Notae Praehistoricae, 36 / 2016 : 103-112

The radiocarbon evidence from the Mesolithic site of Well-Aijen (NL): a Bayesian model

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1. Introduction

Because of severe floods in the Province of Limburg in the early '90s, the Province of Limburg and the Dutch government planned a large-scale civil project to prevent future floods of the Meuse. This project includes lowering of floodplain levels and the construction of new channels and is combined with extraction of sand and gravel for commercial goals.

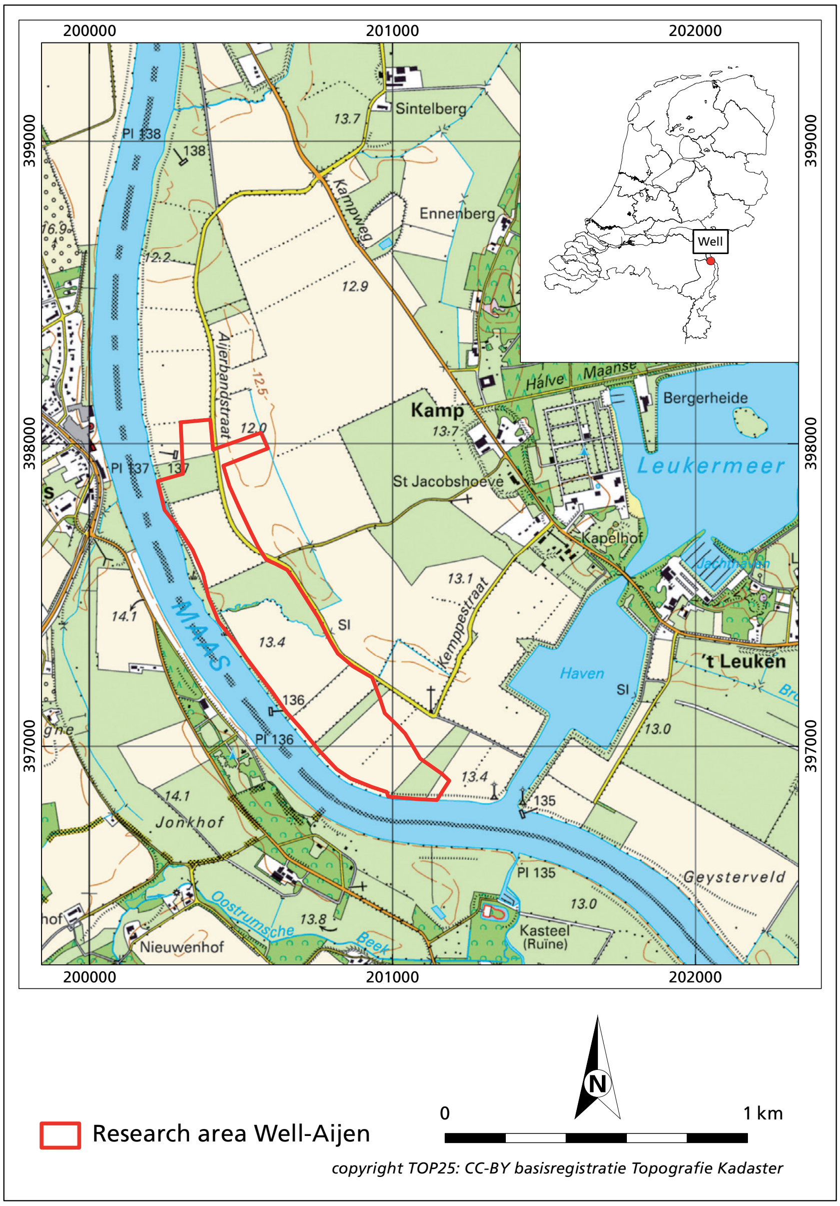

Fig. 1 – Position of the site of Well-Aijen within the Netherlands and the Meuse valley.

This paper deals with the area south of the hamlet Aijen and north of the village Well, one of many locations selected for preventive measures (Fig. 1). Before the construction of a new channel an extensive program of test trenches and archaeological assessments has been conducted in the area of the construction work (Tichelman, 2004; Kimenai & Mooren, 2014; Bouma & Muller, 2011). At these locations, the prehistoric landscape was found to be covered with substantial layers of river sediments during the Roman and post-Roman period and therefore very well preserved. Many artefacts and features from the Mesolithic and Neolithic period have been documented (Fig. 2). From early on it was clear that these sites where of major importance for understanding stone-age occupation in the river valley.

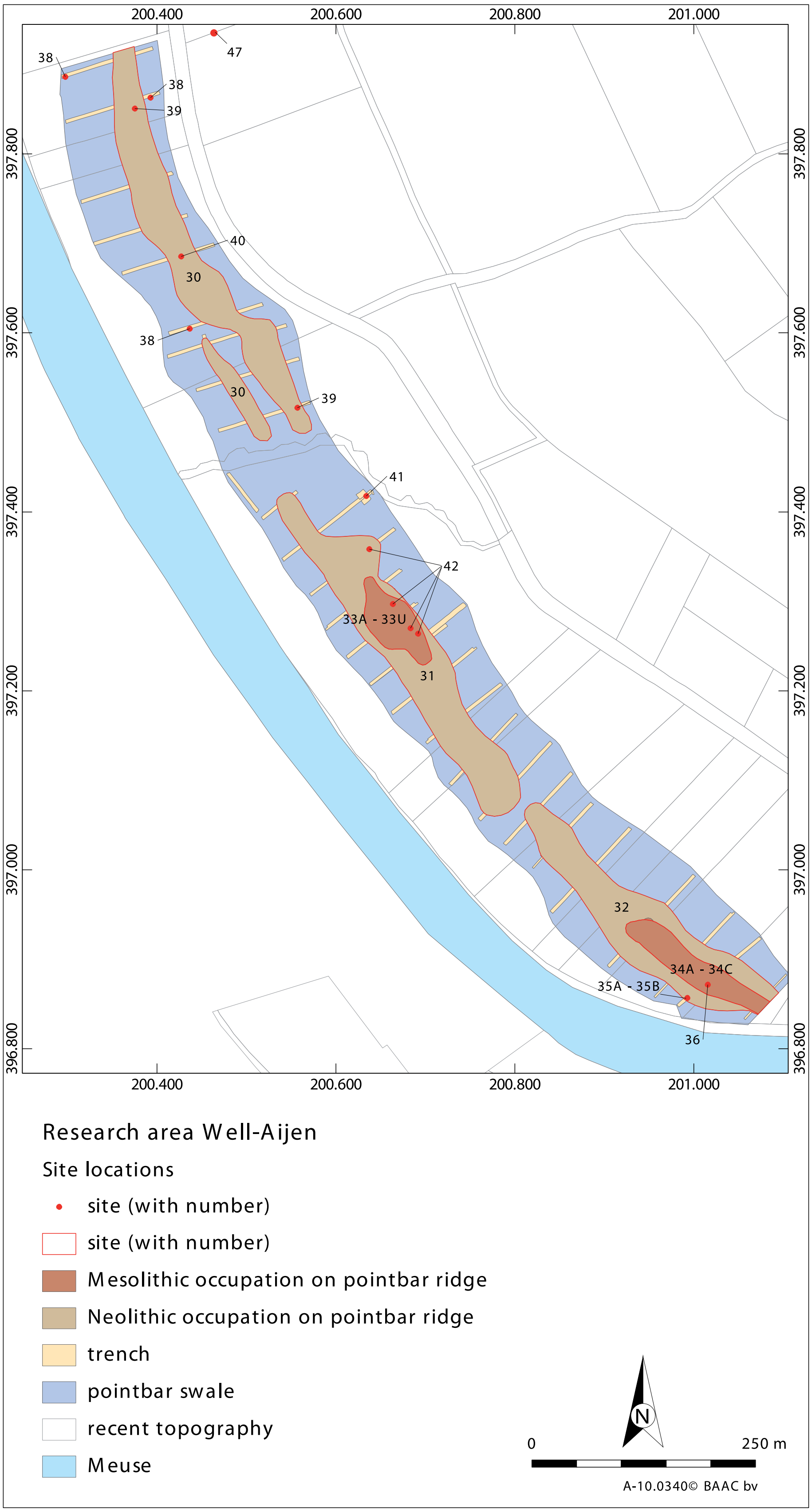

Fig. 2 – Distribution of the prehistoric sites at Well-Aijen.

Because *in situ* preservation of the site was not an option a large-scale excavation was planned, funded by the Province of Limburg. Between 2012-2014 ADC and BAAC (two cultural resource management companies) collaborated in the excavation, Vestigia Consultancy supervised and the Dutch State Department for Cultural Heritage was the commissioning authority. A full report will be published in 2017.

The excavations are finished, but the data are still being analysed. Nevertheless, some preliminary conclusions can be drawn already. Prehistoric occupation is found on the fossil riverbanks (levees) of the Meuse (Fig. 2). The analysis of the excavated data shows a strong relation between occupation and the river. The location of sites changed over time as the course of the river Meuse changed as well. The earliest use of the river levees is dated in the preboreal Mesolithic period and ends in the Iron Age when the area starts to be covered with layers of river sediments. Since different zones or places along the river were used in different periods, there seems to be a strong relation between the evolution of the landscape, changes in vegetation and the behaviour of the people who used this landscape. A chronological framework is of utmost importance to get a clear view on these relations through time. Therefore, 84 samples have been analysed for AMS-^{14}C-dates, of which 43 are related to the Neolithic or younger occupation phases, while 31 belong to the Mesolithic occupation phases.

2. The Mesolithic site

During the three excavation campaigns, fifteen Mesolithic flint scatters or clusters have been excavated. Based on the composition of the microliths eight clusters 47, 33E, 33F, 33G, 33H, 33K, 33L and 33U can be relatively dated in the Early Mesolithic. They are mainly characterised by points with natural base (obliquely truncated points and unilaterally backed points), but also by some triangles, points with retouched base and/or crescents. Other types, like hybrids or needle-shaped points, occur incidentally. Clusters 33S, 33Q and 33I have the same typological composition but differ by the presence of some backed bladelets (33S, 33Q) or a single invasively retouched microlith (33I). Whether these are part of the assemblage or intrusive remains unclear. Clearly of a younger, Middle Mesolithic age are clusters 34A, 34C and 35D which are characterised by a significant amount of backed bladelets, combined with invasively retouched microliths (cluster 34A) and some Early Mesolithic types (Tab. 1). Finally the armatures of cluster 35AB only consist of trapezes and transverse arrowheads. At cluster 35D, a single trapeze was found. Furthermore in both Late/Final Mesolithic clusters small amounts of pottery were collected. However the relation between the flint and the pottery within cluster 35D could not be corroborated due to bioturbation and the later covering of the site.

	Cluster 34A	*Cluster 34C*	*Cluster 35D*
Obliquely truncated points	1		
Triangles	2		
Needle-shaped points		1	
Backed bladelets	31	7	8
Invasively retouched microliths	6		
Undefined microlith fragments	4	3	
Symmetric trapezes			1

Tab. 1 – Typological composition of the microliths found within the Middle Mesolithic clusters.

3. The chronological evidence

3.1. Stratigraphic evidence

Within three excavation areas the lithic remains seemed to occur in two different levels. The Early Mesolithic clusters 33L and 33K are situated on top of each other, clearly separated by a sandy river deposit. On the other hand within the two other areas no such sterile layer could be observed, yet it is clear that cluster 33Q overlies 33G while cluster 33I overlies 33H/U.

3.2. Radiocarbon evidence

Except for the Middle Mesolithic cluster 34A which is dated on unknown charcoal, only charred hazelnut shells were selected for radiocarbon dating (Tab. 2). Due to the extreme fragmentation of the burned hazelnut shells, the samples had to be composed of two or more small fragments; yet only fragments from the same excavation grid cell of 50 x 50 x 5 cm were combined in view of limiting possible contamination. Selection of samples was carefully done following the guidelines set by Crombé *et al*. (2009; 2013). Samples were retrieved as much as possible from latent surface hearths, as indicated by concentrations of overheated lithic artefacts (Sergant *et al*., 2006). If this was not feasible, samples were taken from within the boundaries of the lithic scatters, avoiding hazelnut shells found outside them. Following this procedure nearly all Mesolithic clusters could be dated by one or more samples, except for clusters 33I, 33Q and 35D which yielded insufficient hazelnut shells[1].

1. Only for site 33I a radiocarbon date from a test trench is available (7334 ± 60 BP). It is however unclear if it can be related to the occupation phase and the flint assemblage.

Lab-code	*Site Reference*	*Context Reference*	*Material*	$\delta^{13}C$	*Radiocarbon Age BP*
SUERC-62696 (GU38626)	Well-Aijen (site 33E)	234991-1	Carbonised seeds : *Corylus avellana* fragments	-24.9 ‰	9255 ± 34
SUERC-62697 (GU38627)	Well-Aijen (site 33E)	234991-2	Carbonised seeds : *Corylus avellana* fragments	-25.4 ‰	9302 ± 34
SUERC-62698 (GU38628)	Well-Aijen (site 33E)	232953	Carbonised seeds : *Corylus avellana* fragments	-25.0 ‰	9448 ± 34
SUERC-62699 (GU38629)	Well-Aijen (site 33S)	230565	Carbonised seeds : *Corylus avellana* fragments	-24.7 ‰	8860 ± 34
SUERC-62700 (GU38630)	Well-Aijen (site 33S)	228391	Carbonised seeds : *Corylus avellana* fragments	-25.2 ‰	8856 ± 34
SUERC-62704 (GU38631)	Well-Aijen (site 33F)	324828	Carbonised seeds : *Corylus avellana* fragments	-22.7 ‰	9379 ± 34
SUERC-62705 (GU38632)	Well-Aijen (site 33F)	318504	Carbonised seeds : *Corylus avellana* fragments	-27.5 ‰	8786 ± 34
SUERC-62706 (GU38633)	Well-Aijen (site 33F)	318508	Carbonised seeds : *Corylus avellana* fragments	-24.0 ‰	8893 ± 37
SUERC-62707 (GU38634)	Well-Aijen (site 33H)	265235	Carbonised seeds : *Corylus avellana* fragments	-23.2 ‰	9258 ± 34
SUERC-62708 (GU38635)	Well-Aijen (site 33H)	265315	Carbonised seeds : *Corylus avellana* fragments	-25.4 ‰	9307 ± 34
SUERC-62709 (GU38636)	Well-Aijen (site 33H)	271839-1	Carbonised seeds : *Corylus avellana* fragments	-26.0 ‰	9218 ± 34
SUERC-62710 (GU38637)	Well-Aijen (site 33H)	271839-2	Carbonised seeds : *Corylus avellana* fragments	-26.6 ‰	9371 ± 34
SUERC-62714 (GU38638)	Well-Aijen (site 33H)	258610	Carbonised seeds : *Corylus avellana* fragments	-25.9 ‰	9343 ± 34
SUERC-62715 (GU38639)	Well-Aijen (site 33H)	258531	Carbonised seeds : *Corylus avellana* fragments	-26.5 ‰	9326 ± 34
SUERC-62716 (GU38640)	Well-Aijen (site 33H)	258771	Carbonised seeds : *Corylus avellana* fragments	-27.1 ‰	9363 ± 34
SUERC-62717 (GU38641)	Well-Aijen (site 33H)	258873	Carbonised seeds : *Corylus avellana* fragments	-26.2 ‰	9288 ± 34
SUERC-62718 (GU38642)	Well-Aijen (site 33K)	154183	Carbonised seeds : *Corylus avellana* fragments	-23.7 ‰	>50000 Background Result
SUERC-62719 (GU38643)	Well-Aijen (site 33K)	154241	Carbonised seeds : *Corylus avellana* fragments	-25.0 ‰	8911 ± 34
SUERC-62720 (GU38644)	Well-ijen (site 33K)	154165	Carbonised seeds : *Corylus avellana* fragments	-27.6 ‰	649 ± 34
SUERC-62724 (GU38645)	Well-Aijen (site 33L)	146092	Carbonised seeds : *Corylus avellana* fragments	-27.8 ‰	9266 ± 34
SUERC-62725 (GU38646)	Well-Aijen (site 33L)	146192	Carbonised seeds : *Corylus avellana* fragments	-24.9 ‰	9200 ± 34
SUERC-62726 (GU38647)	Well-Aijen (site 33L)	146212	Carbonised seeds : *Corylus avellana* fragments	-23.5 ‰	9310 ± 34
SUERC-62727 (GU38648)	Well-Aijen (site 33G)	247812	Carbonised seeds : *Corylus avellana* fragments	-25.8 ‰	9327 ± 34
SUERC-62728 (GU38649)	Well-Aijen (site 34A)	434129	Charcoal: Unknown	-24.7 ‰	8542 ± 34
SUERC-62729 (GU38650)	Well-Aijen (site 34A)	431909	Charcoal: Unknown	-24.9 ‰	8544 ± 34
SUERC-62730 (GU38651)	Well-Aijen (site 34A)	436249	Charcoal: Unknown	-23.8 ‰	8577 ± 34
SUERC-62734 (GU38652)	Well-Aijen (site 34C)	567841	Carbonised seeds : *Corylus avellana* fragments	-24.9 ‰	7111 ± 34
SUERC-62735 (GU38653)	Well-Aijen (site 35A)	380625	Carbonised seeds : *Corylus avellana* fragments	-26.3 ‰	5846 ± 34
SUERC-62736 (GU38654)	Well-Aijen (site 35B)	380032	Carbonised seeds : *Corylus avellana* fragments	-24.6 ‰	5452 ± 34
SUERC-62737 (GU38655)	Well-Aijen (site 35A)	373597	Carbonised seeds : *Corylus avellana* fragments	-27.1 ‰	5808 ± 34
SUERC-62738 (GU38656)	Well-Aijen (site 47)	127588	Carbonised seeds : *Corylus avellana* fragments	-24.6 ‰	9207 ± 34
SUERC-62739 (GU38657)	Well-Aijen (site 47)	10969	Carbonised seeds : *Corylus avellana* fragments	-23.9 ‰	9255 ± 34

Tab. 2 – List of the 31 Mesolithic radiocarbon dates from Well-Aijen.

3.3. OSL evidence

An OSL date was obtained from the sandy river deposit in between 33L and 33K. The obtained results is: 9.1 ± 1.2 ka (before 2013).

3.4. Bayesian modelling

The radiocarbon dates (Tab. 2) can be used directly to interpret the archaeological results. Bayesian modelling of the dates allows the inclusion of different chronological archaeological data. In radiocarbon dating, Bayes' theorem is used to include absolute a priori knowledge about a dated event or function into non-Gaussian probability distributions of its dates, in order to obtain a preferably more accurate and precise posterior probability distribution of this event. Bayesian modelling of radiocarbon data integrating archaeological or other stratigraphic or depositional information has been introduced over two decades ago (Buck *et al.*, 1991; Buck *et al.*, 1992). It was only after user friendly software was developed by Bronk Ramsey (1995; 2001; 2009), Stuiver and Reimer (1993) and others that these techniques have become more widely and easily applied by archaeologists, but also critically evaluated (Steier & Rom, 2000). Calibration, analysis and Bayesian modelling of the dates were performed using Oxcal 4.2 (Bronk Ramsey, 2009) and the IntCal13 curve (Reimer *et al.*, 2013).

At Well-Aijen, the association of the dated samples with Early, Middle and Late Mesolithic artefacts allowed typological ordering of the dates into a Sequence of three contiguous Phases (without hiatuses) (filled blue boxes in Fig. 3). By using a simple Boundary (arrows in Fig. 3) to bound the phases, a uniform distribution with random ordering of the dates is assumed within the Phase. In addition, various samples associated with a single hearth were combined into a single modelled date using the R_combine function (blue lined boxes in Fig. 3). The dates were only combined if they passed a Chi-squared test at 5 %. Finally, stratigraphic information was also included as a contiguous sequence as a refinement within the Early Mesolithic phase because site 33L hearth 2 (with 3 combined dates) was covered by an OSL dated sediment layer on which the site 33K-154241 dated sample was retrieved. The association of sample 34C-567841 with Middle Mesolithic artefacts was unclear, therefore it was marked as an outlier (marked by "?"). This prior information is schematically illustrated in Fig. 3.

The results of the modelling procedure are shown in Fig. 4 and Tab. 3. The results indicate a good fit for the general model. The date on sample 33F-318504 has a bad agreement index, however, as it stands out of the distribution of the Early Mesolithic phase and as a consequence, the boundary between the Early and Middle Mesolithic period is modelled quite early, i.e. between 10125 cal BP and 9725 cal BP. Similarly the boundary between the Middle and Late Mesolithic period is modelled with a large uncertainty, between 9532 cal BP and 6584 cal BP. This is due to the lack of (uniformly distributed) samples during the Middle Mesolithic period.

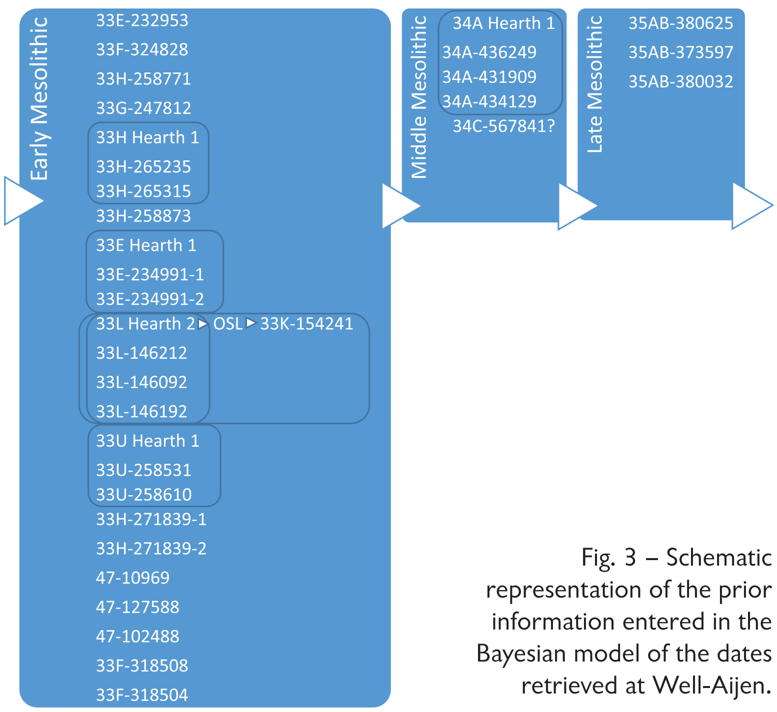

Fig. 3 – Schematic representation of the prior information entered in the Bayesian model of the dates retrieved at Well-Aijen.

Name Amodel 77.5 Aoverall 77"	Unmodelled (BP)			Modelled (BP)			Indices			
	from	*to*	%	*from*	*to*	%	*Acomb*	*A*	*P*	*C*
Sequence Well-Aijen										
Boundary Start Early Mesolithic				10809	10593	95				99
Phase Early Mesolithic										
R_Date Site 33E-232953	10761	10581	95	10720	10575	95		90.6		99
R_Date Site 33F-324828	10695	10515	95	10681	10514	95		102		99
R_Date Site 33H-258771	10686	10503	95	10676	10501	95		102		99
R_Date Site 33G-247812	10654	10423	95	10652	10424	95		101		99
R_Combine Site 33H Hearth 1	10571	10398	95	10571	10398	95		99.8		99
R_Date Site 33H-258873	10581	10301	96	10582	10301	95		100		100
R_Combine Site 33E Hearth 1	10570	10304	95	10570	10305	95		99.8		100
Sequence 33L>33K										
R_Combine Site 33L Hearth 2	10520	10299	95	10543	10301	95		103		100
N OSL	11435	6635	95	10499	9995	95		84.5		100
R_Date Site 33K-154241	10182	9914	95	10185	9934	95		98		100
R_Combine Site 33U Hearth 1	10650	10441	95	10649	10440	95		101		100
R_Date Site 33H-271839-1	10496	10261	95	10496	10263	95		100		100
R_Date Site 33H-271839-2	10691	10511	95	10676	10509	95		102		100
R_Date Site 47-10969	10554	10287	95	10553	10286	95		100		99
R_Date Site 47-127588	10491	10254	95	10491	10254	95		99.9		99
R_Date Site 47-102488	10486	10248	95	10486	10248	95		100		100
R_Date Site 33F-318508	10184	9894	95	10184	9930	95		101		100
R_Date Site 33F-318504	10115	9661	95	10156	9779	95		36.9		100
Boundary Transition Early to Middle Mesolithic				10125	9725	95				99
Phase Middle Mesolithic										
R_Combine Site 34A Hearth 1	9548	9500	95	9548	9503	95		95.7		100
R_Date Site 34C-567841	8006	7861	95	8006	7861	95			80	99
Boundary Transition Middle to Late Mesolithic				9532	6584	95				98
Phase Late Mesolithic										
R_Date Site 35AB-380625	6743	6561	95	6741	6560	95		98.8		100
R_Date Site 35AB-373597	6715	6498	95	6715	6498	95		100		100
R_Date Site 35AB-380032	6303	6197	95	6306	6201	95		99.3		100
Boundary End Late Mesolithic				6322	4436	95				98
Length Early Mesolithic				*508*	*1015*	*95*				*99*
Length Middle Mesolithic				*528*	*3461*	*95*				*98*
Length Late Mesolithic				*342*	*3935*	*95*				*96*

Tab. 3 – Results of the Bayesian modelling at Well-Aijen (A: agreement index, P: outlier probability, C: convergence).

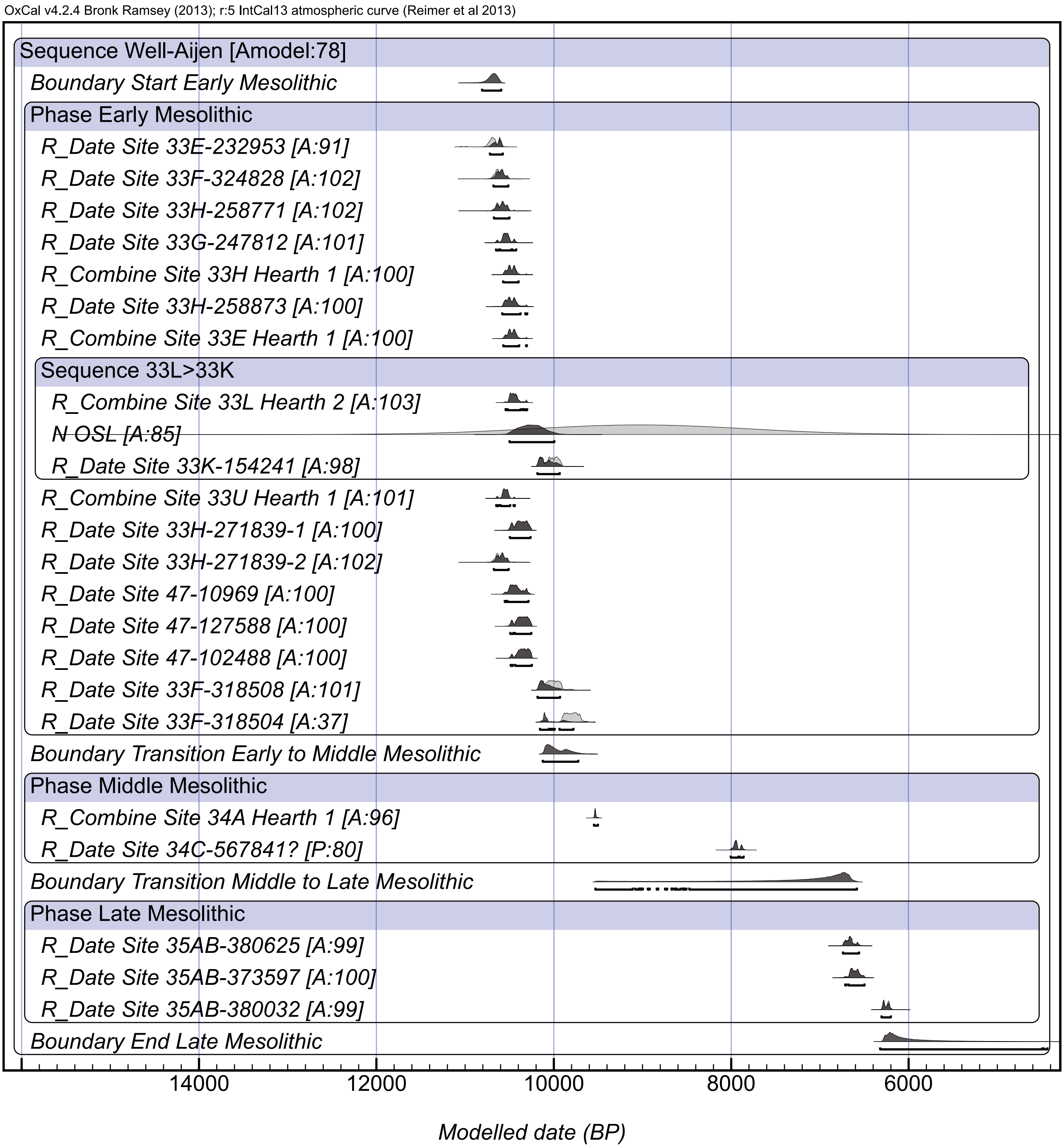

Fig. 4 – Results of the Bayesian modelling at Well-Aijen (Modelled and calibrated date ranges at 2σ, A: agreement index, ?: outlier marker with P: outlier probability).

4. *Conclusions*

If we accept the above modelling results, the start of the Middle Mesolithic at Well-Aijen is situated well before the onset of the cooling event known as the 9.3 ka cal BP event, as known from the Greenland ice-core records (Rasmussen *et al.*, 2007) and the deep-sea cores (Bond *et al.*, 1997). According to the most recent INTIMATE event stratigraphy (Blockley *et al.*, 2012; Rasmussen *et al.*, 2014) this abrupt climate event started at 9350 cal BP and ended at 9240 cal BP. In a recent paper Robinson *et al.* (2013) demonstrated on the basis of a critical analysis of the available radiocarbon evidence that the appearance of invasively retouched microliths, which mark the start of the Middle Mesolithic, was a direct response to this cooling event. Robinson *et al.* suggest that the latter led to environmental stress which triggered the development of inter-regional social networks, e.g. by expanding long-distance raw material exchange and creating particular socially symbolic artifact types.

The radiocarbon dates from Well-Aijen presented in this paper, in particular those from cluster 34A, seem to contradict this theory. However, we should be cautious as the latter are conducted on samples of undetermined charcoal fragments. Earlier studies (Crombé *et al.*, 2009; 2013) have emphasized the problems and risks with this kind of samples in dating unstratified Mesolithic contexts. Charcoal samples can be affected by the old wood effect or may be of natural origin (forest fires) making them less reliable. Similar doubts can be addressed to three recently obtained dates on cremated human bones from the Middle Mesolithic site of Rotterdam "Beverwaard" (Zijl *et al.*, 2011). As no cross-dating with other dating material has so far been done, the reliability of these bone dates remains unverified. Inter comparison research on other sites (Crombé *et al.*, 2013) has shown that cremated bone dates are often not compatible with other dates from the same context, especially for the Late glacial and Early/Middle Holocene (> 5000 uncal BP). Based on all these arguments, we currently conclude that a start of the Middle Mesolithic prior to the 9.3 ka cal BP cooling event remains to be proven.

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Abstract

Salvage excavations at the wetland site of Well-Aijen led to the discovery of numerous Mesolithic (and Neolithic) sites. This paper discusses the chronology of the Mesolithic occupation of the site by means of a Bayesian modelling of the radiocarbon evidence. Finally the results are discussed in terms of the transition of the Early to the Middle Mesolithic and its synchronicity with the 9.3 ka cal BP cooling event.

Keywords: Well-Aijen, Province of Limburg (NL), Mesolithic, radiocarbon dates, Bayesian modelling, 9.3 ka cal BP event.

Samenvatting

Bij preventieve opgravingen op de wetland vindplaats van Well-Aijen kwamen meerdere mesolithische (en neolithische) sites aan het licht. In dit artikel wordt de chronologie van de mesolithische bewoning via een Bayesiaanse modellering van 31 koolstofdateringen, hoofdzakelijk uitgevoerd op verkoolde hazelnootschelpen, geanalyseerd. Bijzondere aandacht gaat hierbij uit naar de overgang van het vroeg naar het midden-mesolithicum en de mogelijke relatie met de 9.3 ka cal BP afkoeling.

Trefwoorden: Well-Aijen, provincie Limburg (NL), mesolithicum, koolstofdatering, Bayesiaanse statistiek, 9.3 ka cal BP event.

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