THE ST ERTH FORMATION: GEOMETRY OF THE DEPOSIT AND MICROPALAEONTOLOGY

R.W. MESSENGER[1], M. B. HART[1], D. PIRRIE[2], L. ALLEN[3], G. K. TAYLOR[1] AND B. DASHWOOD[1]

Messenger, R.W., Hart, M.B., Pirrie, D., Allen, L., Taylor, G.K. and Dashwood, B. 2005. The St Erth Formation: geometry of the deposit and micropalaeontology. *Geoscience in south-west England*, **11**, 93-98.

In 1999 a paper was presented to the Ussher Society which described, in some detail, the location of the St Erth Formation and the history of the minerals workings. At that time the authors described the results of a resistivity survey across part of the area, which, it was hoped, would locate *in-situ* sands and fossiliferous clays. In October 2003, using the same equipment (an ABEM Terrameter and Lund Imaging System), further lines have been documented which provide more data on the distribution of the marine sediments of Late Pliocene age. In conjunction with this additional survey work a number of shallow cores were drilled in an attempt to locate the fossiliferous clays that, since 1886, have been known to lie in this area. In most cores only wet moulding sand was recovered. In two cores thin clay interbeds were found and a limited marine fauna of foraminifera identified. Associated with these foraminifera are abundant bolboformid-like microfossils.

At a location close to the site of the trench excavated by Prof. G.F.Mitchell in the 1970s a few samples of weathered clay were recovered by hand auger. These samples also contain abundant foraminifera and the 'bolboformids'. Samples collected by Millett during the original quarrying operations, and which are in The Natural History Museum (London), also contain beautifully preserved foraminifera and a diverse assemblage of these unusual 'bolboformids'.

[1]*School of Earth, Ocean & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, U.K. (E-mail: mhart@plymouth.ac.uk).*

[2]*School of Geography, Archaeology and Earth Resources, Camborne School of Mines, University of Exeter in Cornwall, Tremough Campus, Penryn, Cornwall, TR10 9EZ, U.K.*

[3]*Porthcurno Telegraph Museum, Eastern House, Porthcurno, Cornwall, TR19 6JX, U.K.*

INTRODUCTION

The St Erth Formation, of late Pliocene age, is only found close to the village of St Erth (Figure 1) in west Cornwall (SW 5564 3520). The present outcrop is extremely limited, although a number of other locations in the area were listed by Roe *et al.* (1999). The "St Erth Sand Pits" Site of Special Scientific Interest (SSSI) was notified under Section 28 of the Wildlife and Countryside Act 1981 as amended, on the 17th December 1986. The citation, which is available on the English Nature website [www.english-nature.org.uk], reads as follows:

> *"St Erth is a famous and classic site for its sequence of Late Pliocene marine sediments, which contain an exceptionally diverse fossil faunal assemblage, particularly macrofossils. It provides a unique source of evidence relating to the geomorphological evolution of S.W. England, former sea-levels and past environments. St Erth has attracted considerable scientific interest and controversy for over a century and will continue to be a focus of research at the highest level."*

The St Erth Formation was discovered in *ca.*1834 (*vide* Mitchell, 1966) and a series of small pits were opened for the extraction of moulding sand. These initial workings closed in about 1874 and were abandoned until 1881 when they re-opened as a source of clay for a new dry dock in Penzance Harbour. During that year Nicolas Whitley, a local geologist, visited the site and collected specimens from the "heaps of broken shells" in the clay pit(s). He described the clays and the fauna in a paper read to the Royal Geological Society of Cornwall in November 1881. The 'blue clay' described by Whitley was seen to rest above 'the fine sands' and below a level of (weathered?) yellow clay, angular stones, clayey loam and soil/head. Whitley (1882) was convinced that these were glacial deposits, although Wood (1885) clearly disagreed with this conclusion, and said as much at a public meeting. Subsequent publications by Kendall and Bell (1886), Bell (1887a, b, 1887-1888, 1898), Johnson (1903), Milner (1922), Mitchell (1960, 1966) and Cullingford (1982) have continued the debate as to the age of the formation.

The various workings of the pits and their subsequent investigation have been fully described by Roe *et al.* (1999). The major investigation of the St Erth Formation was by Mitchell *et al.* (1973) where the authors describe the sedimentology and palaeontology of the area, largely based on a newly excavated section. Subsequent workers (Jenkins, 1982; Head, 1993) have either used these samples for their investigations or re-assessed material in the Millett collection, which is housed in The Natural History Museum, London.

In recent years the Department for Environment, Food and Rural Affairs (DEFRA) has begun measuring performance by the creation of "Public Service Agreements" both within the ministry and in external centrally-funded organisations. English Nature has been asked to ensure that 95% of SSSIs (by area) in England are in either "favourable" or "unfavourable-recovering" condition by 2010; definitions of these terms are available on the English Nature website [www.english-nature.org.uk]. As an SSSI, it is clear that the St Erth Sand Pits no longer show the

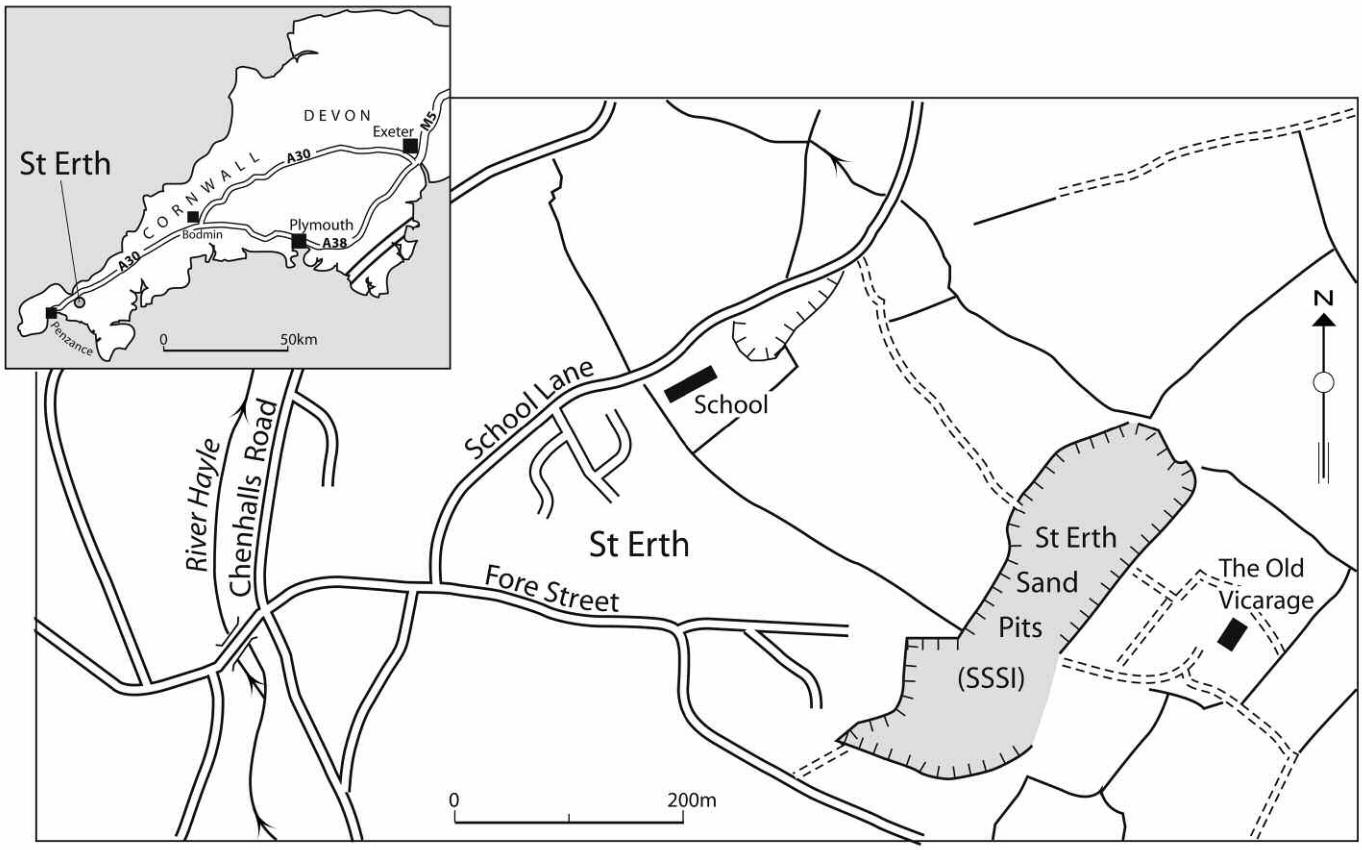

Figure 1. *Location of St Erth in the west of Cornwall and the present boundary of the St Erth Sand Pits SSSI (based on the English Nature website).*

features of interest (fossiliferous marine sediments) as almost all the sand and clay has been removed from the old quarries that lie within the present SSSI boundary (Figure 1). Our present work was stimulated by a need to know where the remaining fossiliferous clays and sands are located in the vicinity of the currently designated site.

GEOPHYSICAL INVESTIGATION

Roe *et al.* (1999) attempted to collect fresh samples of the clays at a number of sites in the old workings and while some clay (with microfossils) was recovered it could not be placed in a proper stratigraphical context. Three resistivity profiles were run, one of which was published (figure 5 in Roe *et al.*, 1999). The work on the St Erth Formation resumed in Autumn 2003 when a further two resistivity lines were run in the same area as the lines run in 1999 (Figures 2, 3). The purpose was the same as before; to locate suitable places to core in the hope of intersecting the clay succession and collecting *in-situ* microfossils.

The equipment used (as was the case in 1999) was an ABEM Terrameter and Lund Imaging System, with an inter-electrode spacing of 5 m ("Wenner Array") along a 200 m long multicore cabling system, coupled to a portable PC for control and interpretation. Examples of processed and interpreted resistivity profile from the site are shown in Figure 4. Resistivity line 2 of the previous study (figure 5 in Roe *et al.*, 1999; presented here as Figure 4(a)) was interpreted as showing an essentially 2-layer system such that a low resistivity (< 40-50 Ωm) wedge in the upper part of the section represents the basin fill clays overlying a higher resistivity (> 100 Ωm) 'basement' representing the underlying Devonian metasedimentary rocks. Given the local geology we would suggest that the clays are underlain by sands, but the geophysical data only indicate that

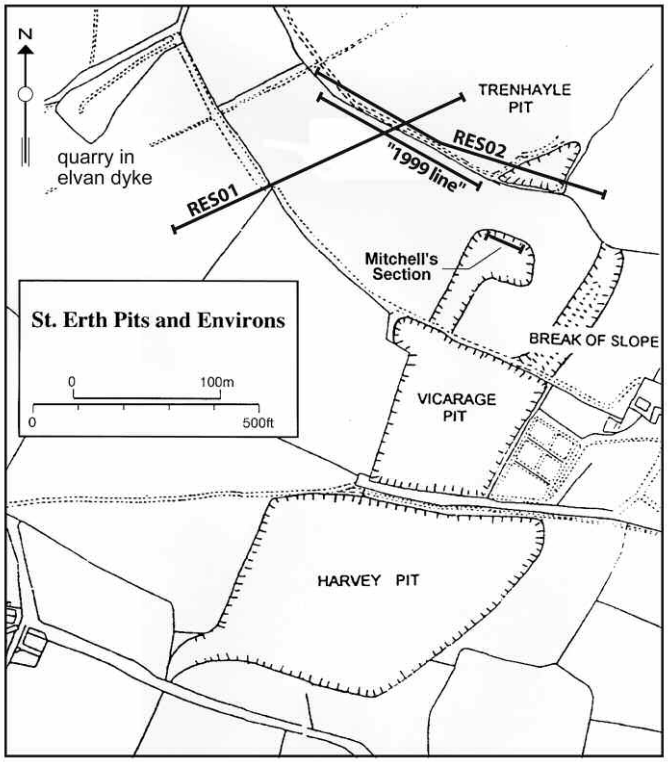

Figure 2. *The St Erth pits with the location of Mitchell's section and the line of the largest of the 1999 resistivity profiles indicated, together with the two profiles (RES01, RES02) run as a part of the 2003 survey. The eastern edge of St Erth village is in the lower left of the map.*

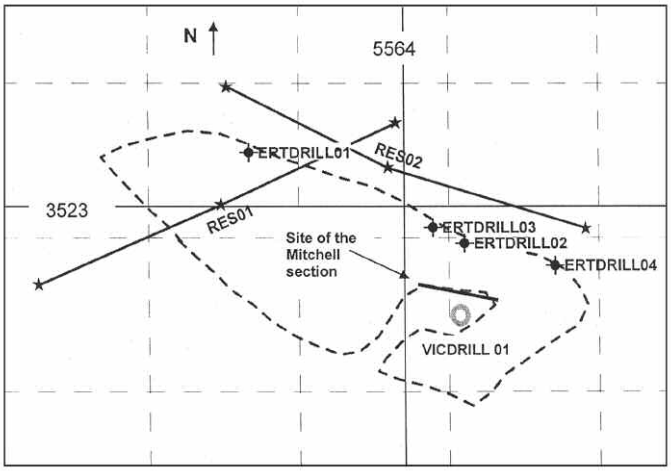

Figure 3. *GPS map of the 2003 investigations, including the RES01 and RES02 resistivity profiles, the drill sites (ERTDRILL 01–04) and the auger hole (VICDRILL 01) adjacent to the Mitchell section. The position of survey lines RES01 and RES02 locate this map on Figure 2.*

beneath the clays are likely to be sediments of intermediate resistivities which could be either sands or weathered bedrock; in either case the greater porosity suggests a greater fluid content than the underlying basement. Line RES02 (Figure 4(b)) is located some 20-30 m to the north and east of Line 2 (see Figure 2) and mimics the original data very closely. Both these lines suggest the presence of a higher resistivity layer overlying the clays and we suspect that this represents the barren sands that were recovered during coring. The cross-profile, line RES01 (Figure 4(c)) was conducted at a high angle to the previous two lines (Figure 2) and shows the basin apparently thinning to the southwest. Interpretation of this line is, however, quite difficult as the geophysical information is limited and we have no core data to confirm the subsurface geology.

The gap at the top of each section is a function of the electrode separation used to conduct the surveys and in future we would hope to use a smaller inter-electrode spacing so as to gain maximum information of the internal stratigraphy of the basin fill. Equally we would hope to improve the depth of penetration of cores along the geophysical lines to provide better ground-truthing of the depths indicated by the resistivity surveys.

It is clear that a considerable thickness of the Pliocene succession lies below the field to the northwest of the known pits/quarries; this would be well outside the defined boundary of the SSSI.

Drilling investigations

With the known *in-situ* clay/sand succession being thickest along the hedge boundary that lies between the 1999 and the RES02 traverses (see Figure 2) it was decided to drill four holes using a COBRA 249 Hammer Drill (Figure 3). It was appreciated that this type of drill might compact the sediments, as well as distorting any sedimentary structures that may be present. Almost all of the sediments recovered were well-sorted, well-rounded coarse-grained marine sands with a high water content. At the site of ERTDRILL 04 the sands were much finer grained and much more like those required for the mould-making work for which the sands were initially exploited. The outline logs for the four holes are shown in Figure 5.

Results of investigation of auger core VICDRILL 01

This core recovered laminated clay/sand sediments that would appear to be *in-situ*. Primary sedimentological features were seen, including yellow, brown to grey plastic clay with very fine red/brown sand and silt laminae containing organic material. Some of the sediment was bioturbated, with this dying out towards the upper part of the core. Structures within the silts and sands show small ripple cross-lamination indicative of a low energy, relatively shallow water environment. Samples of blue silty clay were washed over a 63 µm sieve and the residue was found to contain several species of foraminifera and ostracods, all of which are indicative of marine conditions.

The foraminifera of the St Erth Formation have been described by Millett (1886a, b, 1895, 1897, 1898, 1902) in a series of papers published by The Royal Geological Society of Cornwall. In these he documented 138 species, all of which are mounted on slides in the collections of The Natural History Museum. Curated with the slides are the washed residues, some of which are stored in glass jars with Millett's labels still attached. In his 1890 Memoir, Reid included the complete list of all the foraminifera described by Millett (Reid, 1890, table XIII, pp. 284-288). In our present work no planktonic foraminifera have been found and this confirms their rarity (Jenkins, 1982). Margarel *in* Mitchell *et al.* (1973) studied the benthonic foraminifera and compared the St Erth fauna with that found in a number of small Redonian basins in western France. He suggested that the water depth at the time of deposition of the St Erth Formation as <100 m. Jenkins (1982) and Jenkins *et al.* (1986, 1988, 1989), on the basis of the planktonic foraminifera, indicated a water depth of 60-100 m and a probable palaeotemperature of 10°C-18°C (Roe *et al.*, 1999).

An abundant element of the 'fauna' appears to be small, spinose calcareous microfossils. These are also present in the samples collected by Millett when the St Erth quarries were in operation, although they do not appear to have been described in any of the literature. This diverse and abundant fauna of 'bolboformid-like' microfossils is found in the <250 µm size fractions and all appear to be quite well preserved. Bolboformids, however, have only been described from open marine sediments of mid-Eocene to mid-Pliocene age (Murray, 1984, 1986; King, 1983; Spiegler and Von Daniels, 1991; Mackensen and Spiegler, 1992; Spezzaferri and Rögl, 2004; Crundwell *et al.*, 2005; Spiegler and Spezzaferri, 2005). If these are not bolboformids then there is a problem in the identification of these 'taxa'. Those illustrated in Figure 6 include forms of unknown affinity. Alternatively they might be the calcareous cysts of dinoflagellates or parts of some other unidentified fossil group. Figure 6(d) is superficially like the apical area of a charophyte oogonium but the whole specimen is discoidal (not ovate) and, in any case, the ornament is concentric rather than spiral. Figure 6(a) is very similar to a Cretaceous pithonellid, though similar forms have been described from the Danian and Miocene (Spezzaferri, *pers comm.*, 2004). Figure 6(b,c,e,f) may be the calcareous cysts of dinoflagellates (Family Calciodinelloidea Deflandre), having some similarity to the Cretaceous genus *Alasphaera* (Keupp, 1979a, b; Spezzaferri and Rögl, 2004, p. 148, pl. 2; Kohring *et al.*, 2005, figures 3-6).

Keupp (1979b, abb.2-7) illustrates *Alasphaera caudata* in both external view and cross section (Keupp, 1979b, abb.1) and it is the wall structure that is critical in the determination of both the genus and the group in general (see, for example, Kohring *et al.*, 2005, figure 1). The hollow cavity is encased in a multi-layer, calcite wall that is ornamented by distinctive irregular prolongations with rough ends. In our material we have observed a slightly complex calcite wall but specimens frequently shatter during sectioning. We have, therefore, been unsuccessful in confirming the presence of an *Alasphaera*-like wall structure.

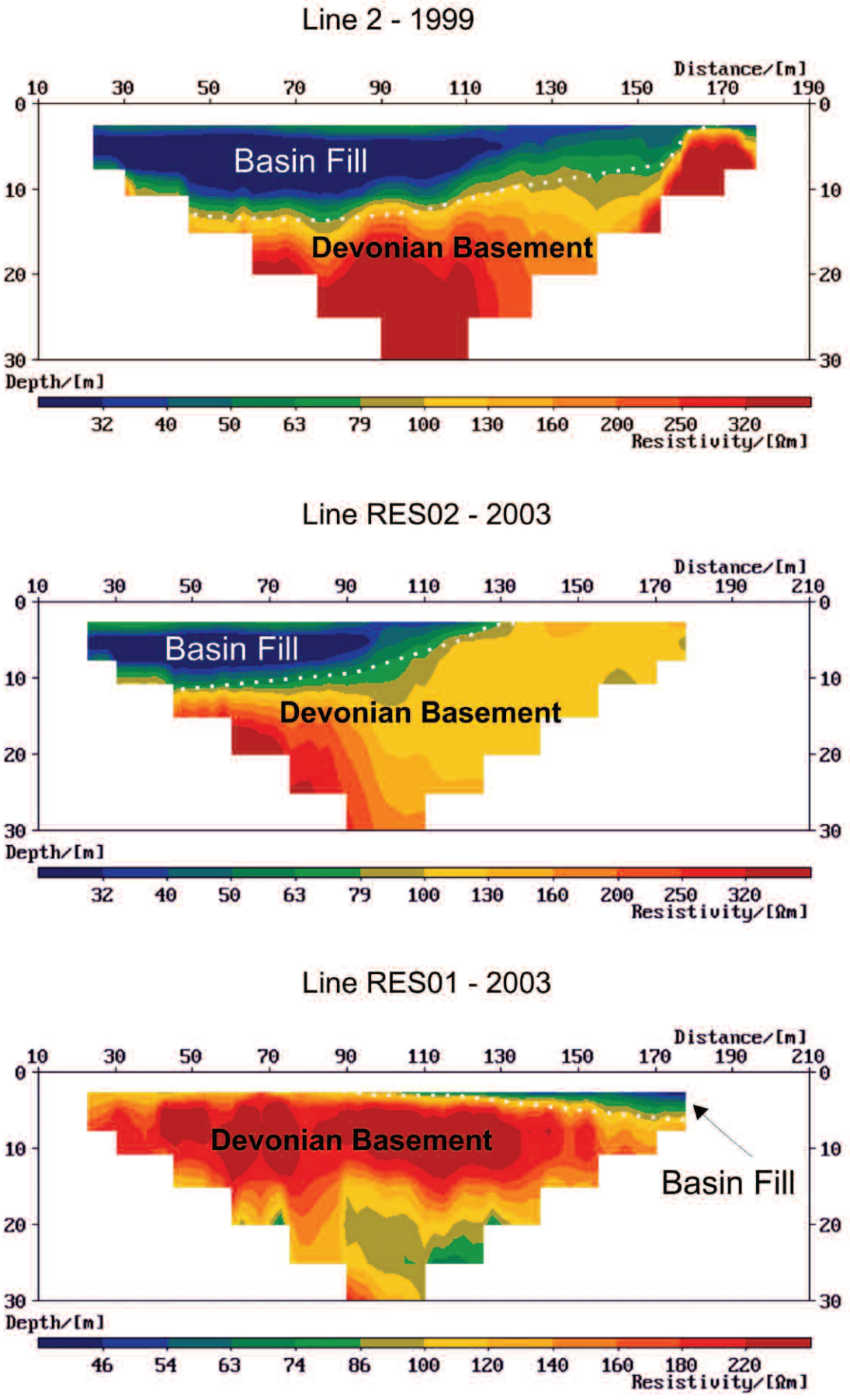

Figure 4. *The three resistivity profiles: (a) Line 2 from the 1999 survey and published in Roe* et al. *(1999); (b) RES02 on Figure 2; (c) RES01 on Figure 3. The lines of white dots in each of the profiles marks the possible base of the sedimentary cover.*

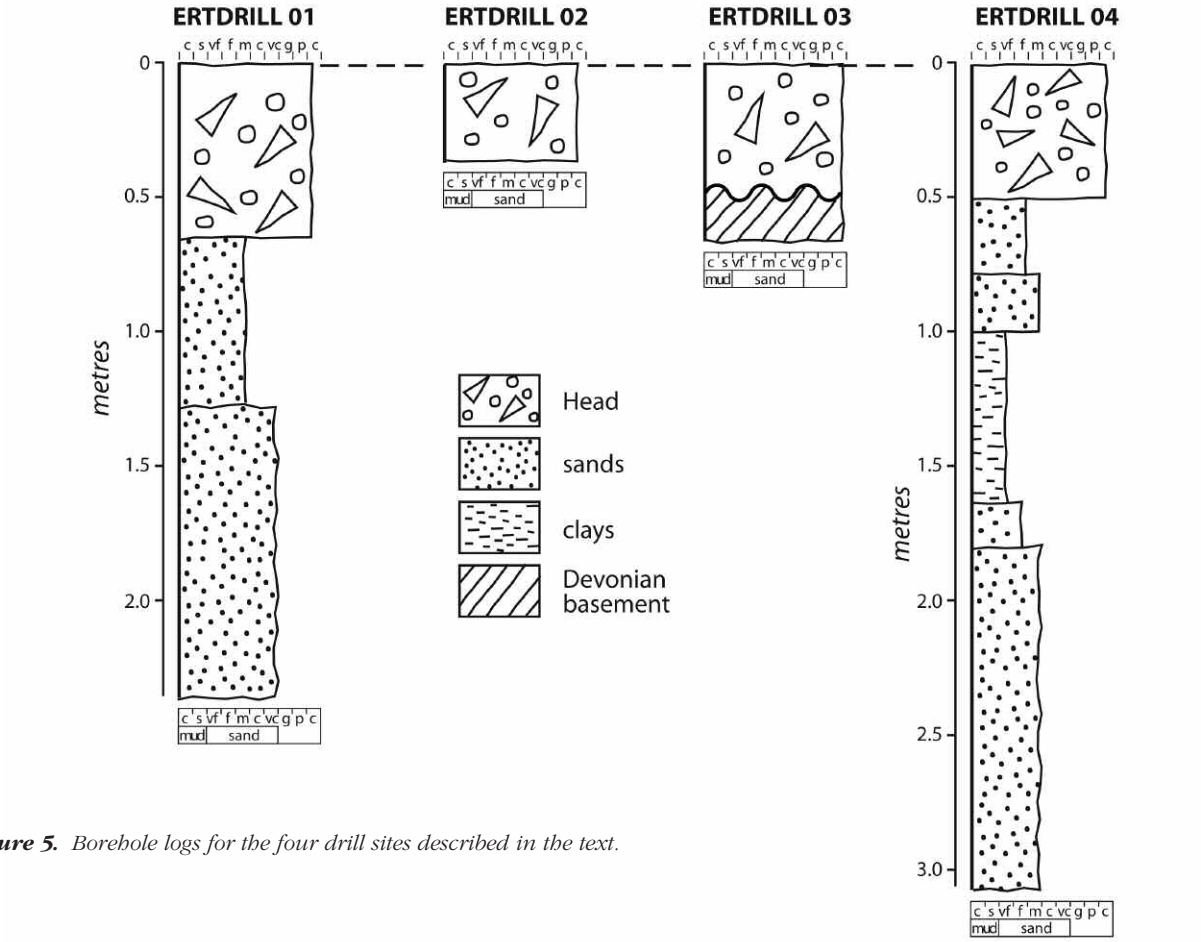

Figure 5. *Borehole logs for the four drill sites described in the text.*

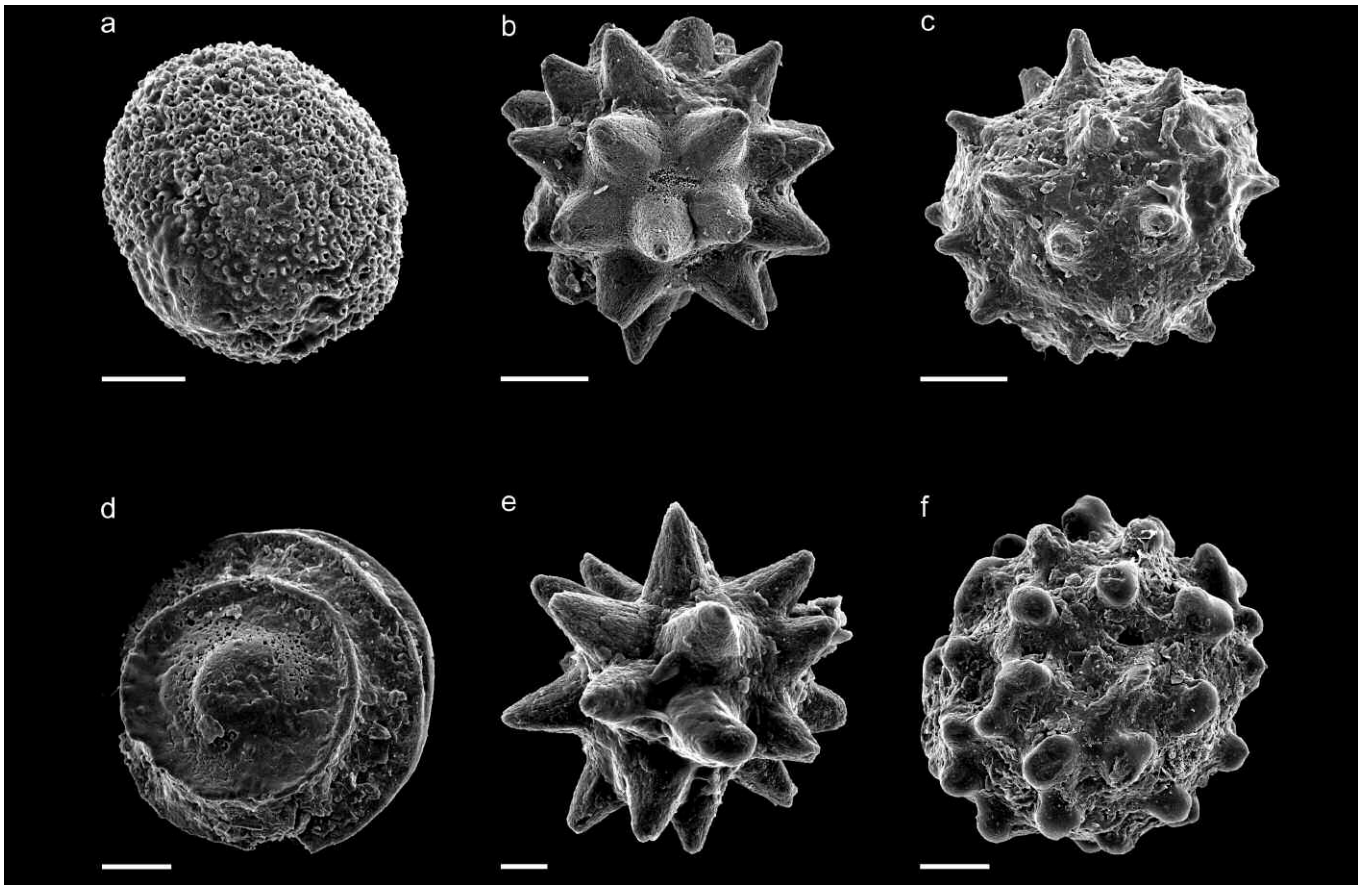

Figure 6. *Examples of the unusual microfossils that have been compared with the bolboformids and the calcareous cysts of dinoflagellates. (**a**) form similar to a Cretaceous pithonellid; (**b,c,e,f**) unknown taxa that may be the calcareous cysts of dinoflagellates related to* Alasphaera *spp.; (**d**) unknown taxon with concentric ornament. All scale bars are 20 µm except (e) which is 10 µm.*

Summary

The "St Erth Sand Pits" Site of Special Scientific Interest has been investigated using a combination of geophysical surveys, drilling and laboratory work on the microfauna. While the old pits are now a valuable local nature reserve, it is clear that the remaining geological interest lies outside the present boundaries of the designated site. Further work would be required to delineate the precise extent of the Pliocene sediments. Samples of the marine clays continue to yield exceptionally diverse and well-preserved assemblages of foraminifera and ostracods. The clays also contain an abundant and diverse assemblage of unusual microfossils that bear an external similarity to bolboformids, but which may be better classified as members of the Family Calciodinelloidea Deflandre (1948).

Acknowledgements

The authors wish to thank English Nature (Cornwall & Isles of Scilly Team) for permission to work on this Site of Special Scientific Interest and the farmers for allowing access. Dr John Whittaker (Natural History Museum, London) provided access to the Collections of F.W. Millett while Silvia Spezzaferri (University of Fribourg, Switzerland) and Penelope Cook (University of Waikato, New Zealand) gave invaluable advice on the bolboformids and related taxa. Bob Morgan and Gus Williams (Camborne School of Mines) assisted with the coring. Peter Bond assisted in the preparation of Figure 6.

References

BELL, R.G. 1887a. The Pliocene Beds of St. Erth. *Transactions of the Royal Geological Society of Cornwall*, **11**, 45-50.

BELL, R.G. 1887b. The Pliocene Beds of St. Erth, Cornwall. *Reports of the British Association for the Advancement of Science*, 718-719.

BELL, R.G. 1887-1888. Excursion to Cornwall. *Proceedings of the Geologists' Association*, **10**, 196-216.

BELL, A. 1898. On the Pliocene shell-beds at St. Erth. *Transactions of the Royal Geological Society of Cornwall*, **12**, 111-166.

CULLINGFORD, R.A. 1982. The Quaternary. In: DURRANCE, E.M. and LAMING, D.J.C. (eds), *The Geology of Devon*. Exeter University Press, Exeter, 249-290.

CRUNDWELL, M.P., COOKE, P.J., NELSON, C.S. and SPIEGLER, D. 2005. Intraspecific morphological variation in late Miocene *Bolboforma*, and implications for their classification, ecology and biostratigraphic utility. *Marine Micropalaeontology*, **56**, 161-176.

DEFLANDRE, G. 1948. Les Calciodinelloidée Dinoflagellés à thèque calcaire. *Botanist*, **34**, 191-219.

HEAD, M.J. 1993. Dinoflagellates, sporomorphs and other palynomorphs from the Upper Pliocene St. Erth Beds of Cornwall, Southwestern England. *Journal of Paleontology*, **67**, Supplement to No.3, The Paleontological Society, Memoir, 31, 62pp.

JENKINS, D.G. 1982. The age and palaeoecology of the St. Erth Beds, southern England based on planktonic foraminifera. *Geological Magazine*, **119**, 201-205.

JENKINS, D.G., CURRY, D., FUNNELL, B.N. and WHITTAKER, J.E. 1988. Planktonic foraminifera from the Pliocene Coralline Crag of Suffolk, Eastern England. *Journal of Micropalaeontology*, **7**, 1-10.

JENKINS, D.G., KING, C. and HUGHES, M. 1989. Neogene. In: JENKINS, D.G. and MURRAY, J.W. (eds), *Stratigraphical Atlas of Fossil Foraminifera* [2nd Edition], Ellis Horwood, Chichester, 537-562.

JENKINS, D.G., WHITTAKER, J.E. and CARLTON, R. 1986. On the age and correlation of the St Erth Beds, S.W. England, based on planktonic foraminifera. *Journal of Micropalaeontology*, **5**, 93-105.

JOHNSON, J.P. 1903. Notes on fossil and Recent shells obtained on a visit to Cornwall. *Geological Magazine*, **10**, 25-28.

KENDALL, F.P. and BELL, R.G. 1886. On the Pliocene Beds of St. Erth. *Quarterly Journal of the Geological Society, London*, **42**, 201-215.

KEUPP, H. 1979a. Lower Cretaceous Calcisphaerulidae and their relationship to calcareous dinoflagellate cysts. *Bulletin Centre Recherche Exploration-Production Elf-Aquitaine*, **32**, 651-663.

KEUPP, H. 1979b. *Alasphaera caudata* n.g.n.sp., eine neue Calciodinelloidea aus Der Unterkreide (Hauterivium) Nordwestdeutschlands. *Neues Jahrbuch Geologie und Paläontologie, Mh.*, **5**, 284-290.

KOHRING, R., GOTTSCHLING, M. and KEUPP, H. 2005. Examples for character traits and palaeoecological significance of calcareous dinoflagellates. *Paläontologische Zeitschrift*, **79**, 79-91.

KING, C. 1983. Cainozoic micropalaeontological biostratigraphy of the North Sea. *Institute of Geological Sciences, Report*, **82/7**, 1-40.

MACKENSEN, A. and SPIEGLER, D. 1992. Middle Eocene to Early Pliocene *Bolboforma* (Algae?) from the Kerguelen Plateau, Southern Indian Ocean. In: WISE, S.W., SCHLICH, R. *et al., Proceedings of the Ocean Drilling Program, Scientific Results*, **120**, College Station, TX (Ocean Drilling Program), 675-682.

MILLETT, F.W. 1886a. Notes on the fossil foraminifera of the St. Erth Clay pits. *Transactions of the Royal Geological Society of Cornwall*, **10**, 213-216.

MILLETT, F.W. 1886b. Additional notes on the foraminifera of St. Erth Clay. *Transactions of the Royal Geological Society of Cornwall*, **10**, 221-226.

MILLETT, F.W. 1895. The foraminifera of the Pliocene beds of St. Erth. *Transactions of the Royal Geological Society of Cornwall*, **11**, 655-661.

MILLETT, F.W. 1897. The foraminifera of the Pliocene beds of St. Erth in relation to those of other deposits. *Transactions of the Royal Geological Society of Cornwall*, **12**, 43-46.

MILLETT, F.W. 1898. Additions to the list of foraminifera from the St. Erth Clay. *Transactions of the Royal Geological Society of Cornwall*, **12**, 174-176.

MILLETT, F.W. 1902. Notes on the Faujasinae of the Tertiary beds of St. Erth. *Transactions of the Royal Geological Society of Cornwall*, **12**, 719-720.

MILNER, H.B. 1922. The nature and origin of the Pliocene deposits of the County of Cornwall, and their bearing on the Pliocene geography of the South-West of England. *Quarterly Journal of the Geological Society of London*, **78**, 348-377.

MITCHELL, G.F. 1960. The Pleistocene history of the Irish Sea. *Advances in Science*, **17**, 313-325.

MITCHELL, G.F. 1966. The St. Erth Beds - an alternative explanation. *Proceedings of the Geologists' Association*, **76**, 345-366. [for 1965].

MITCHELL, G.F., CATT, J.A., WEIR, A.H., McMILLAN, N.F., MARGEREL, J.P. and WHATLEY, R.C. 1973. The Late Pliocene marine formation of St. Erth, Cornwall. *Philosophical Transactions of the Royal Society*, **B226**, 1-37.

MURRAY, J.W. 1984. Biostratigraphic value of *Bolboforma*, Leg 81, Rockall Plateau. In: ROBERTS, D.G., SCHNITKER, D. *et al., Initiual Reports of the Deep Sea Drilling Project*, **81**, Washington (U.S.Government Printing Office), 535-539.

MURRAY, J.W. 1986. *Bolboforma* from North Atlantic Sites, Deep Sea Drilling Project Leg 94. In: RUDDIMAN, W.F., KIDD, R.B., THOMAS, E. *et al., Initial Reports of the Deep Sea Drilling Project*, **94**, U.S. Government, 813-814.

REID, C. 1890. *The Pliocene Deposits of Britain*. Memoirs of the Geological Survey of the United Kingdom, HMSO, London, 326pp.

ROE, L., HART, M.B., TAYLOR, G.K. and MARKS, A. 1999. The St Erth Formation: History of the clay workings, geological setting and stratigraphy. *Proceedings of the Ussher Society*, **9**, 304-309.

SPEZZAFERRI, S. and RÖGL, F. 2004. *Bolboforma* (Phytoplankton Incertae Sedis), *Bachmayerella* and other Calciodinelloidea (Phytoplankton) from the Middle Miocene of the Alpine-Carpathian Foredeep (Central Paratethys). *Journal of Micropalaeontology*, **23**, 139-152.

SPIEGLER, D. and SPEZZAFERRI, S. 2005. *Bolboforma* – an overview. *Paläontologische Zeitschrift*, **79**, 167-181.

SPIEGLER, D. and VON DANIELS, C.H. 1991. A stratigraphic and taxonomic atlas of *Bolboforma* (Protophytes, Incertae sedis, Tertiary). *Journal of Foraminiferal Research*, **21**, 126-158.

WHITLEY, N. 1882. The evidence of glacial action in Cornwall and Devon. *Transactions of the Royal Geological Society of Cornwall*, **10**, 132-141.

WOOD, S.V. Jr. 1885. On a new deposit of Pliocene age at St. Erth, near the Land's End, Cornwall. *Quarterly Journal of the Geological Society of London*, **41**, 67-73.