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MULTI-PROXY ANALYSIS OF A LATE HOLOCENE SEDIMENT CORE FROM SWANPOOL, FALMOUTH, CORNWALL.

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Microfossil (diatoms, palynomorphs), inorganic chemical and mineral magnetic analysis of a 4.5 m sediment core from the deepest part of Swanpool, Falmouth indicates that a sharp contact between oxidised brown laminated clays, and overlying black, anoxic laminated muds, records the change in lake physics, chemistry and ecology which followed lowering of lake level and connection to the sea in 1826. At the contact, marked changes in the subfossil diatom flora, in favour of taxa more tolerant of increased salinity, and an increase above the contact in authigenic phosphorus concentration, and a corresponding decrease in biogenic silica, occur. Changes in pollen stratigraphy indicate a decline in both frequency and concentration of arboreal taxa and grasses, and an increase in species of open, maritime habitat.

Impact of mining upon Swanpool may be seen in peaks in sedimentary IRM/x and heavy metal concentrations which occur mainly above the clay/mud contact. Although Swanpool mine was operational for about a century, its most active phase took place during the 1850s. In the deeper parts of the core, there are indications of other events, in the form of changes in the subfossil diatom flora and in frequencies of *Myriophyllum* pollen, which may be associated with marine influence on what was then essentially a body of fresh water. In the topmost sediments, concentrations of sedimentary authigenic phosphorus increase, as a result of remobilisation of the element owing to deoxygenation of the sediment water interface (SWI) after connection of the pool to the sea. Further variations in the diatom flora take place, and the curve for *Pinus* pollen expands, perhaps owing to planting of ornamental trees in nearby Falmouth.

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INTRODUCTION

The research described in this paper is part of a project begun in 1997, the ultimate aim of which is to test whether a signal of rising sea level around the coasts of Southwest Britain may be identified for recent decades using fine resolution microfossil and other multi-proxy studies of sediments of a set coastal lakes and lagoons (Loe Pool, Swanpool [Cornwall], Slapton Ley [Devon], the Fleet [Dorset], Bosherston Lakes [Dyfed]). The time interval selected for the study is the last two millennia, and analogues for modern sea level rise are being sought amongst sediments deposited over that period initially by studying the signal of known rapid changes *(cf* Dawson & Foster, 1995). These features will then be used in order to characterise events identified earlier in the sedimentary record, and eventually to test whether the most recent sediments of bodies still open to the sea (i.e. Swanpool, the Fleet), are currently recording an increase in marine influence.

Swanpool is of particular importance to this study, as the site is known to have been connected artificially to the sea at a specific date. The sedimentary record of this change is therefore a valuable source of information with which to interpret the signal of other episodes of unknown provenance. In addition, like Loe Pool, Swanpool has also been affected by inputs of mine waste, so that its sediments also offer the opportunity to discriminate between the effects of that process, and a documented connection to the sea.

SITE DESCRIPTION

Swanpool (Figure 1) is a mixo-oligohaline lagoon 1 km south of Falmouth whose hydrology, chemistry and limnology were extensively investigated during the 1970s (Barnes *et al.,* 1971; Crawford *et al.,* 1979; Dorey *et al.,* 1973; Little *et al.,* 1973). Details of its hydrology, morphometry and physical limnology are given in Table 1. The pool is unusual amongst UK lakes in that it is brackish, and possesses a halocline, overlying a body of saline, generally anoxic hypolimnetic water.

Property/determinand	Value
Area (A)	5.5 ha
Maximum depth (z_{max})	3 m
Altitude (above OD)	5.06 m
Catchment area (D)	3.26 km^2
Hydraulic residence time (τ_w)	9-14 days
Chlorinity residence time (τ_{chlor})	35-50 days
Mean chlorinity	1.6 ‰
surface	0.2 - 4 ‰
deep waters	6.5 - 10 ‰
Mean salinity	2 ‰
surface	0.2 - 7 ‰

Table 1. *Swanpool - morphometry, hydrology and physical limnology.*

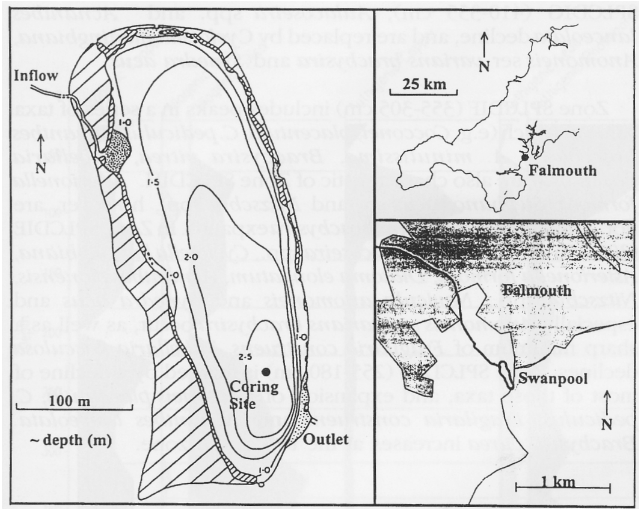

Figure 1. *Swanpool and its location*

The surface of the pool is located only 5.06 m above OD, and therefore 0.25 m *below* mean High Water Mark Spring Tide (HWMST). Consequently, during episodes of high (spring) tide, seawater flows into the pool, and increases its salinity beyond that of normal fresh waters (Table 1). Surface salinity is therefore greatest during spring and autumn, and lowest during summer and winter. Salinity of deeper waters varies on a more complex basis, but, as a result, Swanpool, remains more or less permanently stratified, with salinity as the cause rather than temperature (Dorey *et al.,* 1973).

Swanpool, especially during summer, is eutrophic, with mean July PO_4-P concentration of 1.8 1^{-1} mg (Crawford *et al.,* 1979). Concentrations in the hypolimnion are higher (12 mg l^{-1}). Commonly recorded planktonic algae include *Anabaena spiroides, Oscillatoria* sp, *Ankistrodesmus gracilis,* six species of *Scenedesmus, Chaetoceros muellerii, Cyclotella meninghiana, Diatoma elongatum, Fragilaria crotonensis,* and *Thalassiosira pseudonana.* The most abundant species is the dinoflagellate *Gyrodinium resplendens,* which forms periodic blooms. Most phytoplankton production occurs between June and December.

The catchment of Swanpool covers 3.26 km', and is 62% urban, 24% grassland, 12% rural non-agricultural, and 2% arable (Data collected by Applied Hydroecology, Stage 3, BSc Environmental Science, University of Plymouth, 1995, under supervision of PEO'S). The pool (Figure 1) itself is now almost surrounded by an urban area, and as well as inflow from its principal tributary, receives water from storm drains which are now the source of its principal nutrient loading.

HISTORY

Swanpool possesses a history associated with lowering of lake level, connection, to the sea, and mining (Little *et al.,* 1973). The pool is shown in Burghley's Map of 1580, and has therefore been in existence since at least that time. It is also mentioned by Leland ([1538-1543], in Chope, 1918), who describes it as 'barred by a bank of sand' and who states that at the time it was known as *Lewine Prisklo* (or Lewine pool), its Cornish name. In 1826, the tunnel which today still connects Swanpool to the sea was built, and lake level lowered. Lake area (A) was reduced from *ca* 10 to the present 5.5 ha. It is thought that before this time, the pool was fresh, and somewhat deeper than today.

According to Hooper (1932), Swanpool Mine, located at the south-west end of the pool, was very ancient, but was most active from 1790 until 1860. Between 1854 and the latter date it yielded some 6000 t of lead ore, very rich in silver (Dines, 1956). In 1856, lead and arsenic smelters were also built on the shore of the pool, or just to the south, but these closed a few years later. Other mines may well have been active in the area during the late C18th, the C19th and early C20th. During the 1960s, the south end of the pool was filled in and made into a car park.

METHODS

A 4.5 m sediment core was collected from the deepest part of Swanpool (Figure 1) in October 1996, using a 'Russian' peat corer (Jowsey, 1966) operated from a raft. Sections were wrapped in foil and plastic sheeting, and stored at 5°C. Samples for microfossil, chemical and mineral magnetic analysis were obtained by removing continuous 25 cm segments, generating a suite of eighteen subsamples. Extracts for diatom and pollen analysis (Figures 2 and 3) were obtained by the procedures described, respectively, in Battarbee (1986), and Moore, Webb and Collinson (1991). Results are expressed either as % total diatom frustules (Figure 2), or, because the extracts also contained *Pediastrum,* % total palynomorphs (Figure 3).

Solutions for sequential inorganic chemical analysis (Figure 4) were obtained using the fractionation procedure described by Engstrom and Wright (1984), according to which it is possible to distinguish between three major components of the sediment, the *authigenic, biogenic,* and *allogenic* fractions. The authigenic component is fixed by chemical precipitation and flocculation *in the lake water column,* and consists of the most mobile (usually ionic) form of each element present, often adsorbed onto particles of clay, humus or other substances as ligands. Biogenic material is, in contrast, fixed by organisms, and therefore records mainly the history of the biota of the lake and its watershed. Allogenic material is minerogenic, and consists largely of matter in crystalline form. As opposed to the authigenic component, which despite its ultimate terrestrial source, refers mainly to changes in lake physics and chemistry, the allogenic fraction constitutes a record of events taking place in the catchment. Concentrations were determined by AAS using a GBC 902 Flame Atomic Absorption Spectrophotometer calibrated with a range of standards for each element.

Mineral magnetic measurements (Figure 5) were performed on samples obtained by drying at 40°C, and then packing material either into Aslon bottles for determination of single sample magnetic susceptibility [χ] using a Bartington Susceptibility Meter MS1E), or plastic cubes for determination of Isothermal Remanent Magnetisation using a MOLSPIN pulse magnetiser and a MOLSPIN fluxgate spinning magnetometer (Thompson and Oldfield, 1986). All microfossil, chemical and mineral magnetic data were processed using the program TILIA (Grimm, 1991, 1992), which enables stratigraphic zonation of sediment profiles via techniques such as CONISS (Constrained **I**ncremental **S**um of **S**quares cluster analysis; Grimm, 1987).

RESULTS

Stratigraphy

Details of the stratigraphy of the core employed in the microfossil, chemical and mineral magnetic analyses described in this paper are given in Table 2. Comparison with the logs of other cores recovered at the same time indicates that this example is typical of the recent sediments of Swanpool. The most marked stratigraphic horizon occurs at *ca* 150 cm, where a sharp transition from black, and then grey/black deoxygenated clay-rich lake mud (FeS *gyttja),* to grey/brown and olive brown, oxygenated, clay-rich lake mud *(clay- gyttja),* takes place.

Diatom analyses (Figure 2)

The core was divided into eight diatom assemblage zones (SPLCDI [**S**wanpool **l**ong **c**ore **d**iatom] A-H) on the basis of the CONISS performed by TILIA. Zone SPLCDIH (450-410 cm) is characterised by a mixed assemblage in which *Aulacoseira* spp., *Fragilaria construens, F. pinnata, Acnanthes lanceolata, Eunotia pectinalis,* and *Tabellaria flocculosa* are the main taxa present, denoting the presence of a shallow, freshwater lake. In Zone SPLCDIG

Swanpool Core 2,	Water depth 3 m, Transparency (SDT) 1 m
27.10.1996	
Unit length (cm)	Description
0-35	Sediment too wet to sample using 'Russian' corer
35-50	Black, sloppy clay/mud smelling strongly of H_2S
50-119	Black and grey banded clay/mud with finer laminations
119-150	Grey/black strongly laminated clay/mud
150-200	Grey/brown faintly laminated lake mud. Coarse silver
	sandy layer at 192
200-265	Olive brown lake mud. Shelly layer with sand at 247
265-337	Paler olive lake mud becoming more grey below 300.
337-350	Woody, fibrous layer
350-400	Olive brown faintly laminated lake mud with plant fibres
400-450	Olive brown faintly laminated lake mud

Table 2. *Stratigraphic log of Swanpool 4.5 m core 2*

SPLCDIG (410-355 cm), *Aulacoseira* spp. and *Acnanthes lanceolata* decline, and are replaced by *Cyclotella meninghiana, Anomoneis* ser *varians brachysira* and *Synedra acus.*

Zone SPLCDIF (355-305 cm) includes peaks in a series of taxa some of which (e.g. *Cocconeisplacentula, C pediculus, Acnanthes lanceolata, A. minutissima, Brachysira vitrea, Tabellaria flocculosa)* are also characteristic of Zone SPLCDIH. *Asterionella formosa, Stephanodiscus* sp. and *Nitzschia* spp., however, are not. *Anomoneis* ser *varians brach ysira* expands. In Zone SPLCDIE (305-255 cm), peaks in *Aulacoseira* spp *Cyclotella kutzinghiana, Asterionella formosa, Diatoma elongatum, Acnanthes plonensis, Nitzschia* spp *Navicula anomoneis* and *Synedra acus* and especially *Anomoneis* ser *varians brachysira* occur, as well as a sharp minimum of *Fragilaria construens. Tabellaria flocculosa* declines. Zone SPLCDID (255-180 cm) is marked by a decline of most of those taxa, and expansion of *Cocconeis placentula, C. pediculus, Fragilaria construens* and *Acnanthes lanceolata. Brachysira vitrea* increases at the top of the zone.

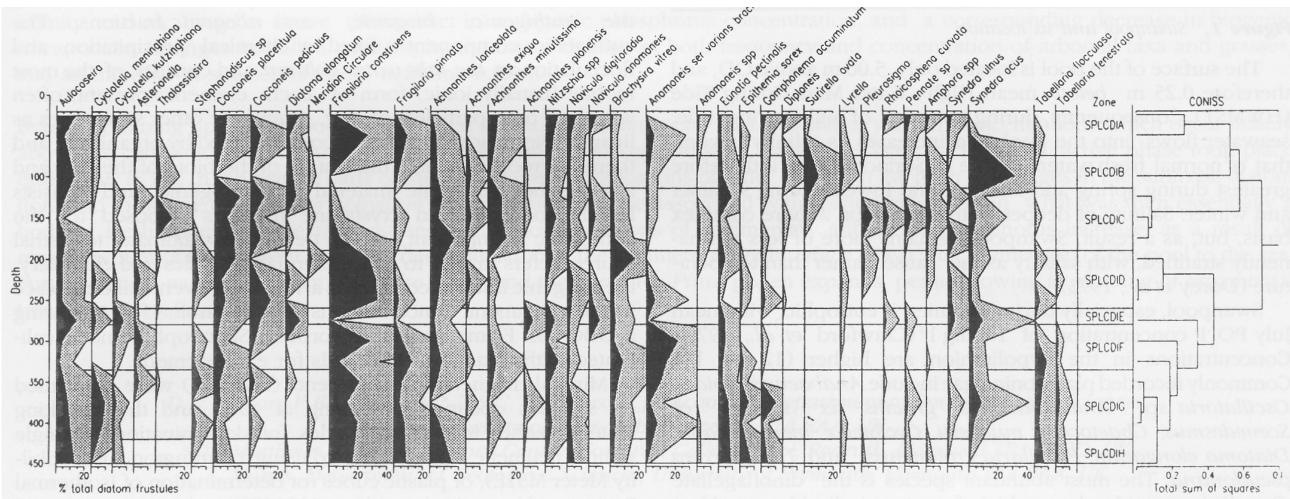

Figure 2 - Diatom analysis of a 4.5 m core from Swanpool (analyst: D.Henon)

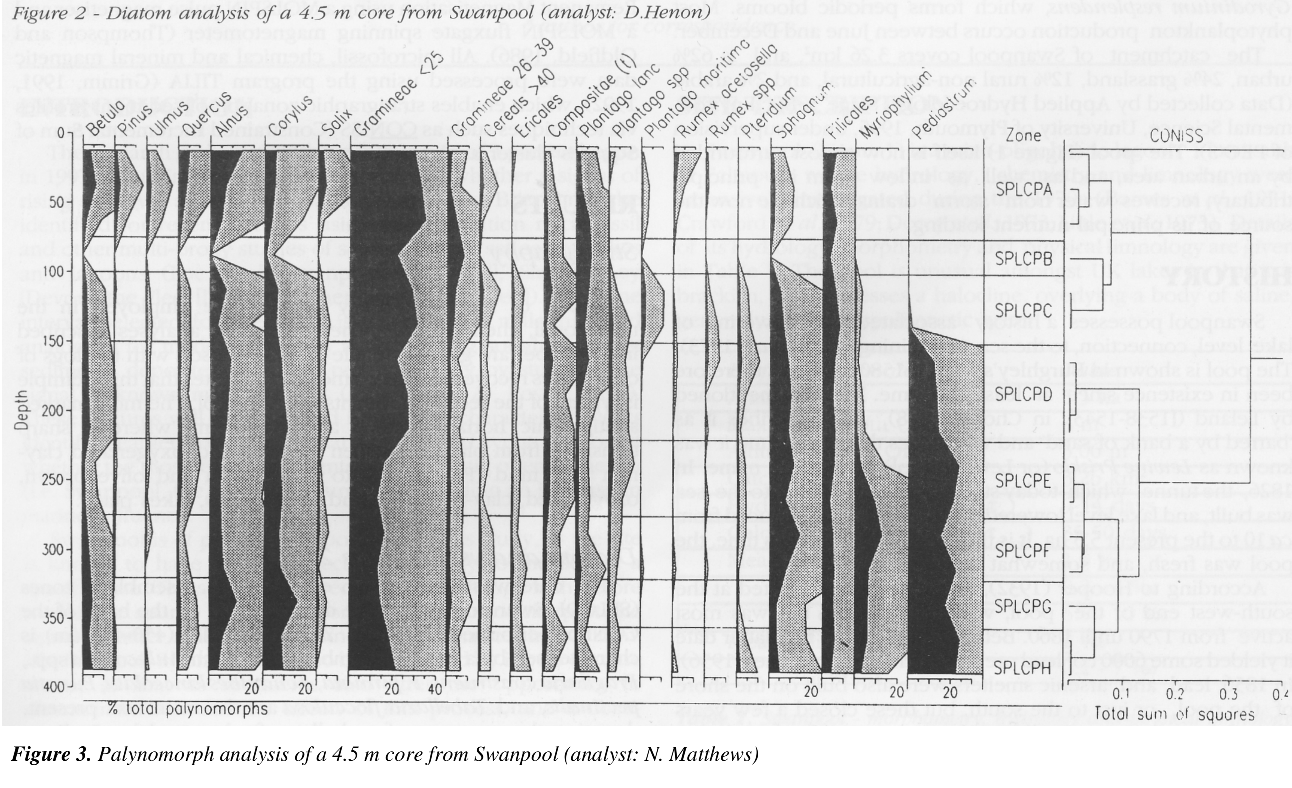

Figure 3. *Palynomorph analysis of a 4.5 m core from Swanpool (analyst: N. Matthews)*

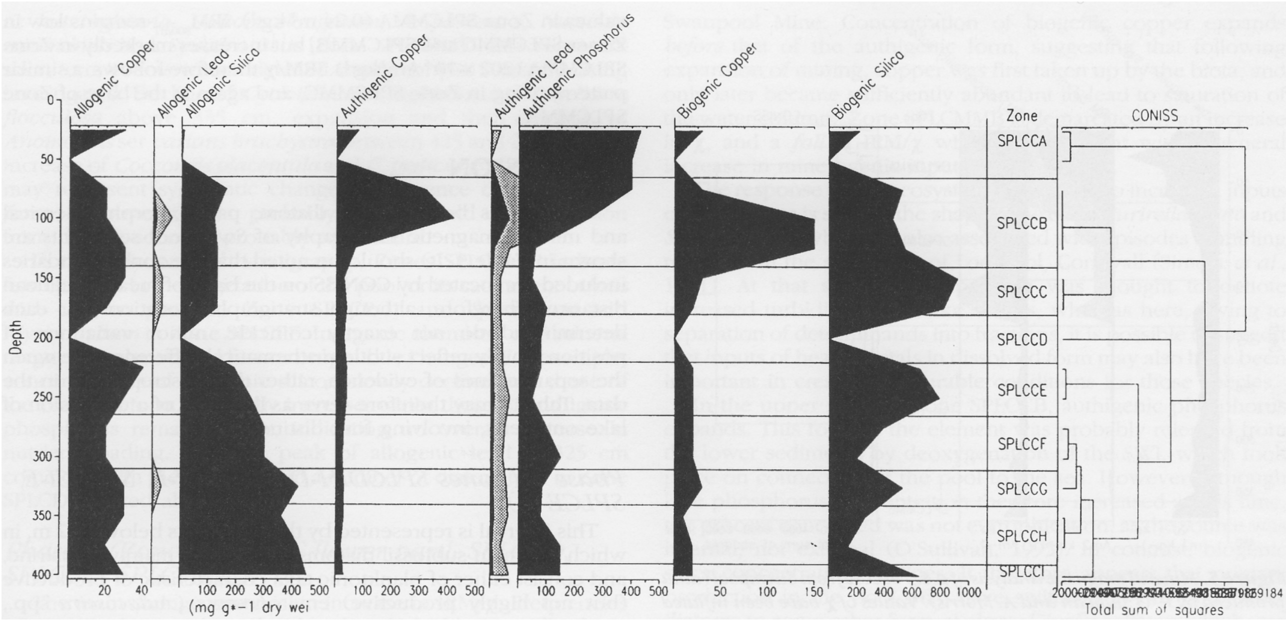

Figure 4. *Sequential inorganic chemical analysis of a 4.5m core from Swanpool (data collected by T. S. C. Williams and P. E. O'Sullivan)*

Zone SPLCDIC (180-120 cm) contains (at 150 cm) the sharp stratigraphic change from brown *clay-gyttja* to black FeS *gyttja* denoting connection of Swanpool to the sea in 1826. Frequencies of *Thalassiosira pseudonana,* a marine species, reach a maximum, along with those of *Cocconeis placentula, Acnanthes lanceolata, A. minutissima, Pleurosigma elongatum, Rhoicosphenia curvata* and an as yet unidentified pennate taxon. In Zone SPLCDIB (120-60 cm), *Aulacoseira* spp., *Diatoma elongatum* and *Eunotia pectinalis expand,* and *Synedra acus* and *Surirella ovata* reach maxima. Both species of *Cocconeis* decline. In Zone SPLCDIA (60-0 cm), *Aulacoseira* spp., *Cocconeis placentula, Diatoma elongatum, Fragilaria construens, F. pinnata* and *Acnanthes minutissima* recover, along with minor taxa such as *Nitzschia* sp., two species of *Navicula, Gomphonema accuminatum* and *Rhoicosphenia curvata.*

Palynology (Figure 3)

Eight assemblage zones (SPLCPH-A) were also used to describe palynomorph stratigraphy (Figure 3). As well as selected terrestrial and wetland pollen and spore taxa, the diagram also presents counts of spores of the freshwater green alga, *Pediastrum.* The variations recorded throughout the diagram are subtle, and denote basically a landscape in which few major vegetation changes have occurred during the period represented by the core. Trees and shrubs (mainly *Betula, Alnus,* and *Corylus)* generally contribute < 40% of total palynomorphs.

In Zone SPLCPH (380-360 cm), the main taxa present are Gramineae < 25 µm (which in this environment, is probably mostly *Phragmites australis)* and *Pediastrum.* In Zone SPLCPG (360-320 cm) *Alnus* and *Corylus* expand slightly. In Zone SPLCPF (320-265 cm), these are replaced by *Sphagnum* and *Myriophyllum,* the second of which then decreases somewhat in Zone SPLCPE (265-220 cm).

Gramineae < 25 µm expands, and *Myriophyllum* and *Pediastrum* decline in Zone SPLCPD (220-150 cm), the former now to very low values. In Zone SPLCPC (150-100 cm), frequencies of a range of taxa, including Cerealia (Gramineae > 40 µm), Compositae (subsect.) Tubuliflorae, *Plantago lanceolata, P. maritima, Rumex,* and *Pteridium* increase, whilst those of *Sphagnum* gradually decline. Spores of *Pediastrum,* present throughout Zones SPLCPH-D, disappear from the record.

In Zone SPLCPB (100-60 cm), tree and shrub pollen decline very low and Gramineae 26-39 µm (mainly meadow grasses) expands, as does *Plantago lanceolata.* Several taxa represented in Zone SPLCPC (Cerealia, Ericales, Compositae: Tubuliflorae, *Plantago lanceolata, P. maritima, Rumex* spp, *Pteridium* and especially *Sphagnum),* also decline very low. In Zone SPLCPA, tree and shrub pollen (mainly *Alnus,* but also including *Pinus)* expands, and *Sphagnum* recovers. *Plantago lanceolata* declines and small amounts of Cerealia and *Rumex acetosella* occur at the top of the section.

Sediment Chemistry (Figure 4)

As explained above, inorganic chemistry of the core was studied using the protocol of Engstrom and Wright (1984), based on sequential extraction of three components, the authigenic, the biogenic, and the allogenic fractions. Broadly, these *all* consist of material which originates ultimately in the catchment of a lake, but the first two are *fixed* by, and therefore refer, respectively, to (a) the chemistry of the lake water column, and (b) the lake biota. Allogenic material occurs in crystalline in form, and is produced by the soils, rocks and subsoils of the catchment. Results (selected determinands only), are shown in Figure 4. Data are expressed in concentration only, so that all values are susceptible to perturbation by influx of other material. Nine zones (SPLCCIA) are defined as follows.

Zone SPLCCI (390-400 cm) represents only a single sample, in which both allogenic and biogenic silicon concentrations exceed 400 mg g^{-1}. In Zone SPLCCH (390-340 cm), the latter declines, but in Zone SPLCCG (340-310 cm) reaches a maximum, accompanied by a peak in allogenic silicon, and small amount (< 5 mg g^{-1}) of allogenic lead. In Zone SPLCCF (310-260 cm), allogenic silicon declines, and biogenic silicon expands, to reach a maximum in Zone SPLCCE (260-220 cm). At the top of that zone, a maximum in allogenic copper occurs. In Zone SPLCCD (220-180 cm) concentrations of allogenic copper and silicon, and of biogenic silicon, fall very low. Small amounts of allogenic lead are again recorded in Zone SPLCCC (180-140 cm), and biogenic silicon reaches maximum values (> 800 mg g^{-1}).

In Zone SPLCCB (140-60 cm), substantial peaks occur first in biogenic (150 mg g^{-1}) and then in authigenic copper (3-400 mg g^{-1}) and in biogenic silicon. Low concentrations of allogenic lead are again recorded, and also a peak *(ca* 20 mg g^{-1}) in authigenic lead. Concentrations of authigenic phosphorus rise from 130 cm upwards. In Zone SPLCCA, concentrations of allogenic copper and silicon, authigenic copper and lead, and biogenic copper and silicon fall, but those of authigenic phosphorus expand beyond 400 mg *g-'.*

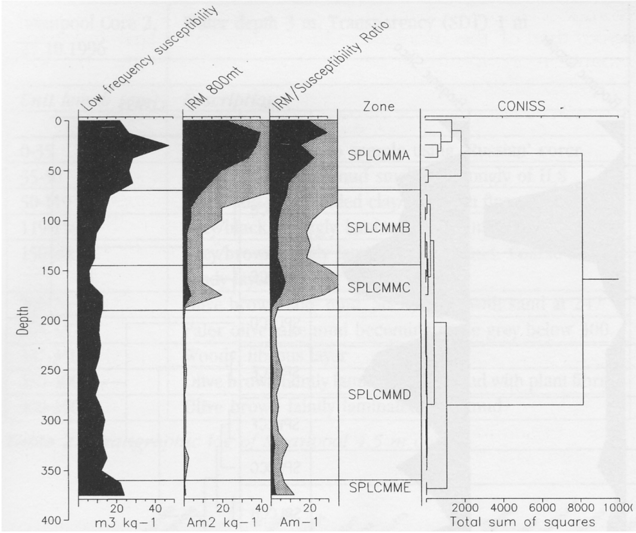

***Figure 5.** Mineral magnetic analysis of a 4.5 m corefrom Swanpool (data produced by P. O'Sullivan and A. Morris). Values of χ have been inflated by a factor of x20, IRMs by 2x 10^3, and IRM/x by x20, in order to illustrate trends using TILIA.*

Mineral magnetic analyses (Figure 5)

The section was divided into five zones (SPLCMME-A) In Zone SPLCMME, low frequency mass specific magnetic susceptibility (χ, Thompson and Oldfield, 1986) is low (*ca* 0.1 $m^3\ kg^{-1}$), as is IRM_{800mT} (15 x 10^{-5} $Am^2\ kg^{-1}$) and IRM/x (<1.5 x 10^{-3} Am^{-1}). These determinands then fall even lower in Zone SPLCMMC, but IRM/χ then rises in Zone SPLCMMC as IRM_{800mT} increases slightly and χ falls. χ then rises in Zone SPLCMMB, reaching maximum values in Zone SPLCMMA (0.24 $m^3\ kg^{-1}$). IRM_{800mT} remains low in Zones SPLCMMC and SPLCMMB, but increases markedly in Zone SPLCMMA (202 x 10^{-5} $Am^2\ kg^{-1}$). IRM/χ therefore follows a similar pattern, rising in Zone SPLCMMC, and again at the base of Zone SPLCMMA.

DISCUSSION

Correlations between the diatom, palynomorph, chemical and mineral magnetic stratigraphy of Swanpool sediments are shown in Table 3. It) should be noted that the zone boundaries included are located by CONISS on the basis of mean Euclidean distance. Therefore, although stratigraphic locations for each determinand do not exactly coincide, minor variations of position mainly reflect subtle mathematical differences between the separate lines of evidence, rather than discrepancies in the data. Table 3 may therefore serve as the basis of a discussion of lake ontogeny, involving four distinct phases.

Phase 1 (Zones SPLCDIH-D, SPLCPH-E, SPLCCI-E, SPLCE-D)

This interval is represented by the sediments below *ca* 2 m, in which the main subfossil diatoms present are mainly lacustrine, and consist either of planktonic taxa characteristic of productive (but not highly productive) environments *(Aulacoseira* spp., *Cyclotella meninghiana),* or benthic, littoral or epiphytic species *(Fragilaria construens, F. pinnata, Acnanthes lanceolata, Anomoneisser varians brachysira, Eunotia pectinalis, Tabellaria flocculosa).* The assemblage is very similar to that recorded in the lower parts of the freshwater lacustrine sediments of Slapton Ley, Devon (Crabtree and Round, 1967; O'Sullivan *et al.,* 1991). It is therefore concluded that during this phase, Swanpool was a shallow, mildly productive, mainly freshwater lake, in which marine influence was not particularly strong.

Peaks in various groups of taxa (eg *Cyclotella meninghiana, Synedra acus* [Zone SPLCDIG], *Stephanodiscus* sp., *Nitzschia* spp., *Acnanthes minutissima, Brachysira vitrea* [Zone SPLCDIF],

Tentative Chronology (AD)	Depth (cm)	Diatoms (SPLCDI)	Palynomorphs (SPLCP)	Chemistry (SPLCC)	Mineral Magnetism (SPLCMM)
  1855 1826 1790	------50------ ------100------ ------150------ ------200------ ------250------ ------300------ ------350------ ------400------ ------450------	**A** - *Aulaocoseira* spp. - *Cocconeis placentula, C. pediculus - Diatoma elongatum - Fragilaria construens - F. pinnata - Acnanthes minutissima - Nitzschia* spp.- *Navicula* spp. ______75______ **B** - *Aulaocoseira* spp - *Diatoma elongatum - Surirella ovata - Synedra acus* ______115______ **C** - *Thalassiosira pseudonana - Cocconeis placentula - C. pediculus - Acnanthes lanceolata - A. minutissima - Pleurosigma elongatum - Rhoicosphenia curvata - Synedra ulnus* ------190------ **D** - *Cocconeis placentula - C. pediculus - Fragilaria construens - Brachysira vitrea* ------260------ **E** - *Aulacoseira* spp. - *Cyclotella kutzinghiana - Diatoma elongatum - Synedra acus* ------280------ **F** - *Fragilaria construens - Acnanthes lanceolata - Anomoneis* ser *varians brachysira - Tabellaria flocculosa* ------335------ **G** - *Aulaocoseira* spp - *Cyclotella meninghiana - Fragilaria construens - F. pinnata - Acnanthes* sp. - *Anomoneis* ser *varians brachysira - Synedra acus* ------420------ **H** - *Aulaocoseira* spp. - *Fragilaria construens - F. pinnata - Acnanthes lanceoloata - Eunotia* sp. - *Gomphonema acuminatum- Tabellaria flocculosa*	**A** - Gramineae < 25 µ - *Alnus - Corylus - Betula - Salix -Rumex* - Filicales ______75______ **B** - Gramineae < 25 µ - Gramineae 26-39 µ - *Plantago lanceolata* - Filicales ------100------ **C** - Gramineae < 25 µ - *Alnus - Corylus - Sphagnum - Plantago - Rumex* - Filicales ------150------ **D** - Gramineae < 25 µ - *Alnus - Corylus - Sphagnum - Pediastrum*- Filicales ------220------ **E** - Gramineae < 25 µ - *Sphagnum - Pteridium - Myriophyllum -Pediastrum* - Filicales ______275______ **F** - Gramineae < 25 µ - *Sphagnum - Myriophyllum - Pediastrum*- Filicales ------320------ **G** - *Alnus - Corylus* - Gramineae < 25 µ - *Pediastrum* - Filicales ______355______ **H** - Gramineae < 25 µ - *Corylus - Pediastrum* - Filicales ************************* *** = limit of analysis	**A** - high authigenic P ______65______ **B** - peak in allogenic Pb, authigenic Cu, Pb, biogenic Cu. Rising authigenic P ------140------ **C** - peak in allogenic Pb, biogenic Si ------180------ **D** - minimum in allogenic Cu, Si, biogenic Si ______2 20______ **E** - peak in allogenic Cu, biogenic Si ------ 265------ **F** - reduced allogenic Si ------310------ **G** - peak in allogenic Cu, Si, Pb, biogenic Si ------340------ **H** - high allogenic Si, Cu ------390------ **I** - high allogenic Si, Cu, biogenic Si ************************* *** = limit of analysis	**A** - high χ, IRM, χ/IRM ------70------ **B** - increasing χ ______145______ **C** - increased IRM, peak in χ/IRM ------ 190------ **D** - very low χ. IRM ------360------ **E** - low χ. IRM ************************* *** = limit of analysis

***Table 3.** Correlations between diatom, palynomorph, inorganoc chemical and mineral magnetic stratigraphy of Swanpool sediments.*

C. kutzinghiana, Diatom elongatum, A. plonensis, Navicula anomoneis and *Synedra acus* [Zone SPLCDIE]) may represent short term events whose detailed stratigraphy is currently being investigated. Decline of *Cyclotella meninghiana* and *Tabellaria flocculosa* above 335 cm, expansion and then decline of *Anomoneis* ser *varians brachysira* between 425 and 260 cm, and increase of *Cocconeis placentula* and *C. pediculus* above 260 cm, may represent systematic change. Occurrence of Asterionella formosa above 355 cm, probably denotes mild eutrophication from diffuse sources, probably agriculture.

In the palynomorph stratigraphy, Zones SPLCPH-F indicate few changes in the vegetation of the pool or its catchment. *Alnus* and *Corylus* peak in Zone SPLCPG, and *Sphagnum* and *Myriophyllum* in Zone SPLCPF. Inorganic chemistry and mineral magnetism also record few or only subtle changes. For example, concentrations of allogenic silicon slowly decline, and those of the biogenic form, gradually increase, whilst those of authigenic phosphorus remain steady, indicating no overall increase in nutrient loading. A minor peak of allogenic lead at 325 cm coincides with the maximum in a number of diatom taxa in Zone SPLCDIF noted above.

Phase 2 (Zones SPLCDIC [lower part], SPLCPD, SPLCCC, SPLCMMC).

The main change noted is an increase in IRM/χ. Frequencies of *Fragilaria construens*, the main subfossil diatom present below 2 m, fall very low, and are replaced by a range of taxa including mainly *Cocconeis placentula, C. pediculis, Acnanthes lanceolata* and *A. minutissima*. In the palynomorph stratigraphy, Gramineae < 25 µm expands, and *Myriophyllum* declines. Biogenic silicon concentration reaches a maximum.

The increase in IRM/χ is interpreted as indicating a change in sediment source, in favour of material with a greater 'haematite' (i.e. unweathered mineral) content (although it could theoretically also represent an increase in the proportion of fine, single domain [SD] magnetite). Parallel changes in diatom and palynomorph stratigraphy, especially the decline of *Myriophyllum*, may record the influence of this change on lake ecology. The peak in biogenic silicon concentration may denote an increase in productivity caused by a rise in input of minerogenic material (an example of *edaphic* eutrophication; O'Sullivan, 1995), but in the absence of influx data, this conclusion must remain preliminary.

Phase 3 (Zones SPLCDIC [upper part] and B, SPLCPC-B, SPLCCB, SPLCMMB).

In the middle of diatom zone SPLCDIC (at 150 cm), peaks occur in *Thalassiosira pseudonana, Nitzschia spp., Pleurosigma elongatum, Rhoicosphenia curvata*, and an as yet unidentified pennate taxon. We interpret this event, which coincides with the sharp contact between the brown freshwater clay-*gyttja*, and the overlying black FeS-*gyttja*, as indicating the initial influx of saline waters resulting from connection of the pool to the sea in 1826 AD. At the same horizon, *Pediastrum* spores disappear from the palynomorph record, again perhaps as a result of the consequent increase in salinity of the pool. Phase 3 therefore immediately post-dates this event, and includes the period of maximum activity of Swanpool Mine (1850-1860; Hooper, 1932).

Zone SPLCPC also contains a significantly increased local terrestrial palynomorph component, probably partly contributed by agriculture (Cerealia, *Plantago lanceolata, Rumex*), but also partly by the cliffs, beach and other habitats around the pool (Compositae subsect. Tubuliflorae, *Plantago maritima*). We interpret this increase as denoting a switch in palynomorph source, away from the essentially riverine spectrum of Zones H-D, to an assemblage which is partly riverine and partly marine. Above 100 cm, this assemblage declines in favour of Gramineae > 40 µm and *Plantago lanceolata*, perhaps indicating a further change in input from agricultural sources.

Determinands recording increased heavy metal input to the pool (allogenic lead, authigenic copper and lead, biogenic copper) expand above 150 cm, indicating a rise in activity at Swanpool Mine. Concentration of biogenic copper expands *before* that of the authigenic form, suggesting that following expansion of mining, copper was first taken up by the biota, and only later became sufficiently abundant to lead to saturation of the water column. Zone SPLCMMB is demarcated by an increase in χ, and a *fall* in IRM/χ which is consistent with a general increase in minerogenic inputs to the lake.

The response of the ecosystem of the pool to increased inputs of mine waste is seen in the shape of peaks in *Surirella ovata* and *Synedra acus*, which are also associated with episodes of mining recorded in the sediments of Loe Pool, Cornwall (Simola *et al.,* 1981). At that site, their expansion was thought to denote increased turbidity of the lake waters, whereas here, owing to separation of determinands into fractions, it is possible to suggest that inputs of heavy metals in dissolved form may also have been important in creating favourable conditions for those species.

In the upper part of Zone SPLCCB, authigenic phosphorus expands. This form of the element was probably released from the lower sediments by deoxygenation of the SWI, which took place on connection of the pool to the sea. However, although lake phosphorus concentration therefore increased at this time, the process concerned was not eutrophication, as the source was internal, not external (O'Sullivan, 1995). In contrast, biogenic silica concentration declines. It therefore appears that primary production in the pool may have switched at this time, from diatoms to some other form of algae. Dinoflagellates, which are more characteristic of marine waters than of fresh, are now the main kind of phytoplankton in the pool (Crawford *et al.,* 1979). Sedimentary dinoflagellate cysts have not yet been counted.

Phase 4 (Zones SPLCDIA, SPLCPA, SPLCCA, SPLCMMA).

In this phase, which represents the topmost part of the stratigraphy, frequencies of *Fragilaria construens*, the main subfossil diatom characteristic of sections below 2 m, recover. Expansion of tree pollen may record growth of Falmouth into the catchment of the pool, and *Rumex acetosella*, recent agricultural change. Concentrations of determinands whose source was Swanpool Mine, decline. Authigenic phosphorus concentration remains high, as a result of the effects of the change in lake chemistry following connection to the sea, in particular the now more-or-less permanent deoxygenation of the SWI. IRM_{800mT} and IRM_{800mT}/χ remain high, either for the same reason, or because of influx of material from eroded spoil heaps.

TENTATIVE CHRONOLOGY

No independent dating of the sediments of Swanpool (eg by ^{210}Pb) has yet taken place. However, using documentary records, it is possible to put forward a tentative chronology of sedimentation of the upper part of the core, based on interpretation of the sedimentary record. The key features employed in order to develop this chronology are:-

(1) the increase of IRM_{800mT} and IRM_{800mT}/χ at the Zone SPLCMMD/C boundary

(2) the stratigraphic change from brown clay-*gyttja* to black FeS-*gyttja*

(3) the maximum of authigenic copper and lead recorded in Zone SPLCCB

As stated above, we tentatively correlate initial expansion of IRM/χ above 2 m with expansion of operations at Swanpool Mine, and increased delivery of unweathered mineral matter to the pool. This event is dated from documentary sources to the year 1790 AD (Hooper, 1932; Dines, 1956). It lies some 50 cm below the change from brown clay-*gyttja* to black FeS-*gyttja* which can be much more firmly dated to 1826 AD (Little et al., 1973). Finally, the peak values of authigenic copper and lead recorded at 100 cm are correlated with the period of maximum activity of Swanpool Mine, which according to Dines (1956), was the period 1850-1860 AD. We use this tentative chronology (Table 3) as the basis of our conclusions set out below. It does of course need calibration by some independent, parallel technique such as ^{210}Pb, but the sediments of Swanpool are also finely laminated, and should these be shown to be varves, they will provide a very detailed chronology of sedimentation of their own.

CONCLUSIONS

(1) Before *ca* 1790 AD, Swanpool was a shallow freshwater lake, existing under conditions of catchment stability and nutrient limitation (i.e. no major increase in nutrient influx from the land). However, the diatom profile records several short term fluctuations, which may therefore merit further investigation. As there is little evidence for catchment change at this time, our hypothesis at present is that these events represent marine influence upon an essentially freshwater pool.

(2) Increase of sedimentary IRM_{800mT} and IRM_{800mT}/χ then implies a rise in input to the pool of detrital minerogenic matter, especially of material rich in haematite (i.e. unweathered local rock) or fine, SD magnetite. This change is correlated with the expansion of Swanpool Mine in 1790 AD (Hooper, 1932; Dines, 1956), and the beginning of influx of greater amounts of mine waste to the pool. There is little response in the palynomorph record, beyond modest expansion of Gramineae < 25 μm, but a peak of *Brachysira vitrea,* the sharp decline of *Fragilaria pinnata,* and expansion of *Cocconeis placentula,* and *Acnanthes minutissima,* indicate that its effect on the ecosystem of the pool was immediate and substantial.

(3) A sharp transition between freshwater *clay-gyttja* and overlying brackish water *FeS-gyttja* records the connection, in 1826, of Swanpool to the sea. The event is marked in the diatom profile by peaks in halophilic taxa *(Thalassiosira pseudonana, Pleurosigma elongatum, Rhoicosphenia curvata),* indicating increased saline influence upon the pool. With increased marine influence, a change in palynomorph source occurred, with expansion of taxa characteristic of littoral and cliff vegetation habitats, such as *Plantago maritima.* Increased salinity also led to decline of the freshwater green alga, *Pediastrum.*

(4) Inorganic chemical analyses then indicate that impact of Swanpool Mine on the pool then intensified, leading in particular to increased copper concentrations in its waters. During this phase, which we correlate with the period of greatest activity of the mine *(ca* 1850-60; Dines, 1956), the diatoms *Surirella ovata* and *Synedra aces,* also recorded in that part of the sediments of nearby Loe Pool which coincides with maximum impact of mining, reach maximum abundance. Mineral magnetic analyses indicate that influx of detrital mineral matter to Swanpool also increased at this time.

(5) After 1860, diatom taxa characteristic of earlier phases (eg *Aulacoseira* spp, *Cocconeis placentula, C. pediculus,* and *Fragilaria pinnata)* recover. IRM_{800mT} and IRM_{800mT}/χ remain high, either as a result of continued inwash of waste from what was now the abandoned mine, or the effects of the change in lake chemistry following connection to the sea. Authigenic phosphorus concentration expands, probably for the same reason. In the topmost sediment, traces of expansion of Falmouth may be found, in the form of expansion of tree pollen, especially *Pinus.*

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