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LATE FLANDRIAN SHORELINE OSCILLATIONS IN THE SEVERN ESTUARY: A GEOMORPHOLOGICAL AND STRATIGRAPHICAL RECONNAISSANCE

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[Plates 1–8]

CONTENTS

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The Severn Estuary on the west coast of Britain is large, macrotidal and well mixed, receiving fine sediment from many sources. Within the last few thousand years, at least four discrete lithostratigraphic units, predominantly of sandy to silty clay, have accumulated along the shores of the estuary in the upper intertidal zone. The three youngest are continuing to be deposited, each beneath a distinctive geomorphic surface reached by a proportion of the tides. These surfaces form a stair-like succession on the salt marshes and high mud flats, the most elevated and outermost of the surfaces overlying the formation that, of the three, began to accumulate earliest. We here describe and name these linked geomorphic and lithostratigraphic features, and outline on a reconnaissance basis their distribution within the estuary.

The (upper) Wentlooge Formation consists of pale green estuarine silty clays that began to accumulate 2500–3000 years ago and ceased to form in the Roman period or soon after. Reclamation during the Roman period isolated the Wentlooge Surface on large areas of tidal wetland in the lower estuary. The soil that developed on this surface is recognized as the Wentlooge palaeosol in those places where post-Roman breaching of the Roman sea defences led to a resumption of tidal sedimentation.

The Rumney Surface is the most elevated of the geomorphic surfaces on the salt marshes of the estuary. It overlies thick largely pink sandy to silty clays, termed the Rumney Formation, that began to form at times ranging from the early mediaeval to the early modern periods. Mediaeval reclamation of wetlands led to the isolation of the Oldbury Surface during the early stages in the accumulation of the Rumney beds. Locally, the breaching of the mediaeval seabanks led to renewed tidal sedimentation on the Oldbury Surface. Wherever the Wentlooge and Rumney formations are seen in contact, the base of the latter so far proves to be sharp and erosional. Locally, the Rumney Formation is found to abut against and smother a low embayed cliff cut into the upper Wentlooge beds.

The Awre Surface forms the intermediate level on the salt marshes and overlies pink to grey sandy to silty clays (Awre Formation) that bank against a low cliff and gently shelving platform cut into older deposits. This unit began to accumulate probably in the 19th century.

The lowest step on the salt marshes is formed by the Northwick Surface, underlain by the grey sandy to silty clays of the Northwick Formation. Like the Rumney and Awre beds, the Northwick Formation abuts against a cliff and shelving platform eroded into older sediments, chiefly the Rumney and Awre formations. The erosion surface at the base of the Northwick Formation dates from the 19th century and the beds themselves from the early 20th century.

The reconnaissance shows that these linked formations and geomorphic surfaces are represented in most parts of the Severn Estuary. The evidence available for dating – archaeological, historical, radiocarbon, and geochemical – points to the broad synchroneity of each formation throughout this extensive area. The geochemistry of the tidal sediments, reflecting the pollution history of the estuary, is particularly useful in the recognition and correlation of the Northwick Formation.

These associated geomorphic and lithostratigraphic features point to the instability of the shores of the estuary and to important horizontal movements of the strand over the last 2000 years. Intrinsic as well as external factors may have controlled these oscillations, but which factor, or factors, was responsible for the movements recorded cannot as yet be decided.

1. Introduction

A line between Sand Point (Weston-super-Mare) and Lavernock Point (Cardiff) marks the transition from the open marine environment of the Bristol Channel to the brackish *milieu* known as the Severn Estuary (see figure 1). Well stirred (Crickmore 1982; Parker & Kirby 1982; Shuttler 1982) and macrotidal (Davies 1964; Heaps 1982), the Severn Estuary opens to the southwest between the Cotswold Hills on the English side, and the upland Forest of Dean and South Wales Coalfield on the Welsh bank. Although bedrock cliffs and rock benches occur at many places along its margins, the shores are chiefly marked by thick tidal muds of recent date.

There is mounting evidence to suggest that the muddy shoreline of the Severn Estuary is unstable, having experienced over the last few thousand years a sequence of horizontal movements, both retreats and advances, locally from a few metres to many hundreds of metres. The evidence for shoreline oscillation centres on a series of linked geomorphological and lithostratigraphic elements which, from this and other estuaries (see, for example, Van Straaten 1954; Reineck 1962; Greensmith & Tucker 1966; Verger 1968; Haynes & Dobson 1969; Hawkins 1979), have in the past been partly characterized as 'marsh cliffs'. Here we outline a reconnaissance study of these features over some 180 km of shoreline within the Severn Estuary, leading us to suggest that each element is distributed over virtually the whole tidal area, and is broadly synchronous within the limits of the available means of dating and correlation (archaeological, historical, radiocarbon, geochemical). Such an unexpected but striking result raises exciting questions about the factors that control shoreline movement, and about the stability in the recent past of other British and mainland European west-coast estuaries. Our research to date, the initial phase of an extended investigation, thus sets the stage for detailed future work in the Severn Estuary, as well as for new departures in the study of estuarine and littoral sediments generally.

2. Setting

The rising post-glacial (Flandrian) sea that invaded the area drowned an intricately dissected landscape (Hawkins 1971; Kidson & Heyworth 1973, 1976) which included the rock-bound channels of the river Severn and its tributaries (Anderson & Blundell 1965; Anderson 1968; Williams 1968). Mud brought to the estuary accumulated as an extensive marginal blanket of estuarine alluvium beneath broad tidal wetlands (see figure 1). These have since been largely reclaimed, beginning in the Roman period (Allen & Fulford 1986) and continuing up to the

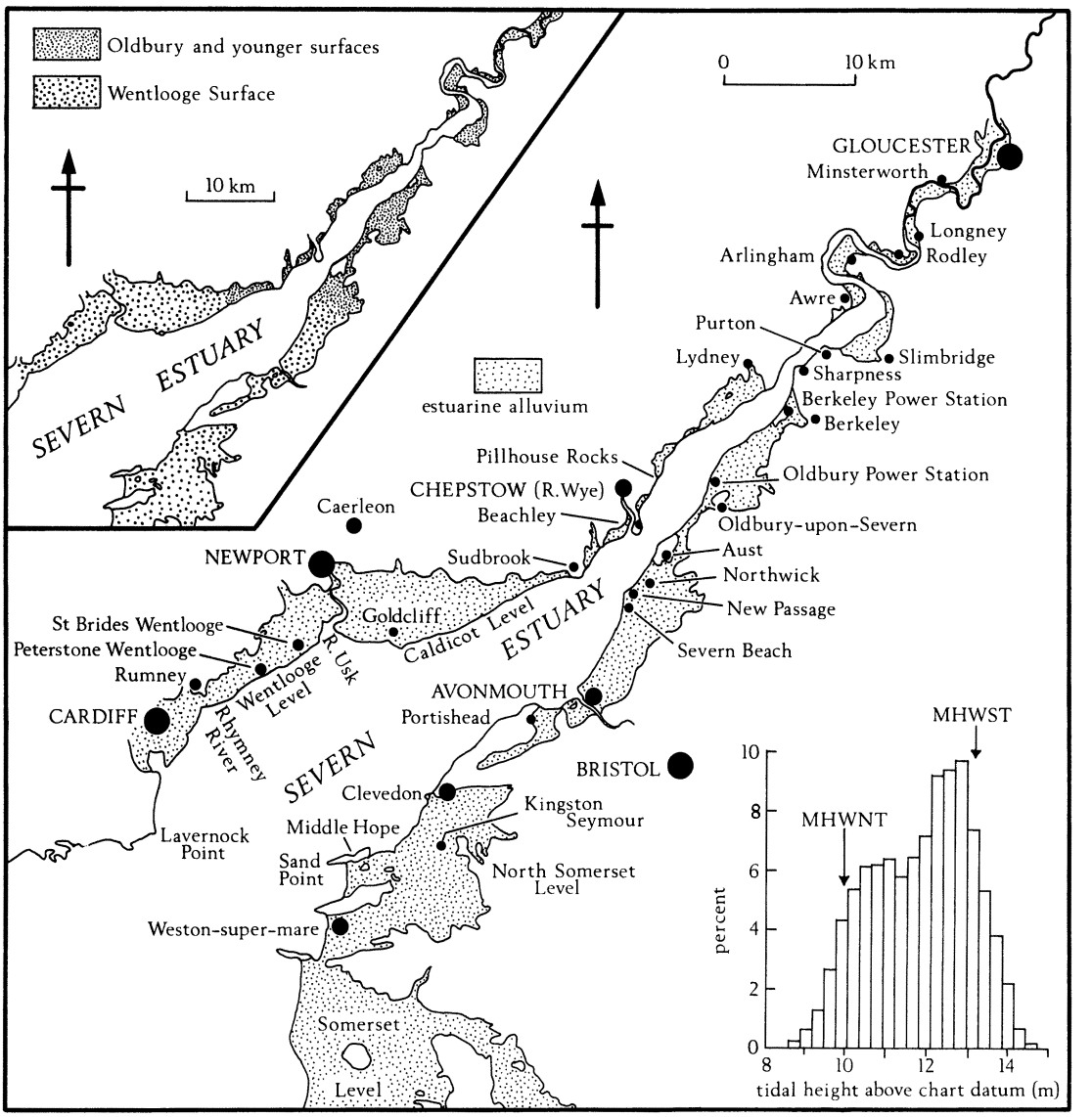


FIGURE 1. The Severn Estuary and the Severn Levels (estuarine alluvium), to show the localities mentioned in the text, the distribution of the older (Romano-British) and younger (mediaeval and later) reclamations (upper left), and the character of the tidal régime at Avonmouth (1980–4) (lower right). Abbreviations: MHWST, mean high water of spring tides; MHWNT, mean high water of neap tides.

present at irregular intervals (Allen 1986), to form what are collectively known as the Severn Levels. Today the levels are tracts of featureless country, criss-crossed by drainage ditches (reens, rhines), and divided from the surviving salt marshes (warths, wharfs) and tidal mudflats by tall seabanks. Shoreline movement under the influence of natural forces has consequently taken place against a lengthy background of human interference; this further complicates the nature and relationships of the tidal deposits, but introduces in compensation its own peculiar evidence of age.

The Severn Estuary is exceeded in tidal range only by the Bay of Fundy. At Avonmouth (see figure 1), on the lower estuary, the mean spring tidal range is 12.3 m, rising to 14.5 m during equinoctial springs, whereas the mean neap range is 6.5 m (Hydrographer of the Navy

1984). Turbulent and powerful tidal streams consequently sweep the estuary (Crickmore 1982; Uncles 1984), which as a whole is very well stirred (Morris 1984; Owens 1984). The heights of high waters, when the estuary is fullest and wave action at the strands most effective (the water level is changing least rapidly), are distributed bimodally (see figure 1), with a peak just below the mean level of high-water springs (13.2 m above chart datum, Avonmouth) and a subordinate maximum about 1 m above mean high-water neaps (10.0 m above chart datum, Avonmouth). The aspect of the estuary ensures that the most effective winds are those from the southwest, the west, and the south (Shuttler 1982). Swell originating in the Atlantic Ocean can also reach the estuary.

Muddy sediment enters the Bristol Channel and Severn Estuary system from several sources, and a total of the order of 10^7 t appears to be dispersed within the water column at spring tides (Parker & Kirby 1982, Collins 1983). Perhaps around 10^6 t is on average supplied annually by the rivers, of which the most important are the Severn, Wye, Usk and Avon. The Severn basin embraces various source rocks, those of Triassic and Jurassic ages, along with Pleistocene glacial deposits, probably being the main contributors to the fine-sediment load. The Old Red Sandstone is perhaps the most important source-rock in the Wye and Usk basins. Coal Measures feed many of the smaller rivers that drain to the coast of South Wales. Fluvial supplies from land masses south of the Bristol Channel are of little importance. Along with fine sediment from natural sources, the rivers in the last 200 years or so have introduced, either in solution or as particulates, a variety of metals and other detritus of either industrial or urban origin (see, for example, Abdullah & Royle 1974, Hamilton *et al.* 1979; Morris 1984, Owens 1984), especially from southeast Wales, the English Midlands, and the Bristol area. Other potential sources of fine sediment are the recurrent cliffs of Old Red Sandstone, Triassic and Jurassic rocks along the shores of the Severn Estuary and Bristol Channel, and the subtidal mud deposits mapped in Swansea Bay, Barnstaple Bay, off Newport and Cardiff, and north of Avonmouth (Dyer 1984). Atmospheric contributions to the area, particularly of pollutants, cannot be ignored.

3. Introduction to geomorphological and lithostratigraphic elements

Without formally naming them, Allen (1985) noted that a sequence of linked geomorphological and lithostratigraphic elements was present on the levels and unreclaimed tidal lands of the Severn Estuary. The main components of this repetitive association (see figure 2*a*) consist ideally of a steep cliff eroded into earlier estuarine alluvium (locally into bedrock or Pleistocene terrace gravel), passing down and across into a gently shelving wave-cut platform, overlain by further estuarine alluvium which culminates upwards in the contemporary sedimentary surface and which may, in places and at times, bury the cliff. An element of lesser importance, and not invariably present, is furnished by a combination of a geomorphic surface and a soil created when a part of the salt marsh hitherto reached by the tide became 'frozen' on the completion of the seabank around a new reclamation. A second subordinate element is a low cliff to seaward of an accreting body of alluvium (see figure 2*a*). Such cliffs, found a little above the level of mean high-water neaps, in many places accompany the youngest lithostratigraphic unit present on the shores of the estuary, and may have been associated with some of the older ones. Mud is in places accreting seaward of these cliffs.

In figure 2*b* we summarize the relationship of these linked geomorphological and lithostratigraphic elements, together with their proposed names, some of which appear, accompanied

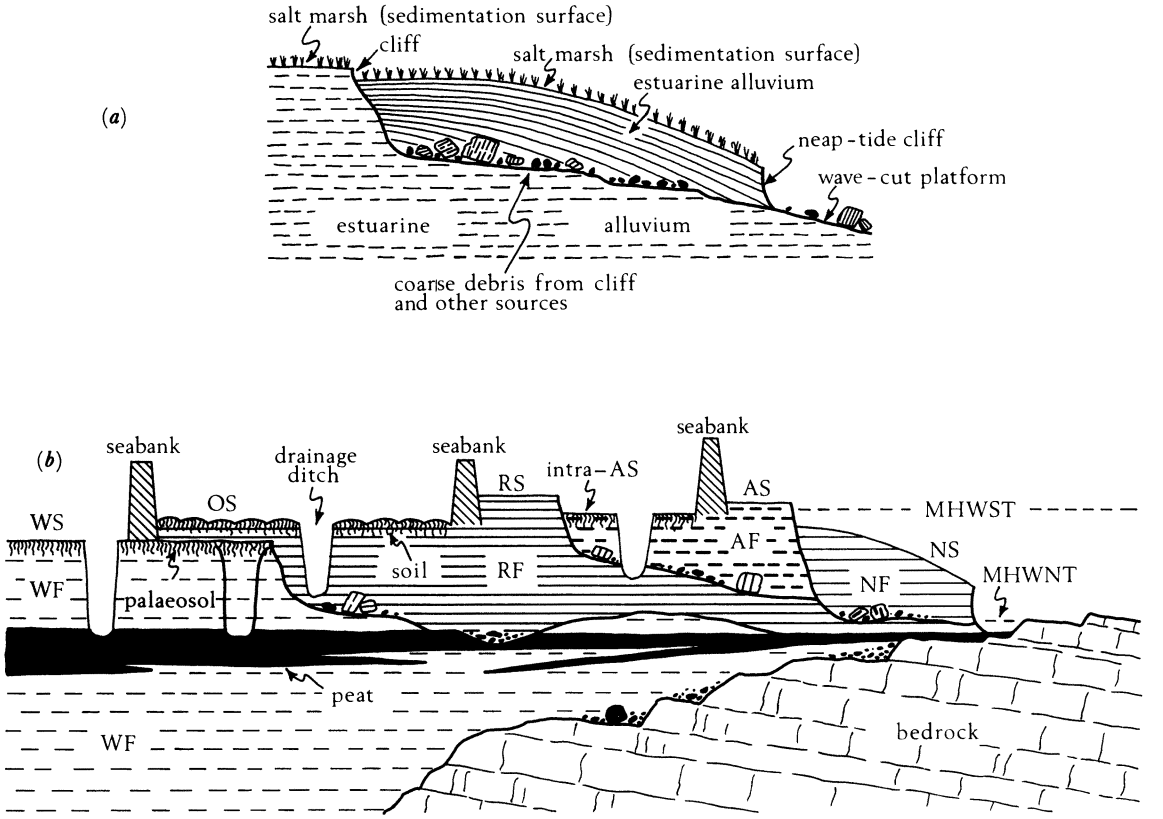


FIGURE 2. Summary of late Flandrian lithostratigraphy and geomorphology in the upper intertidal zone of the Severn Estuary. (*a*) The fundamental lithostratigraphic unit and associated geomorphological features. (*b*) Idealized relationships in the Severn Estuary. The (upper) Wentlooge Formation and younger sediments above the peat total about 3–4 m in thickness. Abbreviations: WF, Wentlooge Formation; WS, Wentlooge Surface; RF, Rumney Formation; OS, Oldbury Surface; RS, Rumney Surface; AF, Awre Formation; AS, Awre Surface; NF, Northwick Formation; NS, Northwick Surface; MHWST, mean high water spring tides; MHWNT, mean high water neap tides.

by brief descriptions, in local archaeological (Allen & Fulford 1986) and sedimentological (Allen 1987) accounts. We take the opportunity here to give a fully documented and formalized definition of the elements shown in figure 2*b*.

Two points require emphasis. First, figure 2*b* depicts the geomorphological elements almost at their most complex; in the commonest arrangement of the Rumney, Awre and Northwick surfaces, the three form a simple, unbroken 'staircase' descending towards the river. These surfaces have a substantially constant elevation only when compared with the local levels of mean high-water springs and high-water neaps; down river they decline in elevation in harmony with the tidal levels. Second, as these surfaces contribute to one and the same general salt-marsh environment, each of the Rumney, Awre and Northwick formations is continuing to accumulate, although not at the same rate. The present accretion rate is least in the case of the Rumney Formation, the Rumney Surface being drowned less often than the Awre Surface, and the latter by fewer high waters than the Northwick Surface still lower within the tidal range. However, as we demonstrate, the three formations differ significantly in the timing of the *start* of accretion.

4. The Wentlooge Formation and Wentlooge Surface

The Wentlooge Formation (see figure 2*b*) is named for spectacular intertidal exposures on the shores of the Wentlooge Level (British National Grid Reference ST 23 77 to ST 31 81) (see figure 1), and for ditch exposures (upper beds only) within the embanked area (see figure 3*a*).

The Wentlooge Formation here varies in thickness from about 5 m near the inner margin of the reclaimed area to 15 m or more along the seabank. Up to four parts are recognized. The

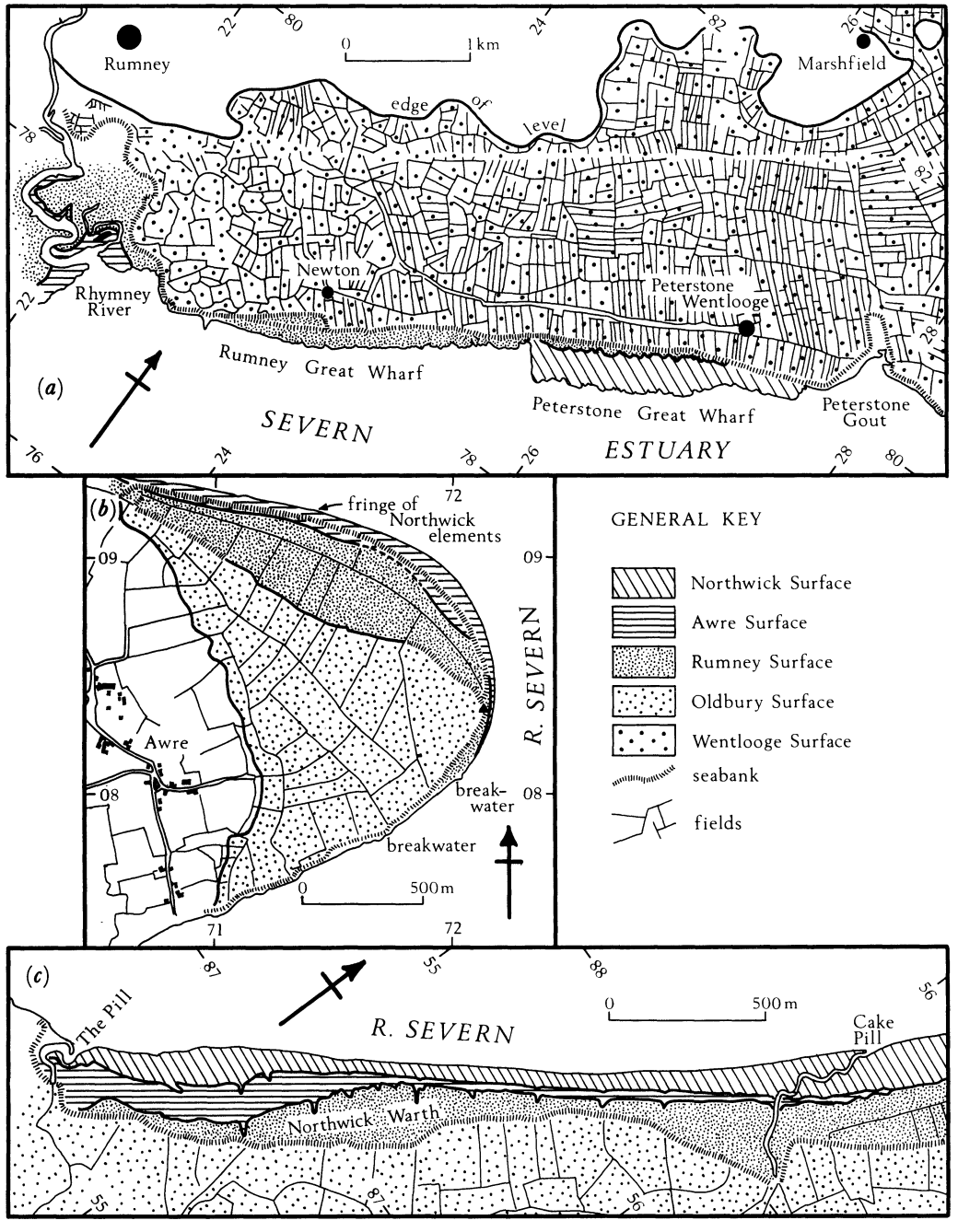


FIGURE 3. Distribution of geomorphic surfaces on (*a*) Peterstone Great Wharf, and at (*b*) Awre and (*c*) Northwick Wharf. See also figure 1.

lowermost is not visible on the foreshore but, according to boreholes sunk by Anderson & Blundell (1965), Anderson (1968), and on behalf of Cardiff City Council (Allen 1987), consists of up to 3 m of locally developed sandy gravels, gravelly sands and sands to silty sands. The deeper-lying of these deposits invite comparison with the buried valley-filling gravels of the River Usk (Williams 1968), but the shallower, situated around about O.D., recall the late Pleistocene beach gravels present along the inner margin of the Caldicot Level to the northeast (Andrews *et al.* 1984). The gravels (or bedrock where these are absent) are succeeded by up to 12 m or so of pale green estuarine silty clays with siliceous marine sponge spicules and mixed open-marine and estuarine diatoms and foraminifera. Lamination and signs of gullying are well developed in the uppermost few metres; at a few decimetres from the top occurs an extensive horizon of large mud-filled desiccation cracks that cut down a metre or so into the clays beneath. Over much of the foreshore there follows a peat bed 0.3–0.6 m in thickness; the sequence of macroscopic remains suggests a succession from *Phragmites* swamp to broad-leaved forest, fallen birch being particularly common. The uppermost Wentlooge Formation is particularly important to the present study. It is magnificently exposed on the tall mud cliff bordering Rumney Great Wharf (see figure 3*a*), at the southwestern end of the Wentlooge Level, and consists of up to 2.5 m of pale green estuarine silty clay with siliceous marine sponge spicules and open-marine to estuarine diatoms and foraminifera, but with local indications of freshwater and terrestrial influences in the form of *Phragmites* and the locally plentiful meadow snail *Cepaea nemoralis*.

At an early date (see below) the Wentlooge Level was embanked, together with some land now regained by the sea, and a rectangular grid of drainage ditches, bottoming out either within or just below the peat, was cut into the uppermost Wentlooge Formation (Allen & Fulford 1986). This formidable undertaking created the Wentlooge Surface (that is, the ground surface of the Wentlooge Level), now about 1.5 m below the level of the adjoining high salt marsh, and led to the growth of a soil within the topmost 0.5–0.8 m of the Wentlooge clays (see 1 of plate 1 and figure 3*a*). Just within the defence at Rumney Great Wharf, and behind the seabank along the Rhymney River, the Wentlooge Surface has an elevation of about 7 m O.D., falling gradually inland to about 5 m O.D. The present seabank lies much further inland than the original one, so that at Rumney Great Wharf, the Wentlooge Surface and the associated soil (in this context called the Wentlooge palaeosol) underlie a metre or more of younger tidal muds (Rumney Formation, see below).

The Wentlooge Formation is volumetrically the most important post-Pleistocene deposit in the Severn Estuary, and represents most of the Flandrian age, with the exception of the last 1800 years or so (see below). Scattered natural exposures along the estuary (see, for example, Welch & Trotter 1961; Locke 1971; Copeland 1981), together with excavations and mainly commercial and water-authority boreholes (Beckinsale & Richardson 1964; Seddon 1964; Anderson 1968; Hawkins 1968, 1971; Williams 1968; Locke 1971; Murray & Hawkins 1976; Cave 1977), suggest that the formation underlies the entire Severn Levels. The peat at the typesite appears to be representative of an estuary-wide peat (or peats) of mid Sub-boreal to early Subatlantic date.

Provisionally, the Wentlooge Surface (see figure 1) embraces the Wentlooge Level, the Caldicot Level (as far northeast as Caldicot Moor), the North Somerset Level, and the level adjoining the River Avon and extending from there to Severn Beach. Each level presents (i) an elevation *ca.* 1–1.5 m below that of the adjoining modern high salt marsh; (ii) soils formed only in pale green estuarine clays; (iii) archaeological evidence (Allen & Fulford 1986; and

below) for the early origin of the artificial drainage if not also of the sea defences; and (iv) no evidence of mediaeval ridge-and-furrow arable (Hall 1981, 1982) (with the sole exception of the Avon–Severn Beach level).

5. The Rumney Formation, Rumney Surface and Oldbury Surface

The Rumney Formation (see figure 2*b*) is named for extensive cliff exposures on Rumney Great Wharf (ST 23 77, 24 78) and the neighbouring Little Wharf (ST 22 77) and Pengam Moors (ST 22 76, 22 77) (see figure 3*a*). Here the beds reach a maximum thickness of 2.7 m between a gravel-strewn erosional surface cut down in places almost to the Wentlooge peat and the surface of the modern salt marsh (chiefly Rumney Surface), about 0.5 m above the level of mean high-water springs (see (1) of plate 1). The formation, in two parts, smothers a deeply embayed flat-topped mud cliff cut into the Wentlooge Formation (Allen 1987). The lower portion consists of poorly laminated pink estuarine silty clays distinctly coarser grained than the upper Wentlooge clays. *Scrobicularia plana* and *Macoma balthica* occur in life position, *Nereis diversicolor* burrows are plentiful, and *Hydrobia ulvae* shells can also be found. These deposits mainly fill the embayments on the coast shaped from the Wentlooge Formation beneath. The upper beds, burying the flat-topped headlands on this concealed coast, and bridging its embayments, are well laminated pink silty clays that grade up toward the surface of the modern marsh into dark grey silty to sandy clays with lenses of shelly to gravelly sand. Like the Wentlooge beds, they yield siliceous marine sponge spicules and open-marine to estuarine diatoms and foraminifera. The highest tides add further silt to the Rumney Surface, with its shallow gullies and marsh pans, and during storms sandy to gravelly debris is locally distributed. These upper beds also yield *S. plana* and *M. balthica*, but only as transported and mainly either disarticulated or broken shells.

The Oldbury Surface, named for the parish of Oldbury-upon-Severn (ST 61 92), dates from a second major period of wetland reclamation, which occurred in the middle and upper estuary early on during accumulation of the Rumney Formation. The feature is characterized by the early arable system called ridge-and-furrow (Hall 1981, 1982), established on pink estuarine clays locally more than 1 m thick, that is well preserved on the fields north and south of Oldbury Pill (see (2) of plate 1). This ancient surface falls as low as 1.1 m below the Rumney Surface at points between the pill and Oldbury Power Station. Provisionally, the Oldbury Surface is mapped wherever ridge-and-furrow has been established on pink estuarine clays (see figure 1). Most of the levels upstream from Caldicot Moor on the Welsh bank and from Severn Beach on the English side are thus included. In places, not separately distinguished, the Oldbury Surface and its associated soil have the same status as the Wentlooge Surface and palaeosol at Rumney Great Wharf, namely, they are smothered by younger estuarine alluvium, consequent upon either the breaching or neglect of the original sea defences (see, for example, Allen 1986).

6. The Awre Formation and Awre Surface

The Awre Formation (see figure 2*b*) is named for cliff exposures (SO 72 08, 71 08, 71 09), in places 2 m high, on the inner bank of the last great meander of the river Severn, overlooked by the village of Awre (see figure 1). Well laminated silty to sandy clays and clayey sands, mid to dark grey in colour, are seen near the triangulation station (SO 721 082) to bank against

a gently shelving wave-cut platform and steep, partly exposed cliff out into pink Rumney beds (see figure 3*b*). The Awre beds thicken toward the river and underlie the whole of the bank upstream. They lack a macrofauna but yield sponge spicules, diatoms and foraminifera like the older estuarine alluvium. A more intricate cliffed contact between the Awre and Rumney formations occurs south of the village (SO 706 073). At both sites, the grey silts underlie a level salt marsh (Awre Surface) that is separated from the Rumney Surface above by a clifflet 0.15–0.2 m high.

Deposition on the Awre Surface (see (1) of plate 2) east of Awre was interrupted by the construction of at least one seabank, as at a few other localities on the estuary. These reclamations are individually small compared with earlier ones and apparently of no single date. The geomorphic surfaces thus isolated are therefore not formally named, but described simply as intra-Awre surfaces and mapped (see figure 1) with the Oldbury Surface.

7. The Northwick Formation and Northwick Surface

The Northwick Formation (see figure 2*b*), the youngest lithostratigraphic element on the muddy shores of the Severn Estuary, is named for cliff exposures at about the level of high-water neaps that range along most of Northwick Warth (ST 55 87, 55 88) southwest of the Severn Road Bridge (see figures 1 and 3*c*).

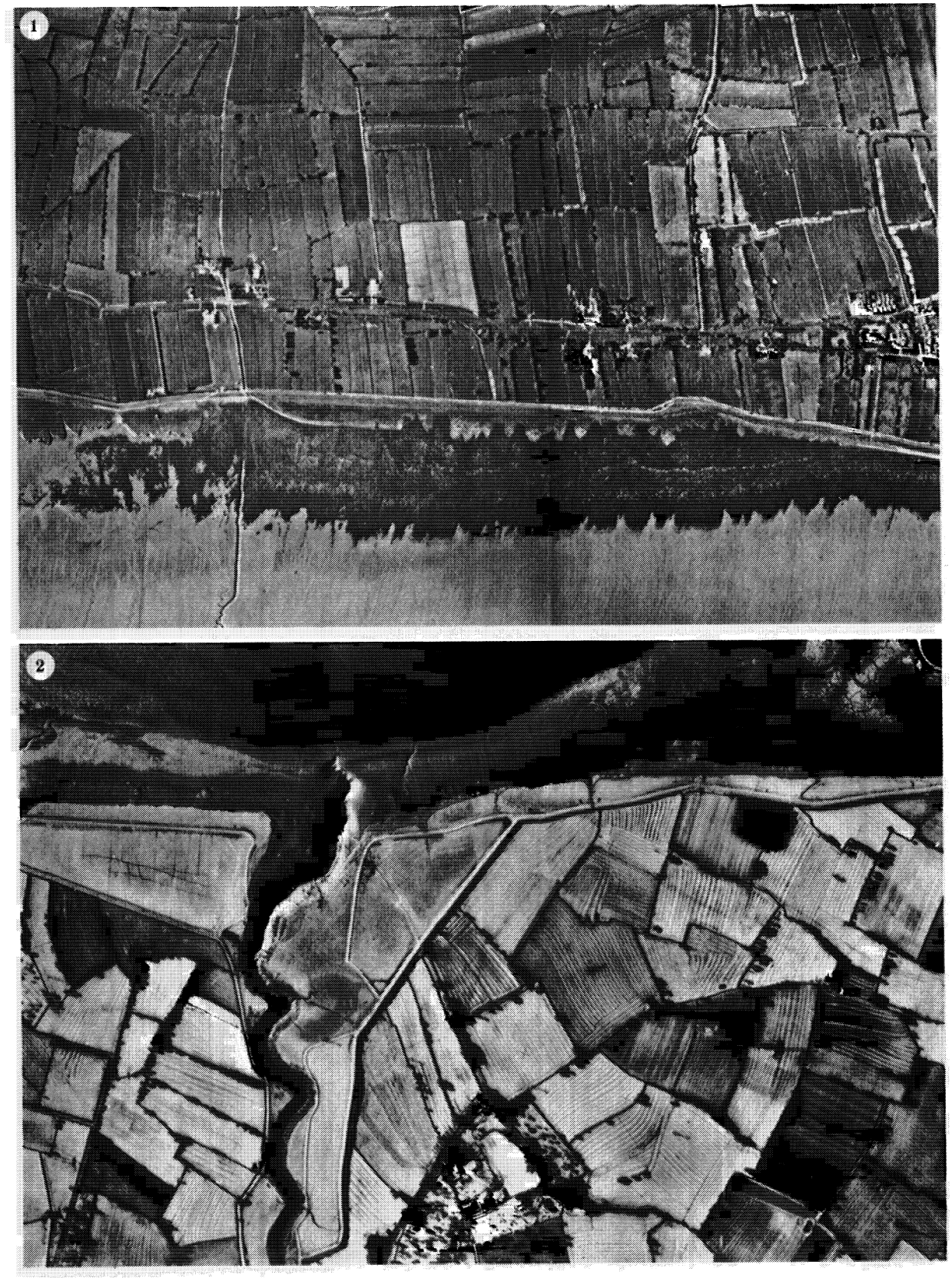
The embayed cliff exposes variable thicknesses of the Rumney and Awre formations and, overlying them, and ranging up to the surface of a *Spartina*-dominated marsh, up to 1.2 m of mid- to dark-grey well-laminated silty to silty-sandy clays with plant roots but yielding siliceous marine sponge spicules and mixed open-marine to estuarine diatoms and foraminifera. These upper beds constitute the Northwick Formation. They sharply and slightly discordantly overlie a planar to slightly uneven surface cut largely into the Awre Formation.

Three well-defined step-like surfaces separated by clifflets are recognizable over most of Northwick Warth (see figure 3*c* and (2) of plate 2). The innermost, ranging outward from the seabank, is the Rumney Surface and the middle one, up to 0.4 m below, the Awre Surface. The *Spartina*-dominated marsh, here called the Northwick Surface, lies in many places approximately 0.25 m below the Awre Surface at the cliff limiting that surface, but towards the river gradually falls over a convex-up profile to the top of the neap-tide feature on which the Northwick Formation is exposed. Hence the beds may thicken towards their inland margin.

Descriptions of plates 1 and 2

Plate 1. Late Flandrian geomorphic surfaces on the Severn Levels, Peterstone Wentlooge and Oldbury-upon-Severn. Photographs Crown Copyright reserved. (1) Air photograph (*ca.* 2.9 by 1.6 km; N to upper right) showing part of the Wentlooge Level (Peterstone Wentlooge appears at right-hand edge). See figure 3*a* for detailed interpretation. (2) Air photograph (*ca.* 1.8 by 1.2 km; N to right) showing the Oldbury Surface (with ridge and furrow, see also (6) of plate 6) in the neighbourhood of Oldbury Pill. The salt marsh to the W of the seabank is formed chiefly of the Rumney Surface (light tone), but a continuous frilly margined development of the Northwick Surface (dark tone) and local developments of the Awre Surface (light to intermediate tone) are also visible.

Plate 2. Late Flandrian geomorphic surfaces on the Severn Levels, Awre and Northwick. Photographs Crown Copyright reserved. (1) Air photograph (*ca.* 1.9 by 1.5 km; N to bottom) showing much of the peninsula encircled by the Awre bend. See figure 3*b* for detailed interpretation. (2) Air photograph (*ca.* 1.4 by 0.9 km) showing part of Northwick Warth between The Pill and Cake Pill. See figure 3*c* for detailed interpretation.



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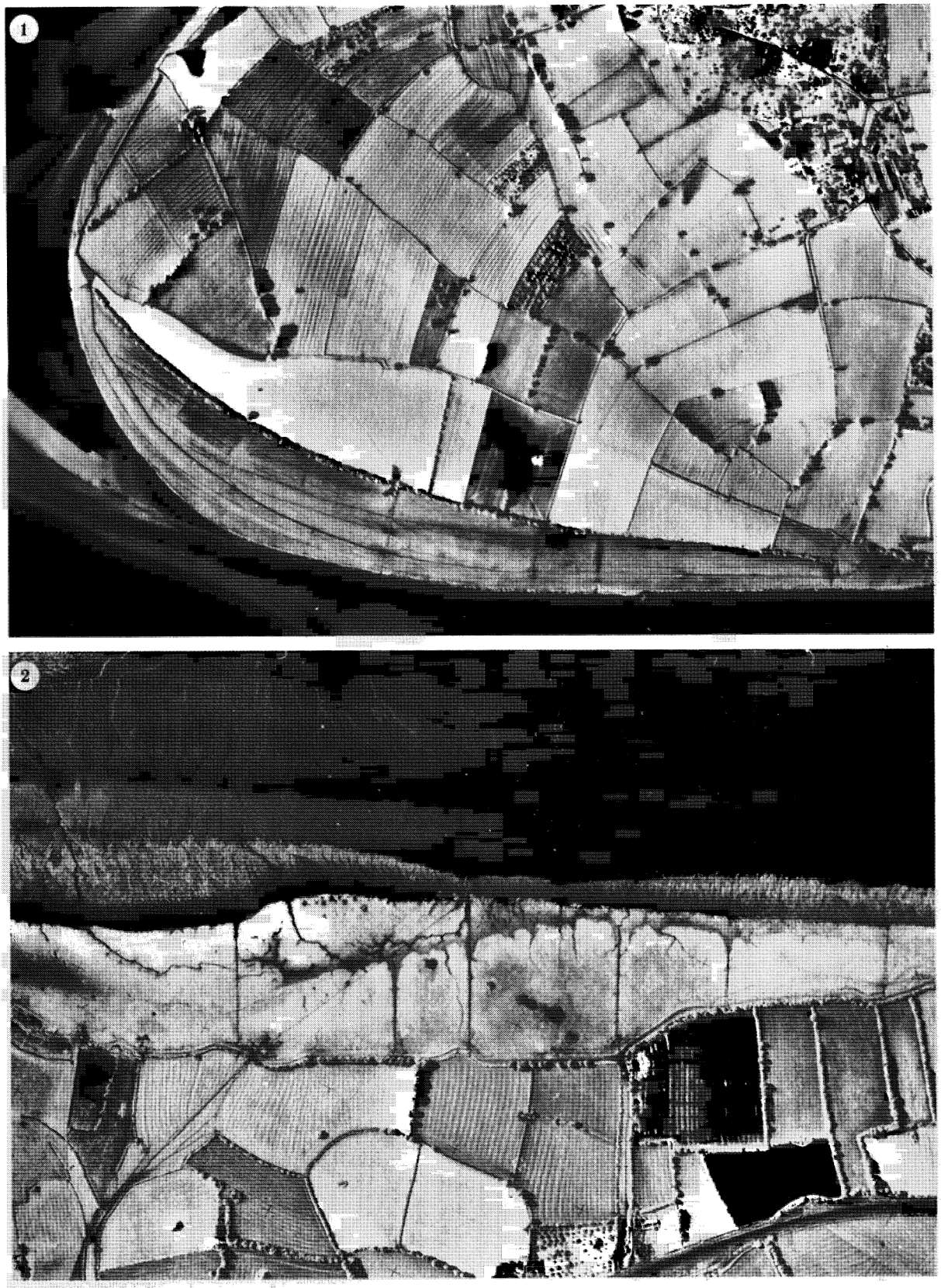

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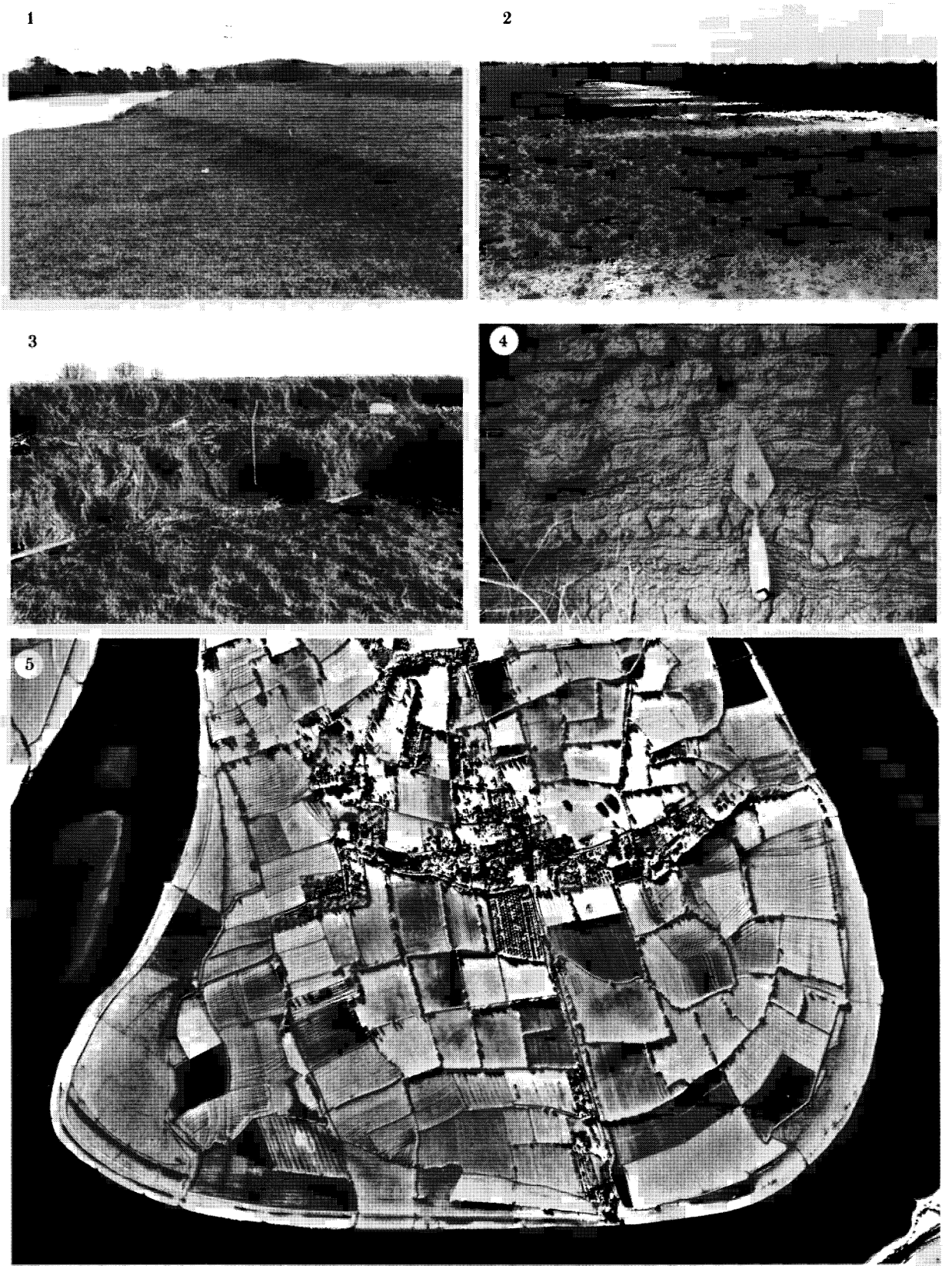

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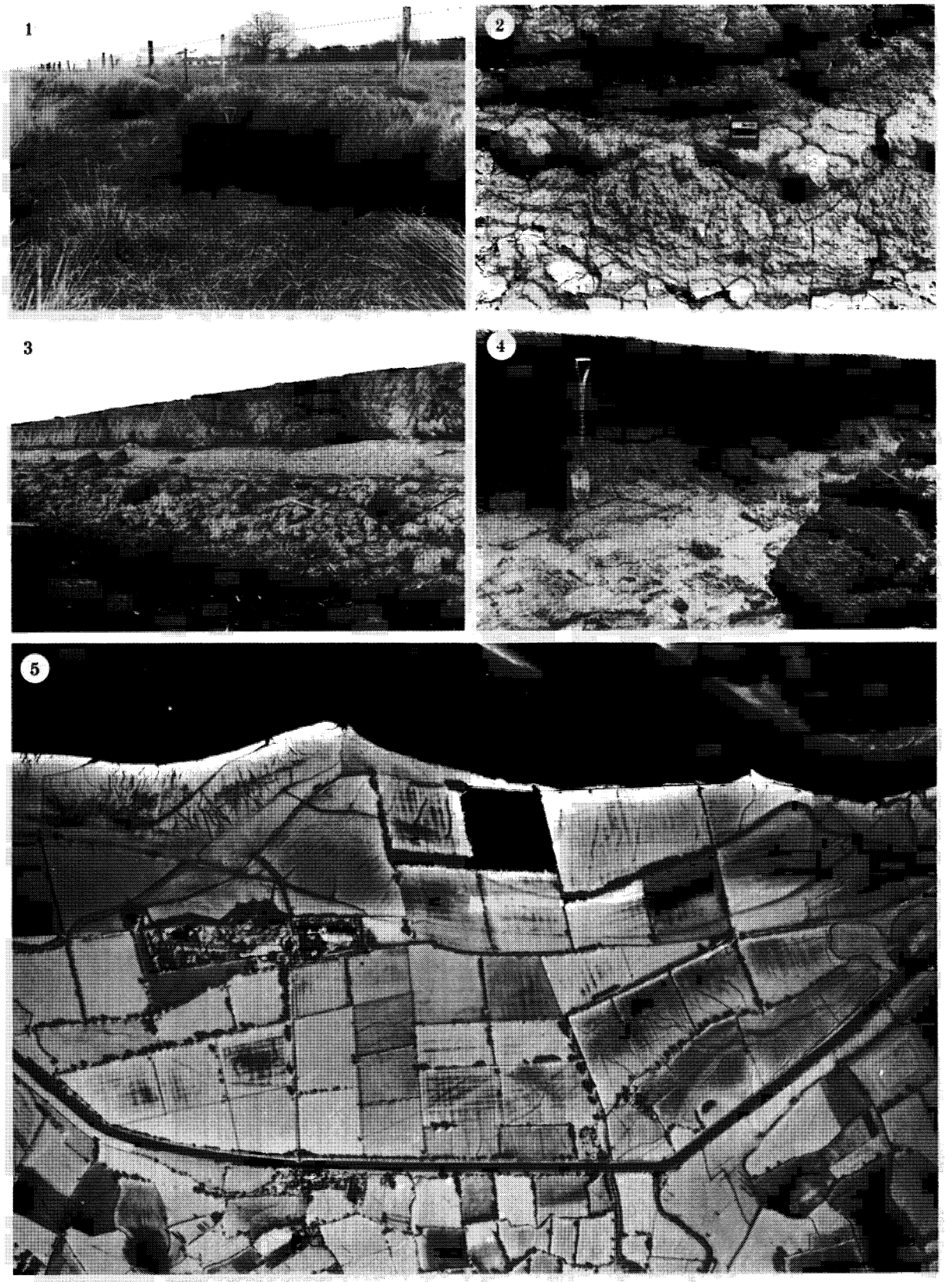

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8. Regional development

(*a*) *Gloucester to Longney*

The river between Gloucester (SO 81 19) and Longney (SO 75 12) occupies a narrow, deep and rather stable channel with sides largely obscured either by vegetation or piling and revetment (see figure 1). In many places cottages, gardens and orchards line the banks. Natural exposures are consequently few, and the geomorphic surfaces can be clearly separated at few places. Rumney and Northwick elements alone have been recognized.

Although the Rumney and Northwick formations are exposed as far north as Gloucester (for example, SO 817 195, 803 177), such elements are best displayed from the bend at Elmore (SO 78 15) downstream to Minsterworth and Elmore Back (SO 76 16). The Rumney and Northwick surfaces, neither more than 10 m wide, range almost continuously along both banks, a bold clifflet up to 0.65 m high separating them (see (1) of plate 3). There may be at least two intra-Rumney surfaces in this reach; the Oldbury Surface is not recognizable as a feature distinguished by ridge-and-furrow. On the right bank at Elmore (SO 796 150) the Rumney Formation consists of at least 1.15 m of structureless, bright pink estuarine silty sands and sandy silts that grade up into 0.4 m of grey interlaminated silty sands and silty-sandy clays. On the left bank north of Windmill Hill (SO 787 166) the river cuts across the Northwick formation and surface (see (1) of plate 3) to expose the Rumney Formation. Feebly laminated bright pink estuarine silty sands and sandy silts (0.9 m) here grade up into interlaminated grey sandy and muddy sediments (0.9 m). Nearer Elmore Back (SO 778 166) up to 1.4 m of the Northwick Formation is seen, consisting of mud-streaked sands and sand-striped silty clays that alternate in decimetre-scale bands. Signs of disturbance by cattle abound.

Exposures are few downstream. Between Bush Crib and Longney Crib (SO 762 119) the

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Descriptions of plates 3 and 4

Plate 3. Late Flandrian geomorphic features and sediments of the Severn Levels, Elmore, Rodley and Arlingham. (1) Left bank of the R. Severn E of Elmore Back (SO 786 166; view to E), where the river cuts across the degraded clifflet separating the Rumney (higher) from the Northwick (lower) surface. Spade 0.94 m long. (2) Smothered ridges (?ridge-and-furrow) on the Rumney Surface at Upper Dumball, Rodley (SO 758 114; view to S). (3) Clifflets separating the Northwick (lower, with spade 0.94 m tall), Awre (intermediate), and Rumney (upper) surfaces, Upper Dumball, Rodley (SO 740 107; view to NE). (4) Laminated silty clays and clayey sands with cattle tramples, Awre Formation, Lower Dumball (SO 721 122). Trowel 0.28 m long. (5) Air photograph (*ca.* 3.5 by 2.3 km; N to lower left) of the peninsula enclosed by the Arlingham bend. The Oldbury Surface is marked by ridge-and-furrow enclosed within a zig-zag mediaeval seabank. The clifflet separating the Rumney and Awre surfaces is clearly visible at the northern tip of the peninsula as a curving dark band enclosed between two seabanks. Photograph Crown Copyright reserved.

Plate 4. Late Flandrian geomorphic features and sediments of the Severn Levels, Arlingham, Frampton on Severn, and Slimbridge. (1) The Northwick Surface (lower, with spade 0.94 m long) separated by a clifflet from a higher surface, Arlingham (SO 694 112; view NNE towards Old Passage Inn). (2) Palaeosol (scale box 50 mm square rests on top) developed on buried Oldbury Surface exposed on river cliff W of Frampton on Severn (SO 738 073). (3) The Oldbury Surface with ridge-and-furrow buried beneath 1.6 m of younger (19–20th century) sediment, cliffs W of Frampton on Severn (SO 736 080; view to N). (4) Upper part of the Rumney Formation and edge of Rumney Surface exposed on Slimbridge Warth (SO 717 056). Spade 0.94 m tall. (5) Air photograph (*ca.* 3.5 by 2.3 km; N towards upper right) of Slimbridge Warth. The Gloucester and Berkeley Canal is the dark line running across the lower half of the photograph; the premises of the Wildfowl Trust appear centre left. Immediately W of the canal (centre right) is an oval embanked development of the Oldbury Surface. Adjoining this to the W is a rectangular reclamation of early 14th century date. An 18th century seabank ranges from this reclamation to the Wildfowl Trust's premises and beyond. To the NW remnants of The Gutt can be traced as dark bands across the fields. The modern sea defence hugs the coast before turning sharply inland towards the premises of the Wildfowl Trust. Photograph Crown Copyright reserved.

Rumney Formation consists of at least 1.05 m of pink interlaminated estuarine silty sands and sandy clays that grade up into similar but grey deposits. Upriver at Wicksgreen (SO 780 146, 758 150), however, the pink and grey deposits are sharply divided by a surface below which lies a plough soil. This contact may therefore record an intra-Rumney surface buried only when the seabank that originally isolated it became breached. The present defence lies some 50 m back from the river.

(*b*) *Rodley bend*

Here the channel widens noticeably as the current traces the first of the great incised meanders downstream from Gloucester (see figure 1). Only the Wentlooge Formation is not exposed.

The east–west cliff below Longney Sands reveals near the point (SO 760 117) up to 2 m of the Rumney Formation. The lowermost 1.4 m consists of pink estuarine silty clays interlaminated with silty sands. These grade up into grey, locally laminated sandy silts and silty sands with abundant roots and developments of soil structure. Surmounting the grey deposits is the Rumney Surface. Although no depositional break is evident on the cliff, the accumulation of the Rumney Formation at Rodley was in places interrupted for a period. The modern seabank lies up to 300 m back from the river, and inland of fields on which water stands to reveal a pattern of faint undulations (see (2) of plate 3), comparable with mediaeval ridge-and-furrow. The undulations are not bold enough to represent unmodified ploughing strips, however, and it is possible that, as at localities downstream (see below), the breaching of an early seabank led to the tidal smothering of part of the Oldbury Surface.

The Rumney, Awre and Northwick surfaces, the last two no wider than a few metres, range side by side (see (3) of plate 3) from the pill east of Crown Point to Blue Boys Farm on the south side of the bend (SO 747 107 to 744 108). Erosion in places shows the Northwick Formation to rest discordantly on the Awre beds, in a section up to 1.8 m thick. Each consists of well laminated, grey silty-sandy clays and silty sands. Abundant roots cut the Northwick beds, and in the Awre Formation cattle and sheep footprints are plentiful.

An extensive level called Lower Dumball ranges from Blue Boys Farm westward to Garden Cliff (SO 744 108 to 720 125). The Oldbury Surface, recognizable by its ridge-and-furrow and pink soils, is evident in places along the inner margin of this level, although its original seabank has now been largely flattened. A clifflet between the Rumney and Awre surfaces may lie concealed beneath the modern defence. The long cliff that borders Lower Dumball exposes up to 1.5 m of well-laminated grey sediments of the Awre Formation, locally much disturbed by cattle trampling (see (4) of plate 3).

Pink and grey Rumney sediments appear at numerous points near Epney and Upper Framilode on the river bank opposite Rodley (for example, SO 762 112).

(*c*) *Arlingham bend*

Relationships in the Arlingham bend, the second of the great loops swept by the river (see figure 1), are incompletely understood, partly because of poor exposure, and partly on account of piecemeal reclamation.

The Oldbury Surface, limited by the innermost (locally two-stage) of a series of seabanks, is readily recognized as a magnificent display of ridge-and-furrow and pink soils encircling the village (see (5) of plate 3). A few decimetres of pink silty to sandy clays of the Rumney Formation above pale green peaty clays of the Wentlooge beds can be seen west of Arlingham

(for example, Cottage Ditch, Westmarsh Ditch), and the Rumney Formation also appears (from behind the Awre Formation) on the river cliff northwest of the village. A temporary section at Church Lane (SO 705 099) to the south showed the Wentlooge peat followed by about 2.5 m of pale green clays and a few decimetres of Rumney beds.

On Arlingham Warth (see (5) of plate 3) the Rumney and Awre surfaces meet at a feature composed of a clifflet and marshy hollow (SO 709 129 to 704 126), a little outside an abandoned sea defence. The feature can be traced with difficulty southwestward through the fields towards the Old Passage Inn (SO 696 113). The modern seabank is mounted on the Awre Surface, outside which is a narrow development of the Northwick Surface. The Northwick Formation and the uppermost of the Awre beds are the only deposits seen on the river cliff between Arlingham Warth and the inn. Both consist of well laminated grey silty clays to silty sands.

Relationships are obscure on the level ranging downstream from Old Passage Inn to the bedrock and gravels of Hock Cliff (SO 72 09). The Northwick Surface, succeeding grey silty clays to silty sands, forms a narrow fringe along most of the river bank and is separated from a higher surface by an equally extensive clifflet (see (1) of plate 4). The thick, well laminated silts and sands exposed on the clifflet are also grey, suggesting either the Awre or Rumney formations. On the level above, however, there is no clifflet to delimit the Awre Surface, in contrast to Arlingham Warth.

(*d*) *Awre bend*

This is the third and last great loop below Gloucester (see figure 1). Awre village overlooks a curved level (see (1) of plate 2), the inner part of which, with ridge-and-furrow and pink soils, consists of the Oldbury Surface, followed outward by the Rumney and Awre surfaces. Near the triangulation station (SO 721 082) the Oldbury Surface lies a striking 1.2 m below the Rumney Surface.

The Trias cliffs that line the outside of the Arlingham bend give place downstream near the electricity pylons to the head of the level. Between the cliff and a small pill 1.2 m of the Rumney Formation is exposed (SO 705 093), grey silts gradually succeeding pink, and on the wharf above the Rumney and Awre surfaces can just be separated at an overgrown clifflet. On the river bank downstream the Northwick formation and surface are at first extensively developed as a narrow, obscuring fringe, but as the triangulation station (SO 721 082) is neared the Awre Formation increasingly appears. Between here and the first breakwater downstream (SO 720 080), a narrow stair-like development of the Rumney, Awre and Northwick surfaces is seen, the river bank trimming each in turn to expose the beds beneath. The Rumney Formation is represented by at least 1.3 m of pink ascending to grey silty to sandy clays with laminae of silty sand. The Awre Formation, banked against a cliff and gently shelving wave-cut platform cut into the Rumney beds, is exposed for 1.5–2 m and consists of well laminated, grey silty clays with abundant roots in the upper part. The Northwick Formation is represented by up to 0.45 m of grey laminated silt with roots. It overlies a gently shelving surface scoured across the older formations. A smaller development of Rumney and Awre elements occurs between the first and second (SO 717 077) breakwaters.

A large pill divides the deeply embayed level southwest of Awre (SO 705 072 to 700 068). The upstream river cliff reveals near Whitescourt almost 2 m of the Awre Formation, banked with a gravelly base against the Blue Lias and cryoturbated gravels of the Main Terrace (Wills 1938). Near the gutter (SO 706 073) a fragment of the Awre formation and surface lies against

a boldly sculptured cliff formed of Rumney beds. Towards the pill these pass beneath a blanket formed of the Northwick Formation. Just westward of the pill, however, the Northwick Formation butresses a cliff cut back into the Rumney Formation, the Rumney Surface lying 0.8 m above the highest levels reached by the Northwick Surface. All three formations and surfaces are detectable on the narrow level that ranges downstream from near the pill to Gatcombe.

(*e*) *Hock Cliff to Purton*

The bank in this great sweep of the estuary (see figure 1) is a bold cliff which skirts on the west a wide level that has changed significantly within historical time, reclamation having advanced in harmony with natural siltation. Relationships are locally complex and not yet fully understood, but all four formations have been recognized.

Hock Cliff (SO 731 089) grades southward near Hock Ditch (SO 735 085) to a level that displays a small development of the Oldbury Surface protected by a defence. The rhines expose 1–2 m of pale green silty clay attributed to the Wentlooge Formation, overlain by a few decimetres of pink Rumney beds. The Rumney Surface reaches from the seabank to the river cliff, where laminated pink grading up to grey silty to sandy clays of the Rumney Formation are exposed for several metres.

The cliff from Hock Ditch southward to Frampton Pill (SO 736 067) reveals up to 3 m of well-laminated pink silty to sandy clays of the Rumney Formation, much disturbed by cattle trampling. Instead of the normal upward transition to grey sediment, however, the pink clays are sharply terminated by a laterally extensive surface underlain by a thin orange- to green-mottled palaeosol with dense root channels (see (2) of plate 4). This is abruptly overlain by up to 1.8 m of well-laminated pinkish grey to grey silty to sandy clays similar to the Awre and Northwick formations. Ridge-and-furrow is extensively preserved on the sharp top of the palaeosol (see (3) of plate 4), and in two places a low seabank built of pink silt is seen in section beneath the draping grey sediments (Allen 1986). The top of the palaeosol is therefore identified as the Oldbury Surface, smothered no doubt as a consequence of the loss to the river of parts of the original defence.

The bold cliff continues southwestward from Frampton Pill, past Frampton Breakwater and Black Rock Breakwater, to Middle Point Breakwater (SO 718 057). Relationships here are uncertain, partly because geomorphic features on the warth were destroyed when fill was taken for the recently improved sea defence. The Awre Formation is the chief exposed unit and, although visible to the extent of more than 2 m, its outcrop is in many places little more than a few metres wide. The Rumney Formation is occasionally exposed on the back walls of large rotational slips.

From Middle Point Breakwater to the Lias cliff (SO 701 043) east of Purton, the river bank at first exposes up to 1.5 m of well-laminated pink then grey silts of what appears to be the Rumney Formation (see (4) of plate 4) and then, toward the stranded masonry breakwater (SO 704 044), the Awre Formation.

The wide level (Slimbridge Warth) ranging southwestward from Frampton Pill to Purton has undergone progressive reclamation, in harmony with unusually rapid natural siltation (Allen 1986). Immediately west of the Gloucester and Berkeley Canal, here largely obliterating the tidal River Cam, lies a substantial development of the Oldbury Surface (see (5) of plate 4), almost totally encircled by a low seabank and established on at least 1.2 m of the Rumney

Formation. The Rumney Surface at Frampton Pill, however, stands 0.7–0.8 m above the ridge-and-furrowed ground. A fragment of the Oldbury Surface, with the characteristic ridge-and-furrow and pink soils, occurs at the southwestern end of the warth (SO 709 041). Adjoining the larger occurrence to the west is a slightly higher (0.1–0.2 m) intra-Rumney surface enclosed within a bold, rectangular sea defence (see (5) of plate 4). This bank runs just inland from the now silted-up remnant of a wide channel (The Gutt) which formerly skirted a large muddy island (The Dumbles) (see (5) of plate 4). Largely to the south of the rectangular intake is a younger seabank that traces the inside of The Gutt for almost 3 km. Nearer the river, and crossing the by then silted-up channel on to the site of The Dumbles, is the youngest (outermost) defence (see (5) of plate 4).

East of Purton, between the curved channel called the Royal Drift and the Lias cliff, lies a narrow salting formed of the Awre and Northwick surfaces, the latter in two parts, a feature apparently restricted virtually to this particular reach (see (1) of plate 5). The Awre Surface is wide and level. Where the Northwick Formation is lacking on the river cliff, the Awre Surface is found to be underlain by 2–3 m of greyish pink grading up into thick (0.5–1 m) grey sandy to silty clays. The two parts of the Northwick Surface are each narrow and slope steeply together at a similar angle towards the river. Thick grey silty clays lie below. The clifflet dividing the two parts is deeply embayed and towards Tites Point the inner portion becomes increasingly fragmentary.

(*f*) *Purton to Sharpness*

The Awre Surface at Tites Point (Purton) (see figure 1) reaches a maximum width of almost 250 m (SO 691 046). On the river cliff up to 1.8 m of the Awre Formation overlies with a gravelly base a shelving platform of marine Silurian and Old Red Sandstone rocks. The Awre Formation consists of well laminated pink grading up to thick grey silty to sandy clays with some sand laminae. Again in two stages, fragmentary developments of the Northwick formation and surface buttress the Awre beds. Further southwest the Awre and Northwick (locally two-stage) surfaces (see (2) of plate 5) range continuously almost to Sharpness (SO 678 035) (see figure 1), the Northwick beds smothering abandoned barges. The Gloucester and Berkeley Canal traces the inner margin of this salting, and at two places the clifflet between the Awre and Northwick surfaces abuts against its bordering revetment (for example, SO 678 035).

(*g*) *Sharpness to Oldbury Power Station*

From the Old Red Sandstone cliffs at Sharpness (SO 66 02) the level widens unevenly southwestward toward the power station at Oldbury-upon-Severn (see figure 1). The bedrock platform extensively exposed between low and mid tide levels in this reach is capped by a thin development of Wentlooge clays and peats. The Oldbury Surface carries a magnificent development of ridge-and-furrow on pink soils and reaches to a seabank that generally falls within 100 m of the coast. At Berkeley Pill the Oldbury Surface lies 0.55 m below the Rumney level. Although the salting is narrow, there are few places at which the descending sequence formed by the Rumney, Awre and Northwick surfaces cannot be seen.

Between the old and new docks at Sharpness (SO 668 031 to 668 022) occurs a wide development of the Northwick formation and surface, its inner parts much obscured by tipping. Air photographs show that the Rumney surface and formation were originally also visible.

The ribbon of salt marsh ranging from the new dock (SO 668 022) to Berkeley Power Station

(ST 658 994) exposes narrow developments of the Rumney, Awre and Northwick surfaces and formations. The Rumney elements are fragmented, appearing chiefly at embayments in the seabank (SO 666 011, 665 008, 664 006) and Berkeley Pill (see (3) of plate 5). A more continuous strip of Awre formation and surface is seen (see (4) of plate 5), and the Northwick beds are also well developed (see (4) of plate 5), particularly upstream in the reach. The tidal currents at times uncover the erosional contact between the pink Rumney beds and the green Wentlooge clays below.

Berkeley Power Station overlooks to the southwest from a gravelly mound a triangular expansion of the salt marsh measuring approximately 600 m by 200 m (centre ST 653 990). The Rumney and Awre surfaces each approach 100 m in greatest width. The Rumney Surface abuts against a low degraded cliff cut back into orange-brown sandy gravels (see (5) of plate 5). Grey silty clays of the Rumney Formation appear for up to 0.2 m on the clifflet marking the outer edge of this feature (see (5) of plate 5), and the pink clays lower in the formation can be seen at neap-tide level along the river bank some distance away. The Awre Surface (see (5) of plate 5), ranging even further along the salting, is limited by a deeply embayed cliff up to 1 m tall butressed by the Northwick surface and formation (see (6) of plate 5). The Awre Formation sharply succeeds Rumney beds at the river bank and consists of well-laminated grey silty to sandy clays with scattered rubble washed from a breakwater or revetment. The Northwick Surface (see (6) of plate 5) is much narrower than the older ones, ending along the river in a low, neap-tide cliff on which up to 0.35 m of the Northwick Formation erosively overlie pink Rumney deposits.

The level between the Berkeley (ST 688 994) and Oldbury (ST 604 945) power stations exceeds 3 km in width and almost everywhere shows well-preserved ridge-and-furrow on heavy pink soils. Ditch-cleaning within this extensive occurrence of the Oldbury Surface (see (7) of plate 5) reveals the Wentlooge Formation (see also Cave 1977), capped by up to 0.85 m of Rumney beds.

Aside from fragmentary Northwick elements, little can be seen on the revetted coast between the triangular salting (ST 650 988) and the plantation (ST 634 979) that overlooks the bedrock (Triassic) platform called Hills Flats. At the plantation there begins a salt marsh up to 180 m wide ranging for 3 km downstream to near Shepperdine (ST 634 797). A survey of this salting prior to improvements to the sea defence showed the presence of fragments of the Rumney surface and formation, as well as long ribbon-like developments of the Awre and Northwick elements. These surfaces and formations are clearly evident in air photographs (see (7) of plate 5), the clifflet separating the Awre and Northwick formations being intricately embayed. The beds are all well exposed on the inner part of Hills Flats and on the adjoining river cliff. As Copeland (1981) noted, the Wentlooge Formation is represented by thin peats and pale green estuarine silty clays. These are sharply overlain on the neap-tide cliff by laminated pink silty clays of the Rumney Formation (see (1) of plate 6), succeeded in turn by grey laminated Northwick deposits. At some places (see (2) of plate 6), compact well-laminated silty to sandy clays attributed to the Awre Formation overlie the Wentlooge beds, but underlie Northwick clays with lenses of Triassic debris washed up to form pocket beaches. Locally, the Rumney Formation is directly succeeded by Northwick gravelly clays (see (3) of plate 6).

(*h*) *Lydney Harbour to Pillhouse Rocks*

Cliffs of Old Red Sandstone form the right bank of the estuary for 6 km between Awre bend and Lydney Harbour (see figure 1). Salt marshes are few and small, revealing only Northwick elements (for example, SO 670 041). From Lydney Harbour (SO 651 104) downstream to Pillhouse Rocks (ST 569 951), a discontinuous level in places more than 1 km wide occurs between the abandoned bedrock cliffline and forbidding mud cliffs that skirt the deep channel northwest of the Lydney, Shepperdine and Beacon sands. Their rapid erosion has largely excluded the Northwick Formation but afforded excellent exposures in older beds.

The seabank that defends the wide level called New Grounds south of Lydney separates an intra-Rumney surface from the Rumney and Awre surfaces (for example, SO 637 066). On the adjoining cliff appear several metres of well laminated grey silty-sandy clays attributed to the Awre Formation. Locally, pink clays of the Rumney Formation can be reached toward the cliff base.

Relationships are complex on the level, Aylburton Warth, between New Grounds and the bedrock platform of Guscar Rocks (ST 600 982). The Oldbury Surface is extensively but incompletely smothered, and there are signs of later but only partly successful reclamation. Further complications are introduced by two large pills with connecting channels. Both the Rumney and Awre surfaces are persistent features outside the seabanks; the cliffs mainly show a thick development of the Awre Formation. Near Guscar Rocks (ST 602 986), however, the river bank reveals up to 3.5 m of the Rumney Formation, its gravelly base overlying Wentlooge silts and peaty clays.

Above Guscar Rocks a low gravel cliff (ST 600 986) overlooks a narrow salt marsh composed only of Awre and Northwick elements. The Awre Surface is narrow, reaching back to the gravel, and the clifflet bounding it on the river side is deeply embayed. The Northwick Surface is broader and descends smoothly to the mudflat.

Between the cliffs of Triassic rocks (ST 585 977) south of Woolaston and Pillhouse Rocks (ST 569 951) is a wide salting called The Warth. At the Broad Stone (ST 578 973) a fragment of the Oldbury Surface is enclosed within a decayed seabank. At Horse Pill (ST 580 973) nearby all four formations, together with the Rumney, Awre and Northwick surfaces, appear in close proximity (see (4) of plate 6). The Wentlooge Formation consists of pale green silty clays. These are sharply overlain on a gravelly base by pink silty clays of the Rumney Formation, thickening gradually toward the river. The Awre Formation, found chiefly between the pill and the bedrock to the northeast, consists of up to 2.5 m of grey laminated clays on a sharp pebble-strewn surface. Within Horse Pill are fragments of the Northwick surface and formation. The river cliffs for 1.5 km to the southwest are dominated by the Awre Formation. Swelling towards the river, it reaches 3 m in thickness and rests erosively on Rumney beds, jumbled blocks of laminated pink clay appearing locally at its base. The Awre Surface on the warth above (see (5) of plate 6) can be traced for the same distance from Horse Pill, and in places is more than 100 m wide. Below Pill House (ST 568 952), where erosion has breached the Awre Surface, a metre or so of blue to green Wentlooge silts emerge at low water from beneath 9–11 m of Rumney beds with a gravelly base. The Awre formation and surface reappear above Pillhouse Rocks (ST 569 953).

(i) Oldbury Power Station to Aust Cliff

This long but relatively simple reach (ST 604 945 to ST 573 902) further extends the broad level that begins near Berkeley (see figure 1). It includes the typesite of the Oldbury Surface (see (2) of plate 1) and is noteworthy for the virtual absence of Awre elements.

The bedrock platform and river bank west of Oldbury Power Station repeat the situation at Hills Flats. Pebbly sands, peats and thin clays of the Wentlooge Formation followed by thicker pale green clays overlie the Triassic bedrock (Allen 1984) and range southwestward into Oldbury Pill (ST 602 938 to 600 928). The Wentlooge clays are sharply succeeded on the north bank of the pill by the Rumney Formation, which here, as at Hock Ditch–Frampton Pill (see above), smothers a portion of the Oldbury Surface. About 1 m of pink shading up to grey clay drapes over and buries a seabank and an adjoining ridge-and-furrowed surface developed on a green-mottled, locally calcareous palaeosol. North of the pill, the surviving Oldbury Surface lies 1.1 m below the Rumney Surface, and in places shows such well preserved ridge-and-furrow that even the paired ditches and dead ground (balks) between ploughed strips are recognizable (see (6) of plate 6). On the river bank north of Oldbury Pill, the Rumney, Awre and Northwick elements appear in step-like conjunction; the Awre formation and surface rapidly break up toward the rocks, the Northwick Formation eventually buttressing the Rumney beds.

The Awre formation and surface are lacking on Cowhill and Littleton warths, between Oldbury Pill and Aust Cliff. Here the Northwick surface and formation are nearly 100 m wide, buttressing an exposed cliff more than 1 m high cut into pink and then grey Rumney beds (see (7) of plate 6). Except toward Aust Cliff, where there is a smooth transition down to the mudflats, the Northwick Surface is limited by a bold neap-tide cliff, on which well-laminated grey silty clays of the Northwick Formation are visible for up to 0.75 m. The ridge-and-furrowed Oldbury Surface is well developed behind the seabank, overlying at least 1 m of the Rumney Formation (Welch & Trotter 1961).

(j) Pillhouse Rocks to the River Wye

Lengthy bedrock cliffs at Sedbury (ST 55 93) and Beachley (ST 55 90) break this right-bank reach (see figure 1) into two limited parts. Sturch Pill (ST 567 950) bisects a small triangular level. Both upstream and downstream of the pill, the Rumney, Awre and Northwick surfaces are in step-like conjunction, but only in the downstream section are the beds well exposed. An Awre element is lacking between the Rumney and Northwick surfaces on the narrow salting between Sedbury Cliff (ST 553 929) and the Beachley rocks (ST 550 920). Near Slimeroad Pill (ST 552 927), however, the bold neap-tide cliff exposes Awre and Northwick beds in sequence.

Another salting forms the left bank of the River Wye at Beachley, between Ewens Rock (ST 545 913) and Beachley Point (ST 547 903). The Rumney, Awre and Northwick surfaces are seen, the last two rather fragmentary, together with good exposures in the beds. Towards the point pale green Wentlooge clays emerge from beneath the modern mud. Pink Rumney clays succeed them sharply and, near the Severn Road Bridge, are themselves overlain by the basal gravels and grey laminated clays of the Awre Formation (see (8) of plate 6). The Northwick Formation consists of well laminated silty clays that bury an uneven surface cut across the older beds.

(*k*) *Aust Cliff to New Passage*

On Northwick Warth, between Aust Cliff (ST 564 893) and New Passage (ST 546 864) (see figure 1), there is a magnificent display of the Rumney, Awre and Northwick surfaces in step-like conjunction (see (2) of plate 2). The Oldbury Surface, lying 0.8–0.9 m below the Rumney Surface, is here up to 5 km wide. All except Wentlooge beds appear on the neap-tide cliff.

From Aust Cliff to Old Passage (ST 563 889), Northwick elements buttress the bedrock and grade down to the mudflat. The Rumney Surface makes its appearance between Old Passage and Cake Pill (ST 560 882) to the southwest. Between it and the Northwick Surface, fragments of the Awre surface and formation are evident. For 2.5 km southwestward from Cake Pill the three surfaces are clearly and continuously separable at embayed clifflets of variable height (see (2) of plate 2, and (1) and (2) of plate 7). The Awre Surface widens southwestward to a maximum of about 100 m, while the Northwick Surface expands to a greatest width of about 125 m.

The Rumney, Awre and Northwick formations are well exposed in sequence on the bold (2 m) neap-tide cliff developed mid way along Northwick Warth (see (3) of plate 7). The Rumney Formation consists of poorly stratified pink silty clays with occasional *S. plana* and *M. balthica* and numerous *N. diversicolor* burrows. Up to 1.5 m is seen but modern mud thickly obscures the base. The overlying Awre Formation sharply overlies a plane to slightly undulose surface that dips gently towards the river. The beds are well-laminated grey silty clays with some roots and burrows, to a maximum visible thickness of 0.75 m. A slight bedding discordance marks the sharp base of the Northwick Formation, composed of locally well-laminated grey silty clays with abundant roots exposed to about 1 m.

(*l*) *Severn Beach to Portishead*

The wide level between Severn Beach (ST 540 847) and Portishead (ST 47 77) is intensely industrialized, and relationships are in many places obscured (see figure 1). Traces of ridge-and-furrow abound in the area behind the seabank north of the River Avon, but the clay pits at Crook's Marsh (ST 542 822) and Hallen (ST 553 803) show that the mediaeval arable was established on Wentlooge clays with peats and not on a cap of Rumney beds. The Wentlooge Surface lies not less than 0.75 m below the Rumney Surface on the adjoining salt marsh, which in addition shows a ribbon-like development of the Awre and Northwick surfaces, but little in the way of exposures.

The coast (The Bin Wall) is heavily defended near Severn Beach, and little can be seen above New Pill Gout (ST 535 833). On Chittening Warth, between this pill and the fuel depot on the marsh (ST 523 813), the Rumney, Awre and Northwick surfaces occur in step-like conjunction (see (4) and (5) of plate 7), reaching maximum widths of up to 75 m. The outer edge of the Rumney Surface is deeply embayed. Industrial development obscures the marsh nearer the River Avon (ST 50 78).

The level between the Avon and Portishead is now occupied by new docks. Air photographs (see also Hawkins 1984), however, show that the Rumney, Awre and Northwick surfaces were all at one time present on St George's Wharf. The Rumney Surface here rose 0.8 m above the defended ground. A remarkable development of Northwick elements occurs at Portbury Wharf (ST 48 77) to the southwest, where either the Awre or Rumney surfaces, or both, were smothered or erosion had reached the sea defence.

(*m*) *Clevedon to Middle Hope*

The rocky coast between Portishead and Clevedon (ST 390 707) only reveals fragmentary Northwick elements. A deep level commences at Clevedon, stretching from there southwestward past the estuaries of the Congresbury Yeo and River Banwell to the promontory of Middle Hope (ST 349 665) (see figure 1). Piecemeal reclamation and repeated attempts through revetting to stabilize this shore have resulted in the destruction of much evidence. Behind the seabank, however, lies the Wentlooge Surface, developed on pale green clays well exposed in the fields and drainage ditches, and situated 1.25 m below the only fragments of the Rumney Surface identifiable on the coast.

The small bay surrounding Clevedon Pill (ST 391 702) is occupied by the Northwick formation and surface. To the south, fragmentary Rumney elements survive near Hook's Ear (Kingston Pill) (ST 384 691 to 383 686). Low down on the shore the Rumney Formation lies erosively on the Wentlooge beds. The uneven contact is overlain by pink to orange silty-sandy clays with abundant shell debris and some pebbles (see (6) of plate 7). The topmost beds – pink silty clays that rapidly grade up into 0.1 m or so of grey clay – appear on a bold cliff capped by the Rumney Surface, against which the Northwick surface and formation lie banked (see (7) of plate 7). At the northern end of the broken cliff (ST 384 691) a fragment of the Awre surface and formation is recognizable. The grey laminated silts overlie a gently shelving platform strewn with blocks and fragments torn from the Rumney cliffs. The Awre Formation is also exposed low on the shore, succeeding the Wentlooge or Rumney beds, or both, erosively. Relationships are obscure in Woodspring Bay, but traces of the three younger formations and surfaces appear along both the Congresbury Yeo and the River Banwell.

(*n*) *River Wye to Cold Harbour Pill*

The geomorphic and lithostratigraphic elements are fully represented between the River Wye (ST 542 913) and Cold Harbour Pill (ST 431 842) (see figure 1), and it is only in the southwest of this reach that defence work obscures relationships. Their disposition is the mirror-image of that seen on Northwick and Chittening warths, on the opposite side of the estuary.

The part of the Caldicot Level developed between the Severn Road Bridge (ST 431 842) and the bedrock at Red Cliff (ST 522 896) locally displays ridge-and-furrow on pink soils and is assigned to the Oldbury Surface. Outside the zig-zag seabank is a step-like development of the Rumney, Awre and Northwick surfaces, each in places more than 50 m wide. The deeply embayed Rumney Surface (see (1) of plate 8) stands 0.4–0.55 m higher than the equally embayed Awre Surface. The latter, however, is barely separable from the Northwick Surface below, the intervening clifflet rising no more than 0.15 m (see (2) of plate 8). All three elements gradually narrow towards Red Cliff and at the bedrock itself only the Awre formation and surface remain. The Awre Formation, exceeding 2 m in thickness, consists of grey well-laminated silty-sandy clays.

The beds are better exposed between Red Cliff and Black Rock (ST 554 882), for here the Rumney, Awre and Northwick surfaces are both narrower and deeply embayed. In places the Northwick Formation buttresses a cliff cut wholly in Rumney beds. The Rumney Formation consists of pink grading up into grey silty clays. The Awre Formation, composed of laminated grey silty-sandy clays, overlies it sharply at an uneven contact (see (3) of plate 8), a few shells and pebbles strewing the erosional base. The Oldbury Surface behind the sea defence preserves ridge-and-furrow and lies approximately 0.9 m below the Rumney level.

The modern seabank between the Triassic promontory at Sudbrook (ST 502 873) and Caldicot Pill (ST 490 872) straddles an ultimately wide development of the Rumney formation and surface and a narrow occurrence of Awre elements (see (4) of plate 8), a revetted cliff bounding the latter to seaward. Little of the Rumney beds is visible, but the Awre Formation consists of grey silty-sandy clays with bands of pebbles and shells. A gradually expanding development of the Northwick formation and surface buttresses the revetment and ranges from near the pill northeastwards to the promontory fort. From Caldicot Pill southwestwards to Collister Pill (ST 453 857) the salting is limited to seaward by a tall revetment and consists largely of Rumney elements. Near West Pill the Northwick formation and surface reappear. Ridge-and-furrow is locally visible on the pink soils of the Oldbury Surface near Caldicot Pill.

The slight embayment in the seabank between Collister Pill and Magor Pill (ST 439 848) contains a broad salt marsh composed of the Rumney, Awre and Northwick surfaces. Near Magor Pill the Rumney elements are bounded seaward by a revetted cliff, buttressed by the Awre surface and formation. Towards Collister Pill, however, the seaward margin of the Rumney surface is a deeply embayed free cliff on which pink to grey silty clays are exposed (see (5) of plate 8). The Awre and Northwick surfaces cannot be separated at Collister Pill but become increasingly distinct towards the southwest with the growth of the intervening clifflet (see (6) of plate 8). Well-laminated grey silty clays make up the Awre and Northwick formations. Tall revetments largely obscure the Rumney and Awre beds developed between Magor and Cold Harbour pills.

(*o*) *Cold Harbour Pill to River Usk*

Most of this shore (see figure 1) is concealed behind a bold masonry defence mounted for the most part on the peat in the uppermost Wentlooge Formation. Although Rumney elements are little in evidence, and Awre features are restricted to one locality, the Northwick Formation is extensively developed.

The shore between Magor Pill and the Triassic–Lias promontory of Goldcliff (ST 365 823) affords extensive exposures of peats and pale green silty clays in the uppermost Wentlooge Formation, at about O.D. to a metre or two above. At many places two peats are recognizable, a lower bed approximately 0.2 m thick divided from an upper peat measuring 0.6–0.8 m by up to 1.25 m of silty clay. As Locke (1971) noted, parts of the (higher) peat are consistently woody, with many *in situ* tree stools and fallen trunks, particularly of birch. *Phragmites* abounds in the lower parts of the upper peat and in the lower bed; the higher parts of the upper bed are locally a *Sphagnum* peat. Wentlooge clays and peat reappear to the west near the Nash breakwater (ST 336 822).

The Rumney Surface appears on the salt marsh at Nash (ST 323 832) and west of Goldcliff (ST 357 824), where the cliff on its seaward side is revetted, and again at the mouth of Goldcliff Pill (ST 363 825) (see (7) of plate 8). Here and in the banks of the pill the formation consists of pink silty clays that grade up into 0.2–0.4 m of grey silty-sandy clays. In places along the channel, and notably on the right bank (ST 362 825), the Awre Surface is developed, the Awre Formation consisting of grey silty-sandy clays. The Northwick formation and surface are continuously banked against a cliff in the Rumney Formation on the coast between Goldcliff and the Nash breakwater. A patchier development extends from the breakwater to the River Usk.

The main part of the Caldicot Level, ranging southwestwards from the early 19th-century reclamation called Caldicot Moor (ST 45 86), conspicuously lacks ridge-and-furrow and is

identified with the Wentlooge Surface. On each side of Goldcliff Pill, for example, the level lies 0.9–1.0 m below the Rumney Surface and is established on pale green silty clays typical of the Wentlooge Formation.

(*p*) *River Usk to Rhymney River*

The coast of the Wentlooge Level (see figure 1) is less obscured by sea defences than the Caldicot Level and reveals fine sections in the Wentlooge and Rumney formations (Allen 1987), together with an extensive display of Northwick elements. The Wentlooge Level is remarkable for its regular rectangular fields which, at the seabank, lie as much as 1.55 m below the Rumney Surface outside the defence (see (1) of plate 1).

A salting up to 150 m wide ranges from New Gout (ST 311 815) on the River Usk to the shore near St Brides Wentlooge (ST 300 815). The Northwick surface and formation buttress a cliff cut in the Rumney beds as far south as the lighthouse (ST 311 829), but beyond are bounded by a tall revetment. Wentlooge clays and peats underlie the foreshore between St Brides Wentlooge and Peterstone Gout (ST 278 807).

Peterstone Great Wharf (ST 278 807 to 254 790), in places up to 250 m wide, is chiefly occupied by the Northwick surface and formation, banked against a deeply embayed cliff exposed to a height of 0.6 m cut into Rumney beds (see (1) of plate 1). To seaward an embayed neap-tide cliff up to 1.25 m tall limits the Northwick elements. The beds consist of well

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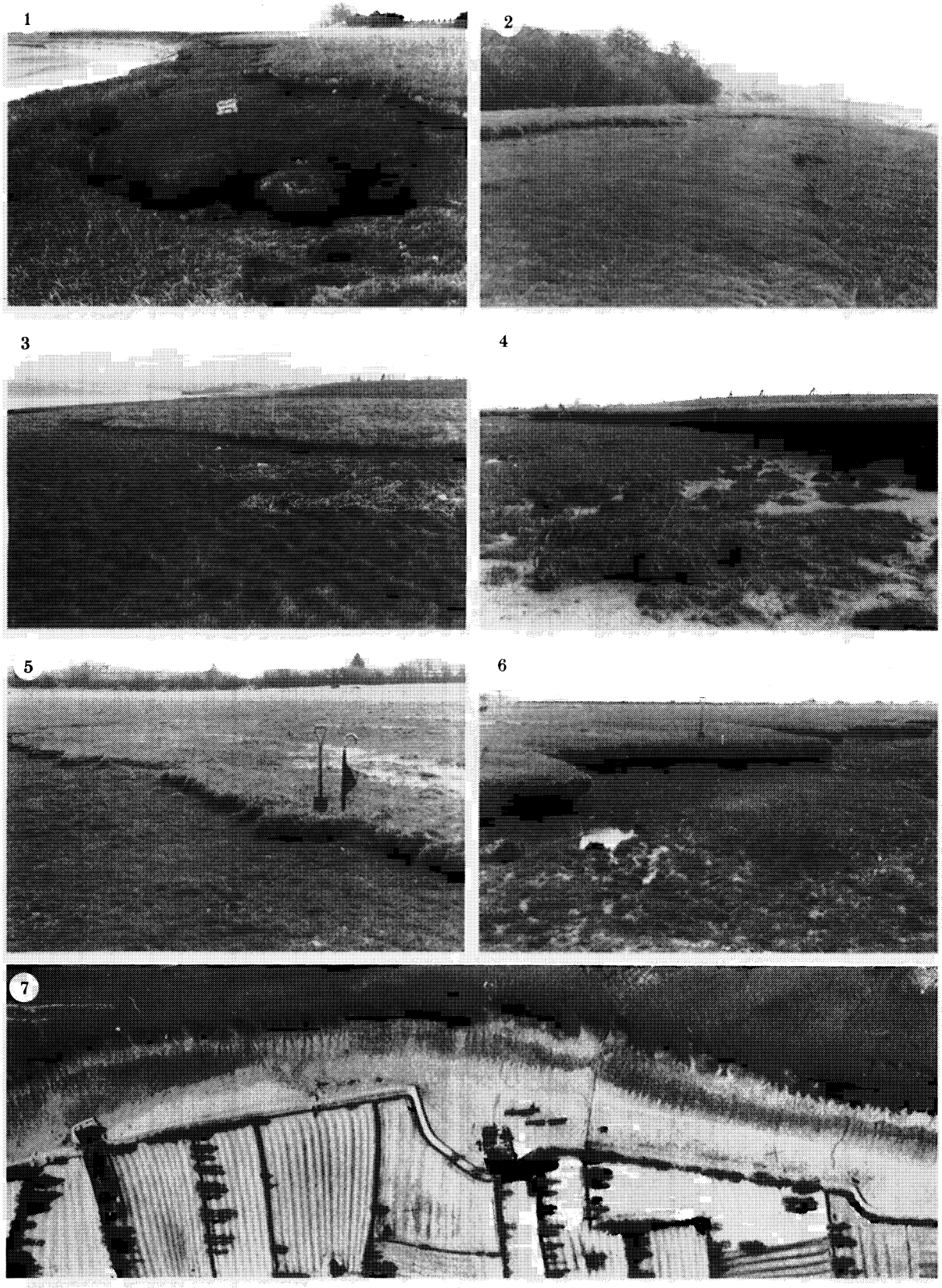
Descriptions of plates 5 and 6

Plate 5. Late Flandrian geomorphic features and sediments of the Severn Levels, Purton, Sharpness, Berkeley and Hills Flats. (1) The lower Northwick (lower), upper Northwick (intermediate, with collecting bag 0.3 m long), the Awre (upper) surfaces, adjoining the Royal Drift, Purton (SO 696 045; view to ENE). (2) The Northwick (lower and intermediate) and Awre (upper) surfaces between Tites Point and Sharpness (Gloucester and Berkeley Canal behind trees to left) (SO 681 038; view to SW). Northeastward from this point, the clifflet separating the two parts of the Northwick Surface dies away, the surface becoming a single feature. (3) The Awre (lower) and Rumney (upper, with spade 0.94 m long) surfaces N of Berkeley Pill (SO 663 004; view to N). (4) The Northwick (lower, with spade 0.94 m tall) and Awre (upper) surfaces N of Berkeley Pill (SO 663 004; view to N). (5) The Awre (lower) and Rumney (upper, with spade 0.94 m long) surfaces, Berkeley Power Station (SO 667 019; view to N). The gravel terrace that forms the inner margin of the level appears (upper right) beyond the Rumney Surface. (6) The Northwick (lower, with umbrella) and Awre (upper, with spade 0.94 m long) surfaces, Berkeley Power Station (SO 667 019); view to S). The clifflet at the edge of the Rumney Surface is faintly visible (upper left). (7) Air photograph (*ca.* 0.9 by 0.3 km; N to upper right) of part of Hills Flats (White House in centre). The Oldbury Surface SE of the seabank shows well developed ridge-and-furrow. On the salting NW of the defence the Rumney (light tone), Awre (light to intermediate tone), and Northwick (light to dark tone) surfaces are visible in descending sequence to the frondescent outer margin of the Northwick Surface. Photograph Crown Copyright reserved.

Plate 6. Late Flandrian geomorphic features and sediments of the Severn Levels, Hills Flats, Oldbury-upon-Severn, Woolaston, Littleton and Beachley. (1) Cliff section exposing the Wentlooge (below scale box 50 mm square), the Rumney (between scale box and pencil), and the Northwick (above pencil) formations, Hills Flats (ST 617 968). (2) Cliff section exposing the Wentlooge (with spade 0.94 m long), Awre and Northwick formations, and the outer margin of the Northwick Surface, Hills Flats (ST 617 968). (3) Cliff section exposing the Northwick Formation (scale box 50 mm square on gravelly base) overlying Rumney beds, Hills Flats (ST 626 974). (4) The Northwick (lower), Awre (intermediate), and Rumney (upper) surfaces on the N bank of Horse Pill, Woolaston (ST 579 972; view to ENE). The Wentlooge Formation appears in the foreshore on the extreme right of the photograph. (5) The Awre (right) and Rumney (left, with spade 0.94 m tall) surfaces on The Warth (ST 577 696; view to NE). (6) Ridge-and-furrow with balks in fields on N bank of Oldbury Pill (ST 608 924; view to NNW). (7) The Northwick (lower, with spade 0.94 m long) and Rumney (upper) surfaces, Littleton Warth (ST 576 904; view to NE). (8) Cliff section exposing the Awre Formation with gravelly base overlying Rumney silts (with spade 0.94 m long), Beachley (ST 544 909; view to SSW).



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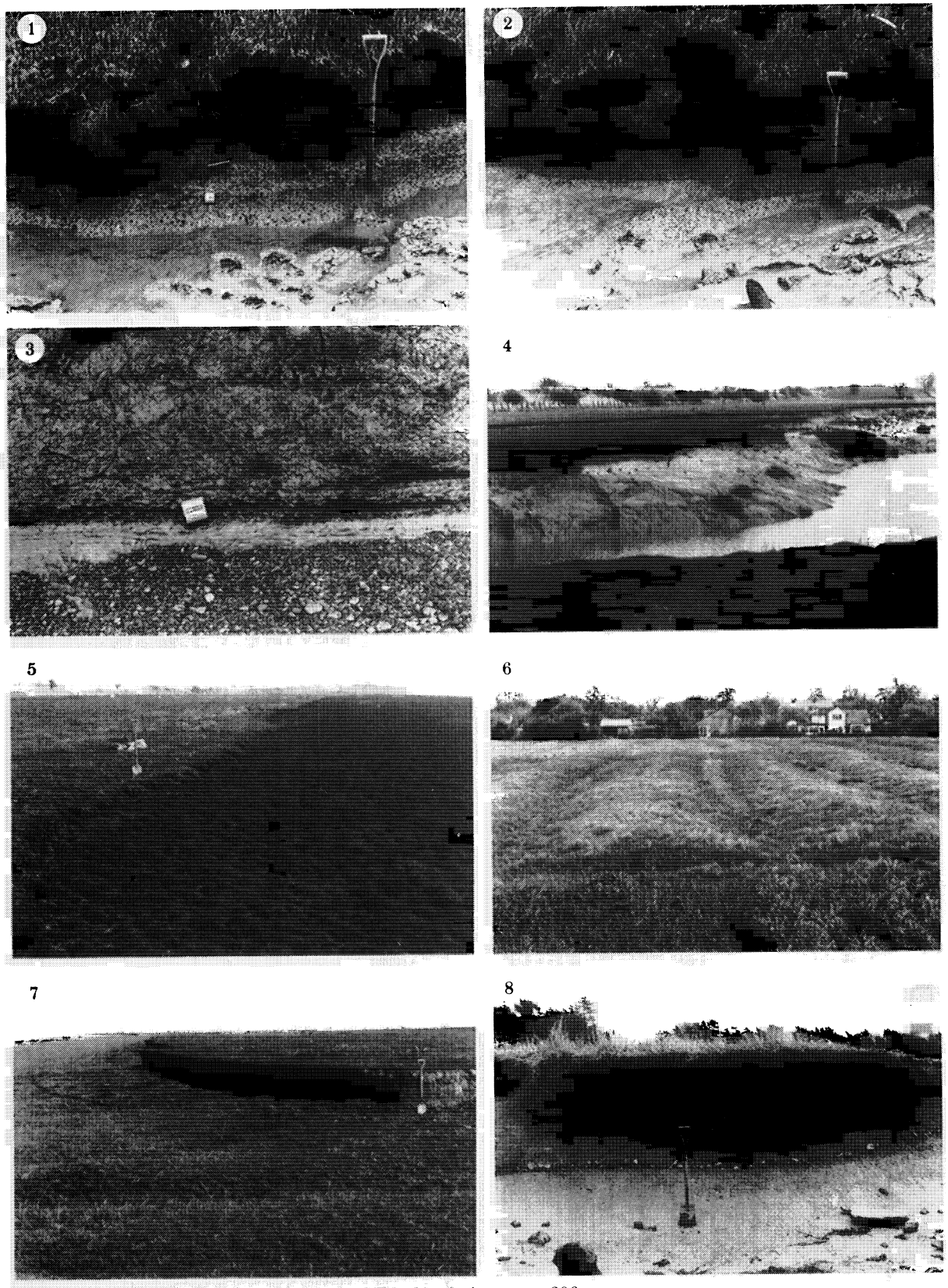

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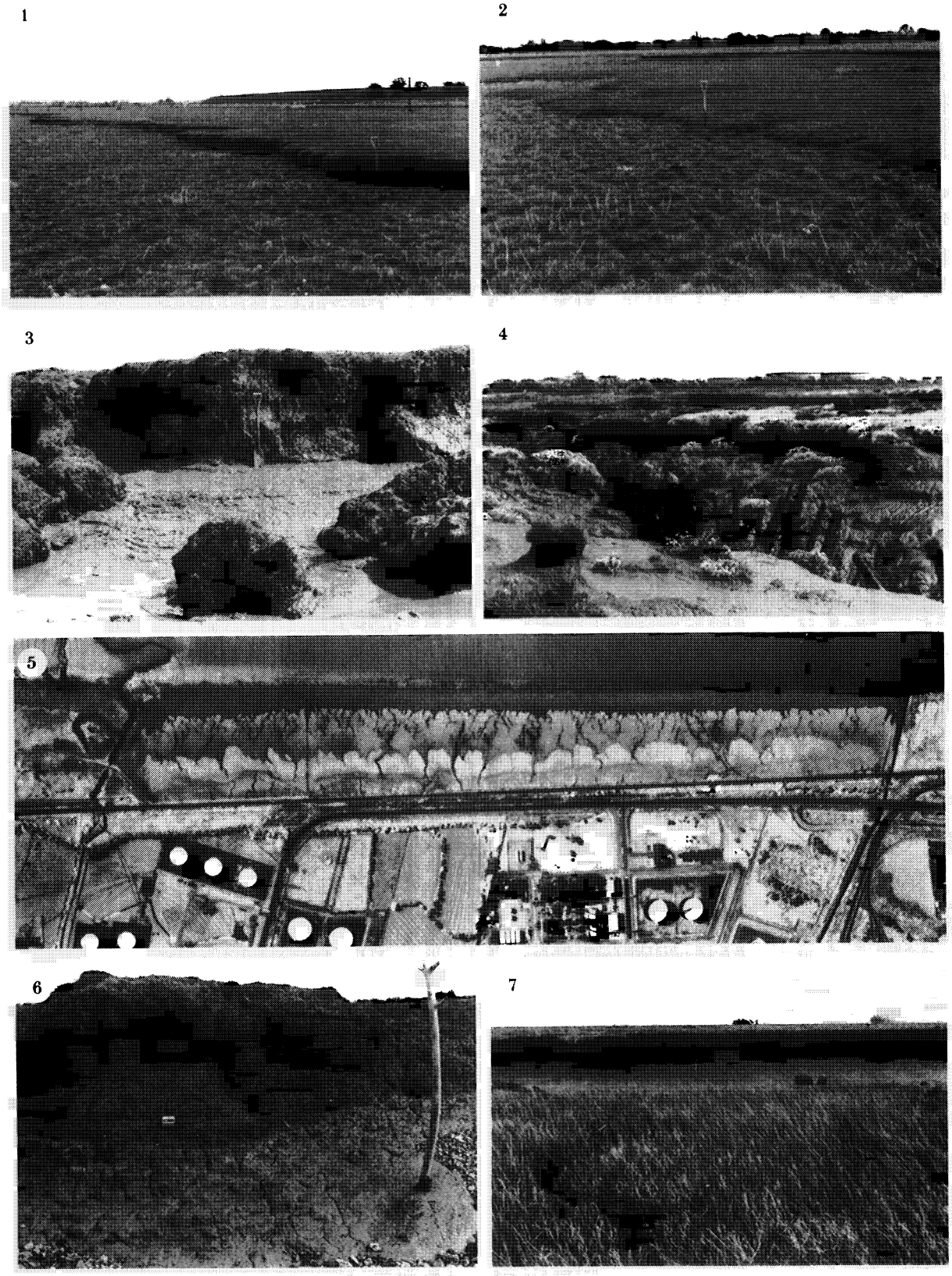

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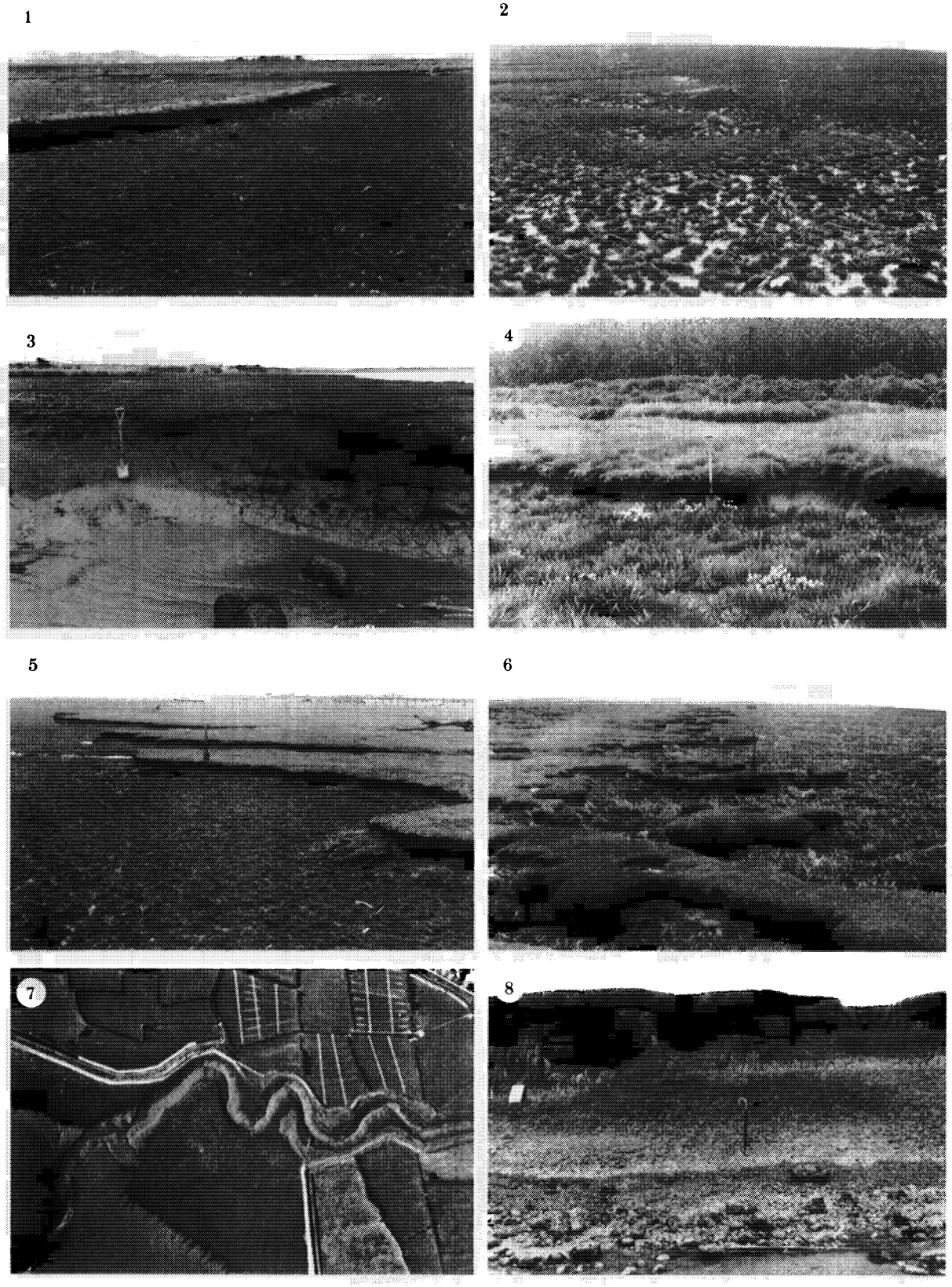

For description see opposite.

laminated grey silty clays with pockets of shells and pebbles at the uneven, erosional base cut into the upper Wentlooge and basal Rumney sediments.

High-water level at Rumney Great Wharf, Little Wharf and Pengam Moors (see figure 3*a*) is marked by a bold and deeply embayed mud cliff 2–3 m tall on which are exposed the upper Wentlooge Formation and, lying sharply above, the Rumney Formation. Locally, the Rumney Formation cuts down from the Wentlooge palaeosol (pale horizon over dark; buried Wentlooge Surface) to fill wide embayments scoured into those beds (see (8) of plate 8). The Awre surface and formation fringe the mouth of the Rhymney River (see figure 3*a*) and these elements recur in some of the gullies that drain Rumney Great Wharf (for example, ST 246 784). The beds are well-laminated grey silty-sandy clays. Northwick elements are lacking, except along the Rhymney River.

9. Age and correlation: archaeological and historical evidence

Archaeologically, the Wentlooge Formation ceased to be deposited during or shortly after the Roman period, when the Wentlooge Surface was also created. The base, however, seems likely to prove to be markedly diachronous.

Descriptions of plates 7 and 8

Plate 7. Late Flandrian geomorphic features and sediments of the Severn Levels, Northwick Warth, Chittening Warth and Kingston Seymour. (1) The Northwick (lower, with spade 0.94 m long), Awre (intermediate), and Rumney (upper) surfaces, Northwick Warth (ST 557 878; view to NNE). (2) The Northwick (lower, with spade 0.94 m long), Awre (intermediate), and Rumney (upper) surfaces, Northwick Warth (ST 553 872; view to NNE). (3) Cliff section exposing the Rumney Formation (spade 0.94 m long rests on upper contact), Awre (between bottom of spade and almost the top of the handle) Formation, and Northwick Formation (above handle), Northwick Warth (ST 553 874). (4) The Northwick (lower) and Awre (upper) surfaces on the S bank of New Pill Gout, Chittening Warth (ST 535 832; view to S). (5) Air photograph (*ca.* 1.5 by 0.6 km; N to upper right) of part of Chittening Warth between New Pill Gout and Stup Pill. The embanked railway (site of seabank) and main road run along the centre of the photograph. Ridge-and-furrow is visible on the Wentlooge Surface between the factory sites. On the salting the Rumney (light tone), Awre (intermediate tone), and Northwick (dark tone with frilled margin) surfaces form a laterally continuous descending sequence. Photograph Crown Copyright reserved. (6) Erosive gravelly contact between the Rumney and Wentlooge formations, Kingston Seymour (ST 379 681). Scale box 50 mm square. (7) Bold cliff exposing the Rumney Formation and separating the Northwick (lower) and Rumney surfaces (upper), N of Hook's Ear (ST 384 690). White stick propped against cliff is approximately 0.9 m long.

Plate 8. Late Flandrian geomorphic features and sediments of the Severn Levels, the Caldicot Level and Wentlooge Level. (1) The Awre (lower, with spade 0.94 m long) and Rumney (upper) surfaces, Mathern (ST 534 902; view to NE). (2) Barely detectable clifflet dividing the Awre (left, with spade 0.94 m long) and Northwick (right) surfaces, Mathern (ST 534 901; view to NE). (3) The Awre Formation (base at bottom of blade of spade 0.94 m long) unevenly overlying the Rumney Formation, Black Rock (ST 515 886; view to NE). (4) The densely vegetated Northwick (lower, with spade 0.94 m long), Awre (intermediate), and Rumney (upper) surfaces, Caldicot (ST 497 873; view to N). The seabank appears just in front of the plantation. (5) The Awre (lower) and Rumney (upper, with spade 0.94 m long) surfaces, near Chapel Tump Farm (ST 448 895; view to SW). (6) The Northwick (right) and Awre (left, deeply embayed, with spade 0.94 m long) surfaces, S of Chapel Tump Farm (ST 444 851; view to NE). (7) Air photograph (*ca.* 1.1 by 0.7 km; N to upper right) of Goldcliff Pill, Caldicot Level. The masonry revetment on which the seabank is mounted appears as a pale line. An extensive development of the Northwick Surface (dark tone) lies to seaward. Small developments of the Rumney Surface are enclosed within the second, third and fourth meanders of the pill, the Awre Surface (not visible in photograph) appearing in addition in the third meander. Photograph Crown Copyright reserved. (8) Cliff exposing the Wentlooge and Rumney formations, Rumney Great Wharf (ST 244 782; view to N). The umbrella (0.85 m long) rests on the Wentlooge Formation. The pale horizon of the Wentlooge palaeosol (headland) appears towards the top of the cliff on the right, but is cut out towards the left by the descending base (bottom of clipboard) of the Rumney Formation (embayment of the pre-Rumney coast).

At several localities in the middle and upper estuary, the sub-Flandrian bedrock surface rises by some metres to form low eminences. The 'upper peats' of the Wentlooge Formation can at such places be seen to thin, merge and apparently grade laterally into muddy, sandy to pebbly soils with root channels. Where this occurs at Oldbury Flats (ST 602 937 to 603 940), the soil beneath the Wentlooge peats and clays yields a scattering of flint artefacts, while on the bedrock surface nearby occur two unequally dense strews (first detected by Dr M. G. Fulford) of debitage presumed to have resulted from the reworking of this soil by the tide in modern times. A collection largely from the strews totalling 543 items (lithologies: Cretaceous flint, Carboniferous and Cretaceous cherts, felsic tuffs, metaquartzite, granophyre) included many blades, cores and core fragments, together with several scrapers and a fabricator. Mr A. G. Brown also kindly identified in the collection a Mesolithic microlith (awl, Mèche de Foret) similar to material from southwest Wales (Jacobi 1980), a broken 'chisel' arrowhead for which a later Neolithic date is most probable (Green 1980), and the butt end of a Beaker-period dagger, most likely to have been current in the earlier Bronze age (Green *et al.* 1982). On this evidence, the Wentlooge beds succeeding the eminence may be no older than the second millennium B.C.

Allen & Fulford (1986) demonstrated physically that the Wentlooge Level was embanked and drained during the Roman period. At the most important site, on Rumney Great Wharf (ST 244 782), the Wentlooge palaeosol seals a large ditch, visible in profile on the mud cliff, infilled with uniform silty clay containing thinly dispersed cultural debris. This includes many second- to mid-fourth-century pottery sherds lacking signs of either abrasion or water sorting. The ditch with its fill ranges up to a horizon within the limits of the Wentlooge palaeosol, and is part of an extensive system of drainage channels whose eroded remnants, visible on the foreshore peat ledge, are indistinguishable in scale and pattern from the open ditches behind the modern seabank. Nearby (ST 245 782), apparently on or near an occupation surface, similar pottery was found to range no lower than 1.1 m below the top of the Wentlooge palaeosol.

It is less certain but highly probable that much of the Caldicot Level was also embanked and ditched during Roman times. At a level in the Wentlooge Formation close above the upper peats exposed on the foreshore, Barnett (1961) recovered from a temporary excavation (ST 32 83) a variety of cultural debris including many second-century pottery sherds. The finds 'were grouped closely together' and this, together with their stratigraphical position, is compatible with a ditch setting, as at Rumney Great Wharf. The close proximity to the top of the peat of the first- and third-century pottery recorded by Boon (1967) from grey estuarine silt at Magor Pill (ST 535 850) is also consistent with rubbish disposed of into either a natural or artificial ditch cut into the upper Wentlooge Formation. The context of the foreshore strews of second-century pottery reported by Nash-Williams (1951) and Boon (1967) from Cold Harbour and Magor pills (ST 432 842, 436 846), re-examined by one of us (J.R.L.A.), also points to derivation from this general stratigraphical level.

On the English side of the Severn Estuary, circumstantial evidence strongly suggests that embankment during the Roman period also created the Wentlooge Surface lying between Clevedon and Middle Hope (North Somerset Level) (see figure 1). Not only are many substantial finds of Romano-British pottery at shallow depths reported from the area (Lilly & Usher 1972), but a commodious house, the Wemberham Villa (ST 404 652), lies in the heart of the level and within the seabanks that line the Congresbury Yeo (Reade 1885; Scarth 1885;

Smyth-Pigott 1885). As Scarth remarked, 'this district was early brought under cultivation' and 'the embankments which are now so carefully attended to, must be Roman in their origin'.

Two important foreshore pottery strews occur upriver, at Oldbury-upon-Severn (ST 60 93) (Green & Solley 1980) and Hills Flats (ST 62 97, 63 98) (Copeland 1981) (see figure 1). The Oldbury sherds are so far dated merely as Romano-British. They cannot have come either from the sandy base of the Wentlooge Formation, which here yields flint tools and production waste (see above), or from the immediately overlying peats and intervening clays, which lack pottery, but could have been reworked from higher up in the Wentlooge Formation. A similar but much smaller and again unstratified strew occurs on the north bank of Oldbury Pill (ST 600 928). At Hills Flats Copeland found 'sherds embedded in clay layers in and above the peat', implying a Romano-British date for the higher parts of the Wentlooge Formation.

Archaeologically, the Rumney Formation is post-Roman. At Rumney Great Wharf, Allen (1987) found Romano-British pottery sherds to be widely dispersed in the basal beds, as well as at higher levels up to and including the present time (see also Allen & Fulford 1986). These transposed sherds are noticeably abraded, in contrast to the sharp angular fragments recovered from the Wentlooge Formation. Romano-British pottery sherds have been reworked into the basal Rumney beds elsewhere on the river, at Horse Pill (ST 580 973) and Woolaston (ST 604 988), where the Wentlooge Formation is also exposed, and at Awre (SO 705 072) far upstream (see figure 1).

The age difference between the Rumney and upper Wentlooge formations is in fact substantial. Above the metalling of the Roman quay at Caerleon (see figure 1), Boon (1978, 1980) discovered pottery of the 13th to early 14th century at the sharp contact between his brown estuarine clay (Rumney Formation) and a grey estuarine clay (Wentlooge Formation) below. Allen & Fulford (1986) found a pottery rim sherd of the 16–17th century at the base of the Rumney Formation where it overlay the Wentlooge palaeosol on Rumney Great Wharf (ST 241 780). Sixteenth-century pottery occurred within the Rumney Formation at Caerleon (Boon 1980).

The only historical evidence for the age of the Rumney Formation comes from a dated reclamation sequence on Slimbridge Warth near Berkeley (Allen 1986) (see figure 1). The rectangular intake shown in (5) of plate 4 was engineered by Thomas Berkeley III in the early 14th century and, building outwards from it, exploits an earlier embanked development of the Oldbury Surface. Both intakes overlie at least 1.2 m of the Rumney Formation; a lesser thickness was observed beneath ridge-and-furrow in a new drain south of Oldbury Pill (ST 599 929). This evidence therefore supports the generally accepted view that ridge-and-furrow, and by implication the Oldbury Surface, is of early or high mediaeval date, although possibly older in rare cases (Hall 1981, 1982).

No artefacts other than transposed Romano-British debris have so far come from the Awre Formation, but historical evidence at one locality assigns the deposition of the beds to no earlier than the earliest 19th century. At a point between Purton and Sharpness (see above) the Awre Surface abuts against the masonry revetment containing the Gloucester and Berkeley Canal, completed in 1827.

At Beachley (ST 545 905) on the River Wye the Northwick Formation overlies an erosional surface strewn with glazed whiteware pottery, possibly a military issue, of late 19th or early 20th century type. The youthfulness of the Northwick Formation is also attested historically. Northwick Warth reveals today a magnificent stair-like development of the Rumney, Awre and

Northwick surfaces (see figure 3*c* and (2) of plate 2). On the Ordnance Survey six-inch map of 1887, however, there appear only the Rumney and Awre surfaces, the embayed clifflet between the two occupying its present-day position. The coast, a cliff eroded in the Awre Formation, retreated between this date and the resurvey for the 1904 map. The 1924 map shows the seaward clifflet bordering the Awre Surface at its present-day position, but gives little sign of a mud accumulation beyond. It is only on later maps that an outward-expanding Northwick surface and formation are depicted. Similar coastal movements are evident at Goldcliff Pill on the Welsh bank (see (7) of plate 8). The 1887, 1902 and 1922 maps reveal a rapid landward retreat of the seaward cliff bordering the Rumney Surface at the mouth of the pill, and no sign of Northwick elements. Later maps and air photographs depict the seaward margin of the Rumney Surface approximately at its 1922 position, together with a growing and ultimately substantial mass of Northwick Formation. Hence the Northwick Formation would seem to date from early in the present century, and the erosional surface against which it is banked from a not much earlier period.

10. Age and correlation: radiocarbon dating

Radiocarbon dating (relative to 1950) has not yet been extensively applied to the Flandrian deposits of the Severn Estuary.

Nine dates are available for the Wentlooge 'upper peats', of which Hawkins (1971) gives seven, and Godwin & Willis (1964) and Allen & Fulford (1986) each give one. These range from 4240 ± 105 a BP to 2180 ± 50 a BP, with an average of 3300 a and a marked clustering in the 3000–4000 a class. For only two dates, however, is there close stratigraphical control. Godwin & Willis (1964) date the top of the peat on the Caldicot Level at 2660 ± 100 a BP The topmost 0.1 m at Rumney Great Wharf gave a date of 2180 ± 50 a BP (Allen & Fulford 1986). The upper peat(s) in the Wentlooge Formation was therefore deposited in the interval from the mid Sub-boreal to the early Subatlantic, an assignment broadly consistent with the limited pollen evidence (Beckinsale & Richardson 1964; Seddon 1964) and with the flint tools recovered from Oldbury Flats (see above).

Bivalve shells, including some paired valves, from the gravelly bases of the Rumney and Northwick formations on the Wentlooge Level gave corrected dates of, respectively, 470 ± 98 a BP and 20 ± 57 a BP (Allen 1987). No dates are available for the Awre Formation.

11. Age and correlation: chemostratigraphy

(*a*) *Rationale*

The Severn Estuary is a very well mixed system that receives fine sediment from many sources, both natural and anthropogenic. Whereas the natural inputs are likely to have changed little over the past few thousand years, the period represented by the beds under study, the anthropogenic contributions – particulate, dissolved and atmospheric – should be time-dependent. In particular, a significant increase in trace metal inputs should have occurred since the mid-18th to mid-19th century, corresponding to industrialization in South Wales, the Bristol area and the West Midlands.

It is well known that many trace metals are readily adsorbed on to the surfaces of fine sediment particles, particularly clay mineral species (see, for example, Burton & Liss 1976;

Förstner & Wittmann 1979). Furthermore, deposited muddy sediments have been shown to retain an historical record of anthropogenic and naturally derived trace metal inputs (Dominik *et al.* 1978; Clifton & Hamilton 1979; Baxter *et al.* 1981; Summerhayes *et al.* 1985). The sediment trace element content therefore has potential stratigraphic value in the Severn Estuary for both relative dating at a site, correlation between geographically separated sections and, should the rates of anthropogenic input be known, the absolute dating of samples.

The trace metals present in muddy salt-marsh deposits from the Severn Estuary have not previously been systematically studied. Work to date has concentrated on the dissolved metals (Butterworth *et al.* 1972; Abdullah & Royle 1974; Radford 1982; Morris 1984; Owens 1984), the suspended mud (Abdullah & Royle 1974; Hamilton *et al.* 1979; Radford 1982), largely subtidal bottom-deposited sediments (Bloxom *et al.* 1971; Chester & Stoner 1975; Hamilton *et al.* 1979; Thorne & Nickless 1981), and a wide range of organisms (summary in Morris 1984; Hopkin *et al.* 1985). The longest time series (*ca.* 100 years) was established by Clifton & Hamilton (1979) and Hamilton & Clifton (1979) using two sediment cores from Swansea Bay.

We investigated four metals, on the basis of a preliminary survey. Zinc, copper and lead were chosen as they exhibited marked time trends and occurred in the sediments at levels which could easily be measured without recourse to elaborate techniques. Chromium was selected for comparative purposes; it showed less time-dependence than the other three but also occurred in readily measurable amounts. Rubidium levels were measured on all samples, as this element has proved to be an excellent grain-size proxy (Ackermann 1980).

(*b*) *Field sampling and laboratory methods*

A stratigraphical profile was sampled on the cleaned salt-marsh cliff at each of 22 sites distributed between ten localities (see figure 4). These were chosen to combine good geographic spread with uniform representation of the upper Wentlooge, Rumney, Awre and Northwick formations. Samples were collected by pushing cleaned plastic tubes (length 0.1 m; I.D. 0.033 m) horizontally into the mud cliff, at a fixed interval of either 0.05 or 0.1 m. A total of 373 samples was obtained.

In the laboratory, samples were extruded from the tubes and air-dried. They were coarsely crushed and split by coning and quartering. Approximately one-quarter of each sample was retained and the remainder ground in a low-Cr stainless-steel Tema barrel for 1 min. In the case of selected samples a cut taken immediately after splitting was also ground using an agate pestle and mortar. All ground samples were stored in Kraft paper bags until required for analysis. A comparison of analyses from the steel- and agate-ground sets showed that no noticeable contamination came from the barrel.

The levels of zinc, copper, lead, chromium and rubidium were determined by X-ray fluorescence analysis of pressed powder pellets using a Bausch and Lomb ARL instrument. Details of detection limits and precision appear in table 1.

(*c*) *Absolute trace metal values*

The stratigraphical distributions of absolute pollutant metal values plotted in figure 5 show that significant time-dependent increases in amount are limited to the younger sediments. Table 2 summarizes the ranges of the metal concentrations represented by our suite of samples, and in table 3 we give comparative values taken from earlier work in the general area. The two sets of means are broadly comparable but in our case are lower for zinc, copper and lead. This

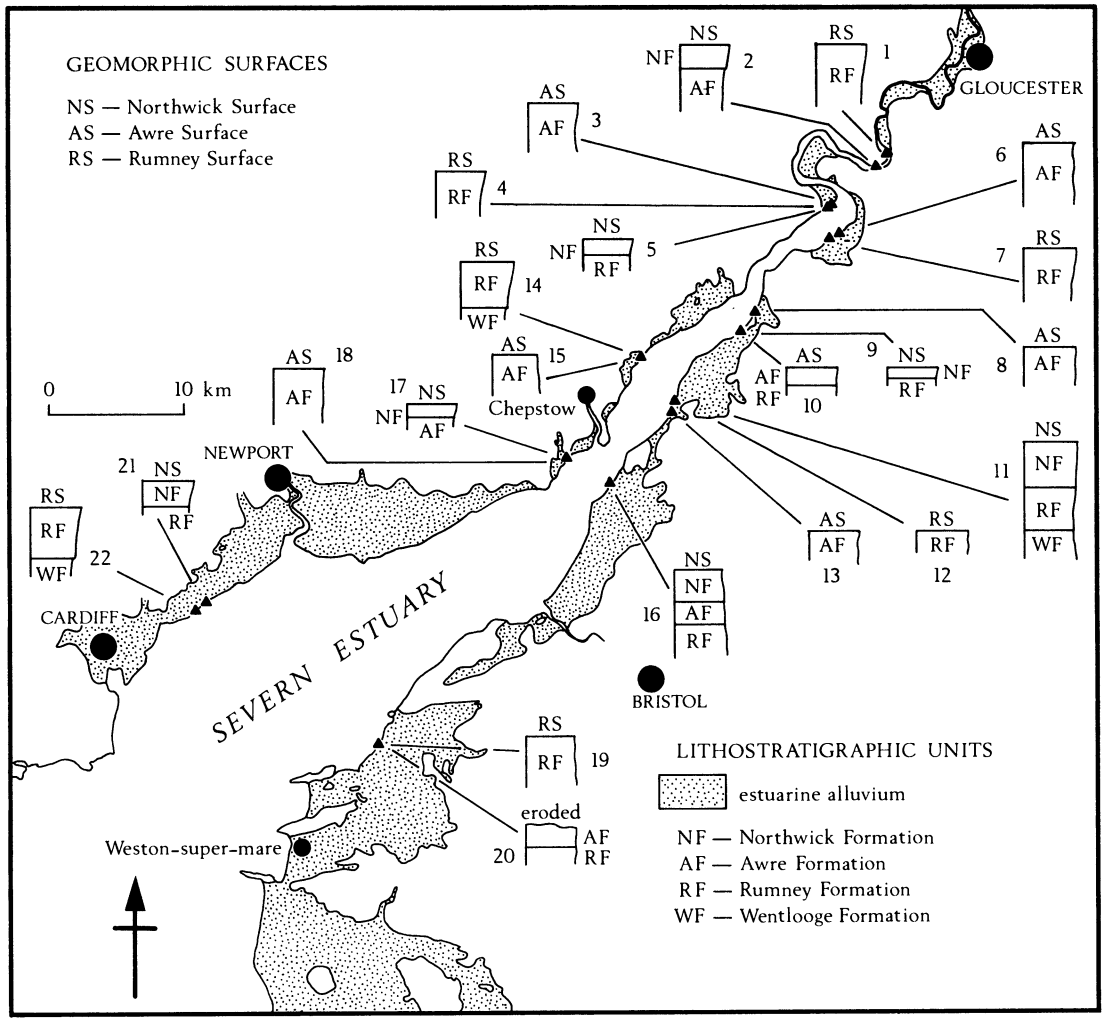

FIGURE 4. Location and summary of stratigraphic profiles sampled for trace metals in the Severn Levels. All natural exposures. Details of localities: (1) Rodley (SO 760 117); (2) Rodley (SO 751 117); (3) Awre (SO 722 083); (4) Awre (SO 721 081); (5) Awre (SO 719 080); (6) Slimbridge Warth (SO 727 060); (7) Slimbridge Warth (SO 716 056); (8) Berkeley Pill (SO 663 003); (9) Berkeley Power Station (ST 653 991); (10) Berkeley Power Station (ST 652 990); (11) Oldbury Power Station (ST 602 937); (12) Oldbury Power Station (ST 602 937); (13) Oldbury Pill (ST 599 931); (14) Woolaston (ST 581 973); (15) Woolaston (ST 580 973); (16) Northwick Warth (ST 553 874; (17) Mathern (ST 524 895); (18) Mathern (ST 522 894); (19) Kingston Seymour (ST 384 691); (20) Kingston Seymour (ST 382 685); (21) Peterstone Wentlooge (ST 259 789); (22) Peterstone Wentlooge (ST 248 785).

is to be expected, as our sampling extended to deposits older and therefore less polluted than any previously examined. The linear correlation matrix in table 4 confirms the visual impression gained from figures 5 and 6 that the metals vary in abundance broadly in harmony. The strongest correlation is between zinc and lead, whereas chromium is poorly correlated with all the other metals. The high correlations involving zinc, copper and lead may reflect similarities in the chemical behaviour of these metals, in addition to their synchronous introduction especially at enhanced levels.

TABLE 1. SUMMARY OF DETECTION LIMITS AND PRECISION OF TRACE METAL ANALYSES BY X-RAY FLUORESCENCE

(Values in parts per million by mass.)

	Zn	Cu	Pb	Cr	Rb
detection limit	10	5	10	5	5
site 15 (Woolaston, 50.6 km)					
mean	323	41.8	93.3	107	122
range	309–341	37–44	92–105	95–119	119–126
standard deviation	11.8	2.9	7.8	8.5	2.7
mean	307	46.0	91.8	106	115
range	302–309	37–50	83–98	89–117	113–120
standard deviation	2.6	4.8	5.2	10.8	2.7
site 11 (Oldbury Power Station, 52.6 km)					
mean	117	23.8	31.4	110	124
range	109–124	21–26	28–37	104–114	121–127
standard deviation	4.8	2.0	3.1	5.4	1.1
site 18 (Mathern, 60.7 km)					
mean	204	45.2	68.0	105	109
range	193–217	44–47	60–76	98–121	104–113
standard deviation	7.7	1.5	5.2	8.5	3.1

The first set of statistics for Woolaston represents four runs using the same pellet prepared from a historical sediment; the second set represents five pellets prepared from this sediment. The statistics for the other two named localities in each case represent five pellets prepared from a historical sediment. The bracketed figures are distances from Gloucester (see below).

(*d*) *Distribution and correlation of trace metals: grain-size corrected values*

We see it as essential to take sediment grain size into account in any attempt to use trace metals stratigraphically, because it is well known that, in general, these metals are adsorbed predominantly on to the finest particles (chiefly clay minerals) (see, for example Goldberg 1974; Thorne & Nickless 1981). It is clear from our regional review of the lithostratigraphy of the Severn Estuary that, generally speaking, the salt-marsh sediments become progressively finer grained downstream. Rather than measure grain size directly, however, it may be more convenient to analyse for a proxy metal. Ackermann (1980) proposed several elements as proxies, including caesium and rubidium, and demonstrated the excellent correlation of, for example, rubidium with the under 20 μm sediment fraction ($r = 0.96$). We accordingly chose rubidium as a grain size proxy and noted, as an additional reason, that its input is unlikely to be significantly time-dependent, since the element is not present in the lattice of any common mineral, and uninfluenced anthropogenically.

Figure 7 depicts for all formations combined the variation of each of zinc, copper, lead and chromium with rubidium. The overriding trends – variation with time and with grain size – are expressed in these scatters. Because the Severn estuary is well stirred (see, for example, Morris 1984), and the metals are associated with the fine fraction, we expect all samples *of the same age* to plot on a single straight line in each arithmetically scaled graph. Hence each plot should contain all the metal values within a definite envelope, where the upper boundary line represents the most polluted (metal-rich) sediments, and the lower defines the natural (pre-industrial or background) state of the deposits. Accordingly, with sources of error taken into account, upper and lower envelope lines were hand-fitted to the plots and carried to the

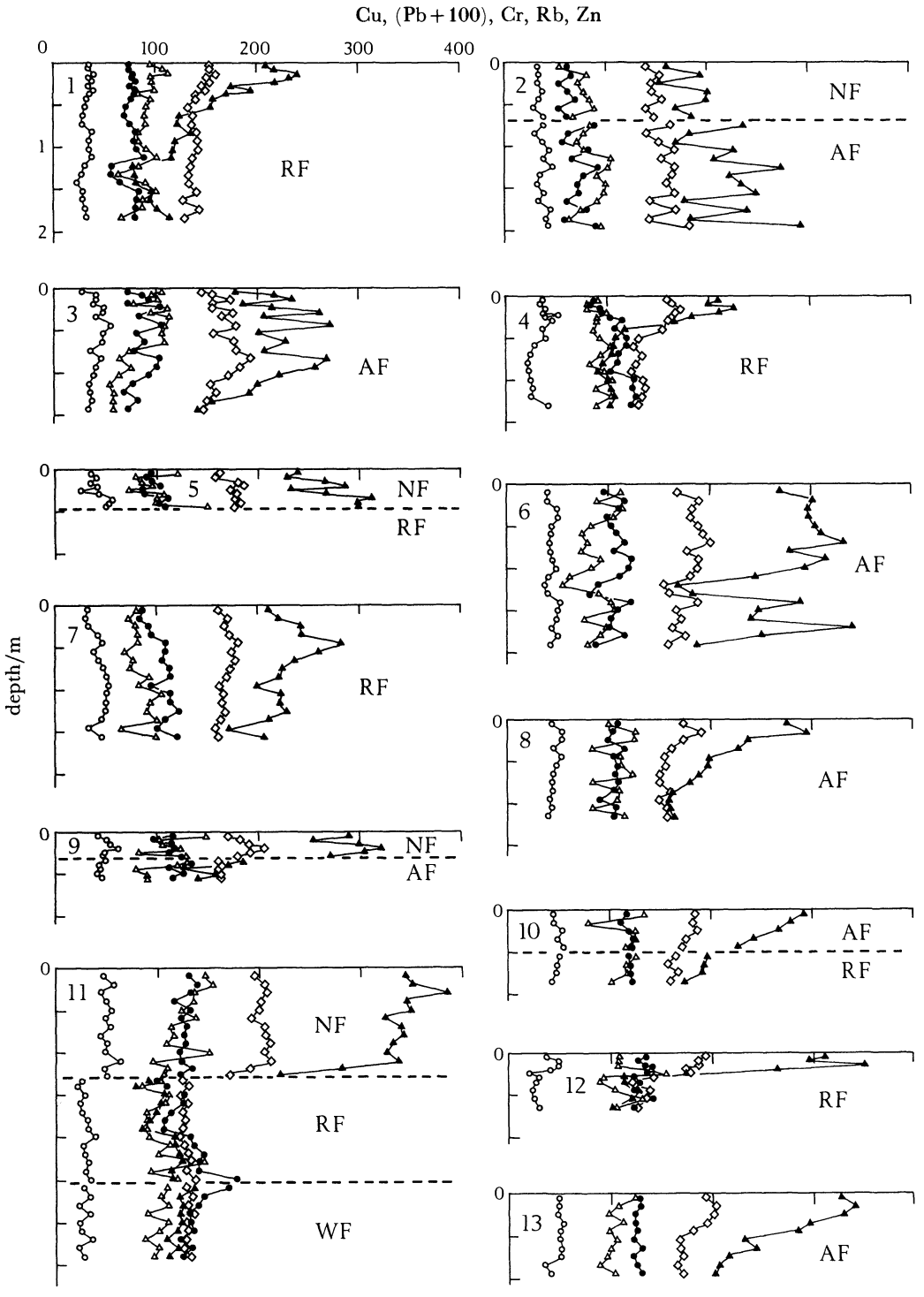

FIGURE 5. For description see opposite.

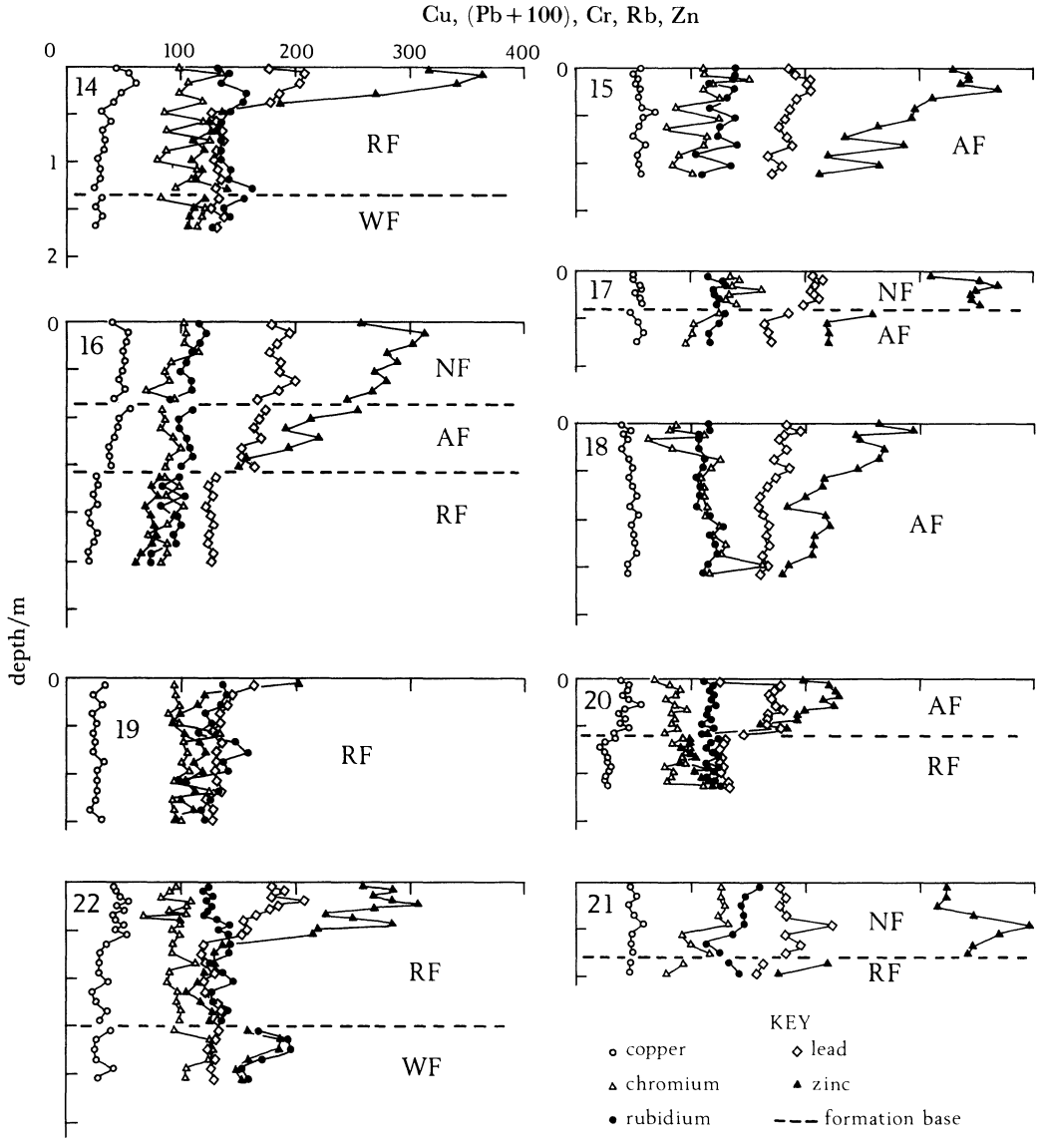

FIGURE 5. Stratigraphical distribution of absolute values (in parts per million by mass) for zinc, copper, lead, chromium and rubidium in profiles from the Severn Estuary (see figure 4 for locations). Key to lithostratigraphic units: WF, Wentlooge Formation; RF, Rumney Formation; AF, Awre Formation; NF, Northwick Formation.

TABLE 2. VARIATION OF TRACE METAL CONCENTRATIONS IN LATE FLANDRIAN SEDIMENTS FROM THE SEVERN ESTUARY (373 SAMPLES)

(Values in parts per million by mass.)

element	minimum	maximum	mean	standard deviation
Zn	60	396	205.3	80.5
Cu	17	63	39.9	10.4
Pb	17	123	60.4	24.9
Cr	54	162	100.2	19.5
Rb	53	196	113.1	23.9

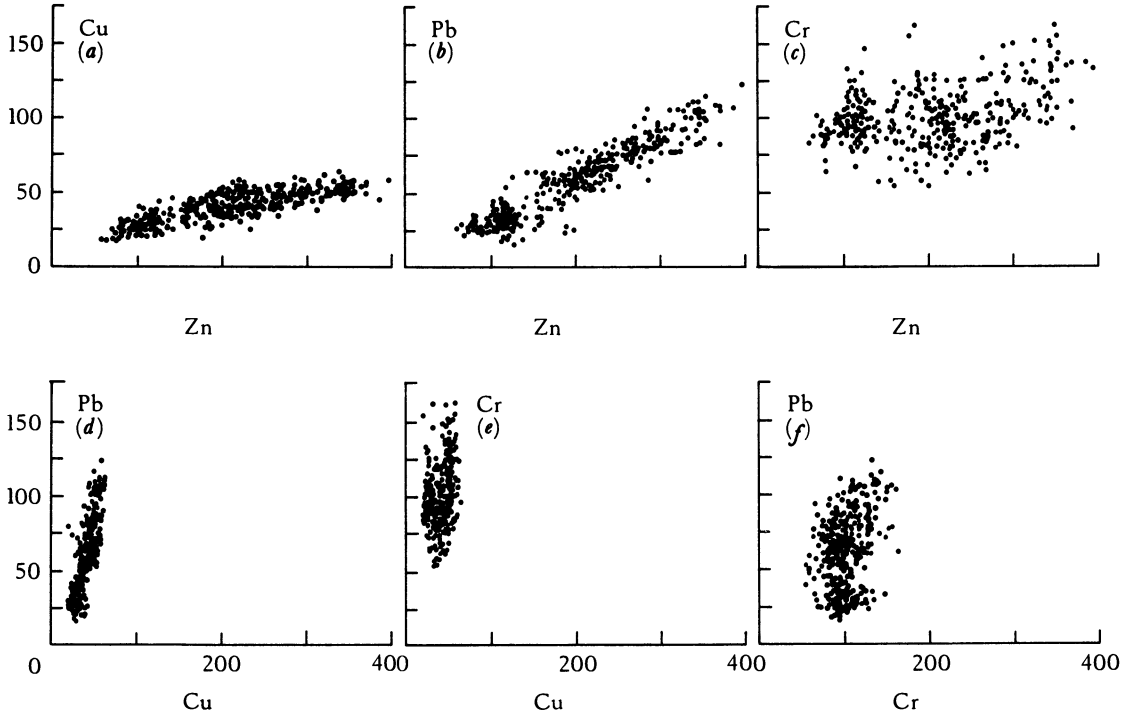

FIGURE 6. Correlations (uniform scales) between absolute values (in parts per million by mass) for zinc, copper, lead and chromium in late Flandrian sediments of the Severn Estuary (all formations, 373 samples). See also table 4.

TABLE 3. SUMMARY OF REPORTED TRACE METAL CONCENTRATIONS (MEAN VALUES) IN SEDIMENTS OF THE SEVERN ESTUARY AND BRISTOL CHANNEL SYSTEMS

(Values in parts per million by mass.)

system	Zn	Cu	Pb	Cr
Bristol Channel[1]	280	38	119	71
Bristol Channel – Severn Estuary[2]	296	94	101	145
Swansea Bay[3]	132	81	172	—

[1] Spectrographic analysis of the under 61 μm size fraction, Chester & Stoner (1975).
[2] XRF analysis of silt, Hamilton *et al.* (1979).
[3] XRF analysis of silt–clay fraction, Bloxom *et al.* (1972).

TABLE 4. LINEAR CORRELATION-COEFFICIENT MATRIX FOR TRACE METALS (ABSOLUTE VALUES) PRESENT IN LATE FLANDRIAN SEDIMENTS OF THE SEVERN ESTUARY (373 SAMPLES)

	Zn	Cu	Pb	Cr
Zn	1	—	—	—
Cu	0.801	1	—	—
Pb	0.931	0.812	1	—
Cr	0.223	0.201	0.189	1

ordinate to define intercept values at zero rubidium (see table 5). Copper, lead and chromium each gave a single, clearly defined intercept. The zinc intercept appeared to show a slight increase with time, but for present purposes the single tabulated value was deemed adequate. The significance of the intercept values is that they effectively characterize a well-washed sediment free from fines. As a check, our intercepts compare satisfactorily with mean metal

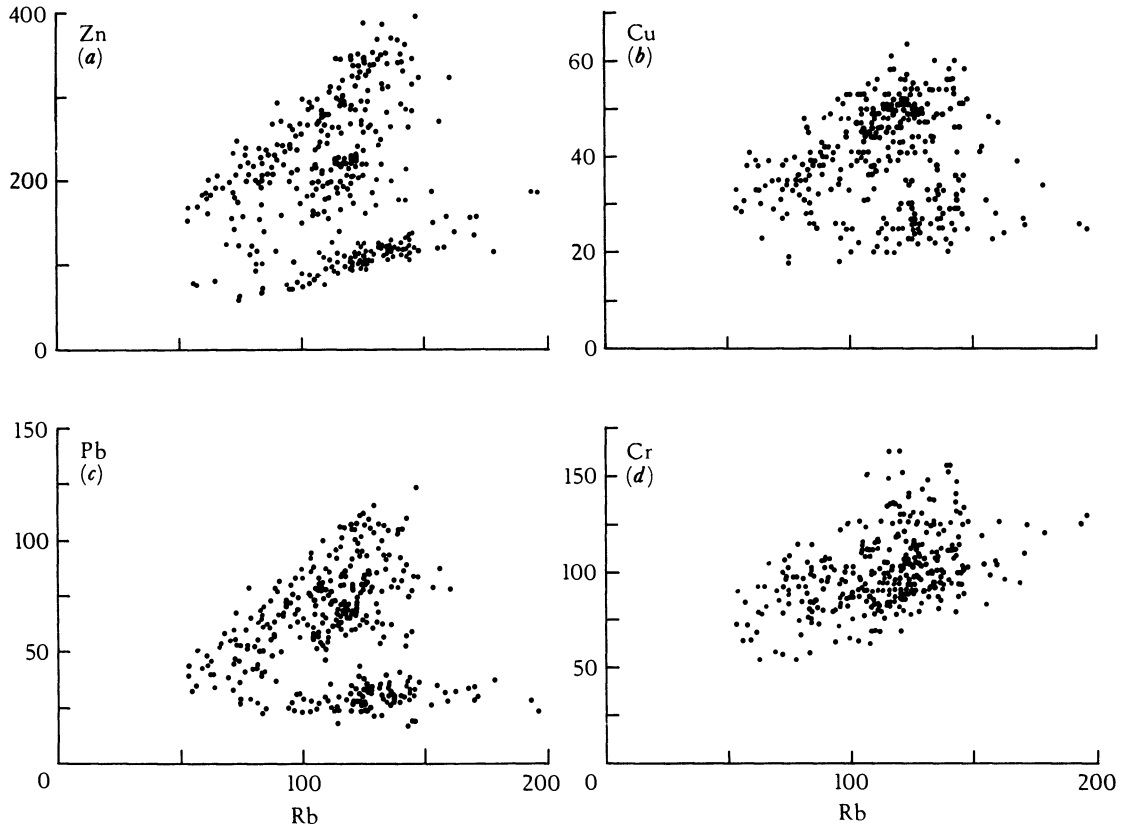

FIGURE 7. Variation with rubidium (parts per million) of absolute values (in parts per million by mass) for zinc, copper, lead and chromium in late Flandrian sediments of the Severn Estuary (all formations, 373 samples).

TABLE 5. TRACE-METAL INTERCEPT VALUES (Rb = 0) DEFINED BY ENVELOPE LINES ON METAL-Rb PLOTS (SEE FIGURE 7)

(Values in parts per million by mass.)

metal	intercept value
Zn	30
Cu	14
Pb	13
Cr	10

values in the sand fraction of Bristol Channel sediments and with average sandstone (see table 5). It should be borne in mind that Hamilton's data are from generally more seaward locations than ours, and that his standard error of the mean on chromium is an astonishing 104 parts per million (by mass).

As the assumption of a linear model is justified by the shapes of scatters in figure 7, and by their representation in terms of single intercept values, we adjusted for grain size the metal concentrations given in figure 5 by calculating non-dimensional metal index values from the linear formula $I_m = (C_m - y_m)/C_{Rb}$, where I_m is the index for the metal m, C_m the measured metal concentration, y_m the single intercept concentration (see table 5), and C_{Rb} the measured rubidium concentration. Applied to each sample in turn, the formula yields a set of index values that are independent of grain size. Any remaining differences among the index values for each metal are therefore due predominantly if not solely to time. It should perhaps be pointed out

that the index value for a given metal and sample is the slope of that line in figure 7 which contains all samples, regardless of grain size, equal in age to the given sample.

The metal index values (see table 6) are almost as well correlated linearly as the absolute concentrations (see table 4). Zinc and lead are again the most closely correlated; worst are the correlations between chromium and the other metals. The corresponding scatter diagrams, however, suggest that, although there has been a general increase in amount of anthropogenically introduced metals in the estuarine sediments, the supply rates have not been constant (see figure 8). The copper–zinc values (see figure 8*a*) cluster in two fields, indicative of an early period of stable supply (low index values) and a later one of changed relative supply (high

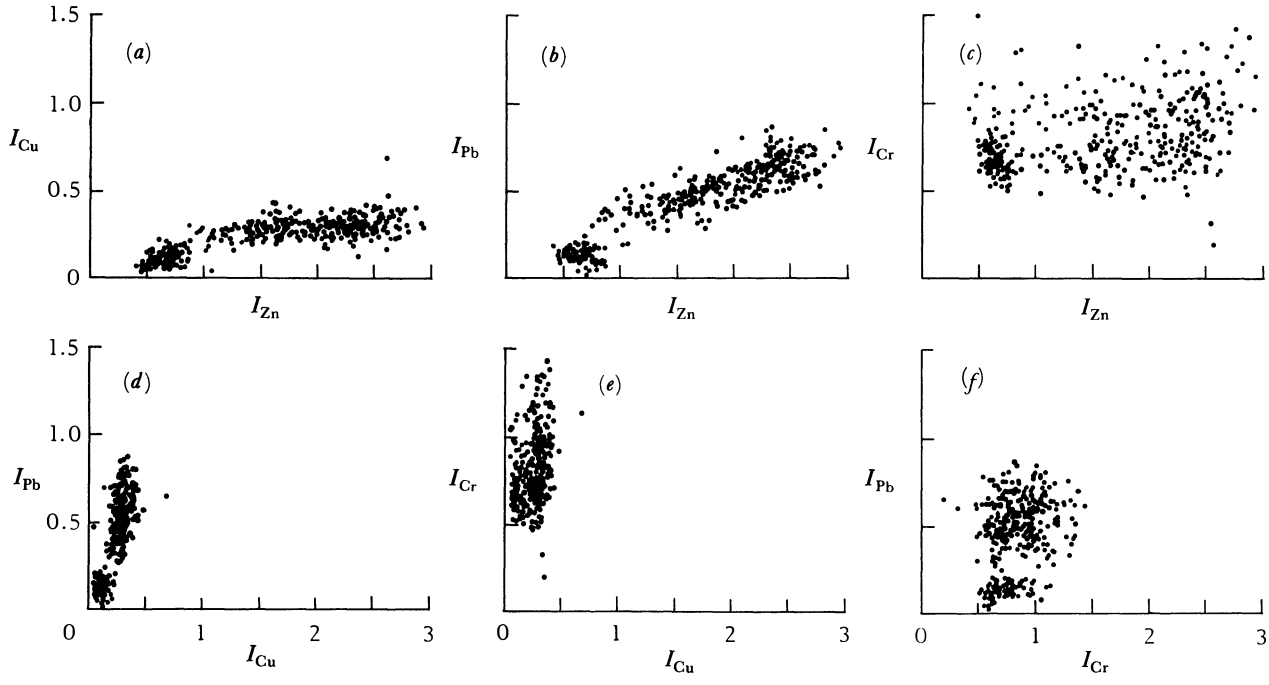

FIGURE 8. Correlations (uniform scales) between the zinc, copper, lead and chromium index values for late Flandrian sediments (all formations, 373 samples) of the Severn Estuary. See also table 6.

TABLE 6. LINEAR CORRELATION-COEFFICIENT MATRIX FOR TRACE METALS (INDEX VALUES) PRESENT IN LATE FLANDRIAN SEDIMENTS OF THE SEVERN ESTUARY (373 SAMPLES)

	Zn	Cu	Pb	Cr
Zn	1	—	—	—
Cu	0.778	1	—	—
Pb	0.926	0.783	1	—
Cr	0.209	0.215	0.184	1

index values), the overall variation being nonlinear and ideally represented by two linear graphs. The lead–copper scatter has a related form (see figure 8*d*), explicable if the later introductions of lead also occurred at an enhanced rate. The lead–zinc data (see figure 8*b*) also cluster in two fields, but give no indication of a change over time in the relative supply, suggesting that the metals came from the same source, or sources, different from the source,

or sources, of copper. Chromium increases slightly with all the other metals (see figure 8*c*, *e*, *f*), but the scatter masks any subtler trends. Chromium appears to have an insignificant anthropogenic input, unrelated to the sources of the other metals.

Figure 9 depicts the stratigraphic variation of the zinc, copper and lead index values at our sites. The data now reveal a much greater spatial uniformity than is evident from the absolute values (see figure 5), in which the sandy upriver beds possess distinctly less in the way of metals than the stratigraphically equivalent clay-rich sediments downriver (see also figure 4). Variation of the zinc index with stratigraphical position is particularly marked and exhibits a clear trend in each formation. A probably synchronous peak in the zinc, copper and lead index values appears in the uppermost Rumney and Awre formations and to some extent in the Northwick beds, similar to that recorded by Clifton & Hamilton (1979) from Swansea Bay. At our sites, however, the metal values in the uppermost one or two samples of a profile may in some cases be diluted with plant root material.

Closely coincident sympathetic changes in the metal index values are widely detectable (see figure 9). The representative linear correlation matrices of table 7 emphasize the close relationship between zinc and lead, reinforcing our inference from the overall analysis (see figure 8*b*) that these elements came over the same period from the same source, or sources. Copper generally is positively but less rigorously correlated with lead and zinc, as would be expected if the sources differed.

(*e*) *Estuary-wide stability of trace metal values*

Given the physically well-stirred character of the Severn Estuary, trace metals should be uniformly distributed in the deposited sediments of a single age, whatever the sources of the metals. However, it is only if this expectation is substantially correct that valid stratigraphical conclusions can be drawn from the metal concentrations.

Figures 4, 5 and 9 establish that the metals reach their maximum abundance at a site a short distance below a formation top, provided that that top coincides with the relevant geomorphic surface (for example, Awre Formation capped by Awre Surface). We have no reason to believe that these maxima are not synchronous and every cause (especially the comparable element concentrations) to correlate them to Clifton & Hamilton's (1979) metal peak. Accordingly, the two largest index values associated with the most recent peak in each site profile were averaged for each of zinc, copper and lead, and then plotted against distance downstream (mid channel) from Gloucester (Over Old Bridge, SO 817 896). Site 9 (Kingston Seymour) was ignored, as the sampling interval appeared to be unacceptably coarse.

The zinc index is statistically independent of downstream distance and the trends for copper and lead are weak (see figure 10). An upstream source for copper may be indicated by the downstream decline in the index. The slight downstream increase in the lead index may point to a downriver source, or sources, for this metal. That the general level of index values is lowest for the Rumney Formation and greatest for the Northwick beds seems to be a sampling effect. As the Rumney Surface lies higher within the tidal range than the Awre Surface, and the latter overlooks the Northwick Surface (see figures 1 and 2*b*), the Rumney Formation has in recent decades accumulated more slowly than the Awre beds and these in turn at a lower rate than the Northwick unit. Consequently, our fixed-interval samples on the whole represent the metal maximum best in the formation which, at the time of greatest pollutant abundance, was

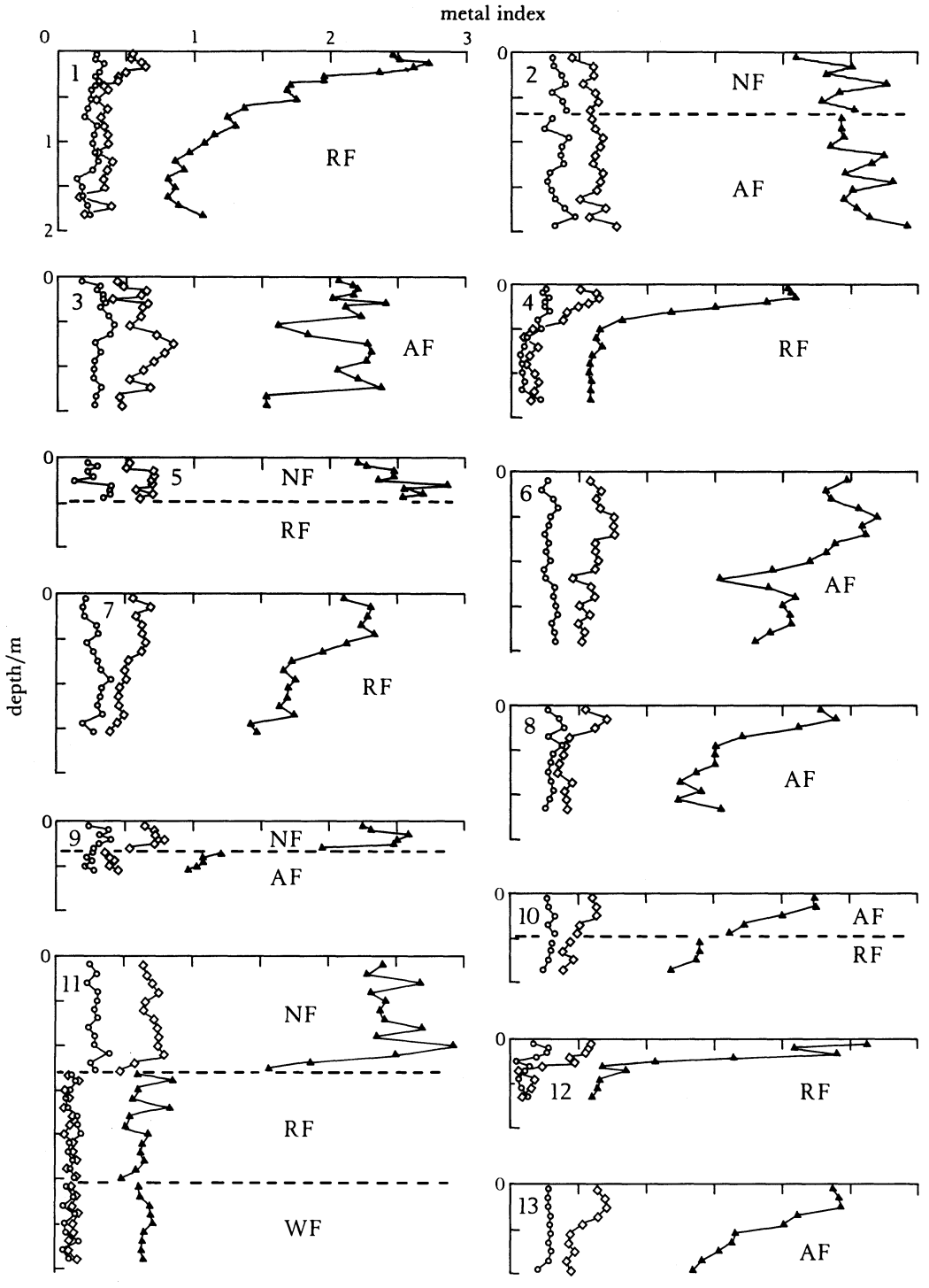

FIGURE 9. For description see opposite.

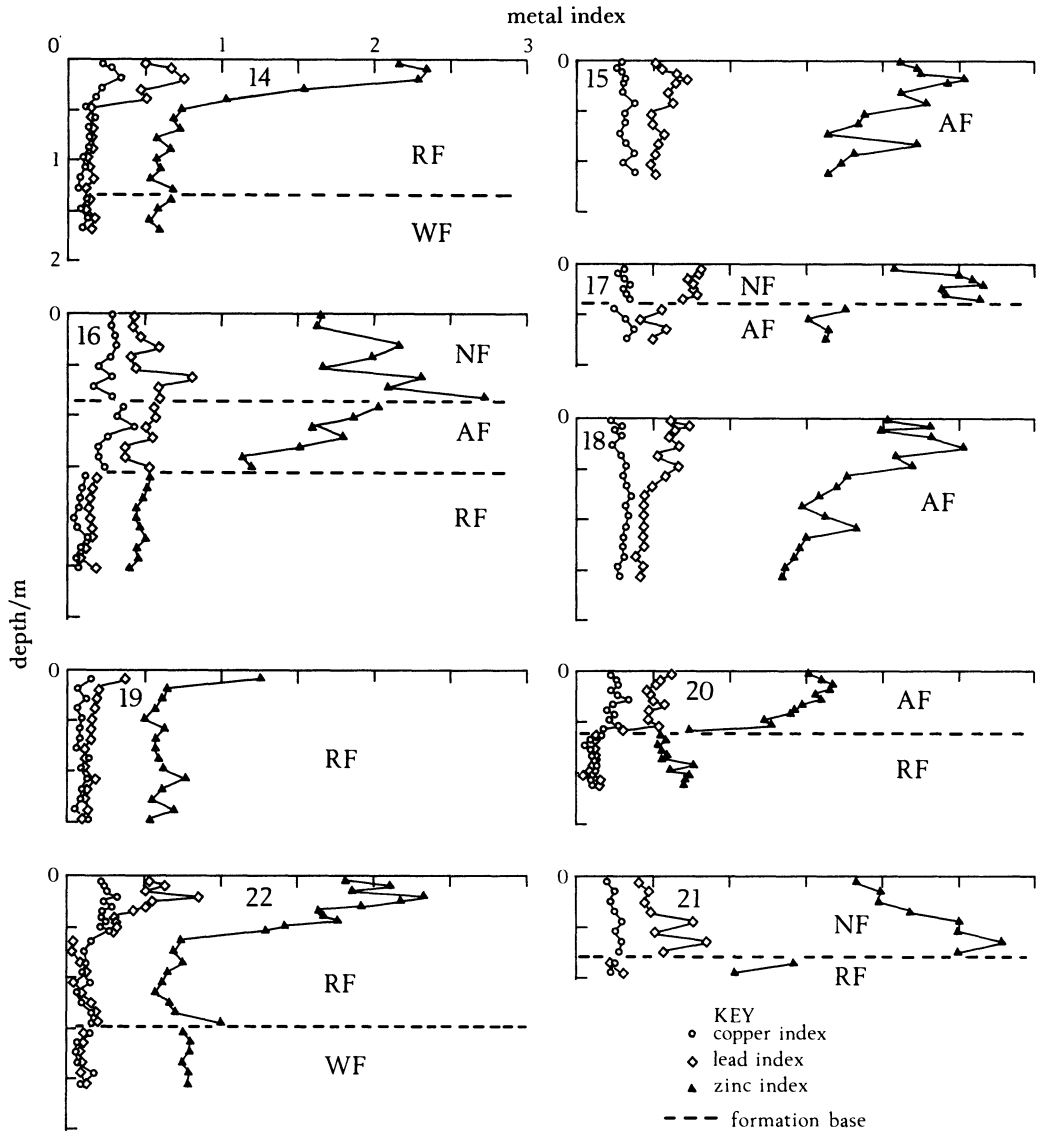

FIGURE 9. Stratigraphical distribution of zinc, copper and lead index values in profiles from the Severn Estuary (see figure 4 for locations). Key to lithostratigraphic units: WF, Wentlooge Formation; RF, Rumney Formation; AF, Awre Formation; NF, Northwick Formation.

accumulating most rapidly, namely the Northwick Formation. We conclude from figure 10 that the estuary is chemically well mixed and that the trace metals are, to a first approximation, probably distributed uniformly at all times.

(*f*) *Chemical characterization of lithostratigraphic units*

The four units whose occurrence we summarize may be characterized chemically in terms of (i) absolute metal concentrations, (ii) the distribution of metal index values, and (iii) the shape of the metal stratigraphic profile.

Figure 11 illustrates the relation between absolute metal and rubidium values for each

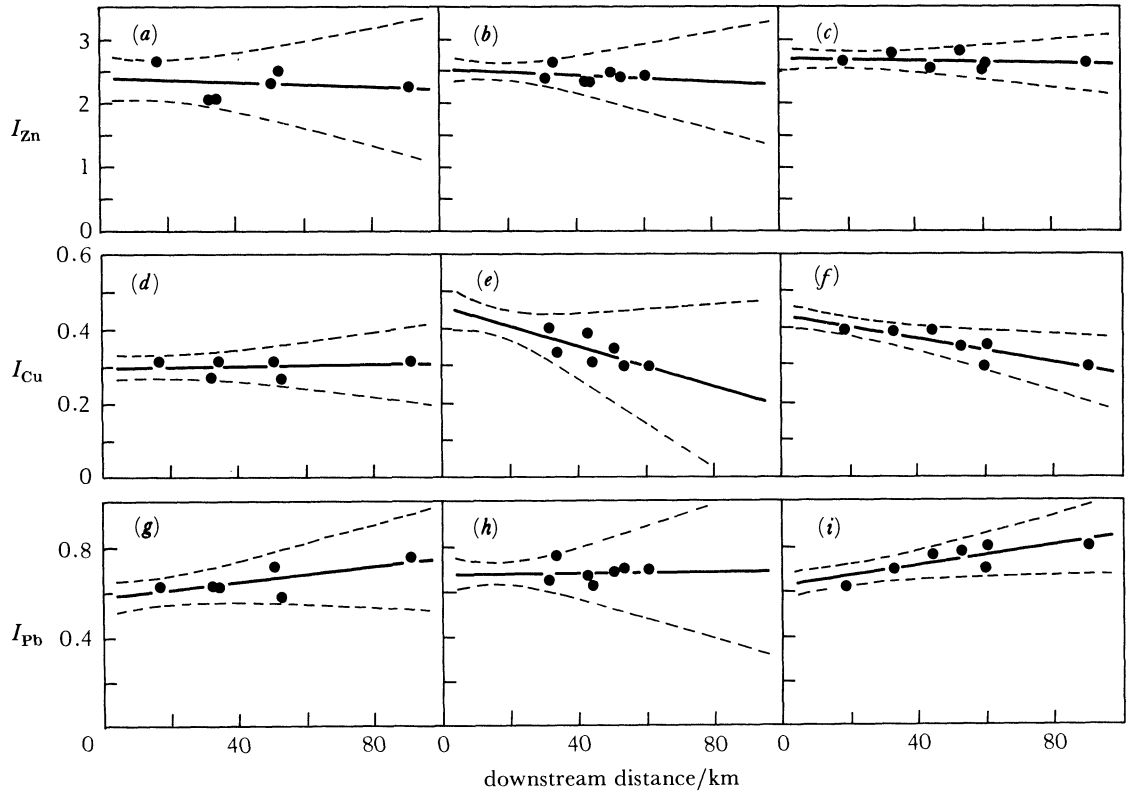

FIGURE 10. Variation with downstream distance (kilometres from Over Old Bridge, Gloucester) of peak metal index values (see text for details of calculation). (*a*, *d*, *g*) Rumney Formation. (*b*, *e*, *h*) Awre Formation. (*c*, *f*, *i*) Northwick Formation. Regression shown as solid line with confidence interval dashed.

TABLE 7. LINEAR CORRELATION-COEFFICIENT MATRICES FOR TRACE METALS (INDEX VALUES) PRESENT IN LATE FLANDRIAN SEDIMENTS OF THE SEVERN ESTUARY (SELECTED SITES)

	Zn	Cu	Pb	Zn	Cu	Pb
	site 3 (18 samples)			site 9 (11 samples)		
Zn	1	—	—	1	—	—
Cu	< 0.1	1	—	0.680	1	—
Pb	0.532	0.186	1	0.904	0.872	1
	site 4 (17 samples)			site 11 (35 samples)		
Zn	1	—	—	1	—	—
Cu	0.782	—	—	0.873	1	—
Pb	0.935	0.784	1	0.985	0.905	1
	site 6 (20 samples)			site 19 (15 samples)		
Zn	1	—	—	1	—	—
Cu	−0.142	1	—	0.439	1	—
Pb	0.815	−0.199	1	0.864	0.423	1
	site 8 (12 samples)			site 21(10 samples)		
Zn	1	—	—	1	—	—
Cu	0.388	1	—	0.706	1	—
Pb	0.882	0.492	1	0.874	0.783	1

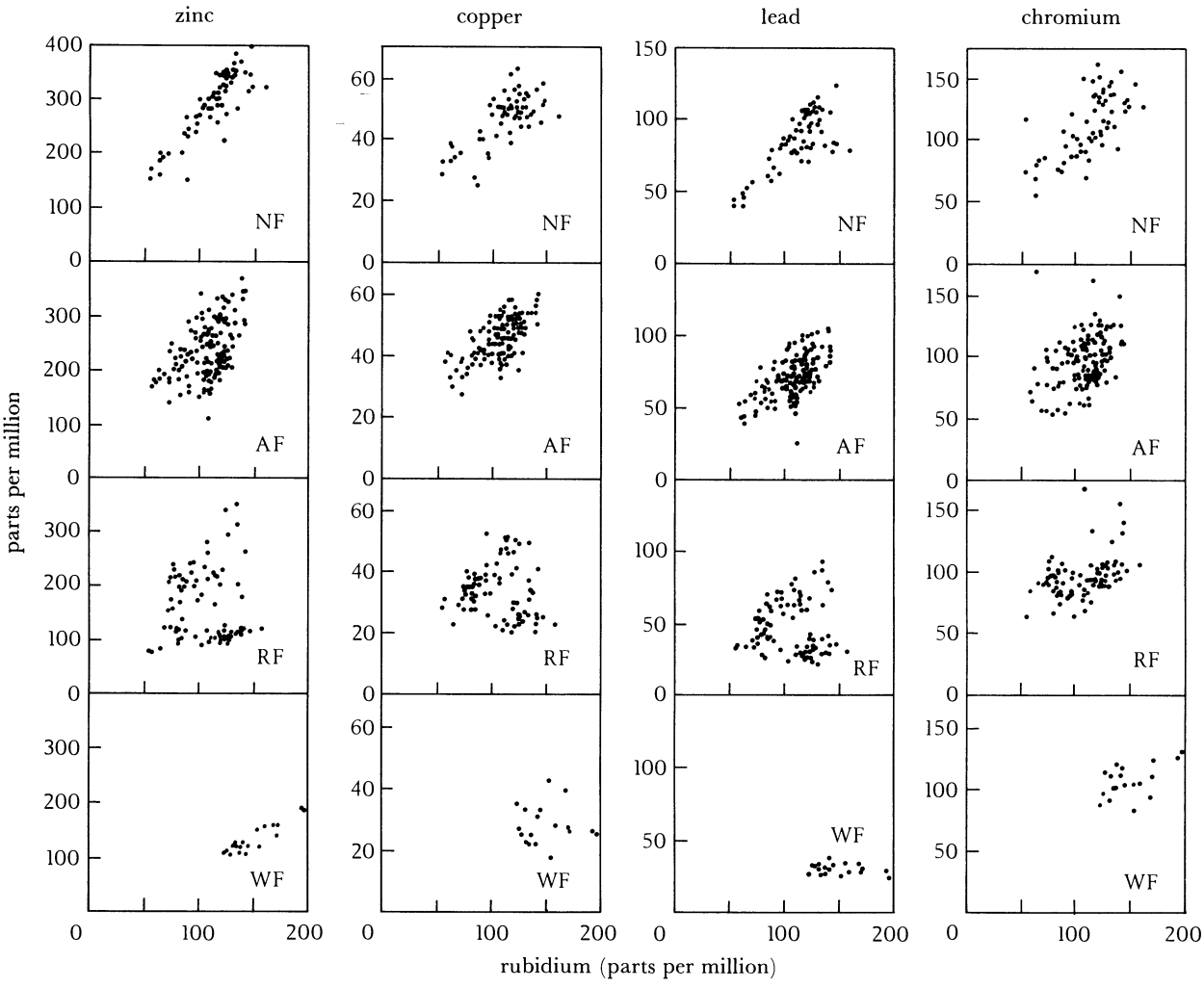

FIGURE 11. Formation-by-formation variation in the absolute values (in parts per million by mass) of zinc, copper, lead and chromium as a function of rubidium (parts per million by mass) for late Flandrian sediments of the Severn Estuary. Key to lithostratigraphic units: WF, Wentlooge Formation; RF, Rumney Formation; AF, Awre Formation; NF, Northwick Formation.

formation; each unit plots in a definite field within which is a characteristic distribution of data points (we used fixed-interval sampling). The Wentlooge Formation presents low metal values of generally little spread. In contrast, the Rumney Formation provides the widest spread of values for each metal, reflecting protracted deposition over changeable times, during which pollution increased significantly. Awre Formation metal values are more restricted in spread than those from the Rumney beds, and the Northwick Formation exhibits a particularly narrow clustering for each element.

Figure 12 and table 8 illustrate the distributions of metal index values by element and lithostratigraphic unit. Although there is some overlap, the pattern for each element is clearly distinctive of a formation. Furthermore, the characteristic distribution for each unit is similar for all the metals except chromium. These patterns emphasize the differing age ranges and therefore metal input histories represented by each of the beds.

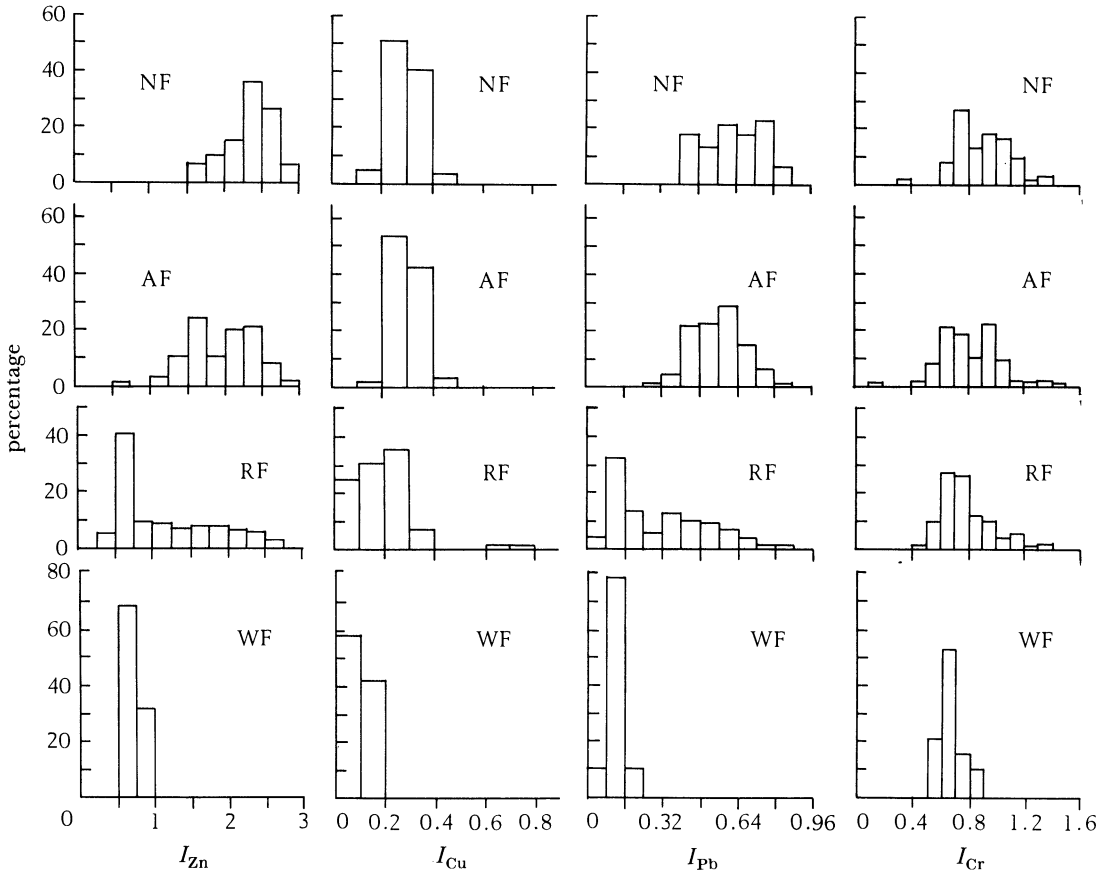

FIGURE 12. Frequency distributions of index values for zinc, copper, lead and chromium considered one formation at a time in late Flandrian sediments of the Severn Estuary. Key to lithostratigraphic units: WF, Wentlooge Formation; RF, Rumney Formation; AF, Awre Formation; NF, Northwick Formation. See also table 8.

Characteristic of the three youngest formations is the vertical variation especially of the zinc index at a site (see figure 13). In particular, a relatively smooth profile is obtained for the Rumney Formation, exhibiting at each site an obvious region of maximum rate of index change. Table 9 summarizes from figure 9 the differences between formations and sites in the estimated maximum value of the rate of change of the zinc index. There is some variation between sites, representing modest differences in sedimentation rate, but where formations can be compared the clusters of values are distinct. Our exclusion of site 9 (Kingston Seymour) from figure 10 is fully justified by the very low deposition rate indicated by the high tabulated rate of change.

(*g*) *Stratigraphical implications of trace metal distributions*

The above summary of the chemostratigraphy of late Flandrian sediments on the margins of the Severn Estuary appears to show that (i) the upper Wentlooge, Rumney, Awre and Northwick formations overall are chemically distinct, and (ii) the overall differences are clearly recognizable as the same from site to site over a horizontal distance of many tens of kilometres. The upper Wentlooge Formation arose at a time of negligible metal pollution. Deposition of the Rumney Formation commenced under similar conditions. Metal pollution had just begun (? early 19th century) when the Awre Formation started to accumulate. The Northwick

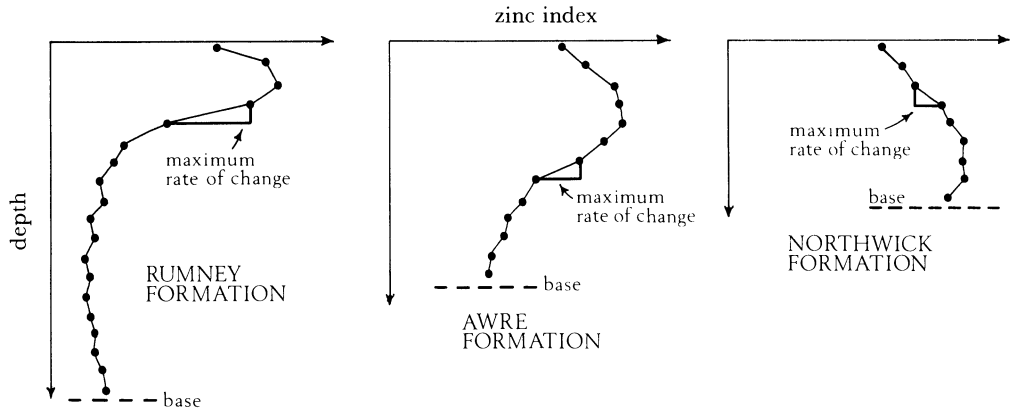

FIGURE 13. Summary of basis for estimation of the maximum rate of change of the zinc index in each of the Rumney, Awre and Northwick formations.

TABLE 8. VARIATION OF METAL INDEX VALUES IN LATE FLANDRIAN FORMATIONS OF THE SEVERN ESTUARY

metal index	minimum	maximum	mean	standard deviation
Northwick Formation (61 samples)				
I_{Zn}	1.57	2.93	2.34	0.31
I_{Cu}	0.123	0.403	0.293	0.060
I_{Pb}	0.407	0.847	0.626	0.123
I_{Cr}	0.320	1.38	0.907	0.194
Awre Formation (133 samples)				
I_{Zn}	0.741	2.91	1.95	0.43
I_{Cu}	0.176	0.467	0.299	0.051
I_{Pb}	0.302	0.847	0.555	0.107
I_{Cr}	0.193	1.43	0.822	0.202
Rumney Formation (160 samples)				
I_{Zn}	0.399	2.72	1.14	0.639
I_{Cu}	0.009	0.772	0.186	0.106
I_{Pb}	0.023	0.867	0.297	0.193
I_{Cr}	0.479	1.33	0.784	0.185
(Upper) Wentlooge Formation (19 samples)				
I_{Zn}	0.529	0.814	0.686	0.082
I_{Cu}	0.056	0.183	0.099	0.040
I_{Pb}	0.051	0.174	0.118	0.032
I_{Cr}	0.501	0.822	0.665	0.083

Formation represents the height of pollution by heavy metals, the concentration values and profile matching those of the *ca.* 1950 A.D. maximum claimed by Clifton & Hamilton (1979). On chemical grounds there is clearly a major stratigraphical break at the base of these beds. The chemical differences for a given lithostratigraphic unit between sites are, generally speaking, less than those between formations. Chemically, the correlation of the formations from site to site is warranted, as is the suggestion that each formation is broadly synchronous within the estuary.

TABLE 9. MAXIMUM RATE OF CHANGE OF THE ZINC INDEX WITH DEPTH (m^{-1}) FOR SEVERAL SITES BY FORMATION (LOWEST ACCRETION RATES ARE IMPLIED BY THE LARGEST MAGNITUDES OF THE RATE OF CHANGE OF THE INDEX)

site	Rumney Formation	Awre Formation	Northwick Formation
1	-5.0×10^{-4}	—	—
4	-6.0×10^{-4}	—	—
5	—	—	1.6×10^{-4}
6	—	-4.2×10^{-5}	—
7	-3.3×10^{-4}	—	—
8	—	-1.9×10^{-4}	—
10	—	-2.0×10^{-4}	—
12	-1.3×10^{-3}	—	—
13	—	-1.9×10^{-4}	—
14	-7.6×10^{-4}	—	—
16	—	—	1.9×10^{-4}
18	—	-6.4×10^{-5}	—
19	-1.4×10^{-3}	—	—
20	—	—	1.3×10^{-4}
21	-4.9×10^{-4}	—	—

12. DISCUSSION

Our purpose is to describe a reconnaissance of the late Flandrian stratigraphy of the muddy margins of the Severn Estuary, with particular reference to the stability of its shores.

Our survey of some 180 km of shoreline leaves us with little doubt that throughout the estuary there occurs a single set of four lithostratigraphic units, the youngest three of which are linked to geomorphic surfaces, although not every locality offers a full representation. At many places the three youngest lithostratigraphic units form a stair-like sequence on the salt marsh. Each muddy deposit is capped by a geomorphic surface, on which tidal silt is continuing to settle, and is banked against an erosion surface composed of a gently shelving wave-cut platform and cliff cut back into an earlier unit (or some pre-Flandrian deposit). Where representation is incomplete, it is common to see either the fourth unit (Northwick) banked against the second (Rumney), the third (Awre) banked against the second, or the second and first (upper Wentlooge) standing alone. Representation is least complete in the uppermost estuary, where the Awre Formation is apparently lacking, and in the most downstream reaches, where this formation and surface are at best fragmentary.

The estuarine clays of the upper Wentlooge Formation began to form probably around the middle of the first millenium B.C. and ceased to accumulate in or shortly after the Roman period. The only clear proof of this is the stratified Romano-British pottery at Rumney Great Wharf, and two radiocarbon dates, from the Wentlooge and Caldicot levels. A wider cast of circumstantial and less conclusive physical evidence – pottery finds of uncertain context (Caldicot Level), stratified pottery finds and pottery strews (North Somerset Level, Oldbury-upon-Severn, Hills Flats) and the Wemberham villa – also links the upper Wentlooge Formation to this period. On an equally wide cast, the formation is chemically of pre-industrial date.

Wherever exposed together, the Rumney Formation is seen sharply to succeed the Wentlooge Formation, the contact at some places being gravelly. The Rumney Formation is clearly post-Roman, for its basal beds locally yield transposed and abraded Romano-British pottery

sherds. There are some indications that the base is diachronous. The single radiocarbon date and pottery sherd recorded from Peterstone Wentlooge in the lower estuary suggest that the Rumney Formation there had begun during the 15th century to fill bays in a dissected coastline, and by the 16–17th century was spreading over the headlands. At nearby Caerleon on the River Usk the base of the Rumney Formation also dates on pottery evidence to the 16th century if not slightly earlier. In the middle estuary at Slimbridge Warth, however, a documented early 14th century reclamation interrupts the continuity of the Rumney Formation, and post-dates a seabank enclosing ridge-and-furrowed ground. At Hock Ditch–Frampton Pill and Oldbury Pill relatively nearby, a ridge-and-furrowed surface, assignable to early or high mediaeval times, accompanies a palaeosol within the Rumney Formation. Chemically, the lower Rumney Formation is also of pre-industrial age.

Although they were clearly formed after the Rumney Formation had been initiated, there is little to suggest the age of the Awre beds. The formation at Sharpness is banked against the revetment containing the Gloucester and Berkeley Canal, completed in 1827, and so partly or wholly post-dates this construction. The earliest Awre beds are slightly metal-polluted, and therefore on general grounds date from the 19th century.

The position of the Northwick Formation is more satisfactory. Historical evidence from Northwick Warth and Goldcliff Pill demonstrates that construction of the erosion surface at its base was well advanced by the late 19th century. Pottery of late 19th to early 20th century type overlies the surface at Beachley; shells from the base at Peterstone Wentlooge date by radiocarbon to the first half of the 20th century. Chemically, the Northwick Formation is only compatible with full industrialization. On all these grounds, the Northwick Formation appears to date from the present century.

Although the evidence for the age and correlation of these lithostratigraphic units is manifestly incomplete, we contend that the assembled data make a *prima facie* case for the broad synchroneity of each formation within the bounds of the estuary. Overall, the chemical evidence is perhaps the most persuasive. For example, the Northwick Formation, identified in the field purely by lithology and successional position, proves to be chemically uniform throughout the entire area. The estuary being well stirred, it seems inescapable that the various representations of this formation are essentially coeval.

The erosional platform and cliff against which the three youngest formations are each banked implies an outward movement or retreat of the shores of the estuary; an inward movement or advance is indicated by the beds themselves. An explanation is demanded for shoreline oscillations of such apparent synchroneity, by the *prima facie* case we make above, and regional extent, by the evidence our field survey. This is not the place to elaborate on that explanation, but at least six hypotheses will in future merit examination. The movements may reflect either a damped oscillatory adjustment of the estuarine system as a whole to the rise and then stabilization of post-glacial sea level, or the position of the shore may fluctuate with the scale and location of major sand banks and channels as controlling currents, short-term sea-level changes, short-term changes of tidal régime, climatically controlled shifts in the discharges of sediment and fresh water into the estuary, or short-term weather changes that affect sea state and, consequently, mud deposition in the upper intertidal zone. The future refinement of the stratigraphy we have sketched, and especially the acquisition of more and better evidence for dating, will provide the constraints within which to seek the best explanation for the coastal instability we infer.

To judge from the evidence available for dating the Awre and Northwick formations, the time scale of instability, assuming that this scale is non-random, is comparatively short and of the general order of 100 years. The apparently unbroken sequence of silty–sandy clays that makes up the Rumney Formation may therefore on closer scrutiny prove to contain cryptic contacts, each of which records the erosive phase of some earlier shoreline oscillation. The puzzling apparent diachroneity of the base of the Rumney Formation could also be a reflection of the polyphase accumulation of these beds.

The beds we describe appear to correspond in the non-tidal floodplain of the River Severn to an apparently unbroken unit of buff red silty clay lying immediately below the floodplain surface in the lower Severn–Avon valleys (Shotton 1978; Brown 1983). Shotton demonstrated at Pilgrim Lock on the River Avon that deposition of these clays could not have begun earlier than about 650 B.C.; at Alcester on the River Alne a Roman cemetery was established in what appears to be the same unit (F. W. Shotton, personal communication 1984).

13. Conclusions

Four defined and described lithostratigraphic units of upper intertidal origin linked to geomorphic surfaces make up the late Flandrian succession on the margins of the Severn Estuary. In upward and inward sequence, they are the (upper) Wentlooge, Rumney, Awre and Northwick formations.

The four are developed throughout the estuary, although not every locality offers a full representation.

Although incomplete, archaeological, historical, radiocarbon dating and chemical evidence combine to make a *prima facie* case for the view that each of these formations is broadly synchronous over the extent of the estuary.

With the exception of the (upper) Wentlooge Formation, each lithostratigraphic unit overlies an erosion surface composed of a cliff and gently shelving wave-cut platform. Each formation therefore seems to record an estuary-wide retreat followed by advance of the shore.

Within the limitations of available dating, shoreline retreat (erosion) occurred during the Saxon to early-mediaeval periods, and again in the 19th and 19–20th century.

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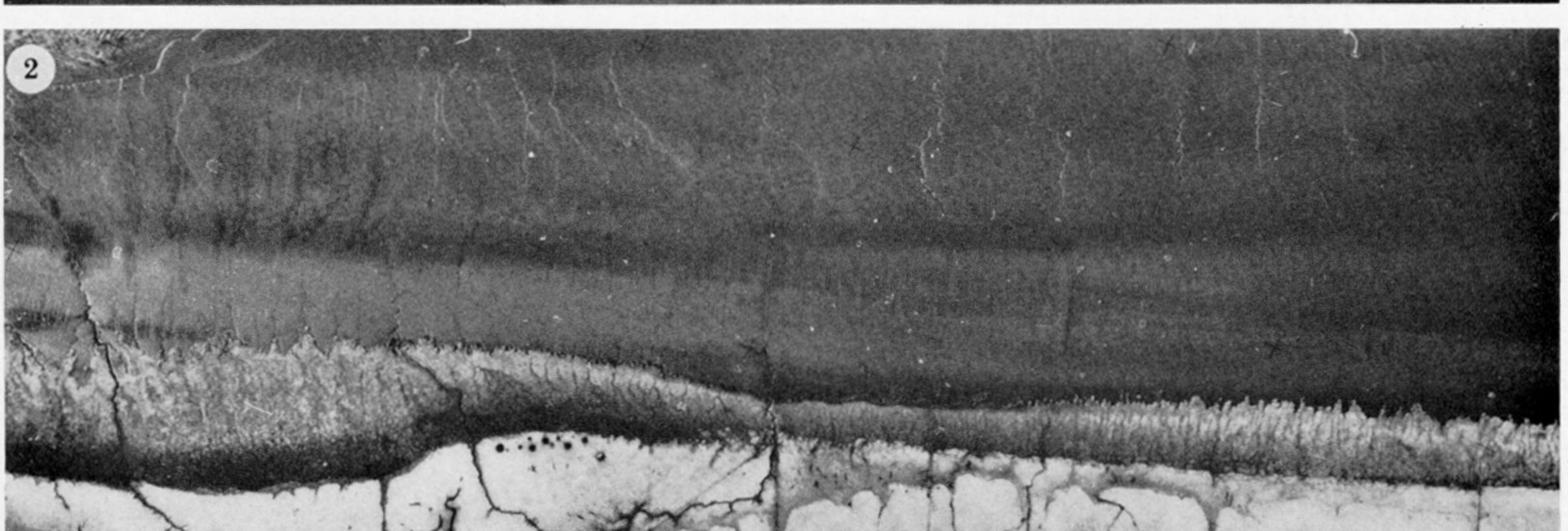

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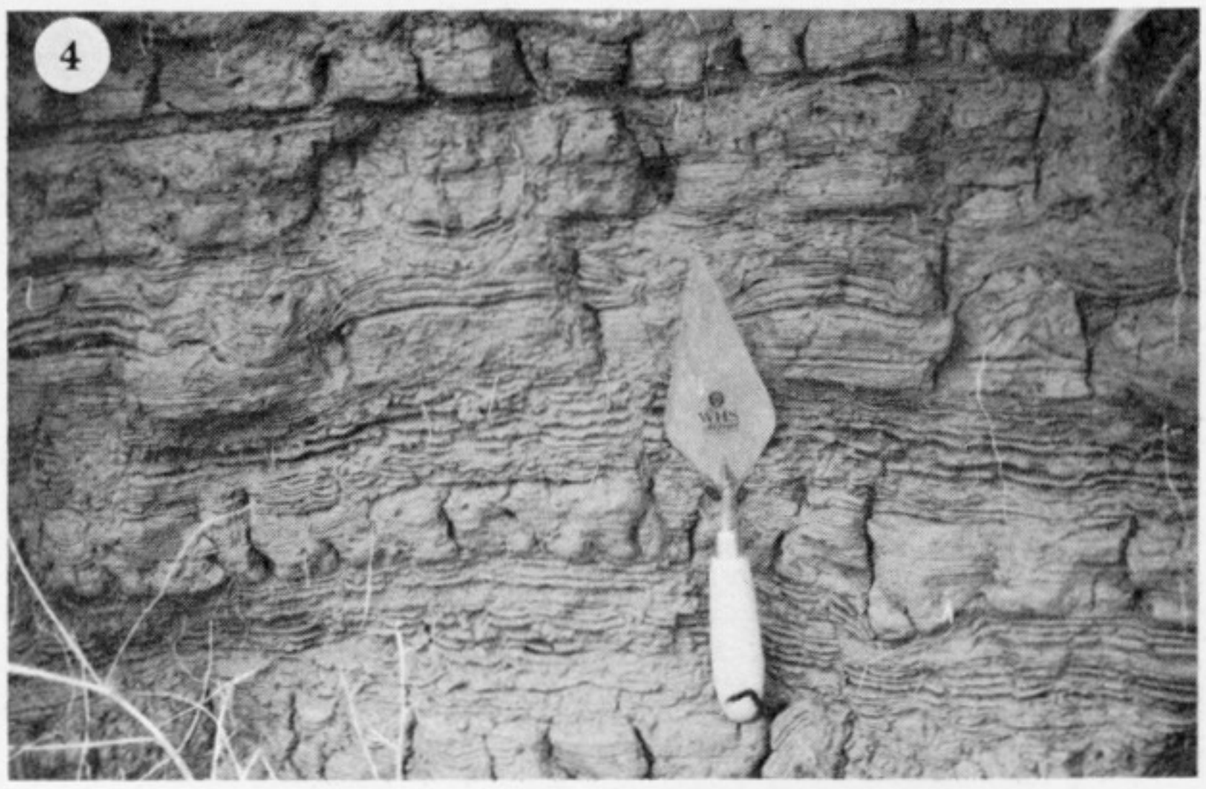

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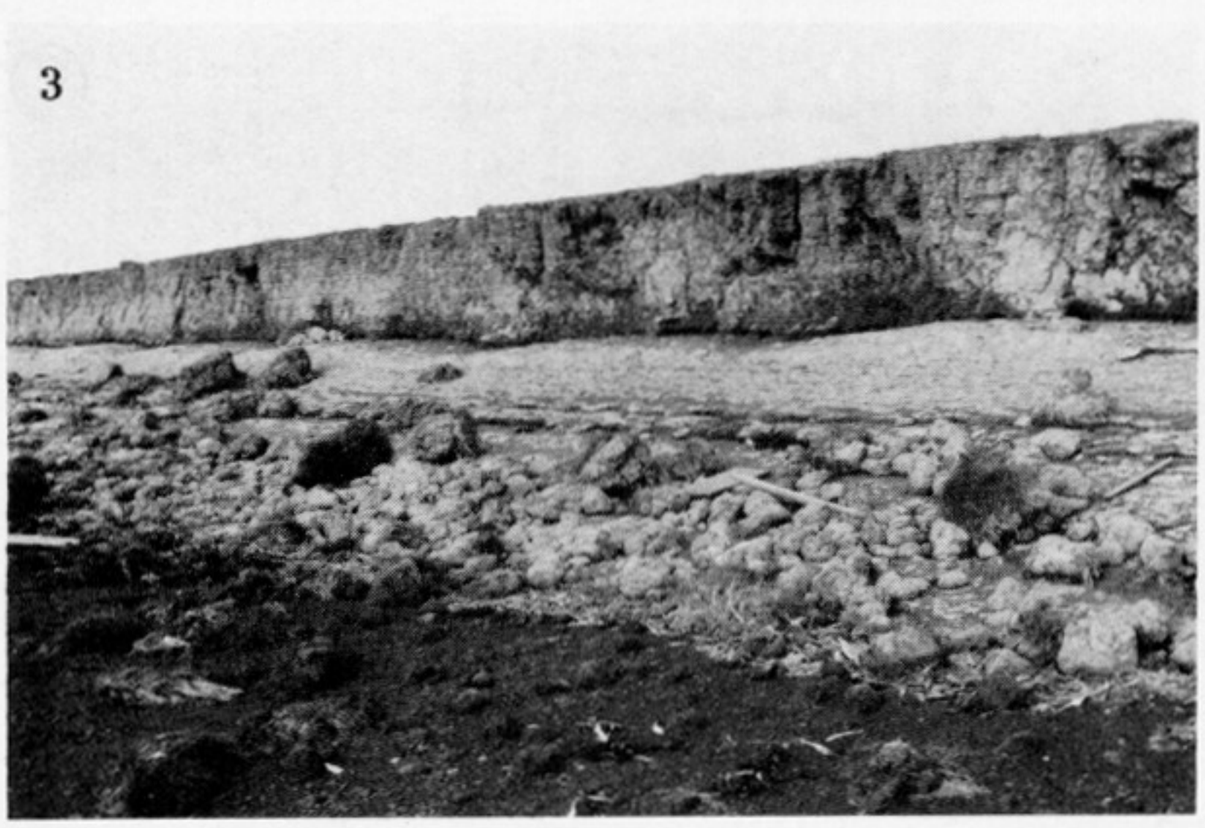

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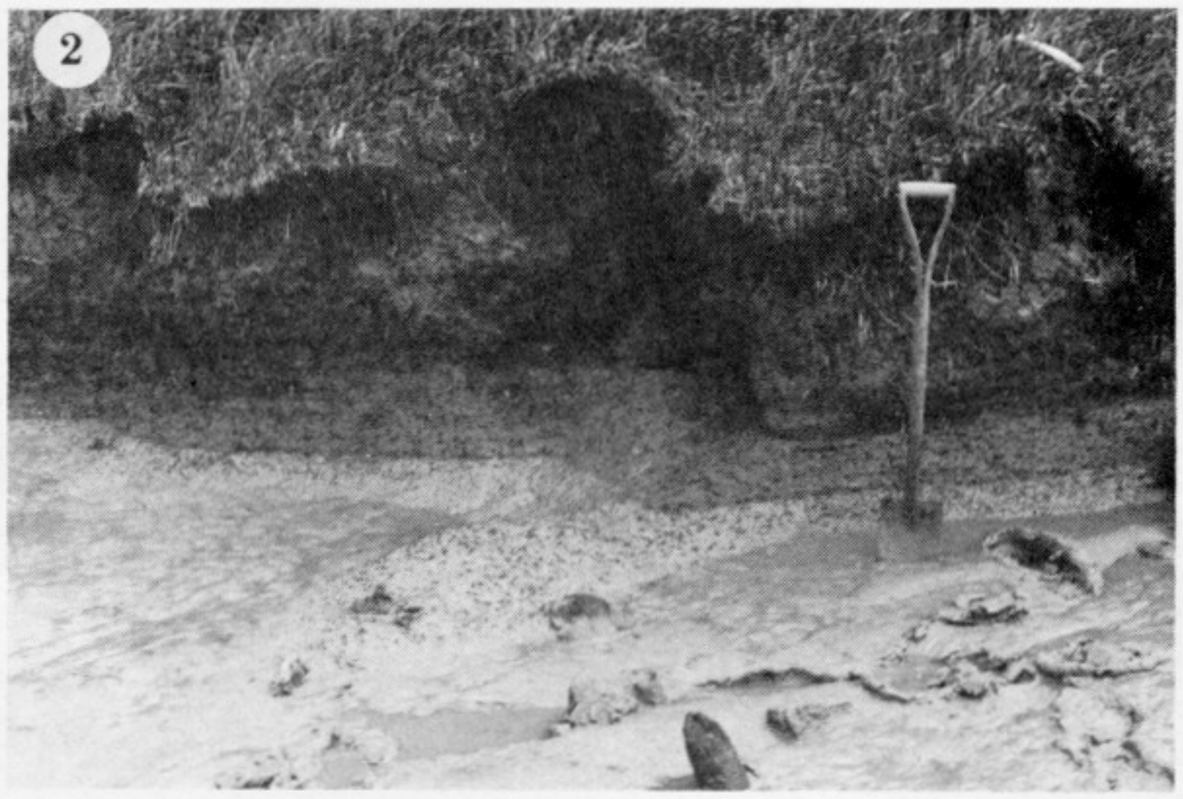

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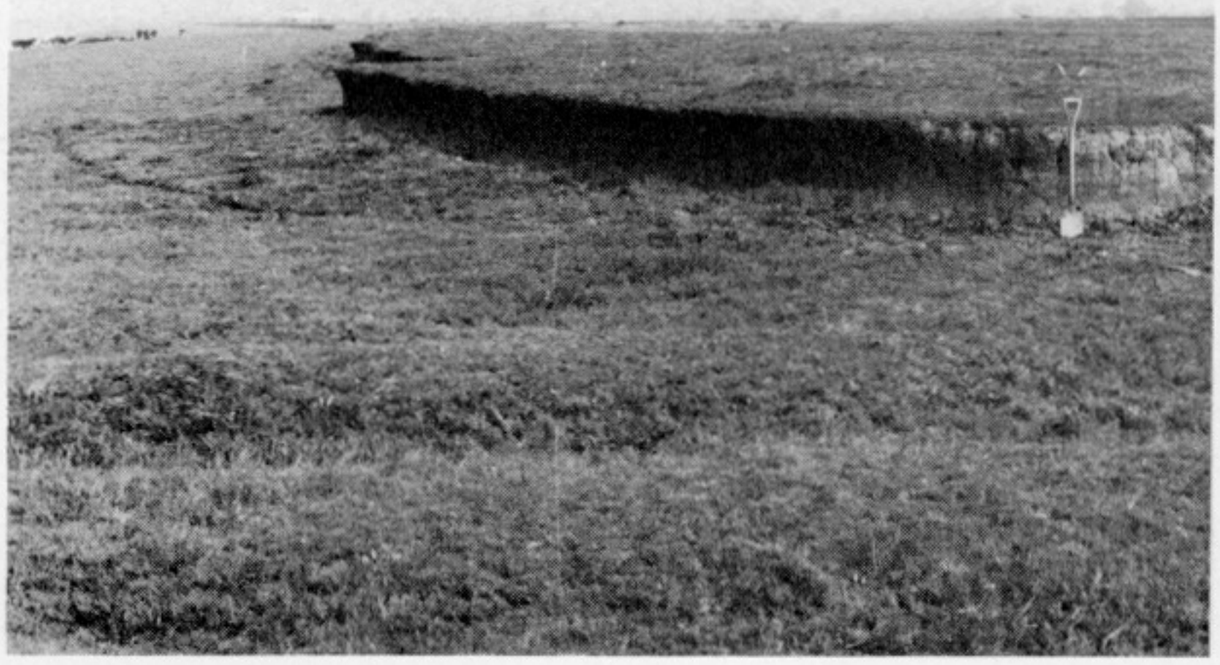

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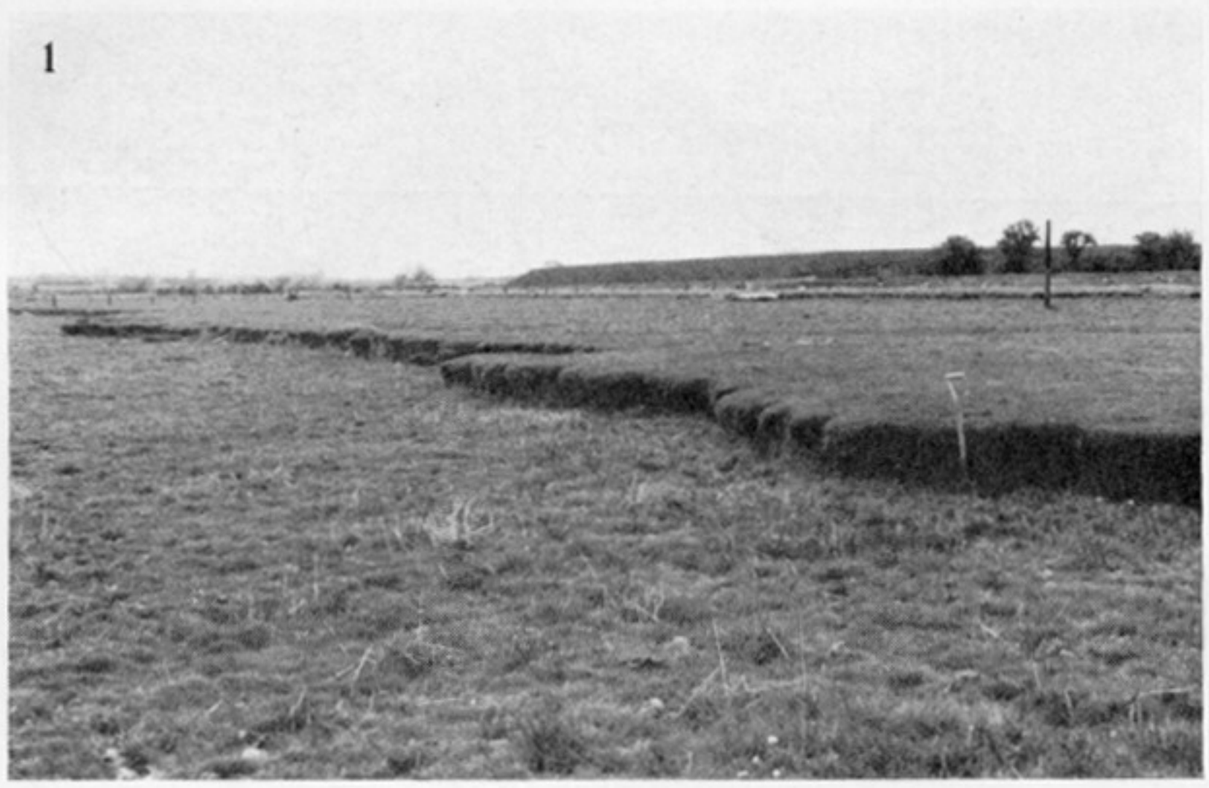

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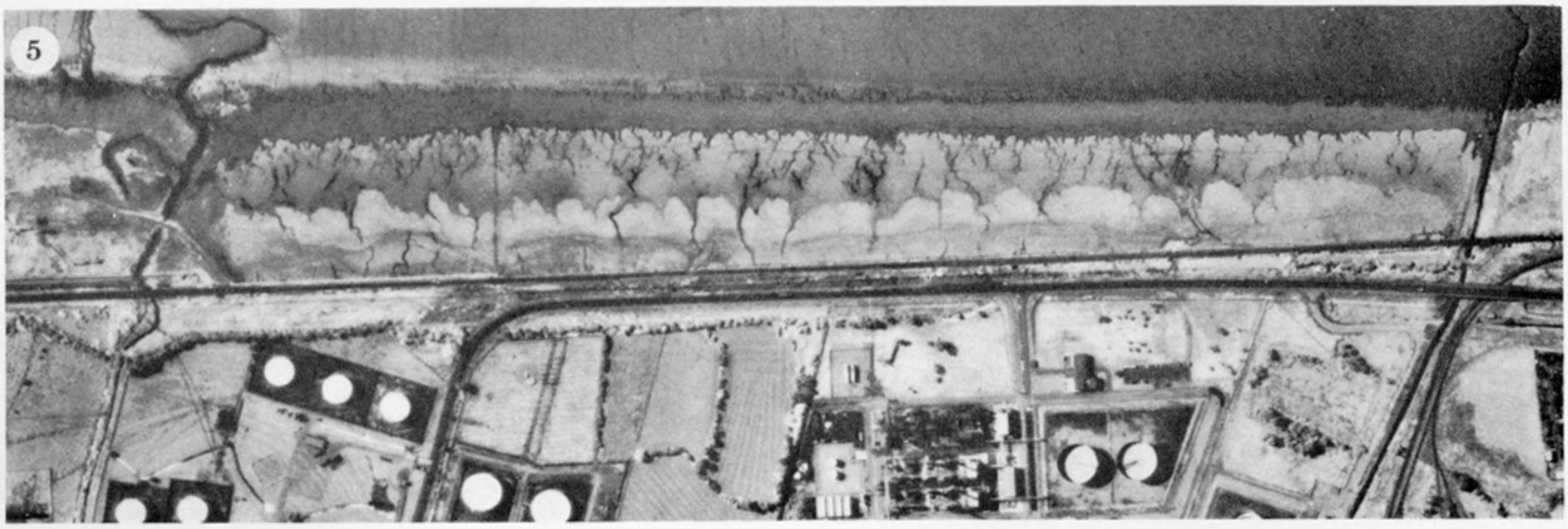

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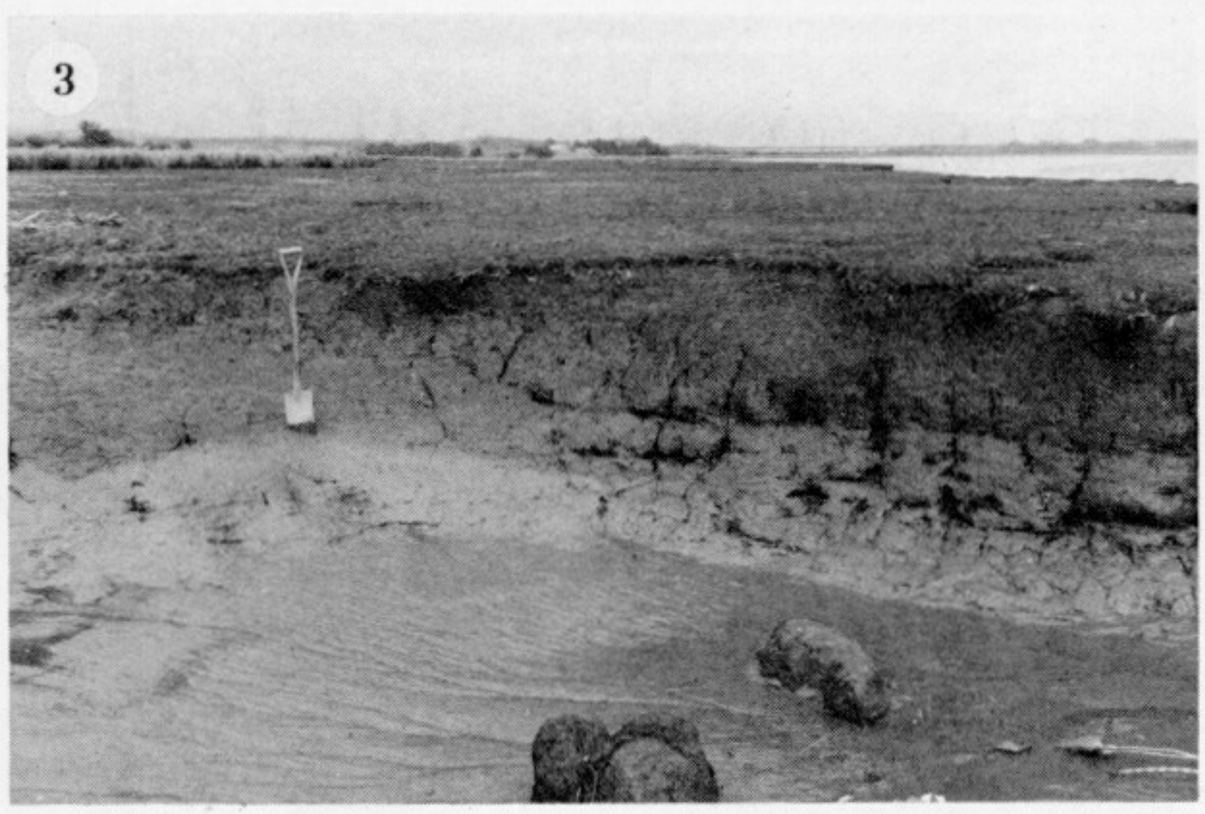

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