THE ST. ERTH FORMATION: HISTORY OF THE CLAY WORKINGS, GEOLOGICAL SETTING AND STRATIGRAPHY.

L. ROE, M. B. HART, G. K. TAYLOR AND A. MARKS

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The St Erth Formation, of Late Pliocene age, has been reassessed using original research documents and papers dating from the late 1800s, maps lodged at Redruth library dated 1877, 1908, and 1936, aerial photographs currently held at County Hall, and the Tithe Maps and Apportionments of 1840 which can be found at the County Archives in Truro. A resistivity survey of the site, with profiles selected on the basis of the historical data, has confirmed the presence of *in-situ* clays that are approximately 10 m thick. These, and the associated sands, appear to rest on erosion surfaces that are approximately 16 m and 28 m above present ordnance datum. The higher level was probably cut in the Early Pliocene (ca. 3 - 4 Ma) while the Late Pliocene event (ca. 2 Ma) indicates that sea-level during sequence TB3/3.8 (Haq *et al.,* 1987, 1988) was some 35 - 45 m above present O.D. (assuming no post-glacial isostatic rebound in West Cornwall).

L. Roe, Royal Cornwall Museum, River Street, Truro TR1 2SJ
M. B. Hart, G. K. Taylor, Department of Geological Sciences, University of Plymouth, Plymouth PL4 8AA
A. Marks, Centre for Science, Cornwall College, Pool, Redruth TR15 3RD

INTRODUCTION

The St Erth Formation was discovered in ca.1834 *(vide* Mitchell, 1966) and a series of quarries opened for the extraction of moulding-sand. This initial working closed in about 1874 and the pit, or pits, were abandoned until 1881 when they re-opened

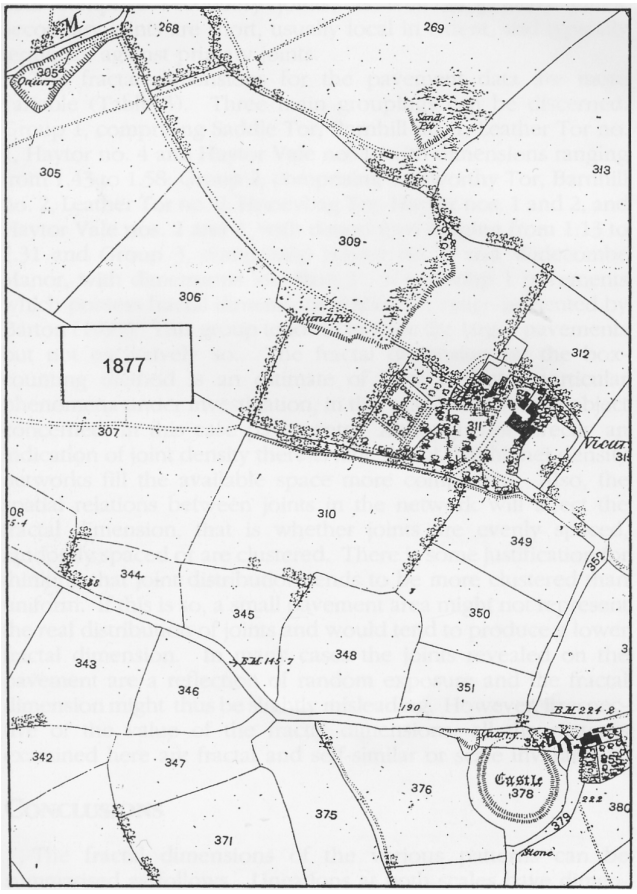

Figure 1. *The St Erth pits in 1877.*

for the exploitation of the clays that were associated with the sands. It was the discovery of abundant mollusc shells within the clays that gave impetus to local, and then national, scientific interest. The clays are now known to be Late Pliocene in age (Jenkins, 1982; Jenkins *et al.,* 1986; Hughes and Jenkins, 1981; Jenkins *et al.,* 1989), based on their rich molluscan and foraminiferal faunas. They appear to have been deposited in about 10-25 m. of water, although there is some debate about the precise figures. The clays may have been redeposited during their formation, a process that would have serious effects on any depth calculations based on the fauna. Head (1993), however, casts doubt on this speculation and regards the palynomorph assemblage as. being *in-situ.* There is considerable interest in the St Erth Formation in the U.K., largely because of a lack of on-shore Neogene sediments with marine fossils. The fauna and flora described by Jenkins *(op.cit.)* and Head *(op.cit.)* have southern affinities and represent a warm period within the generally falling temperatures of the Cenozoic.

The outcrop of the St Erth Formation is limited and most research has concentrated on excavations (documented in Mitchell *et al.,* 1973) and trial pits. The Pliocene sediments are preserved in a 'notch' in the killas surrounding the Land's End and Godolphin granites and because of their limited geographical extent it is clear that much research has involved material which may have been spoil, or at best disturbed, during the quarrying operations of the last century. In order to generate a sampling programme for further investigations, the senior author has investigated all the historical records of the area to determine which areas are 'disturbed' and which areas can be assumed to be *'in-situ'* sediment.

EARLY DOCUMENTATION

All early research would have been based on the 1877 map (Figure 1) as this contains information on the location of the quarry (igneous rocks) and the two sandpits that had been worked for moulding-sand. This map, along with the 1907 and 1934 updates can be found in the "Cornish Studies" section of the Redruth Library. This series of maps shows quite clearly that large quantities of materials for industrial use were being removed while the literature indicates that large numbers of samples were being collected from the locality and, as is evident from photographs taken at the time (see Bristow, 1996, fig.78) that the workings were quite extensive.

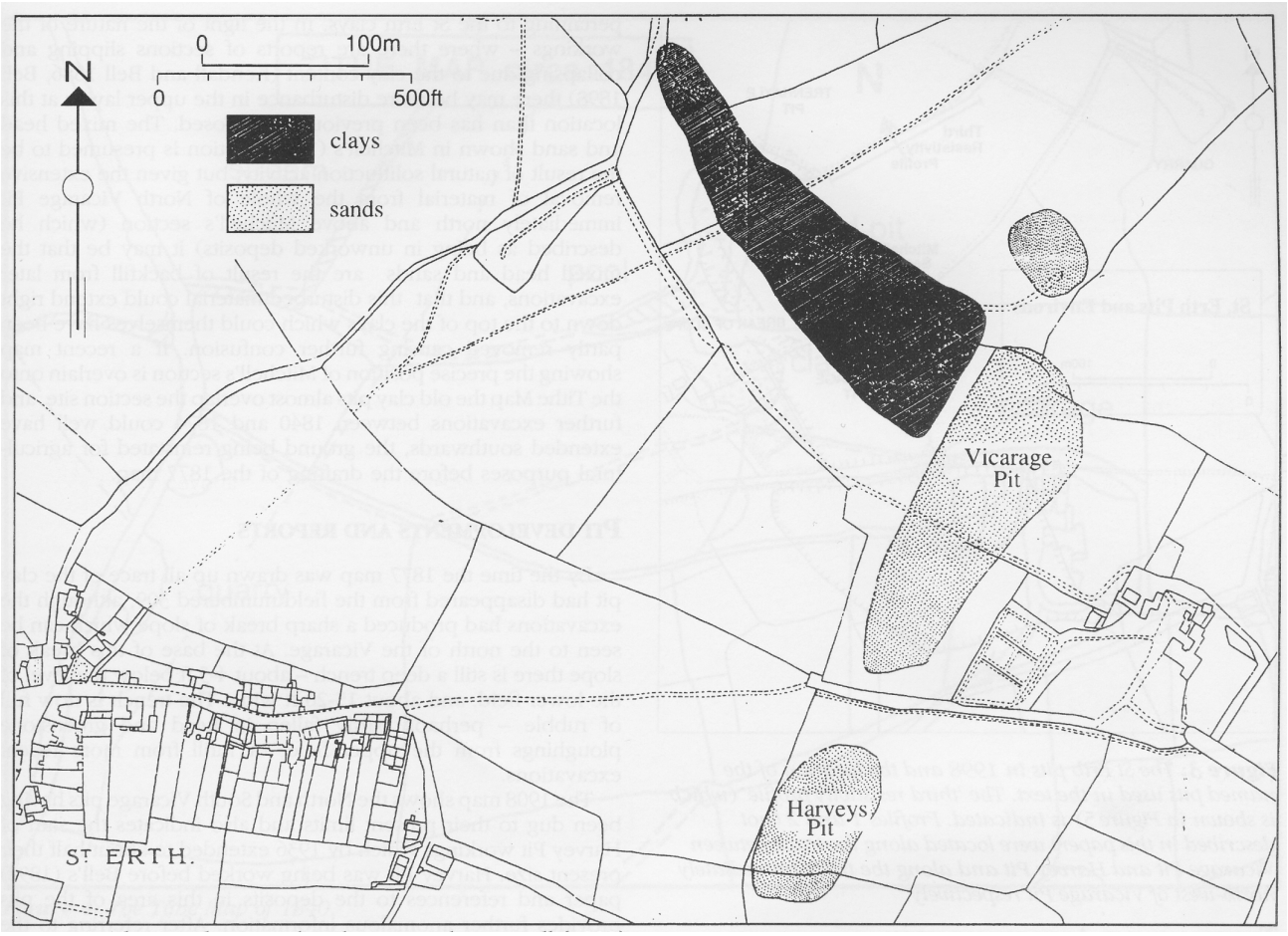

Figure 2. *The St Erth pits and geology according to Bell (1898).*

the workings were quite extensive. Unfortunately the *precise* locations of the workings and the various authors' sampling points are very difficult to ascertain. A good example of the problem is the vague nature of the positional referencing of Whitley's (1881) section which he describes as being "a quarter of a mile north of the vicarage", which could be on the edge of Trenhayle Pit or near the break in slope in North Vicarage Pit or even towards the north-west corner of North Vicarage Pit. Bell (1887a) refers to the "left hand corner of the section exposed during the excavations of the past autumn". All these rather vague references to both the quarrying operations and the collection of material for scientific study make the construction of an accurate three-dimensional picture of the deposit almost impossible. It is also true that any apparent lateral variations in facies would not have been fully appreciated at that time. Sedimentary structures in the sands were not recorded although Whitley, in his lecture of 1881 to the Royal Geological Society of Cornwall, illustrated a section through part of the succession in some detail (reproduced in Mitchell, 1966, fig.3). His section is described by Mitchell as lying to the north of the Vicarage and aligned north-south. The associated description is typical of those at the end of the last century and includes reference to a highly variable thickness of sand and clay, with the latter lying as lenses within the former. This explanation is in keeping with many of the other descriptions which draw attention to rapid lateral variations.

Bell's paper of 1898 gives details of 4 sections across the outcrop, all of which record quite different successions of clay and sand. Bell himself found this variability difficult to explain, indicating that ..."the Rev. Mr. Carter, the Vicar, tells me he has proved (the clay) to 12 feet without reaching the bottom, and at less than 10 yards off I found not more than 6 inches and about 4 feet between the two cuttings". There are, unfortunately, no details as to the *precise* location of any of these observations, although Bell indicates an area of clay on his map (Figure 2).

THE VIEW OF MITCHELL (1965 AND 1973)

Mitchell, because of his interest in Pleistocene climates, studied the St Erth Beds in some detail, ascribing them to the Cromer Warm Period. He attempted to reconstruct the various records (e.g., Milner, 1922) into a series of hypothetical sketch sections (Mitchell, 1966, fig.4), some of which still included reference to Boulder Clay. Mitchell *(op.cit.)* appears to want the clays deposited in the Cromer Warm Period and then to deform them by the injection of Boulder Clay during the Lowestoft Glaciation. In a detailed analysis Mitchell describes the other comparable deposits known from south-west England and South Wales, including those at Fremington (Mitchell, 1960; Stephens, 1966, 1970; Cullingford, 1982). Funnel, in the discussion of Mitchell (1966) describes in some detail the warm-water nature of the foraminiferal fauna of the St Erth Beds and concludes that a Plio-Pleistocene age for the assemblage is the best he can suggest with the available material. Throughout the discussion Mitchell *(op.cit.)* is urged to re-open a section at St Erth and this is what subsequently happened in 1966. His now-famous trench section (Mitchell *et al.,* 1973, figs 7,9) shows the clays, sands, gravels, head and large areas of 'discoloured clays'. The surface 2-3 m. of sediment that lies across the section may, or may not, be *in-situ* and there is certainly an area of made ground in the centre of the profile. In his earlier work Mitchell (1966) tended to follow Whitley's view that these were possibly clays of glacial origin that had been thrust into the local succession. It is now thought that these altered clays have been leached and discoloured *in-situ* as a result of groundwater moving through the succession.

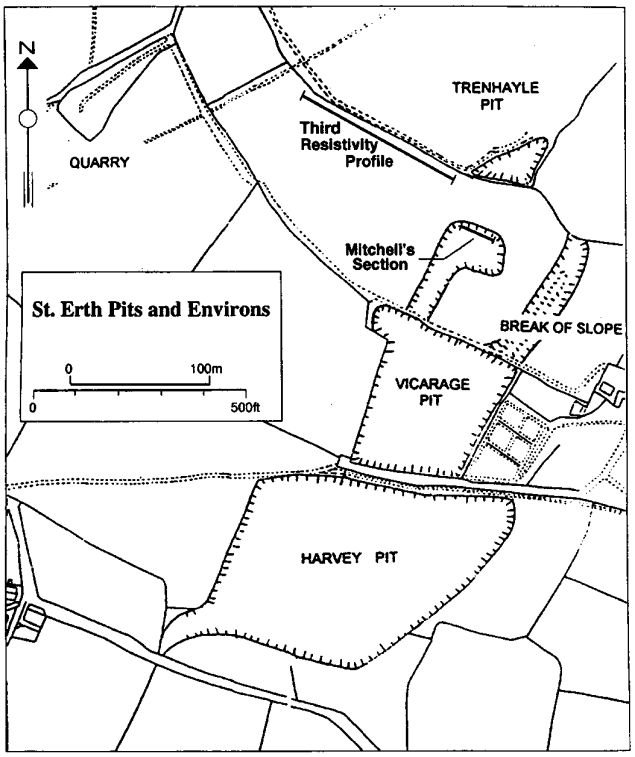

Figure 3. *The St Erth pits in 1998 and the location of the named pits used in the text. The 'third resistivity profile' (which is shown in Figure 5) is indicated. Profiles 1 and 2 (not described in this paper) were located along the track between Vicarage Pit and Harvey Pit and along the track immediately north-west of Vicarage Pit respectively.*

TITHE MAP AND APPORTIONMENTS

The fact that Mitchell very nearly expended a great deal of time (and money) into opening up a section that may have contained a high percentage of made ground has led the authors to consider how best to determine where *in-situ* clays/sands may still be preserved. To date, the Tithe Maps and Apportionments - which are held in the County Archives in Truro - have not been used as a resource for researching the St Erth Formation. These maps (Figure 4) are dated 1840 and include interesting information which sheds new light on later research.

By the time that the Tithe Map of 1840 was drawn up there were already well defined sand pits in the area, as well as one clay pit. The digging of this clay was noted in the Apportionments as being of taxable value and this means that it was being actively worked in 1840. It is also interesting to note that many of the field boundaries and all the footpaths except one correlate very closely with those shown on current maps. As the Apportionment books carefully document each field by name, acreage, owner, use and tithe value, inaccuracies would be extremely unlikely.

It has been noted that the pits in the north of the site were worked from 1834 until 1874. The extension of the pits over the 35 years following the drafting of the Tithe Map can be expected to have been quite extensive since by the time the 1877 map was drawn there was a considerable break of slope, of some 12-15 ft (4-5 m), at the western end of what became the North Vicarage pit. This indicates a substantial removal of material.

There are a number of points to note as a result of information gleaned from the Tithe Map. The pool near the Trenhayle sand pit suggests both deep working and a high clay content in this area. Although there is no mention of clay being dug at this specific site we can presume that the clay probably extends beneath this area or at least horizons of sand with a high clay content. The area of North Vicarage Pit showing clay workings has never been referred to in any other research papers pertaining to the St Erth clays. In the light of the nature of the workings — where there are reports of sections slipping and collapsing due to the clay content (Kendall and Bell 1886, Bell 1898) there may be more disturbance in the upper layers at this location than has been previously supposed. The mixed head and sand shown in Mitchell's (1966) section is presumed to be the result of natural solifluction activity, but given the extensive removal of material from the whole of North Vicarage Pit immediately north and above Mitchell's section (which he described as being in unworked deposits) it may be that the mixed head and sands are the result of backfill from later excavations, and that this disturbed material could extend right down to the top of the clays which could themselves have been partly removed causing further confusion. If a recent map showing the precise position of Mitchell's section is overlain onto the Tithe Map the old clay pits almost overlap the section site, and further excavations between 1840 and 1874 could well have extended southwards, the ground being reinstated for agricultural purposes before the drafting of the 1877 map.

PIT DEVELOPMENTS AND REPORTS

By the time the 1877 map was drawn up all trace of the clay pit had disappeared from the field numbered 309, although the excavations had produced a sharp break of slope which can be seen to the north of the Vicarage. At the base of this break of slope there is still a deep trench — about 4-5 ft below the level of the lower field, and about 15-20 ft wide. The trench is now full of rubble — perhaps partly fallen in head and greenstone ploughings from the upper field, or infill from more recent excavations.

The 1908 map shows the North and South Vicarage pits having been dug to their present limits and also indicates the start of Harvey Pit workings which by 1936 extended to about half their present size. Harvey Pit was being worked before Bell's (1898) paper and references to the deposits in this area of the pits provides further anomalous information. After referring to the clay layer as being confined to a triangle running only 140 yds from Trenhayle to the Vicarage Pits, being deepest to the northeast and thinning out to the west and south, he then went on to describe blue and yellow fossilliferous clays found in Harvey Pit which was at that time only open at the southern end some few hundred yards from Trenhayle. These references to clay in Harvey Pit were contradicted by Milner (1922) who described a number of sections while working for the Cornish Sand Company, none of which contained the thick clay beds described by Bell.

It is interesting that one of the clay pits on the 1840 map (Figure 4) lies just to the north of a field boundary that is present on Bell's map (Figure 2) and is still present today. The geophysical profile, that is described later, was taken immediately to the south of that field boundary in the hope that the clays in that area have never been disturbed or removed.

TILE 1996 EXCAVATIONS

Using the data available to them Mitchell and co-workers selected a number of sites to investigate and excavated a number of pits including the famous trench section (for location of the trench see Figure 3). Our present knowledge of the succession largely comes from the many samples collected as part of that investigation. Figure 5 shows the cross-section of the old pit (as it was in 1966) together with the position of the trench section. Mitchell *et al.'s* sections (1973, figs 7, 9) show many features that may be disturbed ground (ex-quarry fill). The clays in their (*op.cit.* fig.9) section appear to be expanding towards the northwest end of the profile (Figure 5) and this pointed towards the adjacent field, and its northern field boundary, as being the best location at which to seek a clay succession using geophysical methods.

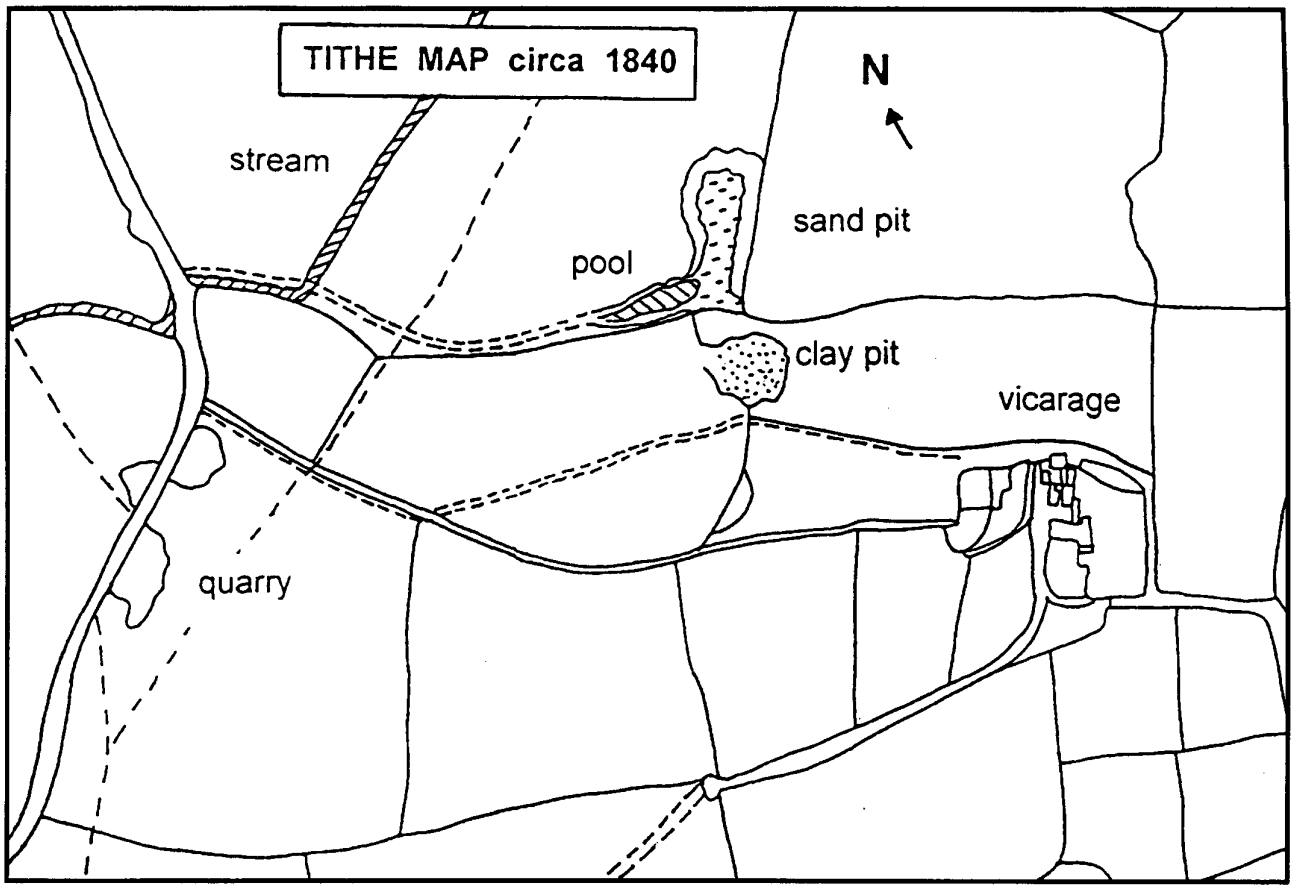

Figure 4. *The Tithe Map of 1840.*

PRELIMINARY GEOPHYSICAL SURVEY

To date three resistivity profiles (see Figure 3) have been undertaken across the approximate strike direction of the outcrop to establish whether the clays provide a suitable geophysical target. The resistivity imaging method has been used. This relatively modern technique combines the traditional profiling and sounding methods such that resistivity pseudo-sections or images are acquired and interpreted. The equipment used comprised an ABEM Terrameter and Lund Imaging System, with an inter-electrode spacing of 5m along a 200 m long multicore cabling system, coupled to a portable PC for control and interpretation. To date the data constitute some 700 m of resistivity profiles with an effective maximum depth penetration of about 30 m but with a normal depth of penetration of about 20 m. The first profile along Vicarage Lane showed a break in resistivity coincident with the margin of the exposed workings suggesting that resistivity should be able to detect such workings. The central profile, across the worked and backfilled pits, shows a highly irregular, chaotic even, interface between relatively low (<50Wm) resistivity layer, thought to be the clays, with a higher but very variable resistivity layer(s) (100-300Wm), thought to be sands, other backfill material and bedrock. The third profile (location shown in Figure 3) shows a very well developed low resistivity layer (<30Wm) which shallows gradually and disappears to both north and south. We interpret this simple section (Figure 5) as undisturbed clays overlying sands and bedrock.

STATIGRAPHICAL INTERPRETATION

A small number of clay samples (collected as near to Mitchell's section as possible; see Figure 3) have been investigated for their foraminiferal content. This work is still on-going and more material will be collected during 1999. The fauna, as currently determined, is extensive and requires a complete reinvestigation. The planktonic component of the fauna is small (<5%) and comprises a limited number of simple, globigerine taxa. We have found no species that were not listed by Jenkins et al. (1986) and our material compares favourably with the specimens that are in the micropalaeontological collections of The Natural History Museum (London): catalogue numbers P.51672 - P.51692. Jenkins et al. (1986), in a series of compelling arguments, conclude that the St Erth fauna lies (Figure 6) in the lower part of the *G. inflata* Zone of Weaver & Clement (1986). The age of the sediments would, according to the Plio-Pleistocene time-scale of Berggren *et al.* (1985), be about 1.9 - 2.1 Ma. This places it exactly within the zone of "maximum flooding" of the TB3/3.8 sequence of Haq *et al.* (1987, 1988). With sequence boundaries at 1.6 Ma and 2.4 Ma this sequence appears to be the likely cause of the deposition of the St Erth Formation. Other sequence boundaries, such as that at 5.5 Ma (approximately the Miocene/Pliocene boundary) or that at 3.8 Ma may have been the cause of the Pliocene erosion surface seen throughout much of south-west England.

The altitude (above ordnance datum) at which the resistivity profile was taken and the depth to the suggested bedrock appears to indicate erosive levels that are approximately 16 m and 28 m above current O.D. If the water depth, proposed by Jenkins *et al.* (1986) is correct, then sea-level 2.0 million years ago was approximately 35 - 45 m above the present level and has, despite the recent advances of the Flandrian transgression, fallen from that level to that of the present day. Jenkin's (1982) suggestion of a temperature of deposition towards "the upper end" (*op.cit.* p.103) of the 10° - 18°C range implies a slightly warmer climate than that of the present day: the sea temperature range in West Cornwall is approximately 8° - 16°C at the present time.

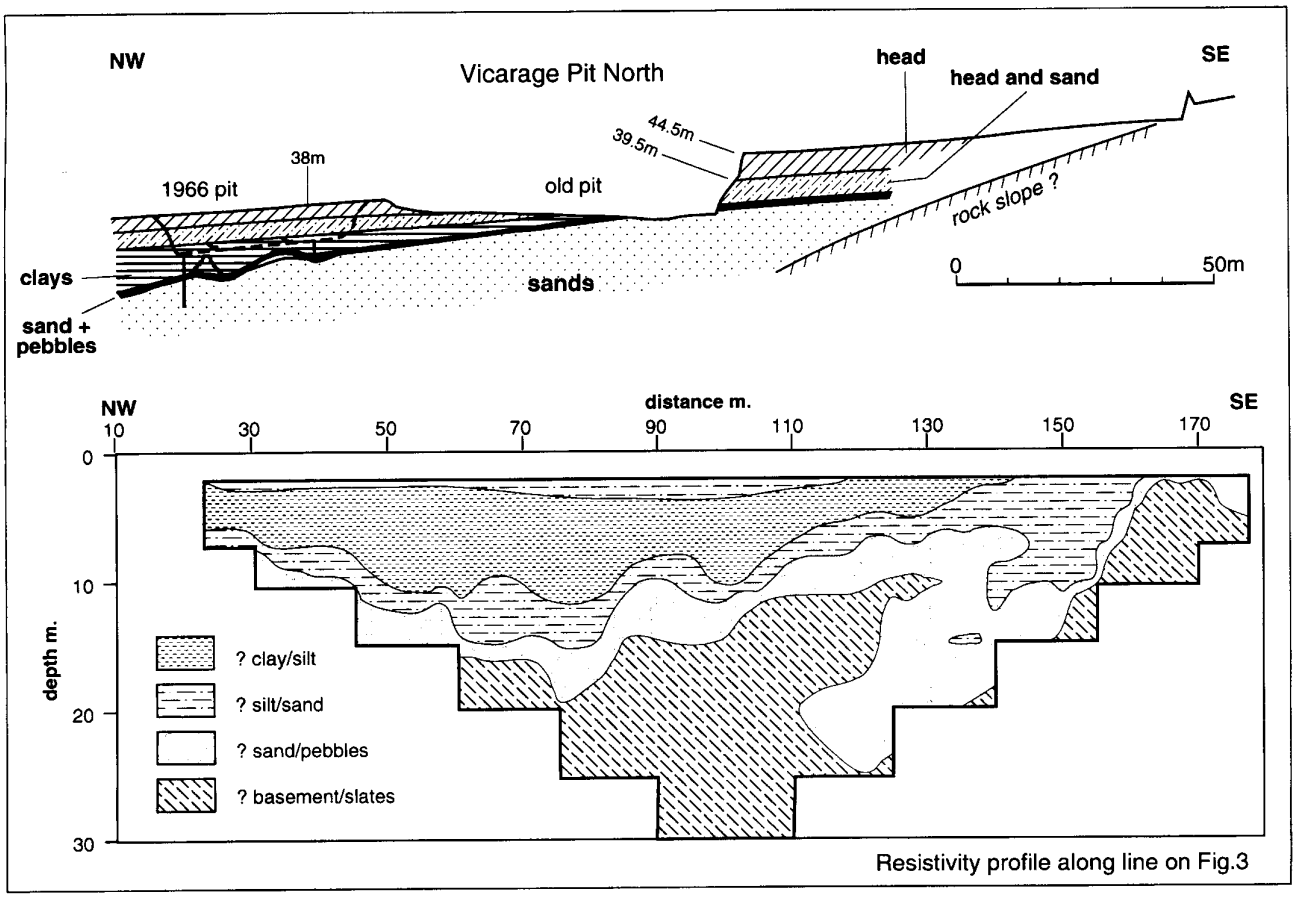

Figure 5. Cross-section across Vicarage Pit North and the Mitchell et al. (1973) excavations. The lower section is an interpretation of the resistivity profile shown in Figure 3. This hillside is on a slight slope, with the south-east end of the profile some 7-8 m higher than the north-west end of the profile. The 'basement' is very close to the surface at 165-175 m, but there is presently no explanation for the gap in the basement between 130 m and 165 m. The location of Mitchell's section is shown in Figure 3.

CONCLUSIONS

Careful scrutiny of historical documents has indicated the possible location of *in-situ* clays within the St Erth Formation. Their presence has been confirmed by a preliminary resistivity survey which will be extended during 1999. Pilot samples for foraminiferal analysis have confirmed the presence of an extensive fauna, including the planktonic taxa described by Jenkins *et al.* (1986). The clays are confirmed as belonging to the *G.inflata* Zone of the Late Pliocene and indicate that sea-levels were approximately 35 - 45 m above present levels at that time.

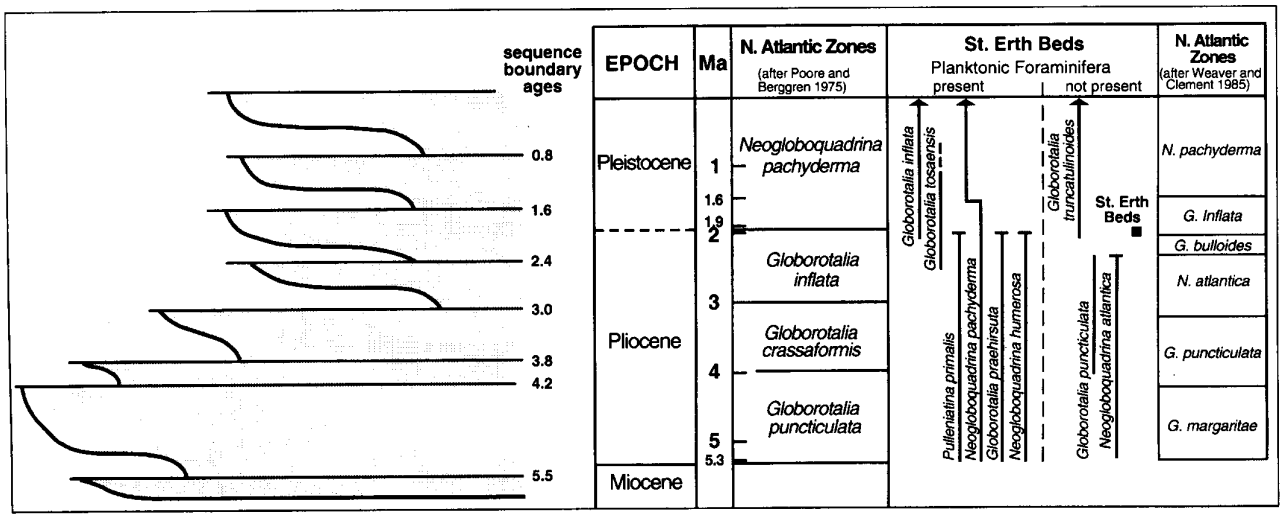

Figure 6. The dating of the St Erth succession using planktonic foraminifera (after Jenkins et al., *1986) and the identification of Pliocene sequences (after* Haq et al., *1987, 1988).*

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