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Degradation of the wetland sediment archive at Star Carr: an assessment of current palynological preservation.

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Abstract

This paper presents the results of an investigation into the preservation status of pollen and other microfossils in the organic sediments at the wetland Mesolithic site of Star Carr. This study assesses the degradation of the pollen record in a profile at the edge of the archaeological site, adjacent to previous pollen work carried out from 1989 to 1991 and using it as a benchmark for comparison. There has been a severe degradation of pollen grains since the earlier work, with the upper peat devoid of pollen and the lower part of the organic profile badly affected. Only the very basal sediments retain well preserved pollen. Comparisons with hydrological and geo-chemical data obtained by other workers during the assessment of the Star Carr site suggest that oxidation caused by drainage and dessication of the organic sediments, perhaps originating in fissures in the drying peat, is a primary cause of the observed severe deterioration of the pollen record. Non-pollen palynomorphs (primarily fungal and algal spores) appear to be better preserved than pollen in the present bio-stratigraphic record, showing little surface degeneration, but are not recorded in the earlier work. The pollen archive in organic sediments at the Star Carr site is now badly damaged. Any further pollen work there should be undertaken urgently but is probably not justifiable.

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1. Introduction

It is now six decades since the publication of Grahame Clark's monograph on excavations at the early Mesolithic archaeological site of Star Carr in the eastern Vale of Pickering in North-East England (Clark, 1954). It was the location of the Mesolithic settlement that first drew Clark to the site, as it lay on the edge of an Early Holocene lake (Candy et al., 2015; Palmer et al., 2015), now termed Lake Flixton, and so promised to provide the palaeoenvironmental data that he needed for his research on Mesolithic economy and land use. The iconic status enjoyed by Star Carr since Clark's work, therefore, is due not only to the prolific flint assemblages (Conneller and Schadla-Hall, 2003; Conneller et al., 2009), but also to the remarkable preservation and diversity of organic material associated with the site, which extended into the wetland sediments (Milner et al., 2011a). The organic components of Early Mesolithic material culture, which do not survive on dry sites, were found in abundance and in an excellent state of preservation, stratified within the waterlogged organic deposits that accumulated in the palaeolake margin and in the reedswamp, fen and carr wetland habitats associated with it. This stratification has allowed the use of palaeobotanical analyses, including both macrofossil (Dark, 2004; Taylor, 2011) and pollen (Walker and Godwin, 1954; Cloutman and Smith, 1988; Dark, 1998a,b,c; Cummins, 2000), to reconstruct the vegetation history around the site, providing an environmental context for the settlement at Star Carr (Innes et al., 2011; Milner et al., 2013). This combination of preserved organic cultural remains and multi-disciplinary study has made Star Carr the 'type' site for the British early Mesolithic, and a model for subsequent studies in wetland archaeology (Milner et al., 2011a;). Not only could questions of site function, economy and seasonality of occupation be addressed, but the deeper understanding of the activities carried out at Star Carr allowed the site to be the hub of conceptual models of early Mesolithic land use, territoriality and interactions with the wider landscape (Clark, 1972).

1.1 Condition of the sediments

The continued existence of the palaeoenvironmental archive at Star Carr, and the potential for further multi-disciplinary analyses there, depends upon the quality of preservation of the waterlogged sediments and organic remains. Excavations in the mid 1980s (Schadla-Hall, 1987; Schadla-Hall and Cloutman, 1985; Mellars and Dark, 1998), however, showed that organic preservation had deteriorated since Clark's work in 1950, and excavations since 2004

(Conneller, 2007; Milner et al. 2011b) have shown that the faunal and wood remains are now severely degraded. Drying, shrinkage and weathering of the peat has occurred and it is clear that modern land-use practices, particularly land drainage, have had an adverse effect on the hydrology and chemistry of the site and its environs (Brown et al., 2011), and therefore on the preservation of the organic material (Holden et al., 2006; Milner, 2007; Milner et al., 2011b). Installation of highly effective land drains in the last decade (Brown et al., 2011; Vorenhout, 2011) has accelerated this process, and the level of the peat surface has dropped considerably. Although the water level and the position of the edge of Lake Flixton fluctuated during the Early Mesolithic (Taylor, 2011), the edge remained a narrow zone and it is the deposits that formed in this lake-edge ecotone adjacent to the Mesolithic settlement (Dark, 1998a; Mellars, 1998) that today contain the archaeological organic remains. These shallow lake-edge peats are vulnerable to modern hydrological change, however, and are suffering the effects of drainage and falling water-tables. The vulnerability of wetland archaeology to such damage is a problem at a national level, and many such sites and wetland landscapes are at risk (e.g. van de Noort et al. 2002; Brunning, 2013; Davis et al., 2015). At Star Carr, a national flagship site for wetland archaeology, the dessication of the organic sediments, and thus the degradation of the materials and information they contain, appears to have accelerated in the last decade, to the point where the archive of archaeological material is badly damaged (Milner et al., 2011b). Recent research at Star Carr, therefore, has concentrated on assessing the present condition of the organic sediments on and close to the archaeological site itself, to provide a benchmark to inform decisions regarding its future management and study (Emerick, 2011). Brown et al.'s (2011) work on the hydrology of the site and its catchment has shown that recent land drainage has been the cause of the dessication and oxidation of the peat causing chemical changes and promoting extreme sediment acidity. Boreham et al. (2011a, 2011b) performed a series of physical and geochemical analyses at the site that also showed severe acidification of the sediments due to lowered and fluctuating water tables. Oxidation and acidification have caused very serious and rapid decay of the antler, bone and wood remains (Milner et al., 2011a). In theory this very high acidity might not have such a severe effect upon pollen grain preservation, but watertable fluctuation, and associated peat de-watering, could well cause their corrosion (Lowe, 1982), and so the palynological record at Star Carr may be in as much danger as the rest of the organic material there. An assessment of current pollen preservation was therefore urgently required.

1.2 Previous palynological work

In this paper we present the results of an assessment of the current palynological status of the peat at Star Carr. We take as our benchmark the palynological analyses closest to the site itself (Day, 1993; Dark, 1998c) in the shallow lake margin peats adjacent to Clark's archaeological excavations (Fig. 1). Cloutman and Smith (1988) had earlier conducted pollen analyses on three profiles from a trench (VP85A) across the peat margin close to the site, and did not report any problems with poor pollen preservation. However, when Dark (1998c) performed more detailed pollen analyses from the same Trench (A), it was clear that the upper peats had been subject to drying and shrinkage. Dark (1998c) also noted a gradual deterioration of pollen and spore preservation with proximity to the surface, with well-preserved pollen being absent above 70 cm from the basal gravel. Dark (1998a) sampled at high resolution (approximately 2 to 4 year intervals) through the Mesolithic occupation phases, and identified phases of vegetation disturbance that coincided with increased microcharcoal percentages and also with the archaeologically-rich levels. Her interpretation that burning and significant disturbance of the local vegetation accompanied the phases of occupation at Star Carr was the first recognition of Early Mesolithic environmental impact there. During recent excavations in 2010 (Conneller et al., 2012) we recovered a peat profile from a new site, 20 metres west of Dark's (1998a) profiles (Boreham et al., 2011b), and have conducted comparable analyses in order to investigate the condition of palynological remains, twenty years after Dark analysed her Star Carr samples.

2. Methods

A bulk sample of the basal 75 cm of sediment was recovered in aluminium monolith tins (numbered 321 and 322) from the southern end of excavation trench SC24 (Fig.2), in a location selected to correspond closely to the altitude and position within the lake-edge peats of the Dark (1998a) profile. The surface altitude of the sampled location was 24.36 m OD. The peat between the top of the upper tin 322 and the ground surface was very dry and badly dessicated, and was not sampled. The sampled lower peat was from the edge of the archaeological site and contained occasional flint flakes, animal bone, and wood pieces; as such it was appropriate to sample in order to test the preservation of pollen and spores close to recent and future excavations. Its lithostratigraphy is shown in Table 1. Other monolith tins were collected from adjacent sections in case the first set proved barren of pollen, but these have not had to be used and are archived.

Pollen samples were analysed at 5 mm intervals, to provide a detailed assessment of microfossil preservation. Twelve samples are from the basal, minerogenic sediments and the remainder from the organic mud and peat above. Samples were prepared at the Department of Geography, University of Durham by means of a sequential application of cold HCL (10%), hot KOH (10%), hot HF (49%), warm HCL (10%) and a brief application of a hot acetolysis mixture (less than one-minute duration), the latter using a $C_4H_6O_3$ (90%) solution with H_2SO_4 (10%). Pollen samples were filtered through a 175 μm sieve at the KOH stage, thus potentially reducing the number of charcoal particles above that size. After cleaning and dehydration (via ETOH), samples were mounted in high-viscosity silicone oil for light microscopic (LM) analysis. Both pollen and charcoal concentrations are calculated using an added exotic Lycopodium spike (Stockmarr 1971). All Poaceae grains (including annular dimensions where grains are 34 μm or larger) as well as microcharcoal particles were measured along their maximum axis. The former procedure has been used to ascertain the relative importance of cereal-like (wild) grass taxa in the assemblage, and particularly Glyceria fluitans (cf. Albert and Innes, 2015), while measurements of microcharcoal are used to assess the relative proximity of fires, with high proportions of smaller charcoal elements indicating more distant fires (Blackford, 2000). Counts of 400 pollen grains were achieved in most cases. Non-pollen palynomorphs (NPPs), mainly fungal spores, have been identified (van Geel and Aptroot, 2006; Innes and Blackford, 2003). Most pollen and spore identification and nomenclature follows Moore et al., (1991) and was achieved at x400 magnification on a standard light microscope, but higher magnifications were used to assess pollen preservation in more detail, according to degradation and damage. There has been considerable previous work on pollen preservation which has included a range of observational criteria, including folding, crumpling, breakage and surface corrosion (Cushing, 1967; Delcourt and Delcourt, 1980; Hall, 1981; Tipping 1987; Twiddle and Bunting, 2010). These criteria have been used to characterise the mode of pollen deterioration - through transportation, in situ or progressive deterioration, and reworking and redeposition of grains. Studies have included species-specific (Campbell, 1999) and experimental approaches (Twiddle and Bunting, 2010). As the focus of this paper is the overall condition of the pollen archive, we have not presented deterioration data for individual taxa.

For this project, a specific aim has been to compare pollen preservation with the earlier study (Dark, 1998c), and assess the potential for future work. Hall (1981) concluded that the best indicators of deterioration were low pollen counts and high frequencies of deteriorated grains. In this study, comparison to the assemblages quantified by the earlier work at the same site can be added as the primary indicator of the deterioration since Dark's earlier samples were taken. In this study, degrees of crumpling, corrosion and folding of pollen are assessed using sub-samples of 50 grains, carefully examined at x1000 magnification in immersion oil. Two classes of pollen degradation are recognized in this assessment, while relatively non-degraded grains are termed "Type 1" reflecting a well-preserved state in relation to each class (see Table 2). The first class of degradation is termed "damage", and includes mechanical folding (type 2) and tearing (type 3) of grains, and may occur in situations involving movement or compression of sediment. The second class of degradation is termed "deterioration", and reflects an erosion of fine micro-sculpturing elements of pollen exines (Type 2) or visible holes in the exine structure (Type 3) under x1000 magnification. Such deterioration might result from either microbial (including fungal) agents or oxidation (Lebreton et al., 2010) of the exterior of the grain.

Counts of pollen, fungal remains and algal spores made at x400 magnification were calculated in terms of percentage of total land pollen (TLP, c. 400 grains) and are shown in Fig.3. Pollen condition assessment counts are based on the 50-grain sub-sample analysed at x1000 magnification, shown as percentages. All pollen, spore and charcoal data have been plotted using the TILIA program (Grimm, 1993).

3. Results

The results of the pollen analysis are shown in Fig.3. Six pollen zones are recognised based on changes in the main pollen taxa, with Betula, Pinus, Salix and Poaceae the major contributors, and these are similar to those of the earlier work by Dark (1998c), who recognised five major pollen zones. Her upper zone dominated by Corylus is missing from this new study at SC24, showing that the later pollen record that Dark recorded is no longer preserved. Most Poaceae grains in the SC24 profile are likely to derive from reedswamp grasses, and Phragmites remains are present in unit 2 of the lithostratigraphy (Table 1). A few grass grains can be identified as of Glyceria type (Albert and Innes, 2015). Salix values in the deepest zone from SC24 are higher than those of Dark (1998c) and may represent growth of Salix closer to the new sampling point, although the two sections are not far apart, as willow growth can be very localised. Minor taxa include many wetland herbs in low numbers, with Cyperaceae and Filipendula most abundant. These minor elements of the pollen assemblage are very similar to those identified by Dark (1998c). Results suggest a mosaic of wetland reedswamp, fen and carr vegetation with birch woodland on the dry land around the site. There are few pollen types present throughout the profile that indicate human impact on the environment, with only single grains of Rumex acetosa and Plantago lanceolata. As the new SC24 profile has no radiocarbon control, precise correlation with Dark's (1998c) pollen record is not possible but in general these new pollen results are very similar to her's, with Early Holocene (pre-Boreal) Betula woodland the local dominant vegetation outside the wetland. High Filipendula values near the base and the absence of a Corylus rise at the top of our diagram confirms that this assessment covers much of the first Holocene millennium, including the Mesolithic settlement phase, as does the dated diagram of Dark (1998b), and so comparisons can be made between the two data sets, although precise correlations are not possible. Microcharcoal results (Fig.4) are also comparable, as might be expected from their proximity (Innes et al., 2004). Three microcharcoal peaks occur in the new profile, as in the previous work, interpreted as showing human activity at the site. Relatively little microcharcoal occurs in the upper part of the new sequence.

3.1 Relative pollen degradation

In monolith 322 and the upper part of monolith 321, field observation had shown the peat to be severely dessicated (Fig.2). At these depths, very little preserved pollen was found. Although similar depths above the peat base had been satisfactory for successful palynology in Dark's earlier profile, those sampled for the present study in 2010 were unable to yield a viable count. Only the lower 400 mm from tin 321, at depths of 725-1125 mm, contained pollen, although preservation levels are variable. Within this broad zone of some preservation, high levels of damaged grains have been recorded, with in some cases over 80% of the 50 grain subsample being damaged. The deteriorated category, most likely to represent post-depositional processes (Bunting and Tipping, 2000), includes many samples with over 60% deteriorated, and some over 80%. Whereas Dark (1998c) recorded less than 5% deteriorated grains, high levels of deterioration and damage are present throughout this new profile, including some horizons without preservation. Total pollen concentration values in the section 725-1125 mm vary from sample to sample, with a range of 200,000 cm^{-3} in basal layers to only 2,000 in some upper levels. Comparable data from Dark (1998c) average 200,000, with peaks at 800,000 and minima around 50,000 (Dark 1998c Fig. 11.3).

The pollen grains of Pinus species are considered more resistant than others to degradation (Sangster and Dale, 1961). The data in Figs.3 and 4 show higher levels of Pinus associated with low total concentrations of pollen, and higher percentages (60%+) of deteriorated grains, with Pinus levels sometimes in excess of 50% of TLP. Maximum values of 20% Pinus were reported by Dark (1998c) which has increased to 60% in SC24-e, suggesting that 50% of all other pollen has been lost, if Pinus pollen remains present in the same frequencies. Juniperus, a thin-walled grain that was present in Dark's (1998c) lower pollen zones, is entirely absent in SC24. In comparison to the original analyses of Dark (1998c), where only isolated crumpled/folded and deteriorated grains were noted, the present analyses produce a high encounter rate of moderately (Type 2) damaged and deteriorated grains. Moderately deteriorated pollen grains (with missing micro-sculpturing elements) are also common, averaging 20% of the sub-sample analysed, in basal levels below 1030 mm where degradation of pollen grains has been overall less severe.

In addition to the high levels of damage and deterioration (60%+) noted in those levels containing what appear to be inflated concentrations of Pinus, three distinct horizons lack countable levels of pollen, suggesting higher rates of degradation across all taxa. These horizons (bands 1-3 in Figs.3 and 4) are at 1015, 925-990 and 740-755 mm. Preservation was also very poor at 810 mm, although a low count was possible. Further evidence for degradation may be inferred from the unidentified fern spores (Pteropsida indet. cf. Filicales), which are considered resistant to oxidation and can be common in soil pollen analyses (Havinga, 1964; Tipping, 2000). The highest values (20-40% of TLP+taxon) are expressed at the boundaries of bands of very low concentration, where levels of severely degraded (Category 3) grains also increase. Dark (1998c) also recorded high values of Pteropsida, although these were in the upper levels of Trench A, M1 (top 400 mm of the profile), from a period classed here as non-polliniferous. In zones where Dark found abundant Pteropsida spores, this study shows uncountably low pollen frequencies, and in levels where Dark (1998c) found low background levels of generic ferns spores (<2%) with occasional peaks, our samples recovered twenty years later contain 5-20%, as with the Pinus data suggesting loss of other taxa.

4. Condition of the pollen archive

The lower 120 mm section of the sediment profile is minero-organic and has a moderately well-defined boundary to the overlying peat. Field estimation of water content while using the Troels-Smith scheme to record the lithostratigraphy (Table 1) during sample collection showed that these lowest levels were clearly saturated and levels of preservation of both macro- and microscopic material are good (section A on Fig. 2). Above these basal levels (section B on Fig.2), however, handling of the peat showed that water content dropped sharply and although the peat was still damp, it was far less so than in section A. It also showed the peat in the upper tin 322 and in the top levels of tin 321 to be dry (section C on Fig.2) and hardly damp at all to the touch. The peat from the top of tin 322 to the surface was extremely dry. Comparing the assessment profile with the descriptions and photographs of Dark‘s work and of the original excavations, it was clear that there has been a distinct fall in surface level, causing dessication and compaction of the sediments in this part of the site, presumably resulting from dewatering and shrinkage of the peat. This compaction has inflated the original concentrations and percentages of microcharcoal and other microfossils, exacerbated by the general pollen decay. Future microcharcoal results, either percentage or concentration, would therefore be skewed, not comparable to Dark’s earlier data, and not an accurate record of original microcharcoal deposition. Our assessment analyses show that there are major problems with pollen preservation in most parts of the sequence. Quality of preservation declines progressively higher in the profile, but not consistently, and there are groups of levels in tin 321 (bands 1, 2 and 3) where preservation was so poor that pollen was absent or at least uncountable. Significant levels of degradation or damage to pollen exines are, however, ubiquitous and are extremely high in several horizons within the profile. Sediments at the level of tin 322 are now virtually beyond use. Carbonate minerals reported by Dark in her earlier analyses were not found in our work, and the chemical changes noted by other studies (Boreham et al., 2011b) seem to have fundamentally altered the profile. French and Taylor (1985) have shown that the destructive effects of dehydration and oxidation begin immediately after sediments cease to be permanently waterlogged, even seasonally, so that even the lower levels at Star Carr are unlikely to sustain well-preserved pollen for very long. As Dark’s (1998c) work did not include NPP analysis, no direct comparison can be made with the fungal spores recorded in the present study, which are therefore omitted from Fig.4. It should be noted, however, that the fungal spores recorded throughout our counted levels show a much lower degree of surface degradation than the pollen, even in the upper parts of tin 321, and so fungal spores in general may well be robust and less susceptible to corrosion and deterioration. Further research is required on this subject.

4.1 Causes of pollen degradation at Star Carr

The fact that recent pollen analyses of Star Carr peat sediments in Monolith 321 show major degradation of pollen grains merits some consideration as to agencies of preservation versus degradation. This can be done moreover in relation to hydrological (Brown et al., 2011) and geo-chemical (Boreham et al. 2011a, 2011b) data so as to more strictly determine factors of a geo-chemical as opposed to biological degradation over the past twenty years. The relative importance of individual factors of degradation is not always easy to assess (Bryant and Holloway 1983). Significantly, very low pH values determined to be pervasive in the case of Star Carr peats would indicate also a situation of very low biotic activity, and given a formerly near-pristine state determined in Dark's (1998c) analyses, a chemical agency during the last two decades is more likely. In the latter case, preservation of pollen by virtue of reduction in pre-drainage conditions in the valley is supported by regional hydrological data (Brown et al., 2011).

Regarding important patterning in the pollen preservation data (Fig.4), that bands of poor preservation are present at various depths hints at factors of degradation beyond simple oxidation originating from surface layers, and might also result from oxidation originating in fissures in the peat bed that are sometimes observable in the profile as light sandy or silty clay layers (Table 1 and Fig.2). Such layers form from expansion and contraction following dehydration and rehydration cycles, a property also observed in wood remains recently recovered from the Mesolithic site (Milner et al., 2011b). Oxidation in the Star Carr peat deposits is also measurable according to redox potential according to chemical analyses (Boreham et al., 2011b), including pH, iron oxide (esp. Iron II versus Iron III) content along multiple bore hole transects which lie between trench A and trench SC24. High redox potential values (Boreham et al., 2011b), but not pH per se although this influences redox (Boreham et al., 2011a), indicate severe oxidation, and most oxidised conditions are very positively correlated with total deterioration of pollen. Both mechanical damage and, more importantly, deterioration might be explained by a strong oxidizing reaction, given the extreme values. Redox (mV) values in excess of 400 (cf. western 5 m of Transect 2 near Monolith 321; Boreham et al., 2011a) appear to align with the pollen degradation Bands 2 and 3 reported in this study. Such a strong oxidizing reaction affecting the pollen is also enabled by the very high acidity of the sediment matrix, although this in itself is not an agent of degradation. It can be assumed that, because of the extremely acidic conditions that have developed at Star Carr during the past two decades, biotic agents of pollen degradation have been of lesser importance, as high acidity must have greatly reduced the rate of microbial activity in these sediments.

5. Conclusions

The assessment analyses in this study show that there are major problems with pollen preservation in many parts of the SC24 sequence, with only the base of the profile still maintaining a relatively close relationship to the more pristine spectra analysed earlier by Dark (1998c), although some less reliable analysis may still practical in the lower 40 cm of the profile. Our sequence, located very close to Dark‘s original profile although not a duplicate section, shows clear evidence of substantial pollen deterioration since her work, to the extent that most parts of the profile are no longer viable for meaningful pollen analysis. While it is still possible to recover a pollen record that corresponds to the time of the Mesolithic occupation, the more fragile pollen types will have been differentially removed, preventing a reliable count, and all pollen types will have been affected by degradation. Although there may be pockets of better preservation, the section assessed in this study is likely to be representative of conditions at the wetland edge of the archaeological site as a whole, although preservation levels may well be better in deeper sediments further into the area of the palaeo-lake. Other more landward areas of the site, which appear even drier than the sampled location, may well be completely degraded. Preservation conditions appear to have been much better when Dark’s analyses were completed and future deterioration is likely to continue unless preventative action is taken at the site. Nothing can be done about the damage that the pollen archive has already suffered, and any proposed palynological work around the Star Carr site itself should be done urgently, although our study indicates that degeneration has proceeded so far that it is already almost too late and any new pollen work would have to be recognised as compromised and unreliable. It is very likely that, nationally, the palaeoenvironmental resource at many other wetland archaeology sites, most of which have received less attention than Star Carr, are at similar risk and require urgent research attention before their palynological archive is destroyed.

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Figure captions

Fig. 1 Location (insets) of palaeo-lake Flixton and the Early Mesolithic site of Star Carr in North-East Yorkshire. The site of the present palynological investigation at the southern end of archaeological trench SC24 is indicated by a white circle. Also shown are the locations of Clark's original excavations (Clark 1954) and of previous palynological work. Dark (1998a) analysed four pollen profiles, one on the southern edge of the Clark excavation area and which is marked here by a circle containing a cross. The other three, M1 to M3, were twenty metres to the east in her Trench A in a north-south transect through the marginal lake-edge deposits. Trench A is the re-opened trench VP85A of Cloutman and Smith (1988) and Dark's profiles are in broadly the same places as Cloutman and Smith's pollen diagrams A3 to A1. Geophysical core transects of Boreham et al. (2011a, b) run between trenches A and SC24. The current 24 m contour line represents the general position of the lake edge during the Mesolithic occupation.

Fig. 2 Monolith tins for palynological analysis (the 50 cm long lower tin is numbered 321 and the 25 cm long upper tin 322) in situ in the section at the south end of trench SC24 at Star Carr (see Fig.1). Adjacent holes in the section are the locations of sampling for other forms of analysis. Note the very dry condition of the upper part of the section, with dessication cracks and crumbly, oxidized peat. On monolith tin 321 section A constitutes the basal part of the profile where pollen preservation is good, section B represents the part where analysis is compromised but still practical, and section C is the part where pollen preservation is so poor as to make analysis non-viable. Tin 322 and above are useless for analysis.

Fig. 3 Palynology of profile SC24. Pollen and spores are calculated as percentages of the total land pollen sum, which includes trees, shrubs and herbs.

Fig. 4 Pinus pollen frequencies, expressed as percentages of total land pollen, pollen preservation classification and microcharcoal concentration data from profile SC24. For damaged and deteriorated pollen, class 1 means well preserved, class 2 means degraded so that identification is difficult but still possible and class 3 means degraded so badly that grains cannot be securely identified.

Table

Table 1. Lithostratigraphy of the sediment profile at SC24. Notation follows Troels-Smith (1955). Surface altitude is 24.36m OD.

Unit	Depth (cm)	Description
11	0 – 30	Crumbly, dessicated, disturbed surface peat with root penetration Sh2, $Th^1$2, nig. 2, strf.0, elas.0, sicc.3+
10	30 – 58	Dry amorphous silty peat with root penetration Sh3, $Th^1$1, Ag++, nig.3, strf.0, elas.0, sicc.3, lim.sup.0
9	58 - 60	Horizontal grey silty clay band As3, Ag1, nig.1, strf. 2, elas. 0, sicc. 3, lim. sup. 4
8	60 – 67	Dry brown amorphous silty peat with wood fragments Sh3, Ag1, Dl +, nig.3, strf.0, elas. 0, sicc.3, lim.sup.3
7	67 – 68	Horizontal grey silty clay band As3, Ag1, nig.1, strf. 2, elas. 0, sicc. 3, lim. sup. 4
6	68 – 72	Very dry brown amorphous silty peat with wood fragments Sh3, Ag1, Dl++, nig.3, elas.0, sicc.2+, lim.sup. 4
5	72 – 87	Brown, damp, silty amorphous peat with plant remains, wood fragments and occasional flint flakes Sh3, Dl1, Ag+, Dh+, Rudimenta culturae b2 nig.3, strf.0, elas.0, sicc.2+, lim.sup. 0
4	87 – 105	Amorphous silty peat with reeds Sh3, Th^2 (Phra.)1, Ag+, nig.3, strf.0, elas.0, sicc. 2+
3	105 – 108	Fine detritus mud Ld4, nig.3, strf.0, elas.0, sicc.2, lim. sup. 0
2	108 – 113	Dark brown sandy silty clay As2, Ga1, Ag1, Sh+, nig. 3, strf. 0, elas. 0, sicc. 2, lim. sup. 1
1	113 +	Medium coarse dark gravel with coarse sand Gg(maj)3, Gs1, nig. 3, strf. 0, elas. 0, sicc. 2, lim. sup. 3

Table 2. Definition of degradation types used in pollen analyses

Class of degradation	Damage definition	Deterioration definition
Type 1	Relatively pristine	Relatively pristine
Type 2	Folded exine	Removal of microsculpturing elements
Type 3	Torn and folded exine	Spheroid holes in the exine with removal of microsculpturing elements

Figure

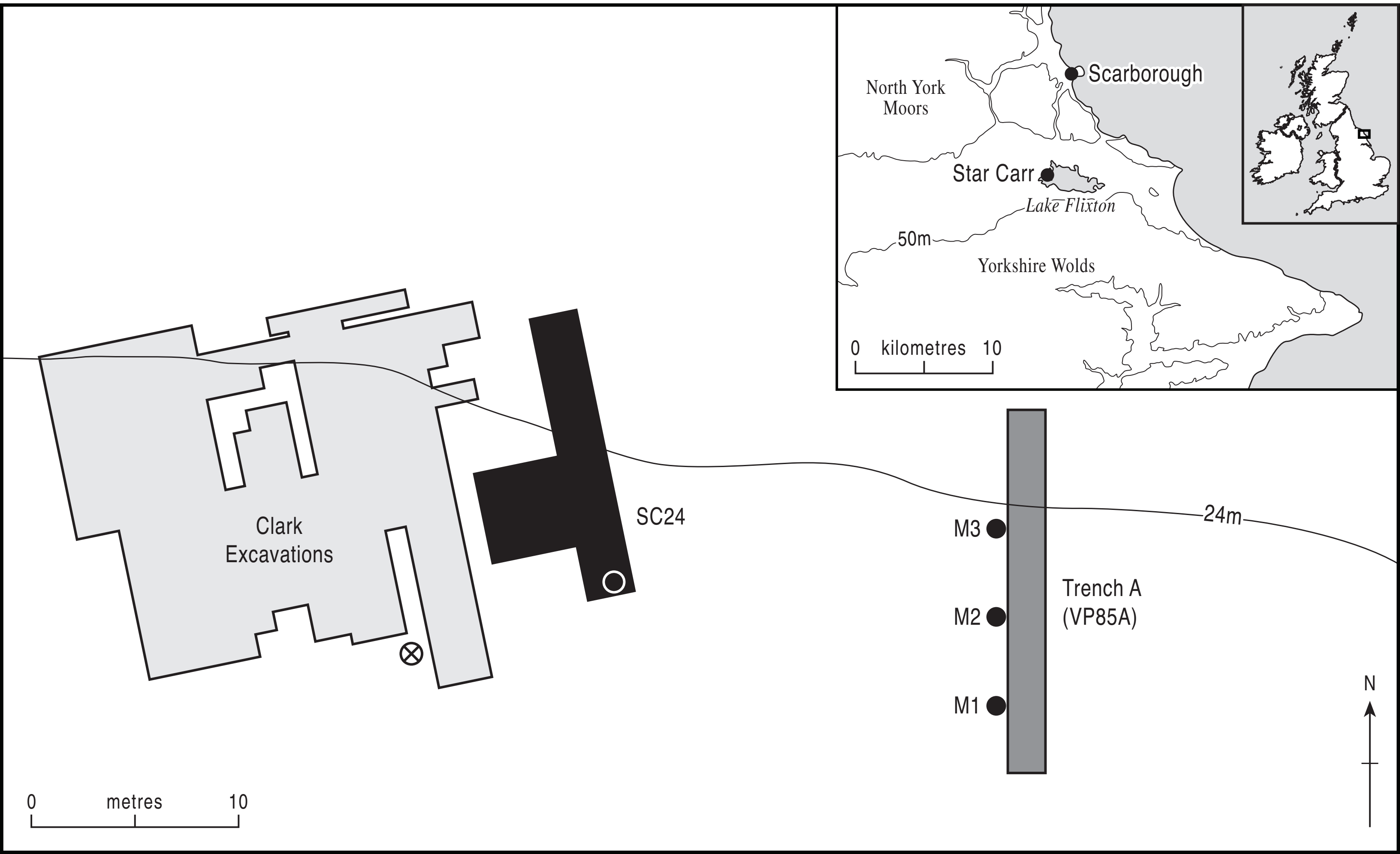
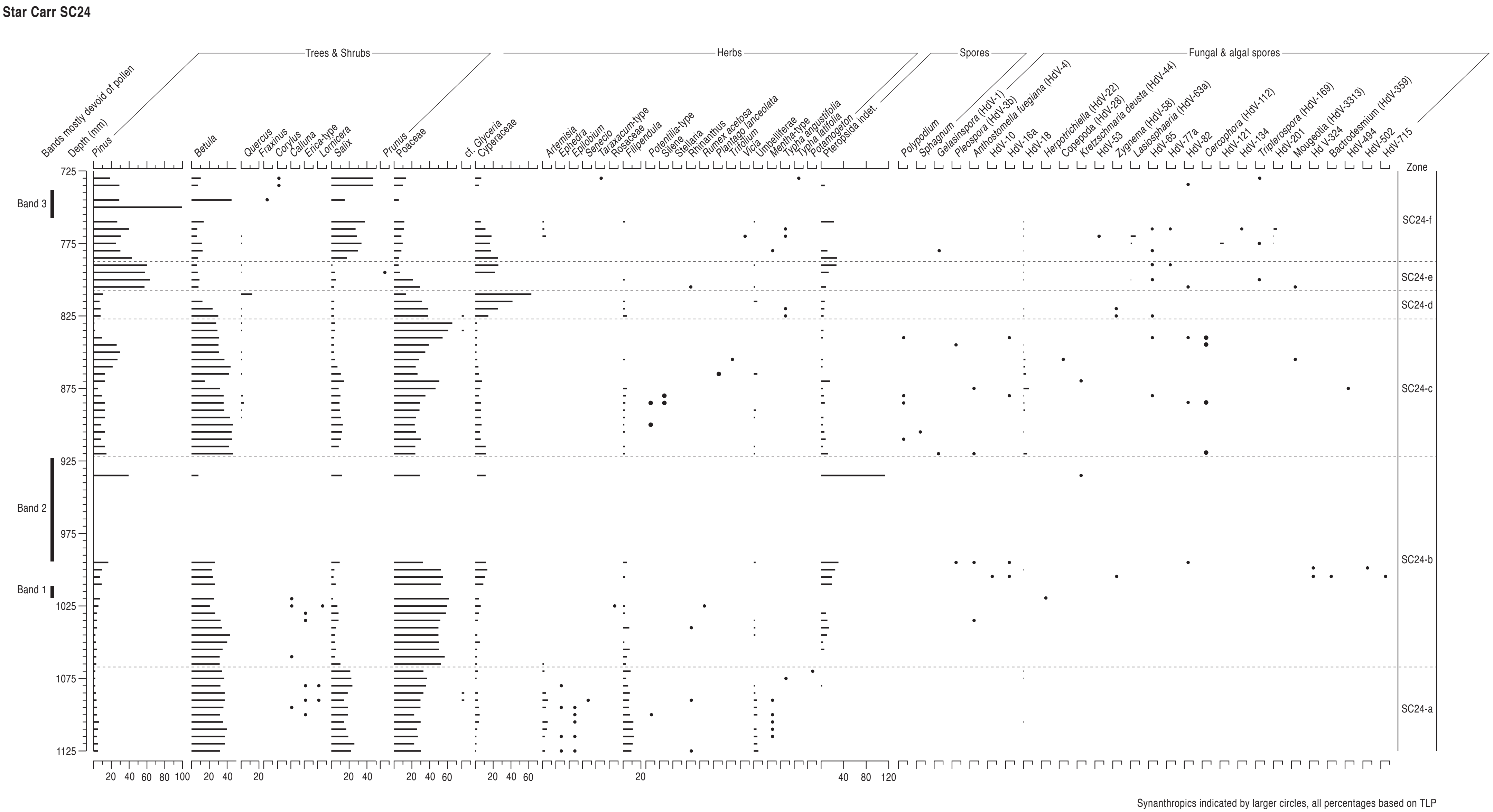

North York
Moors
Scarborough
Star Carr
Lake Flixton
50m
Yorkshire Wolds
0 kilometres 10
Clark
Excavations
SC24
M3
M2
M1
Trench A
(VP85A)
24m
N
0 metres 10

Figure
Click here to download high resolution image

Figure


Star Carr SC24
Trees & Shrubs
Herbs
Spores
Fungal & algal spores
Bands mostly devoid of pollen
Depth (mm)
Pinus
Betula
Quercus
Fraxinus
Corylus
Calluna
Erica-type
Lonicera
Salix
Prunus
Poaceae
cf. Glyceria
Cyperaceae
Artemisia
Ephedra
Epilobium
Senecio
Taraxacum-type
Rosaceae
Filipendula
Potentilla-type
Silene
Stellaria
Rhinanthus
Rumex acetosa
Plantago lanceolata
Trifolium
Vicia
Umbelliferae
Mentha-type
Typha angustifolia
Typha latifolia
Potamogeton
Pteropsida indet.
Polypodium
Sphagnum
Gelasinospora (HdV-1)
Pleospora (HdV-3b)
Anthostomella fuegiana (HdV-4)
HdV-10
HdV-16a
HdV-18
Herpotrichiella (HdV-22)
Copepoda (HdV-28)
Kretzschmaria deusta (HdV-44)
HdV-53
Zygnema (HdV-58)
Lasiosphaeria (HdV-63a)
HdV-65
HdV-77a
HdV-82
Cercophora (HdV-112)
HdV-121
HdV-134
Tripterospora (HdV-169)
HdV-201
Mougeotia (HdV-3313)
Hd V-324
Bactrodesmium (HdV-359)
HdV-494
HdV-502
HdV-715
Zone
Band 3
Band 2
Band 1
SC24-f
SC24-e
SC24-d
SC24-c
SC24-b
SC24-a
Synanthropics indicated by larger circles, all percentages based on TLP

Figure

Star Carr SC24

relative pine pollen, pollen preservation and microcharcoal concentration