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THE WALLINGFORD FAN GRAVEL

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with an appendix on an organic bed associated with the Gould's Grove Member at Amey's pit, Oakley Wood

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The Wallingford Fan Gravel comprises a sequence of flint gravels, chalky in their basal part and also in an uppermost member of restricted occurrence. A fossiliferous unit mid-way in the sequence, the Gould's Grove Member, contains a soil horizon and a

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fauna that suggests a subarctic environment of deposition. The Fan Gravel has been subjected to cryoturbation and intense leaching. It is probable that the deposit was originally largely a calcareous chalk–flint gravel. The Fan Gravel accumulated mainly as a solifluxion, but in part as a fluviatile deposit, in a valley tributary to that of the Thames. Subsequent downcutting by the Thames has isolated the deposits on the face of the Chalk escarpment of the Chilterns. The precise correlation of the Fan Gravel is uncertain but the bulk of the deposit is of mid-Pleistocene age and may be contemporaneous with the Upper Winter Hill Terrace of the Thames. The uppermost chalky member is probably of early Devensian age.

1. Introduction and previous work

The Wallingford Fan Gravel extends along the face of the Chalk escarpment of the Chiltern Hills, on the eastern side of the Thames valley near Wallingford (figure 1). It lies mainly between 90 and 120 m (300 and 400 ft) above O.D., some 45 to 60 m (150–200 ft) above the present-day flood plain of the Thames. The main body of the gravel lies on a shelf-like feature formed by the outcrop of the Melbourn Rock, a bed of hard chalk at the base of the Middle Chalk. In the north it spreads westwards across the Lower Chalk outcrop, and some small outlying patches cap hills on the Upper Greensand.

The gravel is composed predominantly of angular flints, with which occur minor quantities of Eocene flint pebbles, small ironstone pebbles presumably derived from Eocene beds, and occasional sarsen (fine-grained quartzite) boulders, of Eocene or later Tertiary age, in a quartz sand matrix. In places the gravel is chalky, particularly in its lower part, and the present-day condition of the deposit probably owes much to post-depositional decalcification. Both the chalk and the other materials that form the bulk of the gravel could have been derived from the Chalk and from Eocene and Drift deposits (mainly Clay-with-flints) capping the Chiltern Hills escarpment to the east. A few pebbles of cherty sandstone derived from the Upper Greensand to the north or northwest are present. Rare 'Bunter' quartzite pebbles are the only far-travelled constituents.

The deposit received brief mention from Prestwich (1892) and Shrubsole (1898), the later author drawing attention to evidence for decalcification. In the first comprehensive account of the deposit, Jukes-Browne & White (1908) classed it as Angular Flint Gravel, a subdivision of Plateau Gravel. They observed that the deposit appeared to spread out as fans extending from the steepest part of the Chalk scarp slope. Arkell (1945, 1947*a*) introduced the name Wallingford Fan Gravels. Although he recognized that the bulk of the deposit represented the decalcified residue of an originally chalky gravel, he still considered that the original chalk content must have been subordinate and that the principal source of the gravel had been the Clay-with-flints. He regarded the intense cryoturbation that affects the surface layers of the gravels as evidence of a solifluxion origin. The occurrence of unworn Acheulian flint implements, suggesting deposition during an interglacial period, led him later (1947*b*) to believe that the lower part of the deposits had originated as a river gravel. Wymer (1968) concurred with these opinions. He described the sections as showing lower and upper gravel divisions separated by a 'varved clay' unit deposited under still-water conditions. The evidence for dating provided by the implements is not conclusive (Roe 1968; Wymer 1968), but Wymer (1968), partly on the basis of its elevation, assigned deposition of the upper part of the gravel to the Gipping Glaciation, i.e. to the Wolstonian Stage as defined by Mitchell *et al.* (1973). In 1973–4, the Institute of Geological Sciences resurveyed the greater part of the Henley (254) Sheet on the 6 in scale. A new edition of the 1:50000 map, based on this resurvey, was published in 1980.

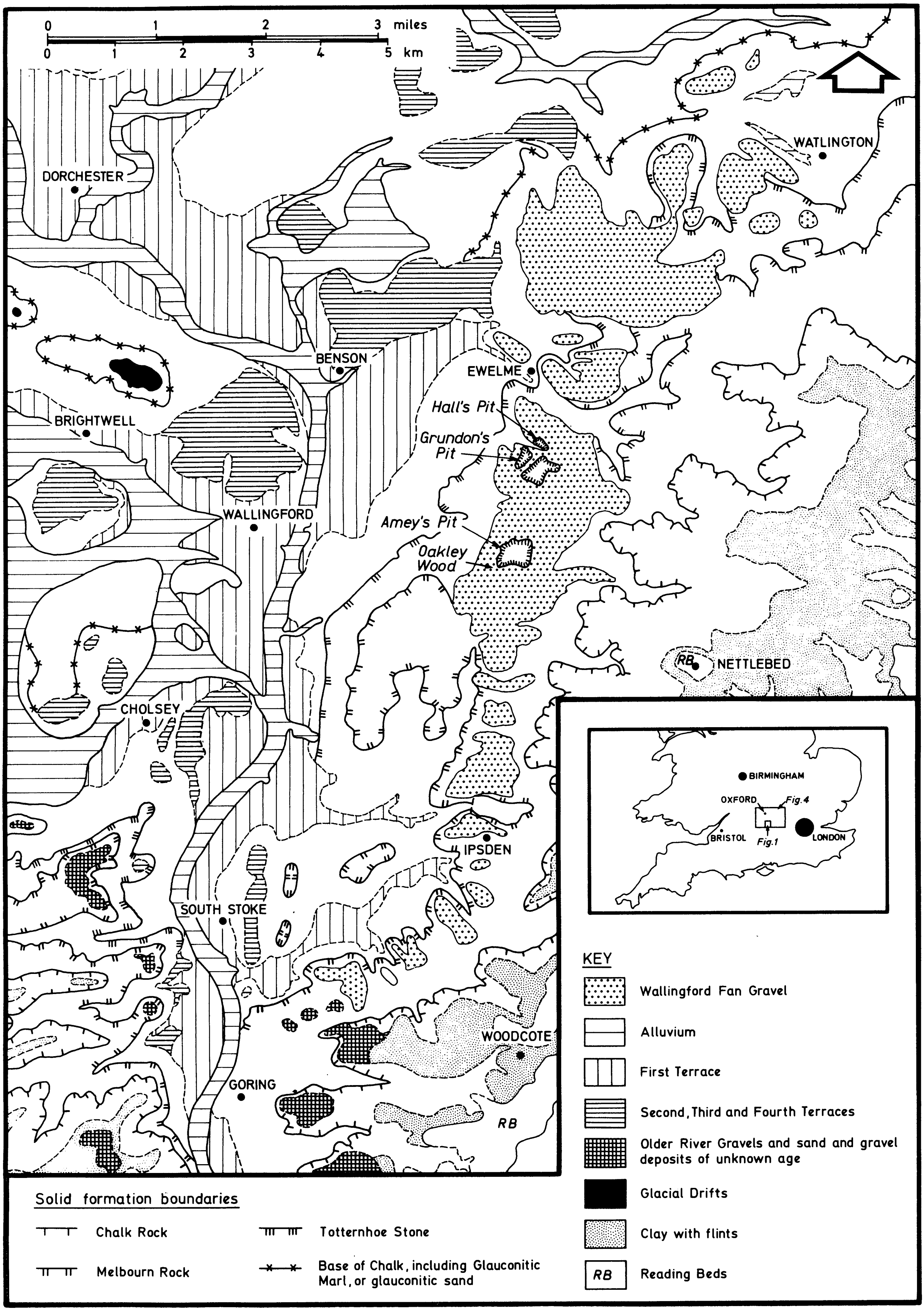

FIGURE 1. Geological sketch map of part of the Thames valley near Wallingford, to show the extent of occurrence of the Wallingford Fan Gravel and its relation to outcrops of geological formations and Drift deposits.

The mapping of the Fan Gravel area was the work of A. W. Kemp and S. R. Mills. B. C. Worssam and A. Horton recorded sections in the gravel and contributed many additional observations between 1973 and 1979, during the latter part of this period in conjunction with J. B. Whittow, who had independently kept the gravel workings under observation for a number of years. In 1977 a summary of the authors' conclusions to date was published in an excursion guide for the Tenth INQUA Congress, held at Birmingham (Horton & Whittow 1977).

The succession of solid strata in the area under discussion (figure 1) is as follows.

TERTIARY	Reading Beds (up to *ca.* 6 m)	grey and red clay
CRETACEOUS	Upper Chalk (65 to 75 m)	white chalk with flints Chalk Rock (1 to 1.5 m)
	Middle Chalk (60 to 65 m)	white chalk with flints in higher beds Melbourn Rock (*ca.* 3 m)
	Lower Chalk (40 to 80 m)	Actinocamax plenus Marls (2 m) grey marly chalk without flints; the Totternhoe Stone, hard grey chalk about 0.3 m thick, is 18 m below top Glauconitic Marl (0.5 to 2 m)
	Upper Greensand	grey fine-grained glauconitic sand and soft cherty sandstone

2. Stratigraphy

(*a*) *Introduction*

The deposits exposed in the three main workings, Hall's, Grundon's and Amey's pits, are summarized in table 1. Wymer's (1968) subdivision of the Fan Gravel into lower and upper gravels separated by a fine-grained deposit holds true only for the workings here designated Amey's 1973 pit and Hall's pit. A more complete sequence displayed in Grundon's pit included two fine-grained units. The higher of these is here defined as the Gould's Grove Member. In Hall's pit this unit occurred as a calcareous silt containing Mollusca and remains of small vertebrates, neither of which have previously been recorded from the Fan Gravel. They indicate a broadly mid-Pleistocene age for this part of the deposit. The southernmost part of Amey's pit, first recorded in 1976, showed a near-surface deposit of chalky gravel that appears to be of much later date than the bulk of the Fan Gravel. This pit and Amey's 1973 pit have together provided the principal evidence for extensive decalcification of the deposits. The gravels in all the pits show bedding disturbed by frost action or by subsidence resulting from solution of the underlying Chalk, or both.

(*b*) *Petrography*

Observations by one of us (J. B. W.) have shown that the detrital mineral content varies from one level to another in the Fan Gravel.

Samples of the sand that occurs as matrix to the flint gravels in the lowermost beds of the Fan Gravel of Amey's pit are generally of coarse-grained quartz sand with fairly common glauconite. Other minerals present are limonite, haematite, plagioclase, zircon, tourmaline, staurolite, rutile, garnet and kyanite. All of these could be of local origin. Sands at a higher level but below the median chalky or clayey sand seam are finer and less rounded. Glauconite is rarely present, possibly as a result of oxidation. Hornblende and brown epidote appear in the mineral suite and may indicate an extraneous source of supply.

A sample of sand from the median seam of Amey's pit was found to be very micaceous, with a mineral suite including epidote in addition to the minerals present in the underlying beds.

In the gravel above the median seam fresh angular flints are dominant but rare rounded discoloured pebbles of flint, vein quartz, Bunter quartzite and ironstone are also present. The heavy mineral suite is similar to that of the gravel below the sand.

Large boulders of sarsen stone (hard pale grey quartzite) up to 0.6 m diameter and two boulders of so-called Hertfordshire puddingstone (up to 0.3 m) have been collected from Amey's pit. The boulders generally occur in the basal part of the gravel associated with a layer of well rounded broken flints, though a few occur higher in the sequence.

Table 1. Sequences within the Wallingford Fan Gravel

(Numbers in parentheses give thicknesses in metres.)

	Amey's pit 1973	Amey's pit 1976	Grundon's pit	Hall's pit
Upper Pleistocene		superficial loam with flints ($\leqslant$ 0.5)		
		marl with chalk pebbles ($\leqslant$ 0.5)		
	absent	chalky gravel, part decalcified (*ca.* 2.0)	absent	absent
		unconformity		
Middle Pleistocene	non-chalky flint gravel ($\leqslant$ 4.5)	non-chalky flint gravel (seen for 4.5)	non-chalky flint gravel	non-chalky flint gravel ($\leqslant$ 4.0)
	Gould's Grove Member, decalcified ($\leqslant$ 1.0)	Gould's Grove Member, part decalcified (*ca.* 1.0)	Gould's Grove Member, part decalcified	Gould's Grove Member, part decalcified
	flint gravel, lower part chalky (*ca.* 2.0)	flint gravel, lower part chalky (> 3.0)	non-chalky flint gravel (*ca.* 2.0) clayey gravel chalk silt (1–2)	non-chalky flint gravel (seen for 2.5)
	absent	absent	greyish brown sand chalky gravel	not exposed
	mélange chalk	mélange chalk	mélange chalk	

(*c*) *Amey's pit*, 1973

In 1973 the best exposures at Amey's pit were provided by a rectangular working (640 891†), up to 15 m deep, with a face some 100 m long on its north side (figure 2, section AB). Excavation by means of a dragline had left the floor consisting of mounds and ridges, some of them steep-sided, rising as much as 5 m above adjacent hollows. In places, both in the hollows and on the crests of ridges, surfaces of hard white chalk with *Inoceramus*, from the basal part of the Middle Chalk, had been laid bare. The uneven floor of the pit appeared therefore to indicate a correspondingly uneven Fan Gravel–Chalk interface. The ridges and hollows showed no consistent orientation and it therefore seemed likely that the hollows were not erosional channels but had been caused by solution. Where not exposing Chalk, the floor of the pit was for the most part covered with a whitish gravel consisting of angular flints and chalk pebbles in a matrix of chalky sand. The bottom of the face exposed a few pinnacles of this chalky gravel, up to 1 m high, showing a sharp junction with the overlying orange-brown, ferruginous flint gravel that

† All grid references quoted lie within 100 km National Grid Square SU unless otherwise stated.

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formed the bulk of the deposits worked. The lower part of the face showed a discontinuous, broadly undulating seam of fine-grained sand with a clayey matrix (Wymer's 'varved clay'), up to 1 m thick. In the topmost 2 to 3 m of the face, vertically orientated flints and the faint outlines of large involutions indicated strong cryoturbation.

Particle-size analysis of the chalky gravel and the brown flint gravel (see appendix and figure 15) suggests that the latter is the residue after decalcification of the former. Decrease in volume of the gravel consequent upon the removal of its contained chalk by solution, if of the order of 30% as indicated by the laboratory analysis, would have lowered the surface of the gravel by as much as 5 m, and must inevitably have caused a certain amount of disturbance of bedding. Furthermore, cryoturbation of the gravel need not have been a depositional feature, as Arkell (1945) and Wymer (1968) assumed, but could have been imposed on originally even-bedded deposits. At the same time the surface form of the deposits may have been modified so that in their present state they represent an altiplanation terrace as described by Te Punga (1956). The attitude of the 'varved clay' seam in face AB, roughly parallel to the floor of the pit, indicates that the subsidence that gave an uneven base to the Fan Gravel took place after this seam was deposited but before the cryoturbation and altiplanation of the gravels. The subsidence was presumably into voids in the Chalk under the gravels, opened up by solution resulting from fissure-flow of groundwater through the Chalk, a different process from that which caused decalcification of the gravels (see later).

(*d*) *Amey's pit*, 1976

A new working was opened between 1973 and 1976, 400 m south of the 1973 section. Excavation by means of a mechanical shovel gave this pit a nearly level floor, and its faces therefore provided sections through Chalk and chalk-rich gravels that in the earlier pit would have been left unexcavated as ridges. Deposits similar to those of the earlier pit are overlain by 1 to 2 m of chalky flint gravel preserved in the cores of involutions at the top of the section. This chalky gravel shows incipient decalcification. The features displayed by the pit are, in ascending order, as follows.

(i) *Chalk*

The Chalk underlying the Fan Gravel was exposed in three trial pits 2 to 3 m deep, sunk during 1979 in the floor of the pit, at P, Q and R of figure 2 (inset map). Pit P showed hard white chalk with abundant *Inoceramus* fragments, pit Q, hard white fine-grained chalk with scattered subangular chalk nodules, and pit R, hard white chalk containing *Inoceramus*, but less abundantly than that in pit P. These rock types are characteristic of the lower part of the Middle Chalk, though whether the hard basal bed, the Melbourn Rock (see table of strata, p. 218), was reached, is uncertain. The chalk in these pits, and in the chalk pinnacles at the bottom of face CD (figure 2), consisted of a mélange of angular lumps of hard chalk with some rounded chalk pebbles and rare angular flints, set in a soft pasty chalk matrix. Its condition resembles that of mélange chalk, described by Higginbottom & Fookes (1971, pp. 93 *et seq.*, pl. 8*b*) as commonly forming a mantle on chalk outcrops of former periglacial zones, and caused by intensive freezing and thawing of chalk *in situ*. The flints in the mélange chalk of Amey's pit were presumably originally scattered over the ground surface and worked their way down while the chalk was undergoing frost-churning, for the lowest occurrence of flint nodules in undisturbed chalk is some 45 m or so stratigraphically above the base of the Middle Chalk.

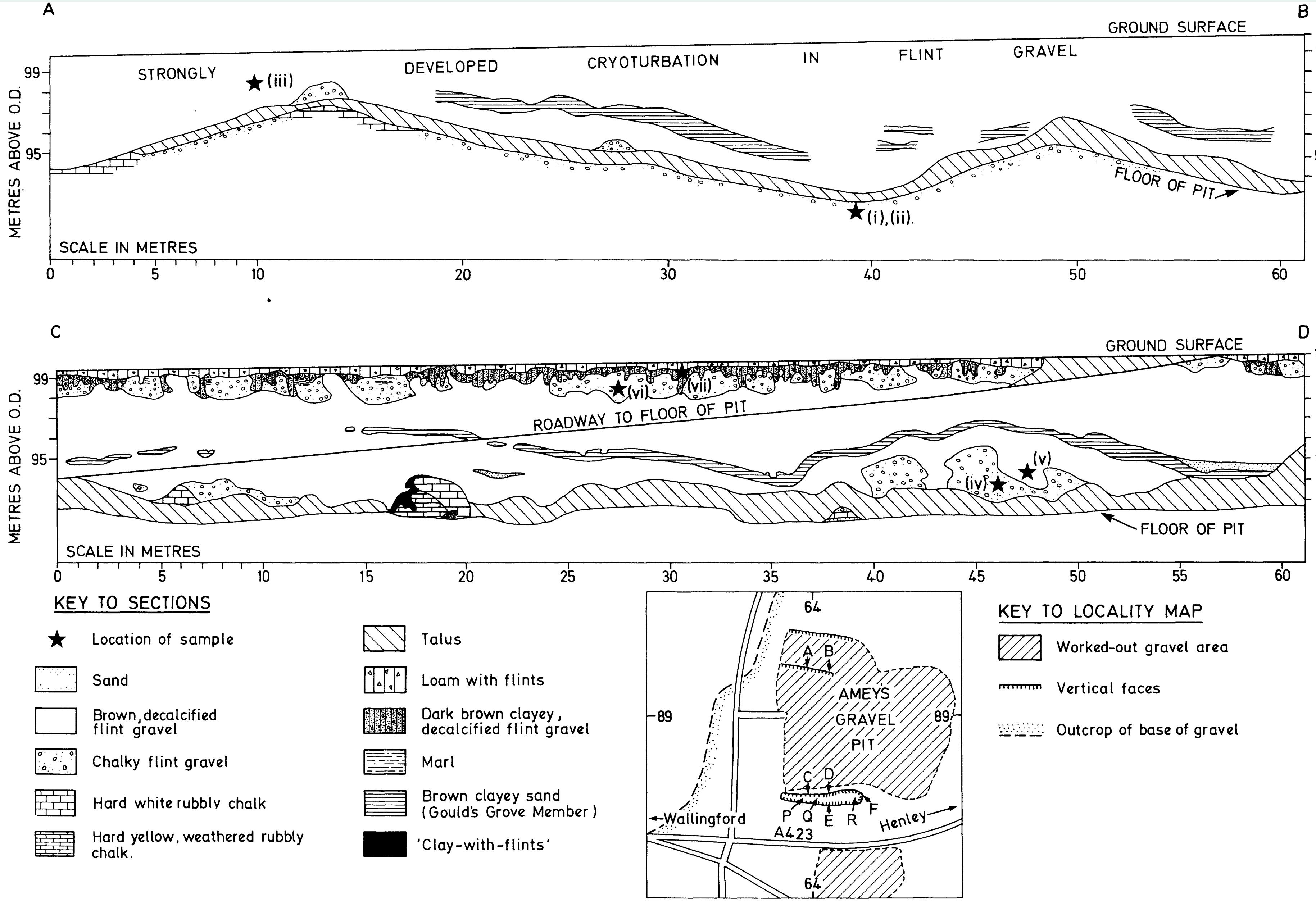

FIGURE 2. Exposures at Amey's pit in 1973 (face AB) and 1976 (face CD). Both sections are drawn at true scale, as one looks north. National Grid coordinates are shown on the margins of the inset locality maps. Numbers (i) to (vii) indicate positions of analysed samples (see **appendix 1**).

The surface of the chalk pinnacle between 15 and 20 m east of C in face CD (figure 2) was draped with a layer of dark brown or black clay which appears to be the product of decalcification (§5*b*).

The greatest thickness of mélange chalk to be seen was 5 m, at the eastern end of the pit, where a pinnacle reached to 2 m above the pit floor, and mélange chalk was seen to 3 m depth in pit R, nearby. At greater depths the mélange would be expected to pass down into closely jointed and then into massive chalk, but no evidence of this was seen.

(ii) *Fan Gravel, lower part*

Brown angular flint gravel into which rose pinnacles of chalky gravel formed the lower part of the Fan Gravel sequence. The chalky gravel varied in composition from place to place. Mostly it consisted of medium-sized chalk fragments and flints in roughly equal proportions, in a finely granular chalk matrix containing a variable amount of quartz sand. However, at 49 m east of C (figure 2), for instance, was a 'pea-gravel' composed predominantly of small chalk pebbles, with a few small angular flints, in a sandy matrix. At 41 m east of C occurred a breccia of subangular fragments of hard white chalk, evidently transported no great distance. Had this been seen underlying the more flinty chalk gravel, rather than occurring as a mass within it, it might have been regarded as *in situ* mélange chalk. Indeed, in some other exposures of material of this type the authors found room for debate as to its precise mode of origin. In most places, though (e.g. the exposure shown in figure 4 and located at F in figure 2), chalky flint gravel, above, could be distinguished from chalk rubble including sparsely scattered flints below, leading to the conclusion that the Fan Gravel is generally underlain by Chalk in a frost-shattered condition. The inclusion of patches of chalk breccia in the chalky flint gravels suggests that the frost-shattering preceded deposition of these gravels. The lack of bedding and the poor sorting of the gravels themselves are indicative of solifluxion.

Particle-size analysis was carried out on the basal chalky gravel (sample iv, figure 2) before and after decalcification in the laboratory, for comparison with yellowish-brown sandy gravel from nearby in the face (sample v). The results (figure 15*b*) indicate a similarity between the laboratory-decalcified and naturally occurring non-calcareous gravel comparable with, though less close than, that found in the 1973 samples (see appendix).

Occasional lenses of fine sand at higher levels in these lower gravels, but below the median clayey sand seam, may indicate the onset of fluviatile conditions of deposition.

(iii) *The Gould's Grove Member*

There is little doubt that the median fine-grained seam of face CD is the same as that exposed in face AB and represents Wymer's 'varved clay'; it is presumed to be equivalent to the sediments that include the fossiliferous bed of Hall's and Grundon's pits, to which the name Gould's Grove Member is applied (see below). In face CD this bed was wholly decalcified. However, an exposure (figure 3) on the south face of the pit (sited at E in figure 2 inset map) showed the lower part of the bed in its original state, as a white chalky sand with faintly defined bedding. It occurs beneath a decalcification 'front' above which the upper part had been converted into brown to grey clayey sand. Results of particle-size analysis of calcareous and decalcified parts of the bed (samples viii and ix) are shown in figure 15*d*. A sample of the calcareous sand from a small exposure in the middle of the pit yielded the molluscan fauna listed in § 3 of this paper.

The decalcified clayey sand bed in face CD showed hollows, apparently eroded as a result of cryoturbation, in its upper surface at 26 and 35 m east of C, while farther west, between 8 and 15 m from C, the bed thinned out altogether, possibly due to frost-churning having disseminated it throughout the cryoturbated gravel. Such a process might also explain the discontinuity of the clayey sand bed in face AB. Variations in the elevation of the bed in face CD probably result from subsidence following post-depositional solution of underlying chalky gravels and Chalk, as in face AB.

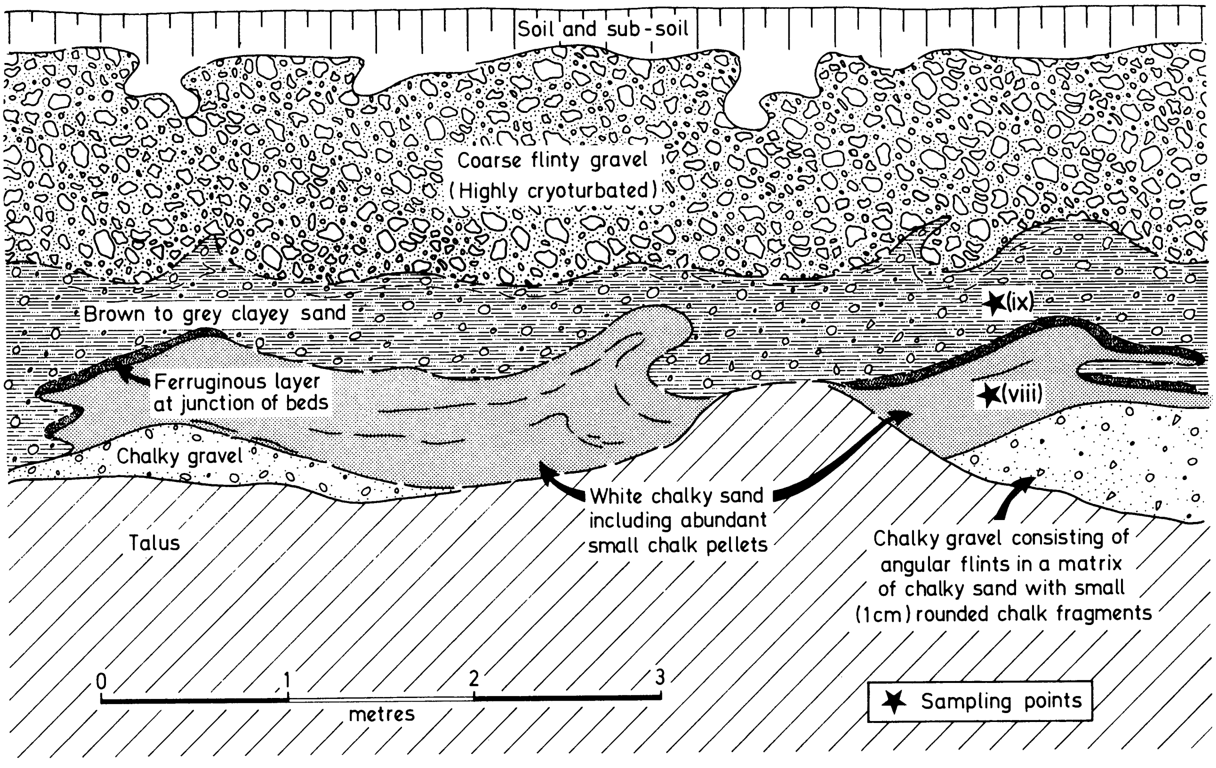

FIGURE 3. Exposure on the south face of Amey's pit, as one looks south, at point E (figure 2, inset map), showing median sand seam, Gould's Grove Member, of the Wallingford Fan Gravel. Numbers (viii) and (ix) indicate positions of analysed samples (see appendix 1).

(iv) *Brown flint gravels above the Gould's Grove Member*

Face CD exposed up to 4.5 m of non-calcareous brown flint gravel above the clayey sand seam, in a strongly cryoturbated condition with no original bedding structures preserved. More pronounced subsidence than in CD is indicated by faces (figures 4, 5, at F on figure 2 inset map) in the eastern part of Amey's 1976 working. In figure 5 the contorted pale brown clay with seams of clay and sand to the left of the central pipe-like structure, and the pale brown clayey silt to its right, represent the median fine-grained bed of face CD. They are overlain by reddish brown non-calcareous flint gravel, which in turn is succeeded by sandy flint gravel and olive-grey silty sand, occupying the core of the pipe, which seems to be a member of the Fan Gravel succession not recognized elsewhere (but see §2*g*). It is suggested in the discussion of face AB (above) that the surface of the gravel spread has been levelled by cryoplanation. The presence of the sand deposit in this pipe suggests the possibility that cryoplanation may not merely have levelled off an uneven surface but in doing so may have swept away whole units of the deposits, amounting to several metres in original vertical thickness.

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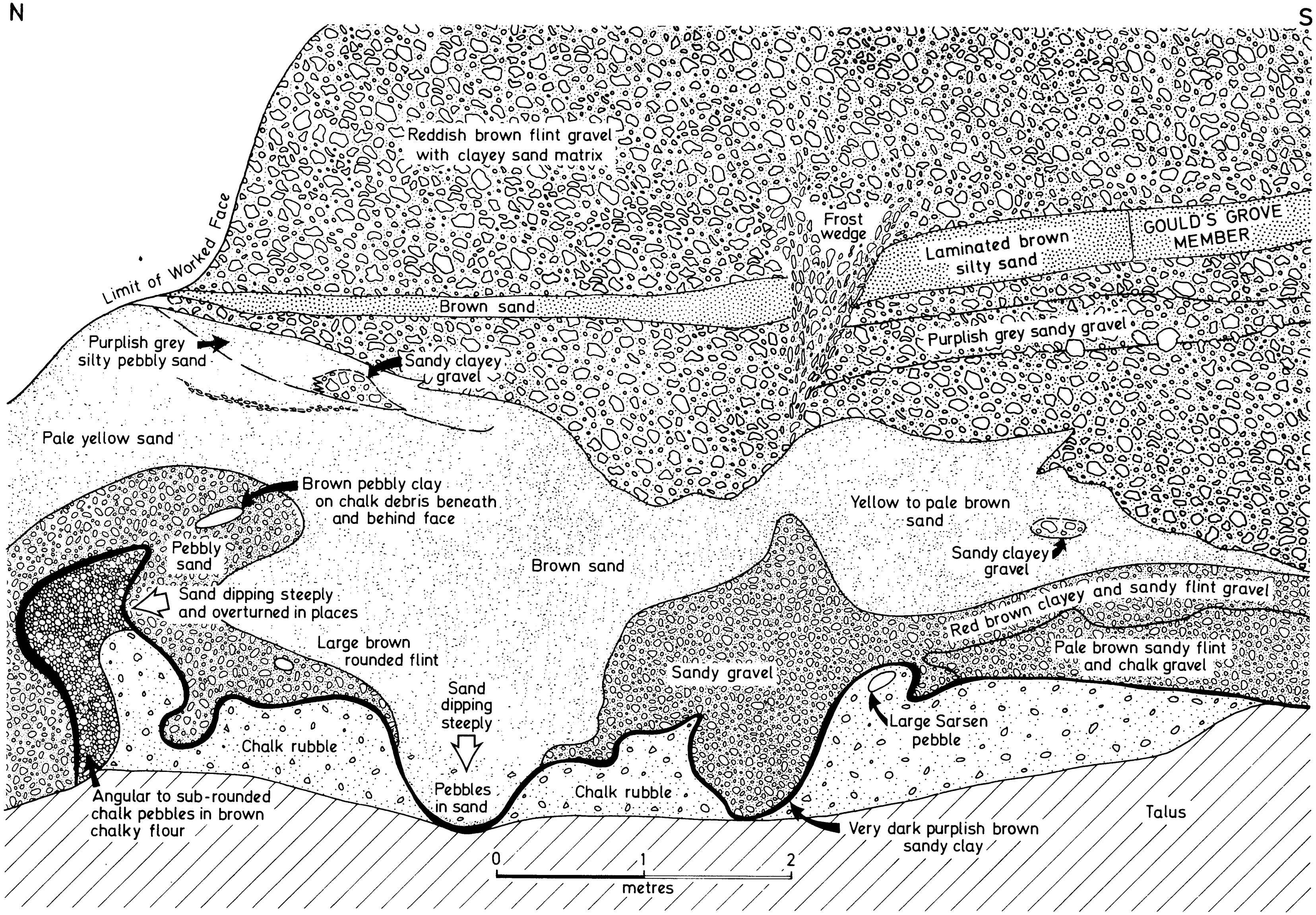

FIGURE 4. Exposure F[1] on the east face of Amey's pit, as one looks east at point F (figure 2, inset map).

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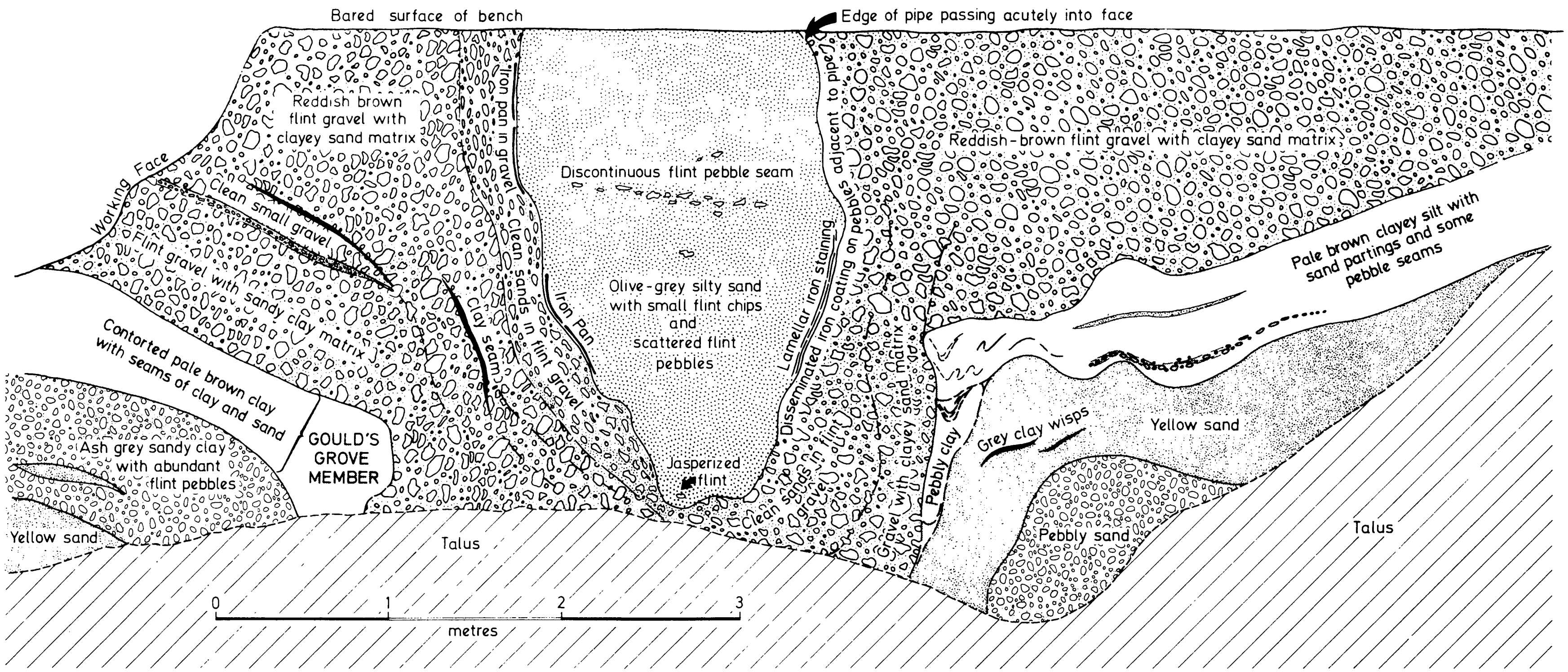

FIGURE 5. Exposure F[1] within Amey's pit, 3 m west of eastern working face at point F (figure 2, inset map).

(v) *The topmost chalky gravel*

This gravel is preserved in pockets that result from a phase of cryoturbation subsequent to its deposition. It was best displayed in face CD, but relics of it were also seen to a depth of about 1.5 m below ground surface on the southern face of the pit (EF). A plane tangential to the bottoms of pockets is nearly parallel to the present ground surface, while truncating the subsidence structures shown by the underlying gravel. This suggests that the present ground surface approximates to the palaeoslope on which the white chalky gravels were laid down.

A solifluxion origin for the gravel is suggested by its grading (figure 15*c*). The flints in sample (vi) show sharper edges than those in sample (iv), while many retain some of the cortex of the original flint nodules. In the cores of some of the larger pockets (e.g. at 15 m east of C) occurs greyish-white marl with chalk pebbles, which may originally have been an alluvial deposit, some 0.5 m thick. The residue of a washed sample proved to be much coarser than that of the fossiliferous silt in the Gould's Grove Member; it included white-patinated angular flint chips up to 1 cm in diameter and much quartz sand. It contained no fauna.

This deposit could have been spread over the underlying gravels at a period long subsequent to their cryoplanation and decalcification, and after they had been trimmed back by erosion to form a terrace. Eastward of Amey's pit the present gravel surface abuts a gently rising chalk slope that farther east steepens into the main Chiltern scarp, where the solifluxion material could have originated. However, the topmost chalky gravel is much older than the late-Devensian Coombe Deposits which floor the valleys incised up to 20 m through the Wallingford Fan Gravel. It is tentatively assigned to an early Devensian cold phase of deposition, although it is possible that it could have formed in a cold phase of post-Hoxnian but pre-Devensian date.

Decalcification of the topmost chalky gravel has proceeded to only a limited extent compared with that affecting the underlying gravels, and the product of decalcification differs in that the flints have a dark brown clayey coating rather than the clean-washed slightly ochreous appearance of those in the older gravels. The colour of the younger decalcified product is in general darker and more reddish brown than that of the older gravels, which may result in part from differences in mineralogy of the deposits and in part from different climatic conditions during the decalcification process (see below).

(vi) *Superficial loam with flints*

The highest deposit exposed in Amey's pit is a yellowish brown loam with scattered angular flints. It is up to 0.5 m thick, and descends into the underlying dark brown decalcified gravel in pockets (figure 2). A surface deposit of this type occurs on the dip slope of the North Downs (Worssam 1963, p. 103) and is common on the dip slope of the Chilterns, and may incorporate wind-blown material (Loveday 1962, p. 93; Catt 1977).

(*e*) *Hall's pit*

In 1976 the floor of Hall's pit (647 905) showed a much greater unevenness than did the pits to the south. The ground surface in the vicinity of the pit lies at about 110 m above O.D. while gravel was being dug to a depth of 11 m. Solid rock was not exposed *in situ* in the floor of the pit but debris of hard chalk on the spoil heaps suggested that the Fan Gravel rests on the basal part of the Middle Chalk. A tripartite sequence could be established through most of this pit, the topmost chalky gravel of Amey's pit being absent. The upper and lower units consist predominantly of coarse gravels while the middle unit varies rapidly in lithology and in thickness (1–3 m). It comprises calcareous silt, bedded clays, silts and sand, which may be interlaminated, and coarser sands and gravels. The term Gould's Grove Member is proposed for this unit. Lenses of sand are developed in the gravels above and below and it is in places difficult to define the upper and lower limits of the Member. Further, because of the lateral variability of the sediments and their various states of decalcification no single sequence can be designated as a type section.

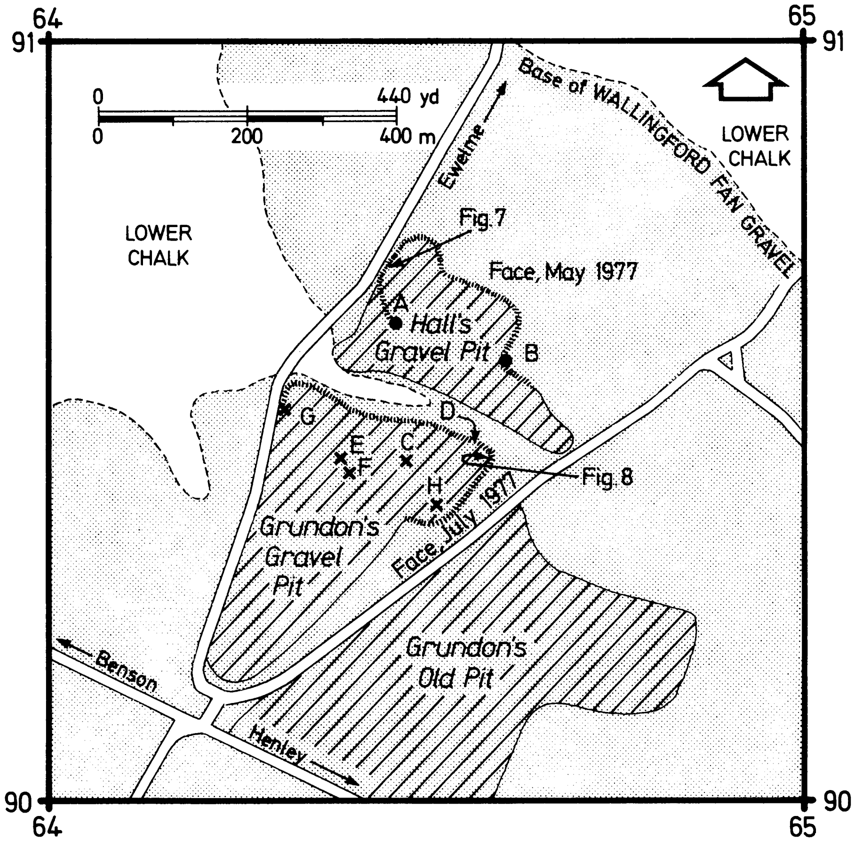

FIGURE 6. Location diagram; Hall's and Grundon's pits.

The most important exposure in the pit was on the west face (6445 9070) (figure 6), where the Gould's Grove Member shows an exceptional thickness (up to 2.3 m) of calcareous silt, probably representing the infill of a channel (figure 7). The lowest unit of the Fan Gravel exposed here consists of ochreous flint gravels overlain by up to 0.3 m of grey sandy and clayey gravel. The basal part of the succeeding Gould's Grove Member comprises up to 0.3 m of medium grey calcareous silt, with much sand and scattered pebbles, and many large crushed gastropods. It is immediately overlain by 0.05 m of brown organic clay, with rare plant fragments, which is probably a soil horizon. The remainder of the member completely fills the channel and consists of pale grey slightly fossiliferous silt, which is weakly stratified, but contains lenses of reddish clayey sand and reddish brown clayey sandy flint gravel and also has small

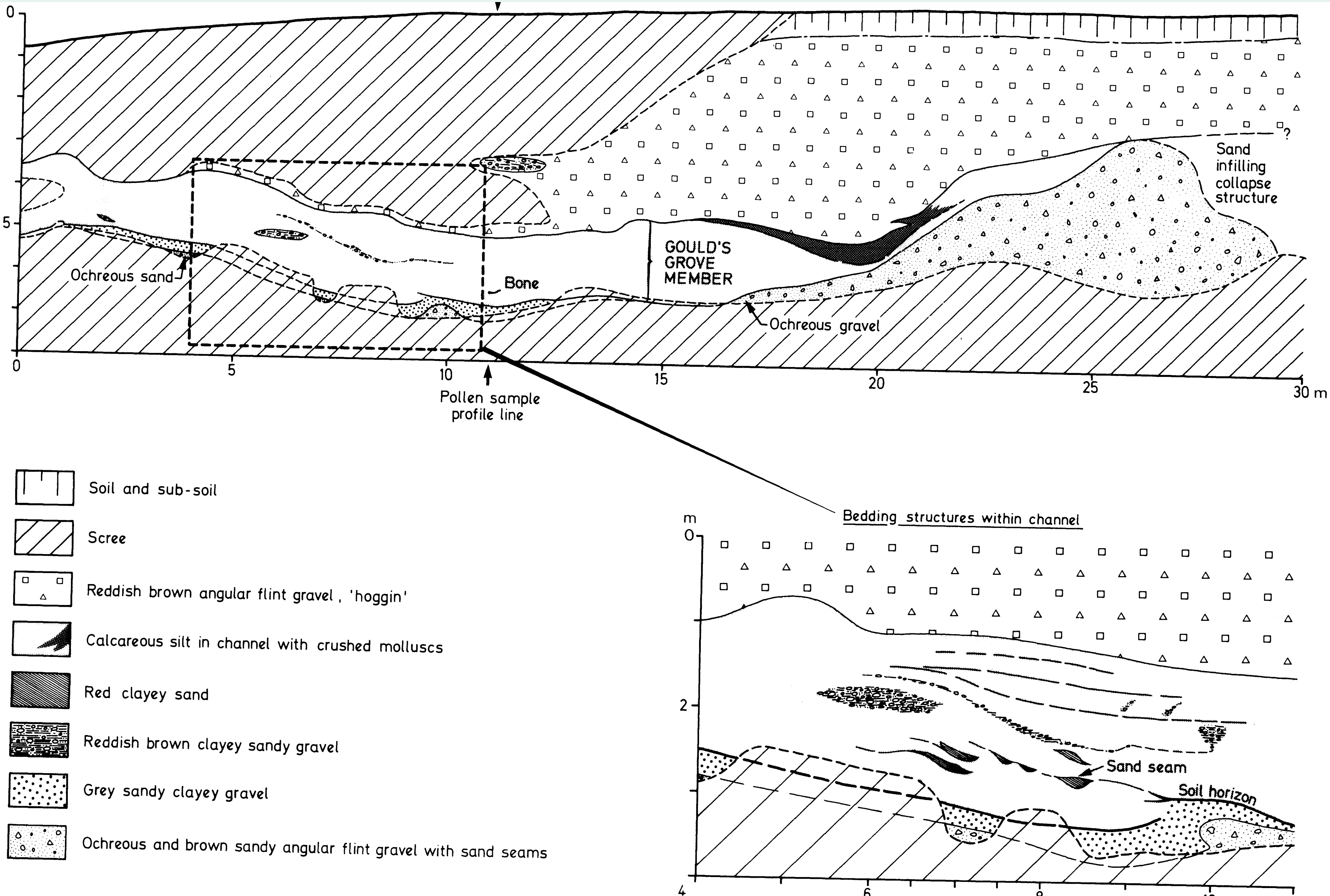

FIGURE 7. Section on the west face of Hall's pit, exposing the Gould's Grove Member.

flint pebbles scattered throughout. Laterally, the calcareous silt is replaced by darker silts, greyish brown silty clays and sands, part of the variation resulting from slight decalcification. The member is overlain by reddish brown angular flint gravel.

The chalk silt facies of the Gould's Grove Member could be traced spasmodically 100 m eastwards into older workings. The sequence on the south face of the pit (figure 6, A), some 50 m from the first section, was as follows.

	thickness m
reddish brown flint gravel, poorly sorted, very coarse angular fragments in a sandy clay matrix with indefinite sand bands; abrupt base	2–4
Gould's Grove Member: sand, pale yellowish grey, well sorted, lenticular; passing into purplish to lilac-tinted grey silt and clay with pockets of well bedded calcareous silt with undulating lamination	0.5–1.5
sand, pale greenish grey, well sorted, with lenses of sandy gravel	0.5–1.5
reddish brown coarse angular flint gravel with a clean sand matrix and beds of sand	seen 2.5

In places the Gould's Grove Member was poorly developed and it may be absent locally; for example on the eastern face (figure 6, B) where the Fan Gravel comprised at least 8 m of completely decalcified and oxidized flint gravel. Frost-wedge structures occur throughout the Hall's pit, being common in the upper part of the sequence but also occurring at the level of the Gould's Grove Member and within the underlying gravels.

(*f*) *Grundon's pit*

In 1976 gravel was being exploited from a northwest trending face (645 904), above which the ground surface stood at an elevation of about 106 m above O.D. The pit was worked to a maximum depth of 10 m and, as in the other pits being worked by dragline, the floor was extremely irregular, due to selective extraction of flint gravel, leaving a hummocky surface composed of chalk gravel, chalk silt, clay and clayey gravel. No unequivocal exposures of *in situ* Chalk were seen but the presence of angular fragments of hard white chalk and of marly chalk suggests that the base of the Middle Chalk lies close to the lower limit of excavation, and confirms the mapping by A. W. Kemp (6 in Geological Map SU 69SW), which shows the pit as partly above Lower Chalk.

(i) *Fan Gravel, lower part*

The oldest bed of the Fan Gravel exposed forms the core of a steep-sided diapiric structure shown in figure 8 and further discussed in § 5. It consists of chalk gravel, with rounded chalk pebbles, angular flints and much less common rounded flint pebbles, set in a matrix of chalky sand with ill defined seams of well sorted sand. Stratigraphically above this comes 1 m or so of slightly clayey greyish brown sand with darker bands marking original bedding features, and then 1–2 m of pale grey chalk silt and clay with rare small flint pebbles and indefinite lamination. The latter resembles lithologies within the Gould's Grove Member. A sample yielded on sieving indeterminate gastropod fragments. To the north of the pinnacle this was followed in upward succession by a bed of greenish grey pebbly sandy clay which passes laterally into very clayey gravel. This bed was succeeded in turn by some 2 m of pale grey to brown coarse angular flint gravel with very small well rounded pebbles of vein quartz, lydite and silty ironstone. The gravel contains pockets of sand and sandy patches but elsewhere is matrix-free. It is succeeded by very ferruginous flint gravel with secondary iron oxides occurring as pebble coatings and as distinct iron-pan bands cementing the gravel, which is overlain by pale brown and greyish brown flint gravel, and then by the Gould's Grove Member. The sequence on the south side of the pinnacle differs, the chalk silt being succeeded by a brown ferruginous gravel which becomes ash grey in places and is succeeded in turn by the Gould's Grove Member.

A roadway excavated into the floor of the pit (figure 6 C), in April 1977, revealed beds in the lower part of the Fan Gravel. It was not possible to establish a sequential relationship between the scattered shallow exposures but these showed poorly sorted chalk and angular flint gravels in close proximity to well sorted chalk gravel with clearly defined cross stratification. Elsewhere leached flint gravel was present.

In July 1977 a face at H in figure 6 showed up to 3 m of unbedded sandy chalk-free flint gravel, pale yellowish grey except for its top 0.5 m, which was ash grey, and overlain with a sharp junction by dark grey decalcified sandy clay, seen for 1 m and taken as the lower part of the Gould's Grove Member. The gravel yielded a worn fragment of an Upper Greensand sponge. Above the face, on a surface cleared in readiness for excavation, was a layer of yellowish grey sandy gravel similar to that exposed in the face and which appeared to have been dumped temporarily during the course of quarrying operations. The rain-washed surface of the layer revealed, as well as worn Upper Greensand sponge fragments, numerous small angular fragments of bone and antler. If one assumes that the gravel had in fact been excavated from the face beneath, these bone fragments are taken as an indication that the gravel was chalk-free when originally deposited, for they would not be expected to survive decalcification. The gravel may have been a channel deposit of a stream that was flowing swiftly enough for any chalk detritus that reached it to be comminuted and carried away as part of the suspension load. The absence of this type of gravel at Amey's pit perhaps arises from that pit being sited closer to the upslope margin of deposition of the Fan Gravels (see figure 1).

(ii) *Gould's Grove Member*

As in Hall's pit, the Gould's Grove Member exhibits rapid lateral changes in lithology. Decalcification and post-depositional disturbances make thickness comparisons meaningless. At the site of the pinnacle shown in figure 8, the Gould's Grove Member comprises a variable, decalcified, sequence of sands and clays. On the south side of the pinnacle it appears to be disconformable on the underlying sediments but the relationship is less clear to the north. The Member is absent over the pinnacle, where flint gravel, which forms the highest division of the Fan Gravel, rests upon the sediments in the core of the structure. The feature has the appearance of a diapir thrust up through the older Fan Gravel deposits, its movement ceasing before deposition of the gravels that overlie the Gould's Grove Member. Subsequent excavation revealed the core of the structure to be elongated NE–SW for at least 10–20 m.

On the northeast face of the quarry (figure 6 D), only 30 m from the diapir, a lenticular bed of ash-grey gravel or pebbly sand occurs at the base of the Gould's Grove Member and truncates wedge-like structures of ash-grey gravel which appear to be indistinctly cryoturbated downward into the underlying reddish brown flint gravel which forms the bulk of the lower part of the Fan Gravel. The basal bed of the Gould's Grove Member is succeeded by a lens of reddish brown clayey to sandy gravel. All these beds are overlain non-sequentially by a persistent reddish brown sand, which is silty in places and contains seams of small pebbles. A short

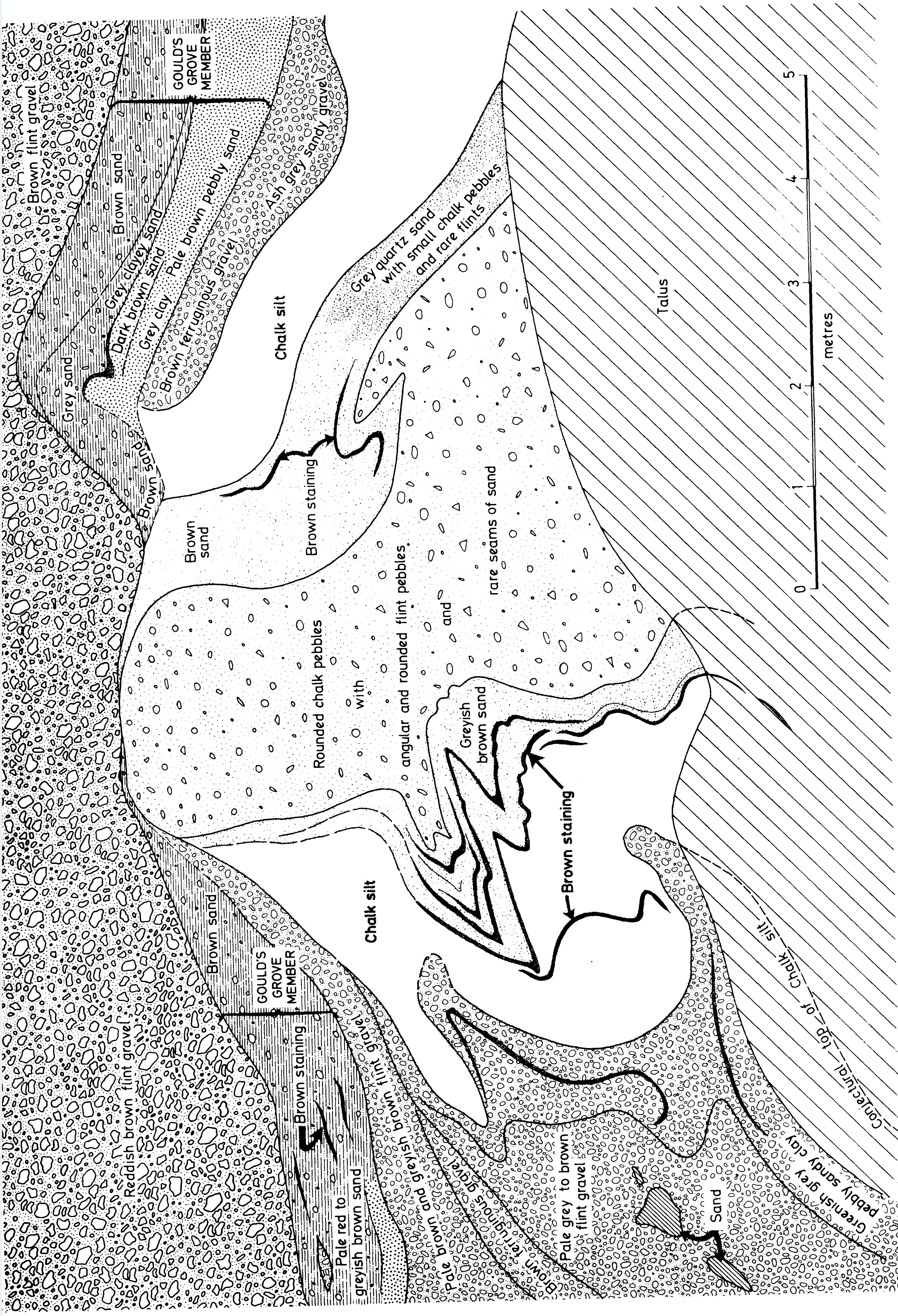

FIGURE 8. Section in Grundon's pit, showing an anticlinal structure in chalky gravel.

distance to the south a second seam of ash-grey gravel is developed within the oxidized lower beds of the Fan Gravel. Here the Gould's Grove Member consists of dark brown, humic, sandy gravel which is overlain by clean brown sand with clay seams, pale greyish clay with thin sand partings, and, at the top, a bed of indefinitely bedded sand.

The following sequence of decalcified beds was recorded on a disused face (figure 6, E) 120 m to the southeast of the above section.

	thickness m
coarse flint gravel	*ca.* 2.5
Gould's Grove Member	
sand, brown and clayey with dark mineral staining	*ca.* 0.1
grey sandy pebbly clay with interbedded pale brown sand with scattered pebbles and coarse sand wisps	0.1
brown sand with darker iron staining	1.22
pale brown to olive-grey soft clay with median dark, humic clay seam; the presence of reddish brown mottling and small ferruginous nodules may be a result of contemporaneous gleying	0.64
grey coarse clean sand	0.03
structureless ash-grey pebbly and clayey sand passing down into reddish brown ferruginous flint gravel with rare vein quartz pebbles	seen 1.5

The thickest and most complex sequence within the Member was exposed at the southwestern extremity (figure 6, F) of the working face in August 1976. The beds showed rapid lateral variations in thickness and lithology and were partly decalcified. The composite sequence was as follows.

	thickness m
reddish brown flint gravel	seen 2
Gould's Grove Member	1.78–1.95 (maximum)
brown sandy clay with scattered pebbles; becoming increasingly grey and more calcareous downward and passing into pale grey calcareous sand which is laterally replaced by very dark grey silty and silty clay resting upon, and partly enclosing, pods and lenses of chalk silt, up to 0.45 m thick, with rare small pebbles and molluscan remains; indefinite boundaries, the uppermost junction being most uneven; pods are generally isolated from each other and represent unleached residuals of once more extensive bed	up to 1.50
gravel with large pebbles in greyish brown clayey matrix; passing laterally into pale grey clayey sand with few pebbles	up to 1.22
dark brown humic sand with up to 30% organic carbon content (I.G.S. laboratory analysis)	0.23–0.30
clean grey sand	0.03–0.13
mottled grey sand with pebbles	0.30
reddish brown flint gravel with angular and rounded pebbles	seen 2+

Lenses of calcareous silt and clay, representing unleached portions of the Gould's Grove Member, have been recorded in various parts of Grundon's pit. An isolated face within the quarry (figure 6, F) showed 2.2 m of gravel overlain by the Gould's Grove Member (0.6–1.5 m) comprising yellow pebbly sand with brown sand seams and lenses of reddish grey pebbly sand succeeded by lilac-grey silty clay, brown sand and, at the top, a pocket of chalk silt which appeared to be laterally equivalent to reddish brown sandy clay. Here the beds are caught up into an intense feature, possibly a frost wedge or part of a larger structure (figure 9). At the northeasterly extremity of the quarry (figure 6, G) the Gould's Grove Member consists almost entirely of chalk silt, some 1.8 m thick, with rare shell remains.

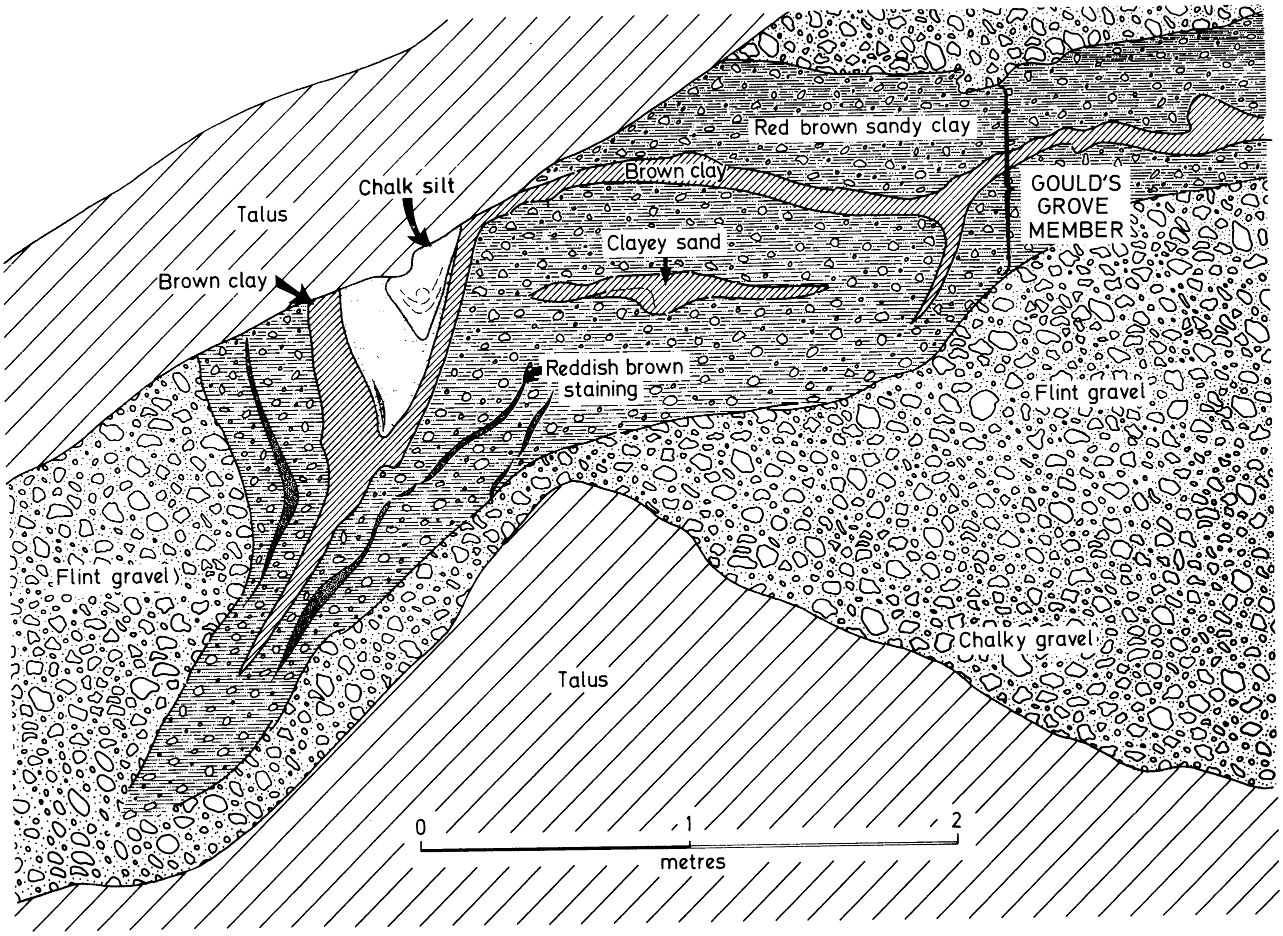

Figure 9. Section in Grundon's pit, showing a possible frost wedge affecting the Gould's Grove Member.

(iii) *Gravels above the Gould's Grove Member*

As in Hall's pit, the Gould's Grove Member is absent locally; where this is so, a continuous gravel sequence extends upward from the floor of the pit. The gravels above the Member may be up to 3 m thick, and with one exception, where they were overlain by a pocket of chalky gravel, a possible remnant of the topmost chalky gravel of the Amey's pit sequence, they are entirely decalcified. At one point a block of chalk, about 1 m in diameter, was seen to underlie the upper gravels (figure 10). It rested on the Gould's Grove Member, here comprising a lens of yellowish green to buff chalk silt or sand with scattered small pebbles which in turn lay non-sequentially upon a lens of pebbly sand with black secondary staining and on brown sand with clay partings. Up to 0.1 m of dark purplish grey clay (Clay-with-flints *sensu stricto*) overlay the chalk block and infilled fine cracks within it, thus suggesting that the mass had undergone partial solution since deposition. It is difficult to ascribe the transport of this mass to normal

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fluviatile processes. The simplest mechanism would be transportation of a frozen mass of chalk by ice flotation under periglacial conditions, into a lake or mere floored by chalk silt.

(g) *Summary of stratigraphy*

The Gould's Grove Member can be traced throughout Hall's and Grundon's pits. In Grundon's pit a second seam of chalky silt occurs near the base of the Wallingford Fan Gravel. Both seams contain molluscan remains. The chalky sand in Amey's pit also contains molluscan remains, but its continuity throughout the large area of the exposed Amey's workings favours

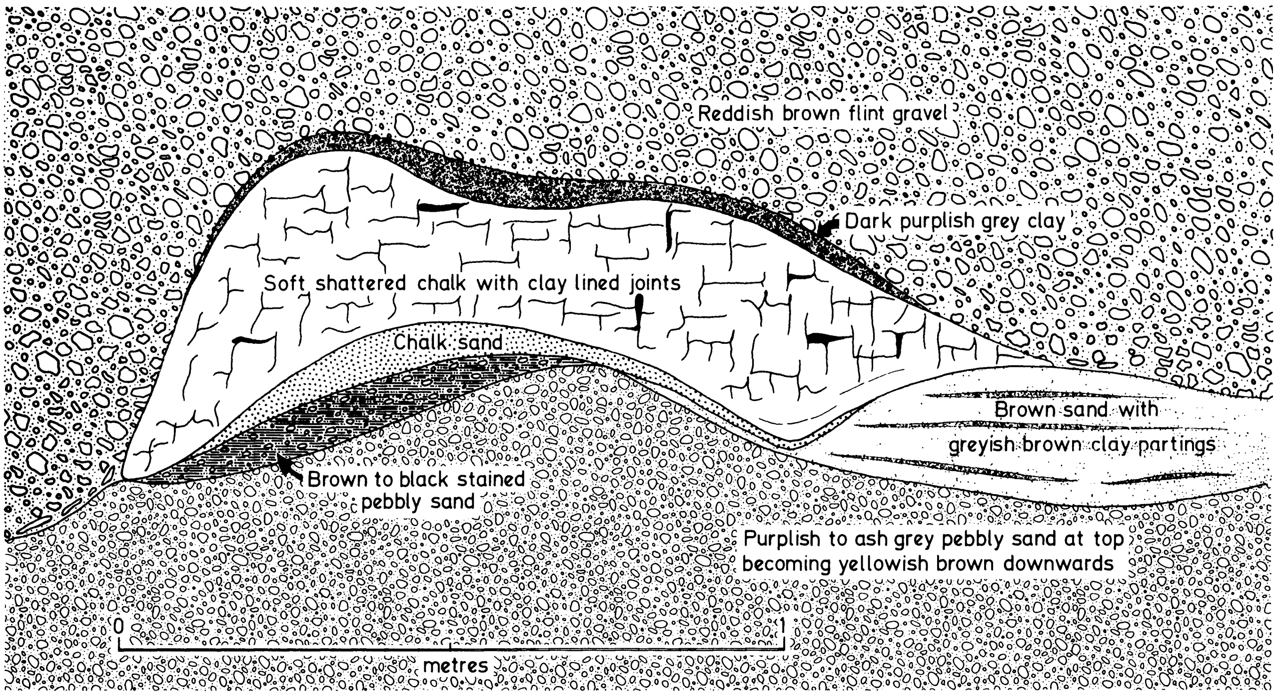

FIGURE 10. Section in Grundon's pit, showing a transported block of chalk resting on sand of the Gould's Grove Member.

its correlation with the persistent Gould's Grove Member rather than with the lower seam of Grundon's pit. This equation is adopted in table 1 and implies that the lower chalk silt of Grundon's pit was not deposited in Amey's pit. There are at least two other possibilities, though these are not favoured by the authors. The first is that the Amey's pit chalky sand seam is equivalent to the lower seam in Grundon's pit, and the Gould's Grove Member is either not represented in Amey's pit, or is represented by the olive-grey silty sand in the pipe illustrated in figure 5. This latter case would imply removal of the bed over the whole Amey's pit area during the cryoplanation that followed deposition of the bulk of the gravels. Alternatively the chalky sand of Amey's pit may be at a horizon different from either of the Grundon's pit horizons.

3. FAUNA AND FLORA

Indeterminate molluscan remains were collected from the chalk silt that occurs near the base of the Wallingford Fan Gravel in Grundon's pit (§ 2*f*(i)). Complete fossils have been found in the Gould's Grove Member in all three of the pits where the formation is currently being worked (table 2). The richest fauna was obtained from the calcareous silt of the exposure in Hall's pit illustrated in figure 7 and designated 'main channel' in table 2. For sampling purposes this bed was arbitrarily divided into three units of almost equal thickness, in upward sequence, A, B and C. The sediment was air-dried and then wet-sieved through 30 and 60 mesh (500 and

Table 2. Non-marine Mollusca from the Gould's Grove Member and the Compton Gap gravels

	Hall's pit						
	main channel			second outcrop 30 m east additional species recorded	Grundon's pit	Amey's pit	Compton Gap gravels (Prestwich 1892)
	top bed (C)	middle bed (B)	bottom bed (A)				
freshwater species							
Valvata cristata Müller	—	—	93	—	—	—	—
Valvata piscinalis (Müller)	—	—	177	—	2	—	—
Bithynia tentaculata (Linné)	—	—	2	—	1	—	—
B. tentaculata (opercula)	—	—	21	—	—	—	—
Lymnaea truncatula (Müller)	1	—	17	—	3	present	3
L. palustris (Müller)	—	—	5	—	1	—	—
L. stagnalis (Linné)	—	—	49	—	—	—	—
L. peregra (Müller)	—	—	3	—	—	—	—
Planorbis cf. *planorbis* (Linné)	—	—	7	—	1	—	—
Anisus leucostoma (Millet)	—	—	22	—	—	—	—
A. vortex (Linné)	—	—	1	—	—	—	—
Gyraulus laevis (Alder)	1	—	3	—	1	—	1
Armiger crista (Linné)	—	—	37	—	1	—	—
Hippeutis complanatus (Linné)	—	—	1	—	—	—	—
Sphaerium corneum (Linné)	—	—	fs.	—	—	—	—
Pisidium obtusale lapponicum Clessin	—	—	6	—	—	—	—
P. subtruncatum Malm	—	—	—	present	—	—	—
P. nitidum Jenyns	—	—	—	present	—	—	—
land species							
Oxyloma pfeifferi (Rossmässler)	57	—	15	-	140	present	—
Columella columella (Martens)	1	—	—	—	1	—	—
Pupilla muscorum (Linné)	6	15	—	—	49	—	226
Vallonia costata (Müller)	—	3	1	—	—	present	—
V. pulchella (Müller)	—	—	—	—	3	—	.
V. excentrica Sterki	5	10	—	—	2	—	—
V. pulchella/excentrica	1	7	—	—	6	—	-
Nesovitrea hammonis (Ström)	—	—	1	—	1	—	—
Deroceras sp.	—	—	3	—	—	—	1
Euconulus fulvus (Müller)	—	—	—	—	6	—	—
Trichia hispida (Linné)	30	1	5	—	107	present	53
Arianta arbustorum (Linné)	fragment	1	—			—	—

250 μm) sieves before sorting. The extracted faunas were examined by M. P. Kerney, who has determined the species shown in table 2. Additional samples collected from a second outcrop 30 m east of the main sample point yielded species of *Pisidium* (table 2). A sample from the top of a calcareous silt in the Gould's Grove Member of Grundon's pit yielded a varied fauna while a comparable horizon in Amey's pit contained only the most abundant species (table 2).

Kerney reports that the Mollusca of division A indicate the existence of a lake, a large body of well vegetated calcareous water, while those of division B and C are almost exclusively terrestrial and indicate an open treeless grassland environment. The shells are fragile and it is probable that the faunas are indigenous, although the terrestrial forms may have been transported a very short distance into the lake. The molluscan faunas suggest cool climatic conditions. The characteristic glacial indicators are *Gyraulus laevis*, *Pisisium obtusale lapponicum* and *Columella columella*. The latter two species are arctic-alpine forms, now extinct in Britain. Nevertheless the richness of the freshwater fauna and the presence of a number of relatively southern forms indicates that the climate was not of full glacial severity.

Remains of small vertebrates and fish were found in association with the Mollusca in the washed residues of the chalk silt in the Hall's pit. A. Stuart has determined the fauna (table 3).

Table 3. Vertebrate fauna from the Gould's Grove Member in Hall's pit

	taxon	material	bed
Pisces	*Esox lucius* L., pike	2 teeth	C
Amphibia	*Rana* sp. or *Bufo* sp., frog or toad	fragments	
Mammalia			
Rodentia	*Microtus gregalis* (Pallas), tundra vole	mandible with $M_{1,2}$	A
	Arvicola cantiana (Hinton), extinct water vole	M_3, I_1	C
	Lemmus lemmus (L.), Norway lemming	M_3	bulk 30 m east
Perissodactyla	*Equus* sp., horse	proximal phalanx	

The sediments in the main channel contained, in division A, *Microtus gregalis* (Pallas) and, in division C, *Esox lucius* Linnaeus, *Rana* sp. or *Bufo* sp. and *Arvicola cantiana* (Hinton). The bone found *in situ* (figure 7) was a phalanx of *Equus* sp. A sample from the second site 30 m to the east yielded *Lemmus lemmus* (Linnaeus).

The poorly preserved bone fragments from Grundon's pit, from a probable horizon below the Gould's Grove Member, have been seen by A. J. Sutcliffe, who reports that they include indeterminate fragments of small artiodactyl, probably a deer or a pig, associated with a single fragment of an antler. The only organic remains previously recorded from the Wallingford Fan Gravel are a mammoth tooth found 'near Britwell House' (*ca.* 668 924), an antler of *Rangifer elaphus* (*Cervus elaphus* Linnaeus) near Blenheim Farm (*ca.* 638 883) (Prestwich 1892), and a rolled fragment of *Mammuthus* (*Elaphas*) tooth in Rumbold's pit (*ca.* 646 927) (Arkell 1945, p. 2).

Stuart reports that although the vertebrate material from Hall's pit is very limited it clearly represents a cold stage. *Microtus gregalis* is nowadays confined to northern Siberia and Alaska, while *Lemmus lemmus*, or a closely related species, occurs from northernmost taiga areas of Siberia to the corresponding regions of North America. The other vertebrates are indicative of an open environment with streams and lakes.

The association of *M. gregalis* with *Arvicola cantiana* is unusual. The former has not been found before the last (Devensian) glaciation (Sutcliffe & Kowalski 1976) although the faunas of the pre-Devensian cold stages are still poorly known. The latter does not occur before the late Cromerian and probably disappeared early in the Devensian.

No determinable pollen was found in the Gould's Grove Member although the humic horizon near the base of the silt (division A) in Hall's pit contained up to 30% organic carbon.

4. Archaeology

No flint implements were found during the present investigation but at least 122 hand axes have been previously recorded from the Wallingford Fan Gravel. They are assigned to the Lower Palaeolithic period, most belonging to the late Middle Acheulian Stage (Wymer 1968, p. 107). Many appear to have come from an old pit south of the present Amey's pit, in Oakley Little Wood (644 886), the Turner's Court pit of Arkell (1947*b*, p. 173).

The bulk of the implements are in prime condition and appear to have come from the cryoturbated gravels above the Gould's Grove Member (Wymer's 'varved clay' seam), but two rolled and patinated hand axes are recorded as having come from 'bedded gravel below the Solifluxion gravel', i.e. possibly below the Gould's Grove Member, in pits at Gould's Grove (probably the eastern, disused working of the present Grundon's pit (645 904) and at Blenheim Farm (*ca.* 638 883), south of the present Amey's pit (Wymer 1968, p. 103).

The implements are similar to Acheulian implements from pits in the Winter Hill Terrace of the Caversham Channel, the height of which above the present Thames is 45 m, comparable with that of the Fan Gravel. In general therefore the evidence of the implements supports that of altitude for correlating the Fan Gravel with the Winter Hill Terrace. According to Wymer (1968, p. 107) this poses an archaeological problem in that the implements are of a more advanced type than would be expected in gravels at this high level and apparently of pre-Hoxnian date (Wymer 1968, p. 107).

5. Cryoturbation and solution structures

The disturbed bedding that characterizes the Fan Gravel appears to have originated by at least four processes: (*a*) diapir-like upthrusting; (*b*) decalcification; (*c*) subsidence in response to solution of the underlying Chalk; and (*d*) cryoturbation.

(*a*) *Diapir-like structures*

A complex anticlinal structure recorded in Grundon's pit (figure 7) showed intense folding, overturning and flaring. It resembled the intrusive plugs of mélange chalk described by Higginbottom & Fookes (1971, pp. 95–96, 114), who postulated periglacial conditions for their development. Sections in another part of the pit in 1978 showed another sharp upfold that extended laterally for at least 10 m, with an amplitude less than 3 m, thus having the form of a narrow anticline rather than a plug. These structures seem to have developed by a process of plastic flow of the core material. This probably occurred under permafrost conditions. Freezing of the surface sediments may have caused an increase in pore pressure in the underlying sediments which migrated upward into a zone of lower hydrostatic pressure. The sequence illustrated in figure 8 shows evidence of contemporaneous erosion. The core of the structure is occupied by chalky gravel, presumed to be the basal part of the Fan Gravel. Gravels higher in the sequence are lenticular and are truncated by seams of reddish brown silty sand. The wedging-out of these younger gravels is accompanied by overlap of the succeeding sands onto the summit of the pinnacle, suggesting that their deposition may have been contemporaneous with gentle elevation. The highest flint gravels extend across the structure, indicating that uplift had ceased before they were deposited. Some of these beds are now decalcified but it is not known if they were so when the structure was developing.

(b) *Decalcification*

Decalcification of the type displayed by the Fan Gravel has been recognized in the development of soil profiles of Brown Earth and Podsolic groups in the Chilterns (Avery *et al.* 1959; Avery 1964). Brown Earth soils are developed on pervious strata in humid regions where leaching of calcium carbonate is accompanied by an active organic cycle, involving rapid decomposition and incorporation of surface litter (Avery 1964, p. 52). Acidic humic material produced at the surface migrates downwards, attacking silicate minerals and releasing aluminium, and dissolving carbonates. Percolating waters carry these metallic ions and colloids downwards until they are precipitated at lower levels, while carbonates are entirely removed. Clay minerals are also transported downwards. The end product is a texturally differentiated profile or leached brown soil or sol lessivé (Duchaufour 1960). Under extremely acid conditions organic metal compounds are produced and facilitate the translocation of iron and aluminium oxides, producing an ash-like leached zone immediately beneath the surface humic layer and, at a lower level, a horizon in which the oxides are deposited. Ash-grey leached gravels were noted within gravels underlying and at the base of the Gould's Grove Member (§2*f*(ii); figure 8). In the same sequences bands of secondary iron-oxide enrichment were also present.

Although most of the Fan Gravel is now non-calcareous, evidence has been discussed above that indicates that much of the deposit was originally chalky and has undergone decalcification *in situ*, as early suspected by Shrubsole (1898). The decalcification appears to have moved progressively downwards, giving rise to a sharp boundary between highly calcareous gravel below and completely decalcified, open-textured ferruginous flint gravel above (figure 3). In places, fine-grained layers (figure 2) and, in one case, a mass of chalk (figure 10) appear to have impeded decalcification and sheltered pockets of calcareous gravel. Where the decalcification has reached the underlying mélange chalk or chalk rubble a thin layer of black or brown clay is commonly developed at the interface (see: figure 2, face CD; figure 11). The greater thickness of the clay layer over the western half of a mound (figure 11), which included impure marly chalk, than over its eastern half, which consisted mainly of hard rubbly chalk, points to the clay being at least in part the residue after solution of the chalk. However, most of the clay may be illuvial clay transported downwards through the gravel. The clay contains thin partings of white dust (?chalk) and rare seams of brown sandy clay, some with flat-lying chips of flint, the banding following the irregular configuration of the surface of the chalk mound. Evidence of a similar dual origin for a clay of this type has been described from chalk sections near Basingstoke by Chartres & Whalley (1975).

Further evidence that the dark grey clay represents the limit of a decalcification 'front' was provided by an exposure on the eastern extremity (6427 8873) of the 1976 Amey's pit (F in figure 2), where the basal clay draped a mound of chalk rubble with overhanging promontories (figure 4) and was sufficiently tenacious to be removed like the peel from an orange. The smooth surface of the underlying mound was found to truncate the constituent chalk pebbles. The exposed surfaces of the pebbles showed differential leaching with harder shell detritus, etc.

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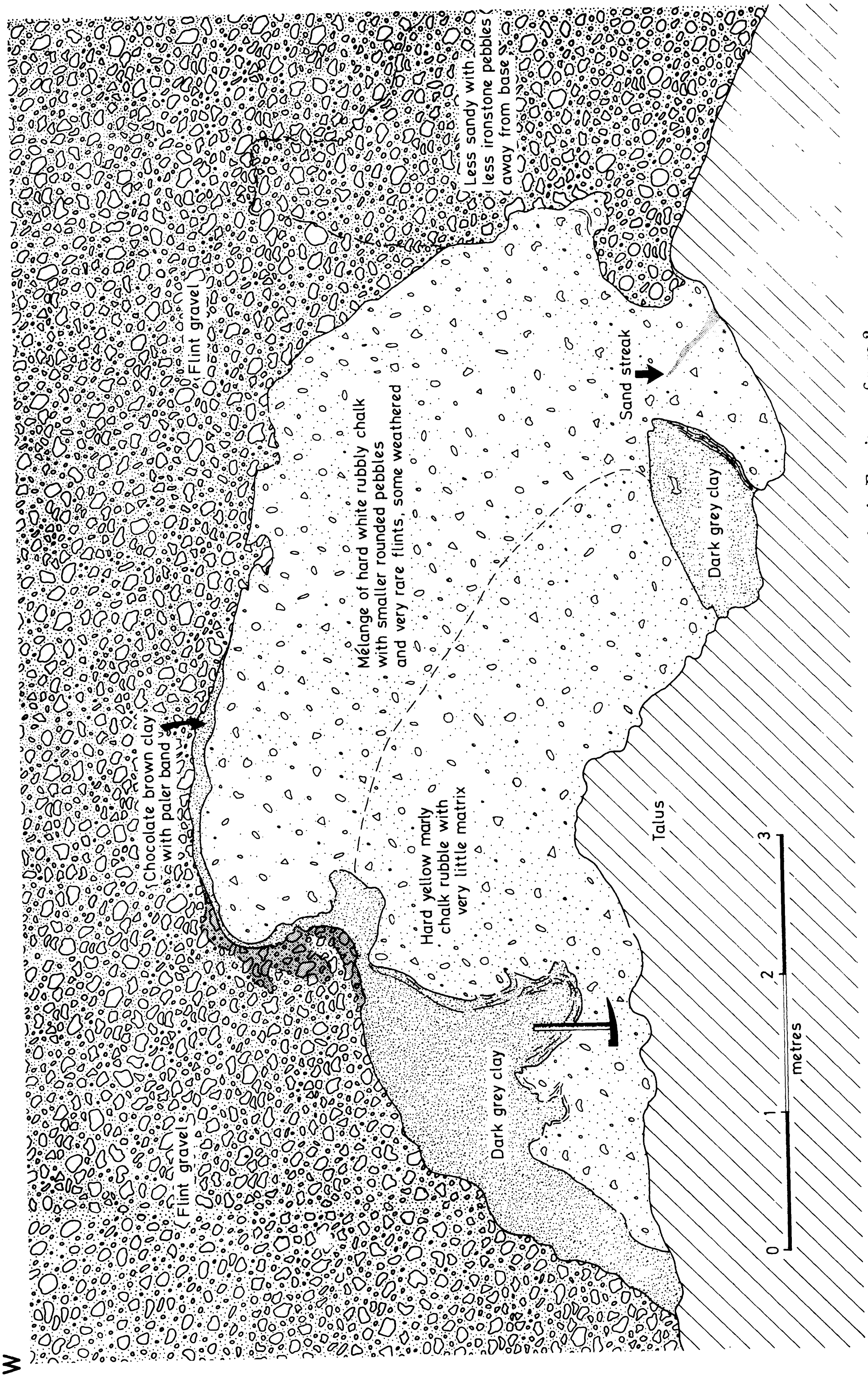

FIGURE 11. Mound of rubbly chalk at bottom of face CD of Amey's pit. For site see figure 2.

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projecting above the exposed pebble surface. Lamellar structures within the overlying dark purplish brown clay parallel the surface of the chalk rubble mound (figure 4) and are comparable with the flow structures described by Loveday (1962, pl. 3, p. 87) and Chartres & Whalley (1975, p. 369). Loveday (1962) concluded that clay layers of this type (his Clay-with-flints *sensu stricto*) were formed during late Tertiary times and early Pleistocene interglacials. However their development beneath the Wallingford Fan Gravel supports the later Quaternary origin for at least a large part of this decalcification favoured by Chartres & Whalley (1975) in the area that they describe.

There is no conclusive evidence from the Fan Gravel of the conditions under which decalcification occurred. Calcium carbonate is most soluble at low temperatures, and the rate of chemical erosion of limestone might therefore be expected to be greater in cold than in warm climates (Corbell 1959). However, the solubility of limestones increases in proportion to the partial pressure of dissolved carbon dioxide in soil waters, and this is much greater in warm climates where the soil has a well developed vegetational cover than in cold climates. On this basis Drake & Wigley (1975) explained the observations of some other workers that erosion rates of limestones at the present day are greater in warm climates than in cold. However, they indicated that exceptions might occur in regions where there is an unusually strong seasonal flow of water, for instance where spring snow melt is the main source of ground water. Solution may have been active in the cold climate during the deposition of the Fan Gravel. Decalcification and rubefaction of the type seen in the Wallingford Fan Gravel have affected many other calcareous gravel deposits in the Thames Basin. The process has been most intense in deposits older than the Fourth or Hanborough Terrace of the Upper and Middle Thames. Thus, although the decalcification of the Fan Gravel to ferruginous gravel may have occurred in an interglacial period subsequent to its deposition, the process was possibly most intense before the deposition of the Fourth Terrace, i.e. before the Hoxnian Interglacial. The presence of only slightly leached chalk gravel near the surface of the deposit shows that the bulk of the decalcification must have been completed by at least the mid-Devensian.

(*c*) *Solution subsidence*

The extremely chalky character of at least the basal part of the Fan Gravel indicates that the sediment was transported by surface waters in a near-saturated condition with respect to $CaCO_3$. However, the evidence of localized subsidence provided by the gravels suggests the possibility of solution of Chalk bedrock beneath the gravel, resulting from the circulation through fissures of large quantities of unsaturated groundwaters. The well known pipes and swallow holes in the Chalk have been ascribed to this type of process by Higginbottom & Fookes (1971, p. 100), who also commented that surface collapse above voids in the Chalk seems most likely to occur where the superficial deposits are relatively thin. The uneven base of the gravel, and undulations of the clayey sand seam in Amey's 1973 pit (figure 2), can be attributed to solution subsidence, as can the pipelike structure in Amey's 1976 pit (figure 5, §2*d*). Comparable subsidence did not accompany or occur after the deposition of the uppermost chalky gravels of Amey's pit.

(*d*) *Cryoturbation*

Sedimentary evidence for the cold climate during deposition of the Fan Gravel is provided by frost wedges and brodel-boden within the gravels. The oldest of these structures appear to affect gravels immediately below the Gould's Grove Member. Examples have been noted in both Grundon's and Hall's pits. Large frost wedges affect the Member itself in Grundon's pit and Amey's pit, where the limited available evidence suggests that they have developed before deposition of the overlying flint gravels. A solitary frost wedge has been noted within these upper gravels (figure 4). Vertically orientated pebbles occur throughout the Fan Gravel, but are most abundant in these upper gravels. Though not forming part of distinctive structures they are undoubtedly the result of frost heaving.

Cryoturbation subsequent to deposition of the Gravel is indicated by the involutions or brodel-boden structures seen at the top of every section, extending down for 1 to 2 m below the present ground surface. Amey's 1976 pit provides evidence that the decalcification of the Fan Gravel and underlying chalk was largely completed before the period of cryoplanation that preceded the deposition of the younger chalky gravels (figure 2). A second period of cryoplanation followed the accumulation and subsequent cryoturbation of the younger chalky gravels (§2d (*v*)).

6. Depositional history of the Wallingford Fan Gravel

Before dissection by the younger coombes descending from the Chalk escarpment the Wallingford Fan Gravel formed a sheet of sediment blanketing the foot of the escarpment. The slightly uneven planar surfaces developed on the deposits slope away from the high ground (figures 1, 12): for example surface levels on the outcrop north of Ewelme descend from about 138 m O.D. down to 96 m O.D. while the major outcrop to the south ranges from the same maximum height down to about 89 m O.D. The generalized inclination of these surfaces ranges from 0° 52′ to 2° 40′, the arithmetic mean of ten measurements being 1° 35′. These fluctuations in level are superimposed on a major reduction in base level to the south–south-east along the face of the escarpment and perpendicular to the other trend. When the generalized base levels of the deposit are plotted, a best-fit line drawn on the minimum altitudes of the deposits of Fan Gravel gives a long profile comparable in gradient to that of river terraces (figure 13).

In any given area the thickness of the deposit appears to increase downhill. Sections in Amey's pits (figures 2, 3, 4) indicate that, at least locally, the surface of the gravel has been modified to form an altiplanation terrace. Viewed on a broad scale (figure 12), however, the altiplanation process may have only slightly modified the original landform.

The western limit of the Fan Gravel outcrops is generally an erosional boundary. However, between Oakley Wood (to the east of Amey's pit) (642 888) and Ipsden (630 852), higher ground, mostly consisting of bare Chalk, but with a thin veneer of gravel locally, is preserved to the west of the outcrops. Between these points the Fan Gravel lies in an elongate depression excavated into Chalk. The distribution of the deposit and the cross profile on the surface of the outcrop are asymmetric, the deposit rising rapidly towards the main escarpment, from which most of its detritus must have been derived (figure 12). It is probable that originally the entire Wallingford Fan Gravel accumulated in a trough separated from the ancient valley of the River Thames by a low ridge of Chalk which provided only a small quantity of detritus. Continued

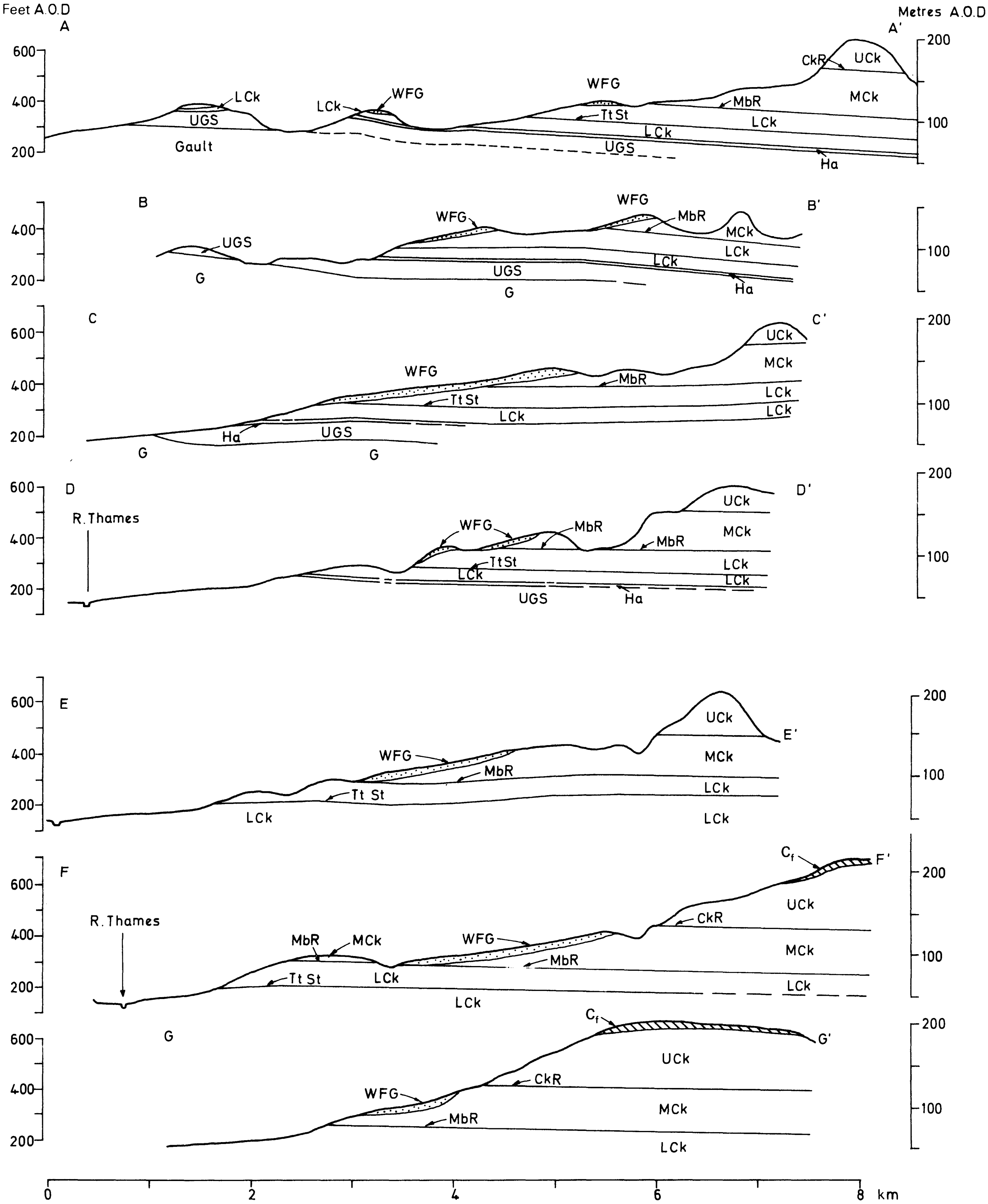

FIGURE 12. Profiles illustrating the distribution of the Wallingford Fan Gravel on the Chalk escarpment.

Symbols. Drift deposits: WFG, Wallingford Fan Gravel; C_f, Clay with flints. Cretaceous strata: UCk, Upper Chalk; CkR, Chalk Rock; MCk, Middle Chalk; MbR, Melbourn Rock; LCk, Lower Chalk; TtSt, Totternhoe Stone; Ha, Glauconitic Marl; UGS, Upper Greensand; G, Gault.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

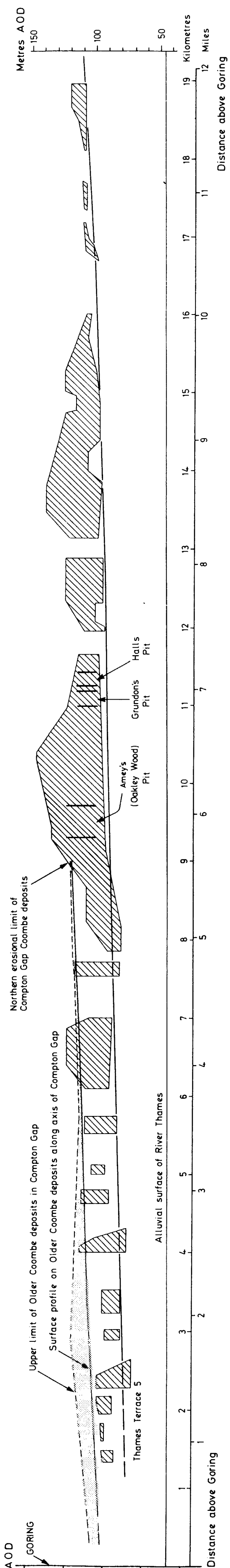

FIGURE 13. Longitudinal profile of the Wallingford Fan Gravel compared with those of the River Thames and of the Compton Gap Deposits.

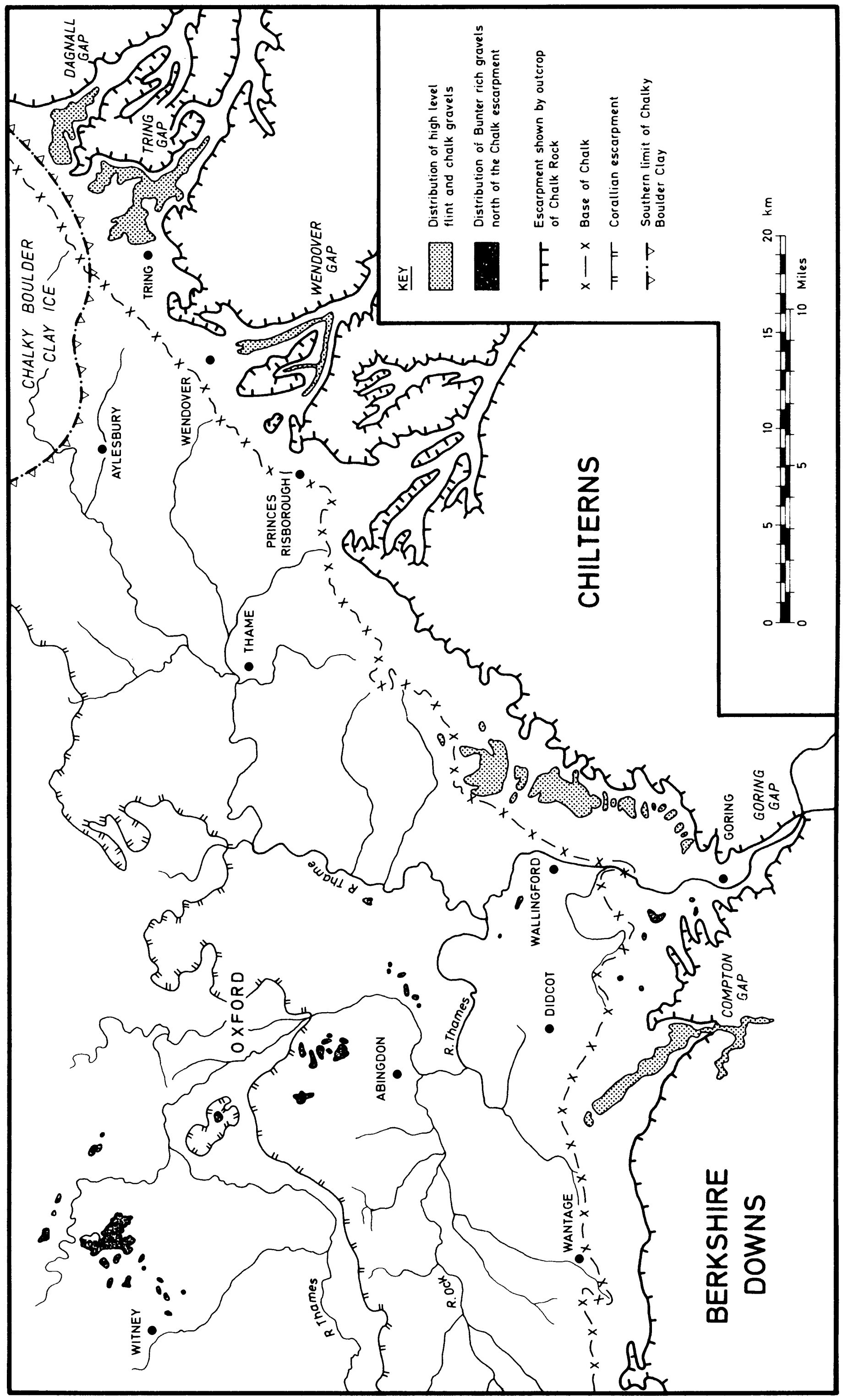

FIGURE 14. Distribution of high-level glacial and Chalk-scarp gravels in the area of Oxford, the Berkshire Downs and the Chiltern Hills.

downcutting by the Thames has almost completely removed the ridge. The coarseness of the bulk of the Wallingford Fan Gravel sediment indicates deposition by powerful torrents, while the poorly sorted character of some of the basal deposits as well as the topmost gravels of Amey's pit are indicative of solifluxion rather than fluvial deposition, The large sarsen boulders found at the base of the gravel in Amey's pit, or those up to 1.8 m in diameter reported by Arkell (1945, p. 2), are unlikely to have been moved by these methods. Although some may have been present on the original Chalk land surface, the majority are reported to lie within the gravel and may therefore have moved into position by a process of gliding or even flotation by icerafts.

Locally, during the initial phase of deposition, as for example in Grundon's pit (figure 8), small ponds existed in which thinly but indistinctly bedded calcareous silts accumulated. Elsewhere rapidly flowing streams were established and bedded sandy flint gravels were laid down. Generally these contain little or no chalk but in places beds and channels infilled with small chalk gravel or coarse sand were deposited. Later conditions became less turbulent and a wide alluvial tract with small channels developed and thin well bedded sands, laminated clays and chalk silts of the Gould's Grove Member were laid down. Within this tract peaty soils developed, but were soon buried beneath chalk flour and silt which accumulated in extensive ponds or small lakes. At times, short-lived fast-flowing streams entered these tranquil environments and laid down thin layers and small channel-filling lenses of gravel. The coarseness of the upper gravel unit results from the return of turbulent flow conditions. Although they are now non-calcareous, the bimodal size analysis curve of sample (iii) from Amey's pit (figure 2) suggests that they were originally chalky.

The evidence of solifluxion at the base of the Fan Gravel suggests that very cold conditions prevailed at first. The climate ameliorated slightly during the deposition of the Gould's Grove Member, but colder conditions returned again during the accumulation of the upper gravels. Subsequently the climate became temperate, warm and humid and the decalcification of the main part of the Fan Gravel commenced. The leaching of the carbonate is so thorough that it indicates a long period of temperate climate either in one period or during shorter recurrent phases. Although dissection of the valley in which the Wallingford Fan Gravel was laid down continued, the deposits in the vicinity of Amey's pit remained in contact with the higher ground to the east and southeast. The climate deteriorated again and soliflucted spreads of ill sorted chalky gravel were locally deposited on the older gravels of the Wallingford Fan Gravel. These younger chalky gravels are preserved in cryoturbation pockets produced in a later cold phase. It is probable that these features were truncated either during this phase or later but certainly before down-cutting of the present coombes and before the partial infilling of the coombes during the late Devensian to early Flandrian Stage. Further slight decalcification after the cryoturbation resulted in the production of a dark brown flinty clay. This late-stage decalcification suggests that warm climates existed at least twice during the history of the Wallingford Fan Gravel.

7. Comparison with other deposits of the chalk escarpment

A local analogue to the coarser deposits of the Wallingford Fan Gravel is provided by chalk–flint Coombe Deposits which form a flat-surfaced spread on the Lower Chalk at Watlington (figure 1). Lithologically they also compare with the Coombe Deposits described from the Chalk valleys of southeast England (see, for example, Smart *et al.* 1966). Most of such Coombe

Deposits are found on the flat floors of former valleys (see, for example, Kerney *et al.* 1964), where the solifluxion process may have passed imperceptibly into one of water transporation. The Gould's Grove Member can be compared with the chalk muds and silts with bands of chalk rubble and a humic mud, thought to be the Allerød interstadial soil, that occur at the foot of the Chalk scarp in the Vale of White Horse (Paterson 1971). The fauna collected from such deposits at Compton Beauchamp (SO 281 885) (Paterson & Jarvis 1976) includes several of the species occurring in the older deposit, suggesting accumulation of both deposits in a comparable environment.

However, the remarkable thickness and wide extent of the Wallingford Fan Gravel distinguishes it from these late-Quaternary analogues. The Wallingford Fan Gravel can best be compared with the similarly situated deposits of comparable extent and probably equivalent age that infill dry gaps in the escarpment of the Chilterns at Wendover, Tring and Dagnall and in that of the Berkshire Downs at Compton (figure 14).

The gravels of the Compton Gap form a broad plain at 118 m O.D. near Harwell (486 864), where they overlie the Lower and Middle Chalk. Traced southwards the outcrop narrows as they cross the feature produced by the Chalk Rock and their surface merges with that of the modern alluvium. In contrast, extensive erosion of their northern extremity results in the deposits occurring above a steep slope rising some 30 m above the Upper Greensand outcrop and 60 m above the nearest alluvial level. The gravels, up to 8.5 m thick, consist of pebbles of angular chalk and flint, with large sarsen boulders in the lower part and a bed of 'white' marl of chalk paste (Prestwich 1882, p. 131). The comparison is further enhanced by the presence of a dark horizon within the marl, which perhaps represents a fossil soil horizon, and a molluscan fauna comparable to that from the Gould's Grove Member (see table 2). The Compton Gap deposits yielded 'remarkably well-preserved' mammalian remains which included *Mammuthus primigenius* (*Elephas primigenius*) *Coelodonta antiquitatis* (*Rhinocercas tichorhinus*), *Equus* sp., *Bison priscus*? and *Rangifer tarandus* (*Cervus tarandus*).

The gravels infilling the Wendover Gap attain a maximum altitude of about 170 m O.D. They consist of angular flint, some rounded flints of Tertiary origin and subrounded chalk fragments in a loamy matrix (Avery 1964). Quartz pebbles occur near the base of the deposit and lenses of clay and sand are present (Sherlock 1922), while mammoth remains are the only fossils recorded. Traced downstream these gravels appear to be continuous with the gravels that underlie the alluvium of the River Misbourne (Sheet 238, Aylesbury).

The gravels in both the Tring and Dagnall Gaps form terrace-like features which extend out in front of the Chalk escarpment (Sherlock 1922; Avery 1964). In the Tring Gap the bulk of the gravel forms a feature at 122–130 m O.D., but the gravel surface rises to almost 152 m O.D. in parts of the southern area and over 183 m O.D. in the northern area. In a section near Tring Station (SP 952 122) the gravel comprised clayey material full of chalk with fresh angular flints, large brown flints, pebbles of Tertiary origin, quartz and sarsen pebbles and fragments of Greensand ironstone (Barrow & Green 1921). The gravel in the Dagnall Gap also reaches a maximum height of about 183 m O.D.

Jukes-Browne (1889) correlated the Wallingford Fan Gravel with the gravels flooring the Compton, Wendover, Tring and Dagnall gaps. These deposits are almost entirely of local origin, although pebbles of quartz occur within the deposits of the Wendover Gap and the Wallingford Fan Gravel, while Bunter-derived pebbles occur in the latter and in the Compton Gap deposits. They all occur partly on or within the Chalk escarpment and all have been truncated by intense erosion associated with the back-cutting of this feature. For the Wallingford Fan Gravel the capture of the stream that deposited the gravel has resulted in isolation of the deposit associated with rapid down cutting of the Thames valley. In contrast the slight erosion by the head waters of the more recent streams rising in the other dry gaps means that the ancient sediments pass beneath the modern alluvium. The best exposed and described deposits, those of the Compton and Wendover gaps, like the Wallingford Fan Gravel are probably fluviatile in part and accumulated in cold subarctic conditions.

There is no biostratigraphic evidence for this correlation, but it is tempting to consider whether all the high-level deposits discussed were laid down at about the same time in separate valley systems which, like the present River Thames, broke through the Chalk escarpment. However, active down cutting by the River Thames, perhaps facilitated by melt waters from the Chalky Boulder Clay ice sheet, resulted in capture of all the head waters of the other streams, thereby isolating the deposits within the existing dry gaps.

8. Age of the Wallingford Fan Gravel

Rare erratic pebbles of Bunter origin (Sherwood Sandstone Group) occur in the Wallingford Fan Gravel. These pebbles were derived from the local deposits of Northern Drift, a mixture of glacial and possibly fluvioglacial sediments which occur around Oxford, and pebbles which can be found on even the highest parts of the Cotswolds. These deposits were deposited during one, or perhaps more, glacial epochs, and were subsequently reworked into deposits at a lower level. In the Moreton-in-Marsh area the deposits of Northern Drift are older than the Chalky Boulder Clay (Tomlinson 1929). At Sugworth, south of Oxford, gravels of Northern Drift type overlie a channel, filled with humic sediment and containing a diverse fauna, which is thought to be of Cromerian age (Shotton *et al.* 1980). The uppermost gravels give rise to a bench and are thought to have been formed by solifluxion of older Northern Drift deposits during a post-Cromerian cold spell.

The Sugworth deposits occur at a higher altitude than the Fourth (Hanborough) Terrace of the Upper Thames, the gravels of which have yielded a molluscan fauna indicative of an extremely cold or subarctic climate. It has been suggested that the Fourth Terrace gravels may have been deposited during the early stages of the glaciation during which the Chalky Boulder Clay at Moreton-in-Marsh was deposited (Briggs & Gilbertson 1973). Certainly at its maximum the melt waters of this Chalky Boulder Clay ice sheet deposited the Third (Wolvercote) Terrace of the Upper Thames.

In the present district the most southerly outcrops of the Wallingford Fan Gravel occur some 30 m below the gravels of Northern Drift type that Kemp (Sheet 254, Henley) refers to the Seventh (Harefield) Terrace of the Thames. The Fan Gravel grades to several small patches of gravel (figure 1) rich in Northern Drift derived pebbles, which lie at about 92–95 m above O.D. or 49–52 m above the present alluvium of the River Thames, and which have been attributed to the Upper Winter Hill Stage of the Fifth Terrace of the Thames. Below the Goring Gap this terrace can be traced towards the Vale of St Albans, where the original outlet was blocked by an ice sheet, which deposited Chalky Boulder Clay (Gibbard 1977). Thus the terrace must be older than the Chalky Boulder Clay of Hertfordshire, which is thought to be of Anglian age. This Chalky Boulder Clay is contiguous with the similar deposits of Bedfordshire and Buckinghamshire. The latter are younger than the high-level gravels of the Chiltern scarp above the Vale of Aylesbury which show lithological and topographical similarities to the Wallingford Fan Gravel.

Thus the Wallingford Fan Gravel is younger than the Northern Drift of Oxfordshire. It may be contemporaneous with the oldest stage, the Upper Winter Hill stage of the composite Fifth Terrace of the River Thames. It is older than the Fourth (Hanborough) Terrace of the Upper Thames and the Chalky Boulder Clay of the Vales of Moreton and St Albans.

9. Conclusions

The Wallingford Fan Gravel was laid down by a combination of solifluxion and fluviatile deposition in an ancient tributary of the River Thames. Ponding occurred during an intermediate stage and the fine-grained silts and sands of the Gould's Grove Member were deposited under subarctic conditions. The presence of contemporaneous frost wedges within the remainder of the gravel suggests that cold conditions persisted throughout the deposition of the Fan Gravel. Diapir-like structures within the gravel may have also been produced by permafrost conditions. The gravel was originally chalky but extensive leaching has removed most of the chalk and has also locally dissolved the underlying solid chalk, producing collapse structures within the gravel. The Wallingford Fan Gravel may have been deposited in the valley of one of several streams that drained the country north of the present Berkshire Downs and Chilterns, passing southeastwards through the gaps at Compton, Dagnall, Wendover and Tring. All of these streams were beheaded by the Thames, which has also completely eroded the western side of the valley in which the Wallingford Fan Gravel accumulated. The precise age of the Gravel is uncertain; it post-dates the introduction of the Northern Drift into Oxfordshire and is older than the Chalky Boulder Clay of the vales of Moreton and St Albans. The greater part of the deposit is of mid-Pleistocene age and could have been laid down at the start of the Anglian Stage or earlier. The topmost chalky gravel of Amey's pit clearly post-dates the deposition and disturbance of the bulk of the Fan Gravel. A Devensian age seems most likely for this part of the deposit.

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Appendix 1. Particle-size analysis of sediments from Amey's (Oakley Wood) pit

Seven samples of chalky gravel and flint gravel were submitted to the Petrology Unit, Institute of Geological Sciences, for particle-size analysis and determination of $CaCO_3$ content. The work was carried out by G. E. Strong (Sedimentary Analysis Laboratory Internal Reports nos 60 and 98). Analysis of two samples of the median sand and silt seam (Gould's Grove Member) from the same pit was carried out at Reading University by J. Verran, in the Department of Geography. The locations of samples (i)–(vii) are shown in figure 2 and of (viii) and (ix) in figure 3.

Samples (i)–(iii) were collected in 1973 (figure 2, face AB), (iv)–(vii) in 1976 (face CD), and (viii) and (ix) also in 1976 (E, figure 2). Their lithology was as follows.

(i) chalky gravel from floor of pit
(ii) another sample of chalky gravel from floor of pit
(iii) flint gravel from 2 m below ground level, 10 m from west end of face AB
(iv) chalky gravel from 6 m below ground surface (SU 6405 8897)
(v) yellowish brown sandy gravel, from 5.5 m below ground surface (SU 6405 8897)
(vi) topmost chalky gravel, 1.5 m below surface (SU 6403 8897)
(vii) flint gravel with dark brown clayey sand matrix, 1 m below ground surface (SU 6403 8897)
(viii) white chalky sand } Gould's Grove Member (figure 3)
(ix) brown to grey clayey sand }

Laboratory method (samples submitted to I.G.S.)

For particle-size analysis, each sample was dry-sieved through square-hole gravel sieves and British standard sand-test sieves. The gravel fractions were size-analysed according to the minimum diameter of each pebble. Distribution curves (arithmetic ordinates) are shown in figure 15*a–c*. Of the samples of chalky gravel collected in 1973, one (i) was size-analysed in its original state, the other (ii) after decalcification in the laboratory. A probably more precise indication of the effect of decalcification was provided by the treatment adopted in 1976, when each chalky gravel sample (iv and vi) was size-analysed both before and after decalcification.

Before decalcification, sample (ii) was weighed dry and its bulk material was picked out by hand and the remaining sample treated with 20% acetic acid (CH_3COOH) buffered with 4.8 g/l CH_3COONH_4 to dissolve the calcium carbonate. Fresh acid was added until all effervescence ceased, when the supernatant liquid was siphoned off and the sample washed in water several times to remove acid and soluble calcium acetate. The final volume and dry mass were then found. Samples (iv) and (vi) were treated similarly except that buffered acetic acid was used only in the initial stage, followed by concentrated hydrochloric acid in the final stages of decalcification. The volumes of these two samples before and after treatment were not determined.

Laboratory method (Reading University)

The Reading University analysis was in two stages.

For removal of carbonates the samples were treated with 10% acetic acid until the effervescence ceased, the reaction being acclerated by using an ultrasonic bath. The samples were then thoroughly washed and oven-dried and the carbonate percentages were calculated from the mass loss.

For particle-size analysis, the samples of decalcified sand were mechanically dispersed in 4% buffered sodium hexametaphosphate solution and wet-sieved through a 4ϕ sieve. The retained particles were oven-dried prior to dry-sieving of the coarser fractions. The fine fractions were determined by the standard pipette method.

Percentage carbonate losses

	(ii)	(iv)	(vi)	(viii)	(ix)
initial mass/g	1159.0	1326.3	1812.5	100.0	100.0
final mass/g	792.7	854.2	1467.9	41.2	99.5
loss (%)	31.6	35.6	19.0	58.8	0.5
initial volume/ml	470.0				
final volume/ml	315.0				
loss (%)	33.0				

Discussion of results of treatment of gravel samples

The curves for the samples from the 1973 working (figure 15*a*) show the widest separation, though the general trend is repeated in the other samples. The chalky gravel (i) shows no significant mode (i.e. most frequently-occurring particle diameter), whereas (ii) and (iii) show a markedly bimodal distribution of particles. Comparison with (i) indicates that the effect of decalcification of sample (ii) has been to remove particles in the ϕ range 0.5 to -3, approxi-

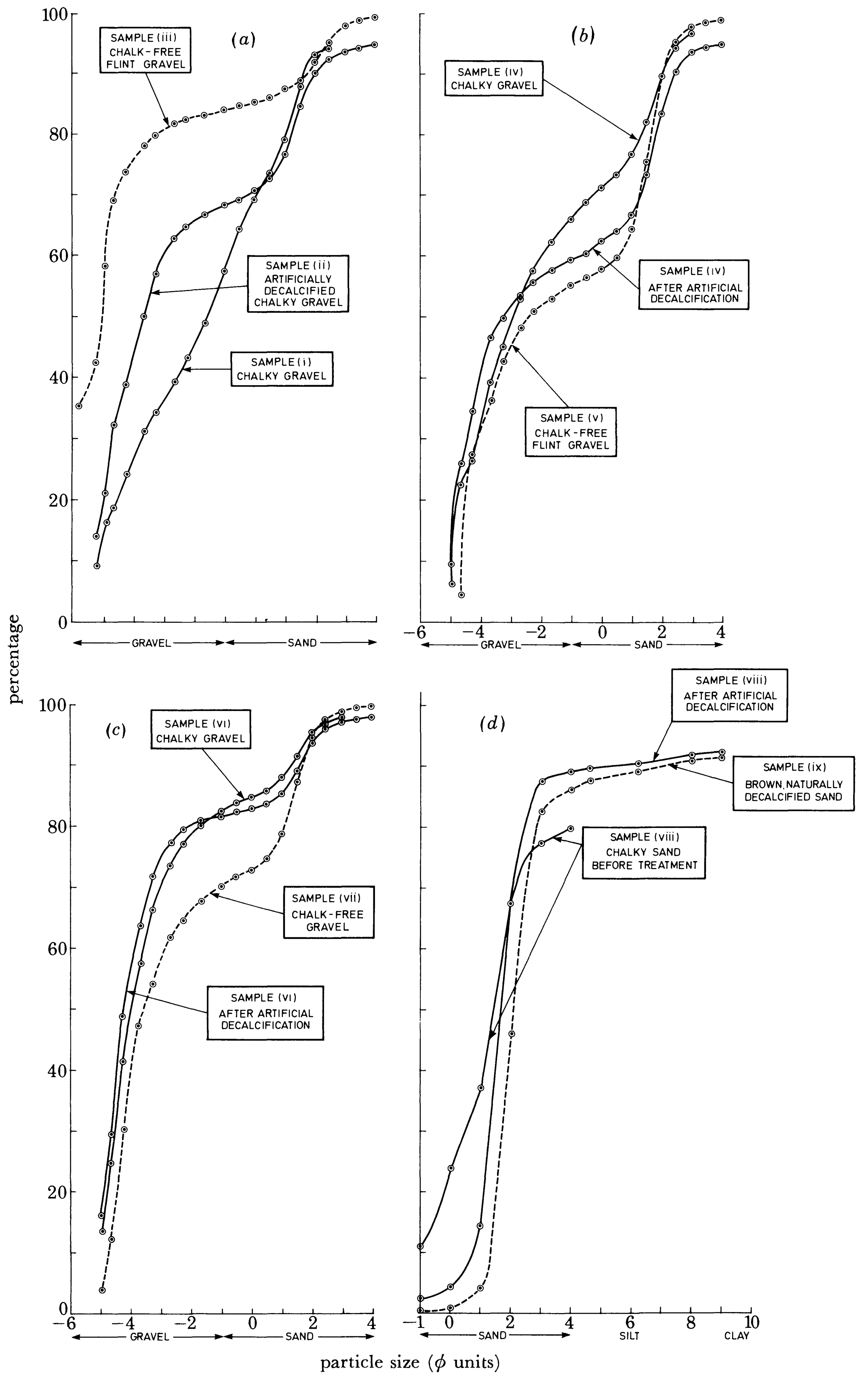

FIGURE 15. Particle-size analyses of sediments from Amey's pit; (*a*) samples (i) to (iii) (*b*) samples (iv) and (v); (*c*) samples (vi) and (vii); (*d*) samples (viii) and (ix). For locations see figures 2 and 3.

mately 0.7–7 mm in diameter. The naturally non-calcareous gravel (iii) has a relative lack of particles in the ϕ range 1.5 to −4 (approximately 0.35–17 mm). It appears therefore that, in a chalky gravel such as (i), particles of sizes intermediate between the gravel-sized flints and the quartz sand to clay that form the coarser and finer fractions respectively of (ii) and (iii) are mainly of chalk. Some of the chalk also occurs in a fine powdery form (5.8 % of sample (i) having $\phi = 3$ and greater). The contrast in specific gravity between flint and chalk, and the readiness with which chalk becomes abraded during transport, may help to explain the wide range of particle sizes shown in the chalky gravel. Sample (iv) (figure 15*b*), like (i) comes from the lower part of the Fan Gravel, but differs slightly from (i) in its original state in showing a tendency to a bimodal distribution of particle sizes. The curve for its laboratory-decalcified product, however, closely resembles that of sample (ii), and is also close to the yellow-brown sandy gravel (v), from nearby in the same exposure.

As figure 2 shows, sample (iii) came from a part of the face where the Gould's Grove silt member was missing. Its original stratigraphical position, whether above or below the silt, is therefore uncertain. While, therefore, figure 15*a* suggests sample (iii) to be the decalcified derivative of an originally chalky gravel similar to (i), the evidence cannot strictly be used to support the stratigraphical conclusion that the gravels above the silt band were originally chalky, as indicated for gravels below the silt band by the results of tests on (iv) and (v). However, the general resemblance, throughout Amey's pit, of the brown flint gravels above the silt band to those below it, in those parts of the face where the silt band is preserved, suggests that their original constitution was similar.

The differences between the topmost chalky gravel of Amey's pit (vi, figure 15) and the basal gravels (i, ii, iv) are remarkable. First, (vi) was relatively less chalky, losing only 19 % mass when acid-treated, whereas (ii) and (iv) lost 31 % and 35 % respectively; secondly, 82.4 % of (vi) is of gravel grade ($\phi = -1$, 2 mm diameter and over) as opposed to 66 % of (iv) and 57.5 % of (i); thirdly, the close match in grading between (vi) and its laboratory-decalcified derivative indicates a bimodal distribution for the chalk in the original sample, thus differing particularly from sample (i).

Both (vi) and (i) are probably solifluxion deposits, but whereas (i) rested directly on mélange chalk, (vi) rested on non-calcareous flint gravel and thus had been transported, if only a few hundred metres, from the outcrops from which its chalk material was derived. Abrasion and sorting of the chalk particles during this transport may explain some of the differences in grading between (vi) and (i).

Although the Gould's Grove Member samples (viii, ix) contrasted in lithology with the other samples their curves (figure 15*d*) show very similar trends to the curves derived from the other samples. Sample (viii) before treatment showed a greater range of particle sizes than either its laboratory decalcified derivative, or the naturally decalcified sample (ix).

† $\phi = -\log_2$ (particle diameter/mm).

Appendix 2. An organic bed associated with the Gould's Grove Member at Amey's pit, Oakley Wood

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Late in 1980 an organic-rich bed became exposed in Amey's pit. At that time the working face paralleled that of 1973 (face AB) but lay some 120 m further north, essentially where the vertical face on the north side of the worked-out gravel area is indicated on the location map (see figure 2). Along the working face the hard white rubbly chalk was periodically exposed revealing a relief amplitude of at least 3 m. Above this the same basic stratigraphy as described in the main account could be deciphered, some 2.5 m of sandy flint gravels devoid of chalk with occasional lenses of well sorted sands overlain by an upper 2.5 m of poorly sorted flint gravels, again without any chalk clasts, set in a silty clay matrix (hoggin). Extensive deformation structures (cryoturbations) affected the upper unit and seemed to be developed downwards from the ground surface. Approximately in the centre of the face (6415 8940), a massive sandy silt bed up to 3 m thick and 25 m across separated the two gravel units. This silt lens would appear to correspond to the Gould's Grove Member as defined in the main paper.

An organic bed occupied a near-horizontal disposition along the exposure, a short distance above the base of the silt bed (figure 16). This layer consisted of a silty sand with humified organic matter forming the matrix and attained a maximum thickness of 0.07 m. Laterally, the bed became progressively attenuated both to the west and east and, in doing so, rose slightly. A short section cut normal to the main exposure showed a southward dip of the organic bed at 6°. This suggests a shallow basin deepening to the south. Shortly after the recording of the section the working face was moved back some 7 m to the north and in the new exposure virtually no trace of the organic bed could be seen; indeed, the entire mass of silt was almost completely eliminated and the central parts of the face were occupied by a large lens of bedded well sorted sands within the lower flint gravels, and the upper gravel unit lay with sharp discordance on the sand lens. In addition the top of a chalk 'high' had appeared and lay within 1.5 m of the level of the formerly exposed organic bed. These relationships are a further demonstration of the dramatic lateral and vertical facies changes that characterize the Wallingford Fan Gravel.

A pollen sample from the organic bed (figure 16) was prepared by conventional procedures, including use of sodium pyrophosphate to disperse clays (Bates *et al.* 1978). A total of 250 grains was counted, exclusive of 36 grains attributed to Lower Tertiary types (mainly saccate conifer grains). Preservation of the pollen was fairly good, although a significant proportion (28.8 % was too corroded or crumpled for identification to be possible. However, this will not affect the general conclusions. The spectrum was as follows (numbers are percentages of total Pleistocene land palynomorphs):

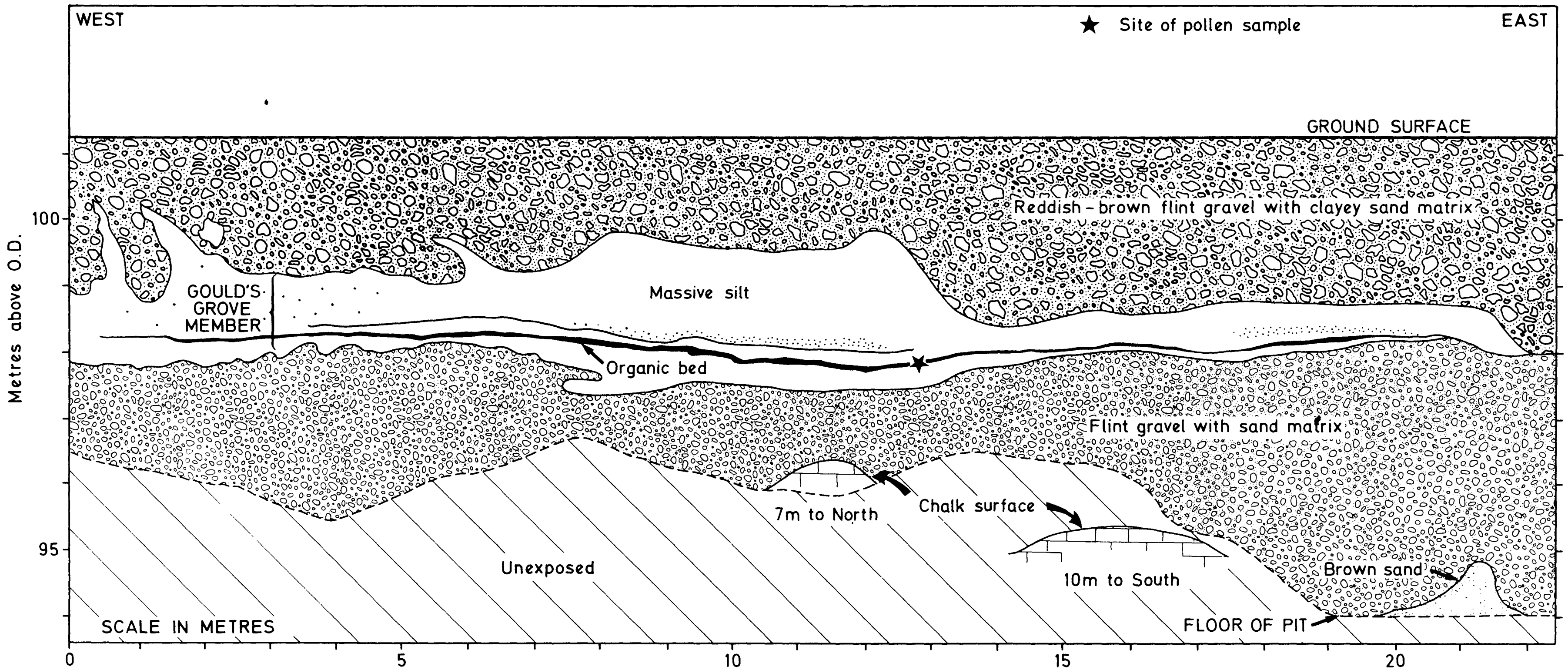

FIGURE 16. The south-facing worked section at Amey's pit, Oakley Wood, as exposed in late 1980. This shows the silt unit that is ascribed to the Gould's Grove Member and the associated organic bed from which the pollen spectrum was obtained. The vertical heights are related to Ordnance Datum.

trees	
Alnus	0.4
Betula	2.0
Pinus	1.6
shrubs	
Salix	1.2
herbs	
Armeria maritima	0.8
Caryophyllaceae	2.8
Compositeae, *Bellis*-type	1.2
Compositeae, Liguliflorae	5.2
Cruciferae	0.8
Cyperaceae	34.8
Gramineae	10.8
Plantago maritima	5.8
Ranunculus-type	0.8
Rosacea	1.2
Rumex acetosella-type	1.2
pteridophytes	
Filicales (monolete)	4.8
Selaginella	0.8
aquatic	
Myriophyllum alterniflorum	2.4
unidentified	28.8

The spectrum is clearly indicative of the open, herb-dominated vegetation of a glacial stage. Tree pollen is represented at such a low frequency that its presence can reasonably be attributed to long distance transport or reworking. The remaining Cyperaceae–Gramineae herb assemblage resembles spectra from several stadials of several different glacial periods (cf. West *et al.* 1974; West 1977), so that it cannot be used for precise correlation of the deposit.

Armeria maritima (Mill.) Willd. and *Plantago maritima* L. are now predominantly coastal plants in Britain that also occur locally on mountains; both are now absent from Berkshire and Oxfordshire (Perring & Walters 1976), although there are Devesian records from Berkshire (Holyoak 1980) and elsewhere inland in southern England (Bell 1969; Godwin 1975). *Selaginella* now has a northern and montane distribution in Britain and is likewise recorded from Devensian deposits in the lowlands.

The overall geometry of the Gould's Grove Member as portrayed in figure 16 is difficult to interpret since the boundaries of the two gravel units have clearly suffered post-depositional disturbance. The limited evidence suggests that it may represent the fill of an abandoned channel cut into the lower sandy flint gravels, possibly after the main phase of gravel deposition had ceased. Early in the fill history, the surface appears to have stabilized for a time to permit the accumulation of the organic material as a detritus mud. This suggestion receives support from the occurrence of pollen of *Myriophyllum alterniflorum* DC., an aquatic plant which grows submerged in water at least 0.5 m in depth. This event was terminated by a further influx of fine-grained sediment with occasional larger clasts. It seems likely that the main mass of the member at this site has not suffered much internal disturbance, although the absence of chalk clasts in the underlying gravels indicates that during the presumed decalcification the whole mass must have experienced some lowering from the position of its original deposition. It is possible that differential lowering of the silt into the lower gravels contributed to its preservation at this specific point and that the apparent cut out to the north is due to lesser subsidence of the silt in that direction and subsequent erosion before the emplacement of the upper poorly sorted gravels.

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