forest litter as these were the dominant spore-producers, at least, of the coal-forming flora (Scott, 1979). More than this one cannot say as the *ex-situ* material provides little information on facies relationships.

In general, arthropods are far less frequently found associated with pteridosperms or pteridophytes. When they are associated, there is also much lycopod debris, suggesting deposition at the forest margin or mixing of litter and minimally transported material from beyond the forest (*cf.* Gastaldo, 1987).

Protorthopterans, whilst commonly associated with sublithology A and lycopods, have a higher percentage occurrence in sublithology B than other determinate arthropods. These sediments, from their trace-fossils and paucity of plant remains are considered to represent shallow lake deposits (Pollard & Hardy, 1991). The low number of Blattodea and other arthropods in this sublithology suggests that some, if not all, the protorthopterans present had different ecological preferences and may have lived chiefly outside the lycopod forest. Their leg morphology suggested to Bolton (1921) that they were ground-feeders, possibly at the margins of the coal swamp. The diversity and abundance of protorthopterans over blattodeans in the Mazon Creek fauna (Westphalian D) of Illinois accords with the postulated drier, more open country dominated by pteridosperms (Richardson, 1956).

The possible palaeodictyopterans are rare and poorly preserved (one in sublithology A and one in B): this accords with their probably having been washed in to the lake from outside the lycopod forest.

Non-marine bivalves were found predominantly in sublithology A/C intermediates containing no plant debris. These fine-grained sediments were probably deposited in a lake (Eager, forthcoming) some distance from shore. The Conchostraca occur in a variety of sublithologies but are commonest in A, associated with abundant lycopod debris, and C which lacks plants. They seemed to have lived in a range of aquatic habitats which in comparison with extant forms were probably of a temporary nature (Tasch, 1964). The presence of comminuted examples suggests that a degree of post-mortem transport, or perhaps predation, cannot be excluded.

ACKNOWLEDGEMENT

I would like to thank Ed Jarzembowski for his great help and encouragement in studying the material in his care.

References

BEALL, B. S. 1991. The Writhlington phalangiotarbids: their palaeobiological significance. *Proc. Geol. Ass.* **102,** 161–68.

BOLTON, H. 1921–22. A monograph of the fossil insects of the British Coal Measures. *Palaeontogr. Soc.* (*Monogr.*), vi +156 pp., 10 pls.

CARPENTER, F. M. 1980. Studies on North American Carboniferous insects. 6. Upper Carboniferous insects from Pennsylvania. *Psyche, Camb.*, **87,** 107–19.

CHALONER, W. G. & M. E. COLLINSON. 1975. An illustrated key to the commoner British Upper Carboniferous plant compression fossils. *Proc. Geol. Ass.*, **86,** 1–44.

FISHER, D. C. 1978. Evidence for subaerial activity of *Euproops danae* (Merostomata, Xiphosurida). *In* (Nitecki, M. H.; ed.) *Mazon Creek Fossils*, pp 379–447. Academic Press, New York.

GASTALDO, R. A. 1987. Confirmation of Carboniferous clastic swamp communities *Nature*, **326,** 869–71.

JARZEMBOWSKI, E. A. 1987. The occurrence and diversity of Coal Measure insects. *J. geol. Soc. Lond.*, **144,** 507–11.

—— 1989. Writhlington Geological Nature Reserve. *Proc. Geol. Ass.*, **100,** 219–34.

NORTH, F. J. 1931. Insect-life in the coal forests, with special reference to South Wales. *Trans. Cardiff Nat. Soc.*, **62,** 16–44.

POLLARD, J. E. & P. G. HARDY. 1991. Trace Fossils from the Westphalian D of Writhlington Geological Nature Reserve, near Radstock, Avon. *Proc. Geol. Ass.*, **102,** 169–78.

RICHARDSON, E. S. Jr. 1956. Pennsylvanian invertebrates of the Mazon Creek area, Illinois. *Fieldiana: Geol.*, **124,** 3–56.

SCOTT, A. C. 1977. A review of the ecology of Upper Carboniferous plant assemblages, with new data from Strathclyde. *Palaeontology*, **20,** 447–73.

—— 1979. The ecology of Coal Measure floras from northern Britain. *Proc. Geol. Ass.*, **90,** 97–116.

TASCH, P. 1964. Branchiopods. In (Kummel, B. & D. Raup; eds) *Handbook of Paleontological Techniques.* pp 89–94. W. H. Freeman & Co., San Francisco. 852 pp.

Upper Kimmeridgian stratigraphy of Aylesbury, Buckinghamshire

Michael J. Oates

OATES, M. J. 1991. Upper Kimmeridgian stratigraphy of Aylesbury, Buckinghamshire, *Proc. Geol. Ass.*, **102**(3): 185–99. Field work carried out in Aylesbury in 1987 demonstrated that the Upper Kimmeridge Clay attains 31 m thickness and has a minor non-sequence at its base. The sequence fits well with the trend of gradual thinning southwestwards, from the relatively thick development of the Wash area to the thin sequence deposited over the Oxford Shallows. The well developed sands within the Pectinatus Zone of the Oxford to Swindon area are represented at Aylesbury only by silty distal intercalations in an otherwise clay sequence. All the Upper Kimmeridgian ammonite-based zones, except the youngest, were recognised, together with the two highest Lower Kimmeridgian zones, but their boundaries could not always be fixed on ammonite evidence alone. The ammonite fauna differs from that hitherto recorded from the Dorset succession only by the presence of *Aulacostephanus autissiodorensis* (Cotteau) of typical continental type, above its coarser ribbed evolute British variant. Species of *Gravesia* spp. were recorded from the uppermost Autissiodorensis Zone and the Elegans-Scitulus zones. Five members are recognised in the Upper Kimmeridge Clay, of which three, Holman's Bridge Shale, Watermead Clay and Elmhurst Silt, are formally described herein.

Trefoil Cottage, Station Road, Padbury, Buckingham, MK18 2BJ

1. INTRODUCTION

A general understanding of the stratigraphy of the English Kimmeridge Clay Formation has been greatly advanced in the last two decades (e.g. Birkelund, Callomon, Clausen, Nohr Hansen & Salinas, 1983; Callomon & Cope, 1971; Cope, 1967, 1978; Cox, Lott, Thomas & Wilkinson, 1987; Cox & Gallois, 1979, 1981; Gallois & Cox, 1976).

However, apart from the Dorset coastal sections and the pit at Westbury, Wiltshire (Fig. 1), this literature is based mainly on cored boreholes; large temporary exposures in the Kimmeridge Clay are therefore of considerable interest and can potentially add much to our local knowledge of the sequence.

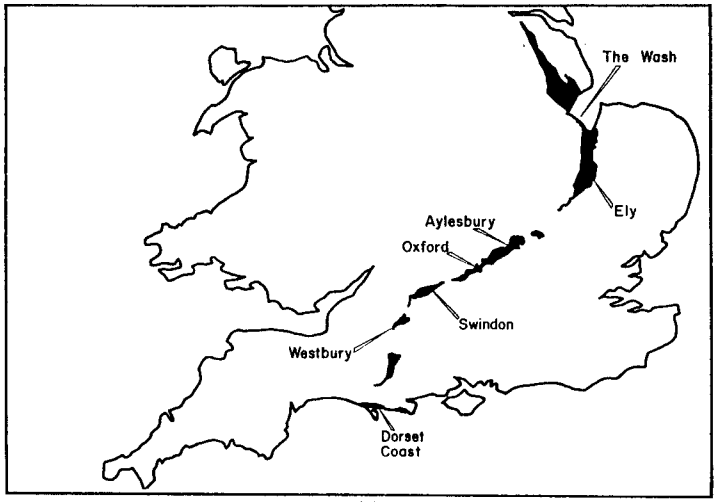
Such a temporary exposure was available throughout the summer of 1987, on the northern outskirts of Aylesbury, in an area where the stratigraphy of the Kimmeridge Clay was notoriously little-known. Excavations on this site (SP 820155), up to 5 m deep, formed the initial stage of development of a residential area called 'Watermead', dominated by a large lake of several acres extent (Fig. 1).

A total section of 15 m was compiled from an approximately 27 acre exposure. A little additional information was available from site survey borehole records. Although lithological samples from these holes were not available, a site survey report indicated a further 5 m of clay beneath the lowest exposure (Fig. 2). Additional information from site survey boreholes (up to 31 m depth) on a new building site developed by Equitable Life Assurance Society in Walton Street, Aylesbury (SP 821134) provided a link between the Watermead section and the highest part of the Kimmeridge Clay which had already been described from nearby temporary exposures (SP 823138 and 822137) (Oates, 1974). A total Upper Kimmeridgian thickness of about 31 m was thus deduced (Fig. 2).

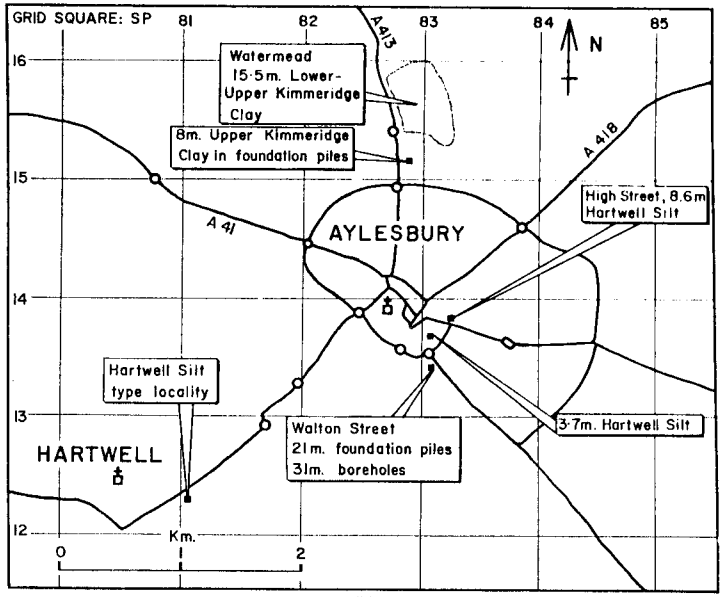
Stratigraphically diagnostic ammonites were abundant and, although generally compacted, were of sufficiently good preservation to allow comparison with those collected from other well documented sections, particularly Dorset, where Cope (1967; 1978) established the modern zonal scheme for the Upper Kimmeridgian.

The excavation attracted a degree of local interest, particularly following the discovery of large marine reptile remains (e.g. *Bucks Herald,* 16 July 1987). The site also provided additions to known ranges and transients of the ammonite fauna from the mid-part of the Kimmeridge Clay Formation, including the only positive record of the Autissiodorensis Zone from the line of discontinuous Kimmeridge Clay outcrop between Dorset and the Wash, and several records of the rather rare ammonite genus *Gravesia.* A large quantity of stratigraphically controlled material has been collected to enable subsequent analysis of the succession should the need arise, and micropalaeontological studies of this material are currently underway. Representative material and figured specimens will be deposited in the Buckinghamshire County Museum, Aylesbury.

The Kimmeridge Clay around Aylesbury was previously assumed to resemble the sequence in the Oxford area, e.g. Cope, Duff, Parsons, Torrens, Wimbledon & Wright (1980, figure 14), but the present paper shows that this is not the case. At Oxford, some 30 km to the west, the sequence is particularly sandy in the Pectinatus Zone, and further west to Swindon, sands may also occur in the Hudlestoni Zone (Gallois & Worssam, 1983).



(a)



(b)

Fig. 1. (a) Kimmeridge Clay outcrop in Southern England, highlighting localities cited in the text. (b) Temporary Kimmeridge Clay exposures in the Aylesbury area.

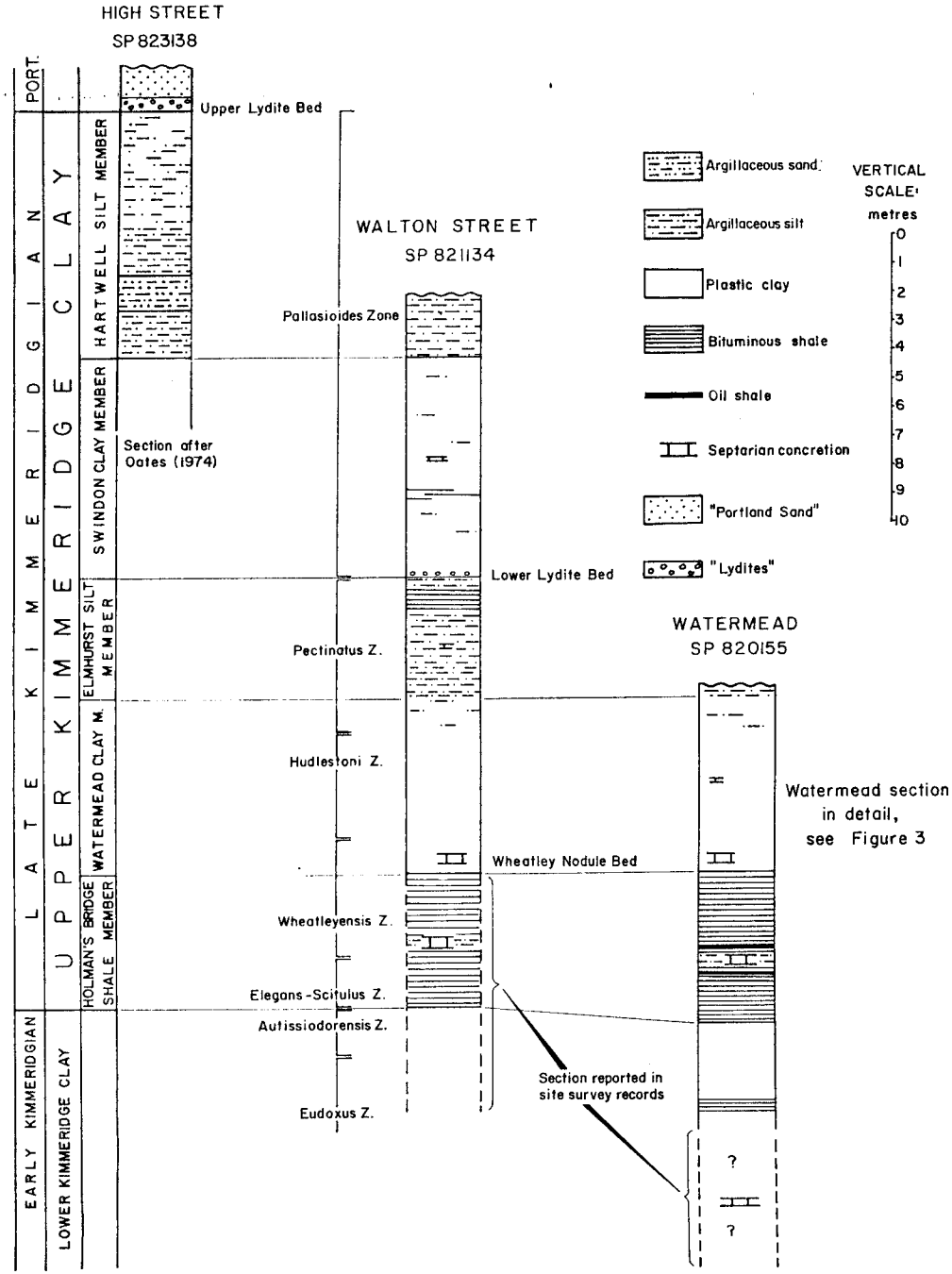


Fig. 2. Correlation of the three temporary sections used to compile a complete Upper Kimmeridge Clay sequence in Aylesbury Lithostratigraphy and ammonite zones are indicated.

Temporary excavations for the M40 motorway 10 km east of Oxford near Waterstock (SP 628049–SP 625047) (Cox, Horton & Sumbler, 1990) in early 1990 provided the details necessary to complete adequately the correlation with former sections at Wheatley (Arkell, 1947).

Although having no formal lithostratigraphic status, the terms 'Lower Kimmeridge Clay' and 'Upper Kimmeridge Clay' have been historically used for convenience (Upper Kimmeridge Clay equating to post Autissiodorensis Zone sediments or beds above Bed 35 of Cox & Gallois, 1979). This boundary coincides with the base of the Upper Kimmeridgian Substage *sensu anglico*.

2. KIMMERIDGE CLAY RECORDS IN THE AREA

The nearest comparable sections to that exposed at Watermead were at Rid's Hill Brickpit (SP664151), Brill (abandoned in 1911) and the Wheatley Brickpit (SP589054) at Littleworth, near Oxford. Rid's Hill pit was worked mainly for the Lower Kimmeridge Clay, and no more than 2.5 m (8 feet) of Upper Kimmeridge Clay, reportedly of the Wheatleyensis Zone, was exposed (Arkell, 1947). (The Elegans and Scitulus zones were not established at this time.) A revised account of the stratigraphy of Rid's Hill has been published recently (Cox & Sumbler, 1989). Beds apparently spanning the interval recorded at Watermead were formerly exposed at Wheatley, and also at Chawley, north of Abingdon and Radley (e.g. Arkell, 1947) (Fig. 4). A late 19th century photograph of Chawley Brickpit by a Mr. C. J. Bayzand is reproduced by Bond, Gosling & Rhodes (1980, p. 23) and a sketch of the same included by Pringle (1926, p. 98). Motorway excavations in 1989/1990 at Waterstock, east of Oxford, allowed some further detail to be added to the general description of the Kimmeridge Clay succession around Oxford. A section from the old records of Wheatley amended by recent field work by the author and H. P. Powell (University Museum, Oxford) is included in Fig. 4.

To the north and east of Aylesbury, only the former exposure at Stewkley (SP 848250) bears any relevance to the Watermead section. There, clays of the 'Pseudomutabilis Zone' (=Eudoxus and Autissiodorensis zones) were dug for bricks (Woodward, 1985; Pringle 1922–3); material from Stewkley in the BGS collections confirms the Eudoxus and possibly Autissiodorensis zones (Cox, 1988, pers. comm.). Pringle's notes also mention the discovery in an adjacent pit (SP 846248) of higher beds of clay with septarian nodules which yielded *Nanogyra virgula* (Defrance), *Protocardia morinica* and large crushed perisphinctids, suggesting that a section similar to at least the lower part of the Watermead succession was once exposed here. A short distance northeast of Stewkley, the Kimmeridge Clay is overstepped by the Aptian Lower Greensand. No significant exposure has existed recently between this point and Ely, Cambridgeshire.

The publication of the results of BGS boreholes at Brill (SP65701412) and Hartwell (SP79261223) (resumés of which appear in Gallois & Worssam, 1983; British Geological Survey, 1988; and Cox & Sumbler, 1989) will add useful data points to our knowledge of the Kimmeridge Clay in Buckinghamshire, proving the nature and thickness of the Lower Kimmeridge Clay, and demonstrating the lateral variation, of the Upper Kimmeridge Clay.

3. LITHOSTRATIGRAPHY

Five distinct lithostratigraphical units are recognised in the Upper Kimmeridge Clay in this area. They are (from above):

—Hartwell Silt Member
—Swindon Clay Member
—Elmhurst Silt Member (new name; type section: Walton Street, Aylesbury)
—Watermead Clay Member (new name; type section: Watermead, Aylesbury)
—Holman's Bridge Shale Member (new name; type section: Watermead, Aylesbury)

The Lower Kimmeridge Clay is not subdivided here. No Kimmeridge Clay in the area is permanently exposed, but the new members should be available in temporary sections from time to time.

The full Upper Kimmeridge Clay succession, compiled from the Watermead excavations, the Walton Street holes and the previously described Hartwell Clay sections, is illustrated in Fig. 2, and the Watermead section is depicted in Fig. 3. The succession is described below in ascending order.

(a) Lower Kimmeridge Clay (8.7 mm, base not seen)

The base of the Kimmeridge Clay Formation was not exposed at Watermead. Beneath the lowest observed beds, excavator operators reported a brown clay which readily flowed water, and the site survey report indicated 5 m of grey clay, including a 10 cm thick nodule layer. Comparison with the published descriptions of the Wash area suggest that the nodule layer may be either the Crussoliceras Band (Birkelund *et al.*, 1983) which is known to exist in the Aylesbury area from the author's observations of a temporary section 4 km north of Watermead (SP 805200) or the equivalent of the underlying hard cementstone doggers seen 0.4 m below the Crussoliceras Band at Waterstock. The beds at the base of the Watermead exposure comprised a medium grey, massive, stiff, poorly fossiliferous, waxy clay passing up into a brownish grey, well-bedded shelly shale (typical oil shale) with a distinct bituminous odour. The two lithological types alternated in successively thinner

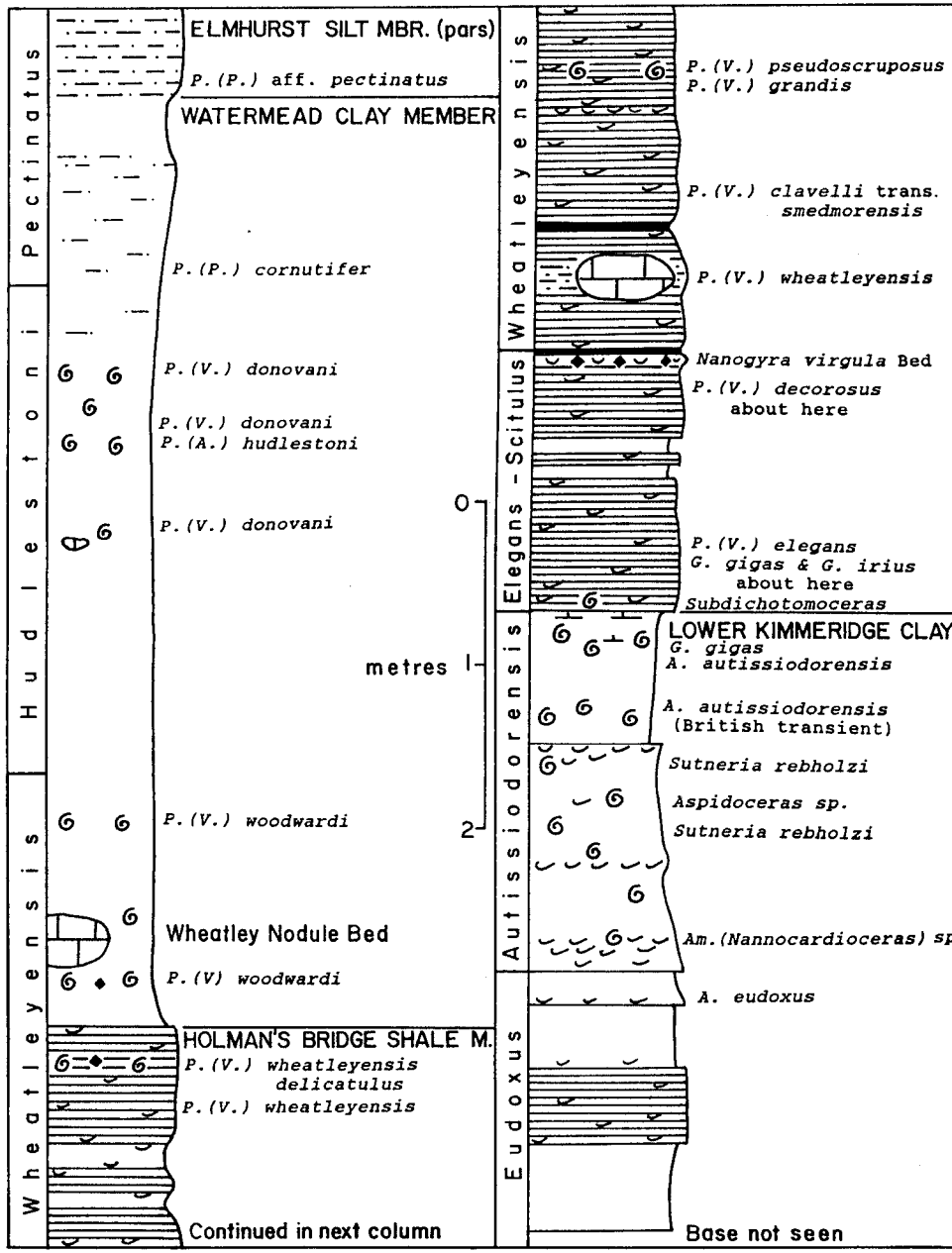


Fig. 3. Detailed section of the Kimmeridge Clay Formation exposed at Watermead, Aylesbury (SP 821134) during summer of 1987. Some important ammonite occurrences and the ammonite zonation are shown. (For key to symbols see Fig

cycles up to an abrupt junction overlain by 2.15 m of dark grey plastic clay, often very shelly, and with occasional mildly phosphatised reworked calcareous nodules, thin discontinuous calcareous mudstone lenses and horizons showing sediment-boring activity. This abrupt junction is taken as the Eudoxus-Autissiodorensis Zonal boundary. Clays below this horizon contained *Nannocardioceras* plasters and occasional *Aulacostephanus* cf. *eudoxus* (d'Orbigny). The Autissiodorensis Zone clays yielded characteristic and abundant *Aulacostephanus*, including the zonal index species (see 4 below). Some horizons of unusual character, towards the top of this unit, are listed below. Their stratigraphic position is related to the base of the Upper Kimmeridge Clay (BUKC).

—0.8 m below BUKC: a 10 cm bed of clay with an abundance of broken, lightly abraded and bored, thick shell fragments, together with reworked, subrounded mildly phosphatised, fragmentary calcareous concretions.

—0.6 m below BUKC: a bed of large, evolute coarsely-ribbed *Aulacostephanus autissiodorensis* and numerous large pyritized *Liostrea bononiae* (de Loriol); thin calcareous lenses also present.

—0.4 m below BUKC: another bed of large *Aulacostephanus autissiodorensis*.

—0.2 m to 0.5 m below BUKC: a bed crowded with well-preserved macronconchs of a large, smooth body-chambered transient of *Aulacostephanus autissiodorensis* (see Section 4 below).

(b) Upper Kimmeridge Clay (31 m)

The base of the Upper Kimmeridge Clay was marked by an abrupt passage up into brown/grey, firm, shelly bituminous shale (including oil shale) from the grey, plastic clays of the underlying unit. The ammonite faunas either side of this boundary suggest that a sedimentary hiatus, involving the higher Autissiodorensis Zone, is represented here, although no erosion surface could be readily detected.

Two new units (the Holman's Bridge Shale and Watermead Clay Members) were fully exposed at Watermead, and another two units (the Elmhurst Silt and Swindon Clay Members) were penetrated fully by site boreholes and many piles driven into the Walton Street development.

(i) Holman's Bridge Shale Member (5.2 m)

The base of this Member at Watermead coincided with the base of the Upper Kimmeridge Clay. The member was a remarkably uniform brownish grey hard bituminous shale with a petroliferous odour, and with plasters of *Isocyprina* and *Protocardia* together with *Pectinatites* spp. throughout. Thin beds of true oil shale were also present. Marine reptile bones, including associated and articulated skeletons were more numerous in this member than elsewhere in the Watermead section. The member can probably be correlated with reportedly similar lithologies at the base of the Upper Kimmeridge Clay around Oxford, and may represent Beds 36 to 42 of Cox & Gallois (1979).

Several horizons which correlated across the Watermead site were recognised:

—1.85 m above the base of the member: a 2 cm thick pyrite-replaced shell bed with abundant *Nanogyra virgula* overlain by a 2 cm paper shale. This pyritic bed was the highest occurrence of *N. virgula* recorded in the area. At an equivalent level in the borehole logs from Walton Street, a thin silt was recorded by site personnel

—2.1 m above the base: a 0.25 m thick greenish/grey, slightly silty, strongly bioturbated calcareous claystone with frequent large discoidal septaria. This bed was distinguishable from a similar but higher horizon with septaria, by its distinct greenish coloration and by the presence of abundant dark grey clay-filled *Thalassinoides* burrows. It also contained a more diverse bivalve fauna than the overlying and underlying shales, particularly in the fairly common occurrence of *Myophorella* and large "*Astarte*". The septaria were characterised by a predominantly white calcite infill. Calcite cementation of these septarian doggers was not complete until compaction was well-advanced, as demonstrated by most of the distorted constituent fossil shells. The fossils were not, however, as severely compacted as in the clays above and below. This horizon was penetrated in Walton Street borcholes and was well exposed at Watermead. It may correlate with the Grey Ledge Stone Band of Dorset.

—2.5 m above the base: a 2 cm thick paper shale of typical rich oil-shale lithology which ignited readily when dry.

—5 m above the base: an abundance of completely flattened pyritized ammonites, mainly *P. (Virgatosphinctoides) wheatleyensis delicatulus* (Neaverson) (Fig. 6c), frequently encrusted by ostreid bivalves or small trochid gastrods.

Specimens of *P. (V.) elegans* Cope (Fig. 6c) and *P. (V.) decorosus* Cope (Fig. 7f) in the lowest 2 m indicate the Elegans-Scitulus zones. The occurrence of *P. (V.) wheatleyensis* Neaverson (Fig. 7g) in the bed of septaria, *P. (V.) clavelli* Cope transitional to *smedmorensis* Cope (Fig. 6a) just above, *P. (V.) grandis* and *P. (V.) pseudoscruposus* 0.95 m above the septaria and *P. (V.) grandis* and *P. (V.) pseudoscruposus* 0.95 m above the septaria and *P. (V.) wheatleyensis delicatulus* near the top of the member indicates the Wheatleyensis Zone. The base of this Zone is taken above the *N. virgula* shell bed 1.85 m above the base of the member (see above), as this bivalve is regionally common only up to the Scitulus Zone (Cox, 1991, pers. comm.), and the first Wheatleyensis Zone ammonites occurred in the septaria just above (Fig. 3).

(ii) Watermead Clay Member (6 m)

The base of this unit was clearly definable in both the Watermead exposure and site records at Walton Street. It is marked by the appearance of dark grey calcareous clay, above the stiff, brown/grey, shelly Holman's Bridge Shale (see above). From engineering reports made available to the author, it is also evident that the compressive strength of the Watermead Member is only about half that of the Holn Bridge Shale, and this alone could be used to picl base in otherwise inadequately described site su records. At Watermead, the member exhibited lithological change. It tended to become sli harder and shalier within 0.2 m of its base, contained very fine silt in its uppermost 2 m Waterstock, the member was reduced by about while a further kilometre west, at Shotover,

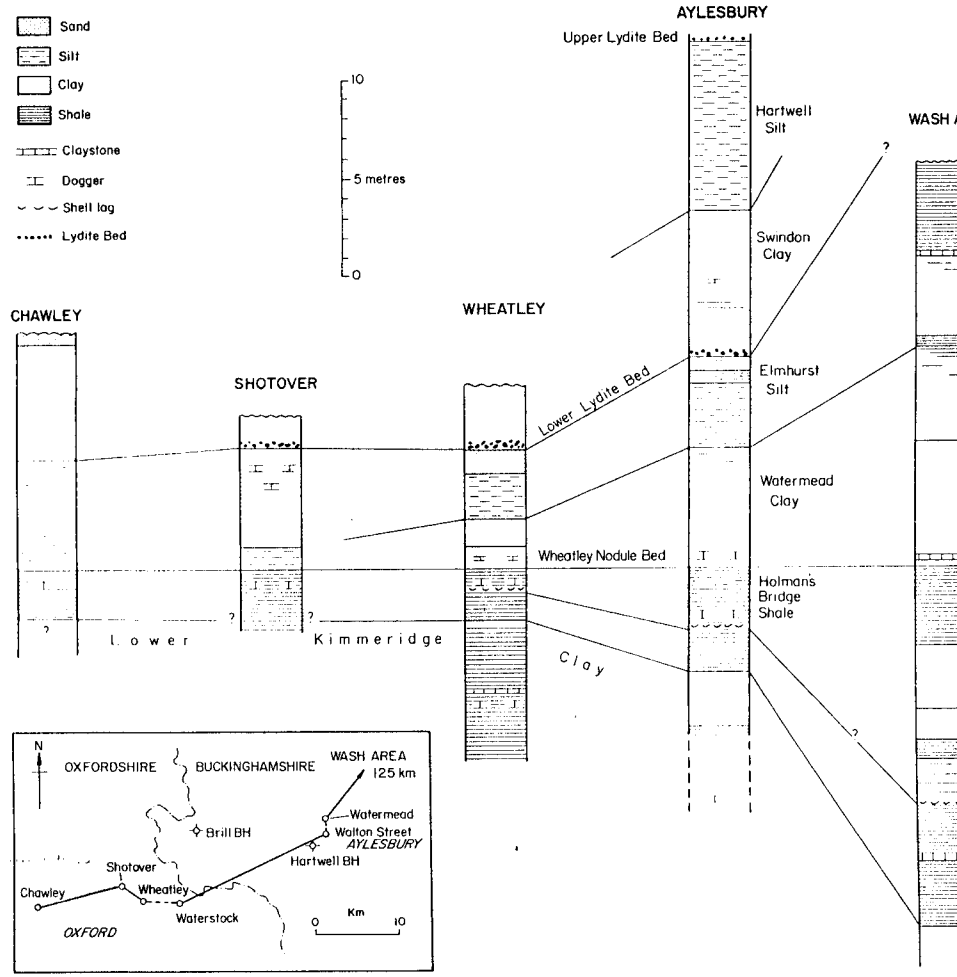


Fig. 4. Correlation of the Upper Kimmeridge Clay from the Oxford area, through Aylesbury, to The Wash. A te correlation of standard Kimmeridge Clay bed numbers (after Cox & Gallois, 1979, amended Cox & Gallois, 1981) is n

member is evidently absent, having been cut out beneath or laterally replaced by silts of the succeeding unit, which overlies directly on to presumed Holman's Bridge Shale (see Fig. 4).

The following distinctive horizons were recorded:

—0.4 m above the base of the member: conspicuous layer of oblate sphaeroidal septarian doggers, normally some 0.4 m diameter, with predominantly honey-brown calcite infill. The doggers contained abundant, partially crushed *P.* (*V.*) *woodwardi* Neaverson (Fig. 7c). The same species, partially crushed and semi-pyritized with white powdery aragonitic shells, occurred in clay at the same level, and also just above, and in a distinct brown-weathering horizon 0.1 m below. The horizon with septaria corresponds to the 'Wheatley Nodule Bed'; the ammonites compare closely with specimens figured from this horizon by Neaverson (1925, Plate III, figs. 1, 3 and 4), and museum collections of material from Wheatley. It has also been possible to correlate these septaria with an horizon of much reduced nodules at Waterstock. This nodule bed was not specifically noted in old records of the Wheatley and Chawley sections (e.g. Arkell, 1947), probably because the nodules were not prominent enough, particularly compared with the obvious and well developed septarian layer a metre or two lower in the section

—2.9 m above the base: a layer of widely spaced, rather irregularly shaped unfossiliferous claystone concretions, approximately 0.15 m diameter

—3.6 m above the base: an horizon particularly rich in ammonites, many of giant size, but particularly with abundant *P.* (*V.*) *donovani* Cope (Fig. 7a). *P.* (*Arkellites*) *hudlestoni* Cope (Fig. 7a) occurs at this level.

—5.1 m above the base: the weathered Watermead Clay included a 10 cm bed of grey silty clay with prominent pale grey streaks of minute selenite crystals, possibly indicating an originally more calcareous bed.

About the basal metre of the member, the 'Wheatley Nodule Bed' fauna indicates the Wheatleyensis Zone while the ammonites 3.6 m above the base of the member are of typical Hudlestoni Zone aspect. Insufficient material was found to fix the boundary more accurately than this. However, as *P.* (*V.*) *donovani* characterizes the higher Hudlestoni Zone (Cope, 1974) and the Zone is relatively thick elsewhere, the boundary has been placed low in the Watermead Member. A single occurrence of *P.* (*Pectinatites*) *cornutifer* Cope (Fig. 7b) indicates the Pectinatus Zone at least as low as 4.6 m above the base of the member, coincident with the lowest occurrence of appreciable fine silt in the clays. A *P.* (*Pectinatites*) aff. *pectinatus* (Phillips) fragment preserved in pyrite, was recovered loose from the weathered zone, and probably comes from between 4 m and 5 m above the base of the unit.

Comparison with the standard Upper Kimmeridge Clay beds of Cox & Gallois (1979) suggests that the basal Watermead Clay Member correlates with base Bed 43 in the Hudlestoni Zone. This would be acceptable only if it can be demonstrated that the range of *P.* (*V.*) *woodwardi* extends higher than the first appearance of *P.* (*V.*) *reisiformis* (an ammonite not recorded from Aylesbury) (Fig. 4).

(*iii*) *Elmhurst Silt Member* (4.5 m)

At Watermead, this Member was only seen to 0.5 m, in the weathered zone. It was however, fully penetrated in Walton Street where the upward passage from clay into a very silty clay which marks its base, was well documented in site boreholes and augured piles.

The unit comprises a dark grey, stiff argillaceous silt. A 1 m thick more laminated and bituminous layer, some 3 m above its base, contained a restricted bivalve fauna mainly of *Isocyprina*. By analogy with fossiliferous sandy Pectinatus Zone to the southwest around Oxford the member is assigned to the Pectinatus Zone. This is supported by the record of *Pectinatites* (*Pectinatites*) spp. in the top part of the underlying Watermead Clay Member, and the presence above of the Lower Lydite Bed.

The areal extent extent of this unit is not yet known, but its upper part probably passes laterally into the 'Pectinatus Sandstone' (or Buckman's 'Shotover Grit Sands') of Wheatley and Waterstock towards the southwest. Typical Pectinatus Sandstone has been seen in a temporary exposure at Chearsley, 10 km southwest of Aylesbury. (Dr. W. A. Wimbledon, 1988, *pers. comm.*) and sands also cap Rid's Hill, Brill (Cox & Sumbler, 1989). At Waterstock, silts extend down to just above a level with abundant *P.* (*V.*) *donovani*. It is possible that the base of the member is diachronous, replacing the entire Watermead Clay member at a point west of Wheatley towards Shotover and Chawley.

(*iv*) *Swindon Clay Member* (7.4 m)

This unit was originally described from the Swindon-Oxford area. At the Walton Street site in Aylesbury, it was a uniform, slightly silty, fossiliferous dark grey/black clay which contrasted with the more diverse and silty lithologies of the Elmhurst Silt below. An occasional calcareous concretion horizon was evident from pile-augured holes. The highest bed of silt at the top of the Elmhurst Silt in a Walton Street borehole was reported to contain occasional subrounded pebbles of 'black crystalline rock'. This bed probably equates with the Lower Lydite Bed, and, if correctly correlated, represents the base of the Pallasioides Zone. The Walton Street site was last developed in about 1965, when gravity-piling took place. From the resultant cores a fauna of hard, black, phosphatised *Pleuromya*, *Hiatella* and *Pectinatites pectinatus* was obtained. These are also known to occur at outcrop locally, where they have been ascribed to the Lower Lydite Bed (Dr. B. M. Cox, 1988, pers. comm.). A bed of silty clay some 0.5 m thick, containing the same fauna in identical preservation, was well exposed at Waterstock, immediately overlying the 'Shotover Grit Sands'. The absence of an obvious Lydite Bed at this horizon in most Walton Street borehole records suggests that the characteristic remanié lithology is only developed in pockets in what must otherwise be a significant omission surface, or more probably that it was simply not noticed in the site survey. The base of the Lower Lydite Bed is taken as the base of the Swindon Clay Member.

Fossils, though compressed, included many aragonitic examples with fiery iridescence when freshly excavated. Badly damaged perisphinctid ammonite fragments were recovered from near the base of the member at the Walton Street site, and well preserved examples of *Pavlovia pallasioides* have been recovered from the basal 2 m at Waterstock.

The transition of this member up into the silty/sandy Hartwell Silt Member was seen in the temporary exposure at the High Street/Exchange Street intersection in Aylesbury (SP 823138, Oates, 1974) and at c. 3.5 m depth in Test Borehole no. 4 on the Walton Street site (unpublished site survey report). The 2–3 m of sediment at about this junction was the least satisfactorily recorded, and a small error in thickness measurement of the Swindon Clay is possible. The ammonite fauna of the uppermost 2.5 m belongs to the Pallasioides Zone (Oates, 1974) which, by inference from the Waterstock section, extends down to the Lower Lydite Bed at the base of the member.

(*v*) *Hartwell Silt Member* (8 m)

This unit (formerly the Hartwell Clay) is the only division of the Upper Kimmeridge Clay in the Aylesbury area which has previously been defined according to modern lithostratigraphic principles (Oates, 1974). The term 'Clay' is replaced here as the lithology is more appropriately called silt, albeit very argillaceous. In this respect, the unit much resembled the Elmhurst Silt Member.

The passage up from the greenish/black, stiff plastic, shelly clay of the Swindon Clay, to the dark grey, silty and sandy glauconitic clay of the basal Hartwell Silt, occurred over a vertical interval of some 10 cm.

A plaster of *Arcomytilus* sp. 3.3 m above the base of the member, and a layer of small, distinctive, partially pyritized septaria 4.5 m above the base should be good local markers. The entire member contained abundant *Pavlovia* spp. indicative of the Pallasioides Zone, and is traceable southwestwards along outcrop to Thame and Brill, beyond which it may be cut out by pre-Portlandian erosion for a short distance, or may pass into the Wheatley Sand. To the northeast, the member can only be traced until it disappears below unconformable Cretaceous strata in the neighbourhood of Stewkley and Wing, some 12 km distant.

The Upper Lydite Bed (0.5 m) which was exposed in the weathered zone at the top of the Hartwell Silt sections described previously (Oates, 1974) is not always seen. Although reportedly containing rolled, phosphatized *Pavlovia rotunda* (Casey, 1967) this bed probably belongs to the Albani Zone, forming the base of the Portlandian strata in the area (Casey, 1967). The Rotunda Zone fauna was derived from clays now unrepresented in the area apart from remanié nodules and fragments.

4. NOTES ON THE AMMONITE FAUNA

Where possible, ammonite occurrences are indicated on the graphic section of the Watermead site (Fig. 3).

(a) Amoeboceras

Amoeboceras apparently becomes extinct within the lower Autissiodorensis Zone (Callomon & Cope, 1971; Gallois & Cox, 1976). The small rectiradiate, finely ribbed species *A.* (*Nannocardioceras*) *anglicum* (Salfeld) which is the youngest known representative of the genus in Dorset and the Wash area also occurred at Watermead, some 2.0–2.5 m below the base of the Upper Kimmeridge Clay, together with the nearly smooth *A.* (*N.*) *krausei* (Salfeld).

The coarser ribbed subgenus *Amoebites* occurs through most of the Lower Kimmeridge Clay, and has been collected by the author from a temporary Eudoxus Zone exposure 4 km north of Aylesbury (SP 805200), but was not seen at Watermead.

(b) Sutneria

Sutennia rebholzi Berckhemer occurred at Watermead in considerable numbers, between 1.0 and 2.0 m below the base of the Upper Kimmeridge Clay, and at a similar stratigraphic horizon in the M40 motorway excavations at Waterstock and in Bed 33 of Gallois & Cox (1976). Its range in the Warlingham Borehole was entirely within the low Autissiodorensis Zone (Calloman & Cope, 1971) and in Bed 33 of Gallois & Cox (1976) in East Anglia.

(c) Aspidoceras

This highly variable genus is discussed in some detail by Callomon (*in* Callomon & Cope, 1971), but there is no modern systematic work on the genus. At Watermead, it occurred, often abundantly, up to 1 m below the base of the Upper Kimmeridge Clay, sizes

varying up to 0.5 m diameter. They most closely resemble specimens of *A. caletanum* figured by Hantzpergue (1987). The ammonite aptychi known as *Laevaptychus* originated from *Aspidoceras* with which genus its range at Watermead coincided.

(d) Aulacostephanus

Aulacostephanus forms the basis for the ammonite zonation of the Eudoxus and Autissiodorensis zones, and was the endemic ammonite population throughout this period. The genus was the subject of systematic research by Ziegler (1962), but there is scope for more detailed stratigraphically controlled analysis of the genus in Britain. At Watermead (and also at Waterstock) a distinct succession of *Aulacostephanus* occurred in the 3.7 m of exposed Lower Kimmeridge Clay.

From shaley clays about 2 m below the base of the Upper Kimmeridge Clay, a population of small, densely ribbed *Aulacostephanus* was recorded. Alone, these are difficult to date beyond 'Eudoxus/Autissiodorensis Zone' but their association with *Nannocardioceras*-rich beds, and comparison with the Wash succession (Gallois & Cox, 1976) suggests the Eudoxus Zone. A variety of *Aulacostephanus* comparable to *A. volgensis* (Vischniakoff) and *A. kirghisensis* (d'Orbigny) occurred throughout the 3.7 m of clays exposed at Watermead.

At both the Watermead and Waterstock exposures, large, evolute, strongly ribbed *A. autissiodorensis* occurred in abundance near the top of the Lower Kimmeridge Clay, and were characteristic of the Autissiodorensis Zone. A remarkably smooth outer-whorled *Aulacostephanus* (mentioned above, and Fig. 6d) occurred in great abundance in a thin bed 0.05–0.2 m below the base of the Upper Kimmeridge Clay, almost to the exclusion of other ammonites. This species, commonly up to 0.3 m diameter, possesses moderately densely ribbed inner whorls, and is rather more evolute than other 'unornamented' *Aulacostephanus* species (eg. *Aulacostephanus jasonoides* (Pavlow) with which it was found in association at Watermead (Fig. 5d). Ammonites from this fauna resemble the rather unornamented specimen of *Aulacostephanus autissiodorensis* from Bar-le-Duc (Meuse) France, figured by Hantzpergue and Lafaurie (1983) who noted that this smooth transient is much closer to the holotype than the coarsely-ribbed British fauna (e.g. Fig. 5a (to which the same name has been applied)).

It is unfortunate that the disconformity just above this horizon precluded the study of any later *Aulacostephanus* forms. However, a search in more complete Autissiodorensis zone sections, such as the Dorset Coast, may well reveal an identical transient fauna at the same stratigraphic level, as is suggested by the record of Borehole CSU 71/65 (Gallois & Cox, 1974, p. 28).

(e) Gravesia

Gravesia, as a stratigraphically significant ammonite, was discussed at length by Cox & Gallois (1981). In northwest Europe, the genus occurs within the Autissiodorensis, Elegans, and Scitulus zones. Although relatively rare in Britain, the occasional occurrence conveniently links the British succession with correlatives on the European mainland.

At Watermead, *Gravesia gigas* (Zieten) occurred, as a rarity, at the junction between the Lower and Upper Kimmeridge Clay (see Fig. 4). *Gravesia gigas* and *G. irius* (d'Orbigny) have also been collected from fallen blocks of the lowest 2 m of the Upper Kimmeridge Clay, but again were scarce (Fig. 5b and c). This is an unusually high occurrence of *G. irius* as, according to Hantzpergue (1987), the species is normally associated with the upper Autissiodorensis Zone, although Salfeld (1913) equated an Irius Zone with the modern Elegans Zone. At Watermead, *G. irius* was found in association with *Pectinatites* (*Virgatosphinctoides*) *elegans* Cope.

(f) Subdichotomoceras

Subdichotomoceras, which is possibly a precursor of *Pectinatites*, occurred in the Lower Kimmeridge Clay at Watermead, but well preserved, near complete shells were only preserved immediately below the top (Fig. 6b). Comparison of rib densities of Watermead material and the holotype of *Subdichotomoceras websteri* (Cope) from Dorset, where the species commonly occurs at a level high in the Autissiodorensis Zone, demonstrates a near affinity (Cope; 1968; Birkelund *et al.* 1983).

(g) Pectinatites

Pectinatites now forms the basis for zonal subdivision of the lower part of the Upper Kimmeridge Clay. All the known subgenera (*Arkellites*, *Virgatosphinctoides*, and *Pectinatites*) (Cope, 1967) were recognised at Watermead. One example of *Pectinatites* s.s. at '20 feet depth' from an excavation in Buckingham Street, Aylesbury, is held in the County Museum collection, as additional evidence of the Pectinatus Zone between the Watermead and Walton Street sections (Fig. 2). Specific identification is based upon their rib density, plots of which from successive horizons quickly demonstrate a good deal of overlap. This probably reflects the evolving nature of the fauna or a degree of intraspecific variation not previously recognized. The most characteristic feature of *Pectinatites* is the horn on the aperture. At Watermead, only one specimen (*Pectinatites* (*P.*) *cornutifer* Cope (Fig. 7b)), at a level 9.7 m above the base of the Upper Kimmeridge Clay, showed this feature.

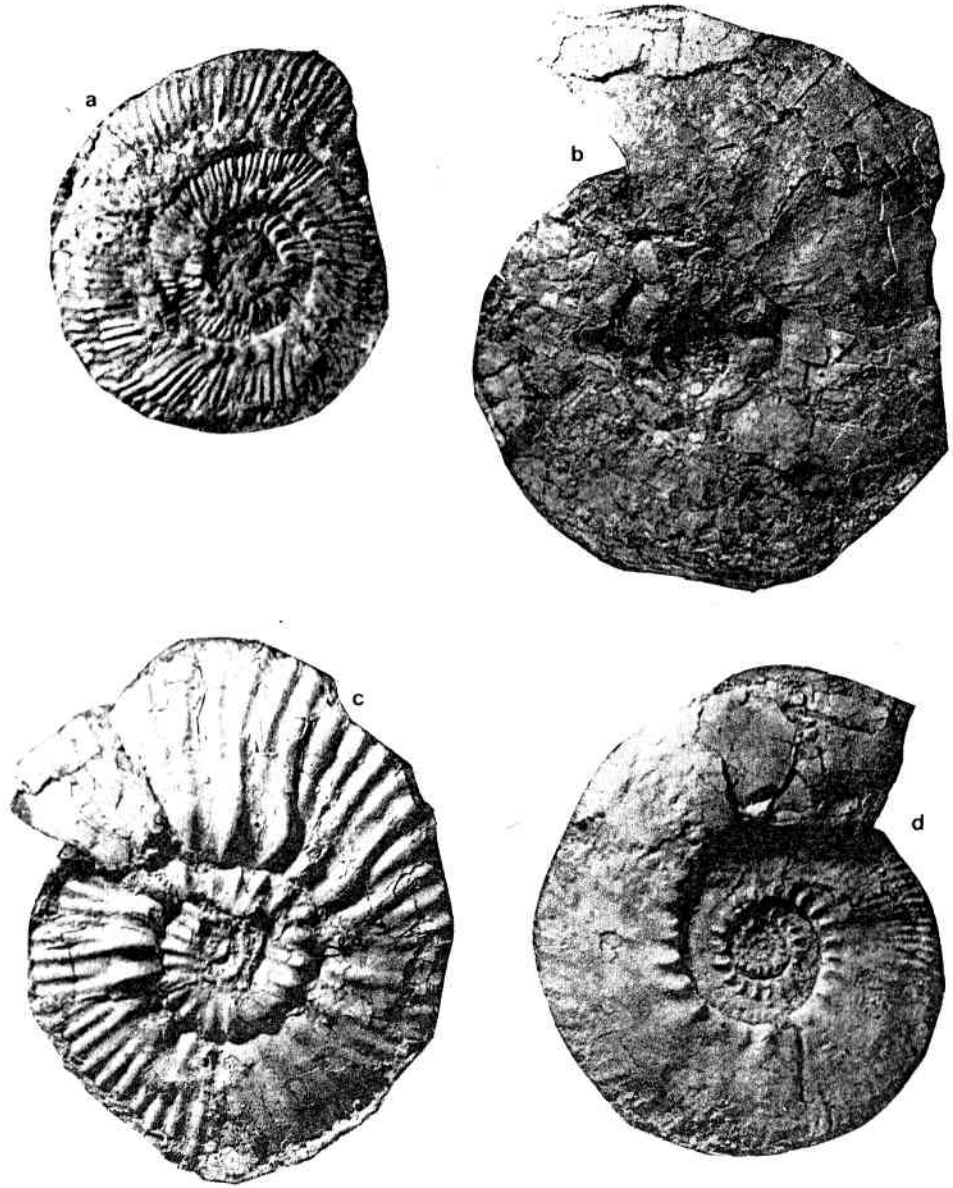


Fig. 5. Ammonites from Watermead. All specimens are in the collections of the Buckinghamshire County Museum, Aylesbury (BCM).
(a) *Aulacostephanus autissiodorensis* (Cotteau) [British transient]; BCM 1991.1.1; 0.4 m below top of Lower Kimmeridge Clay; Autissiodorensis Zone; × 0.28.
(b) *Gravesia irius* (d'Orbigny); BMC 1991.1.2; ex Holmans Bridge Shale [in association with *P.* (*V.*) *elegans*, Fig. 6c]; Elegans Zone; × 0.28.
(c) *Gravesia gigas* (Zieten); BCM 1991.1.3; ex basal 2 m of Holmans Bridge Shale; probably Elegans Zone; ×0.38.
(d) *Aulacostephanus jasonoides* (Pavlow); BCM 1991.1.4; ex top 1 m of Lower Kimmeridge Clay; Autissiodorensis Zone; ×0.4.

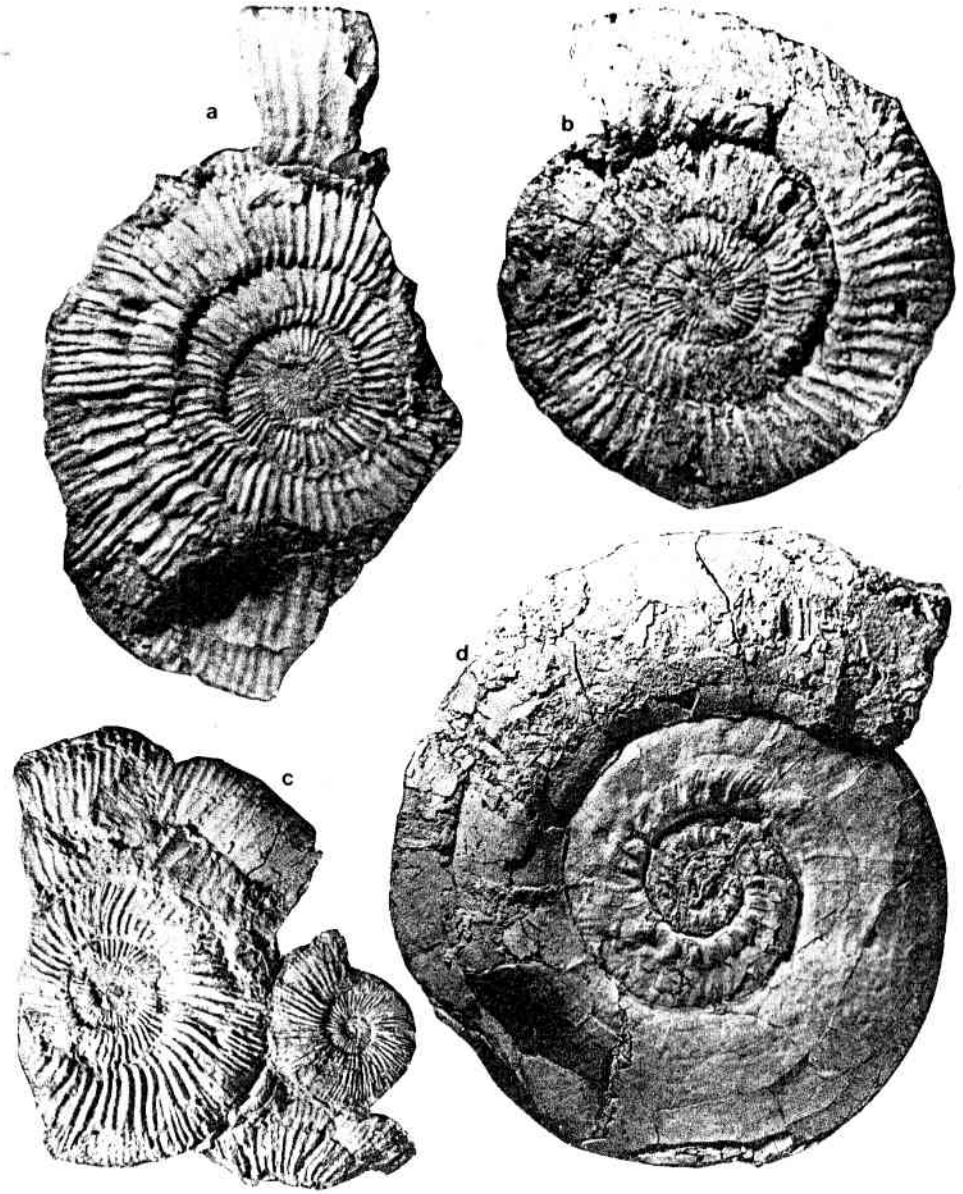


Fig. 6. Ammonites from Watermead. All specimens are in the collections of the Buckinghamshire County Museum, Aylesbury (BCM).
(a) *Pectinatites* (*Virgatosphinctoides*) *clavelli* Cope trans. *smedmorensis* Cope; BCM 1991.1.5; ex Holmans Bridge Shale; Wheatleyensis Zone; ×0.28.
(b) *Subdichotomoceras websteri* Cope; BCM 1991.1.6; top surface of Lower Kimmeridge Clay; Autissiodorensis Zone; ×0.28.
(c) *Pectinatites* (*Virgatosphinctoides*) *elegans* Cope; BCM 1991.1.7; ex basal 2 m of Holmans Bridge Shale [in association with *Gravesia irius*, Fig. 5b]; ×0.38.
(d) *Aulacostephanus autissiodorensis* (Cotteau); BCM 1991.1.8; 0.15 m below top of Lower Kimmeridge Clay; Autissiodorensis Zone; ×0.4.

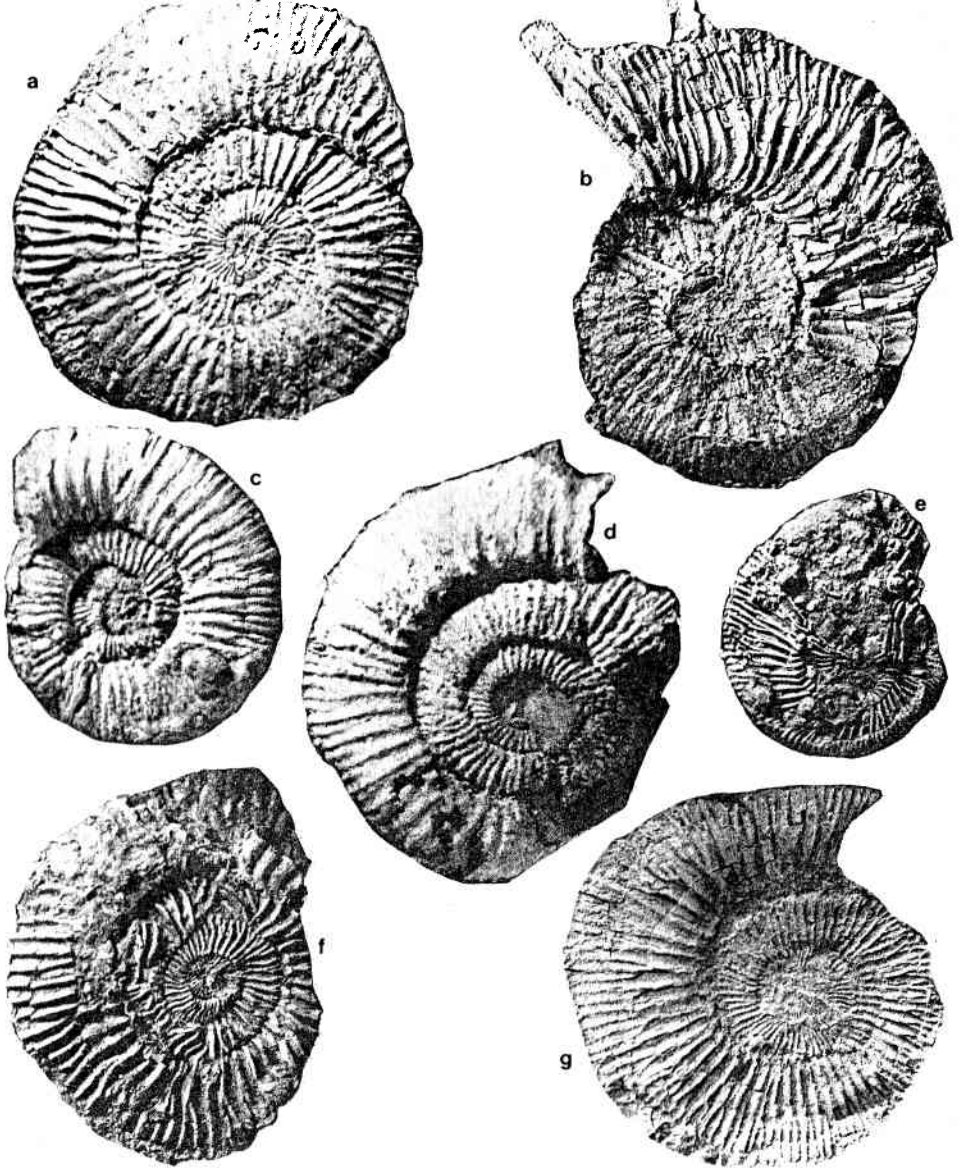


Fig. 7. Ammonites from Walton Street (Fig. 7a) and Watermead (Figs. 7b–g). All specimens are in the collections Buckinghamshire County Museum, Aylesbury (BCM).
(a) *Pectinatites* (*Virgatosphinctoides*) *donovani* Cope; BCM 1991.1.9; about 3 m above base of Watermead Clay [=18 below ground level]; Hudlestoni Zone; ×0.6.
(b) *Pectinatites* (*Pectinatites*) *cornutifer* (Buckman); BCM 1991.1.10; 4.6 m above base Watermead Clay; Pectinatus Zon ×1.0.
(c) *Pectinatites* (*Virgatosphinctoides*) *woodwardi* (Neaverson); BCM 1991.1.11; Wheatley Nodule Bed, near base Watermead Clay; Wheatleyensis Zone; ×0.6.
(d) *Pectinatites* (*Arkellites*) *hudlestoni* Cope; BCM 1991.1.12; 3.5 m above base of Watermead Clay; Hudlestoni Zone; ×0.3
(e) *Pectinatites* (*Virgatosphinctoides*) *wheatleyensis delicatulus* (Neaverson) with small trochid gastropods adhering to she BCM 1991.1.13; 5 m above the base of Holmans Bridge Shale; Wheatleyensis Zone; ×0.67 m.
(f) *Pectinatites* (*Virgatosphinctoides*) *decorosus* Cope; BCM 1991.1.14; ex Holmans Bridge Shale; Scitulus Zone; ×0.87.
(g) *Pectinatites* (*Virgatosphinctoides*) *wheatleyensis* Neaverson; BCM 1991.1.15; doggers, 2.1 m above base of Holma Bridge Shale; Wheatleyensis Zone; ×0.6.

5. REGIONAL SETTING

Comparison of Upper Kimmeridge Clay thicknesses between Chawley, Oxfordshire (Arkell, 1947), and the Wash area (Gallois & Cox, 1974), demonstrates a gradual thickening ENE along the strike of the Kimmeridge Clay outcrop (Fig. 4). This is close to being parallel with the original shoreline of the northern flank of the London-Brabant Massif in Late Jurassic time (assuming that the massif was still a subaerial feature). The higher proportion of sand (particularly in the Pectinatus Zone) and non-sequences in the thinner sections (on the palaeogeographical feature called the 'Oxford Shallows') also suggest deposition in nearshore shallow water, where proximity to a sandy clastic source of sediment and sensitivity to small sea-level changes would have their greatest effect upon the stratigraphic sequence.

Sand development in the Kimmeridge Clay at the Pectinatus Zone level also occurs in the North Sea in, for example, the Claymore Field (UK Offshore block 14/19) (Harker, Gustav & Riley, 1987) where major sand input coincided with a marine regression at the onset of the main phase of late Cimmerian tectonism. To the southeast of Aylesbury, downdip, beneath the Cretaceous cover, the higher Jurassic beds are apparently progressively cut out by the base Cretaceous unconformity. At Puttenham, five kilometres northwest of Tring, a water boring encountered Kimmeridge Clay with septaria beneath Lower Greensand (Whitaker, 1982), which implies erosion down to at least the Hudlestoni Zone,whereas in the Tring-1 Borehole (SP 912103), Lower Greensand of Aptian age rests directly upon a fossiliferous Upper Oxfordian (Corallian) limestone. In the Little Missenden Borehole (SP 916007; Strahan, 1916) Sherlock (1922) reported Gault Clay (presumed Albian age) over the Oxford Clay (Callovian-Oxfordian).

ACKNOWLEDGEMENTS

Access to both development sites readily given by Royco (Watermead) and Equitable Life Assurance Society (Walton Street). Personnel from contractors T. Taylor Contracting Ltd., and Peter Felton of Ove Arup & Partners assisted by reporting and collecting material of interest, and providing site borehole logs. Thanks are due also to Superior (UK) for allowing the release of details from the Tring-1 Borehole. The author benefited from many conversations with Prof. J. H. Callomon and Dr. Beris Cox, who also helpfully commented upon the manuscript. Dr. J. C. W. Cope kindly verified, and in some instances provided, several ammonite identifications cited herein. Roy Harvey and Mike Gray assisted with draughting and photography respectively.

References

ARKELL W. J. 1947. *The geology of Oxford.* Oxford University Press, Oxford.

BIRKELUND T., J. H. CALLOMON, C. K. CLAUSEN, H. NOHR HANSEN & I. SALINAS. 1983. The Lower Kimmeridge Clay at Westbury, Wiltshire, England. *Proc. Geol. Ass.*, **94,** 289–309.

BOND J., S. GOSLING & J. RHODES. 1980. *The Clay Industries of Oxfordshire. Oxfordshire Brickmakers.* Oxfordshire Museum Service Publications, No. **14**.

BRITISH GEOLOGICAL SURVEY. 1988. BGS Boreholes 1984–1986. *Report of the British Geological Survey,* **19,** No. 1

CALLOMON, J. H. & J. C. W. COPE. 1971. The stratigraphy and ammonite succession of the Oxford and Kimmeridge Clays in the Warlingham Borehole. *Bull. Geol. Surv. Gt. Br.* **36,** 147–76.

CASEY, R. 1967. The position of the Middle Volgian in the English Jurassic. *Proc. Geol. Soc. Lon.* **1640,** 128–33.

COPE, J. C. W. 1967. The palaeontology and stratigraphy of the lower part of the Upper Kimmeridge Clay of Dorset. *Bull. Br. Mus. (Nat. Hist.) (Geol.),* **15,** 3–79.

—— 1968. *Propectinatites*, a new Lower Kimmeridgian ammonite genus. *Palaeontology,* **11,** 16–18.

—— 1974. Upper Kimmeridgian ammonite faunas of the Wash area and a subzonal scheme for the lower part of the Upper Kimmeridgian. *Bull. Geol. Surv. Gt. Br.*, **47,** 29–37.

—— 1978. The ammonite faunas and stratigraphy of the upper part of the Upper Kimmeridge Clay of Dorset. *Palaeontology*, **21,** 469–533.

—— K. L. DUFF, C. F. PARSONS, H. S. TORRENS, W. A. WIMBLEDON & J. K. WRIGHT. 1980. *A Correlation of Jurassic Rocks in the British Isles. Part Two: Middle and Upper Jurassic.* Special Report, Geol. Soc. Lond., **15**.

COX, B. M. & R. W. GALLOIS. 1979. Description of the standard stratigraphical sequences of the Upper Kimmeridge Clay, Ampthill Clay and West Walton Beds. *Inst. Geol. Sci. Rep.*, **78/19,** 68–72.

—— & R. W. GALLOIS. 1981. The stratigraphy of the Kimmeridge Clay of the Dorset type area and its correlation with some other Kimmeridgian sequences. *Inst. Geol. Sci. Rep.*, **80/4,** 1–44.

——, A. HORTON, & M. G. SUMBLER. 1990. The Upper Kimmeridge Clay of the M40 Motorway, east of Oxford. *Proc. Cotteswold Nat. Field Club.*, **34,** 261–69.

—— & M. G. SUMBLER. 1989. The Upper Jurassic sequence at Rid's Hill, Buckinghamshire, and the age of the Brill Serpulite Bed. *Proc. Geol. Ass.*, 100, 353–62.

——, G. K. LOTT, J. E. THOMAS & I. P. WILKINSON. 1987. Upper Jurassic stratigraphy of four shallow cored boreholes in the UK sector of the Southern North Sea. *Proc. Yorks. Geol. Soc.*, **46,** 97–109.

GALLOIS, R. W. 1979. Geological investigations for the Wash Water Storage Scheme. *Inst. Geol. Sci. Rep.*, **78/19.**

—— & B. M. COX. 1974. Stratigraphy of the Upper Kimmeridge Clay of the Wash area. *Bull. Geol. Surv. Gt. Br.*, **47,** 1–28.

—— & —— 1976. The stratigraphy of the Lower Kimmeridge Clay of eastern England. *Proc. Yorks. Geol. Soc.*, **41,** 13–26.

—— & B. C. WORSSAM. 1983. Stratigraphy of the Harwell Boreholes. *Inst. Geol. Sci. Rep.*, FLPU **83–14**.

HARKER, S. D., S. H. GUSTAV & L. A. RILEY. 1987. Triassic to Cenomanian stratigraphy of the Witch Ground Graben. *In* (Brooks, J. & K. W. Glennie; eds) *Petroleum Geology of North West Europe.* 809–18.

HANTPERGUE, P. 1987. Les ammonites Kimméridgiennes du Haut Fond d'Europe occidentale (Perisphinctidae, Aulacostephanidae, Aspidoceratidae). Unpubl. Docteur des Sciences Naturelles. Université de Poitiers.

—— & G. LAFAURIE. 1983. Le Kimmeridgien quercynois: un complement biostratigraphique du Jurassique superieur d'Aquitaine. *Geobios,* **16,** 601–11.

LORIOL, P. DE, & G. COTTEAU. 1986. Monographie Paleontologique et geologique de l'étage Portlandien du departement de l'Yonne. *Bull. Soc. Sci. Hist. Nat. Yonne.*, Ser. 2, Vol. 1.

NEAVERSON, E. 1925. Ammonites from the Upper Kimmeridge Clay. *Pap. Geol. Dept., Univ. of Liverpool,* **1,** 1–52.

OATES, M. J. 1974. The stratigraphy and palaeoecology of the Hartwell Clay (Upper Kimmeridgian) of Aylesbury, Buckinghamshire. *Proc. Geol. Ass.*, **85,** 367–75.

PRINGLE, J. 1922–23. Manuscript note in his copy of Woodward 1895. (Copies in *County Museum, Aylesbury* and *B.G.S. Library, Keyworth.*)

—— 1926. Geology of the Country around Oxford, 2nd ed., *Mem. Geol. Surv., Gt. Br.*

SALFELD, H. 1913. Certain Upper Jurassic Strata of England. *Q. Jl. geol. Soc. Lond.*, **69,** 423–30.

SHERLOCK, R. L. 1922. The Geology of the Country around Aylesbury and Hemel Hempstead. *Mem. Geol. Surv., Gt. Br.*

STRAHAN, A. 1916. On a Deep Boring at Little Missenden, in Buckinghamshire. *Sum. Prog. Geol. Surv., for 1915.*

WHITAKER, W. 1892. Some Hertfordshire Well-Sections (second paper). *Trans. Herts. Hist. Soc. & Field Club,* **6,** 53–64.

WOODWARD, H. B. 1895. The Jurassic Rocks of Britain, Vol. 5. The Middle and Upper Oolitic Rocks of England (Yorkshire excepted) *Mem. Geol. Surv., Gt. Br.*

ZIEGLER, B. 1962. Die Ammoniten-Gattung *Aulacostephanus* im Oberjura. *Palaont. Z.*, **35,** 79–89.