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Palaeoclimate reconstruction and age assessment of the Miocene flora from the Trwyn y Parc solution pipe complex of Anglesey, Wales, UK.

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Abstract

The Trwyn y Parc solution pipes on the Isle of Anglesey, Wales, UK are one of only three onshore Miocene fossil flora bearing sites. Here we revise the palynostratigraphy and present new palaeoclimate data for this geoheritage site. By comparison to palynological data from northern Europe the age has been refined from Miocene to Middle Miocene, possibly Langhian. This is confirmed by palaeoclimate reconstructions comparable to the German Middle Miocene, especially the Langhian after the Middle Miocene Climatic Optimum (MMCO). This new information not only confirms the regional importance of Trwyn y Parc, but shows it to be of national importance Our findings show that this Regionally Important Geodiversity Site (RIGs) is of national importance as it is the oldest onshore fossiliferous Neogene deposit in the UK. Based on this, and the unique fossil flora preserved at Trwyn y Parc, the site has significant geoheritage value and should be upgraded to Geological Conservation Review (GCR) status and subsequently protected as a Site of Special Scientific Interest (SSSI).

1. Introduction

The geology of the United Kingdom (UK) has a dearth of onshore Miocene sediments (Walsh et al. 1999; 2018; Hall et al. 2015; Lee et al. 2018). Those that are present are small outliers (Walsh et al. 1987), karstic fills (Walsh et al. 1996; 1999; 2018) or weathering horizons (Hall et al. 2015). The Brassington Formation in central England (Fig. 1) is the most widely studied due to the presence of sediments in around 60 karstic pits and the presence of abundant palynological and palaeobotanical remains in the Kenslow Member (Pound and Riding 2016; Walsh et al. 2018; Pound et al. 2012a; 2019; O'Keefe et al. 2020). The uppermost Kenslow Member of the Brassington Formation was shown to be diachronous (Pound and Riding 2016). Based upon a revised palynostratigraphy of the original data and new samples analysed, the Kenslow Member at Bees Nest Pit was redated to the Serravallian, whilst the Kenslow Member at Kenslow Top Pit was assigned a Tortonian age (Pound et al. 2012; Pound and Riding 2016). Conversely the St. Agnes outlier in Cornwall (Fig. 1), southwest England has yielded only 19 recognised pollen taxa in a few productive samples (Walsh et al. 1987). An age assignment of Miocene was deduced from comparison to more complete Neogene sections in mainland Europe and the presence of *Monocolpopollenites* and *Porocolpopollenites vestibulum* (Walsh et al. 1987).

A complex of 15 solution pipes at Trwyn y Parc on the Isle of Anglesey (*Ynys Môn*) in northwest Wales has yielded an abundant palynoflora assigned to the Miocene (Fig. 1). The solution pipes developed in a Neoproterozoic limestone megaclast of the Gwna Group mélange that contain multi-coloured clays and breccia (Morawiecka et al. 1996; Horák and Evans 2011) Palynological analysis of a black clay from the composite pipe 11/12 yielded a palynoflora of 62 taxa (Table 1) (Walsh et al. 1996). This palynological assemblage was dominated by *Pinuspollenites* spp. (15.6%), *Inaperturopollenites concedipites, I. dubius* and *I. hiatus* (13.7%) with *Alnipollenites verus*

(9.4%), *Nyssapollenites kruschi* (6.8%) and *Araliaceoipollenites edmundi* (4.5%) as the dominant angiosperm pollen taxa (Walsh et al. 1996).

The Trwyn Y Parc solution pipe complex is a Regionally Important Geodiversity Site (RIGS) for its important fossil flora and geomorphology that provides evidence towards the dating of landscape development in the rest of Wales (Burek 2008; Campbell 2009; Campbell et al. 2014). Due to the important fossil flora preserved and the implications for providing landscape development dating for northern Wales, a restudy of the site is required. In this brief paper we provide an initial revision to the age of the Miocene solution pipes at Trwyn y Parc on the Isle of Anglesey, Wales. This revised age is based on an updated analysis of the original palynostratigraphy (Walsh et al. 1996) and new palaeoclimate reconstructions.

2. Methods

Unfortunately, the original slides of the palynological assemblage cannot be located and no reference is made to their storage location in the original work (Walsh et al. 1996). Therefore to revise the palynostratigraphy, the original taxa list (Table 1) from Walsh et al. (1996) was compared to Cenozoic palynological work from northern Europe (Denmark, Germany, the Netherlands, Poland and the UK). To reconstruct palaeoclimate for the Trwyn y Parc site the Co-existence Approach (CA) was used (Utescher et al. 2014). The CA compares the range of each fossil taxon's nearest living relative to determine an overlapping range for the assemblage (Supplementary Table 1). Following the recommendations of Utescher et al. (2014) *Sciadopitys* was removed from the analysis due to the highly restricted modern biogeography and the known wider ecological niches it occupied in the Neogene (Mosbrugger et al. 1994; Figueiral et al. 1999). The botanical assignments of Walsh et al. (1996) were first updated following Utescher and Mosbrugger (2010), Stuchlik et al. (2001; 2002;

2009; 2014) and Pound and Salzmann (2017). Although it has faced some criticism, the CA continues to be widely used largely due to its simplicity of the technique and consistency of reconstructions from it (Utescher et al. 2014; Vieira et al. 2018). The reconstructed palaeoclimate of Trwyn y Parc was then compared to CA reconstructions of Germany (Mosbrugger et al. 2005) and other northwest European sites (Pound et al. 2012b; Burls et al. 2021). As the CA reconstructs a range of equal possibility within which all taxa could have co-existed, the results are presented in this format both in the text and graphically.

3. Results

We present two lines of evidence that allow the refinement of the age assigned to the sediment filling the Trwyn y Parc solution pipes from Miocene to Middle Miocene (possibly Langhian). Firstly, we revise the palynostratigraphy to take advantage of 25-years of advances made in European Neogene palynology. Secondly, we reconstruct the palaeoclimate and compare this to reconstructions from Germany to climatologically date the assemblage.

3.1. Revised palynostratigraphy

Overall, the pollen and spore assemblage recovered from Trwyn y Parc shows greatest resemblance to those reported from the Middle Miocene of Germany (Utescher et al. 2020) and Poland (Worobiec 2009; Worobiec et al. 2021). An assemblage dominated by *Pinuspollenites* spp., *Inaperturopollenites concedipites, I. dubius* and *I. hiatus*, *Alnipollenites verus*, *Nyssapollenites kruschi* and *Araliaceoipollenites edmundi* suggests a warm-temperate forest and swamp (Worobiec and Szulc 2010). The variety of angiosperm taxa present in the pollen assemblage suggests it is older than the youngest occurrence of the Kenslow Member of central England (Tortonian) and possibly older than the oldest occurrence of the Kenslow Member (Serravallian) (Pound and Riding 2016). What is unusual about the Trwyn y Parc assemblage is the near absence of *Sciadopitys* pollen (0.58%) (Walsh et al. 1996). Pollen of *Sciadopitys* is a common element of the European Miocene assemblages and leaf litter of *Sciadopitys* can dominate the uppermost portion of a lignite seam suggesting it could be the penultimate floral component of raised bogs (Mosbrugger et al. 1994; Figueiral et al. 1999). In the UK Neogene record, *Sciadopitys* is present in the Serravallian and early Tortonian of the Kenslow Member and forms 1-10% of the assemblage (Pound et al. 2012a; Pound and Riding 2016), the Zanclean Coralline Crag (Andrew and West 1977), the Piacenzian Red Crag (Head 1998) and the Pleistocene St Erth Beds (Head 1993). Its near absence from the Trwyn y Parc pollen assemblage could therefore be habitat related, or indicative of an age older than Serravallian. In the Rhenish Main Seam, *Sciadopitys* is more infrequent in sediments older than the Serravallian (Utescher et al. 2020).

Individual taxa also point to a Middle Miocene age for the Trwyn y Parc palynomorph assemblage. Although more typical of the Paleogene (Kohlman-Adamska and Ziembińska - Tworzydło, 2001), *Fususpollenites fusus* (*Trigonobalanus*) is found in the Rhenish Main Seam during the Langhian (Utescher et al. 2020) and is reported from the Burdigalian-Langhian of the Łukowa-4 borehole (Gedl et al. 2016). *Engelhardtioipollenites quietus, Neogenisporis neogenicus, Platycaryapollenites miocencius* and *Podocarpites libellus* have an upper age range of Middle Miocene in the Polish Neogene (Stuchlik et al. 2001; 2002; 2009; 2014). Whilst the Polish record also shows that *Pterocaryapollenites stellatus* has a range of Oligocene to Pliocene (Stuchlik et al. 2009), in the Rhenish brown coals *Pterocaryapollenites stellatus* has sporadic occurrence from the Burdigalian (Utescher et al. 2020). The co-occurrence of these taxa would suggest a Middle Miocene age.

3.2. Palaeoclimate reconstruction

The CA reconstructs a warm-temperate climate with a Mean Annual Temperature (MAT) of 17.2 – 18.1°C and a Mean Annual Precipitation (MAP) of 1217 – 1356 mm. Cold Month Mean Temperature (CMMT) was reconstructed as 4.3 – 5.8°C and the Warm Month Mean Temperature (WMMT) as 26.5 – 27.8°C. Comparing these CA reconstructed values to other CA derived palaeoclimate reconstructions from Germany shows greatest overlap with reconstructed climate space from the Langhian and Serravallian (Fig. 2). There is no overlap with the Tortonian (Fig. 2), suggesting that either the palaeoclimate of northwest Wales was warmer and wetter than Germany or the Trwyn y Parc palynomorph assemblage comes from a warmer and wetter interval of the Miocene. Whilst there is some overlap with the Aquitanian and Burdigalian, it only relates to the reconstructed WMMT (Fig. 2). Although there is overlap in the reconstructed climate space between Trwyn y Parc and Germany for the Langhian and Serravallian, this trend isn't consistent for all parameters (Fig. 2). For the Langhian, the Trwyn y Parc MAT is higher than sites in Germany with comparable CMMT, whilst the CMMT is too cold for sites in Germany with comparable MAT (Fig. 2). For the Serravallian, both the Trwyn y Parc MAT and WMMT are greater than their comparable contemporary sites in Germany (Fig. 2). Overall, comparing the reconstructed palaeoclimate of Trwyn y Parc with sites in Germany, using the same technique, suggests the climate is most likely one of the Middle Miocene and possibly the Langhian.

4. Discussion

The palynostratigraphy and reconstructed palaeoclimate for the Trwyn y Parc solution pipe fill has substantially revised the assigned age from Miocene to Middle Miocene, possibly Langhian (Fig. 3). As a key locality of the Welsh Coastal Plateau, the age refinement can contribute to the understanding of the inherited landscape features of Wales and the rest of the UK (Rowberry et al. 2007; Rowberry 2012). Walsh et al. (1996; 1999) considered the sediment and palynomorphs from within the Trwyn y Parc solution pipes to have been derived from the surface of a broad planation feature (Menaian Surface). As the original dating only enabled an age assignment to the Miocene, this landscape feature was considered “pre-end Miocene” in age (Walsh et al. 1999). Following their argument, our refined age suggests that this broad planation feature must have been part of the landscape by the Middle Miocene at the latest.

Our new age assignment of Middle Miocene, possibly Langhian suggests this important RIGS is the oldest onshore Neogene in the UK (Fig. 3) and contains the only Langhian flora preserved in the British Isles. Despite being currently protected by a non-statutory RIGs designation (Campbell 2009), the unique nature of the Trwyn y Parc site within the UK shows that it merits protection by registration as a Geological Conservation Review Site (Ellis et al. 1996) and statutory protection as a Site of Special Scientific Interest (SSSI). As the only known onshore strata of Middle Miocene, possibly Langhian age in the UK they are representative of this time interval in UK stratigraphy. The palynological flora preserved within the Trwyn y Parc solution pipe complex is of special interest as the only evidence of a Middle Miocene past environment in the UK and the potential for future discoveries is high. This final point is exemplified by recent discoveries and advances made from restudying the Serravallian – Tortonian Kenslow Member in Derbyshire, England (Pound et al. 2012a; 2019; Pound and Riding 2016; Walsh et al. 2018; O’Keefe et al. 2020). The nationally important Kenslow Member flora forms part of the Bees Nest and Green Clay SSSI designation (Natural England 2021). The flora preserved in the Trwyn y Parc solution pipe complex is of equal importance to that of the Kenslow Member for our understanding of the evolution of floras and the complex interplay of climate change and terrestrial environments.

Whilst the flora of the Trwyn y Parc solution pipes contain an assemblage distinct from the Kenslow Member of the Brassington Formation, the reconstructed climatology is comparable to the older Kenslow Member samples (Pound and Riding 2016). Whilst this is not surprising, considering both sites can be assigned to the Middle Miocene (Fig. 3), it does imply that both come from relatively warm intervals. The later Langhian (post-MMCO) and Serravallian are characterised by cooling global climates (Steinthorsdottir et al. 2020), but comparing the non-MMCO Langhian palaeoclimate reconstructions with Serravallian data from Germany also shows a degree of temperature stability (Fig. 2). On the edges of northwest Europe and in Iceland, this warmer-than-expected post-MMCO has been attributed to the moderating influence of the Gulf Stream (Denk et al. 2013; Utescher et al. 2017). A palaeo-Gulf Stream could have contributed to sustained near subtropical winter temperatures (around 6°C CMMT) through much of the later Middle Miocene as reconstructed from the Trwyn y Parc flora and others from Germany (Fig. 2). Although reconstructions from Denmark suggest warmer winters, than those reconstructed for the Trwyn y Parc flora, with a CMMT of around 10°C (Larssen et al. 2011). It is only by the Late Miocene and Pliocene that many humid thermophilic plants, that survived the end of the MMCO, begin to go regionally extinct (Donders et al. 2009; Martinetto et al. 2017; Vieira et al. 2018).

5. Conclusions

From a revision to the palynostratigraphy, the palynological assemblage from the Trwyn y Parc solution pipes is assigned to the Middle Miocene, possibly Langhian. This is supported by the palaeoclimate reconstructions which show greatest similarity to those of Langhian reconstructions in Germany. This important RIGS is shown to be more unique than previously appreciated, as the oldest onshore fossiliferous Neogene in the UK. The unique nature, being a representative geological feature of Middle Miocene and of special interest , for helping to understand the long-term Neogene climate – biota interactions in the western most peninsula of Neogene Eurasia all suggest that the site should receive additional geoconservation protection measures.

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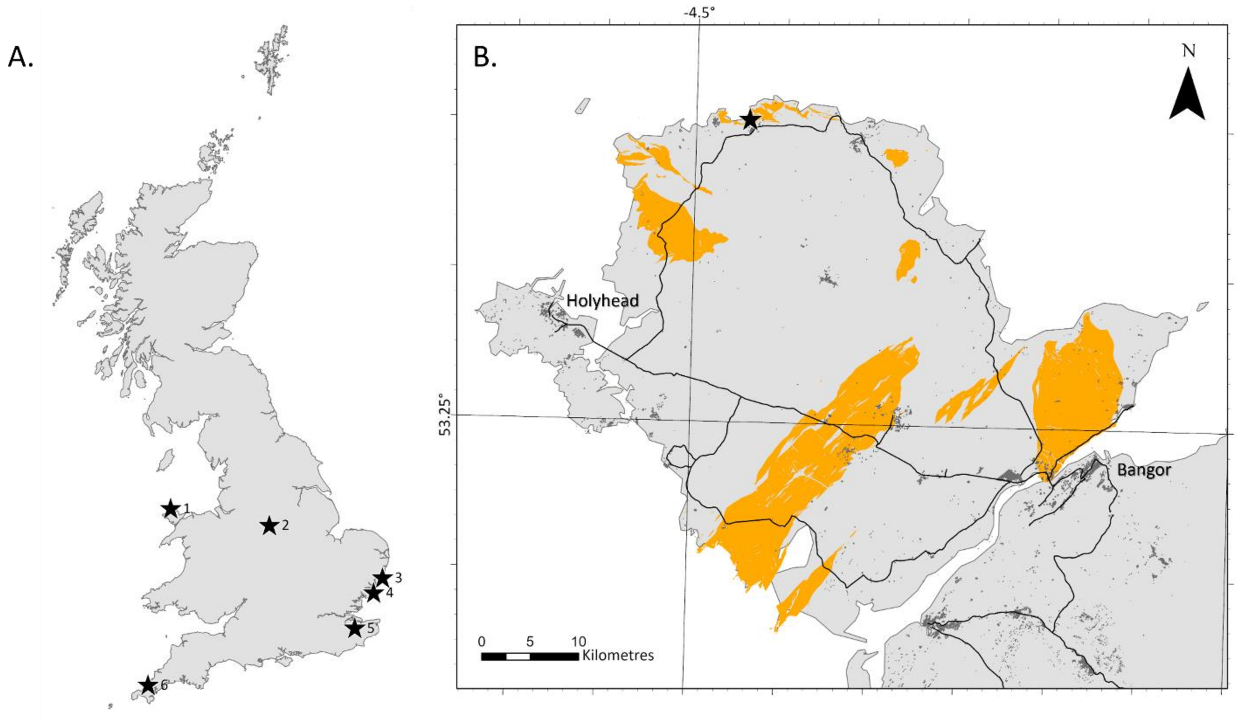

Figure 1 *Location of Trwyn y Parc and other Neogene fossiliferous onshore deposits in Great Britain. A. Map of Great Britain showing the locations of fossiliferous Neogene deposits mentioned in the text. 1. Trwyn y Parc, 2. Brassington Formation, 3. Coralline Crag, 4. Red Crag, 5. Lenham Beds, 6. St Agnes Outlier. B. Map of Anglesey showing the location of the Trwyn y Parc solution pipes on the northern coast (location 1 in A). Location of the solution pipes is shown by the star, major roads in black and settlements in dark grey. The vivid orange shows the geological extent of Gwna Group on Anglesey*

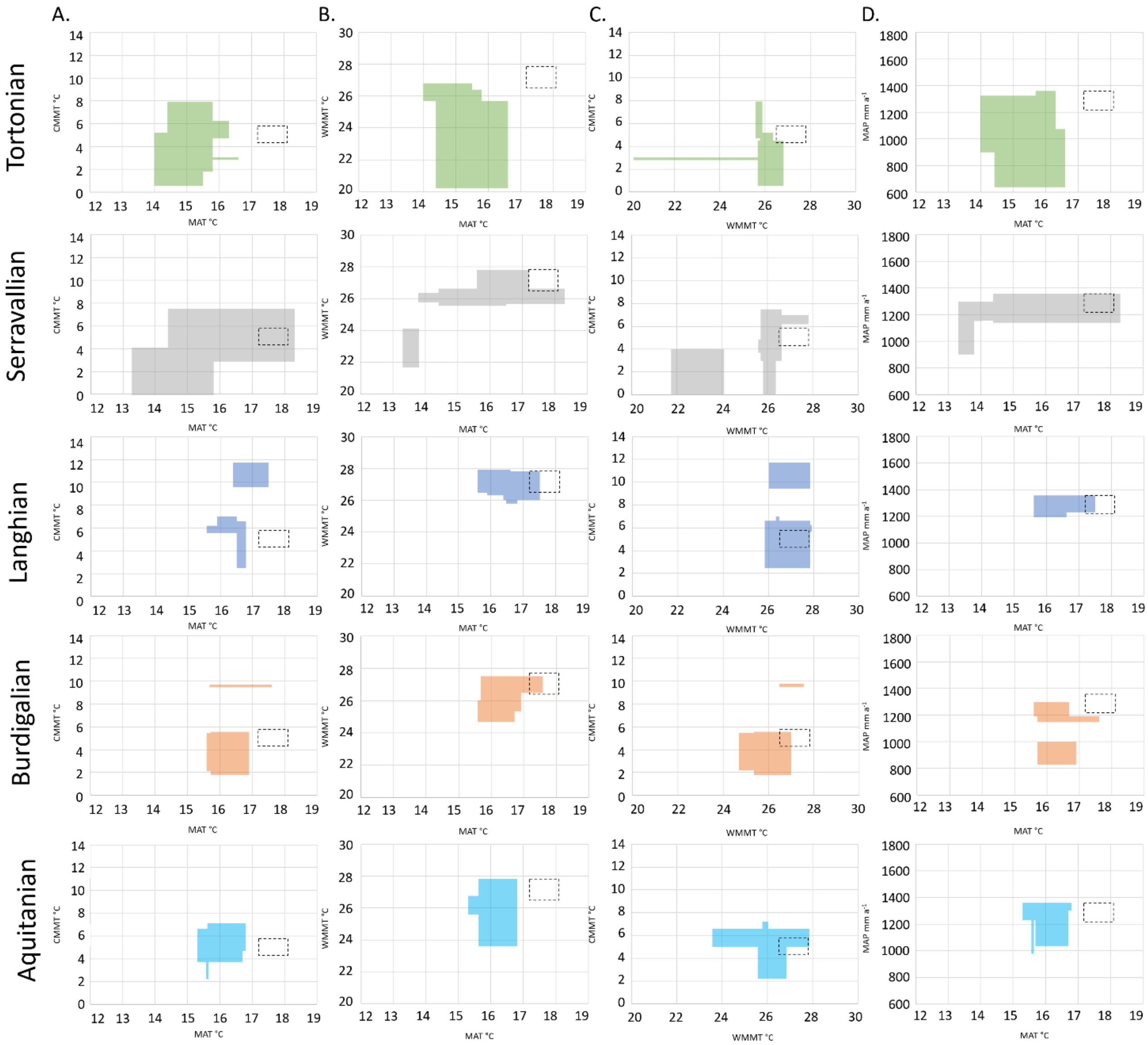

Figure 2 *Reconstructed palaeoclimate of Trwyn y Parc (dashed black box) compared to reconstructed palaeoclimates of Germany (coloured areas). A. Mean Annual Temperature (x-axis) against Cold Month Mean Temperature (y-axis). B. Mean Annual Temperature (x-axis) against Warm Month Mean Temperature (y-axis). C. Warm Month Mean Temperature (x-axis) against Cold Month Mean Temperature (y-axis). D. Mean Annual Temperature (x-axis) against Mean Annual Precipitation (y-axis). Note the elevated Cold Month Mean Temperature values in the Burdigalian and Langhian of Germany (Columns A and C) that may reflect the warmest portion of the Middle Miocene Climatic Optimum and suggests Trwyn y Parc does not contain a peak-warmth Middle Miocene Climatic Optimum flora.*

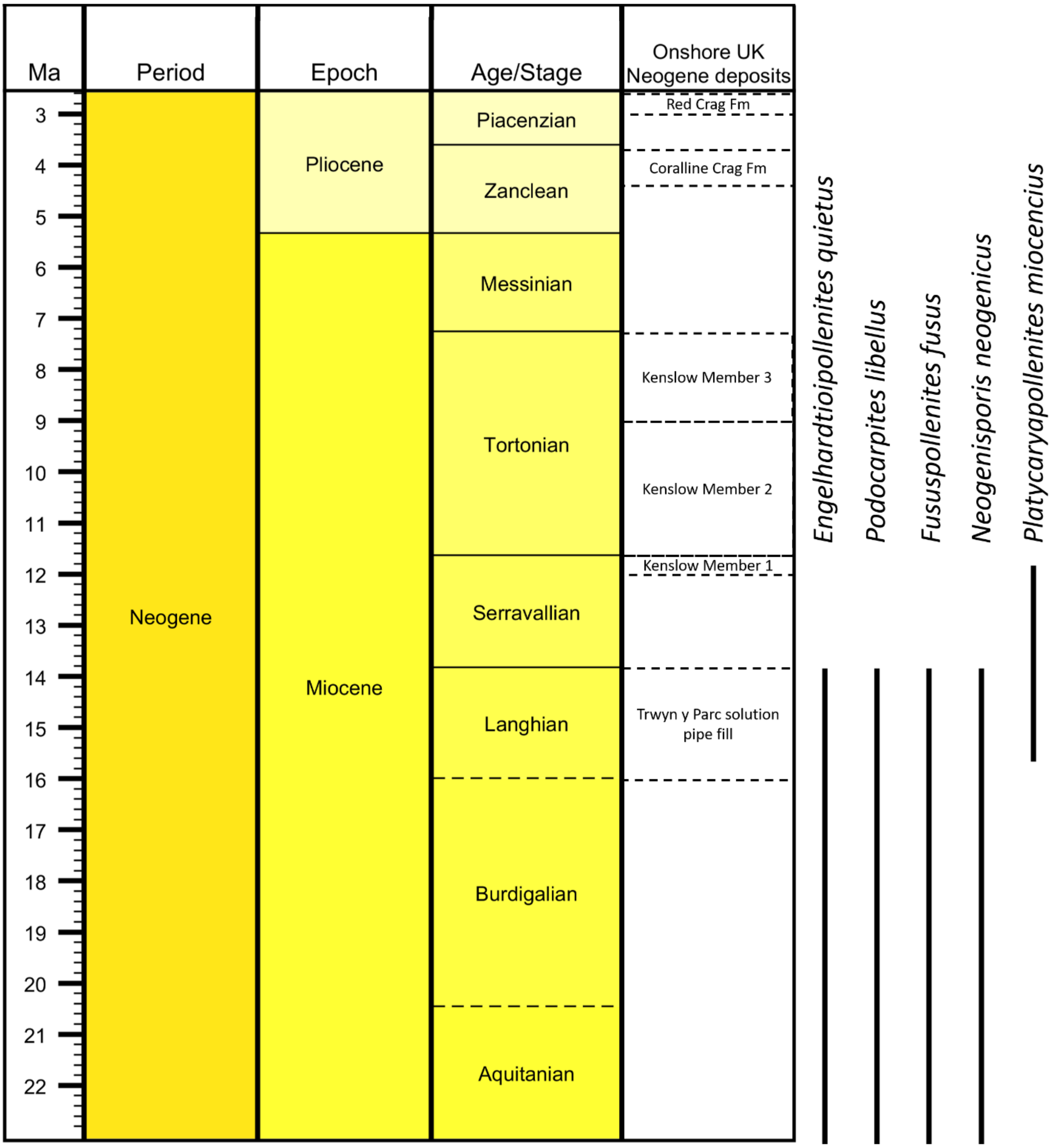

Figure 3. *Stratigraphy of UK Neogene deposits and the relative position of Trwyn y Parc as determined in this paper. Stratigraphical range of key taxa mentioned in the text are presented as well. Age determination of the deposits come from: Red Crag (Head 1998); Coralline Crag (Vignols et al. 2019); Kenslow Member 1,2 and 3 (Pound et al. 2012a; Pound and Riding 2016).*

Table 1. *Taxa list for the black clay from the composite pipe 11/12 at the Trwyn y Parc site. Reproduced from Walsh et al. (1996) with updated botanical affinities and references from which those came.*

Phylum	Class	Family	Taxon	Reference
Bryophyta	Sphagnopsida	Sphagnaceae	*Stereisporites* sp.	
Tracheophyta	Lycopodiopsida	Lycopodiaceae	*Camarozonosporites* / *Lycopodiaceaesporis* sp.	
	Polypodiopsida	Gleicheniaceae	*Neogenisporis neogenicus*	Stuchlik et al., 2001
		Lygodiaceae, Dicksoniaceae (Cyatheaceae)	*Leiotriletes neddenioides*	
			Leiotriletes sp.	
		Marattiaceae, Polypodiaceae	*Echinosporis* sp.	Baldoni, 1992
		Osmundaceae	*Osmundacidites* sp.	Stuchlik et al., 2001
		Many	*Laevigatosporites haardi*	
	Pinopsida	Cupressaceae	*Inaperturopollenites concepidites*	
			Inaperturopollenites dubius	
			Inaperturopollenites hiatus	
			Sequoiapollenites sp.	
		Pinaceae	*Abiespollenites latisaccatus*	
			Piceapollis sp.	Stuchlik et al., 2002
			Pinuspollenites alatus	
			Pinuspollenites labdacus	
			Pinuspollenites sp.	
			Tsugaepollenites sp.	
		Podocarpaceae	*Podocarpites libellus*	
		Sciadopityaceae	*Sciadopityspollenites* sp.	
	Liliopsida	Poaceae	*Graminidites* sp.	Stuchlik et al., 2009
	Magnoliopsida	Adoxaceae	*Caprifoliipites viburnoides*	
		Aquifoliaceae	*Ilexpollenites iliacus*	
			Ilexpollenites margaritatus	Stuchlik et al., 2014
			Ilexpollenites propinquus	
		Araliaceae	*Araliaceoipollenites euphorii*	
		Betulaceae	*Alnipollenites verus*	
			Betulaepollenites betuloides	Stuchlik et al., 2009
			Carpinites carpinoides	
		Cletheraceae, Cyrillaceae	*Tricolporopollenites exactus*	
		Ericaceae	*Ericipites* sp.	
		Fabaceae	*Tricolporopollenites fallax*	
			Tricolporopollenites liblarensis	
			Tricolporopollenites quisqualis	
		Fagaceae	*Castaneoideaepollis oviformis*	Stuchlik et al., 2014
			Castaneoideaepollis pusillus	
			Faguspollenites verus	
			Fususpollenites fusus	
			Quercoidites asper	
			Quercoidites henrici	
			Quercoidites microhenrici	

Hamamelidaceae	*Tricolporopollenites indeterminatus*	
Iteaceae	*Iteapollis angustiporatus*	
Juglandaceae	*Caryapollenites simplex*	Stuchlik et al., 2009
	Engelhardtiopollenites quietus	
	Platycaryapollenites miocencius	
	Pterocaryapollenites stellatus	
Malvaceae	*Intratriporopollenites* sp.	Stuchlik et al., 2014
Myriaceae	*Myricipites bituitus*	Stuchlik et al., 2009
	Myricipites coryphaeus	
	Myricipites microcoryphaeus	
	Myricipites rurensis	
Nyssaceae	*Araliaceoipollenites edmundi*	Stuchlik et al., 2014
	Nyssapollenites kruschi	
	Nyssapollenites krushchi ssp. *Rodderensis*	
	Nyssapollenites psuedocruciatus	
Santalaceae	*Spinulaepollis arceuthobioides*	
Styracaceae	*Tricolporopollenites pseudocingulum*	
Symplocaceae	*Symplocoipollenites vestibulum*	
Ulmaceae	*Celtipollenites verus*	Stuchlik et al., 2009
	Ulmipollenites undulosus	
Vitaceae	*Vitispollenites* sp.	Stuchlik et al., 2014