Kirtlington Quarry: its history and geology and the search for early mammals

Eric F Freeman

Abstract: Kirtlington Quarry, a well-known former exposure of Middle Jurassic rocks north of Oxford, was worked for cement production from 1907 until 1929. Important but largely unpublished research undertaken there at the time by Charles J. Bayzand, a museum assistant and geological lecturer, is placed in the context of better known work by M. Odling and W.J. Arkell, his contemporaries at Oxford University. When integrated with the quarry's industrial archaeology and growth, as reconstructed from old maps and cement production records, Bayzand's work suggests that a sediment rich in mammal and other microvertebrate fossils, the Kirtlington Mammal Bed, was once extensively exposed, but went unrecognised, and had been largely quarried away prior to its eventual discovery in 1974. Augmented by more recent work, the old research by Bayzand, Odling and Arkell allows the palaeoecology of the Mammal Bed to be modelled, including coastal dune-fields and mammal remains from the faecal debris of theropod dinosaurs.

Since the days of Robert Plot (1640–1696), and his *Natural History of Oxford-Shire*, the area to the north of Oxford (Fig. 1), with its former profusion of quarries in highly fossiliferous Jurassic strata, and its proximity to the learned folk of Oxford University, has played an important part in the development of geology.

Thus biostratigraphy and geological mapping were pioneered in Britain by William Smith (1769–1839), a blacksmith's son born and bred in Churchill, in north Oxfordshire, while the Reverend William Buckland (1784–1856), more fortunately placed in life as an Oxford don, was an early pioneer in various branches of palaeontology. Not only did he formally describe the bones of the first known dinosaur, the theropod *Megalosaurus* (Buckland, 1824), but in the same paper also mentioned the discovery of two small mammal fossils, the first known from the Mesozoic, and whose existence prior to the Tertiary was doubted by the then mainstream opinion (Goodrich, 1894). Both sets of fossils had come from the Stonesfield Slate, a flaggy Middle Jurassic sandstone then mined for use as a roofing material at Stonesfield, some 16 km northwest of Oxford (Aston, 1974; Horton, 1860).

Between 1868 and 1870, a quarry near Enslow Bridge in the Cherwell valley, 9 km east of Stonesfield, exposed a rich assemblage of the gigantic bones of *Cetiosaurus*, the first named sauropod dinosaur, previously described only from isolated finds. These were found at the junction between two of the classic Middle Jurassic rock units named by William Smith, the Forest Marble and the Great Oolite. The bones were acquired by the Oxford University Museum, which had been opened in 1857, with William Smith's nephew, John Phillips (1800-1874) as its first director. Phillips (1871) described the cetiosaur bones in the same year that Richard Owen (1804–1892) published a thin monograph (Owen, 1871) on the scanty collection of Mesozoic mammal fossils that had been found since Buckland's day, mainly from Stonesfield and Swanage.

After this landmark year, attention shifted to the western United States, where Marsh and Cope's rivalry produced a torrent of superb dinosaur and Mesozoic mammal fossils, and few new mammal fossil finds were reported from the English Jurassic over the next century.

Meanwhile, a large quarry had been opened for cement production in the Cherwell valley at Kirtlington, about 2.5 km northeast of Enslow Bridge and in the same Middle Jurassic sediments that had yielded Phillips's cetiosaur bones. Kirtlington Quarry attracted considerable attention from geologists at Oxford University and its museum, including the unsung hero of this story, C.J. Bayzand. The geological sections that he, his contemporaries and later workers left behind, both in print and unpublished in archives, provide a valuable record of the site's stratigraphy (Figs 2, 3).

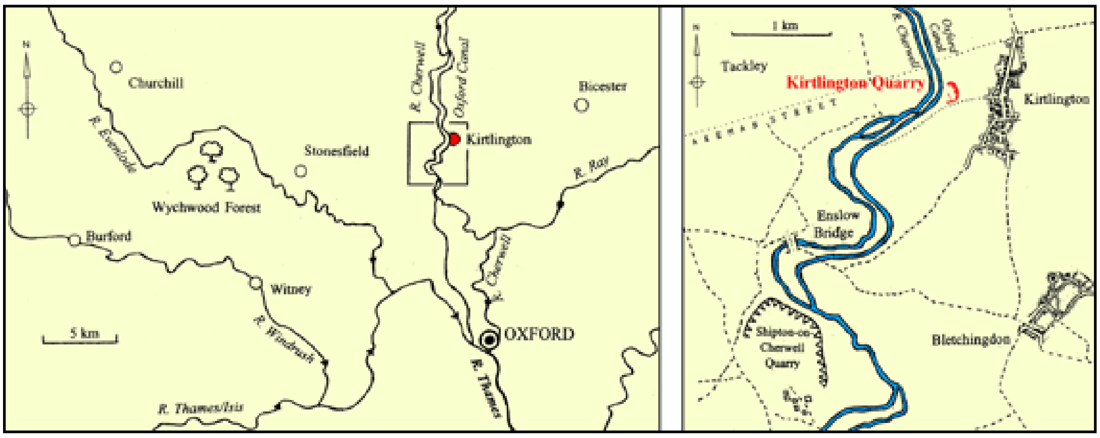

***Figure 1**. The Oxford and Kirtlington areas.*

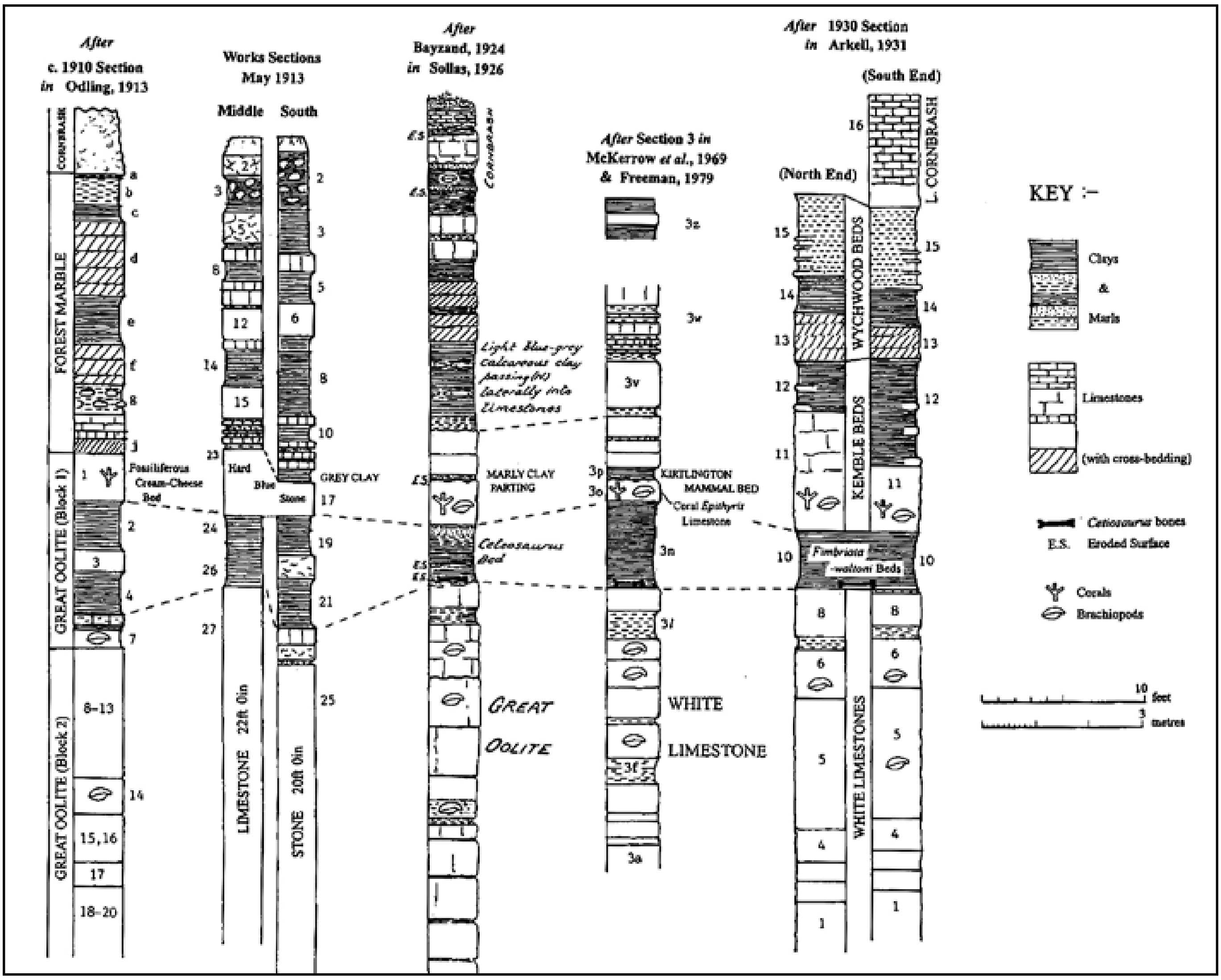

Figure 2. *Sections measured at Kirtlington Quarry; the two Works Sections are detailed in Table 1.*

Stratigraphy at Kirtlington

The Oxford Portland Cement Co. Ltd. worked its quarry at Kirtlington from late 1907 until October 1929, exposing a sequence in the Upper Bathonian from the thick beds of the marine White Limestone, through the thin and impersistent clays, marls and limestones of the Forest Marble, up to the rubbly limestones of the Lower Cornbrash.

As Figure 2 shows, the nomenclature of the local Jurassic rocks has become woefully inconsistent over the years. Of necessity, in this largely historical account, the names used have had to follow closely those used by the earlier authors. Note in particular that the White Limestone and the Great Oolite (as understood in Phillips, 1860) are synonymous, used as the context requires. However, a significant grey micrite is referred to consistently throughout as the Coral *Epithyris* Limestone, as this is more descriptive than such earlier names as Upper Epithyris Bed, Third Epithyris Bed

Works Section, Middle, 15 May 1913	Works Section, South end, 15 May 1913
1) Top soil 1ft 0in	1) Top soil 1ft 0in
2) Soft stone 1ft 3in Very much split	2) Shelly clay full of broken stones 3ft 6in
3) Brown clay full of loose stones 1ft 9in	3) Grey clay 2ft 9in Good
4) Grey clay 6in	4) Cement stone 1ft 0in
5) Rubbly cement stone 2ft 0in	5) Grey clay 2ft 0in
6) Grey clay 3in	Lower 2ins practically cement stone
7) Cement stone 9in	6) Hard grey stone 2ft 0in Building stone
8) Grey clay 1ft 3in	7) Shaley clay 1ft 0in
9) Cement stone 6in	8) Blue clay 4ft 0in
10) Hard grey stone 1ft 0in	9) Cement stone 6in
11) Sandy clay 2in	10) Shaley clay 1ft 0in
12) Grey stone 2ft 0in	11) Hard stone 4in
13) Cement stone 6in	12) Sandy clay 3in
14) Grey clay 2ft 3in	13) Hard stone 6in
15) Hard grey stone 2ft 0in Building	14) Sandy clay 1in
16) Sandy clay 2in	15) Hard stone 6in
17) Cement stone 4in	16) Grey clay 9in
18) Sandy clay 3in	17) Hard blue stone 2ft 0in
19) Cement stone 3in	18) Blue clay 1ft 0in Runs into no. l9
20) Sandy clay 2in	19) Grey clay 1ft 6in
21) Soft stone 6in	20) Soft crumbling stone 1ft 6in
22) Sandy clay 3in	21) Grey shaley clay 3ft 0in
23) Hard blue stone 4ft 0in	22) Cement stone 1ft 0in
24) Blue clay 1ft 9in	23) Soft stone 1ft 0in
25) Shaley clay 1ft 0in	24) Sandy clay 3in
26) Brown peaty clay 1ft 9in	25) Stone 20ft 0in To floor of quarry.
27) Limestone 22ft 0in To quarry floor.	
TOTAL 49ft 7in	TOTAL 52ft 5in

Table 1. *Sections at Kirtlington Quarry (Oxon History Centre, file 5368).*

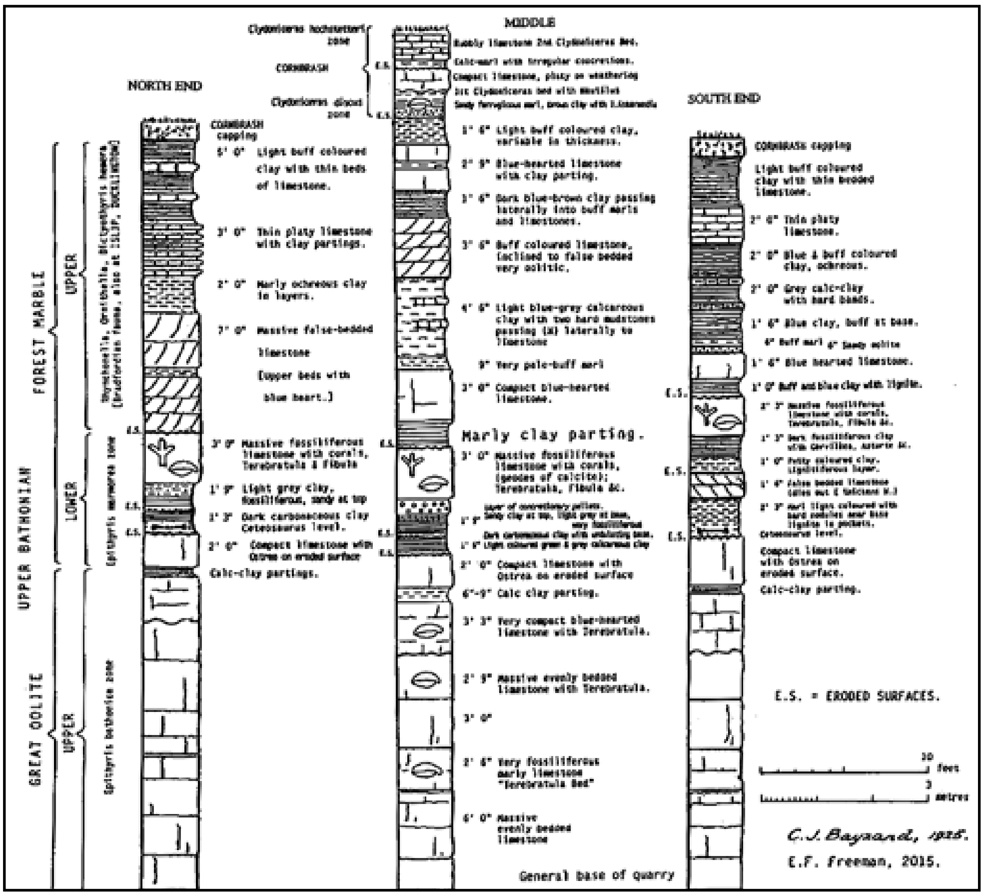

***Figure 3**. Sections at Kirtlington Quarry, re-drawn from Bayzand's unpublished sketches dated 1925.*

***Figure 4**. Charles Bayzand, in about 1924 (courtesy of OUMNH).*

and Fossiliferous Cream Cheese Bed. This micrite is historically significant as it is almost certainly the Grey Marble mentioned by Plot (1676/7), then being worked at Bletchingdon as an ornamental stone. It seems also to be the original Forest Marble of the Wychwood Forest, whose trade-name was appropriated and extended by William Smith in 1799 to cover the whole sequence between the Great Oolite and the Cornbrash (Arkell, 1933, pp286-8; Smith, 1820).

The first geologist known to have worked in Kirtlington Quarry was Marmaduke Odling (1886-1956), the son of Oxford University's Professor of Chemistry. In May 1913 he read a paper to the Geological Society on the Middle Jurassic rocks near Oxford (Odling, 1913), which contained a section measured at Kirtlington Quarry. Odling did not record when he measured his section, but as he had thanked the cement company's directors for granting him access to their quarry, and as his 1913 paper seems to have been based on a BSc thesis submitted to the University in the previous year, a reasonable estimate would be late 1910.

Coincidentally, on 15 May 1913 an unnamed worker at the cement company measured two sections to record the raw materials available for making Portland cement. The two sections, called Works Sections, Middle and South (Fig. 2) do not record their palaeontology, but the sequence of beds is consistent with the other measured sections. One notable difference, however, is the greater interest shown in the clay horizons; one of only one inch (25 mm) thick is recorded, while another bed of clay earned a value judgement of 'good' (Table 1). In contrast, little interest was shown in the limestones, the Great Oolite being dismissed as "Stone 20ft 0in" and "Limestone 22ft 0in". This is of relevance to the industrial archaeology of the quarry, and indirectly to the *Cetiosaurus* fossils that it yielded for the museum.

Odling made no reference to bones of *Cetiosaurus* from the quarry, but in 1923–1924 these started to be uncovered in some quantity (if not quality) at the base of the prominent clay bed in the middle of the quarry face, at the same horizon where they had been found near Enslow Bridge over fifty years earlier.

The next to describe the quarry in the mainstream literature was William Joscelyn Arkell (1904–1958) who, as a member of the Arkell brewing family was financially independent and made his life's work the Jurassic of Britain (Arkell, 1933) and eventually of the whole world. His detailed work at Kirtlington (Arkell, 1931, pp. 570–574) was carried out in 1930, just after the cement company had moved to a new quarry at Shipton-on-Cherwell.

The quarry at Kirtlington had greatly expanded since Odling's day, and its long east face provided Arkell with some 130 m of exposure to study, record in detail at two places, and photograph. At the time, he even had cause to comment favourably on the beneficial effects of a few months of weathering on the quarry faces. However, by the 1960s, when active research resumed at the quarry, such was the degraded state of its faces that the palaeoecological work was confined to six small, isolated exposures (McKerrow *et al.*, 1969).

***Figure 5**. The Kirtlington Mammal Bed exposed in 1975, almost spanned by the length of the hammer and resting on the irregular top of the Coral* Epithyris *Limestone that is freshly exposed [SP49462001].*

In November 1974 Martin Ware (1915-1998) and the author sampled a bed of medium-brown marl exposed in the northeastern corner (Fig. 5). This yielded a rich freshwater assemblage of ostracods, gastropods and charophytes (Ware & Whatley, 1980) and also an abundant fauna of the bones and teeth of crocodiles, turtles, small dinosaurs and mammals (Freeman, 1976, 1977, 1979). This brown marl, hitherto just bed '3p' of McKerrow *et al* (1969), was renamed the Kirtlington Mammal Bed, the quarry becoming "the richest site in the world for small terrestrial vertebrates from the Bathonian. The diverse tiny bones of [...] frogs, salamanders, turtles, lizards, crocodilians, pterosaurs, dinosaurs, mammal-like reptiles and mammals have been found there, many of them representing the oldest occurrences of their groups in the world" (Benton & Spencer, 1995, p. 156).

Charles Bayzand, 1878-1958

Born in Oxford on 4 April 1878, Charles John Bayzand (Fig. 4) was one of the younger children (of at least eight) of William Joseph Bayzand, an artist, and his wife, Sarah Jane. After being educated locally, possibly at St. Edward's School, in 1896, he secured a position at the Oxford University Museum as a junior assistant. Some six years later, he moved out of his overcrowded parental home, when in August 1902 he married Elizabeth Alice Poulter, with whom he was to have two children, Cyril Charles (1903–1964) and Peter Lawrence (1914–1945).

At the museum, Bayzand answered to the geology professor, William Johnson Sollas (1849–1936) (Vincent, 1994; Morrell, 1997). Sollas and his new assistant seem to have got on well together, and Bayzand worked diligently at his museum duties through his twenties and thirties. During this period, he joined the Geologists' Association (in February 1910), and shortly afterwards was joint leader of one of its field meetings around the local quarries, including the then new Kirtlington Quarry (Allorge & Bayzand, 1911).

In the First World War Bayzand was conscripted into the Royal Flying Corps in 1916, the Muster Roll of the Royal Air Force subsequently listing Air Mechanic First Class 29589 Bayzand C.J. by trade as a "Photographer" at four shillings (20p) per day. His service records are obscure, but it is certain that in March 1918 he was based in England, then at least being spared combat duties. Whatever his military duties were (instructor?, dark room technician?), Bayzand obviously performed them well, as he was promoted twice, being demobbed from the RAF in February 1919 with the rank of Corporal Mechanic.

Bayzand's military service proved to be the making of his subsequent career, as Oxford University relaxed its entry requirements to give ex-servicemen the chance to sit for a degree upon their return. This Bayzand did and after only two years earned a First Class BA (Oxon.) in geology in 1921 (followed by an MA in 1925). This would have been almost a formality for him, as he had for some twenty years been assisting his professor when he lectured to the undergraduates. Aged about 43, Bayzand was then promoted to Demonstrator, in which role he undertook formal teaching duties. He was further promoted to 'University Demonstrator' in 1927, and later in the same year was elected to the Geological Society, at the same time as his son Cyril. Bayzand's elevation to the teaching staff did not deprive him of the more hands-on museum duties with which he had started 30 years earlier, for in the official museum report for 1928 Sollas records: "The arrangement of a collection of rocks and fossils to illustrate, in conjunction with a fine series of photographs from the field, the geology of the Oxford District, is making great progress. This work is under the especial care of Mr. Bayzand, who devotes himself to it *con amore.*"

The exhibit on which Bayzand was working remained on display at the Oxford University Museum until the late 1980s (Humphries, 1986). It prominently displayed some of the cetiosaur bones from the museum's collection, which had been augmented since Phillips's day by others newly found at Kirtlington Quarry; these had been presented to the Museum by the Oxford Portland Cement Company after a public display at the Town Hall in 1923.

In addition to his duties at the museum, Bayzand had freelance business interests. He advertised himself in the Oxford *Kelly's Directory* of 1925 as a 'consulting geologist and water expert', seemingly in partnership with his son Cyril at an office in St. Aldate's Street, Oxford. Another sideline was curatorial work for various local and school museums, one of which, at Sherborne School in Dorset, was to involve him in 1911 at the periphery of a minor controversy. This concerned the authenticity or otherwise of an engraving of a horse's head on a fragment of Pleistocene bone found locally (Torrens, 1978; Farrar, 1979). Many years later, this led J.A. Douglas (1884–1978) to make the fanciful suggestion, based on the Sherborne horse's head affair, that the notorious Piltdown forgery had been carried out by W.J. Sollas, his predecessor as Professor of Geology at Oxford (Halstead, 1978).

Bayzand retired from the Oxford Museum in 1948, aged 70, five years later than normal. Following the death in 1942 of his wife of forty years, and then in December 1945 of his son Peter while on active service in Egypt, Bayzand married Ethel Selender Peirce in 1947; she was to survive him (by 15 years) when he died on 6 October 1958 at Oxford's Radcliffe Infirmary following an operation for prostate cancer. He left an estate worth £7623 11s 7d, which when compared to the £28 15s left by his father 43 years before, shows that he had done rather well for himself over the years.

Describing Charles Bayzand, Vincent (1994, p. 55) commented that he "cannot always have been the easiest of colleagues ... " and "Bayzand was always jealous of his position". He gave as an example Bayzand's curmudgeonly behaviour towards the young Stuart McKerrow when he arrived in Oxford in 1947. William Stuart McKerrow (1922–2004) had served in the Royal Navy, from 1942 to 1945, mainly in protecting convoys in the North Atlantic, and had earned a Distinguished Service Cross for gallantry. But in 1947, as a junior newcomer to Oxford, arriving with a First in geology from Glasgow, McKerrow managed to ruffle the elderly Mr Bayzand's feathers merely by offering, rather tactlessly, to help him with his teaching duties. Bayzand seems to have liked his teaching duties, judging by letters of thanks from former pupils, which moreover he had chosen to keep. Also, a photograph in the Oxford Museum archives shows him in middle age happily demonstrating the wonders of a local quarry to a party of schoolboys. So, in his defence, if Bayzand was "jealous of his position", perhaps it was because he had to wait so long to achieve it.

Reflecting his family background, Bayzand's intellectual strengths were in the visual arts, as a photographer, as a geological draftsman and as a designer of museum displays, *con amore*, rather than as a writer of learned articles and books. He could not hope to compete academically with such well-heeled high-flyers as Odling and Arkell, and probably never tried to. He seems to have published only one short article entirely under his own name, and that merely an inconsequential account of a field meeting to the Stonesfield area, led by his professor (Bayzand, 1909). Otherwise, he appeared as a junior co-author, or was buried deep in other people's more substantial writings. One such, chanced upon in an Oxford bookshop, will be discussed next.

W. J. Sollas (1926)

In August 1926, the British Association for the Advancement of Science held its 94th meeting in Oxford, re-visiting the scene of the legendary battle of Huxley versus Wilberforce over *The Origin of Species* 66 years earlier. The countryside and quarries around Oxford provided the participants with venues for field excursions, a commemorative volume, *The Natural History of the Oxford District*, being published by the Oxford University Press. This contained articles covering all aspects of natural history, archaeology, museums etc; the geology of the area was dealt with by W.J. Sollas, in a chapter entitled 'The geology of the country round Oxford'. This reviewed the research then in progress at Oxford, including two appendices, by Arkell, on the Corallian, and K.S. Sandford (1899–1971), on Pleistocene river gravels.

Of the illustrations in Sollas's contribution, eleven are geological sections drawn and signed by C.J. Bayzand. All are realistic representation of the rocks, alongside details in Bayzand's handwriting. As examples of geological draughtsmanship they are exceptional, and in most cases represent the results of Bayzand's own observations and measurements. This was freely acknowledged by Sollas: "It is to the remarkable pioneer work of Mr. C.J. Bayzand that we are indebted both for our knowledge of the existence and significance of the numerous eroded surfaces which interrupt the continuity of the Jurassic series and for the identification of its zonal subdivisions by means of fossils. It is on material furnished by him that this brief summary of results is mainly based." (Sollas, 1926, p32). One of Bayzand's sections shows Kirtlington Quarry (Fig. 6).

Bayzand's section was not used to illustrate any publications of his own, just Sollas's, and in his museum display on the geology of the Oxford district. Being so obscurely published, Bayzand's work was largely overlooked by his contemporaries and later workers. Only Arkell (1931) and Richardson *et al.* (1946) cited Sollas (1926) and subsequently, Bayzand's illustrations slipped into literary oblivion.

Bayzand drew preliminary drafts of his Kirtlington Quarry section, and these survive in the Hope and Arkell Libraries in what is now the Oxford University Museum of Natural History. Among these are drafts showing not only that section, designated 'Middle' which appeared as Figure 6 in Sollas (1926), but also two others, called by Bayzand 'North End' and 'South End'. Also recorded were the facts that (at least) the 'Middle' section was measured on 31 October 1924 by

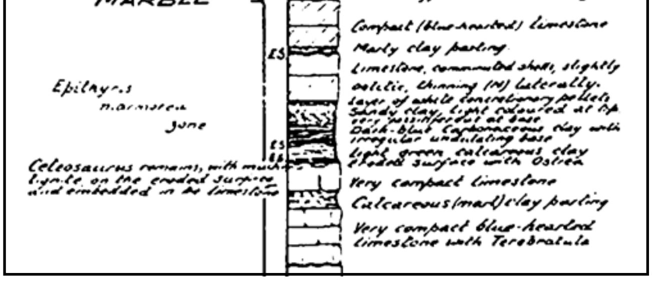

***Figure 6**. Part of Bayzand's section (in Sollas, 1926); note the 'Marly clay parting' between the two limestone beds.*

***Figure** 7. The long east face of Kirtlington Quarry in 1923, with an annotated enlargement of the central section (photos: C Bayzand, courtesy of OUMNH).*

'C.J.B. + K.S.' (almost certainly Kenneth Sandford), and that the 'South End' section occurred 'near road entrance'. These three sections have been re-drawn almost word-for-word to form Figure 3.

The Kirtlington Mammal Bed

When found in 1974 the Kirtlington Mammal Bed was a thin (25 cm) medium-brown marl, devoid of bedding surfaces, and containing scattered shell, limestone and plant debris (Freeman, 2015). It lay immediately above that widespread and distinctive, grey micrite mentioned earlier, known as the 'Coral *Epithyris* Limestone', and extended over 21.5 m of outcrop, before pinching out rapidly at both ends. The only exposure, in the northeastern corner of the quarry was overgrown, and most of the Mammal Bed there had earlier been removed, and could not then be found anywhere along the heavily degraded long east face of the quarry. From the absence of any clays or marls at the appropriate level in Odling's and Arkell's published sections, we then concluded that the Kirtlington Mamma1 Bed was a single lens of freshwater sediment within a shallow marine or estuarine Forest Marble sequence, possibly a remnant of a silted-up river.

This conclusion changed when Bayzand's section was found in Sollas, 1926. This showed a sediment which he called a 'Marly clay parting' at the same position as the Kirtlington Mammal Bed, directly overlying the Coral *Epithyris* Limestone, and in turn overlain by a limestone layer of similar thickness, effectively becoming the 'filling' in a 'limestone sandwich' (Fig. 6). It now seems likely that Bayzand's 'Marly clay parting' was the Kirtlington Mammal Bed, observed by him when freshly exposed. Bayzand did not quote a thickness for it, but his drawing shows it as about 12 cm thick. Nor did Bayzand tell us its colour, suggesting that it was probably similar to the adjacent buff and grey limestones.

Of Bayzand's three unpublished sections (Fig. 3), the one marked 'Middle' is largely identical to that in Sollas (1926), except for one oddity; the 'Marly clay parting' is now shown with a thickness of about 45 cm. It seems likely that this was the thickness actually measured in his section and recorded as raw data, whereas the published version (in Sollas, 1926) showed only a rough average of about 12 cm to represent a bed both impersistent and variable in thickness.

Bayzand's also took photographs of the quarry and one, of its long east face, was annotated for use in his museum exhibit (Fig. 7). It shows the 'limestone sandwich', about 1.8 m thick, extending along the east face, directly above the Ceteosaurus Bed, and between the two limestone beds, the Kirtlington Mammal Bed, (labelled therein as 'Marly clay parting') estimated to vary in thickness from about 12 to 36 cm. Bayzand's unpublished sections (Fig. 3) confirm the variability of this bed. In the 'North End' section, it is absent, and a massive unit of cross-bedded limestone takes its place above the Coral *Epithyris* Limestone. In contrast, in the 'South End' section, it appears as a measured bed 1ft (30 cm) thick of 'Buff and blue clay with lignite'.

As found in 1974, the Kirtlington Mammal Bed was grey to buff in colour when dry, and although it contained scattered plant fragments (probably *Equisetites*), it did not contain lignite or other organic matter sufficient to produce any blue redox discolouration.

Of the three earliest sections (Fig. 2), Odling's shows only 30 cm of a cross-bedded limestone directly overlying the Coral *Epithyris* Limestone (his Bed 1), thereby resembling both Bayzand's 'North End' section and my 1974 Section D (see below). In the two 1913 'Works Sections', there is a 'Hard blue stone' that can only be the Coral *Epithyris* Limestone; in the 'South' section this is overlain by Bed 16, a 'grey clay' of thickness 9 in (22.5 cm), which also appears to be the Kirtlington Mammal Bed.

Neither of Arkell's sections shows any marl or clay at the appropriate level. The one at his 'North End' was still partly visible in the 1970s, with the Coral *Epithyris* Limestone overlain directly by a cross-bedded limestone with no intervening clay or marl parting (Freeman, 1979, Section D). However, by the 1970s, the site of Arkell's 'South End' section had been obscured by slumping and vegetation. One of Bayzand's photographs shows the southeastern corner of the quarry in 1924, with the 'limestone sandwich' having its 'filling' of no great thickness, if of any at all, the horizon being annotated simply as an 'eroded surface'. It is therefore likely that at the two points where Arkell examined and measured the rocks, the 'Marly clay parting' was indeed absent. However it is visible in one of his photographs (Arkell, 1933, Plate 13); at the extreme left of this, it is clearly absent, although a bedding plane at the appropriate level is visible within the Kemble Beds; then, slightly to the right, the bed abruptly appears, with a thickness of *c.*16 cm, before it is hidden from sight by talus along the rest of the quarry face.

Finally, in 1925 and 1935, J. Rhodes of the Geological Survey took seven photographs of the quarry, of which one seems to show at its extreme right edge what was to become Section 3 of McKerrow *et al.* (1969), but in August 1935 then in pristine condition (Richardson *et al.,* 1946, Plate 5, photograph A6577).

Summarising, of the ten separate sections (Figs 2, 3), one certainly shows the Kirtlington Mammal Bed (at 21 cm thick), while another four probably show it, with thicknesses ranging between 12 and 45 cm. It is significant that in three of the sites where it is absent, its place above the Coral *Epithyris* Limestone is taken by cross-bedded limestones.

Quarry Expansion and a Missed Opportunity

Small-scale quarrying had been undertaken at Kirtlington since at least 1425, long before the Oxford Portland Cement Company started operations in 1907 (Dodsworth, 1972; Humphries, 1986). The cement production required both limestone and clay, the latter being in the shortest supply at Kirtlington. The excess limestone of the Great Oolite was either temporarily left *in situ* to form terraces (on one of which the cetiosaur bones were found in the early 1920s), or was dumped on spoil heaps (which in 1920 were shaped into a useful access ramp up to Mill Lane).

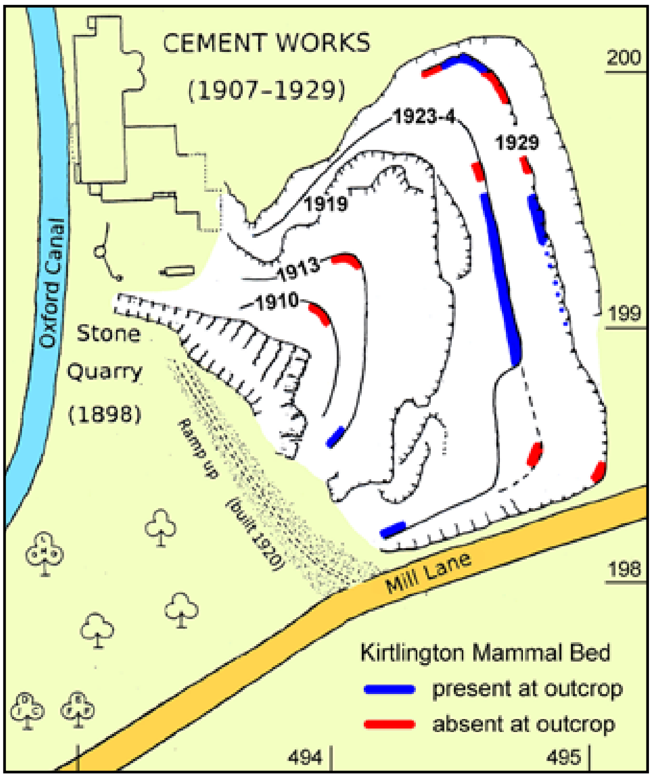

Figure 8*. Development of Kirtlington Quarry. The mapped quarry faces of 1919 and 1929 are supplemented with positions estimated from cement production records. The widespread but patchy distribution of the Kirtlington Mammal Bed is demonstrated by its suspected former presence (blue) compared to its absence (red). The National Grid numerals are 100 m apart and are in grid square SP. (Sources: Ordnance Survey 1:2500 maps of 1899, 1922 and 1974; McKerrow et. al., 1969; Dodsworth 1972; Oxfordshire History Centre, file 5368.)*

The quarry produced an estimated 295,300 tons of cement from an area of 17,900 square metres during its 22 years of life. From the various archive maps of the quarry and records of its annual cement production, it has been possible to estimate roughly where the quarry faces were when Bayzand and the others were measuring their sections. This then allows the locations of these and of Bayzand's photographs to be approximated to within about 10 m or so. In turn this then shows just how widespread, but patchy, was the occurrence of the Kirtlington Mammal Bed in the quarry (Fig. 8).

When processed in the 1970s, the Kirtlington Mammal Bed was found to be extraordinarily rich in mammal fossils compared to most other such sites, yielding on average one tooth for every 10.5 kg of dry sediment that was wet-sieved and sorted down to 0.5 mm. This does not take into account all the other micro-vertebrate fossils in the sediment, the same 10.5 kg yielding, for example, about 50 complete or partial crocodile teeth (Freeman, 1979). Taking Bayzand's published thickness of c.12 cm as a rough, and perhaps minimal, average of its thickness, over 22 years the 17,900 square metres of the quarry sent some 2150 cubic metres, 3900 tonnes of the Mammal Bed to the cement kiln, and some 370,000 mammal fossils to their destruction. So, contrary to their unfortunate reputation, Mesozoic mammals were not rare in life, nor now as fossils. They are just difficult to find.

Palaeoecology of the Mammal Bed

The thickness of the Bathonian White Limestone, its oolitic texture and its fauna of brachiopods, well-preserved and abundant at several levels (but, significantly, without ammonites or corals), all point to deposition under warm, high-energy, near-shore marine conditions. In contrast, the thin and impersistent beds of the overlying Forest Marble point to less stable, more localised and complex palaeoenvironments. Only the two beds at its base are continuous throughout the quarry and beyond, the lower of the two, Bayzand's Ceteosaurus Bed, being the dark clays lying on the eroded upper surface of the White Limestone. Recognised from its macrofauna of sauropod bones (Phillips, 1871), and its microfauna of freshwater and marine ostracods (Bate, 1965; McKerrow *et al*., 1969), the Ceteosaurus Bed represents a coastal marsh environment on the margins of the tropical White Limestone sea.

In this palaeogeographic context the overlying Coral *Epithyris* Limestone, is anomalous. For a relatively thin unit within the Forest Marble, it is remarkably widespread, extending throughout the Cherwell valley, and over a distance of 45 km from Burford in the west, via Witney and the Wychwood Forest, to near Bicester in the east (Hull, 1859; Arkell, 1933; Richardson *et al*., 1946). At Kirtlington, its content of broken coral, bivalve and brachiopod debris within a matrix of non-oolitic, pale-grey micrite suggests formation originally in a marine, low-energy, fringing back-reef environment, offshore from the coastal marshes of the Ceteosaurus Bed, and beyond even the shallow coastal waters of the White Limestone sea.

It is suggested that the Coral *Epithyris* Limestone formed as a tempestite, when a tropical storm or tsunami transported aragonitic mud, broken coral and other chaotically jumbled bio-debris from an offshore reef, and dumped it on the coastal marshlands of the Ceteosaurus Bed. In so doing it raised the local topography and thereby altered the hydrology. After the lower part of the aragonitic mud had hardened to form an impermeable layer, namely the Coral *Epithyris* Limestone, an elevated water table allowed a new, relatively stable freshwater environment to develop above the coastal marshlands.

The Kirtlington Mammal Bed was then deposited in this freshwater environment, which the archival evidence from the 1920s suggests was more extensive and complicated than thought in the 1970s from the limited field observations then possible, and from the sections published by Odling (1913) and Arkell (1931, 1933). Even so, the information now available (Fig.8) is still very limited, but such as it is, suggests a series of shallow well-oxygenated ponds rather than a single, more substantial lake deepening towards its middle.

In three of the places where the Mammal Bed has been reliably recorded as being absent, its place is taken by cross-bedded calcarenites. These were formed sub-aerially as dunes by wind action on the unconsolidated remnants of the tempestite debris, and a dune-field developed above the Coral *Epithyris* Limestone, with shallow bodies of freshwater accumulating in low-lying areas between the dunes. Subsequently, these became infilled with locally derived materials to form the Mammal Bed. Most of the ground mass of this sediment was fine calcite dust probably blown in from the dunes nearby, the Mammal Bed thereby having the character of a loess. It is remarkably uniform in grain size, both horizontally and vertically (Freeman, 1979) and is free of bedding surfaces, suggesting that during deposition the Mammal Bed was being continuously homogenised, perhaps by bioturbation produced by the wading of largish tetrapods.

The scattered plant debris seen in the Mammal Bed suggests that in the damp areas at the base of the dunes there were plant thickets, perhaps of horsetails, whose isolated dead leaf and stem segments were blown by the wind into the pools nearby. No other more luxuriant vegetation seems to have lived in the vicinity, only one small fragment of a fern leaf having been found in the Mammal Bed, and there are no known insect fossils. Most of the plant debris is preserved as limonitic impressions, but occasional fragments occur as fusain (charcoal), suggesting that although the local vegetation could be dry enough to burn, it was too widely dispersed to fuel major brush fires.

The palynology of the Mammal Bed (Table 2) suggests a more diverse flora, although from a wider catchment area. Specifically: "Marine influences are absent. The microplankton composition suggests brackish or more likely freshwater conditions. The miospore composition indicates the lack of proximity to dense, pteridophyte (swamp) vegetation. Most of the components are derived from hinterland (gymnosperm) elements. Without knowledge of the sedimentological setting a confident interpretation is difficult, although I would tentatively suggest a low energy, coastal plain/shallow freshwater lake environment, with a relatively sparse swamp vegetation. Perhaps a 'pond' on a mud flat-type setting could be inferred." (Jim Fenton, *pers.comm.*)

Evidence of the non-saline nature of the water is also given by the frog and salamander fossils, as well as well-preserved freshwater gastropods (*Bathonella* and *Valvata*) (Fig. 9), ostracods (*Timiriasevia* and *Theriosynoecum*) (Ware & Whatley, 1980), and gyrogonites from stonewort plants (Charophytes), whose calcareous encrustations may also have contributed to the fabric of the Mammal Bed.

Microplankton
brackish/freshwater algae:
Leiospheres/Tasmanites sp. (thick walled) 55%
Schizosporis rugulatus 5%
S. parvus 1%
S. spriggii 2%
Botryococcus (freshwater alga) 6%

Miospores
Araucariacites australis 5%
Baculatisporites spp. 1%
Bisaccate pollen 3%
Callialasporites microvelatus 1%
C. turbatus 3%
Cerebropollenites mesozoicus 1%
Deltoidospora spp. 9%
Dictyophyllidites harrisii 1%
Klukisporites variegatus 2%
Verreticulisporis giganteus 5%

Rarer miospores seen outside the formal count of 200 were *Callialasporites dampieri, C. minus, Classopollis torosus* (tetrads), *Retitriletes australoclavatidites, Vitreipollenites pallidus.*

***Table 2**. The palynology of the Kirtlington Mammal Bed, as determined by Jim Fenton of Simon Petroleum Technology; percentages are based on a count of 200.*

The dune-field environment that is proposed would have been harsh, and was capable of supporting only small animals. Even the dinosaurs were small, being mainly fabrosaurs, herbivores that probably found food and shelter in the plant thickets around the pools. Chelonian fragments are common in the Mammal Bed, but whether turtles too were living and feeding in the local environment or merely visiting to lay their eggs in the dunes, is unknown.

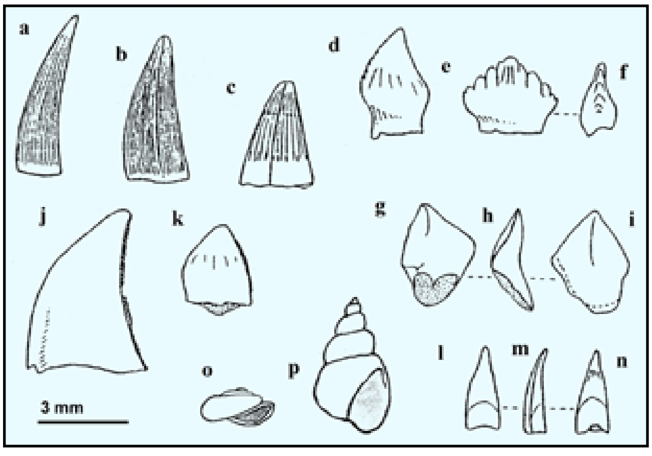

***Figure 9**. Larger freshwater or terrestrial fauna of the Kirtlington Mammal Bed; **a**, **b**, **c**: dwarf goniopholid crocodile teeth; **d**, **e**, **f**: fabrosaurid teeth; **g**, **h**, **i**:probable fabrosaurid maxillary tooth, internal, lateral and external views; **j**, **k**: theropod teeth; **l**, **m**, **n**: pterosaur tooth, external, lateral and internal views; **o**, **p**: freshwater gastropods,* Valvata *and* Bathonella *respectively.*

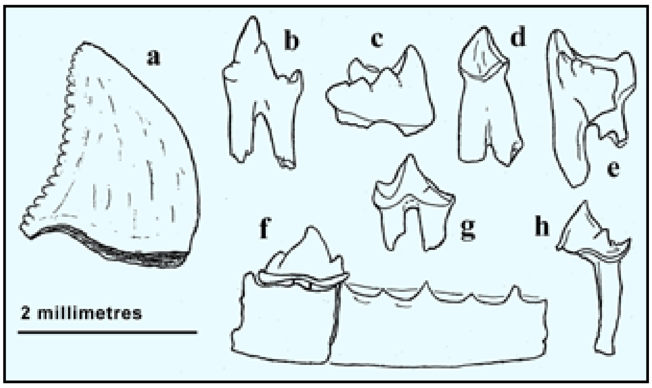

***Figure 10**. Fossils from the Kirtlington Mammal Bed; **a**, theropod dinosaur tooth (found by Martin Ware); mammal fossils :– **b**, **c**, **d**, **e**:* Palaeoxonodon ooliticus*;*
***f**, **g**, **h**:* Cyrtlatherium canei.

Even in this harsh environment, small ectotherms such as the dwarf crocodiles whose teeth (Fig. 9) greatly outnumber and outweigh those of other animals (Freeman, 1979), could have subsisted on a diet of the resident amphibians and fish. The lowest level of this food chain would have been the planktonic freshwater algae of Table 2, which would have supported a fauna of small herbivores, predominantly larval amphibians (tadpoles). In turn this would have supported a population of small obligate carnivores (adult amphibians, juvenile dwarf crocodiles and perhaps fish). Fossils of fish are relatively scarce at Kirtlington; the largely durophagous nature of their teeth, suggests they fed on the freshwater mussels and gastropods that are now found in the Mammal Bed. But while the relative scarcity of the fish fossils may be a genuine reflection of their rarity as live animals, it may also be caused by the crocodiles' slow, ectothermic digestive processes that might be expected to leave little or no skeletal material to be excreted and fossilised.

Predators with an endothermic metabolism, such as theropod dinosaurs and pterosaurs, required a higher intake of prey, and they would need a larger hunting territory in which the dune-field's pools could only provide a drink and the occasional opportunistic meal (Fig. 11). Their higher metabolic rates and correspondingly faster digestive transit times would produce droppings containing an abundance of undigested (but broken) skeletal material from their prey; this included mammals and small terrestrial reptiles (*Cteniogenys* and *Marmoretta*) caught outside the immediate environment of the dune-field. Such occurrences in the fossil record were termed coprocoenoses by Mellett (1974), who pointed out the similarity of fracture patterns between small Tertiary mammal fossils and analogous bones extracted from recent carnivore droppings. Discovery of a small tooth of a carnivorous theropod dinosaur prompted the search for mammal fossils in what little remained of the hitherto neglected 'Marly clay parting' at Kirtlington (Fig. 10).

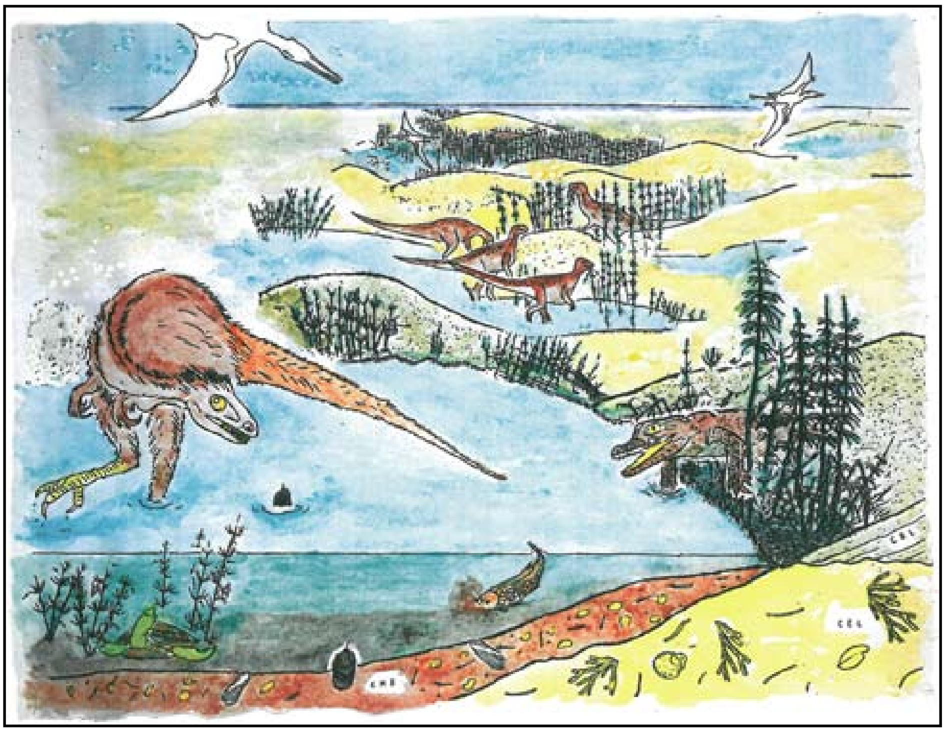

***Figure 11**. Oxonia Antiquior. A hot summer's day among the coastal dunes of lime-sand, between which shallow freshwater ponds are fringed with horsetails. Fabrosaurid dinosaurs graze, secure by virtue of their size from the attentions of the small theropod wading in the pool. It is stalking a small fish* (Lepidotes) *that is churning through the mud, looking for freshwater mussels. A dwarf crocodile watches in the hope that an adult frog or salamander will be flushed from cover. After circling in from the coast, a pterosaur eyes the scene below with the same idea. A turtle keeps under cover behind* Chara *plants, upon which graze small freshwater gastropods* (Bathonella)*, and tadpoles. One of the theropod's droppings has sunk into the mud, where its content of undigested mammal teeth will be found by palaeontologists 165 million years later. (CEL = Coral* Epithyris *Limestone; KMB = Kirtlington Mammal Bed; CBL = cross-bedded limestone.)*

Acknowledgements

To all the kind people who've helped me with this project over the years, to Mike Benton, Mark Dickerson, Chris Duffin, Roy Elmes, Jim Fenton, Richard Furminger, Philip Highton, Eliza Howlett, Len Marobin, Dave Martill, Tamara Miller, Dave Mugridge, Mick Oates, John O'Sullivan, Philip Powell, Hugh Torrens, Helen Winning, and the helpful staff at the Oxford Univerity Museum of Natural History, I give my grateful thanks.

References

Allorge, M.M. & Bayzand, C.J., 1911. Excursion to Oxford University Museum, Enslow Bridge, Kirtlington and Woodstock. *Proc. Geol. Assoc.,* **22**, 1-5.

Arkell, W.J., 1931. The Upper Great Oolite, Bradford Beds and Forest Marble of south Oxfordshire, and the succession of gastropod faunas in the Great Oolite. *Q. J. Geol. Soc.,* **87**, 563-629.

Arkell, W.J., 1933. *The Jurassic System in Great Britain.* Oxford: Clarendon, 681 pp.

Aston, M.A., 1974. *Stonesfield Slate*. Oxfordshire Museum publication, 5, 85 pp.

Bate, R.H., 1965. Freshwater ostracods from the Bathonian of Oxfordshire. *Palaeontology,* **8**, 749-759.

Bayzand, C.J., 1909. Excursion to Oxford, Stonesfield and Fawler, May 9th 1908. *Proc. Geol. Assoc.,* **21**, 25-29.

Benton, M.J. & Spencer, P.S., 1995. *Fossil Reptiles of Great Britain*. Geological Conservation Review, 10, 386 pp.

Dodsworth, C., 1972. The early years of the Oxford cement industry. *Indust. Archaeol.* **9**, 285-295.

Farrar, R.A.H., 1979. The Sherborne controversy. *Antiquity,* **53**, 211-216.

Freeman, E.F., 1976. Mammal teeth from the Forest Marble (Middle Jurassic) of Oxfordshire, England. *Science,* **194**, 1053-1055.

Freeman, E.F., 1977. Triassic extinction or Jurassic vacuum? *Nature,* **266**, 305.

Freeman, E.F., 1979. A Middle Jurassic mammal bed from Oxfordshire. *Palaeontology,* **22**, 135-166.

Freeman, E.F., 2015. The amateur geologist and Mesozoic mammals – a cautionary tale. *Amateur Geologist,* 9, 12-16.

Goodrich, E.S., 1894. On the fossil Mammalia from the Stonesfield Slate. *Q. J. Microscopical Sci.,* **35**, 407-431.

Halstead, L.B., 1978. New light on the Piltdown hoax. *Nature,* **276**, 11-13.

Horton, W.S., 1860. On the geology of the Stonesfield Slate and its associate formations. *Geologist,* **3**, 249-258.

Hull, E., 1859. The geology of the country around Woodstock, Oxfordshire. *Mem. Geol. Surv. G. B.*

Humphries, V., 1986. *Kirtlington: an Oxfordshire village*. Chichester: Phillimore, 151 pp.

McKerrow, W.S., Johnson, R.T. & Jakobson, M.E., 1969. Palaeoecological studies in the Great Oolite at Kirtlington, Oxfordshire. *Palaeontology,* **12**, 56-83.

Mellett, J.S., 1974. Scatological origin of microvertebrate fossil accumulations. *Science,* **185**, 349-350.

Morrell, J., 1997. *Science at Oxford 1914-1939: transforming an arts university.* Oxford: Clarendon, 473 pp.

Odling, M., 1913. The Bathonian rocks of the Oxford district. *Q. J. Geol. Soc.,* **69**, 484-513.

Owen, R., 1871. *Monograph of the fossil Mammalia of the Mesozoic formations*. London: Palaeontographical Society, 115pp.

Phillips, J., 1860. On some sections of the strata near Oxford. No.1. The Great Oolite in the valley of the Cherwell. *Proc. Geol. Soc.,* **16**, 115-119.

Phillips, J., 1871. *Geology of Oxford and the Valley of the Thames*. Oxford: Clarendon, 523 pp.

Plot, R., 1676/7. *The Natural History of Oxford-Shire, being an essay toward the Natural History of England.* Oxford: The Theater, 358 pp.

Richardson, L., Arkell, W.J., Dines, H.G. & Morison, C.G.T., 1946. Geology of the country around Witney. *Mem. Geol. Surv. G. B.*

Smith, W., 1820. *Geological map of Oxfordshire*. J. Cary, London.

Sollas, W.J., 1926. The geology of the country round Oxford. 32-71 in *The natural history of the Oxford district,* ed. J.J. Walker, Oxford University Press.

Torrens, H.S., 1978. The Sherborne School Museum and the early collections and publications of the Dorset Natural History and Antiquarian Field Club. *Proc. Dorset Nat. History Archaeol. Soc.,* **98**, 32-42.

Vincent, E.A., 1994. *Geology and Mineralogy at Oxford 1860-1986: History and Reminiscence*. Oxford, 245 pp.

Ware, M. & Whatley, R., 1980. New genera and species of Ostracoda from the Bathonian of Oxfordshire, England. *Revista española de micropaleontología,* **12**, 199-230.

Eric F. Freeman
146 Haydons Road, London SW19 1AE.