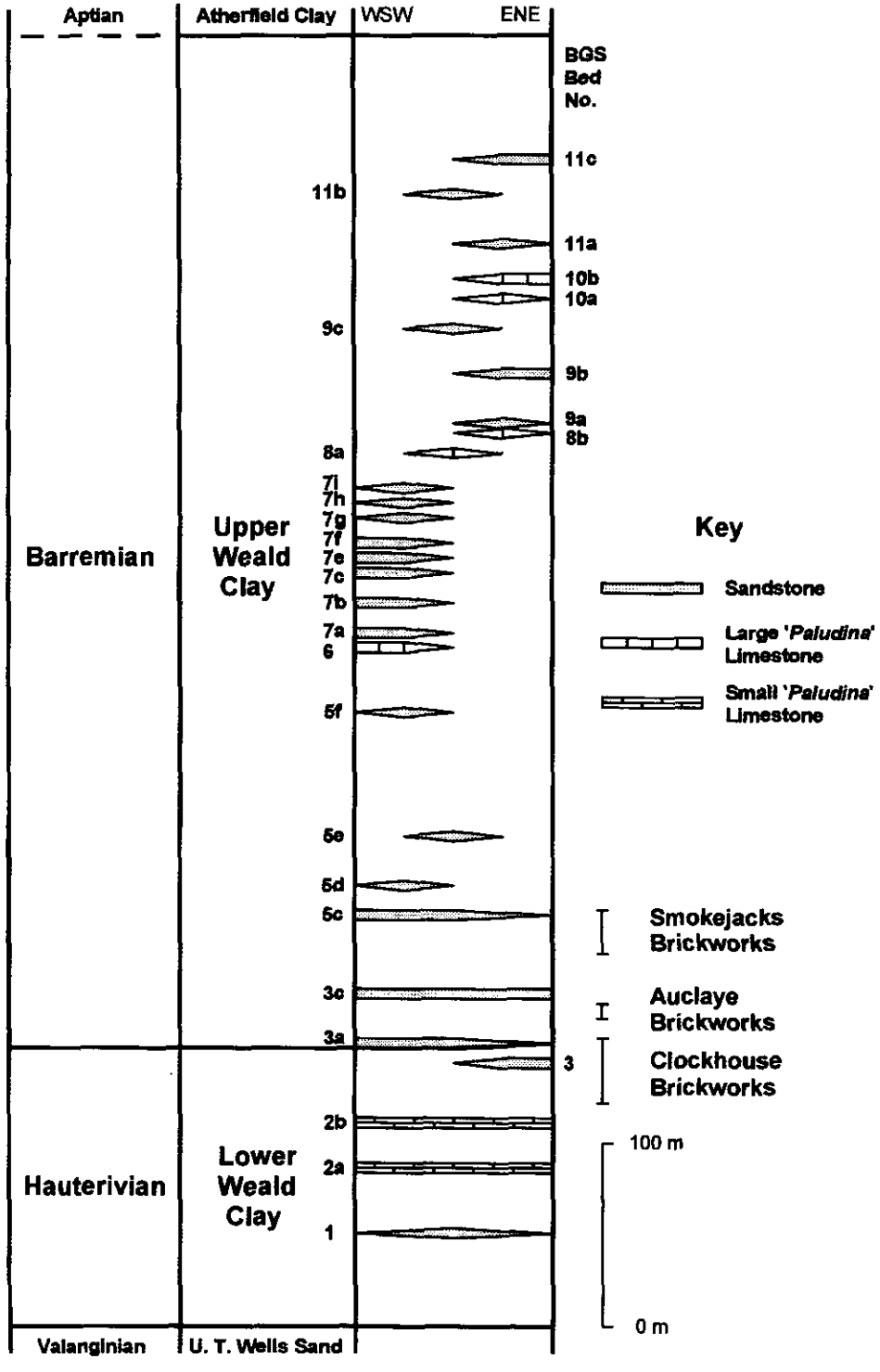

Figure 2. The stratigraphy of the Weald Clay in Surrey showing the positions of the numbered sandstone and limestone beds, and the sections exposed in Smokejacks Brickworks pit and at other localities mentioned in the text. The interbed thicknesses were calculated using information from Thurrell *et al.* (1968), Gallois & Worssam (1993), and the associated British Geological Survey (BGS) maps (301 and 302). The numbered bed thicknesses are mostly exaggerated.

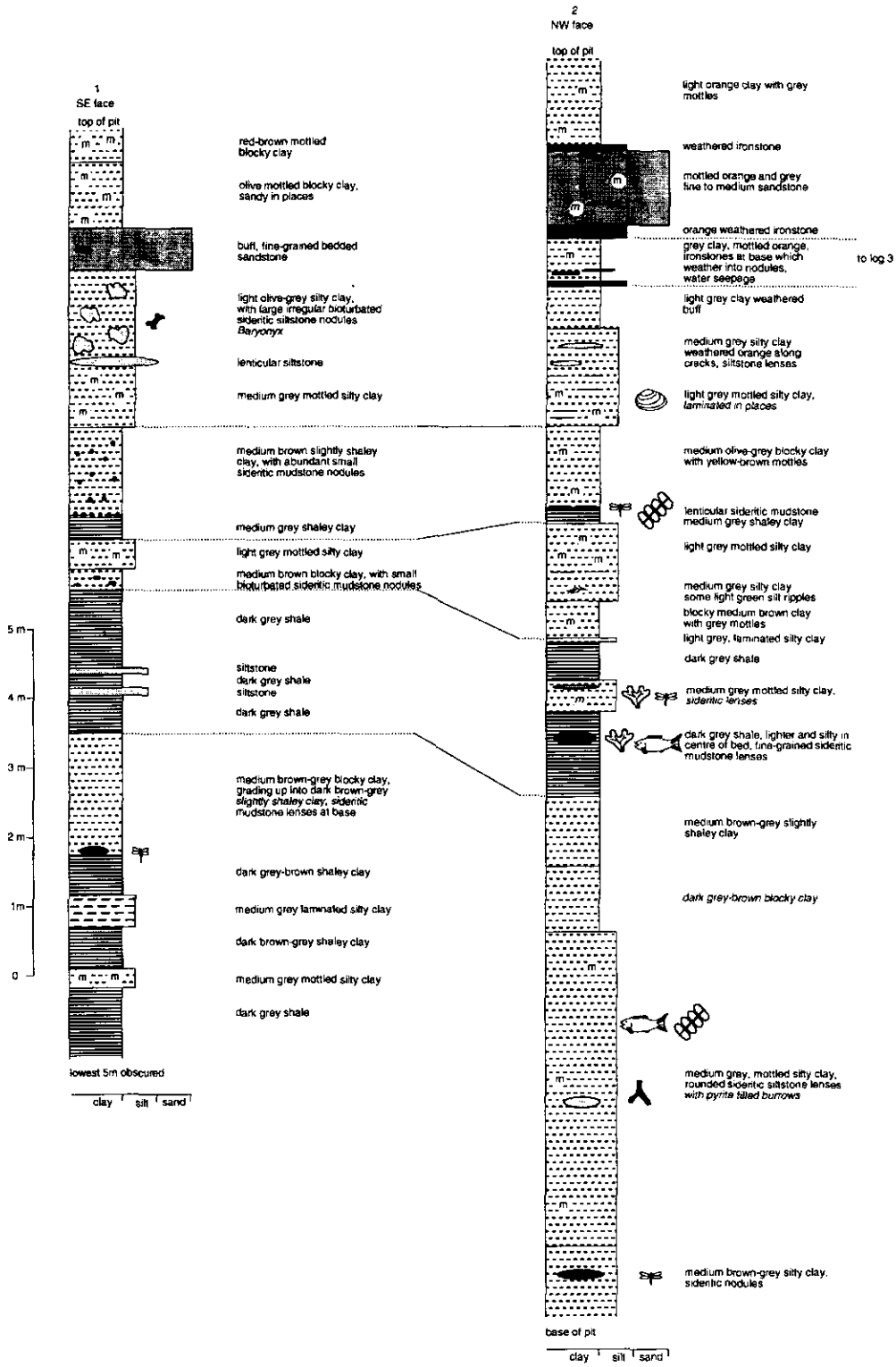

Figure 3. Detailed lithostratigraphical logs from four different parts of the pit at Smokejacks Brickworks indicating horizons where fossils were found *in situ*.

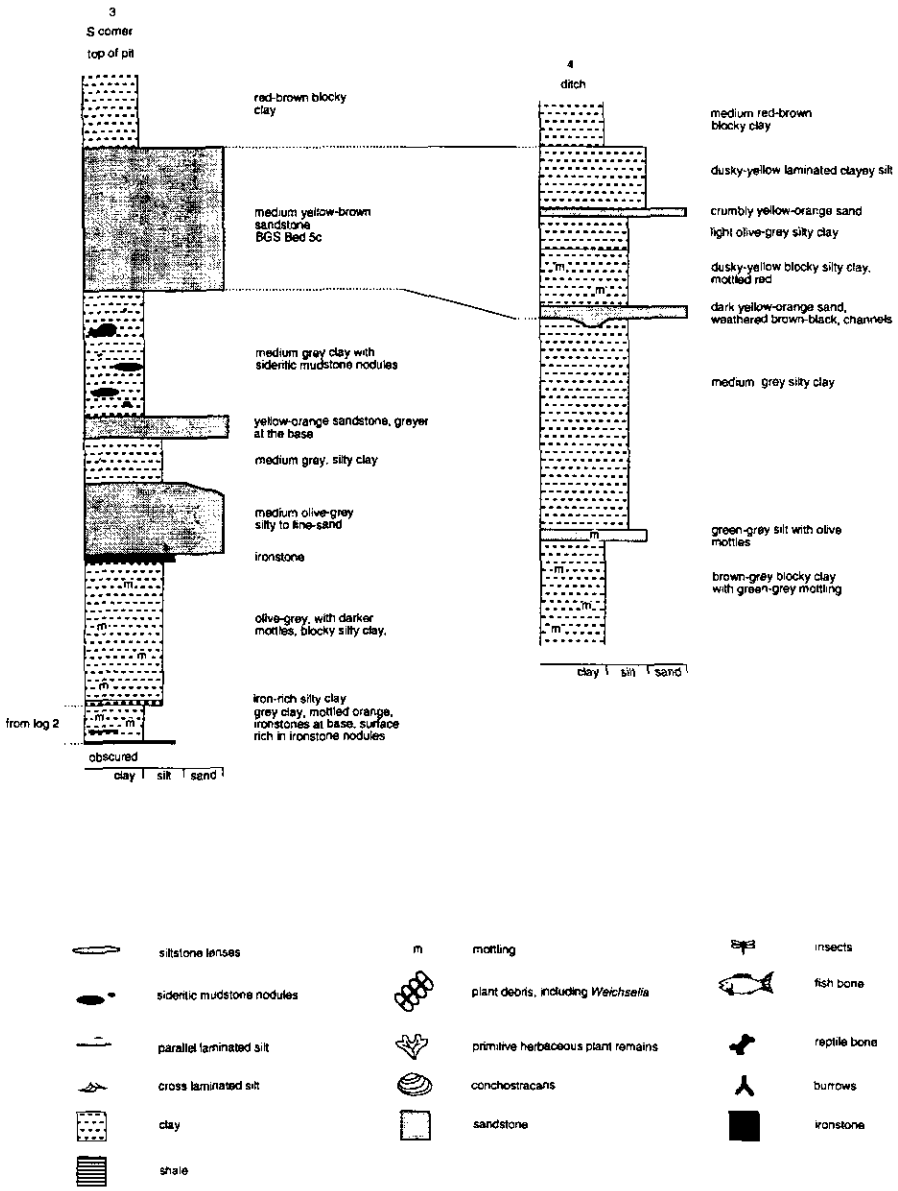

Figure 3. (*Continued.*)

pit and the positions of the sections. Sections 1 and 3 were measured in gulleys cutting through the weathered southeast face and southern corner of the pit, 2 at the northern end of the actively worked northwest face and 4 in a ditch west of the pit. The position of *Baryonyx* was taken from an unpublished composite section measured in 1983 by Mr C. P. Palmer. It is shown on Section 1 to lie about 7 m below the base of BGS Bed 5c. There is a striking amount of lateral variation in many of the beds, as can be seen from comparison of the sections. This is particularly apparent in the sandstone beds towards the top of the pit; other details of these are given in Gallois & Worssam (1993). Allen (1981) published a detailed section through BGS Bed 5c from an exposure 200m east of

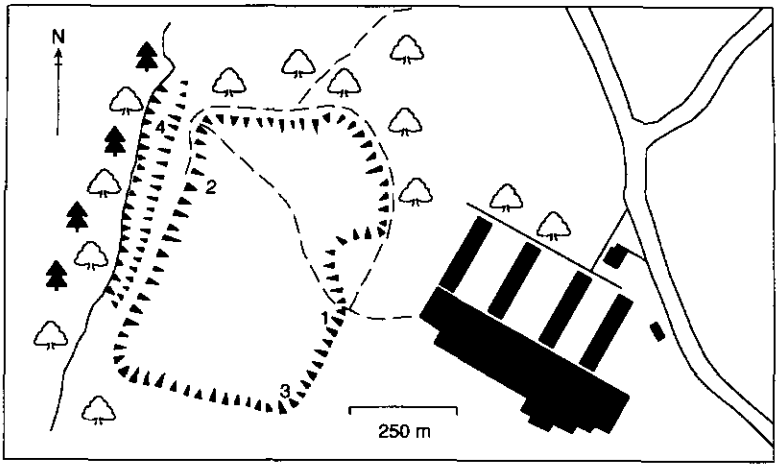

Figure 4. Site map of Smokejacks Brickworks, Surrey (buildings in black) and adjoining clay pit showing the positions of the four lithostratigraphical sections in Figure 3. The dashed lines indicate the position of tracks.

the pit. We were unable to measure a section on the northeast face because it was too weathered. However, it appears that there are four sandstone beds present towards the top of the pit on this face. The clay beds below them appear to be thicker than elsewhere in the pit.

Two distinctive horizons can be traced around most of the pit. One is a medium olive-grey clay that weathers medium brown (which has a thin medium grey shaley clay at its base), sandwiched between two light-medium grey mottled silty clay beds (see Sections 1, 2). The mottling in these grey silty clay beds refers to patches of lighter or darker clay because of varying concentrations of silt, probably caused by bioturbation. The other horizon is a grey clay, mottled orange, with ironstones at its base (see Sections 2, 3). The ironstones act as an impermeable layer which causes water seepage on the face of the pit, enabling this bed to be easily colonized by plants. The dip is 0.5°S, owing to the influence of the Walliswood Anticline to the north and the Oakwoodhill syncline to the south (see Gallois & Worssam, 1993, p. 90).

Biostratigraphy

The biostratigraphical scheme for the Weald Clay is based on ostracods belonging to the genus *Cypridea* and, according to Anderson (1985), consists of 5 zones subdivided into 31 faunicycles. No ostracods of this genus have been found at Smokejacks. However, since the *Cypridea clavata* Zone includes the top of the Lower Weald Clay and the lower three-quarters of the Upper Weald Clay in the Warlingham (Surrey) borehole (Anderson, *op. cit.*), and as Smokejacks lies fairly low down in the Upper Weald Clay, it is presumed to lie within the *C. clavata* Zone.

Chronostratigraphy

Worssam (1978) considered the base of the Weald Clay to correspond to the Valanginian/Hauterivian boundary and the top of the Weald Clay to the Barremian/Aptian boundary. This view still has general acceptance although some authors place the top of the Weald Clay in the Aptian (see Allen, 1990). Worssam (*op. cit.*) also indicated that the Lower/Upper Weald Clay boundary roughly corresponds to the Hauterivian/Barremian boundary, although, as noted

above, the position of this boundary within the Weald Clay has often been misinterpreted.

The Lower/Upper Weald Clay boundary was indicated by Anderson (1985) to correspond to the boundary between his Ewhurst (88) and Capel (89) ostracod faunicycles. Anderson in Gallois & Worssam (1993, p. 122) stated that at Clockhouse Brickworks (Capel, Surrey) the Capel faunicycle "occurs in a silty clay about 0.5 m below the top of the pit" and is presumed to extend into the overlying sandstones, which form BGS Bed 3a. Anderson (1985) placed the Ewhurst/Capel faunicycle boundary at a depth of 432.2 m in the Warlingham borehole. Using palynomorphs Hughes & McDougall (1990) placed the Hauterivian/Barremian boundary between 1415–1423 ft (431.3–433.7 m) in the Warlingham borehole. A sequence of sandstones and sandy mudstones occurs at this depth (Worssam & Ivimey-Cook, 1971). Therefore, in Surrey the Hauterivian/Barremian boundary may be conveniently taken to be at the Lower Weald Clay/Upper Weald Clay boundary, which lies at the base of BGS Bed 3a and closely corresponds to the Ewhurst/Capel faunicycle boundary. This means that the sediments exposed at Smokejacks Brickworks, which, as already noted, lie fairly low down within the Upper Weald Clay, were deposited during the early Barremian.

3. Palaeontology

Smokejacks Brickworks has yielded a diverse fossil fauna and flora over the past decade. The discovery of the new theropod dinosaur species *Baryonyx walkeri* in 1983 has been the most celebrated find at the pit (see Milner & Croucher, 1987; Fortey, 1991). In addition, the pit has also yielded an important insect fauna and many well preserved specimens of a primitive aquatic or marsh-dwelling herbaceous plant. A faunal and floral list is given in Table 1, information for which was taken mainly from Jarzembowski (1991a) with additional identifications by us, Dr E. A. Jarzembowski, Mr P. Austen and Dr C. R. Hill (pers. comm. 1990–94).

Invertebrates

Many fossil insects have been found at Smokejacks. They were found in sideritic mudstone and siltstone lenses, but most of these were not *in situ*; therefore, the exact stratigraphic position of most of the specimens is not known. However, some insects have been recovered from *in situ* lenses at a number of horizons below the medium olive grey clay horizon (see Sections 1, 2). 22 families and superfamilies in 10 orders are recorded (Table 1) (see Jarzembowski, 1990, for common names of orders), but so far only two species identifications have been published (in Jarzembowski, 1991b). They are the Wealden termite *Valditermes brenanae* Jarzembowski and a sphecid wasp—*Archisphex boothi* Jarzembowski. An undescribed snipe fly wing (Diptera: Rhagionidae) from this site was figured by Jarzembowski (1977). The actual numbers of insect specimens have not been counted, but the relative abundance of the orders appears to be similar to that for Auclaye Brickworks, Capel, Surrey (in Jarzembowski, 1991a) except that Trichoptera (caddisflies) have not been recorded and Diptera (true flies) are much rarer at Smokejacks.

Smokejacks has yielded the youngest example of the extinct lacewing family Brongniartiellidae (Figure 5), which has been identified as belonging to the genus *Pterinoblattina* (Jarzembowski, 1987). Ross & Jarzembowski (1993) gave the range of this family, based on published records, as extending from the Lower

Table 1. Faunal and floral list for the Upper Weald Clay (early Barremian) at Smokejacks Brickworks, Surrey

Invertebrates:
- Arthropoda:
  - Insecta:
    - Odonata:
      - Aeschnidiidae
      - Corduliidae
    - Blattodea:
      - Mesoblattinidae
    - Isoptera:
      - Termopsidae:
        - *Valditermes brenanae* Jarzembowski, 1981
    - Orthoptera:
      - Acridoidea
      - Elcanidae
      - Grylloidea
      - *Hagloidea*
    - Hemiptera:
      - Cicadellidae
      - Fulgoroidea (incl. Cixiidae)
      - Palaeontinidae
      - Progonocimicidae
    - Coleoptera:
      - Cupedidae (incl. Ommatidae)
      - Elateroidea
    - Diptera:
      - Mycetophiloidea
      - Rhagionidae
      - Tipuloidea
    - Hymenoptera:
      - Gasteruptiidae
      - *Sphecidae:*
        - *Archisphex boothi* Jarzembowski, 1991
    - Mecoptera:
      - Orthophlebiidae
    - Neuroptera:
      - Brongniartiellidae:
        - *Pterinoblattina* sp.
      - Psychopsidae
  - Crustacea:
    - Conchostraca:
      - Antronestheriidae
    - Isopoda
    - Ostracoda
- Mollusca:
  - Bivalvia:
    - *Filosina* sp.

Vertebrates:
- Reptilia:
  - Dinosauria:
    - Ornithopoda:
      - Iguanodontidae:
        - *Iguanodon bernissartensis* Boulenger, 1881
        - *Iguanodon* sp.
    - Theropoda:
      - Baryonychidae:
        - *Baryonyx walkeri* Charig & Milner, 1986
    - Sauropoda
  - Pterosauria
  - Crocodylia:
    - Goniopholidae:
      - *Goniopholis* sp.
- *Chondrichthyes:*
  - Elasmobranchii:
    - Hybodontidae:
      - *Hybodus basanus* Egerton, 1845
- Osteichthyes:
  - Actinopterygii:
    - Semionotidae:
      - *Lepidotes mantelli* Agassiz, 1833-37
  - Teleostei

Plants:
- Pteridophyta:
  - Lycopsida:
    - Isoetaceae:
      - *Isoetites* sp.
  - Equisetopsida:
    - Equisetaceae:
      - *Equisetum* sp.
  - Filicopsida:
    - Dicksoniaceae:
      - *Onychiopsis psilotoides* (Stokes & Webb), 1824
    - Matoniaceae:
      - *Phlebopteris dunkeri* (Schenk), 1871
      - *Weichselia reticulata* (Stokes & Webb), 1824
    - Osmundaceae:
      - *Cladophlebis* sp.
- Gymnospermophyta:
  - Pinopsida:
    - Cheirolepidiaceae:
      - *Pseudofrenelopsis* sp.
      - ?*Classostrobus* sp.
      - '*Brachyphyllum*' sp.
      - '*Elatocladus*' sp.
- Anthophyta

Jurassic up to the Berriasian. The Smokejacks record means that the stratigraphic range of this family now extends from the Lower Jurassic to the Barremian.

Other arthropods that have been recorded from the sideritic lenses include unidentified ostracods (non-cyprid), undescribed isopods and an undescribed genus and species of conchostracan. Conchostracans are very common in the light grey mottled silty clay bed just above the olive grey clay horizon (see Section 2). The only other invertebrates found were poorly preserved bivalves attributed to the genus *Filosina* (Jarzembowski, 1991a).

Most of the invertebrate fossils have been deposited at the Booth Museum of

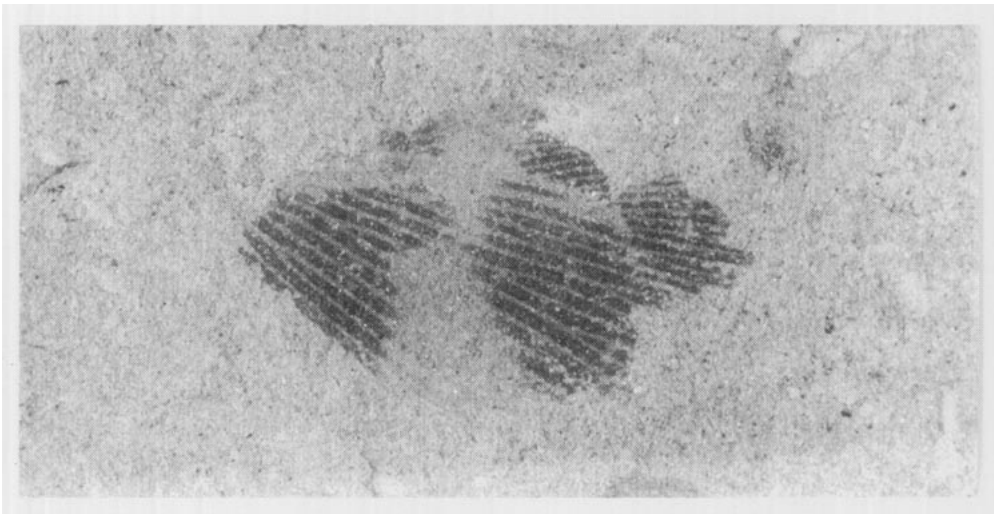

Figure 5. *Pterinoblattina* sp. (Neuroptera: Brongniartiellidae), the youngest fossil brongniartiellid lacewing; Upper Weald Clay (early Barremian), Smokejacks Brickworks. NHM specimen no. II524, Jarzembowski Collection, length 7.5 mm.

Natural History, Brighton, but some of the insects are housed in the Natural History Museum (NHM).

Vertebrates

Smokejacks Brickworks has provided a range of vertebrate material preserved in several different taphonomic contexts. The majority of the finds are isolated teeth or pieces of bone. Some of the earliest records are those of Rivett during the 1940s and '50s. These consisted of about 100 bones belonging to several individuals of *Iguanodon* (including *I. bernissartensis* Boulenger), the remains of a '*Titanosaurus*-like' sauropod and about 30 gastroliths (Rivett, 1953, 1956). These fossils were recovered from sandstone beds at the top of the pit. Many of the *Iguanodon* bones were fragmented and enclosed in pyrite; some showed evidence of rounding, possibly due to fluvial transportation. A partial skeleton of an *Iguanodon* was recently excavated from near the top of the northeast face. Crocodile teeth, a scute, part of a pterosaur limb bone and *Iguanodon* teeth have also been recorded from this site (Jarzembowski, 1991a). They were collected together from the spoil of an excavation just below the water seepage horizon at the western end of the southwest face.

Most of the reptilian remains recorded from Smokejacks were preserved in the clay or sandstone beds, although *Baryonyx* was found in large sideritic siltstone nodules (see Section 1) associated with *Lepidotes* teeth and scales, and a small *Iguanodon* humerus (Charig & Milner, 1986). The nodules at this horizon are irregular in shape and may contain swirls of silt or even sand. This is reminiscent of the red clay exposed on the foreshore near Hanover Point on the Isle of Wight (Hampshire) that has been trampled by dinosaurs, although none of the nodules seen at Smokejacks look like footprint casts.

Fish remains consist mainly of scales, occasional teeth, fin bones and pieces of head plate belonging to *Lepidotes mantelli* Agassiz. They are scattered over the surface of the weathered clay beds. A tooth belonging to *Hybodus basanus*

Egerton was found in the light grey, mottled, silty clay with abundant conchostracans. Teleost debris is concentrated on the base of the insect-bearing sideritic lenses, in thin phosphatic layers within the lenses, or locally along laminae within the clay beds.

The Rivett collection and *Baryonyx* are housed in the NHM. Other vertebrate fossils collected by the authors have been deposited in the Booth Museum of Natural History, Brighton (including a piece of pterosaur limb bone; specimen no. 018824) and at Bristol University.

Plants

Plant remains are common at Smokejacks. They consist mainly of pieces of the fern *Weichselia reticulata* (Stokes & Webb) and a herbaceous aquatic or marsh-dwelling plant. *Weichselia* is concentrated locally in layers within the clay and in sideritic lenses (see Section 2; Jarzembowski, 1991a, fig. 8). The herbaceous plant was first figured as a questionable liverwort in Jarzembowski (1991a, fig. 7), but it belongs in the Anthophyta; it is described elsewhere (Hill, in press). It occurs in sideritic lenses at two horizons (see Section 2), being extremely abundant and well preserved in the lower horizon, but less common and poorly preserved in the upper horizon. Pieces of other ferns (Filicopsida), horsetails (Equisetopsida), club mosses (Lycopsida), and conifer twigs and cones (Pinopsida) are occasionally found in the sideritic lenses and clay.

Fern specimens have been deposited in the Booth Museum of Natural History, Brighton, and many specimens of the aquatic plant have been deposited in both the Booth Museum and the NHM.

4. Conclusions

The 23 m of sediments exposed at Smokejacks Brickworks are shown to belong to the Upper Weald Clay in the *Cypridea clavata* Zone, and to have been deposited during the early Barremian.

The lithologies exposed in the pit and their fossil fauna and flora appear to display a change from a lacustrine/lagoonal to a fluvial/mudplain environment. The lowest 13 m includes beds of dark grey shale with fossil fish, possibly aquatic, herbaceous plants, conchostracans, isopods and ostracods. The fish, aquatic plants and conchostracans indicate freshwater, but the isopods (which mainly live in marine environments today) may be indicative of more saline water. The sediments were probably deposited in a shallow lake or lagoon in which the salinity may have fluctuated. Conchostracans today like very shallow ephemeral water bodies; hence, the light grey mottled silty clay with abundant conchostracans probably indicates a shallowing of the lake/lagoon. The top 10 m of the section includes laterally variable beds of sandstone and has mainly yielded dinosaur remains and terrestrial plant debris. Allen (1981, p. 389) interpreted BGS Bed 5c at Smokejacks as having been deposited "as an ?estuarine shoal". These beds, however, could have accumulated on mudflats and in sluggish channels. The succession is topped by a red clay, which suggests subaerial weathering and indicates emergence.

This paper provides a stratigraphic and palaeontological framework for the Upper Weald Clay at Smokejacks Brickworks. Jarzembowski (this issue) interprets the terrestrial environment in the context of the insect fauna. We hope that our paper will stimulate further research at this site by sedimentologists

and palaeontologists, enabling an improvement on the brief palaeoenvironmental interpretation outlined above.

Acknowledgements

Many thanks go to Mr Carballo of Ockley Building Products Limited, Smokejacks Brickworks, for allowing us to visit the pit on many occasions; Dr E. A. Jarzembowski for supplying information on the insects for the faunal list, some of which came from his unpublished thesis; Mr P. Austen and Dr C. R. Hill for supplying information on the plants for the floral list; Mr C. P. Palmer (NHM) for the use of his unpublished log; Mr P. Crabb (NHM) for photographing the brongniartiellid wing in Figure 5; Prof. D. J. Batten and an anonymous referee for the comments on the original manuscript; and last, but certainly not least, to Prof. P. Allen for his support, guidance and enthusiasm for anything Wealden. Liz Cook acknowledges the financial support of the University of Bristol Alumni Association and the National Geographic Society (fieldwork grant number 4705-92).

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