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The diet of Late Neolithic farmers of the Belgian Meuse basin inferred using dental microwear texture analysis

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Abstract

Early farmers of the Belgian Meuse basin are found in collective internments nested within karstic valley crevices, caverns, rockshelters and caves, and comprise the principal source of knowledge about the Neolithic period prior to the northwest European Bronze Age. Three well-studied assemblages from the Belgian Meuse basin, radiocarbon dated to ~4,635 to ~3,830 years before present, include the rockshelter of Bois Madame in Arbre, the Caverne de la Cave in Maurenne and the cave of Sclaigneaux. These cave burials have been dated to the Late Neolithic, although one date from Maurenne is from the preceding Middle Neolithic. Chronology, geography and dental type are proposed to account for the differences within and between sites. Dental microwear texture analysis is performed on deciduous and permanent molars from Bois Madame (n = 18), Maurenne (n = 24) and Sclaigneaux (n = 25) by scanning epoxy casts of the original dental impressions using a white-light confocal profiler, followed by scale-sensitive fractal analysis. A non-significant difference in enamel surface complexity and anisotropy across sites exists for both deciduous and permanent molars. The individuals buried in these caves ate coarse foods regardless of chronology or geography. It is also possible that deciduous molars wear differently than their permanent counterparts or that a greater amount of exogenous grit entered the oral cavity, either of which may explain the higher complexity in the former. Between-site differences may have been difficult to identify because of the pronounced variation of Sclaigneaux and Maurenne. It is suggested that a common regional diet characterized the early farmers of Belgium throughout the Late Neolithic, and much of the diet derived from harder foods, or poor processing technology was used. Late Neolithic farmers of the Belgian Meuse basin may have depended extensively on wild foods that required heterogeneous jaw movements typical of early and middle Holocene foragers.

Keywords: *dental microwear, paleodiet, Neolithic, Belgium, deciduous molar, permanent molar.*

Résumé

Les restes osseux et dentaires des premiers agriculteurs du bassin mosan belge découverts dans des sépultures collectives nichées dans des crevasses, des cavernes, des abris sous-roche et des grottes de la vallée karstique constituent la principale source de connaissances de la période néolithique pour cette région du nord-ouest de l'Europe. Notre étude de micro-usure dentaire porte sur trois assemblages qui ont déjà fait l'objet d'études archéoanthropologiques : l'abri-sous-roche du Bois Madame à Arbre, la caverne de la Cave à Maurenne et la grotte de Sclaigneaux. Ces sépultures ont été datées du Néolithique récent, bien qu'une date du site de Maurenne soit du Néolithique moyen. Différents paramètres comme la chronologie, la localisation géographique et le type dentaire ont été envisagés pour expliquer les différences observées au sein des sites et entre ceux-ci. L'analyse de la texture des micro-traces d'usure dentaires a été effectuée sur des molaires déciduales et permanentes du Bois Madame (n = 18), de Maurenne (n = 24) et de Sclaigneaux (n = 25). Nous avons scanné des moulages positifs en résine époxy (réalisés à partir d'empreintes dentaires en silicone) à l'aide d'un microscope confocal en lumière blanche, suivi d'une analyse fractale géométrique. Une différence non significative s'observe pour la complexité et l'anisotropie de la surface de l'émail entre les différents sites pour les molaires déciduales et permanentes. Les Néolithiques mosans étudiés consommaient des aliments de texture grossières indépendamment de leur origine chronologique ou géographique. La plus grande complexité des *patterns* d'usure chez les molaires déciduales peut s'expliquer par le fait qu'elles s'usent différemment que leurs homologues permanentes ou que les immatures aient ingéré une plus grande quantité de particules abrasives exogènes. S'il a été difficile d'identifier des différences entre les sites, c'est probablement dû aux variations importantes de micro-usure à Sclaigneaux et Maurenne. Notre étude suggère que les premiers agriculteurs de Belgique se caractérisaient par régime alimentaire régional commun tout au long du Néolithique récent et qu'une grande partie de ce régime était dérivé d'aliments durs ou issus de techniques de préparation de mauvaise qualité. Elle indique également que les individus du basin mosan datés du Néolithique récent pourraient avoir largement dépendu d'aliments d'origine sauvage qui nécessitaient des mouvements de mâchoires hétérogènes typiques des chasseurs-cueilleurs du début et du milieu de l'Holocène.

Mots clés : micro-usure dentaire, paléo-alimentation, Néolithique, Belgique, molaire déciduale, molaire permanente.

1. Introduction

Collective burials were apparently quite common during the Eurasian Neolithic (SUBIRÀ *et al.*, 2014; WATERS-RIST *et al.*, 2016; LÓPEZ-ONAINDIA *et al.*, 2018). Numerous collective burials also are known from the karstic caverns of the Belgian Meuse River basin. Out of the 250 cave and rockshelter burials known to contain human remains, over 200 have been radiocarbon dated to the Late Neolithic (BRONK-RAMSEY *et al.*, 2002; TOUSSAINT, 2007; POLET, 2011). Interest in prehistoric human remains in Belgium has spanned nearly two centuries and was initiated by the discovery during the winter of 1829-1830 of a Neandertal child, Engis 2, from Schmerling Cave, called the second cave of Engis, along with the intrusive Neolithic remains of Engis 1. These discoveries drove further exploration of the caves, and additional sites were opened, such as Hastière rockshelter, excavated from 1867 to 1873 (ORBAN *et al.*, 2000; TOUSSAINT *et al.*, 2011; TOUSSAINT, 2007; VANDERVEKEN, 1997, 2007).

More recently, multiple Neolithic samples from these caves were radiocarbon dated (BRONK-RAMSEY *et al.*, 2002; DUMBRUCH, 2003; DE PAEPE & POLET, 2007; TOUSSAINT, 2007). Although there are single burials, such as the deliberate internment of a child (TOUSSAINT *et al.*, 2003), most contain a handful to more than a dozen individuals (POLET, 2011). A few, particularly those from the final/late Neolithic include over 40 adults and children, such as the rockshelter of Bois Madame in Arbre, the Caverne de la Cave in Maurenne and the cave of Sclaigneaux (Fig. 1).

Some caves contained multiple discrete burials such as Hastière rockshelter (ORBAN *et al.*, 2000; TOUSSAINT, 2007; VANDERVEKEN, 2007). Others contain a single large funerary assemblage such as Bois Madame of the Burnot valley, in which it is uncertain as to whether the remains were actually buried, or randomly deposited on the floor of the cave (DUMBRUCH, 2003). A wide range of funerary behaviors are noted for the Late Neolithic burials, and are likely explained as the purposeful repositioning of remains, either as secondary reburials or to add additional bodies, supported by evidence of cut-marks with flint tools and cremation of some of the remains (TOUSSAINT *et al.*, 2001; TOUSSAINT, 2007; POLET, 2011). The larger collective burials include both female and male adults, although a third to a half of the individuals are subadults with deciduous teeth (TOUSSAINT, 2007; POLET, 2011).

Since habitation sites are scarce, these collective burials present much of what is known about the early farmers of Belgium. Dietary reconstructions have included inventories of faunal remains in the burials (DUMBRUCH, 2003), stable isotopes (SEMAL *et al.*, 1999; BOCHERENS *et al.*, 2007), dental wear (SEMAL *et al.*, 1999) and microwear (GARCÍA MARTÍN, 2000; SHERRILL & WILLIAMS, 2019). The Neolithic revolution presumably restricted the heterogeneity of foods typical of foragers, and may have reduced the consumption of wild plants in the diet. Meanwhile, increasing sedentism may have allowed for reliable access to grindstones and other heavy tools, although this is apparently not always the case (DA-GLORIA & SCHMIDT, 2020). In other locations, sedentism allowed for a more consistent intensity of food processing regimes resulting in a softer diet than a hunting and gathering way of life. At the same time, food processing with stone implements inadvertently introduced a greater degree of mechanically hard silicates and grit (MOLLESON & JONES, 1991; SCHMIDT *et al.*, 2020). Yet Neolithic diets appear to have been variable in ingesting hard particulates contingent

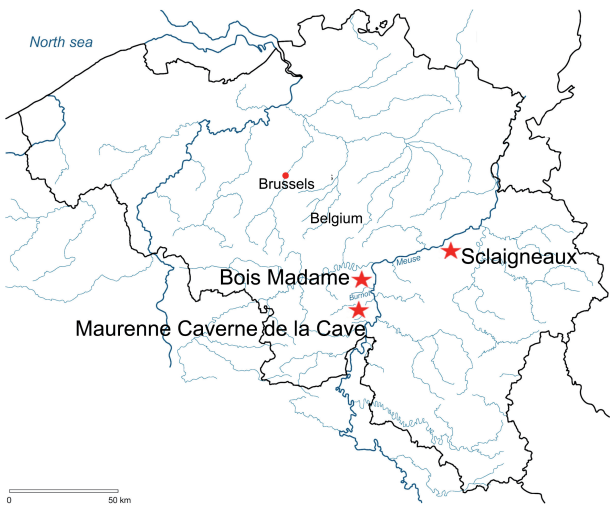

Fig. 1 – Map of Belgium showing the location of the rockshelter of Bois Madame, the Caverne de la Cave in Maurenne and the cave of Sclaigneaux.

on the dependence of fishing, food processing techniques and cultural traditions.

Previous dietary inferences from stable carbon isotopes suggest a mixed diet of farmed and wild foods and little differentiation between the caves (SEMAL *et al.*, 1999; BOCHERENS *et al.*, 2007). Buccal microwear using scanning electron microscopy and the method of Molleson & Jones (1991) together with occlusal dental wear suggest a coarse diet, perhaps from poorly processed foods, fish scales, or other hard or abrasive foods (SEMAL *et al.*, 1999; GARCÍA MARTÍN, 2000). Stereomicroscopy of dental use-wear features indicates a lack of differentiation of the diet across time period and location, and that fine grit particles and hard foods capable of puncturing the enamel surface were masticated (SHERRILL & WILLIAMS, 2019). However, the variation in deciduous and permanent molars between cave burials has not yet been fully explored.

1.1. Dental differences between adults and children

It has been known for decades that deciduous teeth are more porous and weaker than their adult counterparts (WILSON & BEYNON, 1989). Deciduous teeth have less than a third of the time to mineralize than the permanent dentition. The deciduous molar crowns mineralize between 3 months in utero and are 60-80 % complete by birth, whereas the first molar begins forming at 7 months gestation and completes crown formation at 3 years (HILLSON, 1996). The other molar crowns form for 3-4 years, and are complete by 7 years for M^2/M_2 and variably but by about 15 years for M^3/M_3 (HILLSON, 1996). From this shorter period of crown formation, it appears the enamel matrix is less mineralized as well. For instance, primary tooth enamel is 81.9 % to 94.2 % mineralized whereas the permanent teeth are nearly completely mineralized approaching 97 % (WANG *et al.*, 2006). If the dental enamel of the primary molars is indeed softer, less mineralized and more porous, it is also true that the bite force of children would be less than that of adults (KELLY *et al.*, 2020). A more limited range of jaw movements also might be a factor (KELLY *et al.*, 2020). For these reasons, deciduous and permanent molars are not necessarily directly comparable.

1.2. Enamel microwear texture

Dental microwear texture analysis has been utilized to reconstruct ancient diets from the Plio-Pleistocene (SCOTT *et al.*, 2005), Middle Paleolithic (EL ZAATARI *et al.*, 2011, 2016; ESTALRRICH *et al.*, 2017; WILLIAMS *et al.*, 2018, 2019) and Holocene (REMY & SCHMIDT, 2016; DA-GLORIA & SCHMIDT, 2020; KELLY *et al.*, 2020). Permanent molars are most often employed, whereas deciduous molars have less frequently been examined (MAHONEY *et al.*, 2016; REMY & SCHMIDT, 2016; KELLY *et al.*, 2020). An experiment was conducted to assess the degree to which complexity of the enamel surface differed between primary and permanent teeth by subjecting deciduous and adult dental elements to abrasives under equivalent conditions (MAHONEY *et al.*, 2016). There was no significant difference in the experimentally induced complexity values between deciduous and permanent teeth (MAHONEY *et al.*, 2016).

Dental microwear texture is utilized to infer the diet of three Late Neolithic collective burials, including Maurenne which may have been utilized for more than 800 years as evidenced by one Middle Neolithic date of 4,635 ± 45 years before present (BP) and three final/late Neolithic dates of 4,160 ± 45 years BP; 3,950 ± 70 years BP and 3,830 ± 90 years BP (BRONK-RAMSEY *et al.*, 2002; TOUSSAINT, 2007). Two additional final/late Neolithic sites include Sclaigneaux, dated to 4,155 ± 35 years BP (DE PAEPE, 2007; De PAEPE & POLET, 2007) and Bois Madame, with two radiocarbon dates spanning 150 years (4,075 ± 38 years BP and 3,910 ± 40 years BP; BRONK-RAMSEY *et al.*, 2002; DUMBRUCH, 2003, 2007). Bois Madame, Maurenne and Sclaigneaux represent among the most recent collective burials of the Late Neolithic, as these funerary behaviors eventually diminished prior to the onset of the Bronze Age (Tab. 1).

It is possible that chronology may explain differences in dental microwear texture characteristics between the caves since Sclaigneaux is dated to be earlier than Bois Madame and the final/late Neolithic dates obtained for Maurenne. However, Sclaigneaux is also more distant from the other caves. Thus geographic difference may account for distinctions between Sclaigneaux and

	Specimen #	*Date in years BP*	*Reference*
Maurenne	AMS OxA-9025	4,635 ± 45	BRONK-RAMSEY *et al.*, 2002
Maurenne	AMS OxA-9026	4,160 ± 45	BRONK-RAMSEY *et al.*, 2002
Sclaigneaux	GrA-32975	4,155 ± 35	DE PAEPE & POLET, 2007
Bois Madame	AMS OxA 10831	4,075 ± 38	DUMBRUCH, 2003
Maurenne	Lv-1483	3,950 ± 70	TOUSSAINT, 2007
Bois Madame	AMS OxA 10830	3,910 ± 40	DUMBRUCH, 2003
Maurenne	Lv-1482	3,830 ± 90	TOUSSAINT, 2007

Tab. 1 - Sequentially arranged dates for the cave burials examined in this study[1].
[1] Dates from Oxford University, UK (OxA) and Groningen, the Netherlands (GrA) utilized Accelerated Mass Spectrometry (AMS), whereas the two final/late Neolithic dates for Maurenne were obtained using conventional methods at the University of Louvain (Lv).

the others farther west (Fig. 1). Since the radiocarbon dates for Maurenne span the Middle and final/late Neolithic, there may be two clusters of diet signatures for this sample. Given the lack of association between the gnathic elements and the samples used for radiocarbon dating, it is not possible to associate individuals with any of the four dates for Maurenne (VANDERVEKEN, 2007). However, since three of four of these dates are situated in the final/late Neolithic it is likely that most individuals derive from the latter time period. Finally, we attempt to classify the diet of these Late Neolithic individuals of the Belgian Meuse basin using published descriptive statistics from agriculturalists, pastoralists and Holocene hunter/gatherers (KARRIGER *et al.*, 2016; SCHMIDT *et al.*, 2016, 2019, 2020; DA-GLORIA & SCHMIDT, 2020).

2. MATERIALS AND METHODS

2.1. Materials

A total of 67 individuals were examined from three caves, including Bois Madame (n = 18), Maurenne (n = 24) and Sclaigneaux (n = 25), originally molded at the laboratory of Anthropology and Prehistory, Royal Belgian Institute of Natural Sciences (RBINS) in Brussels. There were a greater number of permanent (n = 45) than deciduous (n = 22) molars included. Samples were chosen on the basis of dental wear stage such that individuals with dental wear greater than a score of 6 were excluded (SMITH, 1984) and only *in situ* molars were utilized to avoid errors of attribution.

2.2. Creation of dental casts

Molars from the cave burials were molded using polyvinylsiloxane (Coltène/Whaledent) at the RBINS, and dental casts were created from these dental impressions at the Bioarchaeology Laboratory of Georgia State University. To create the dental casts, epoxy-resin and hardener (Buehler) were mixed for five minutes, followed by five minutes of centrifuging. The mixture was then poured onto the molds, which were nested within pre-hardened putty (Buehler) crucibles to stabilize the catalyzing casting material. The dental casts were allowed to cure for 24 hours before extraction.

2.3. Data capture

The dental casts were subsequently scanned at the University of Indianapolis. The protocol for scanning includes the use of the "Indie" machine (ARMAN *et al.*, 2016), comprising a white-light confocal profiler (Sensofar Plµ) at 100x magnification (Solarius Development Inc.). Scans were obtained from facet 9 or 11, which are both classified as Phase II facets (KAY & HIIEMAE, 1974; KAY, 1981). Phase II facets crush and grind food particles when the jaws are engaging in the power stroke while fully occluded (KAY & HIIEMAE, 1974; KAY, 1981; KRUEGER *et al.*, 2008). A total of four scans were created from a viewing field of 138 x 102 µm, and stitched together using an automated process prior to analysis (SCHMIDT *et al.*, 2019). The scans were examined using SolarMap 5.1.1 to level the surface and remove surface particulates. A two-dimensional scan was created for each individual to investigate the surface for evidence of postmortem taphonomy. The individual was included only when the scan was validated as representing microwear reflecting masticatory behavior (Fig. 2, Fig. 3 and Fig. 4). To further ensure the absence of postmortem artifacts and defects from casting, 3-D surface reconstructions were closely evaluated through visual inspection (Fig. 2, Fig. 3 and Fig. 4).

The scans were imported into scale-sensitive fractal analysis programs, Sfrax® and Toothfrax®. These programs were utilized to calculate texture variables to estimate surface complexity and the degree of patterning of microwear (SCOTT *et al.*, 2006, 2012; UNGAR *et al.*, 2012; SCHMIDT *et al.*, 2016, 2019). Mastication of hard and tough foods results in distinct textures of wear on the microscopic level. Dental microwear texture analysis was invented to explore occlusal topography and surface damage from the processing of dietary items (SCOTT *et al.*, 2006, 2012; EL ZAATARI *et al.*, 2011; UNGAR *et al.*, 2012; ARMAN *et al.*, 2016; SCHMIDT *et al.*, 2016, 2019, 2020; KRUEGER *et al.*, 2017, 2019; WILLIAMS *et al.*, 2018, 2019). However, the wear surface differs depending on the scale of observation, such that a macroscopic view may render a smooth topography but lower objectives may appear increasingly coarse (SCOTT *et al.*, 2006). Scale-sensitive fractal analysis renders an approximation of surface complexity by estimating topography roughness via different scales of observation. Complexity, or Area-scale fractal complexity (Asfc), estimates the extent to which a hard or brittle diet characterizes the individual (SCOTT *et al.*, 2005, 2006, 2012; CALANDRA *et al.*, 2012; DESANTIS *et al.*, 2013; SCHMIDT *et al.*, 2019). A low value for complexity is suggestive of a diet lacking hard objects, such as seeds, seed shells, nuts, extraneous grit, sand, phytoliths and other plant or animals foods with hard or brittle adherents or parts (SCOTT *et al.*, 2012; CALANDRA *et al.*, 2012; DESANTIS *et al.*, 2013; SCHMIDT *et al.*, 2020). Elevated values indicate an enamel surface is complex with numerous pits and other features from the mastication of resources resistant to the mineralized structure of the enamel matrix.

Another distinction in enamel surface microwear texture is the degree of constancy

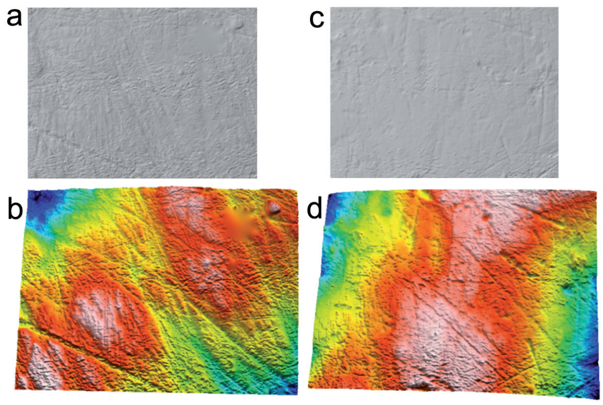

Fig. 2 – Two-dimensional (above) and 3-D enamel surface reconstructions (below);left = permanent / right = deciduous of Bois Madame, a/b = BM Md 97, c/d = BM Md 38.

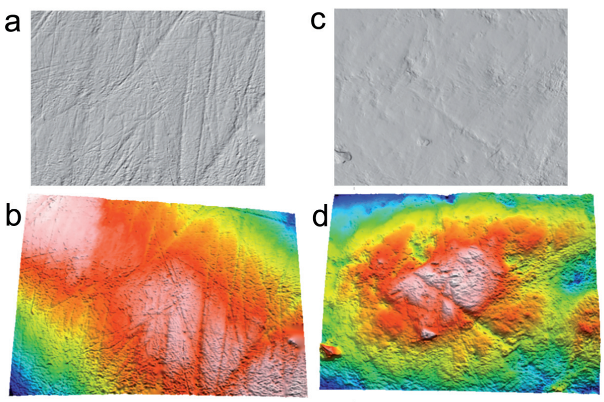

Fig. 3 – Two-dimensional (above) and 3-D enamel surface reconstructions (below); left = permanent / right = deciduous molars of Maurenne, a/b = Maurenne 43, c/d = Maurenne 91.

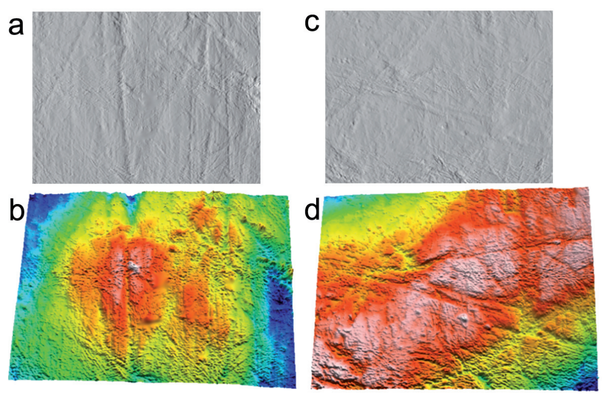

Fig. 4 – Two-dimensional (above) and 3-D enamel surface reconstructions (below); left = permanent / right = deciduous of Sclaigneaux, a/b = Sclaigneaux 98, c/d = Sclaigneaux 35.

of scratch orientation. Patterning of scratches can range from haphazard to highly directional. A lack of heterogeneous jaw movements signals the consumption of tough foods and is approximated by anisotropy, or exact proportion length-scale anisotropy of relief (epLsar), which estimates the directional patterning of microstriations on the enamel surface. In nonhuman primates, high anisotropy is found in taxa that consume large amounts of leaves, stems, grasses and other nonreproductive plant tissues (SCOTT *et al.*, 2006, 2012). In humans, high levels of anisotropy have been interpreted as the result of repetitive masticatory practices, such as the thorough chewing of tough foods or a diet comprising large amounts of fibrous plant cellulose (EL ZAATARI, 2010; SCHMIDT *et al.*, 2016, 2019, 2020; WILLIAMS *et al.*, 2018).

2.4. Comparative context

To reconstruct the diet of these Neolithic individuals, 95% confidence intervals were calculated based on Holocene human samples analyzed using the same instrumentation and protocol developed at the University of Indianapolis (KARRIGER *et al.*, 2016; SCHMIDT *et al.*, 2016, 2019, 2020; DA-GLORIA & SCHMIDT, 2020). These included a worldwide sample of 10 forager groups (n = 181) and 15 farming communities (n = 392; SCHMIDT *et al.*, 2019). Two of these 25 groups were also individually compared to the Late Neolithic individuals of Belgium. Since both wild and domestic foods were consumed by Late Neolithic farmers of northern Europe, we included Archaic Amerindians from Indiana (USA; n = 34), dated to 3,500 to 5,500 years BP as they are associated with both wild and domesticated resource consumption (SCHMIDT *et al.*, 2020). To control for ecogeography and to provide a contrast with the preceding Late Neolithic, we included farmers from Early Bronze Age England (n = 21; KARRIGER *et al.*, 2016). A sample of Xiongnu pastoralists from Late Bronze/Iron Age Mongolia (n = 49) is also included as herders tend to have among the softest diets of known human subsistence patterns with low complexity values compared to foragers and farmers, although similar anisotropy values to farmers (KARRIGER *et al.*, 2016; SCHMIDT *et al.*, 2016). PaleoAmerindian foragers from Lagoa Santa (n = 23) of Minas Gerais, Brazil, dated 11,000-7,000 years BP (DA-GLORIA & SCHMIDT, 2020), were included since a subadult sample, albeit permanent molars, was available (n = 14; Tab. 2).

2.5. Expectations

It is anticipated that Sclaigneaux will differ from the other two caves as it is the most distant geographically, situated about 35 km east of Maurenne (Fig. 1). It may also be the case that Maurenne and Bois Madame will be more similar to one another since they are separated by a distance of approximately 15 km. This expectation is predicated on the extent to which micro-ecogeographic distinctions exist from east to west and north to south within the Meuse river basin of Belgium.

	Complexity Mean (N)	*SD*	*95 % CI*	*Anisotropy Mean (N)*	*SD*	*95 % CI*
Foragers	1.47 (168)	0.578	1.38–1.55	0.0027 (181)	0.0013	0.0025–0.0029
Farmers	1.36 (385)	0.566	1.29–1.40	0.0035 (392)	0.0018	0.0033–0.0037
Pastoralists	0.92 (49)	0.311	0.83-1.01	0.0034 (49)	0.0017	0.0029–0.0039
Lagoa Santa	2.45 (23)	1.02	2.01–2.89	0.0029 (23)	0.0015	0.0023–0.0035
Lagoa Santa subadult	2.64 (14)	1.15	2.01-3.33	0.0028 (14)	0.0014	0.0020-0.0036
Archaic Indiana	1.26 (34)	0.471	1.01-1.42	0.0026 (34)	0.0011	0.0022-0.0030
Early Bronze Age England	1.34 (21)	0.443	1.13-1.54	0.0041 (21)	0.0016	0.0034-0.0048

Tab. 2 - Descriptive statistics for the comparative samples[1].

[1] Foragers and farmers from Schmidt et al. (2019); pastoralists from Karriger et al. (2016); Lagoa Santa from Da-Gloria and Schmidt (2020); Archaic Indiana from Schmidt et al. (2020); and Early Bronze Age England from Karriger et al. (2016)

Sclaigneaux may also differ from Bois Madame because its dating is earlier (Tab. 1). One of the dates for Maurenne approximates the dating of Sclaigneaux. Two other final/late Neolithic dates for Maurenne overlap those for Bois Madame (Tab. 1). Maurenne is associated with the latest radiocarbon date of the series; however, this collective burial is also associated with the earliest, a Middle Neolithic estimate (Tab. 1). Therefore, it is expected that Maurenne will be the most variable of the collective internments to the degree to which chronological differences accord with dietary proclivities and food availability.

It is anticipated that the Late Neolithic cave burials of the Belgian Meuse basin will be more similar to foragers and farmers and distinct from pastoralists in dental microwear texture characteristics since herders consume fewer plant resources and thus have much lower complexity values than do agriculturalists and hunter/gatherers (SCHMIDT *et al.*, 2016). Foragers generally have the hardest and most poorly processed diets, frequently indicated in higher complexity values than farmers and herders. Farmers on the other hand have less heterogeneous diets and often consume fibrous foods leading to elevated anisotropy (SCHMIDT *et al.*, 2019). Previous dietary reconstructions based on faunal remains (DUMBRUCH, 2003), isotopes (SEMAL *et al.*, 1999; BOCHERENS *et al.*, 2007) and dental microwear (SEMAL *et al.*, 1999; GARCÍA MARTÍN 2000; TOUSSAINT *et al.*, 2001) suggest these people were practicing agriculture, but also exploited fish and other aquatic resources as well as wild plants and animals. Therefore, we expect the Late Neolithic cave burials to exhibit relatively high complexity like forager/farmers from Archaic Indiana, and elevated anisotropy similar to farmers of Early Bronze Age England.

Analysis of Variance (ANOVA) is included to test for differences between caves, and is conducted separately for deciduous and permanent molars. Bivariate comparisons with deciduous and permanent molars demarcated with convex hulls encompassing 100 % of the variation are shown with the expectation of no difference in the enamel microwear texture of the two dental types across cave burials. The 95 % confidence intervals for the comparative samples along with the two dental types from the Belgian Meuse are presented separately for complexity and anisotropy.

3. Results

Deciduous molars for each cave exhibit consistently higher values for complexity than their permanent counterparts (Tab. 3). Complexity values for Maurenne are the highest for both permanent and deciduous comparisons followed closely by Sclaigneaux (Tab. 3). Those for Bois Madame display lower complexity but with the same pattern of the deciduous molars exhibiting higher values than permanent ones. Similarly, for anisotropy, the deciduous molars exhibit higher values per cave burial (Tab. 3).

When the caves are compared to one another using a separate ANOVA for deciduous and permanent molars, none of the *p* values demonstrate statistically significant differences (Tab. 4). This includes when only deciduous molars

	Complexity Mean	*SD*	*95 % CI*	*Anisotropy Mean*	*SD*	*95 % CI*
Bois Madame deciduous (n = 6)	1.990	0.408	1.56-2.42	0.0024	0.0016	0.0007-0.0041
Bois Madame permanent (n = 12)	1.367	0.469	1.07-1.67	0.0018	0.00095	0.0012-0.0024
Maurenne deciduous (n = 6)	2.574	0.680	1.86-3.29	0.0031	0.00139	0.0016-0.0045
Maurenne permanent (n = 18)	1.545	0.738	1.18-1.91	0.0019	0.00103	0.0014-0.0024
Sclaigneaux deciduous (n = 10)	2.566	1.259	1.67-3.47	0.0028	0.00146	0.0018-0.0038
Sclaigneaux permanent (n = 15)	1.526	0.529	1.23-1.82	0.0018	0.00106	0.0013-0.0024

Tab. 3 - Descriptive statistics for each cave burial separated into results for permanent and deciduous molars.

are examined, when the permanent ones are isolated and when all molars are tested for differences between the caves. However, the F value for deciduous molars, describing the between to within-group variation across cave burials, is relatively close to 1.0 suggesting substantial, but not significant, group differences exist (0.793). The same could be said for when all molars are compared across cave burials (0.983; Tab. 4).

	Complexity		*Anisotropy*	
	F value	*p* value	F value	*p* value
Deciduous molars (n = 22)	0.793	0.467	0.282	0.757
Permanent molars (n = 45)	0.342	0.712	0.016	0.985
All molars (n = 67)	0.983	0.380	0.125	0.883

Tab. 4 - Results comparing Bois Madame, Maurenne and Sclaigneaux using Analysis of Variance (ANOVA).

In bivariate comparisons of complexity and anisotropy, distinctions between the two dental types are evident, although much overlap is also present (Fig. 5). Maurenne exhibits the greatest degree of separation between deciduous and permanent molars. Deciduous molars from Maurenne present both greater complexity and only a single primary molar, Maurenne 25, can be found within the convex hull of the secondary dentition (Fig. 5). Meanwhile, Bois Madame exhibits the greatest overlap between deciduous and permanent microwear textures (Fig. 5). However, for anisotropy, one individual from Bois Madame (BM Md 37) is much higher than the permanent molars. The variation in deciduous molars from Sclaigneaux is more pronounced than in the permanent teeth owing to an extreme value for complexity in Sclaigneaux 73b and an

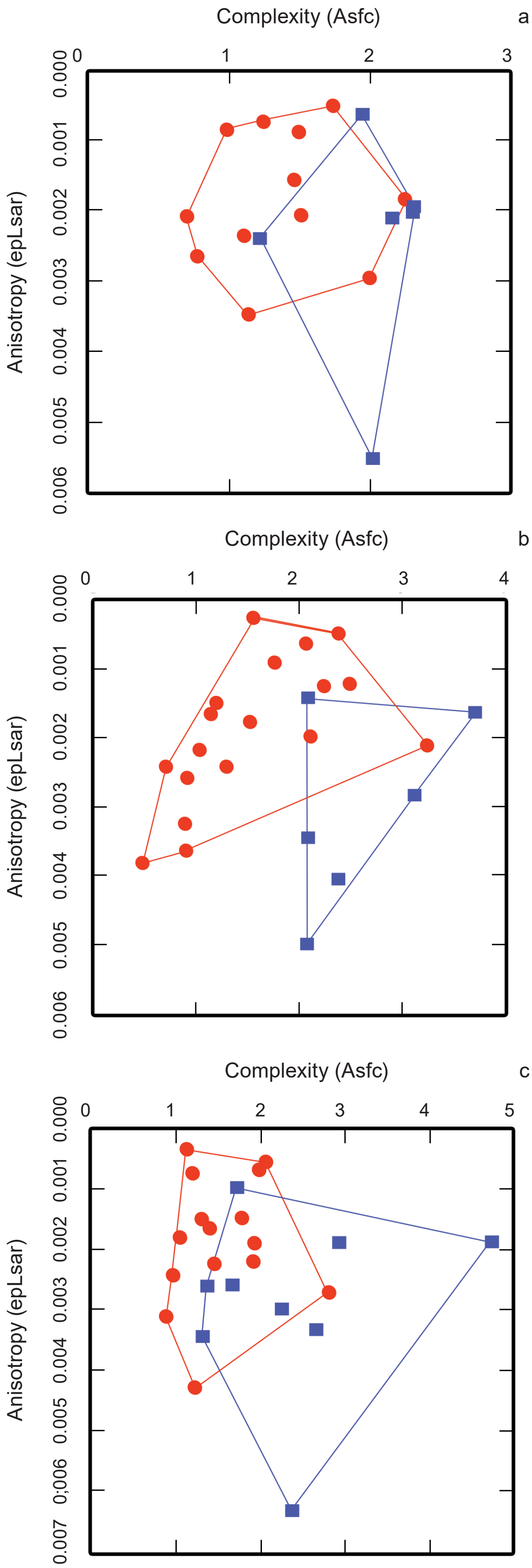

Fig. 5 – (opposite) Bivariate comparisons of complexity and anisotropy for Bois Madame (a), Maurenne (b) and Sclaigneaux (c) with the distribution of deciduous (blue squares) and permanent red circles) molars demarcated by convex hulls inclusive of 100% of the variability of the dental type.

outlier for anisotropy, Sclaigneaux 115 (Fig. 5). Most permanent molars from Sclaigneaux exhibit relatively low anisotropy with the exception of Sclaigneaux 66, whereas most of the deciduous teeth examined present elevated complexity of the enamel surface. However, not all deciduous molars show evidence for a hard and brittle diet. This is particularly true at Sclaigneaux where nearly half of the deciduous molars exhibit relatively low complexity, and are similar to the permanent dental type (Fig. 5).

When the values calculated for the Neolithic caves of the Belgian Meuse basin are compared to those from other Holocene populations, a number of patterns emerge (Fig. 6). For instance, Late Neolithic deciduous molars from the cave burials are somewhat homogenous as a group. However, the permanent molars of the cave assemblages are even more similar to one another for both complexity and anisotropy. For complexity, the 95 % confidence intervals for deciduous molars from the Late Neolithic cave burials most closely align with those of PaleoAmerindians of Lagoa Santa (Fig. 6). In contradistinction, the permanent molar complexity for the cave burials of the Belgian Meuse basin align most closely with the worldwide samples of foragers and farmers but not pastoralists with softer diets (SCHMIDT *et al.*, 2016). Maurenne followed by Sclaigneaux exhibit higher means and most closely resemble Archaic Indiana and the worldwide assemble of foragers, whereas Bois Madame with a lower value is most similar to Early Bronze Age England in terms of the hardness of food resources in the diet (Fig. 6).

Considering anisotropy, the permanent molars from the Belgian Meuse basin are most distinct from Early Bronze Age England. In addition, the values for the Late Neolithic cave burials are substantially lower than those observed for pastoralists and the worldwide assemblages of foragers and farmers (Fig. 6). However, the 95 % confidence intervals for the permanent molars of the Late Neolithic caves do overlap those of Archaic Indiana and Lagoa Santa suggesting a diet like that of archaic forager/farmers and early Holocene foragers of the Americas, and unlike that of dedicated food producers across the world. The deciduous molars of the Belgian Meuse basin exhibit higher values and the means are most similar to the worldwide assemblage of forager values, as well as those of Lagoa Santa and Archaic Indiana. The means for the deciduous molars from the Belgian Meuse basin are decidedly distinct, albeit with large 95 % confidence intervals, from the worldwide group of farmers, pastoralists and Early Bronze Age England (Fig. 6).

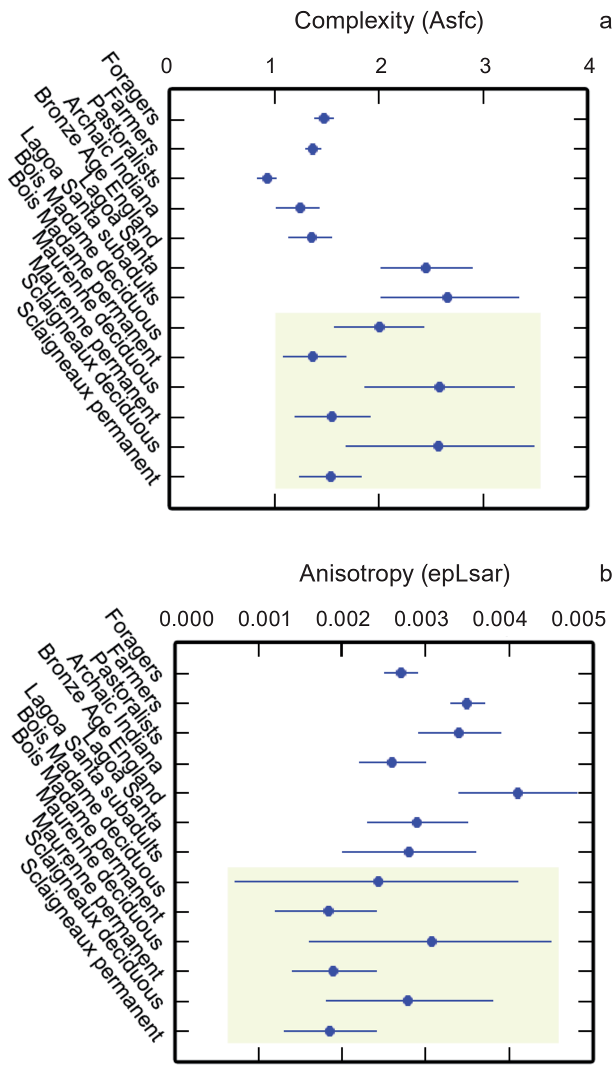

Fig. 6 – Means of complexity (a) and anisotropy (b) with 95% confidence intervals for worldwide samples of foragers and farmers, as well as pastoralists from Late Bronze/Iron Age Mongolia, early Holocene paleoforagers from Lagoa Santa, Brazil, Archaic Indiana forager/farmers and Early Bronze Age farmers from England; Late Neolithic individuals from Belgium are shaded.

4. Discussion

The diet of the Late Neolithic individuals buried in caves of the Belgian Meuse basin was likely to have been most similar to paleoforagers of early Holocene Lagoa Santa, and secondarily to Archaic forager/farmers of Indiana. Archaeological evidence of subsistence at Lagoa Santa include deer, armadillos, peccaries, birds, crocodiles, amphibians, various teleost fish species and mollusks, as well as numerous plants such as xixá (*Sterculia chicha*), jatobá (*Hymenaea* sp.), palm nut (*Syagrus flexuosa*), araticum (*Annona classiflora*) and pequi (*Caryocar brasiliense*; DA-GLORIA & SCHMIDT, 2020), whereas Archaic Indiana forager/ farmers consumed chenopods (*Chenopodium*) of the goosefoot family, sumpweed (*Iva annua*), knotweed (*Polygonum erectum*), sunflower (*Helianthus annuus*) and a number of nuts and drupes, including acorn, hickory, chestnut, walnut and beechnut, as well as white-tailed deer, rabbit, fish and shellfish (CHAPMAN & WATSON, 1993; YARNELL, 1993; SCHMIDT *et al.*, 2020). The diet of young children from the Late Neolithic of the Belgian Meuse basin represented by deciduous molars was similar in mechanical hardness to a subadult sample from Lagoa Santa. Interestingly, Lagoa Santa subadults present higher complexity values than a mixed subadult/adult sample (DA-GLORIA & SCHMIDT, 2020), resembling the higher values of deciduous molars compared to the lower ones for the secondary teeth from the Belgian Meuse basin (Fig. 6). There also seems to be an age-effect among Medieval children from Canterbury, England, where older individuals had the hardest diets, while those between four and six years, the toughest (MAHONEY *et al.*, 2016), and for children at Herculaneum, where older children had higher complexity values than younger ones (REMY & SCHMIDT, 2016). Meanwhile, the relatively elevated complexity values for the permanent molars of the Belgian Meuse basin resemble those of Archaic Indiana, Early Bronze Age England and worldwide samples of foragers and farmers, indicating a diet including hard/brittle foods, poor processing technology, or some combination of both.

Although there is much overlap, the diets of young children and older individuals of the Late Neolithic of the Belgian Meuse basin depart the greatest at Maurenne, and secondarily at Sclaigneaux (Fig. 5). It is possible that the difference in enamel microwear textures of deciduous and permanent molars could be the result of differing diets (KELLY *et al.*, 2020). Other explanations could be how food is masticated, the structural components of the dental types, the size, shape and strength of the ascending ramus and masticatory musculature, the degree of food processing as well as the sand and grit load brought into the oral cavity (KELLY *et al.*, 2020; SCHMIDT *et al.*, 2020).

Regardless of dental type, Sclaigneaux followed by Maurenne exhibit the coarsest diets, while at Bois Madame the diet was somewhat softer (Fig. 5). The same patterns hold for anisotropy, although Maurenne exhibits more individuals with relatively elevated anisotropy compared to Sclaigneaux with the exception of Sclaigneaux 66 (Fig. 5). Those at Bois Madame tend to show slightly lower values excepting one outlier, BM Md 37 (Fig. 5). The low anisotropy values from the Belgian Meuse basin are distinct compared to the much higher values from Early Bronze Age England, the worldwide sample of farmers as well as pastoralists from Late Bronze/Iron Age Mongolia. Elevated anisotropy is associated with the consumption of tough, fibrous foods typically but not exclusively the result of processing agricultural staples in Holocene humans (SCHMIDT *et al.*, 2019). Low values, particularly for the permanent molars, suggest a diet that was masticated with heterogeneous jaw movements, like those characterizing the consumption of wild foods often found in hunter/gatherer diets. Poor processing technology could have also contributed to lower anisotropy. The smooth, repetitive jaw movement characterizing later agriculturalists is simply not possible when plant foods are processed using rudimentary techniques. In fact, many individuals sampled from pre-agricultural/ pre-ceramic paleoforagers from Lagoa Santa have low anisotropy values (DA-GLORIA & SCHMIDT, 2020), resembling those of the Late Neolithic cave burials of the Belgian Meuse basin.

Although the caves of the Belgian Meuse basin are associated with agricultural implements, these Late Neolithic peoples relied on a wide variety of foods that required different motions of the jaws to process. Not all of the caves contain artifacts (TOUSSAINT, 2007). In many of the caves, only human remains are recorded (TOUSSAINT, 2007), although some were excavated in the 19th century and associated artifacts and faunal fragments could have been lost. In contrast, the inventories of other burials are extensive, such as at Bois Madame of the Burnot Valley (Fig. 1), excavated in 1938, where more than 15,400 bone fragments are known, including approximately 5,400 human remains of at least 40 individuals (DUMBRUCH, 2003). The animal remains are voluminous at the site, including terrestrial and aquatic (mollusks) resources. These include mammals, such as horses, artiodactyls, non-ruminants (pigs), bovids, cervids, goats, carnivores such as dogs and foxes, cats, both wild and domestic, badgers, polecats, rabbits, hares, insectivores (shrews) and bats, as well as birds and amphibians, such as salamanders, toads and frogs (DUMBRUCH, 2003). Although some of these animal remains may not have an anthropogenic origin, certainly some added to the diet. A limited number of stone and bone artifacts as well as ceramics were also recovered, suggesting a broad-based, but perhaps poorly processed diet, largely devoid of tough, fibrous plant tissues.

5. CONCLUSION

The diet of the Late Neolithic of Belgium differed from Early Bronze Age England in which anisotropy in particular renders the two distinct. In fact, it is possible that the individuals buried during the Late Neolithic in the karstic caves and rockshelters of the Belgian Meuse river and its tributaries incorporated greater amounts of hard and resistant food particles typical of poorly processed forager diets. The lack of directionality of microstriations, or anisotropy, found in permanent molars suggest a diet bereft of tough foods characterizing most farmers and pastoralists. With respect to the Late Neolithic cave burials of Belgium, there appears to be a common diet with little differentiation across time period and geography. Differences between the caves are subtle. Bois Madame appears to have the least dietary variation, whereas Maurenne and Sclaigneaux had more broadly-based diets, particularly those of young children with deciduous molars. The diet was likely coarse and poorly processed with few tough, fibrous foods consumed, and resembling early Holocene foragers and archaic forager/farmers from the Americas and dissimilar to Bronze Age farmers of northern Europe and elsewhere.

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