THE LATE PLIOCENE MARINE FORMATION AT ST ERTH, CORNWALL

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[Plates 1 to 6]

CONTENTS

New excavations were made in the long-abandoned sand and clay pits at St Erth, Cornwall, from which rich collections of marine mollusca and foraminifera have come in the past. The sediments and stratigraphy revealed are described, and the results of detailed studies of the fossils (mollusca, foraminifera, ostracoda, and plants) in the marine clay are given. The sand member is well sorted, and in places contains two fine-sand populations, one of beach and the other of dune origin. The clay

† Elected F.R.S. 15 March 1973.

member was probably deposited not far below low-water mark in a sea whose water temperature was higher than that of Cornwall today, at the time that the final Boytonian beds of the Pliocene Coralline Crag were being deposited in East Anglia, and the Pliocene *marnes à Nassa* were being deposited at Bosq d'Aubigny in Normandy. Sea level appears to have been lowered by about 45 m to its present level since the marine clay was deposited. The possibility of crustal movement in Cornwall is referred to.

1. Introduction

There is at St Erth (556352), near Hayle in Cornwall, a deposit of high-quality moulding-sand which has been exploited intermittently since the early part of the nineteenth century. It gave rise to an important foundry at Hayle, where large castings for many early iron structures in Britain were made. In places the moulding-sand is capped with clay, and in 1881, when the clay was being worked as a puddling-clay, marine fossils were discovered in it. Since then many collectors have visited the deposits, a number of papers have been published, and a general consensus has emerged that the clay is Pliocene *s.l.* in age. The clay in turn is capped with a layer of solifluction-earth or head.

The first paper to describe the clay said it was a 'tough boulder clay, with marine shells' (Whitley 1882), and as it has now been shown (Mitchell & Orme 1967) that ice capable of depositing boulder clay did reach the Scilly Islands, it seemed desirable that the St Erth deposits should be re-examined.

Accordingly in 1966 I received grants from the British Association, the Geologists' Association and the Geological Society, which enabled me to make some excavations in the pits at St Erth. The Vicar, Rev. R. S. Slater, freely gave me permission to work on his land, and Mr and Mrs Elliott who then occupied the Old Vicarage (which gives its name to the main pit) gave me every facility. Mr C. S. Halford and Mr M. Jennings gave tireless help in the field. A bulldozer and a trench-digger were hired from Messrs George Williams (Cornwall) Ltd, and without the interest of the foreman, Mr Hodge, and the skill of the operators, much less would have been achieved. Mr R. D. Penhallurick, Dr F. Strauch, Professor Charles Thomas, and Dr R. G. West, F.R.S., visited the site during the excavation, and gave valuable assistance and advice. The work lasted from 1–25 August, 1966.

2. The site and its setting

In a paper in 1965 I gave a general description of the vicinity of the site, and a history of its working, and repetition here will be avoided as far as possible.

The village of St Erth (figure 1) lies on the east slope of the valley of the Hayle River. East of the village the ground rises to a knoll at 75 m (250 ft). The knoll has a cap of altered dolerite or greenstone, and marks the last height on an interrupted ridge which is capped in places by patches of dolerite, intruded as a sill into the local Upper Palaeozoic slates. The slates are also penetrated by dykes of elvan. The ridge runs N–NE to S–SW, and ends at the Hayle River. On the northern face, below the dolerite cap at about 60 m (200 ft), the slope of the ridge steepens (figure 2). The Old Vicarage of St Erth, which marks the site of the famous clays and sands, lies on rock near the top of this steeper slope. Below the vicarage, and NE of the village, the slope is interrupted by a short, blunt spur which runs NW above the 23 m (75 ft) level for a distance of about 275 m (300 yd) before the slope drops again. The St Erth school stands on the nose of the spur. There is thus a notch in the solid rock where the flatter top of the spur meets the steeper hill slope below the vicarage at a height of about 30 m (100 ft).

After a marine transgression had deposited sand and clay to a height of at least 40 m (130 ft) over the surrounding countryside to an unknown extent, that part of the deposit that rested in the notch was immune from erosion. Moving water could not reach it, and there was no slope down which it could flow during the freeze–thaw stages of the Pleistocene. On the knoll of higher ground above there was only a limited amount of debris available to be moved by

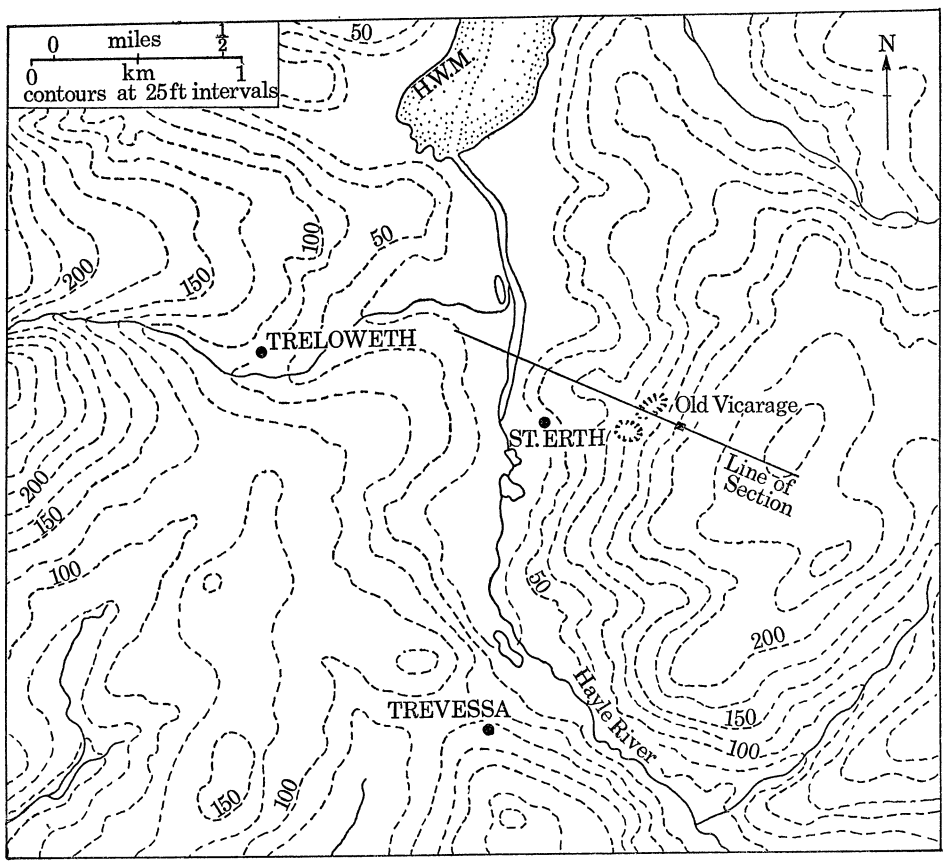

FIGURE 1. Contour map of the basin-like valley and estuary of the River Hayle in the vicinity of St Erth.

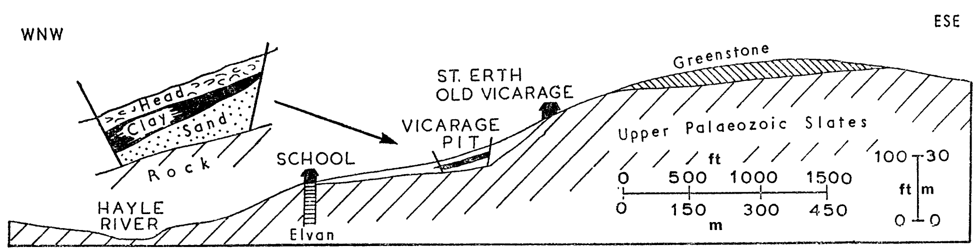

FIGURE 2. Sketch-section through the Vicarage Pit and its vicinity at St Erth.

solifluction, and the earth-flows passed over the sands and clays in the notch, burying them with head, but failing to remove them (figure 3, plate 1). If similar deposits did once have a wider extent on the surrounding slopes, they have since been removed by solifluction and other eroding agencies. In my earlier paper (Mitchell 1965, p. 347) I suggested that the top of the spur might have been planed by wave action which cut a bench and a cliff. Closer inspection of the terrain discounts the necessity for wave action. The spur ends in a low knoll of elvan separated from the main ridge by slightly lower ground (figure 5), and I now consider that the solid rock topography emerged subaerially.

The width of the deposits in the notch is about 520 m (570 yd), and the length downslope perhaps 275 m (300 yd). Shallow valleys partly separate the low elvan knoll from the hill slope, and the deposits project downslope into the valleys for a short distance (figure 5).

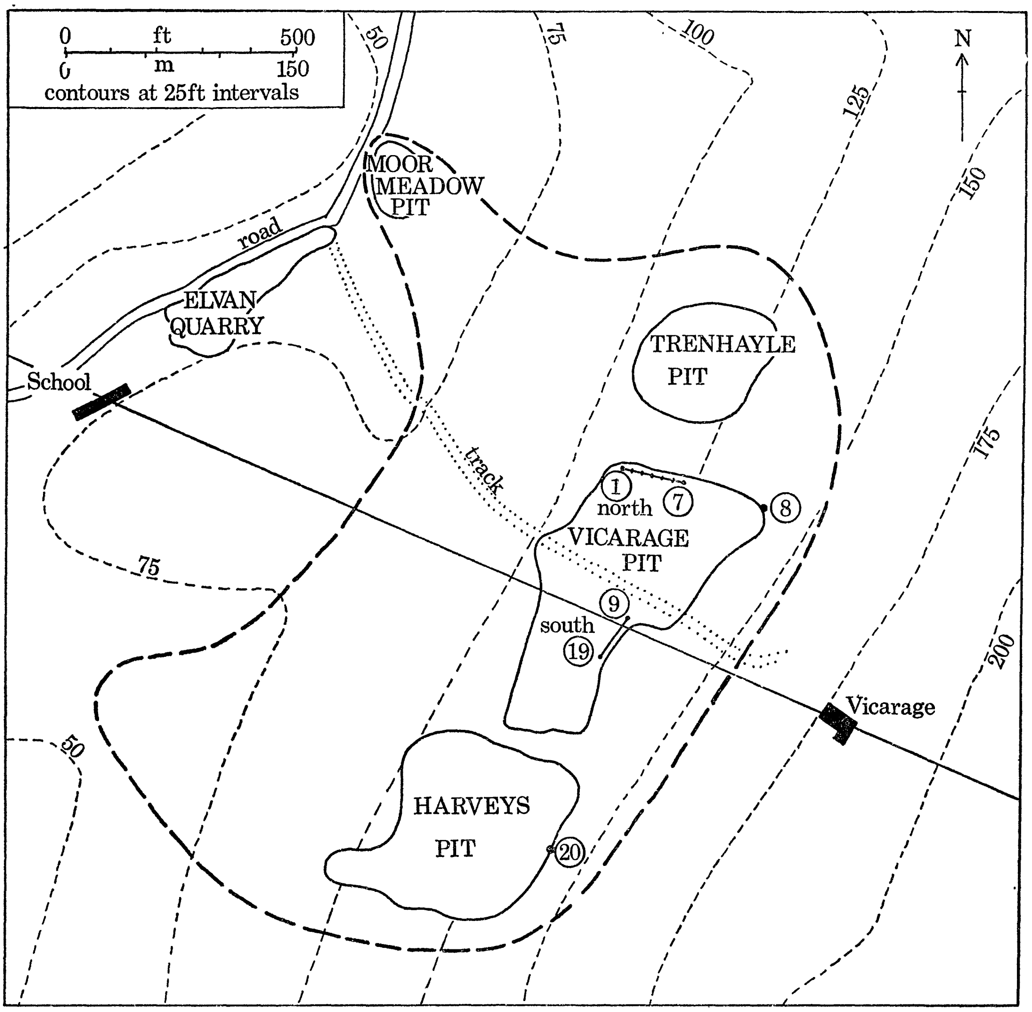

FIGURE 5. Map of the sand-pits at St Erth.

To the N–NE the rock ridge above the Old Vicarage ends in the valley of the Tolroy River. Before the river is reached, two further spurs protrude westwards (figure 6). Just north of Trenhayle a minor ridge runs westwards; the 125 and 100 ft contours are relatively straight as they cross the ridge, suggesting an erosional feature, and there is a relatively flat area between the 100 and 75 ft contours, but there are no records of sand or clay here. The spur that runs NW from Tolroy to Downes has a very flat top between the 125 and 100 ft contours, and it seems not impossible that some sand and clay might have survived where the hill slope flattens out into the top of the spur, as at St Erth. There are a number of old mine workings here, but there is no record of sand or clay.

The lower ground between the St Erth spur and the spur at Trenhayle carries a distinctive feature, a shallow gutter-like depression cut into the general slope. The depression is not occupied by a stream of any size, and may be a nivation-hollow cut in a later glacial episode. Similar features can be seen at Meadowside, Halenkene and south of Tolroy, and part of the valley of the Tolroy River appears to be etched out in the same way (figure 6).

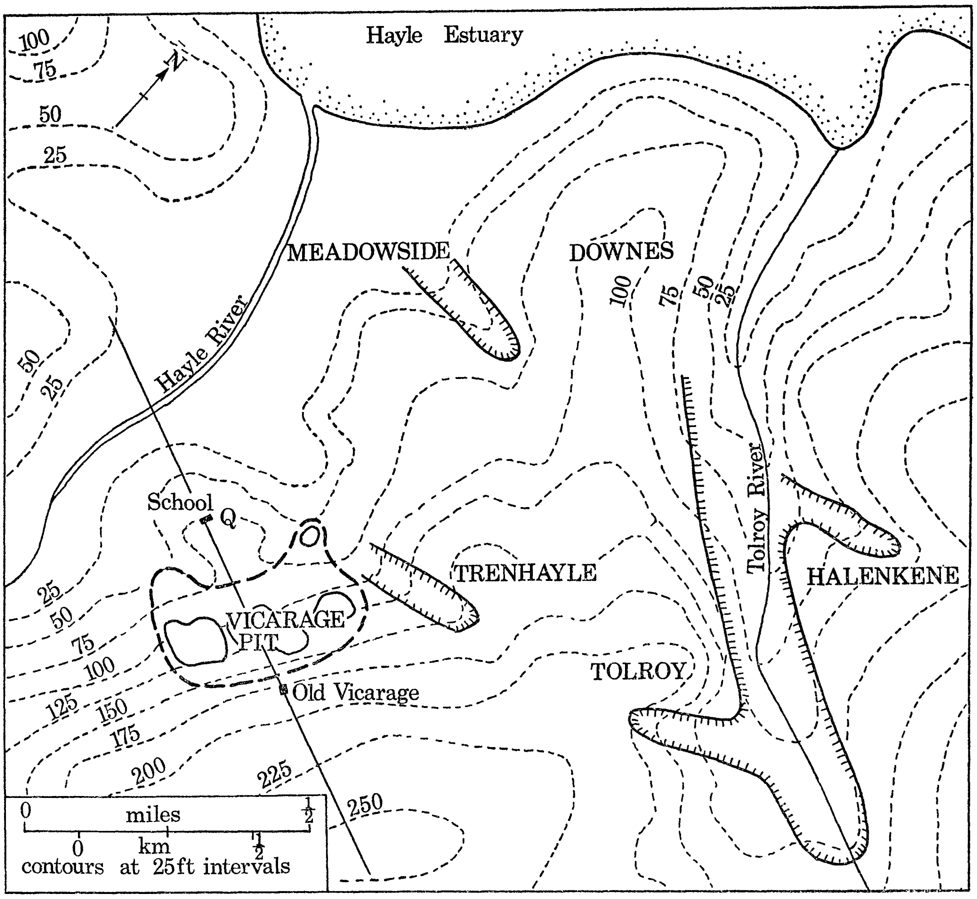

FIGURE 6. Sketch-map of the sand-pits at St Erth and their environs.

3. THE PITS AND THEIR DEPOSITS

The pits at St Erth have not been worked for many years, and are now heavily overgrown with trees and bushes. They are also clogged with disturbed material, because it has to be remembered that it was only a relatively thin layer of sand that had the desired moulding qualities, and the sands overlying this layer were left dumped in the pit. Much of this dumped material has since been levelled and brought under cultivation. The pits thus have a highly confused aspect.

Alfred Bell (1898) has a map which shows three pits indicated by stippling, and to the NE a relatively large area indicated by closely spaced diagonal lines, but very typically no key to the map is given. Within the area marked by lines he refers to clay at 50 ft O.D. by the roadside at Moor Meadow, and my map (figure 5) follows him in indicating a now-vanished source of clay here. The pits indicated by stippling still exist, though that at Trenhayle on the north has been largely filled in. Weathered clay, red sand and sand with small rounded stones can still be seen here, and Bell records shelly clay in this pit.

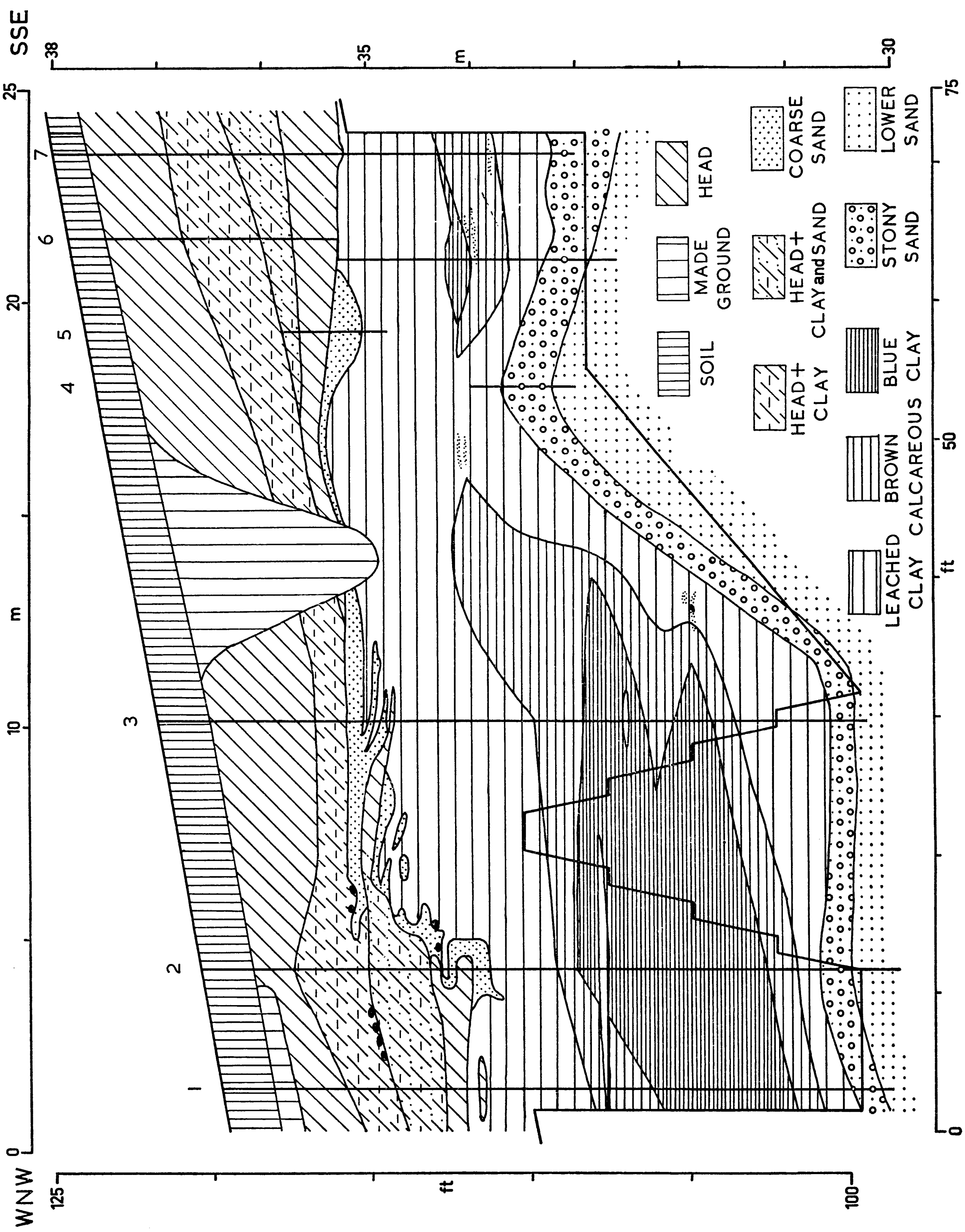

FIGURE 7. Section to illustrate the deposits in the north part of the Vicarage Pit, St Erth.

The central pit, the well-known Vicarage Pit, is much the largest, and is conveniently divided into a north and south part by a now disused track leading up to the Old Vicarage. Bell's account (1898) suggested that clay was found only in the north part, and this coincided with our experience. Prior to my arrival Mr Halford and Mr Penhallurick (of the Royal Institution, Truro) had noted shells in this part of the pit, and inspection of the NW corner showed that the north wall of the pit, which had here been advancing into virgin ground at the time of its abandonment, was still standing. With the aid of a bulldozer the wall face was

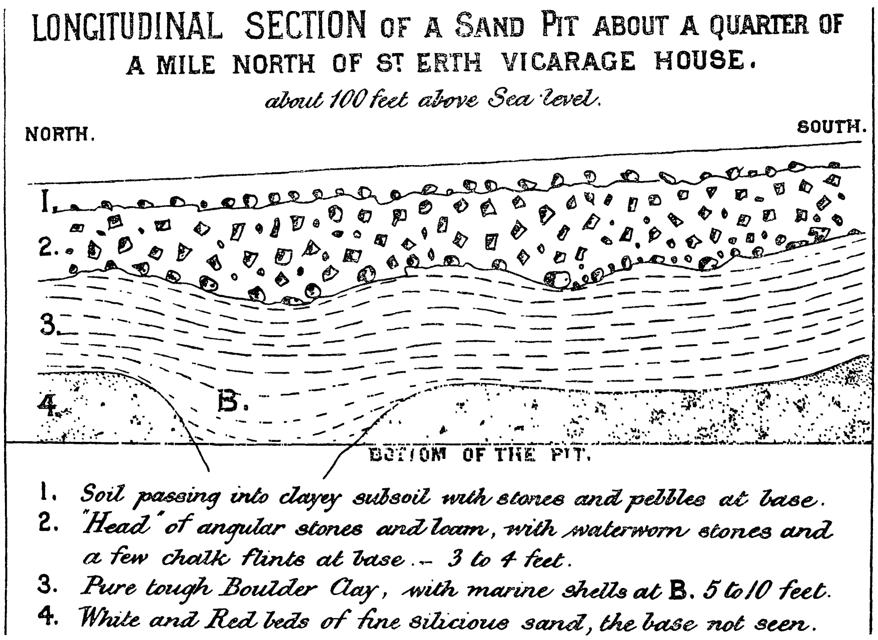

Figure 8. Whitley's section (1881) of the deposits in the north part of the Vicarage Pit, St Erth.

scraped clean for a distance of 25 m, and a strip of the floor of the pit parallel with the wall was lowered until undisturbed leached clay was exposed all over the floor of the strip. A trench-digger then excavated a trench 1 m wide through the clay into the top of the underlying sand (figure 4, plate 1). Seven detailed profiles were recorded,† and samples for sedimentological, botanical and zoological study were collected. The section shown in figure 7, which is essentially a dip section, is based on the profiles. It is remarkably similar to the section (figure 8) drawn by Whitley when the clay was first exposed in 1881.

The section reached down into fine sand, and at profile 2 this was shown by augering to have a thickness of more than 480 cm. The top of the sand was curiously irregular in level, and contained to a depth of about 30 cm, a considerable amount of small rounded pebbles. The conditions which could introduce small stones into the upper layers of a sand deposit with an irregular surface are not easy to picture.

A marine clay, originally calcareous, highly fossiliferous and blue in colour rested on the sand. In the 1966 profiles the clay reached a thickness of 4 m, and none of the older records indicate a substantially greater thickness. At some points the sand content was relatively high. In the section its highest surviving level was at about 35 m O.D. Later elevation in relation to

† These are not printed here, but are deposited with the Royal Society: copies may be purchased from the National Lending Library, Boston Spa, Yorkshire, LS23 7BQ, Great Britain (reference number SUP10011). Also deposited are profiles 10, 12, 13 and 15 mentioned on page 11.

sea level and burial by solifluction-earth or head had exposed the clay to weathering. Sandwiched between a relatively permeable head above and a sand containing water under artesian pressure below, both the upper and the lower surfaces of the clay had been attacked by chemical weathering.

The unweathered clay was rich in non-detrital ferrous iron compounds which were responsible for its blue colour, and the first effect of weathering was to oxidize these compounds and change the colour from blue to brown. Leaching of calcium carbonate was the next effect, and this caused the clay to become non-calcareous and the majority of the fossils to disappear. Solution was not the only fate of the fossils. With compaction and dehydration the clay had shrunk in volume, and the pressures associated with shrinkage had crushed most of the lamellibranch shells; the more robust gastropods had sufficient strength to survive these pressures, and on the whole the fossil gastropods were in much better condition than the lamellibranchs.

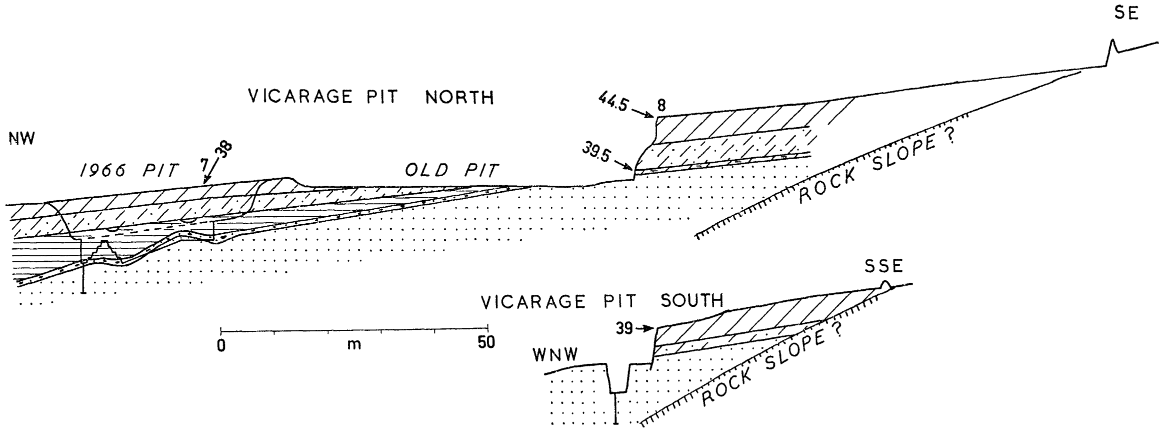

FIGURE 9. (Above): extended section parallel with the slope of the ground in the north part of the Vicarage Pit, St Erth. (Below): sketch section parallel with the slope of the ground in the south part of the Vicarage Pit.

In the upper and lower layers of the clay weathering had caused both the formation of structures and the movement of clay. Near both the upper and the lower surfaces a blocky structure with clay-skins on the peds had developed. In the upper part below the blocky structure a coarse prismatic structure, again with clay-skins on the faces of the peds was present. A strongly developed clay-skin separated the bottom surface of the clay from the underlying sand.

The two types of weathering, oxidation and leaching of carbonate, had not operated in a regular manner but had left lens-like masses of unaltered clay usually enveloped by larger masses of oxidized but still calcareous clay; these were contained between upper and lower layers of clay which were both oxidized and leached. As a result the 'blue clay' appears and disappears and thickens and thins in an almost capricious fashion.

Head, a confused mass of coarse sand, clay and broken rock, forms the top of the section. As material set in motion by freeze-thaw cycles moved down the slope, a coarse sand was the first material to arrive, and this may be derived from a basal coarse sand, not seen in 1966, but described by Kendall & Bell (1886). At profile 2 the layers in which it was first deposited were later contorted by further movement. The next layer upwards was a mixture of clay, sand and stone. In the field it was thought that this clay was derived from marine clay still farther up the hillslope, and now moved down by solifluction, but laboratory studies of clayey sand still *in situ* at a higher level (profile 8, figure 9, above) showed that that clay was significantly dif-

FIGURE 3. Looking W–NW down the solifluction-earth slope to the St Erth school; the bushes in the left foreground are in the NW corner of the north part of the Vicarage Pit; the section shown in figure 7 runs parallel to the edge of the pit.

FIGURE 4. Looking along the line of the section in the north part of the Vicarage Pit, St Erth, from profile 1 towards profile 7 shown in figure 7; the wall of the pit behind the ranging-rods is largely in head; the trench is in clay.

(*Facing p.* 8)

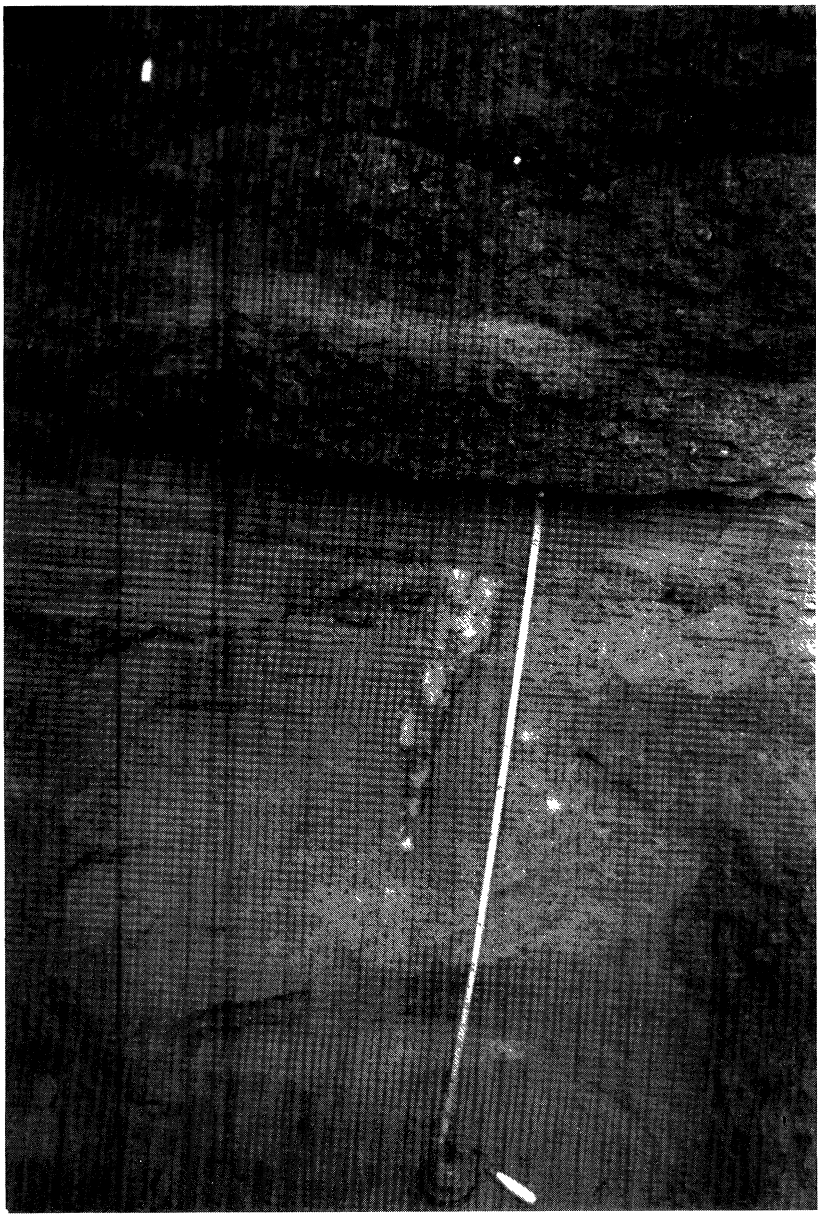

Figure 12. Wedge-cast in sand, truncated by soliflucted sand, which is overlain by stony head (see profile 10, figure 10). The tape measure is extended to 150 cm.

ferent from the marine clay. The origin of the clay in the head is thus uncertain. The top layer of the head was largely composed of blocks of slate set in a loamy matrix.

At profile 8 (figure 9), farther uphill on the east wall of the northern part of the old Vicarage Pit, the detailed section was:

Vicarage Pit North, profile 8, height 44.50 m

0–165 cm	soil (all Ap horizon)
165–325 cm	firm indurated head, projecting as a ledge
325–440 cm	disturbed sand from former workings thrown against old wall of pit below ledge
440–495 cm	undisturbed coarse sand with small rounded stones, suggestion of stratification dipping downslope
495–500 cm	clayey sand, grey-brown in colour (sediment sample 6)
500–700+ cm	fine stone-free sand, orange in colour flecked with black manganese oxide, no bedding visible (sediment sample 7)

The deeper parts of the sands and the rock surface on which they rest have not been seen in recent years.

Both Kendall & Bell (1886) and H. Dewey (unpublished records in the Institute of Geological Sciences) illustrate sections which show the deeper deposits in the north part of the Vicarage Pit resting on rock, but it must be remembered that there is no certainty that they made the record from their own observations and not from what the quarrymen told them. Dewey's record is as follows:

Vicarage Pit North, Dewey record, *ca.* 1925

0–180 cm	head
180–275 cm	brown moulding loam
275–400 cm	free flowing yellow sand
400–650 cm	green loamy clay passing down into blue clay with marine shells
650–700 cm	'grit' of coarse fragments and nodules of weathered slate, quartz and igneous rock
700–800 cm	mottled calcareous clay, with shells and coarse rounded sand-grains and small stones
at 800 cm	shelf of Devonian rock

Dewey thus describes the marine clay as resting directly on rock, and being divided by or containing a lens of coarse sand or fine gravel 50 cm thick. It is possible that the loam and sand (180–400 cm) above the clay had been moved downslope by solifluction.

Kendall & Bell (1886) illustrate the succession of the beds by a figure, but unfortunately the thicknesses of the beds are not recorded. The sequence recorded is essentially the same as our record, except that it extends down to the rock.

Vicarage Pit North, Kendall and Bell record, 1885

vegetable soil

'head', an argillaceous deposit containing many angular fragments of killas and other local rocks

fine yellow sand

thin layer of 'growder', i.e. very coarse quartzose ferruginous sand

yellow clay without fossils, passing down into blue clay with many fossils
layer of scattered quartzose pebbles
fine quartzose sand, yellow above and purplish below
very coarse highly ferruginous sand
elvan dyke

These authors record an observed dip of about $3\frac{1}{2}°$ to 4° N–NW in the fine sand, but considered that the true dip was 5°.

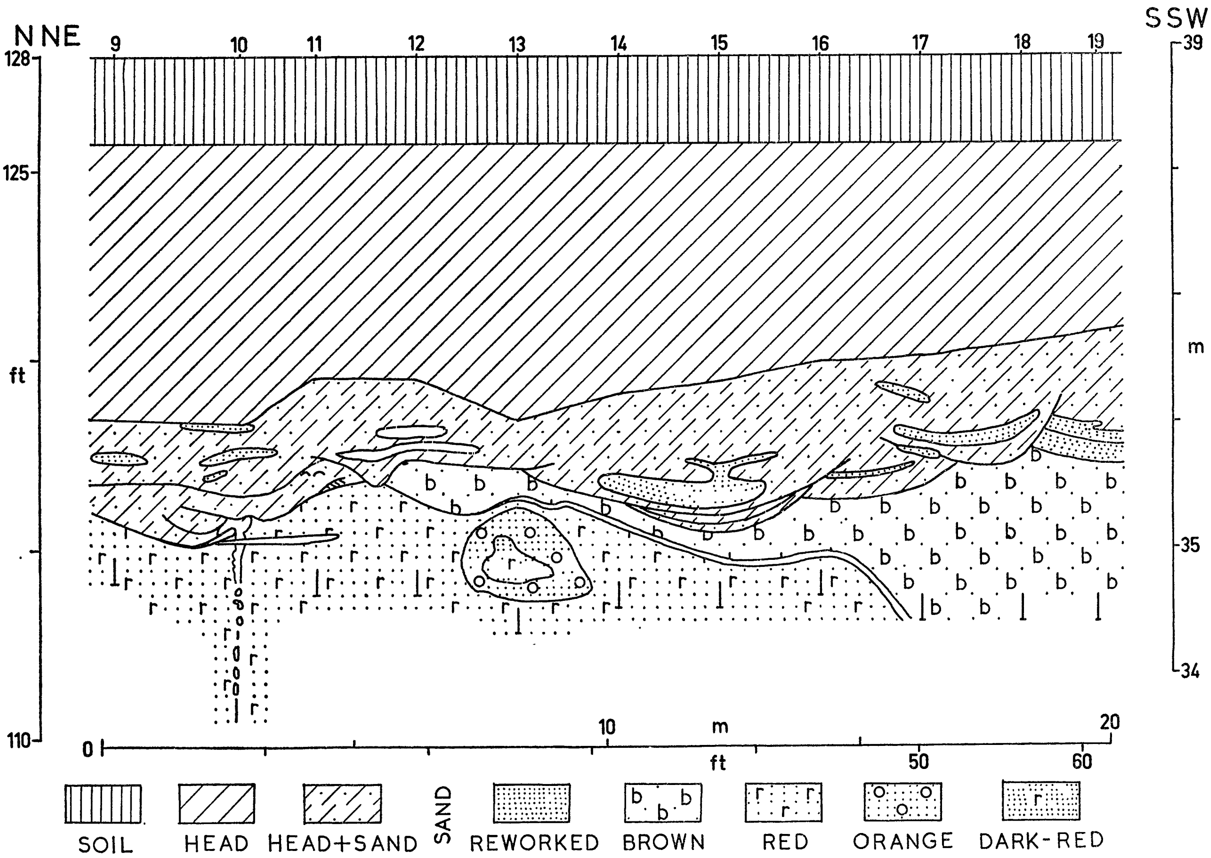

FIGURE 10. Section at right angles to the slope of the ground to illustrate the deposits in the south part of the Vicarage Pit, St Erth.

A. Bell (1898) records that the fine sands, which are free-flowing and white to pale yellow or red in colour, pass down into ferruginous sands and gravels: these are coloured by oxides of iron and manganese disposed in horizontal streaks or bands, known by the diggers as 'smoke', and are sometimes cemented into loose blocks or even a hardpan of varying density and colour, called 'cinders' by the workmen.

The old records suggest that the sands, with their included seams of pebbly gravels, are at least 5 m (15 ft) thick. With a hand auger we proved the sand to at least this thickness, but because the well-sorted sand bound on the auger shaft, it was not possible to go to a greater depth.

We then transferred to the south part of the Vicarage Pit, and cleaned a section 20 m in length parallel with the ridge, i.e. a strike section essentially at right angles to the section in the north part of the pit. Eleven profiles† were measured at 2 m intervals, and from them the section seen in figure 10 was drawn up.

In the section the clay was absent, and head, the upper part rich in stone and the lower part rich in sand, rested directly on the fine sand. This was a strike section at right angles to the downslope movement of the head, and the channels down which the head moved could be seen in cross-section. Permafrost with formation of ice-wedges or sand-wedges must have preceded the solifluction because the top of a wedge-cast had been truncated by solifluction, and some sand formerly higher in the cast could be seen to have moved sidewards and downwards (figure 12, plate 2). The wedge was 15 cm wide at the top, and 3 cm wide at the point where it became discontinuous 50 cm below the top. Farther down the crack in the sand could be traced to a level 130 cm below the top of the wedge. It is not impossible that the structure was originally a sand-wedge, and the sand fill may be primary.

Solifluction must have caused coherent masses of sand to move downslope. One such small mass is seen in profile 15, separated from the main sand below by solifluction-flows of head. The particle size analyses of the sand in the head (sediment sample 8) and of the sand below the head (sediment sample 9) were identical. Dewey recorded thick deposits of brown moulding loam and of free flowing yellow sand above the clay, and it is possible that such loam and sand was not in primary position, but having originally been deposited before the clay, it had been moved down on top of the clay by later solifluction. The final effect of solifluction was to emplace a superficial layer of head rich in local stone.

Chemical processes had taken place in the lower sand, which had a strong colour, yellow and orange-reds predominating. In Brittany a strong colour in a sand is taken as an indication of considerable age, but it is not clear whether the colour is primary, or whether it has developed with weathering and time. It is impossible to say what colour the St Erth sand was when it was first deposited, but there has certainly been relatively late movement or changes in oxidation-reduction of iron, and manganese has probably moved also.

The formation of the wedge-cast (profile 10) was obviously a relatively recent event. The sand which filled the wedge must differ in some of its properties from the surrounding sand with the result that iron has been concentrated along the plane of contact between the two, and the sand filling the wedge is more bleached than the surrounding sand. In profile 10 there was at a depth of 385 cm a thin lens of paler sand with a lateral extent of more than 1 m. This lens intersected the wedge, and its colour was the same both in the wedge and in the surrounding sand. This colour change must postdate the formation of the wedge-cast.

At the south end of the section the sand was yellowish brown (10YR 5/8) in colour. As one moved north a thin diagonal band of grey sand with brown rims separated this yellowish brown sand from sand which was yellowish red (5YR 4/6) in colour, and this colour persisted to the north end of the section. One got the impression that some sort of chemical front was moving across the sand and bringing this colour change in its wake.

The pit on the south was first known as Harvey's Pit, and in it Bell (1898, p. 119) records very thick mottled clay, which was probably leached shelly clay. The pit was later extended, presumably eastwards towards the ridge, as the Cornish Sand Company's Pit. Milner (1922) studied the sands here, and in outline his sequence is: head and surface soil, 60–120 cm (2–4 ft); sands, 120–720 cm (4–24 ft), resting on an eroded Palaeozoic rock floor, consisting of slate intersected in one place by an elvan dyke.

† The detailed records of four of these profiles have been deposited; see p. 7.

He remarks that the sands vary considerably both laterally and in depth, and that apart from some minor irregularities in bedding, there is a marked dip in the whole series of 5° northwestwards. Current-bedding is not a marked feature, although it may be detected in some instances on a small scale. There is a grit band with small pebbles of quartz, killas, greenstone and schorlaceous material, though it is impersistent and of little value as a horizon. There are other seams of pebbles, all well worn, and the majority quartz. Milner does not record coarse sand at the base, nor clay at any level.

Today the walls of the pit are very much slumped, and I did not do more than measure a short profile at the top wall of the pit:

Harvey's Pit, Profile 20, height *ca.* 45 m

0–30 cm	soil (all Ap horizon)
30–80 cm	head, composed of blocks of dolerite set in a matrix of loamy sand
80–110 cm	head, composed of dark-red sand (with yellower and blacker streaks), with small stones and blocks of dolerite (up to 20 × 25 cm)
110–170 cm	sand, perhaps soliflucted, dark red in colour with black streaks and pale clayey lenses
at 170 cm	thin discontinuous seam of small stones
170–200+ cm	red stone-free sand (sediment sample 10)

4. The sediments

By J. A. Catt and A. H. Weir

Introduction

The heavy minerals in the sand member of the St Erth Formation were described by Boswell (1918, 1923), Milner (1922) and Groves (1931), but other petrographic aspects of the deposits have not previously been studied. On the evidence of the heavy minerals in the 'Cornish Red' moulding sand of Harvey's Pit, Boswell (1918, p. 202) suggested that the deposits were derived mainly from the West Country granites; he also reported the chemical composition of the sand and the particle size distribution of both the moulding sand and an open sand containing insufficient clay for moulding purposes. Milner's list of heavy minerals from Harvey's Pit resembles Boswell's; he noted that the nearby deposits at St Agnes and St Keverne are petrographically similar to the St Erth sands, and suggested that most of the detritus was locally derived, but that the staurolite came from Brittany and the kyanite from the Lower Greensand of Wiltshire. Later, Boswell (1923) reinvestigated the Cornish 'Pliocene' deposits, and noted the rarity of many minerals (pyroxenes, amphiboles, biotite, chlorite, epidote and garnet) that are common in older Cornish rocks. However, Groves (1931) recognized typical Dartmoor detritals in the St Erth Beds, and supported Milner's suggestion of an easterly source for much of the detritus.

Table 1 shows the particle size distribution of seven samples representing the main subdivisions of the deposits recognized in the North Vicarage Pit excavations, two samples of sand from the South Vicarage Pit, and one from Harvey's Pit. Two methods of mechanical analysis were used: amounts of clay and three silt fractions were estimated by the pipette sampling technique, and fractions > 50 μm were subdivided by sieving. Detailed particle size distribution of > 50 μm fractions (figure 11) was determined with a tower of sieves with meshes at

0.25 ϕ intervals. Mineralogical work was restricted to the fine sand and clay fractions, because these are the main components of the deposits. Table 2 shows the mineralogical composition of the fine sands, which were analysed with a petrological microscope. Amounts of the principal clay minerals in the five samples containing appreciable quantities of clay (table 3) were determined by X-ray diffraction techniques. The morphology of the clay particles was studied by transmission electron microscopy, and the surface features of sand grains were investigated with a scanning electron microscope.

Conditions of deposition

The fine sand fractions of all ten samples studied contain both detrital and non-detrital minerals, but non-detrital constituents (calcite, collophane, glauconite and pyrites) are more common in the shelly grey clay than in the sands. The collophane comprises several forms of organically accumulated calcium phosphate, mainly fish remains. Shell fragments and foraminiferal tests account for most of the calcite, the remainder occurring as spherulitic concretions, which probably formed by precipitation of carbonate in mildly alkaline water. The glauconite pellets in the grey clay are bright green and completely unoxidized, which suggests they were formed during deposition of the clay, and were not derived from an earlier sediment, so that they confirm the marine origin of the clay.

TABLE 1. PARTICLE SIZE DISTRIBUTION OF SEDIMENTS FROM THE ST ERTH MARINE FORMATION

(In weight % of oven dry samples.)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
gravel > 2 mm	1.3	0.0	0.0	13.6	0.7	0.4	0.1	0.0	0.2	0.3
coarse sand 500–2000 μm	20.4	0.1	0.1	5.1	0.4	0.3	0.2	0.0	0.1	0.2
medium sand 250–500 μm	33.6	0.7	0.8	4.5	1.0	1.6	3.3	0.6	0.6	3.4
fine sand 50–250 μm	38.6	21.8	33.7	48.9	76.8	61.2	91.3	86.4	81.2	77.5
coarse silt 20–50 μm	0.0	7.3	9.2	3.0	2.0	3.5	1.6	0.5	0.5	0.8
medium silt 5–20 μm	0.8	16.5	10.0	3.1	3.6	6.9	0.0	2.3	2.4	0.8
fine silt 2–5 μm	0.6	10.8	9.2	2.8	1.0	1.4	0.7	1.4	2.7	2.0
clay < 2 μm	4.7	42.8	37.0	19.0	14.5	24.7	2.8	8.8	12.3	15.0

(1) Coarse sand in channel at top of marine clay, North Pit, profile 5, 235–245 cm. (2) Shelly calcareous marine clay, North Pit, between profiles 2 and 3, *ca.* 250 cm. (3) Sandy lens in marine clay, North Pit, profile 6, 390–395 cm. (4) Sand with small stones below marine clay, North Pit, profile 4, 400–410 cm. (5) Sand below stony sand, North Pit, profile 4, 450–460 cm. (6) Clayey sand below head, North Pit, profile 8, 495–500 cm. (7) Sand below clayey sand, North Pit, profile 8, 508–518 cm. (8) Sand in head, South Pit, profile 15, 340–350 cm. (9) Sand below head, South Pit, profile 15, 410–420 cm. (10) Sand below head, top of Harvey's Pit, profile 20, 180–200 cm.

Pyrites occurs partly as infillings of foraminiferal tests and partly as small irregular concretions. In alkaline conditions the synthesis of pyrites can occur only in a reducing environment (Nicholls 1963; Berner 1964). Reducing conditions during deposition probably account for the colour of the unweathered clay, because non-detrital iron minerals are grey, bluish grey or greenish grey ferrous compounds in oxygen-free environments. In the brown decalcified margins of the marine clay the iron minerals have been oxidized by postdepositional weathering.

It is difficult to reconstruct the conditions in which the sandy deposits above and below the marine clay were laid down, because they contain no fossils and very little non-detrital material. Glauconite is slightly more abundant than in the sand fraction of the marine clay (table 2), but many of the grains are partly oxidized to limonite. This could indicate that they were derived from an earlier sediment, but the extent of postdepositional oxidative weathering in the marine clay shows that much of the alteration in these pellets could have occurred since the sands were deposited. The nearest richly glauconitic deposit from which detritus might have been derived is the Upper Greensand of south Devon, the closest outliers of which are on the Haldon Hills, approximately ninety miles ENE of St Erth. Some of the strongly oxidized pellets could have been transported this distance, but others only slightly oxidized have obviously never suffered

TABLE 2. MINERALOGICAL COMPOSITION OF FINE SAND (50–250 μm) FRACTIONS FROM THE ST ERTH MARINE FORMATION

(Light minerals as percentages of fine sand, heavy minerals as parts per thousand of the heavy fraction.)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
light fraction (s.g. < 2.9)										
% quartz	93	42	50	79	87	78	85	87	86	82
% rock fragments (slates, quartzites)	5	7	7	12	8	15	9	8	8	12
% calcite (including shell fragments)	—	35	30	—	—	—	—	—	—	—
% collophane	—	11	8	—	—	—	—	—	—	—
% glauconite	1	1	1	4	2	2	1	2	3	1
% muscovite	< 1	< 1	< 1	—	—	< 1	—	—	< 1	—
% alkali felspar	1	2	3	4	3	3	4	2	2	3
% flint	< 1	1	1	1	< 1	2	1	1	1	1
heavy fraction (s.g. > 2.9)										
% heavy minerals in fine sand	0.33	0.06	0.16	0.49	0.22	0.59	0.18	0.39	0.21	0.17
total no. of grains counted	1126	829	834	870	910	1933	1143	820	893	1020
‰ magnetite	38	18	25	77	69	18	38	28	30	17
‰ haematite	82	105	166	101	130	41	166	132	141	275
‰ limonite	65	10	58	42	90	654	158	284	85	124
‰ ilmenite + leucoxene	54	326	267	153	146	83	101	147	149	73
‰ pyrites	—	51	4	—	—	—	—	—	—	—
‰ tourmaline	645	228	158	335	380	120	422	212	360	418
‰ colourless zircon	42	106	155	101	74	32	29	50	122	29
‰ rose pink zircon	3	1	—	5	1	1	2	—	3	2
‰ apatite	—	6	6	—	—	—	—	—	—	—
‰ staurolite	20	7	6	22	24	8	28	15	34	20
‰ kyanite	10	11	23	22	18	6	7	17	15	3
‰ andalusite	15	6	—	2	4	6	7	2	4	2
‰ epidote	2	17	9	30	3	1	2	1	—	10
‰ clinozoisite	—	—	4	37	1	—	—	1	—	5
‰ yellow rutile	5	11	22	14	18	6	7	33	27	—
‰ red rutile	8	8	15	18	22	7	10	16	11	3
‰ brown rutile	—	8	11	—	1	1	1	2	1	—
‰ brookite	—	2	8	—	—	1	1	1	—	—
‰ anatase	—	—	4	3	2	1	1	2	1	2
‰ topaz	10	14	13	25	12	4	14	32	3	15
‰ augite	—	1	—	—	—	—	—	—	—	—
‰ hornblende	—	6	4	—	—	—	—	17	1	—
‰ actinolite + tremolite	—	1	1	3	—	—	—	—	1	—
‰ biotite	1	27	17	2	1	9	6	6	8	2
‰ chlorite	—	14	5	1	—	1	—	—	—	—
‰ garnet	—	14	17	5	2	—	—	1	—	—
‰ monazite	—	2	2	2	—	—	—	—	1	—
‰ sphene	—	—	—	—	1	—	—	1	—	—
‰ spinel	—	—	—	—	—	—	—	—	1	—
‰ corundum	—	—	—	—	—	—	—	—	2	—
‰ talc?	—	—	—	—	1	—	—	—	—	—

For explanation of column numbers see table 1.

such a journey. Unless an unknown local source was involved, at least part of the glauconite in these beds therefore probably originated during deposition in a marine environment.

As Boswell (1918) noted, many of the sands of the St Erth Formation are unusual, because they are composed almost entirely of clay and well-sorted sand (i.e. the particle size distribution required for a good moulding sand). The production of well-sorted sand by the progressive removal of finer and coarser fragments cannot occur in an environment that allows deposition of as much as 24 % clay (table 1). This suggests that the sand was not sorted during deposition of the sand member, but was derived already sorted from an older sediment.

The subdivisions of > 50 μm fractions at 0.25 ϕ intervals (figure 11) shows that almost all the sand in samples 4–10 ranges in size from 3.25 ϕ (105 μm) to 2.0 ϕ (250 μm); gravel is fairly common in samples 1 and 4–6, but medium and coarse sand is rare, especially in samples 5–10. However, the distribution of fine sand between 2.0 ϕ and 3.25 ϕ is not the same in all the samples, because sands of two main sizes are involved. These are a finer sand with a mean size near 3.0 ϕ (125 μm) and a slightly coarser sand with a mean size near 2.4 ϕ (200 μm). The fine sand of samples 6, 7 and 10 is composed almost entirely of the coarser of these, but the sand of samples 5, 8 and 9 is a mixture of fine and coarse components in the approximate ratio 2:1. The sand in sample 4 is also a mixture of the same two components, but in the ratio 2:3. Two types of well-sorted sands were therefore incorporated in many of the deposits; at times the supply of finer sand failed completely (samples 7 and 10) or almost so (sample 6), but all the deposits contain some of the coarser sand.

The lack of sand other than that contributing to the two main fine sand components suggests that the sources of the well-sorted sands were close to the site of final deposition. If the sediment had travelled far, the well-sorted sands would have been diluted more with sand of other sizes. The standard deviations (σ) of the sand samples 5–10 are < 0.37 ϕ (figure 11), but as many of these are mixtures the standard deviations of the two fine sand components, considered individually, must be very small (probably < 0.20 ϕ). Such well-sorted sands occur only in dunes or marine beaches (Friedman 1961), and the presence of two distinct, well-sorted and locally derived populations suggests that both types are involved.

A study of the surface textures of quartz sand grains by the scanning electron microscope showed important differences between the two sand components. Grains of the coarser sand of sample 7 are often moderately well or well rounded, and have essentially smooth surfaces with arcuate or V-shaped depressions (figures 13*a*, *b*, plate 3), which Krinsley & Margolis (1969) attribute to grinding in a high-energy aqueous environment. Similar features are evident in the coarser sand component separated from sample 5 (figures 13*c*, *d*). However, the finer sand component from sample 5 contains very few grains with this surface texture. Instead, some of the well-rounded grains are extremely smooth with only a few, very small surface features (figure 13*h*); others have a platy surface (figure 13*f*), which is sometimes modified by smoothing and partial elimination of the plates (figures 13*e*, *g*). All these features have been attributed to wind action or partial dissolution and redeposition of the silica in subaerial environments (Krinsley & Smalley 1972), which suggests that much of the finer sand component could have been derived from dunes. However, not all the grains of the fine component show surface textures typical of aeolian environments, and many were perhaps modified subsequently in marine or other conditions.

The coarser sand component was therefore derived from beach sands without detectable modification, and the finer component at least partly from dunes, but with some modification of surface textures and possibly also with some mixing with sand from other sources. The environment that allowed reworking of beach and dune sands in these ways and also favoured deposition of clay was probably brought about by rising sea level and a marine transgression after a long period of fairly stable sea level. During the transgression beach sands were carried landwards and partly mixed with old coastal dune sands. Redeposition occurred partly in the calm, shallow, muddy waters of temporary lagoons, which were possibly fed by streams carrying

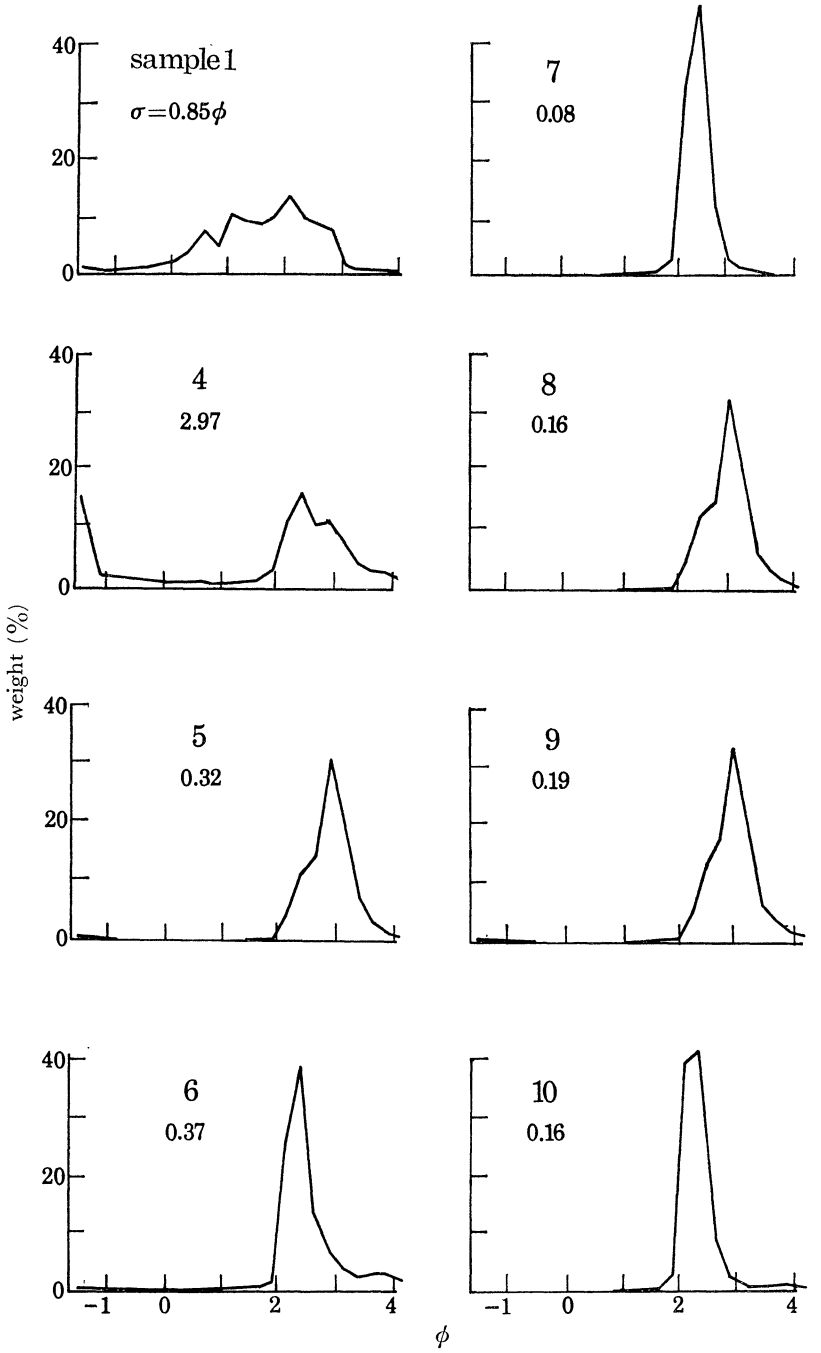

FIGURE 11. Particle-size distributions of > 50 μm fractions of selected sandy deposits of the St Erth formation, based on sieving at 0.25 ϕ intervals.

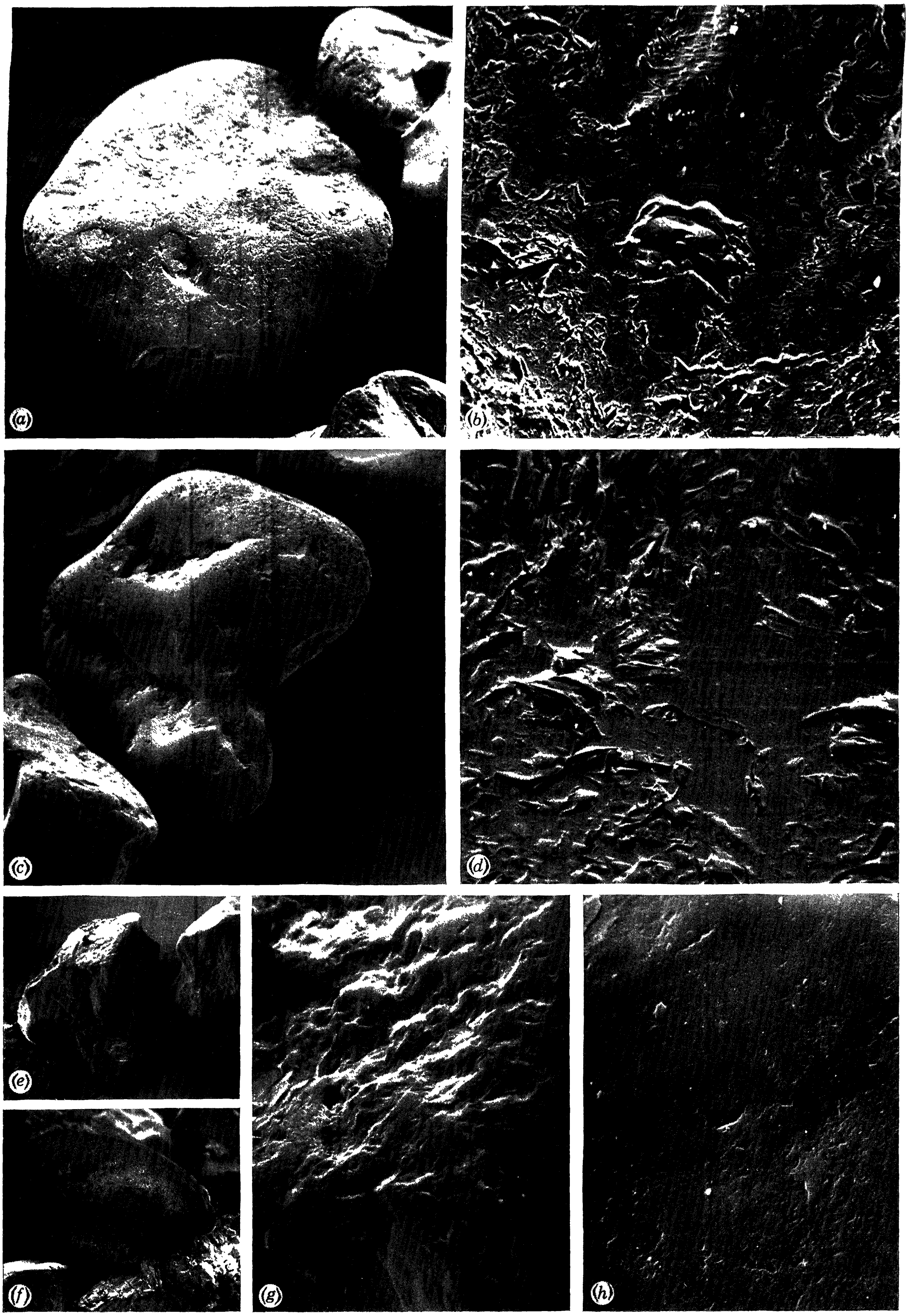

FIGURE 13. Scanning electron micrographs of the surface textures of sand grains from the St Erth Beds: (*a*) well rounded grain from sample 7 (× 185); (*b*) detail of surface texture of grain from sample 7 (× 1850); (*c*) grain from 180 to 250 μm fraction of sample 5 (× 185); (*d*) detail of surface texture of grain shown in (*c*) (× 1850); (*e*) grain from 50 to 125 μm fraction of sample 5 (× 185); (*f*) grain from 50 to 125 μm fraction of sample 5 (× 185); (*g*) detail of surface texture of upper surface of grain shown in (*e*) (× 1850); (*h*) detail of surface texture of smooth grain from sample 5, 50–125 μm fraction (× 1850).

(*Facing p.* 16)

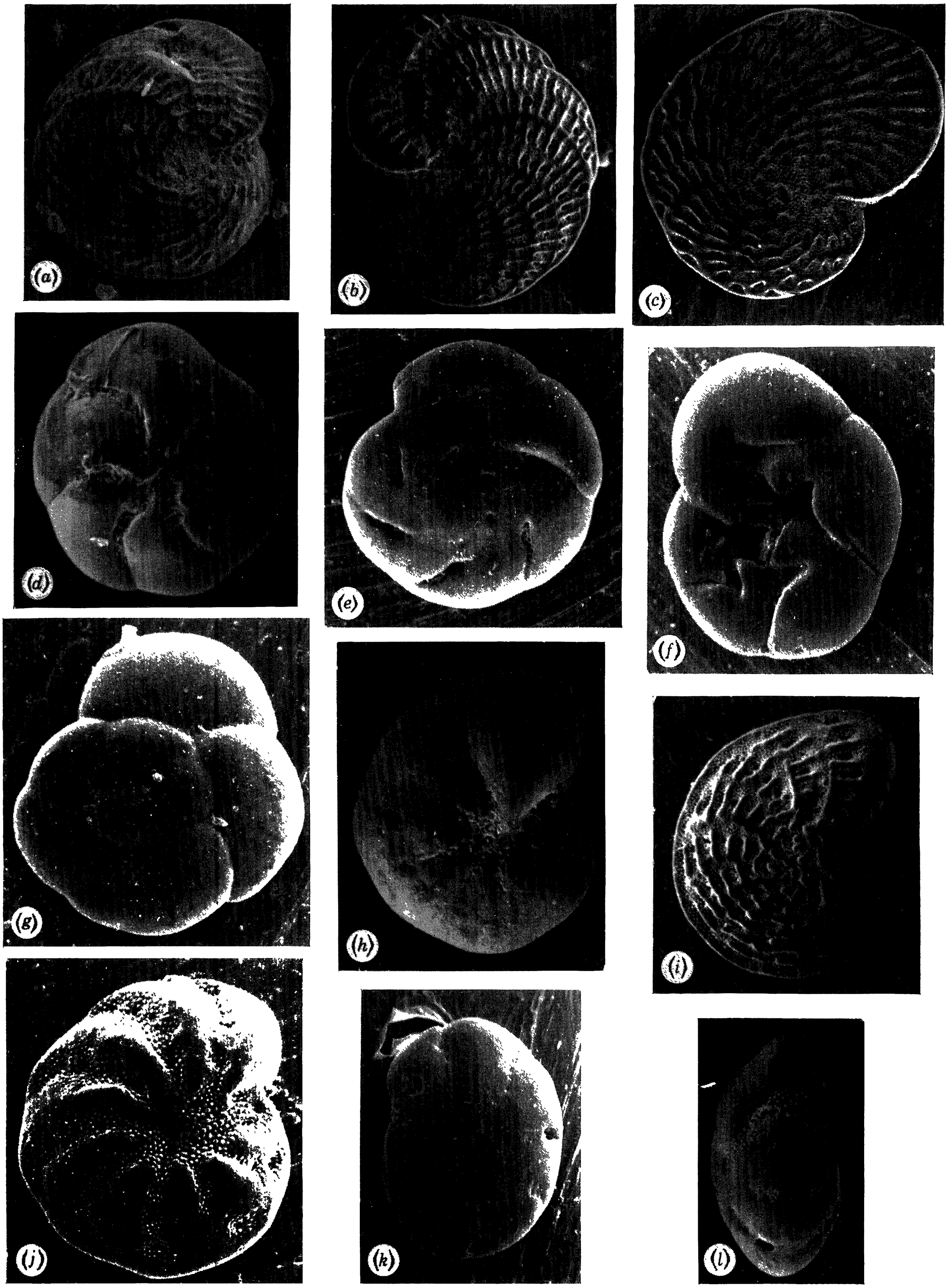

FIGURE 14. Foraminifera, St Erth:

(*a*) *Faujasina subrotunda* (Ten Dam & Reinhold) (× 120).
(*b*) *F. carinata* (d'Orbigny) (× 100).
(*c*) *F. compressa* (Margerel) (× 180).
(*d*) *Monspeliensina pseudotepida* (van Voorthuysen) (× 120).
(*e*) *M. pseudotepida* (van Voorthuysen) (× 90).
(*f*) *Monspeliensina* sp. (× 180).
(*g*) *Monspeliensina* sp. (× 180).
(*h*) *Aubignyna mariei* (Margerel) (× 180).
(*i*) *Elphidium pseudolessonii* (Ten Dam & Reinhold) (× 180).
(*j*) *E. haagensis* (van Voorthuysen) (× 180).
(*k*) *Elphidiella occidentalis* (Margerel) (× 170).
(*l*) *E. occidentalis* (Margerel) (× 150).

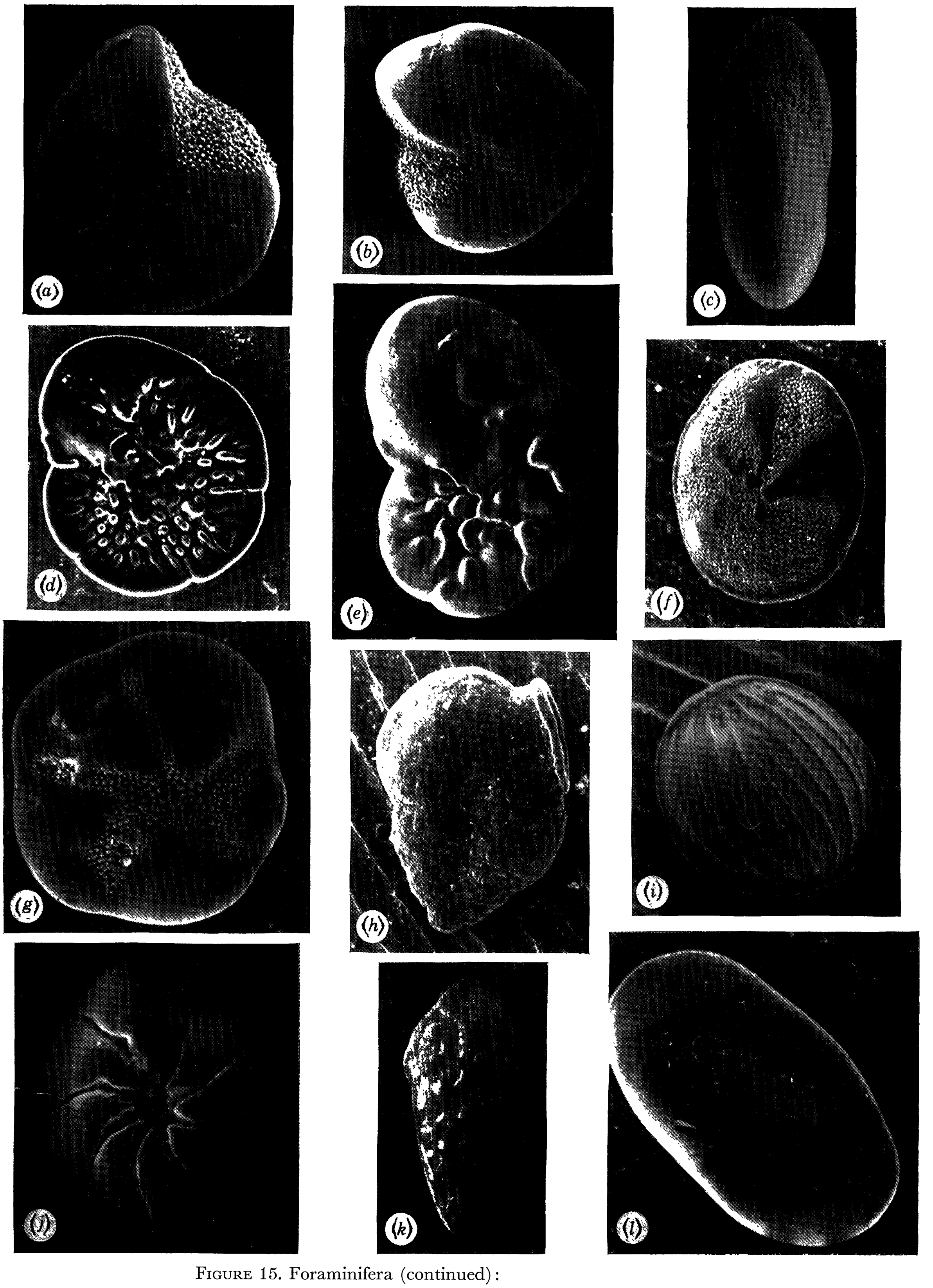

FIGURE 15. Foraminifera (continued):

(*a*) *Elphidiella hannai* (Cushman & Grant) Sables de Kallo (× 180).
(*b*) *E. hannai* (Cushman & Grant), Whitlingham (× 130).
(*c*) *E. hannai* (Cushman & Grant), Ludham (× 180).
(*d*) *Discorbitura cushmani* (Margerel), St Erth (× 180).
(*e*) *D. granuloumbilicatula* (van Voorthuysen), St Erth (× 120).
(*f*) *Buccella frigida* (Cushman), St Erth (× 180).
(*g*) *B. frigida* (Cushman), Ludham (× 180).
(*h*) *Bolivina gibbera* (Millett), St Erth (× 170).
(*i*) *Fissurina cornubiensis* (Millett), St Erth (× 180).
(*j*) *Ammonia* sp., St Erth (× 90).
(*k*) *Bolivina robusta* (Brady), St Erth (× 120).
(*l*) *Polymorphina? fissurata* (Margerel), St Erth (× 180).

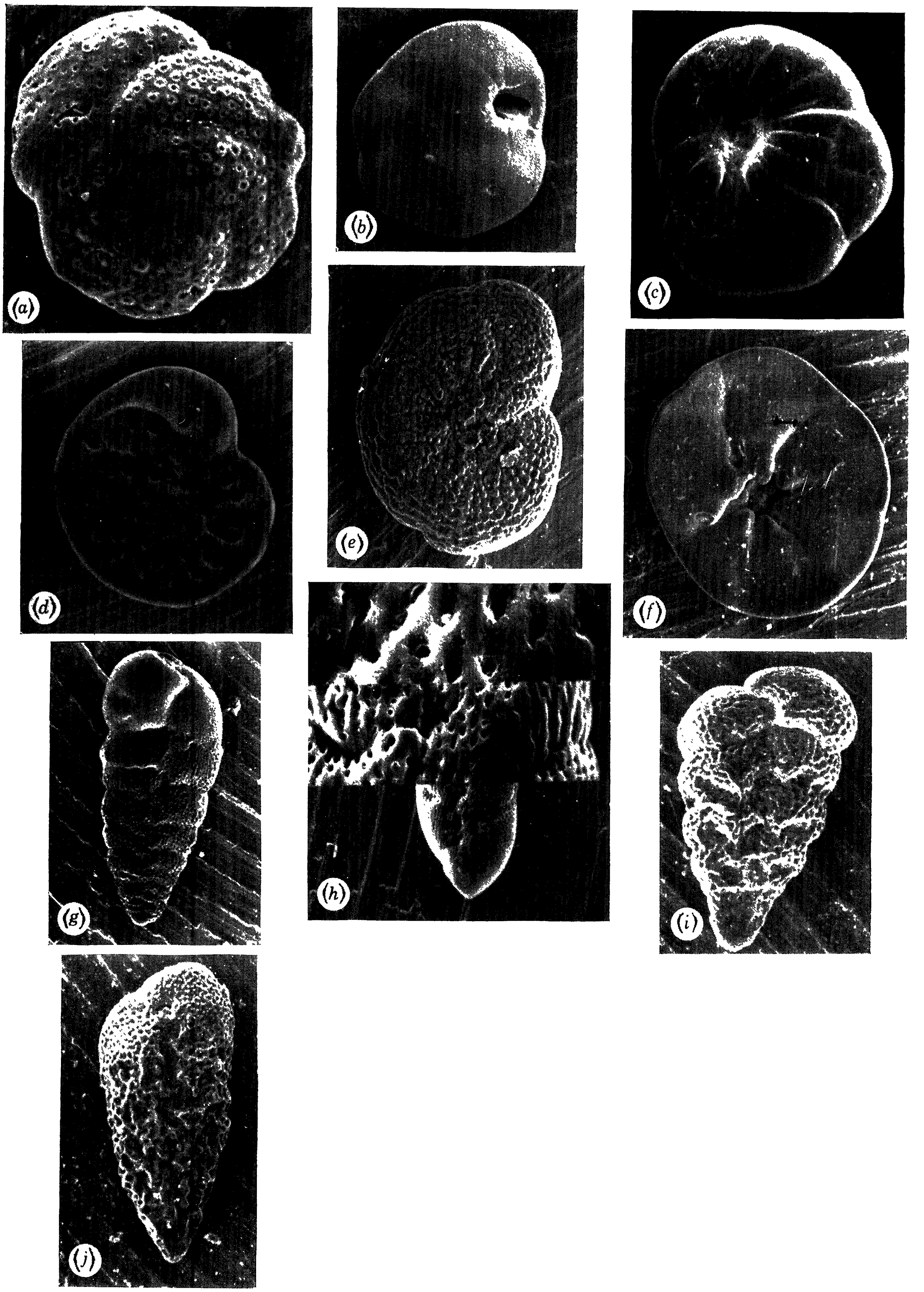

FIGURE 16. Foraminifera, St Erth:

(*a*) *Alabamina* sp. (×180).
(*b*) *Buccella nuda* (Margerel) (×180).
(*c*) *Heronallenia lingulata* (Burrows & Holland) (×150).
(*d*) *Rosalina* aff. *granulosa* (Margerel) (×130).
(*e*) *Glabratella baccata* (Heron-Allen & Earland) (×170).
(*f*) *Rosalina nitida* (Williamson) (×170).
(*g*) *Bolivinia varabilis* (Williamson) (×180).
(*h*) *B. variabilis* (Williamson) (×180), (×600), (×1800).
(*i*) *B. pseudoplicata* (Heron-Allen & Earland) (×150).
(*j*) *B. pseudoplicata* (Heron-Allen & Earland) (×120).

clay, some sand (including shale fragments) and gravel from the land surface. This environment would also allow formation of the main non-detrital constituents in the sediments.

The ultimate source of the detritus

The fine sand fractions contain materials derived both from local sources (e.g. slate and quartzite fragments from local metasediments) and possibly more distant ones (e.g. flint). As Milner (1922) and Groves (1931) suggested, most of the heavy minerals are probably derived ultimately from the granites, but many of the grains are well-rounded and could have suffered two or more cycles of erosion. The two well-sorted fine sand components are mineralogically similar, probably because there was interchange of sand between the beach and dune environments during the long period of stability preceding the transgression.

Table 3. Mineralogical composition of clay fractions from the St Erth marine formation

(Amounts of each mineral are estimated from peak intensities of the X-ray diffractometer traces, and are only approximate.)

	(2)	(3)	(4)	(6)	(10)
% interstratified smectite-mica	42	43	48	20	22
% mica	40	38	40	40	43
% kaolinite	16	14	12	35	34
% chlorite	2	4	—	—	—
% quartz	trace	trace	trace	trace	trace
% goethite	—	—	—	5	trace

For explanation of column numbers see table 1.

The clay fractions of the St Erth Formation are composed mainly of mica, kaolinite and interstratified smectite-mica (table 3). Transmission electron micrographs show that the kaolinite occurs partly in large subhedral flakes, which have slightly rounded corners, but otherwise resemble morphologically primary kaolinite crystals in the kaolinized granites. The rounding probably results from slight abrasion in streams draining the granite masses. However, not all the clay is so derived, because the primary kaolinite deposits contain mica and a little montmorillonite, but no interstratified smectite-mica.

Lateral correlation of the deposits

Correlation of the deposits seen in the three main pits at St Erth is difficult, because the lithological units are laterally impersistent. However, vertical variations in the mineralogical composition of clay fractions and the particle size distribution of the deposits can be used as a basis for correlating beds exposed in Harvey's Pit and the South Vicarage Pit with those in the North Vicarage Pit. Sandy deposits (samples 4 and 5) from horizons below the shelly clay in the North Vicarage Pit contain mixtures of both well-sorted fine sand components, but at profile 8 at a higher level, the clayey sand (sample 6) and the sand beneath it (sample 7) contain only the coarser component. The moulding sand beneath the head at the top of Harvey's Pit (sample 10) also contains only the coarser component, and therefore is probably equivalent to samples 6 and 7 from profile 8 in the North Vicarage Pit. However, the sand beneath the head in the South Vicarage Pit (sample 9) and the detached mass of similar sand within the head (sample 8) both contain mixtures of the coarse and fine components in the approximate ratio 1 : 2. This particle size distribution is matched only by the lowest deposit (sample 5) seen in the North Vicarage Pit.

The clay fractions of samples 6 and 10 contain more kaolinite but less interstratified smectite-mica than the clay fractions of samples 2, 3 and 4. This change in clay composition occurs at about the same horizon as the change in particle size distribution of the fine sands, so the sandy deposits as a whole seem to form two series. The sands below the shelly clay in the North Vicarage Pit (samples 4 and 5) and the sand in the South Vicarage Pit (sample 9) seem to form one series, whereas those at the east side of the North Vicarage Pit (samples 6 and 7) and the moulding sand in Harvey's Pit (sample 10) form another. The head rests on the first of these in the South Vicarage Pit but on the second in Harvey's Pit and the east side of the North Vicarage Pit.

5. The fossils in the clay

5.1. *The Mollusca*

By Nora F. McMillan

The earliest reference to the St Erth shells is by Whitley (1882), who described the site and listed 10 species of Mollusca, determined by G. B. Sowerby Jnr. Three years later a paper by Wood appeared (1885); in the ensuing discussion upon it J. Gwyn Jeffreys stated that he had recognized 50 species of St Erth shells, about two-thirds of them extinct.

Next Kendall & R. G. Bell (1886) described two further sections and listed 72 species, plus 'about twenty more which do not seem to be known either in a fossil or recent state'. In the following year R. G. Bell (not R. W. Bell as stated in the title of the paper) re-examined the deposit and obtained many fossils from about 100 kg of the clay.

R. G. Bell later wrote (1887, pp. 49–50) 'Nearly all of the whole of the Mollusca which have been recently found are of a southern type, confirming the opinion previously arrived at in the paper above alluded to, that the tendency of the fauna was largely in the direction of the Mediterranean and Italian Pliocene forms. The absence or extreme rarity of peculiar Northern or Boreal Mollusca is very emphatic on this point, showing the difference between the Molluscan fauna of the Eastern and Western Pliocene Seas in Britain. At the same time there is a certain number of species present both in the Crag of Suffolk and St Erth, quite sufficient to show that the deposits in point of time were nearly identical.'

R. G. Bell's careful work and sound conclusions have been rather lost sight of in the voluminous writings of his brother Alfred, who also excavated at St Erth.

Although an excellent collector Alfred Bell was an inveterate species-maker, and as he sold material widely he tended to separate 'species' on what appear to be the slenderest of claims. In 1893 he produced a very long list of St Erth species, including many new species as of 'E. & B.' (i.e. Etheridge & Bell). These new species are very inadequately described and not figured. In a subsequent paper (1898) Bell gave a revised version of his earlier (1893) paper, indicating also the location of all the species mentioned as well as those figured.

The latest records of shells from St Erth are those of Johnson (1903) who listed 24 species, including some undetermined species, and a note on the St Erth *Odostomia* species by Corgan (1969).

The material I received from Professor Mitchell totalled 45 kg of clay comprising

16 samples from several profiles at the site. Six samples came from the following levels in profile 3.

395–455 cm	light brown calcareous clay
415–425 cm	grey-blue calcareous clay
430–440 cm	all grey-blue calcareous clay
450–460 cm	
500–520 cm	
520–550 cm	

These six samples represented a sequence through the fossiliferous clays, and all had a similar physical appearance.

Taken as a whole the samples yielded a total of 21 species of Mollusca, and the distribution of the species was almost identical throughout. *Bittium reticulatum* var. *scabra* (*B. trinodosa* of Bell), *Nassarius semireticosus*, *Nucula* spp. and *Myrtea spinifera* occurred frequently in every level, with *Venerupis aurea*, *V. rhomboides* and *Ostrea edulis* (a characteristic small form) distributed almost as universally.

In profile 1, 500–510 cm, a sample came from the lower part of the blue shelly clay which was much sandier than any of the other samples from any of the profiles. The molluscan fauna only differed from that of other samples from the same profile in possessing two valves (a pair) of the freshwater bivalve *Pisidium henslowanum*. Six samples from profile 2 yielded 20 species of Mollusca of which the same seven species as in profile 3 were as generally distributed. Thus it seemed no useful purpose would be served by listing in detail the species obtained from each sample. Instead, a full list of all the molluscan species identified will be given with notes on each species.

Notes on some additional species found subsequently on the clay-dump from Professor Mitchell's excavation have been included, and I am grateful to Mr R. Markham, Mr R. D. Penhallurick, Mrs S. M. Turk, and Mr P. S. Wilson for allowing me to see their finds and to refer to them in this report.

Identification of this St Erth material has not been easy. The bivalves were, almost without exception, represented only by small fragments, and many of the gastropods were very small and similarly imperfect. This was not due to damage caused by the washing and sorting process, because untouched clay showed molluscan remains in the same fragmentary condition.

For the identification of the Pyramidellidae I have compared the St Erth specimens with material determined by J. T. Marshall.

The arrangement and nomenclature of the recent species obtained follow those of Winckworth's list (1932). This list, though partially superseded by the unfinished list of Bowden & Heppell (1966, 1968), and admittedly out of date in some respects, has been followed because it was felt that in a paper not wholly malacological fairly familiar names should be used so that conclusions based on the molluscan evidence could be evaluated by workers in other fields. For the fossil species I have followed van Regteren Altena, Bloklander & Pouderoyen (1965).

The Mollusca have been deposited in the British Museum (Natural History).

GASTROPODS

Gibbula magus (Linnaeus, 1758). One very young shell.

Gibbula cf. *umbilicalis* (da Costa, 1778). A small fragment.

Monodonta erthensis (A. Bell, 1898). One fine shell (h 17 mm, b 18 mm) obtained by Mrs Turk. The species is closely allied to the Mediterranean *M. turbinata* (Born, 1780).

Tricolia pullus (Linnaeus, 1758). Two apical fragments.

Lacuna suboperta (J. Sowerby, 1813). One. This species, known only fossil, occurs fairly frequently in the East Anglian Crags (Waltonian, Newbournian and Butleyan) (Harmer 1921, p. 669).

Eulimene terebellata (Nyst, 1835) var. *conica* (Bell, 1898). One shell, 7 × 4 mm. Although I am doubtful of the validity of Bell's variety I have left the specimen under his name as it seems referable there. The species is a Red Crag fossil, abundant in the Waltonian but becoming much less frequent in the later horizons (Harmer 1920, p. 595).

Hydrobia ulvae (Pennant, 1777). A couple of typical shells, and three small examples of a short stumpy form.

Cingula pentadonta (Kendall & R. G. Bell, 1886). Eight specimens. This species is apparently confined to St Erth, and the five well-marked denticulations within the outer lip make it easily recognizable. Bell (1898) described two varieties (a single shell in each case) without the characteristic denticulations, but the eight shells here recorded are all typical.

Alvania montagui (Payraudeau, 1826). One perfect shell. Nordsieck (1968) gives the range of *A. montagui* as being the Mediterranean and the Atlantic shore of southern Spain, and quotes *sardea* (Risso) as a synonym. Harmer's *A. dubiosa* appears to be the same species.

Bell (1898) recorded this species (in the British Museum (Natural History) collection), and Mr Penhallurick also obtained a fragment.

A. cancellata (da Costa, 1778). One shell (Mr Penhallurick).

Alvania sp. A single complete shell I have been unable to refer to any known species. Short and plump, it has well-rounded whorls with two deeply incised lines encircling the top of each whorl, just below the suture, but no other sculpture.

Turritella (*Haustator*) *triplicata* (Brocchi, 1814) form *erthensis* (Harmer, 1918). Only one full-sized example was obtained from my samples, but many shells measuring up to 60 mm in height were labelled 'miscellaneous shells *ex* blue clay profile 1'. Small specimens (up to about 10 mm high) occurred rather sparingly in nearly every sample; their 'prominent single carina' (to quote A. Bell) makes them look very unlike the adult specimens. I have followed van Regteren Altena *et al.* (1965) in regarding *T. erthensis* (Harmer 1918) as a form of the highly variable *T. triplicata* (Brocchi); Beets (1946) considered it a distinct species. It is one of the most characteristic shells of the St Erth deposit and has been noted by every worker; the same form (*erthensis*) has been recorded by van Regteren Altena *et al.* (1965) from some Dutch localities.

Potamides tricinctus (Brocchi, 1814). One specimen, 20 mm high. This species ranges from the Coralline Crag through the Red Crag to the Icenian, and has also been recorded from the Lenham beds.

Bittium reticulatum (da Costa, 1778) var. *scabra* (Olivi, 1792). Olivi's variety has priority over Bell's *trinodosa* (1898). It is the most abundant St Erth shell in every sample. Shells measured up to 12 mm high and had 12 whorls, whilst Recent Venetian specimens (coll. Tomlin) are only 9.5 mm high with 11 whorls.

B. reticulatum is a gregarious species, living from l.w.s.t. down to 20 m, and often associated with *Zostera*.

Epitonium frondiculum (S. V. Wood, 1848). Mr R. Markham has lent me a *Scalaria* from St Erth referable to this species. The St Erth shell is in good condition but lacks the 2–3 upper whorls. In its imperfect state (5 whorls only) it measures 12.5 mm high and 5 mm across; it has thin erect foliar laminae, 15 on the body whorl, and the interstices between the laminae are quite smooth.

E. frondiculum is, according to Harmer, a common Coralline Crag species, occurring also rarely in the Red Crag (Waltonian and Newbournian).

Calyptraea chinensis (Linnaeus, 1758). Fragments quite frequent, most of the material belonging to the form *muricata* (Brocchi, 1814).

Polinices hemiclausus (J. de C. Sowerby, 1824), *Natica proxima* (S. V. Wood, 1848). A fine shell, 29 × 25 mm, was obtained by Mr Wilson, still retaining much of its colouring. It was milk chocolate colour with a broad zone of darker brown around the basal part of the body whorl, and a paler zone immediately around the umbilicus.

P. polianus (della Chiaje, 1830). One shell, 15 × 10 mm.

Natica multipunctata (S. V. Wood, 1842) or *N. millepunctata* (Lamarck, 1822). One operculum (7 × 4 mm) referable to one or other of these two species was obtained, but no shell. *N. millepunctata* is a Mediterranean–Lusitanian species, and *N. multipunctata* (East Anglian Crags) is an allied, fossil species.

Natica cf. *beyrichi* (von Koenen, 1882) var. *goodmani* (Harmer, 1921). Two *Natica* specimens are tentatively referred here. Both were found by Mrs Turk. The larger shell (h 14 mm, b 12 mm) has a fairly well-marked umbilical ridge, but in the smaller specimen the ridge is obsolete, and there are clear traces of a distinct brown zone around the umbilicus.

Trivia avellana (J. Sowerby, 1823). One shell.

T. testudinella (S. V. Wood, 1842). One shell, 7.5 × 11.5 mm.

Nassarius mutabilis (Linnaeus, 1758). Of this characteristically Mediterranean species, Harmer (*Pliocene Mollusca* I, p. 315) remarks 'St Erth, not very rare', but no specimens were obtained from the material I examined. However, a juvenile was found by Mr Penhallurick, and a fine shell (35 × 21 mm) by Mr P. S. Wilson.

N. semireticosus (Bell, 1898). After *Bittium reticulatum* var. *scabra* this is the most abundant of the St Erth shells, and is well represented in every sample. The three largest shells in the present material measure 30 × 15 mm, 29 × 13 mm, and 27 × 14 mm, but the majority are much smaller. Harmer (1914, p. 65) records shells up to 40 mm high.

N. recticostatus (Bellardi, 1882). ? Two shells, each 8 mm high. I have followed Harmer (1921, p. 321) in determining these specimens, but the identification is not certain as I have not been able to make comparisons with authentic material.

Mangelia costulata smithi (Forbes, 1840). A single perfect shell (Mr Penhallurick). Harmer (*Pliocene Mollusca* I, pp. 248–9) regards the form *smithi* as a species, but Winckworth (1932, p. 230) considered it to be a subspecies (? perhaps a geographical race) of the Mediterranean *M. costulata* (Risso 1826).

M. compacta (Bell, 1898). One shell, 4 mm high, complete except for a broken outer lip.

M. keepingi (Bell, 1898). A single shell.

Odostomia plicata (Montagu, 1803). Three shells.

O. unidentata (Montagu, 1803). One almost complete shell.

O. conoidea (Brocchi, 1814). One imperfect shell; the damaged aperture does not show the characteristic grooves, but Marshall (1898, p. 230) states that only about 30 % of recent shells possess this feature.

Turbonilla spp. Harmer described and figured a number of new species of *Turbonilla* from St Erth, mostly very small, but the clay samples which I examined yielded only a few examples of *Turbonilla elegantissima* (Montagu 1803).

Ringicula ovata (Bell, 1898). Four shells. Also obtained by Mr Penhallurick.

R. searlesii (Bell, 1898). Three shells.

Tricla lignaria (Linnaeus, 1758). One fragment. Bell (1898) records the North American *T. punctostriata* (Mighels), but not the present species.

Ellobium pyramidale (J. Sowerby, 1824). Two shells, the larger 10 mm high, and a fragment.

BIVALVES

Nucula spp. Fragments were frequent in every sample, but complete valves were very rare. A few nearly complete valves are referable to *N. nucleus* (Linnaeus, 1758), but some of the fragments suggest *N. turgida* (Leckenby & Marshall, 1875).

Nucula trigonula (S. V. Wood, 1840). One valve, collected by Mr Wilson.

Chlamys opercularis (Linnaeus, 1758). Fragments only, rather uncommon.

Lima lima (Linnaeus, 1758). One small fragment (3×1 mm) of this Mediterranean species, which also occurs in the Atlantic from the Canaries to Cape Verde.

Ostrea edulis (Linnaeus, 1758). Single valves of a small rounded form occurred occasionally, and fragments were frequent. All the material appeared to belong to Bell's variety *sinuosa*, described as being 'flat and shallow, and almost circular in outline, without fimbriations or costae...'. A specimen with the valves still opposed came from the junction of the blue and grey-brown clay in profile 1.

Thyasira flexuosa (Montagu, 1803). Two valves.

?*Loripes lacteus* (Linnaeus, 1758). A fragment is doubtfully referred to this species.

Myrtea spinifera (Montagu, 1803). Fragments occurred in every sample, but only one fairly complete valve was found.

Montacuta truncata (S. V. Wood, 1840). One valve, *ca.* 5 mm long. This is a Coralline Crag species.

Mysella bidentata (Montagu, 1803). Three valves.

Cardium tuberculatum (Linnaeus, 1758). One fragment.

C. papillosum (Poli, 1795). Two fragments.

C. ovale (Sowerby, 1840). Two valves.

C. scabrum (Philippi, 1844). One small valve.

Venus ? *striatula* (da Costa, 1778). One very young valve seems nearest to this species, but has more ribs than undoubted *striatula* of the same size.

Venerupis aurea (Gmelin, 1791). Fragments occurred in nearly every sample, but no complete valves were obtained.

V. rhomboides (Pennant, 1777). Fragments were frequent, but the species was much less common than *V. aurea.* Possibly some fragments belong to the form *sarniensis* (Turton, 1822).

? *V. pullastra* (Montagu, 1803). One doubtful fragment.

Irus irus (Linnaeus, 1758). One very worn fragment.

Abra alba (W. Wood, 1802). Hinge-fragments and valves of very small specimens of an *Abra* were fairly frequent. Dr van der Mark, who is making a special study of the European fossil *Abra* species, has examined the St Erth material, and considers it all belongs to *Abra alba* (W. Wood). He further remarks that all the St Erth specimens agree best with *A. alba* of the Upper Pliocene–Lower Pleistocene near Antwerp.

In addition to the marine species listed above, a single species of fresh-water bivalve was obtained. This was *Pisidium henslowanum* (Sheppard, 1823) of which a pair (detached) and a single valve were found. Mr A. W. Stelfox and Dr M. P. Kerney kindly determined these shells.

The total number of species identified was 56 (35 gastropods and 21 bivalves, including *Pisidium henslowanum*). Alfred Bell stated several times that the molluscan fauna of the St Erth deposit comprised 200–300 species, and in his last paper (1898) he listed and briefly described more than 60 new species and varieties. Almost all are attributed to 'Etheridge & Bell' (a few to 'R. Bell', or merely 'Bell'), although the author of the paper was Alfred Bell. The explanation of this seeming inconsistency is that Alfred Bell and Etheridge planned a joint monograph upon the St Erth fauna, and the new species credited to both workers were those described in preparation for the monograph (see Bell 1893, p. 624). The monograph was never published, though probably much of the material eventually appeared in Harmer's *Pliocene Mollusca.*

At first sight the relatively meagre molluscan fauna obtained in 1966 is very disappointing when one considers Bell's remarks about a fauna of 250 species, but he probably dealt with very large quantities of the shell-bearing clay, and in addition he drew largely upon various older collections (he lists seven in his 1898 paper). He was also an excellent and indefatigable collector. His analysis (1898, p. 127) of the number of molluscan species he recorded is however very revealing – 'of the 250 species 50 % are only known from one to three examples, about 15 % are fairly common, 5 % plentiful'. Here, coupled with his well-known species-making proclivities, is further reason why the fauna of the 1966 excavations appear so much poorer. Someone sometime will have to undertake the huge task of critically evaluating each of Alfred Bell's 'new species' (including those from St Erth). In the meantime I see no point in swelling the list of species with a host of Etheridge & Bell 'new spp.', many of which are based on fragments, inadequately described, and frequently not figured. In this connexion I may remark that my experience of dealing with other molluscan material named by Bell has been an enlightening process (see McMillan 1964).

Of the 55 species of Mollusca recorded in this report 34 are recent species. Disregarding the freshwater *Pisidium henslowanum,* there are 33 species to be considered. The seven most frequent are *Bittium reticulatum* var. *scabra, Nucula nucleus, Myrtea spinifera, Venerupis aurea, V. rhomboides, Ostrea edulis* and the extinct *Nassarius semireticosus.* All the six recent species now live at low water or beyond, and this, when coupled with the absence of such littoral genera as *Patella, Littorina, Nucella* and *Mytilus,* indicates that the St Erth clay was accumulated beyond low water. *Zostera* suggests deposition not much below low water; in the Mediterranean today *Z. marina* is found down to 10 m below low-water mark (Tutin 1942), and the great abundance of *Bittium,* frequently associated with *Zostera,* supports this hypothesis. Reid & Flett (1907) considered that the St Erth clay contained 'shoal-water Mollusca, not truly littoral', and with this I agree.

The geographical distributions of the 33 recent species may be summarized as follows:

living in Cornwall now	27 species
Channel Islands only	2 species
Mediterranean and Lusitanian (non-British)	4 species

None of the recent species is more common north of Cornwall.

Such northern genera as *Buccinum, Colus, Neptunea* and *Astarte* are absent from the St Erth clay, and this absence, taken along with the presence of Mediterranean species and the predominantly 'warm' aspect of the recent British species, indicates a temperature higher than that of Cornwall today.

Extinct species form almost a third (21 species) of the Mollusca recorded in this report. The following list gives their names and stratigraphical range (chiefly in Britain):

Lacuna suboperta	Red Crag only
Eulimine terebellata	Red Crag only
Potamides tricinctus	Coralline–Red–Icenian Crags
Epitonium frondiculum	Coralline and Red Crag
Natica multipunctata†	Coralline and Red Crag
Polinices hemiclausus	Coralline and Red Crag
Trivia avellana	Coralline and Red Crag
T. testudinella	Coralline and Red Crag
Nassarius recticostatus	Astian of Piedmont (Upper Pliocene)
Ellobium pyramidale	Coralline–Red–Icenian Crags
Turritella triplicata form *erthensis*	St Erth (common); also at a few Dutch localities
Monodonta erthensis *Cingula pentadonta* *Natica* cf *beyrichi* var *goodmani* *Nassarius semireticosus* *Mangelia compacta* *Mangelia keepingi* *Ringicula ovata* *R. searlesii*	All in Britain from St Erth only‡
Nucula trigonula	Coralline Crag only?
Montacuta truncata	Coralline Crag only? Bell (1898) also recorded this species at St Erth

If we exclude the six species which are peculiar to St Erth, the three which also occur in Holland, and *Nassarius recticostatus* (of which the identity is uncertain), we are left with 11 Crag species of which two are confined to the Red Crag, two apparently to the Coralline Crag, while the remaining seven species occur in both the Coralline and the Red Crag. The absence of northern forms places the St Erth fauna earlier than the Waltonian Red Crag, and the abundant *N. semireticosus* suggests a date towards the end of the Coralline Crag. The species-group *N. reticosus* (J. Sowerby) – of which *N. semireticosus* forms a part – first appears in the Coralline Crag of Boyton, and because of this the Boyton Crag is sometimes treated as a separate unit, the Boytonian, later than the main part of the Coralline Crag. To this Boytonian unit the St Erth fauna is tentatively referred.

A. Bell (1898) clung firmly to his conviction that the St Erth fauna was of 'mio-pliocene date (Messinian)'. Since then a variety of ages have been suggested for St Erth (for summary see West (1967, p. 39)). Dr P. Brébion, in his unpublished thesis (1964) (to which he kindly allows me to refer), considers the gastropod fauna of St Erth to be of Redonian age. He points out that in many cases species closely allied to those of the St Erth deposit are present in the

† In the list I have considered the naticid operculum to be that of *Natica multipunctata* (the Crag species), but it could equally well be that of *N. millepunctata* (the Mediterranean species).

‡ Three of these species, *Turritella triplicata* form *erthensis*, *Mangelia keepingi* and *Ringicula ovata* also occur in a few Dutch deposits of Pliocene–Older Pleistocene age (van Regteren Altena *et al.* 1965).

Redonian deposits. But in his table of correlation he equates St Erth with the Boytonian, and places it above the Redonian of St-Jean-la-Poterie.

While our knowledge of the St Erth molluscs still leaves a lot to be desired, on present information it seems unlikely that the deposit can be older than the Coralline Crag.

A molluscan fauna in secondary position in glacial gravel at Killincarrig, Co. Wicklow, also contains a number of Crag species (McMillan 1938). The Killincarrig fauna includes northern forms such as *Neptunea despecta*, *N. antiqua* and *Trophonopsis clathratus*, which are quite unknown at St Erth. Because of these northern forms the Killincarrig shells have been assigned to the Oakley Horizon of the Waltonian Red Crag. The St Erth fauna with its strongly marked southern affinities is older, and probably belongs to the Boytonian unit of the Coralline Crag.

5.2. *The Foraminifera*

By J. P. Margerel

Introduction

The Foraminifera of the marine clay at St Erth were first studied by F. N. Millett between 1887 and 1905. Millett listed 138 species and varieties, and most of his collection is preserved in the British Museum of Natural History in London. Since then there has been no full revision of the microfauna; W. A. Macfayden examined some material in 1932, and B. M. Funnell (in Mitchell 1965) has discussed the fauna, particularly with regard to its palaeoecological and stratigraphical implications. In my study I have compared the St Erth fauna with those from rather similar deposits in the south of Cotentin in western Normandy.

The material studied

There were eight samples taken at different levels between 340 and 555 cm at profile 1 in the north part of the Vicarage Pit (see figure 7).

Speaking generally, they were of a clay with a varying sand content, in which the quartz fraction varied in importance according to the depth.

The fossils were extracted by separation with carbon tetrachloride, after washing and sieving on a sieve with a mesh of 100. The Foraminifera are deposited in the Institut des Sciences de la Nature, the University, Nantes.

The foraminiferal fauna

More than 100 species of benthic foraminifera were identified (see table 4); most of them belonged to the families of Miliolidae, Glandulinidae, Discorbidae and Elphidiidae, but very few species were common. Because of the small size of some of the samples studied, only the relative frequencies have been considered, and the abundant species have been separated from the others. In this way it is possible to point out the characteristic species of the deposit; these are *Quinqueloculina cliarensis*, *Q. seminula*, *Monspeliensina pseudotepida*, *Ammonia* sp., and *Faujasina subrotunda*. There are only a few other species which need to be considered from the point of view of correlations.

In my samples the agglutinating forms were represented only by a single species, *Textularia deperdita*, although Millett recorded several such forms, including *T. sagittula*.

The Lagenidae and the Glandulinidae were represented by numerous species, and the most frequent forms were *Lagena sulcata*, *Fissurina lucida*, *F. orbignyana*, *Oolina lineata* and *O. squamosa*. It is necessary to mention *F. cornubiensis* (figure 15*i*, plate 5), a form restricted to St Erth.

Table 4. The foraminifera of St Erth

Rare to frequent species, +; common species, ×.

sample no. ...	66/15	66/14	66/13	66/12	66/11	66/10	66/9	66/8
depth ...	545–555 cm	520–530 cm	490–500 cm	460–470 cm	440–450 cm	410–420 cm	380–390 cm	340–350 cm
Species identified in samples from profile 1								
Textularia deperdita d'Orb.	.	+	+	+	.	+	+	.
Quinqueloculina aspera d'Orb.	.	+	.	.	+	.	.	.
Q. cliarensis (H. A. & E.)	.	.	×	×	×	×	×	×
Q. lata Terq.	.	.	+	+	.	.	.	.
Q. cf. *lecalvezae* Marg.	.	+	.	.	+	.	.	.
Q. quadrata Norv.	.	+	+	+	+	+	+	.
Q. schlumbergeri (H. A. & E.)	.	.	+	.	+	.	+	.
Q. sclerotica Kar.	.	+	+	+	.	.	.	.
Q. seminula (Lin.)	.	×	×	×	×	+	×	.
Q. stelligera Schlumb.	.	+	.	+	.	.	+	.
Triloculina cuneata Kar.	.	+	.	.	.	.	+	.
T. trigonula (Lamk)	.	+	.	.	.	.	+	.
T. williamsoni Terq.	.	.	.	.	+	.	.	.
Triloculina sp.	.	.	.	.	+	+	+	.
Miliolinella sp.	.	+	+	.	+	.	.	.
Lagena clavata Will.	.	+	+	.	+	+	.	.
L. gracillima Seg.	.	.	.	.	+	.	+	+
L. laevis (Mont.)	+	.	.	.	.	.	+	.
L. sulcata (W. & J.)	+	+	.	+	+	+	+	+
Lagena spp.	+	+	+	+	+	+	+	+
Lenticulina rotulata (Lamk.)	.	+	.	.	.	.	.	.
Nodosaria pyrula d'Orb.	.	.	.	+	+	+	.	.
Fissurina annectens (B. & H.)	+	.	.	.	+	.	.	.
F. cornubiensis (Mill.) (figure 15*i*, plate 5)	.	.	.	+	.	.	+	.
F. foraminata (Matt.)	.	+	.	.	.	.	.	.
F. formosa (Schw.)	.	.	+	.	.	.	+	.
F. fasciata (Egg.)	+	+	.	.	+	.	.	.
F. lucida (Will.)	+	+	+	+	+	.	+	+
F. milletti Marg.	.	+	.	.	+	.	+	.
F. orbignyana (Seg.)	+	+	+	+	+	.	+	+
F. silvestrii (Buch.)	.	+	.	.	.	.	.	+
Fissurina spp.	+	+	+	+	+	+	+	+
Oolina acuticosta (Rss.)	+	+	.	.	.	.	.	.
O. hexagona (Will.)	.	+	.	.	.	.	+	.
O. lineata (Will.)	+	+	.	+	+	+	+	+
O. squamosa (Mont.)	+	+	+	+	+	+	+	+
Polymorphina ?fissurata Marg. (figure 15*l*)	.	+	.	.	+	.	.	+
Sigmomorphina semitecta (Rss.) *terquemiana* (Forn.)	+	+	.	+	.	.	.	.
S. undulosa (Terq.)	.	.	.	+	.	.	+	.
S. williamsoni (Terq.)	+	.	.	+	.	.	+	.
Bolivina gibbera Mill. (figure 15*h*)	.	.	.	.	.	.	+	.
B. pseudoplicata H. A. & E. (figures 16*i, j*, plate 6)	+	+	+	+	+	+	+	+
B. robusta Brady (figure 15*k*)	+	+	+	+	+	+	+	+
B. variabilis (Will.) (figures 16*g, h*)	+	+	.	.	+	.	.	+
B. elongata d'Orb.	+	+	+	+	+	.	+	×
Angulogerina angulosa (Will.)	+	+	+	.	.	.	.	+
Trifarina bradyi Cushm.	.	+	+	.	+	.	+	+
Aubignyna mariei Marg. (figure 14*h*, plate 4)	+	+	+	+	+	+	+	+
Buccella frigida (Cushm.) (figure 15*f, g*)	+	+	+	+	+	+	+	+
B. nuda Marg. (figure 16*b*)	.	.	.	.	.	.	.	+

TABLE 4. (*cont.*)

sample no. ...	66/15	66/14	66/13	66/12	66/11	66/10	66/9	66/8
depth ...	545–555 cm	520–530 cm	490–500 cm	460–470 cm	440–450 cm	410–420 cm	380–390 cm	340–350 cm
Species identified in samples from profile 1								
Discorbitura cushmani Marg. (figure 15*d*)	+	.	.	+	+	+	.	+
D. granuloumbilicatula v. Voorth (figure 15*e*)	+	+	.	.	.	.	+	.
Epistominella cf. *exigua* (Brady)	.	+	+	.	.	.	.	.
E. irregularis Marg.	.	.	.	.	.	.	.	+
Glabratella baccata (H. A. & E.) (figure 16*e*)	.	.	+	+	.	.	.	.
G. patelliformis (Brady)	.	.	+	.	.	.	.	.
Glabratella sp.	+	+	.	.	.	.	.	.
Heronallenia lingulata (B. & H.) (figure 16*c*)	+	+	.	.	.	.	.	+
Neoconorbina caveti Marg.	.	.	.	.	.	.	+	.
N. milletti (Wright)	+	+	+	.	+	.	.	.
N. subrotunda (Terq.)	+	.	.	.	.	.	.	.
Rosalina globularis d'Orb	.	+	.	.	.	.	.	.
Rosalina aff. granulosa Marg. (figure 16*d*)	+	+	+	.	+	+	.	+
R. nitida (Will.) (figure 16*f*)	+	+	+	+	+	+	+	+
Monspeliensina pseudotepida (v. Voorth) (figures 14*d, e*)	+	+	+	+	+	×	×	+
Monspeliensina sp. (figures 14*f, g*)	.	.	.	.	.	+	+	.
Pararotalia serrata (T. D. & R.)	.	+	+	+	+	+	+	.
Ammonia punctatogranosa (Seg.)	.	+	+	+	+	+	+	+
Ammonia 'beccarii' (Lin.)	.	.	.	.	.	.	+	+
Ammonia sp. (figure 15*j*)	×	+	+	×	+	+	+	+
Asterigerinata nitidula (Chaster)	.	+	.	.	.	.	.	+
Elphidium clavatum (Cushm.)	.	.	+	.	.	.	.	+
E. gourinardi Marg.	+	.	.	.	.	.	.	.
E. haagensis v. Voorth (figure 14*j*)	.	+	+	+	+	+	+	+
E. earlandi Cushm.	+	.	+	+	+	+	+	+
E. incertum (Will.)	.	+	+	+	.	+	+	+
E. pseudolessonii (T. D. & R.) (figure 14*i*)	+	+	+	+	+	+	+	+
E. selseyense (H. A. & E.)	.	+	+	.	.	.	.	.
E. umbilicatulum (Will.)	.	.	.	+	.	.	.	.
Elphidium sp.	.	.	+	+	+	.	+	.
Elphidiella occidentalis (Marg.) (figures 14*h, l*)	+	+	+	+	+	+	+	+
Faujasina carinata d'Orb (figure 14*b*)	+	+	+	+	+	+	+	+
F. compressa Marg. (figure 14*i*)	+	+	.	+	+	+	.	+
F. subrotunda T. D. & R. (figure 14*a*)	×	×	×	×	×	+	×	×
Cribrononion sp. Marg.	+	.	.	.	.	.	.	.
Protelphidium tuberculatum (d'Orb.)	+	+	+	.	+	+	.	.
Cibicides advenus (d'Orb.)	+	+	+	+	+	.	.	+
C. lobatulus (W. & J.)	+	+	+	.	+	+	.	+
Cibicides aff. *pseudoungerinanus* (Cushm.)	.	.	.	+	.	.	+	+
C. refulgens Montf.	.	.	.	+	.	.	.	.
Planorbulina mediterranensis d'Orb.	+	.	.	.	.	.	.	.
Nonion pauperatum (B. & W.)	.	.	+	.	.	+	.	+
Astrononion stellatum Cushm. & E.	+	.	.	+	+	.	+	+
Heterolepa frequens Marg.	+	.	+	+	+	.	+	.
Hanzawaia nitidula (Bandy)	.	+	.	+	+	.	+	+
Fursenkoina schreibersiana (Czjzek)	+	+	.	+	+	.	+	+
Alabamina tuberculata (B. & W.)	.	.	.	+	.	.	.	.
Cassidulina caribeana Redm.	.	+	+	+	+	+	+	+
C. carinata Seg.	+	+	.	+	+	.	+	+
C. crassa d'Orb.	.	+	.	.	.	.	.	.
Cassidulinoides bradyi Norm.	+	+	.	.	.	.	.	+

The Polymorphinidae are relatively rare; the only interesting species is *P. fissurata* (figure 15*l*, plate 5), known from the Redonian, and wrongly attributed by Millett to *Sagrina bifrons* Brady.

The Boliviniidae are principally represented by two species, *Bolivina pseudoplicata* (figures 16*i*, *j*, plate 6) and *B. robusta* (figure 15*k*); the latter form seems to have affinities with *B. laffittei*.

The family Discorbidae has the largest number of species, of which three are always present; *Aubignyna mariei* (figure 14*h*, plate 4), *Buccella frigida* (figure 15*f*) and *Rosalina nitida* (figure 16*f*). It has to be noted that *B. frigida* occurs in a form clearly different from that of the English Pleistocene, as at Ludham, for example (see figure 15*g*); the edges are sharper, and the sutural zones are very granular; frequently the granular ornamentation invades the whole umbilical face of the test. This form is very similar to that of the Pliocene deposits of the south of Cotentin (Bosq d'Aubigny, Picauville). Millett included two different species under the name *Rosalina parisiensis*; these are *Discorbitura cushmani* (figure 15*d*) and *Rosalina* aff. *granulosa* (figure 16*d*). The first is easily distinguished from the second by its peripheral aperture.

The Rotaliidae are represented by two very abundant species, *Monspeliensina pseudotepida* (figure 14*d*, *e*) and *Ammonia* sp. (figure 15*j*). The first is important in Plio-Pleistocene associations; it appears in the Miocene (Helvetian); present in the Faluns† of Touraine, it develops in the Pliocene in the west of France, in Belgium and in Holland, and in the last two countries is found also at the base of the Pleistocene.

It is the family of Elphidiidae that at St Erth constitutes the major part of the fauna in nearly all the samples (rising to more than 60 %). Only the sample from 410 to 420 cm showed a reversal of this tendency in favour of *Monspeliensina pseudotepida*. The species of greatest abundance is *Faujasina subrotunda* (figure 14*a*). It is accompanied by two other species, both much less frequent, *F. carinata* (figure 14*b*) and *F. compressa* (figure 14*c*). Among the *Elphidia*, *E. haagensis* (figure 14*j*) and *E. pseudolessonii* (figure 14*i*) are very common. *Elphidiella hannai* (figure 15*a*–*c*), identified by Funnell (in Mitchell 1965), was not found in the material sent to me. On the other hand, *E. occidentalis* (figure 14*k*, *l*), did occur; it corresponded to a form described in the Redonian, where it is very widespread; its characteristics are quite different to those of *E. hannai*, although its overall appearance might make one think of juvenile stages of this species. On the other hand, *E. hannai* has recently been found in a deposit so far accepted as Miocene, l'Orchere-de-Montjean (between Nantes and Angers), with characters identical with those of the form found in the Waltonian and Scaldisian.

Palaeoecological significance

Funnell (in Mitchell 1965) has made a study of the palaeoecological significance of the St Erth microfauna, and the present study has not brought forward anything new.

The association at St Erth has a very similar aspect to that which is found in a clayey facies in a limited number of small western Redonian basins in the west of France, in the Vendée, and above all to the south of Rennes. The fauna of these basins suggests that the depth of water was less than one hundred metres.

† The term 'falun' indicates a partly consolidated shelly sand, comparable petrographically to the English Crags. Originally the term was restricted to Miocene formations in Touraine, Anjou and Brittany, but it is now used for all the Neogene deposits of western France that display a sandy shelly facies.

Stratigraphical interpretation

If the foraminiferal fauna in the St Erth deposit is compared with that of the Pliocene deposits of the west of France, close correlations are evident.

The association of foraminifera that is found in the 'marnes à *Nassa prismatica*' at Bosq d'Aubigny, and in a general way in the clayey Pliocene facies of the south of Cotentin, is altogether comparable with that at St Erth. The association is characterized by the presence of *Faujasina subrotunda*, *F. carinata*, *F. compressa*, *Monspeliensina pseudotepida*, *Aubignyna mariei* and *Bucella frigida* (granular form). However, the diversity of species in the French deposits is not as great as at St Erth.

St Erth has equally strong affinities with the faunas of the Redonian deposits of western France along the Atlantic coast as far as Anjou. In fact Redonian species constitute nearly 90% of the St Erth fauna. Further, in the French clayey-sandy facies one finds associations of the same type, although the *Faujasina* species are not present there.

The relative ages of the deposits with *Faujasina* and the Redonian deposits have been discussed (Poncet 1968; Margerel 1970*b*). Complete studies from which one could draw positive conclusions are still all too rare, because one cannot overlook the possibility that there could be lateral transitions between the falunian facies, attributed to the Redonian, and the clayey-sandy facies which is regarded as more recent.

The great similarity between the foraminiferal faunas of the formations at St Erth, the south of Cotentin and the Redonian deposits, allows them to be considered as belonging to a similar biozone. This biozone is characterized by the forms of moderately warm, even temperate, seas, which do not show any significant indication of climatic deterioration. If the appearance of boreal forms is regarded as a criterion of definition of the Plio-Pleistocene boundary, this biozone is then of Pliocene age. On the other hand, Atlantic influences may have been able to retard the appearance of cold species, and thus make the climatic criterion insufficient for determining the Plio-Pleistocene limit. This is the whole problem in correlations between the formations of St Erth and the west of France and those of the Plio-Pleistocene of the northern European basin, a problem which will only be solved by determinations of absolute age.

5.3. *The Ostracoda – a preliminary note*

By R. C. Whatley

I regret that a motor accident in South America has prevented me from completing my contribution to this paper. Many of the ostracoda in the St Erth marine clay have not been previously described, and I hope to deal fully with the fauna in a later publication.

The number of ostracod species present at St Erth is extremely large, probably as many as 100. The main well-preserved element which represents the biocoenosis is probably highest Pliocene to lowest Pleistocene, but there are also older elements from the Pliocene and probably the Miocene. The abraded appearance of some of the older forms indicates that they are obviously reworked and extraneous, but others show more or less the same preservation as the presumably indigenous main element.

The fauna is very close to that of the Plio-Pleistocene of western France, and has an overall warm water aspect. Many of the species are still living around the south part of the British Isles, but the real home of the fauna is in the Lusitanian province. The fauna is very different from the Ipswichian fauna at Selsey (Whatley & Kaye 1971), and appears to be substantially different from the Calabrian and Sicilian ostracod faunas.

The fauna includes the following forms:

Aurila convexa
Cnestocythere truncata (Reuss)
Cytheropteron alatum
Leptocythere pellucida and three other species
Loxoconcha elliptica
L. rhomboidea
Neocytherideis complicata (Ruggieri, 1955)
Paracytheridea triquetra (Reuss)
Paradoxostoma, 3 spp.
Semicytherura, 5 spp.

After further study, the Ostracoda will be deposited in the British Museum (Natural History).

5.4. *Other animal fossils*

The following list (which does not claim to be comprehensive) has been compiled from the identifications of various workers; the name of the worker or a reference to a publication follows the name of the fossil. For some of the older records the nomenclature may now be out of date.

PORIFERA	
Cliona sp.	A. Bell 1898
Leucandra caminus Häckel	G. J. Hinde (in Kendall & Bell 1886)
Leuconia Johnstonii Carter	G. J. Hinde (in Kendall & Bell 1886)
COELENTERATA	
Alcyonaria sp.	Kendall & Bell 1886
Melobesia sp.	Kendall & Bell 1886
BRYOZOA	
Cellaria crassa S.V.W.	A. Bell 1898
Hornera striata M. Edw.	A. Bell 1898
Lepralia pallasiana Moll.	Kendall & Bell 1886
L. (*Microporella*)	Kendall & Bell 1886
L. violacea Johnston	Kendall & Bell 1886
Melicerata Charlesworthii M. Edw.	Kendall & Bell 1886
Pustulopora clavata Busk	Kendall & Bell 1886
ANNELIDA	
Eunicidae	J. D. George 1966 (pers. comm.)
CRUSTACEA	
Balanus sp. (? *bisulcatus*)	A. Bell 1898
Carcinus (*Maenas*) sp.	A. Bell 1898
Gonoplax rhomboides Fabr.	A. Bell 1898
Macropipus cf. *puber*	Mrs A. C. Evans 1966 (pers. comm.)
Maia squinado Latr.	A. Bell 1898
Portunus corrugatus Penn.	A. Bell 1898
P. holsatus	Mrs Turk 1966 (pers. comm.)

P. marmoreus Leach	Sedgwick Museum
P. pusillus	A. Bell 1898
Xantho floridus Leach	A. Bell 1898
ECHINODERMATA	
Cucumaria dubiosa Herdm.	A. Bell 1898
Echinus esculentus L.	A. Bell 1898
E. etheridgeii A. Bell	A. Bell 1898
Spatangus purpureus Müll.	A. Bell 1898
TUNICATA	
Leptoclinum tenue Herdm.	A. Bell 1898
PISCES	
Anarrhicas lupus	Kendall & Bell 1886
Galeus canis	A. Bell 1898
Various unidentified bones, vertebrae, jaws and otoliths	

5.5. *Plant fossils*

The content of macroscopic and microscopic plant debris in the clay was very small, and most of the material was in very poor condition. 250 pollen were counted in each of ten samples, but there was no significant difference between the counts. Of the 2500 pollen counted, 58 % was tree pollen, 21 % Ericales, 17 % Chenopodiaceae, 2 % Gramineae, 1 % Cyperaceae, all others 1 %. In the following table the relative percentages of all tree pollens (where the value was 1 or greater) is shown after the names of the trees. A sample of clay was examined by Dr Maj-Britt Florin, Uppsala, but she reported that the clay did not contain any diatoms. The following identifications, many of which are tentative were made:

Estuary and salt-marsh					
Armeria sp.	cal, p	Chenopodiaceae	p	*Zostera noltii*	s
Fresh water					
Chara sp.	osp	*Pediastrum* sp.	co	*Potamogeton* sp.	p
Typha sp.	p				
Damp soil					
Cyperaceae	utr, p	*Filipendula* sp.	p	*Juncus* aff. *balticus*	s
Selaginella selaginoides	msp				
Woodland and dry soil					
Alnus sp.	p 2	*Artemisia* sp.	p	*Rubus* cf. *idaeus*	fst, th
Corylus sp.	p 10	cf. *Cerastium* sp.	s	*Spergula* sp.	p
Ilex sp.	p	Compositae	p	*Urtica* cf. *dioica*	s
Salix sp.	b, p	cf. *Draba* sp.	s		
Ulmus sp.	p	Gramineae	ca, p		
Hedera sp.	p	*Ranunculus* cf. *flammula*	a		

Coniferous woodland, heath and bog

Abies sp.	p 1	*Calluna* sp.	p	*Sphagnum* sp.	l, sp
Betula sp.	p 1	*Empetrum* sp.	p		
Picea sp.	p 3	*Erica* cf. *tetralix*	l	aff. *Adiantum* sp.	sp
Pinus sp.	p 81	*Erica* sp.	l, p	*Osmunda* cf. *regalis*	sp
Tsuga sp.	p 1	cf. *Vaccinium* sp.	s	*Pteridium* sp.	sp

(Key: a, achene; b, bud; ca, caryopsis; cal, calyx; co, colony; fst, fruit-stone; msp, megaspore; osp, oospore; p, pollen; s, seed; sp, spore; th, thorn; utr, utricle.)

Estuary and salt-marsh

The most satisfactory identification made was that of *Zostera noltii*, Hornem. Though no complete fruits were found, there were many pieces, representing at least 20 fruits. Apices, bases and fragments of epidermis, brown in colour, were found. On the pieces from the walls of the fruits, the epidermal cells, which were laterally extended, were arranged in vertical tiers, about 24 to the circumference. The fossils were compared with recent fruits of *Z. noltii*.

	measurements/mm	
	fossils	recent
basal scar	0.085–0.14	0.085
apical exit pore	0.21–0.33	0.24
width of flank cells	0.125–0.14	0.125
height of flank cells	0.007	0.007

Today in the British Isles *Zostera noltii* grows between tide-marks.

Pollen of Chenopodiaceae, which amounted to 17 % of all pollen counted, indicates salt-marsh in the vicinity, and the *Armeria* may also have grown in the salt-marsh.

Woodland and dry soil

There must have been some deciduous trees in the vicinity, among which *Corylus* and *Alnus* were the most prominent. *Salix* and *Ulmus* were also present, but there is no record of *Quercus*. *Ilex* and *Hedera* occurred sparingly. The shrubs and herbs are wide-ranging taxa, and yield no significant information.

Coniferous woodland, heath and bog

The dominant pollens are *Pinus* 47 % of all pollen (81 % of all tree pollen) and Ericales 21 % of all pollen. Though the preservation was poor, *Calluna*, *Empetrum* and *Erica* were represented among the Ericales pollen. Other conifers represented by pollen are *Abies*, *Picea* and *Tsuga*, while some damaged grains suggested Cupressineae and *Taxus*.

Some of the macrofossils were carbonized. Six carbonized fragments of coniferous leaves, none exceeding 1 mm in greatest dimension, were found. All showed epidermal and stomatal cells characteristic of the Conifers, but the small size of the pieces precluded detailed identification. Of the heathers, four leaves and 15 leaf fragments, all carbonized, were clearly *Erica*, perhaps *tetralix*. Where the epidermis survived, it appeared to be identical with the epidermis of artificially charred leaves of *E. tetralix*. The largest intact leaf was 1.4 mm long and 0.6 mm wide; the rolled margins did not meet, but exposed the midrib and the undersurface of the leaf.

On two small (0.35 mm long) carbonized leaf fragments the rolled margins were in contact, which suggested that they belonged to some *Erica* other than *tetralix*. Two carbonized fossils were clearly fragments (greatest dimension 0.6 mm) of ericaceous anthers. One fragment suggested *E. tetralix*, but the damaged and distorted state ruled out any closer identification.

Among the non-carbonized material from the clay were two ericaceous seeds. One small crushed seed was light-brown in colour, and oval in shape (0.37 mm long, and 0.22 mm across); its shape and size suggested *Erica*, but the elongate cell-pattern suggested *Vaccinium*. One immature seed was typical in shape for *Vaccinium*, though flattened and damaged. Dark-brown in colour, 0.30 mm long and 0.25 mm across, it was in the size range for immature seeds of *V. vitis-idaea*. It showed the characteristic *Vaccinium* cell-pattern, with elongate cells surrounded by ridges.

There were some leaf-fragments and spores of Sphagnum, and unidentified spores of other mosses. The ferns were represented by spores of *Adiantum*-type, spores of *Osmunda* which were of *regalis*-type, and spores of *Pteridium*.

There were also some small globular (0.2 mm in diameter) black fungal fruiting-bodies.

If there were sand dunes or other sandy deposits in the vicinity of the site as the sedimentological report suggests, there will have been sandy soils, and these may well have developed podsols with mor surfaces beneath pine and occasional other coniferous trees and heathers in the field layer. This mor will have been full of carbonized plant debris, damaged pollen of local origin and fungal sclerotia, and when sea level rose, allowing clay to be deposited on top of sand, the waves will have eroded the soil, and its contained vegetable debris will have been secondarily deposited in the clay.

Fossils of such provenance dominate the plant list, which merely indicates that there was a conifer–heath association in the immediate vicinity of the site, and does not give any general picture of the surrounding countryside as a whole. None the less the total absence of the pollen of such late Pliocene forms as *Sequoia*, *Taxodium*, *Sciadopitys*, *Liquidambar* and *Nyssa* is remarkable.

After further study, the plant material will be deposited in the British Museum (Natural History).

6. The formation of the deposits

The St Erth marine formation rests undisturbedly on a rock-surface, which was probably shaped by subaerial erosion. It follows therefore that the major topographic features of the district must have been shaped before the marine transgression that deposited the formation took place.

A thick layer of sand was first deposited. In the 1966 excavations only the upper part of the sand which was fine in texture was seen; earlier workers described sand to a thickness of 6 m, and recorded coarser material in its lower layers. In both the main 1966 sections (figures 7 and 10) the fine sand was built up of two types, one slightly coarser and of beach origin, and the other slightly finer and principally of dune origin, though perhaps with some other components. At higher levels only the coarser type was present. There may have been a coastal belt of sand dunes which were overwhelmed by and engulfed in the beach sand being deposited by the rising sea; when sea level rose still farther only beach sand was available for deposition.

The deposition, or rather re-deposition, of these sands probably took place in the shallow waters of clayey lagoons, and in this way the sands acquired their clay content. In the final stages of sand deposition small pebbles were added to the deposit, and then some change in conditions, perhaps a further rise in sea level, initiated the deposition of highly fossiliferous clay. Though now very much influenced by weathering, originally the clay was probably very uniform, and perhaps deposited in a relatively short time in a sea which was deficient in oxygen and mildly alkaline. The fossil evidence suggests that the water temperature was higher than that in the sea round Cornwall today.

The fossils contained in the clay suggest that the water depth at the time of deposition was about 10 m. In the north part of the Vicarage Pit the clay survived to a height of about 35 m; if we add 10 m to this for water depth we arrive at a minimum figure of 45 m (150 ft) for the height of the sea above its present level in the vicinity.

But before concluding that there must have been a eustatic rise in sea level to this height, we must remember that some French workers consider that such inundations of valleys may indicate the local depression of a basin as much as the eustatic rise of the sea, and that the height to which marine deposits can be traced need not necessarily indicate the rise of the main ocean to that level. South of Vannes in Brittany the Golfe du Morbihan appears to be a small basin of recent subsidence. Dr Brébion (1964) considers that the area around the mouth of the Loire was unstable in late Tertiary times, and that several transgressions and regressions took place.

The southwestern arm of Hayle Estuary (figure 1) could be interpreted as being the last remnant of such a basin, and as it is now coming to be realized that many sedimentary basins of various sizes and ages lie concealed beneath the waters of the Irish Sea, the possibility of vertical movement in the vicinity of St Erth cannot be ruled out. Although a *prima facie* case for a transgression to a height of 45 m can be made out, if we seek to compare this height with the height of the late Pliocene sea in East Anglia, we must consider not only the well-established down-warping of the south end of the North Sea basin, but also the possibility that there may have been crustal movement in the St Erth region also.

After the accumulation of a considerable thickness of clay, the direction of sea-level movement was reversed, and the deposits became subject to erosion. We cannot tell how much clay was removed, and there may have been still younger deposits which have completely disappeared. After a period of time of unknown length, the climate became severe and permafrost developed. Contraction of the surface of the sand in the south part of the Vicarage Pit produced at least one wedge-shaped fissure, which filled either with ice as an ice-wedge, or with sand as a sand-wedge. Modern analogy suggests that at the time of its formation the mean annual air temperature in Cornwall must have been below -5 °C.

Conditions must then have changed – perhaps the climate became less severe, or continued erosion steepened the surrounding slopes – and material started to sludge down the slopes as solifluction-earth or head. The upper part of the fill of the wedge moved, as did the surrounding sand. The downslope movement of sand must have bared rock farther upslope, and as this moved downslope it formed the stony upper layers of the head.

In the north part of the Vicarage Pit the clay and sand were resting on a relatively horizontal rock surface, and in the absence of a slope they could not be moved by solifluction. Material did move down from the slope above them, but fortunately it did not remove them, but rather buried and protected them.

7. The age of the marine formation

In theory the transition from the Pliocene to the Pleistocene should be marked by evidence of a fall in temperature. This fall in temperature need not be the earliest recorded, because it is now realized that the refrigeration that culminated in the 'Ice Age' probably began in the Neogene.

The definition of the boundary between the Pleistocene and the Pliocene presents special difficulties, and provides a problem that has been with us for some time, and will still be with us for a considerable time to come. In 1948 at the London International Geological Congress the boundary was placed in Italy at the base both of the marine Calabrian and of the continental Villafranchian, the two bases being presumed to be contemporaneous. More recent work has shown that this is not the case, and in 1972 in Montreal the International Union of Geological Sciences revised the definition as follows: 'As an initial definition of the base of the Pleistocene in a marine environment in the Mediterranean region, there is chosen the lowest level in the section at Le Castella, Catanzara, Calabria, at which fossils of *Hyalinea baltica* (Schrotter) first occur'. *H. baltica* is a cold form.

In the marine environment of the North Sea Basin the base of the Pleistocene has recently (van Voorthuysen, Toering & Zagwijn 1972) been placed at the level at which the arctic-marine foraminifer *Elphidium oregonense* (Cushman & Grant) first appears.

In East Anglia – a marginal environment of the North Sea basin – the base of the Pleistocene is placed at the base of the Waltonian stage of the Red Crag (Mitchell, Penny, Shotton & West 1973), although a type site and a type fossil have yet to be accepted. It is almost certain that the boundary when defined will lie at the first appearance of a cold-loving foraminifer somewhere between the Coralline Crag at Boyton, characterized by the species-group *Nassarius reticosus* (J. Sowerby) and sometimes referred to as the Boytonian, and one of the facies of the lower Red Crag as developed in the vicinity of the Naze, though not necessarily at the Walton site itself.

At St Erth we are in a marine environment in the Atlantic region – where should the boundary be placed? Among the molluscs the abundance of *Nassarius semireticosus* (a member of the *N. reticosus* species-group) coupled with the absence of cold forms suggests that we cannot be higher than the Boytonian unit of the Coralline Crag. Among the foraminifera the connexions with French deposits thought to be Pliocene and the absence of cold forms point in the same direction. Farther north in the Irish Sea the re-deposited Crag at Killincarrig contains northern molluscs such as *Neptunea despecta*, *N. antiqua* and *Trophonopsis clathratus*, unknown at St Erth but present in the Oakley horizon of the Waltonian Red Crag. When the boundary between Pliocene and Pleistocene can be defined in this Atlantic region it will almost certainly have St Erth, Bosq d'Aubigny and the Redonian deposits of western France below the boundary, and the Killincarrig 'Crag' above the boundary.

It is to be regretted that the plant fossils identified at St Erth cannot contribute to the solution of this problem. The bulk of the material was in secondary position in the clay, having been washed by wave action out of the local soils, and so can give only a local and limited picture. Miss R. Andrew and I examined a pollen-sample from Bosq d'Aubigny, kindly provided by Professor Funnell. Pollen was very scarce, and only some 35 tree pollen grains were noted; of these 20 were *Pinus*, five were *Abies*, and the following forms were represented by one or two grains each – *Betula*, *Corylus/Myrica*, Cupressaceae, *Engelhardtia*, cf. *Ostrea* and *Tsuga*. Non-arboreal pollen included Chenopodiaceae, Compositae, Ericales and Gramineae. The overall impression is not unlike St Erth. *Engelhardtia* is not recorded at La Londe by Elhai (1963), who considered that deposit to be of Reuverian age. van der Hammen, Wijmstra & Zagwijn (1971) are of opinion that *Engelhardtia* disappeared from NW Europe at the end of the Miocene.

The recognition of glacial deposits in the Scilly Islands (Mitchell & Orme 1967), coupled with the fact that the first description of the clay at St Erth (Whitley 1882) was a boulder clay (see figure 8), made a re-examination of the St Erth deposits imperative. Preliminary work (see Mitchell 1965) did not completely rule out the possibility that the deposits might be Pleistocene, but the results of the 1966 excavations show that while the uppermost layers – the head – are Pleistocene, the underlying clay and sand are almost certainly late Pliocene in age.

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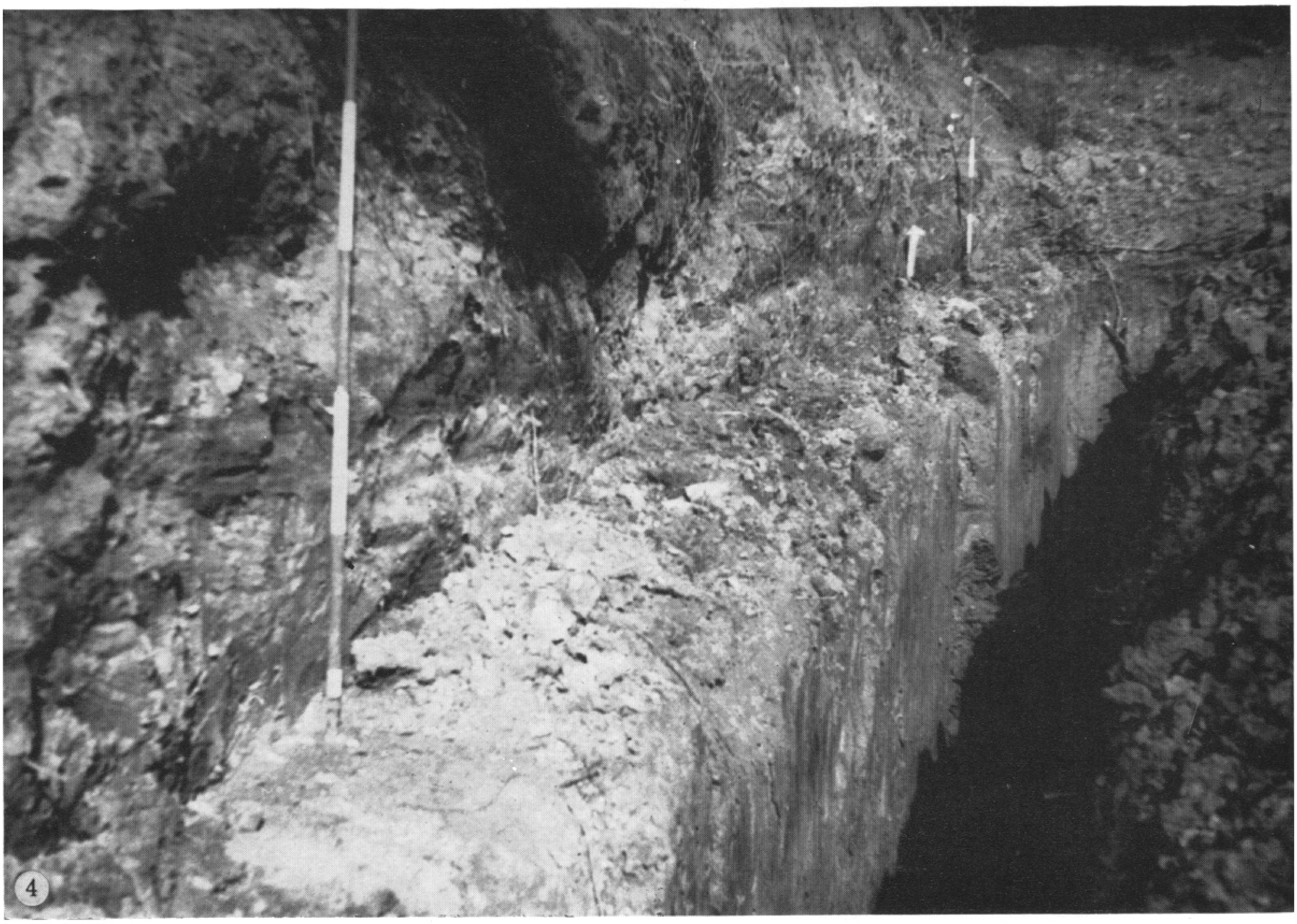

FIGURE 3. Looking W–NW down the solifluction-earth slope to the St Erth school; the bushes in the left foreground are in the NW corner of the north part of the Vicarage Pit; the section shown in figure 7 runs parallel to the edge of the pit.

FIGURE 4. Looking along the line of the section in the north part of the Vicarage Pit, St Erth, from profile 1 towards profile 7 shown in figure 7; the wall of the pit behind the ranging-rods is largely in head; the trench is in clay.

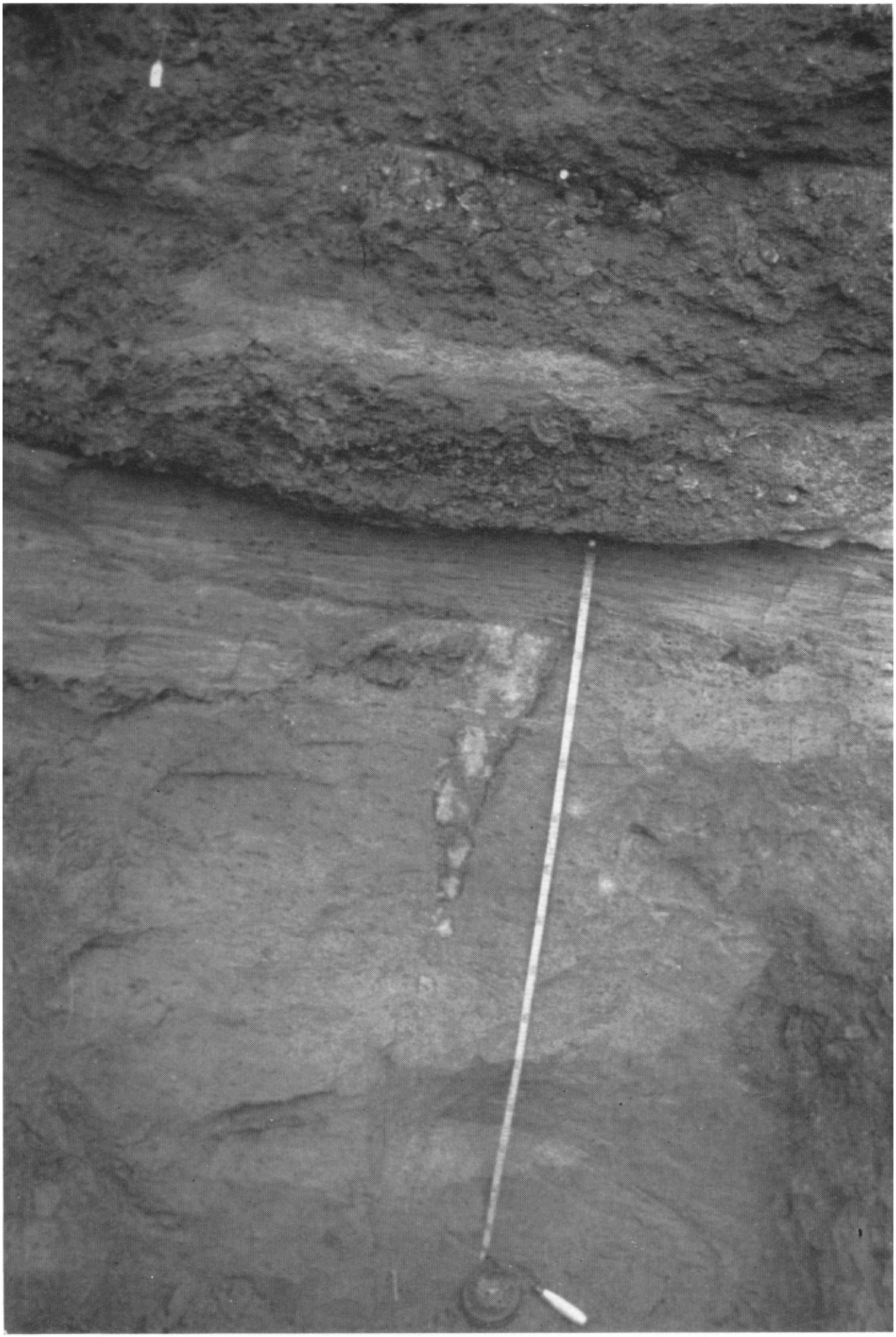

FIGURE 12. Wedge-cast in sand, truncated by soliflucted sand, which is overlain by stony head (see profile 10, figure 10). The tape measure is extended to 150 cm.

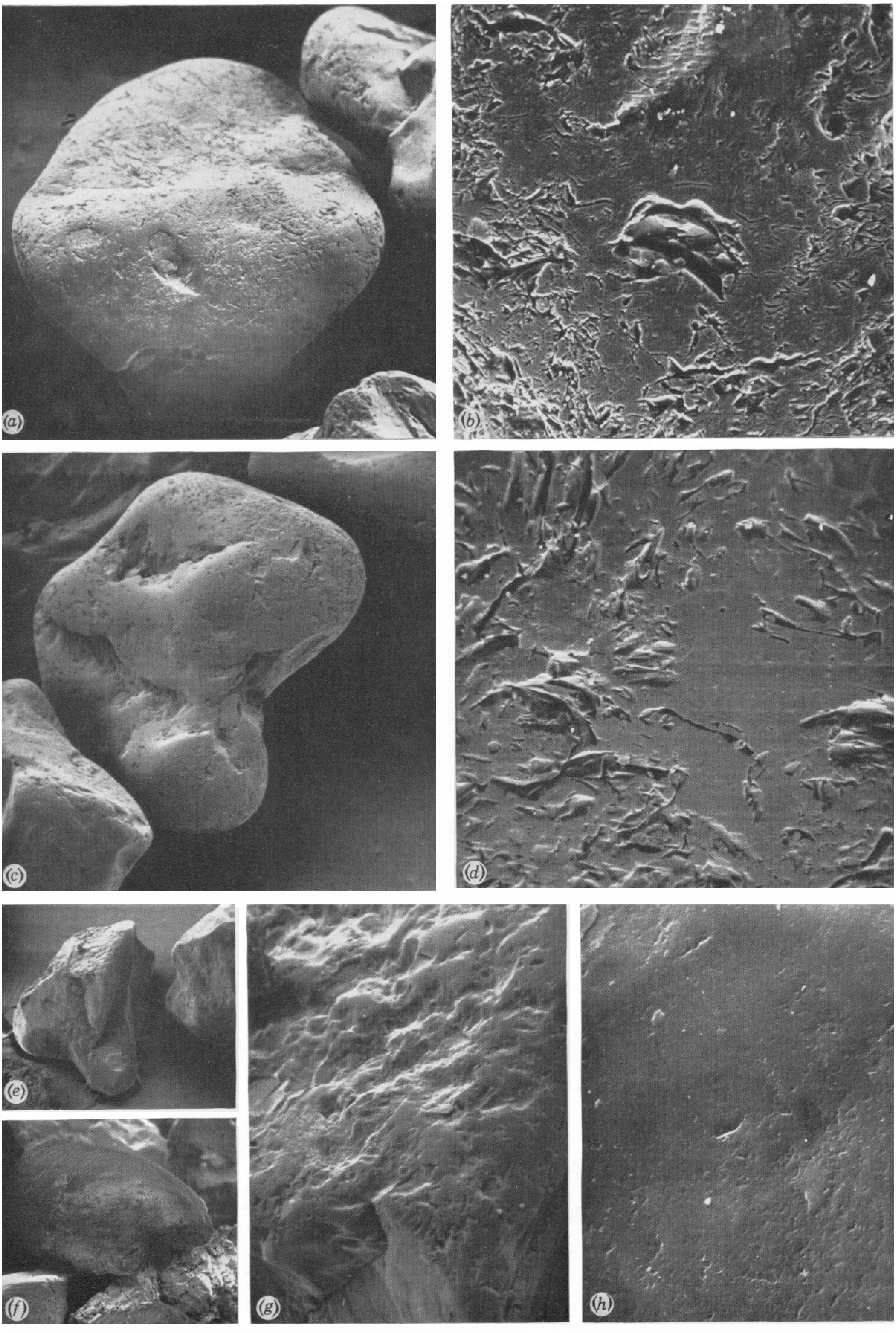

FIGURE 13. Scanning electron micrographs of the surface textures of sand grains from the St Erth Beds: (*a*) well rounded grain from sample 7 (× 185); (*b*) detail of surface texture of grain from sample 7 (× 1850); (*c*) grain from 180 to 250 μm fraction of sample 5 (× 185); (*d*) detail of surface texture of grain shown in (*c*) (× 1850); (*e*) grain from 50 to 125 μm fraction of sample 5 (× 185); (*f*) grain from 50 to 125 μm fraction of sample 5 (× 185); (*g*) detail of surface texture of upper surface of grain shown in (*e*) (× 1850); (*h*) detail of surface texture of smooth grain from sample 5, 50–125 μm fraction (× 1850).

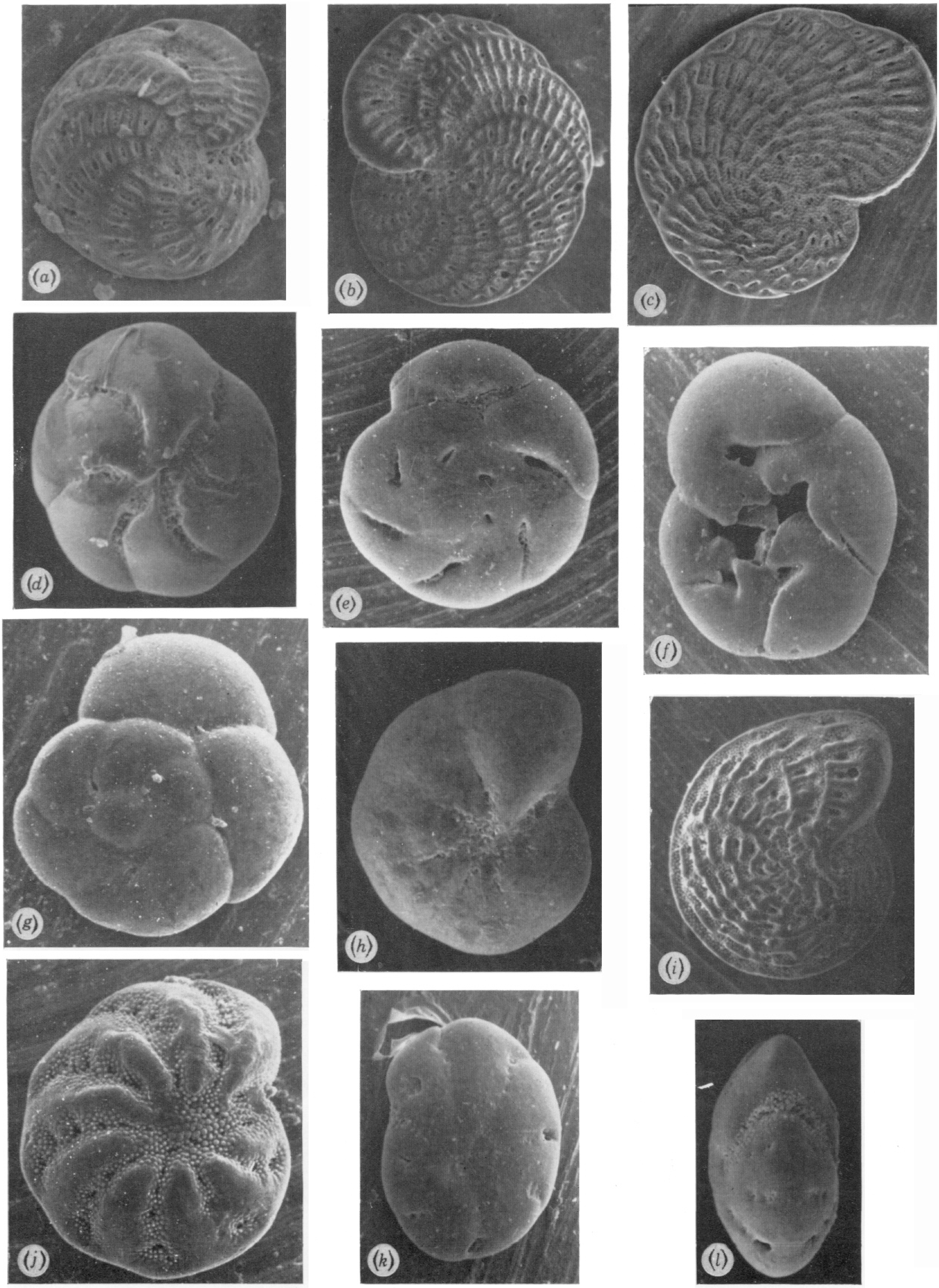

FIGURE 14. Foraminifera, St Erth:

(*a*) *Faujasina subrotunda* (Ten Dam & Reinhold) (× 120).
(*b*) *F. carinata* (d'Orbigny) (× 100).
(*c*) *F. compressa* (Margerel) (× 180).
(*d*) *Monspeliensina pseudotepida* (van Voorthuysen) (× 120).
(*e*) *M. pseudotepida* (van Voorthuysen) (× 90).
(*f*) *Monspeliensina* sp. (× 180).
(*g*) *Monspeliensina* sp. (× 180).
(*h*) *Aubignyna mariei* (Margerel) (× 180).
(*i*) *Elphidium pseudolessonii* (Ten Dam & Reinhold) (× 180).
(*j*) *E. haagensis* (van Voorthuysen) (× 180).
(*k*) *Elphidiella occidentalis* (Margerel) (× 170).
(*l*) *E. occidentalis* (Margerel) (× 150).

FIGURE 15. Foraminifera (continued):

(*a*) *Elphidiella hannai* (Cushman & Grant) Sables de Kallo (×180).
(*b*) *E. hannai* (Cushman & Grant), Whitlingham (×130).
(*c*) *E. hannai* (Cushman & Grant), Ludham (×180).
(*d*) *Discorbitura cushmani* (Margerel), St Erth (×180).
(*e*) *D. granuloumbilicatula* (van Voorthuysen), St Erth (×120).
(*f*) *Buccella frigida* (Cushman), St Erth (×180).
(*g*) *B. frigida* (Cushman), Ludham (×180).
(*h*) *Bolivina gibbera* (Millett), St Erth (×170).
(*i*) *Fissurina cornubiensis* (Millett), St Erth (×180).
(*j*) *Ammonia* sp., St Erth (×90).
(*k*) *Bolivina robusta* (Brady), St Erth (×120).
(*l*) *Polymorphina? fissurata* (Margerel), St Erth (×180).

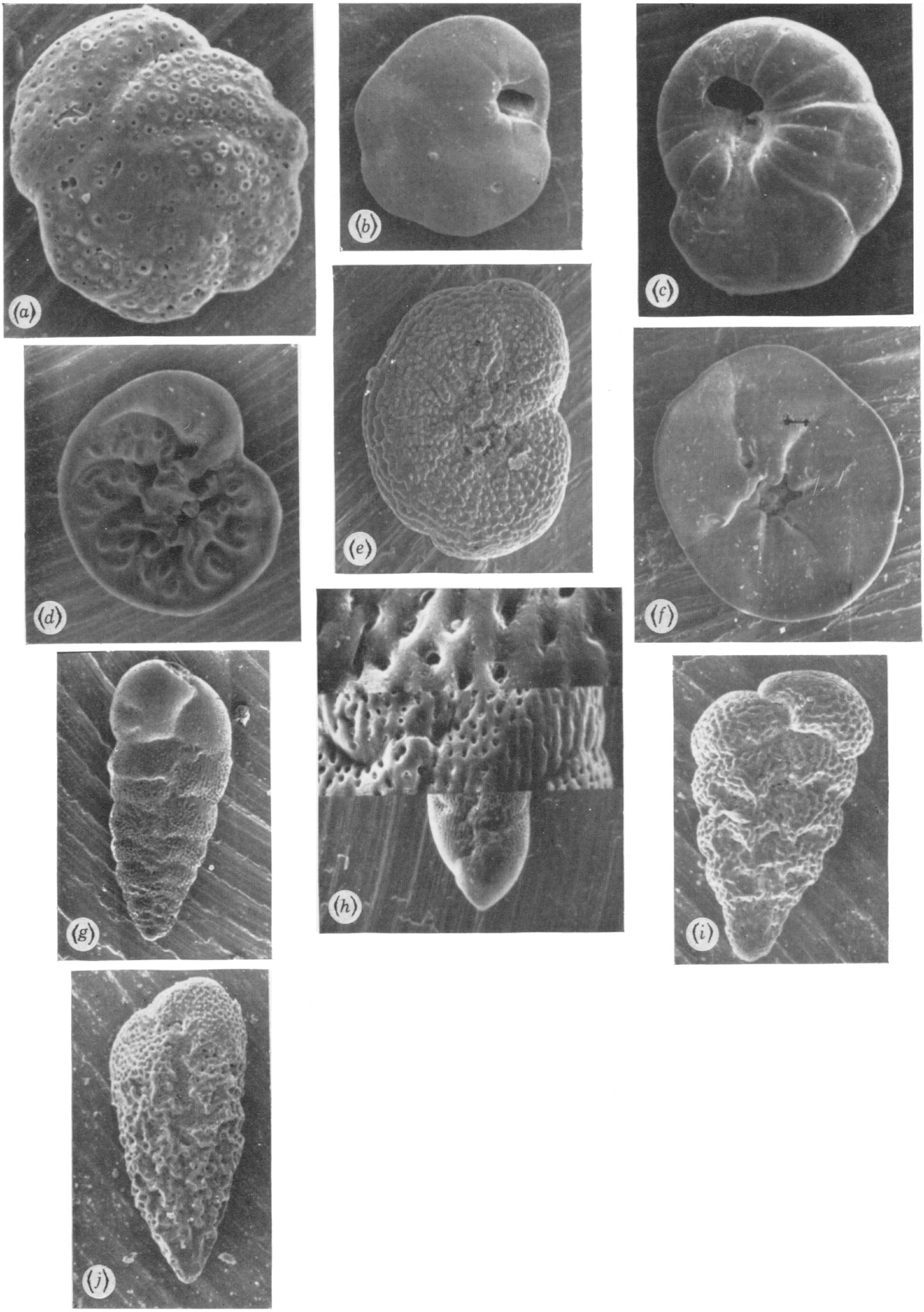

FIGURE 16. Foraminifera, St Erth:

(*a*) *Alabamina* sp. (× 180).
(*b*) *Buccella nuda* (Margerel) (× 180).
(*c*) *Heronallenia lingulata* (Burrows & Holland) (× 150).
(*d*) *Rosalina* aff. *granulosa* (Margerel) (× 130).
(*e*) *Glabratella baccata* (Heron-Allen & Earland) (× 170).
(*f*) *Rosalina nitida* (Williamson) (× 170).
(*g*) *Bolivinia varabilis* (Williamson) (× 180).
(*h*) *B. variabilis* (Williamson) (× 180), (× 600), (× 1800).
(*i*) *B. pseudoplicata* (Heron-Allen & Earland) (× 150).
(*j*) *B. pseudoplicata* (Heron-Allen & Earland) (× 120).