New radiometric ages for the Early Upper Palaeolithic type locality of Brno-Bohunice (Czech Republic): comparison of OSL, IRSL, TL and 14C dating results

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A B S T R A C T
New radiometric data are reported from the recent excavation of the type locality of the Early Upper Palaeolithic entity of the Bohunician. Recently obtained radiocarbon (14C) data on charcoal are compared with new Optically Stimulated Luminescence (OSL) dating of sediment. OSL ages were determined on sediment from the archaeological occupation at Brno-Bohunice, as well as from the over- and underlying loessic sediments. Multiple techniques were applied, which all gave congruent results. While a dual protocol (post IR-OSL) failed the quality criteria tests, ages were obtained by Multiple-Aliquot-Additive-Dose (MAAD) on polymineral material and Single-Aliquot-Regeneration (SAR) on fine grain quartz extract as well as on polymineral material. Fading tests show significant loss of Infrared Stimulated Luminescence (IRSL) after storage for 3 and 12 months for one sample, but little or no fading for others. The resulting (uncorrected) age estimates are smaller than those on quartz by OSL methods. The latter are considered to be more reliable estimates of the sedimentation age of these deposits. The measured OSL doses do not show a simple distribution and the lowest 5% was used for age calculation to represent the most likely sedimentation age. The quartz from the loess overlying the archaeological layer is OSL dated to 30.9 ± 3.1 ka, while the sediment for the paleosol which contains the archaeological layer gave an age of 58.7 ± 5.8 ka. The attribution of this paleosol to the Hengelo interstadial is therefore questionable. However, if the Hengelo interstadial is correlated with the Dansgaard/Oeschger (D/O) event 12, statistical agreement within 2-sigma is achieved. The OSL result for the archaeological layer is in accordance with a weighted average TL date on heated flint artifacts of 48.2 ± 1.9 ka from this layer as well as calibrated radiocarbon data (CalPal Hulu 2007) from nearby locations. However, radiocarbon data on charcoal samples obtained during excavation at Brno-Bohunice 2002 provide age estimates between 30 and 40 ka 14C-years, which translate to approximately 33–44 ka on the calendric time scale according to the Hulu 2007 model. For the underlying loess a depositional age of 104.3 ± 10.6 ka was obtained by OSL. The presented OSL ages indicate that a simple correlation of soil sequences between sites within a region has to be verified by chronometric dating.

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1. Introduction

Any understanding of the evolutionary significance of the cultural ‘transition’ from the Middle to Upper Palaeolithic or the biological change from archaic to modern hominins requires an improvement in the chronological resolution of Early Upper Palaeolithic archaeological entities across Eurasia in Oxygen Isotope Stage 3 (see e.g. Zilhão and d’Errico, 2003; Jöris and Adler, 2008; Roebroeks, 2008). The present paper reports on a dating project involving OSL, IRSL, and 14C methods, combined with published TL dating results (Richter et al., 2008), designed to refine the chronological position of the Bohunician, a distinctive Early Upper Palaeolithic entity of Central Europe, at the type locality of Brno-Bohunice, Czech Republic. The presentation of these results also represents an opportunity to discuss which 14C age determinations made for various localities on the Red Hill (Cerveny Kopec) of Bohunice over the last thirty years have relevance to the archaeological entity known as the Bohunician. Uncalibrated radiocarbon data are here referred to in 14C-years because of their lack of dimension and BP is not added because of the implicit
convention that all radiocarbon data are related to 1950 (Stuiver and Polach, 1977).

2. The Bohunician industrial type

The Bohunician was first described as an industrial type or technocomplex found in southern Moravia, Czech Republic, consisting of a Levallois-like core technology with a significant blade component and Upper Palaeolithic tool types (Olive, 1981, 1984; Svoboda, 1980, 1987a, 1990). Initially, however, the type-collection from Brno-Bohunice or Bohunice Kejbaly (a local field name), located on the western margin of the city of Brno (Fig. 1), Moravia, was defined by Valoch (1976) as a Szeletien de facies levallois, based on Valoch’s emphasis of two articulated characteristics in the type-collection: 1) Levallois-like core reduction apparent in elongated Levallois points, and 2) bifacial leaf points previously associated with the Szeletian as defined by Červinka (1927) and Prošek (1953). These two characteristics were also found in large surface collections from other localities in southern Moravia (Svoboda, 1980, 1987a). Subsequent excavation of stratified assemblages at Stránská skála on the east side of the Brno Basin, however, produced assemblages with the distinctive core reduction strategy but lacking the leaf points of the type-site or the surface collections (Svoboda, 1983, 1987a, 1991). The reliability of the context of the Stránská skála assemblages, as well as the lack of collection protocols for the Brno-Bohunice type-collection (see below), led to a redefinition of the Bohunician technology (Svoboda and Škrchal, 1995) and a clearer division of the Early Upper Palaeolithic in the region into two local technocomplexes, the Bohunician and the Szeletian (Svoboda, 1983, 1984, 1987a). The Stránská skála Illa and III refits presented by Svoboda and Škrchal (1995) demonstrated that Bohunician technology exhibits a fusion of Upper Paleolithic initiation of the core with a crested blade, followed by often bidirectional volumetric exploitation of the core volume for Levallois points and blades, for which core residuals suggest discoidal or flat cores, or the production of Upper Paleolithic blades on the narrow, lateral edge of the flattened core. While several views exist on Bohunician technology (Nerudová, 2001; Škrchal, 2003b; Tostevin and Škrchal, 2006; Valoch, 2003, 2008), Svoboda and Škrchal’s (1995) definition currently has a wider acceptance in the field (Sitlivy and Zíjea, 2007, pp. 390–394).

The local Early Upper Palaeolithic technocomplexes are currently recognized as chronologically successive on the radiocarbon time scale but with significant overlap (see Svoboda et al., 1996, pp. 99–130; Richter et al., 2008). The Szeletian, a technocomplex more widely known throughout Central Europe and argued to be the persistence of Micoquian tool types into an Upper Paleolithic context (Allsworth-Jones, 1986, 1990), appears only after 39 ka 14C (Valoch, 1984, 1993), but possibly lasting until 26 ka 14C (Adams and Ringer, 2004). The Bohunician in contrast is present in the region between 41 and at least 33 ka 14C (Svoboda and Bar-Yosef, 2003), or between 47 ka (Zoller, 2000) and 180 ka (Bluszcz et al., 1994) by thermoluminescence (TL) dating of sediments (Table 1 and for a list of chronometric dating results see Richter et al., 2008). At face value, the older ranges of these TL results, specifically from Dzierzyszaw I in southern Poland (Bluszcz et al., 1994), are unlikely to be correct and older ranges of these TL results, specifically from Dzierzyszaw I in southern Poland (Bluszcz et al., 1994), which is also the most northerly example of the Bohunician and outside of the Middle Danube proper. The Bohunician has not yet been found in direct stratigraphic superposition over the Middle Palaeolithic (MP) Micoquian in the region, as the Bohunician is not found in cave sites where the MP is preserved. The Bohunician, however, underlays the first ‘classic’ Upper Palaeolithic technocomplex, the Aurignacian, e.g. at Stránská skála Illa the Aurignacian is found within the upper portion of the upper soil of the Interplenioglacial soil complex (Svoboda, 1991). While the stratigraphic positions of these industries provide the backbone of the chronostratigraphy of the region, it is evident that other dating approaches are needed in order to verify the attribution of the soils to distinct climatic events and especially their proposed contemporaneity at several sites.

As with the regional context, the inter-regional significance of the Bohunician in the pattern of the Middle to Upper Palaeolithic transition across Eurasia also requires more direct radiometric data and improvements in archaeological method and theory to answer the questions raised by the Bohunician (Tostevin, 2006, 2007). While the archaeological arguments for the inter-regional origins of the Bohunician are beyond the scope of the present paper, its importance for the question of modern human origins can be succinctly stated in the diversity of claims for the origins of the Bohunician in Moravia (summarized in Richter et al., 2008) as a product of anatomically modern humans (Mellars, 2006), by implication of its local (East Central Europe) origin as a product of Neanderthals (Zilhão, 2006), as an entity of Near Eastern origin (Valoch, 1976, 1982, 1986, 1990; Kozlowski, 2004; Škrchal, 1996, 2003a,b; Tostevin, 2000, 2003a,b; Tostevin and Škrchal, 2006; Mellars, 2006), and of a western European origin (Nerudová, 2001).

3. The type-site of Brno-Bohunice

The initial type-collection from Brno-Bohunice, published by Valoch (1976, 1982), was extracted from bulldozer trenches according to stratigraphic location, in addition to a limited excavation of less than 2 m2 (Valoch, 1982, 2008), but no systematic collection protocols for the three-dimensional positions of artifacts were used and no sieving was done for the four localities of Kejbaly I–IV. In 2002, a 3 m wide by 21 m long strip of intact sediments adjacent to Kejbaly IV was excavated (Škrchal and Tostevin, 2003, 2005; Tostevin and Škrchal, 2006) and is referred to as Brno-Bohunice 2002. This excavation resulted in a detailed study of the artifact distribution within the paleosols and the application of modern proveniencing and collection protocols to artifact recovery (see McPherron and Dibble, 2002). These new data confirm the presence of a single archaeological layer within the Lower Paleosol and the association of characteristic products of Bohunician blade-levalloisian technology with the on-site production of leaf points (Škrchal and Tostevin, 2005). The stratigraphic section of the 2002 excavation also corroborates the stratigraphic picture seen at the Stránská skála localities. In general, the geology of the site is well studied as it is directly adjacent to a classic Pleistocene geological profile (Dambłon et al., 1996): the modern soil covers a loess stratum, which overlies two paleosols, the Upper and Lower Last Interplenioglacial soils, with thicknesses of about 30 cm and 30–50 cm in the main concentration (area A), respectively, above
a loess deposit. The sediments are bioturbated, as was previously recognized by Valoch (2008), who additionally noted pebbles at the base of the Lower Paleosol as evidence of sheet floods. This pebble horizon was also recorded in the 2002 excavation (Sˇkrdla and Tostevin, 2005). Micromorphological analysis is pending for the 2002 excavation, but micromorphology at the site of Bohunice II, or Družba (Fig. 1) showed the genetic identity of the autochthonous soil (pseudogley with a trend towards ‘arctic’ brown soil) with the substratum and a slight disturbance by periglacial conditions of the heavily calcified sediment (Smolı´kova´, 1976). As the Bohunice II (Družba) site cluster is 600–800 m to the southwest of the Bohunice Kejbaly site cluster and the few published artifacts (Valoch, 1974) are not diagnostic of the Bohunician in the view of the present authors, both the lithic assemblage and Smolıková’s analysis may represent an archaeologically, pedologically, and taphonomically different context than the Kejbaly sites, including the Brno-Bohunice 2002 excavation. Nevertheless, Smolıková’s results are an indication that the sedimentation of the deposits on the Red Hill (Cerwený Kopec) was not as straightforward as it may appear from macroscopic observations.

The vertical distribution of piece plotted artifacts (Fig. 2) shows a small assemblage of non-diagnostic artifacts in the Upper Paleosol (n = 43) while the Lower Paleosol at Brno-Bohunice 2002 contains a single vertical distribution of a large number of artifacts (n = 3360) of about 30–50 cm spread. Such a vertical distribution is a common phenomenon for sites in pedogenically altered loessic sediments, but contrasts with Valoch’s (2008) reported 5–10 cm spread of the artifact horizon in Kejbaly IV (Fig. 1). Artifacts in the 2002 assemblage do not show any damage due to large scale movement, and frost broken pieces were always found at distances below 10 cm apart. Only in one case is a conjoin documented between an artifact attributed to the Upper Paleosol with an artifact attributed to the Lower Paleosol (Škrdla and Tostevin, 2005, p. 56). These two artifacts, however, were excavated from the boundary of both paleosols and so the attribution of one or both artifacts to a particular paleosol may be problematic. All other production sequence refits (14 sequences, some of which combined more than two items) and conjoins of breaks (35 instances) were found solely within the Lower Paleosol. This led to the interpretation of the site as the accumulation from one occupation series, which created the observed palimpsest, by humans who produced the Bohunician assemblage with a later very short visit by probably Upper Palaeolithic humans who left only a few artifacts in that area. The occurrence of the archaeological material within a soil also provides a relative age estimate for the assemblage as either pre-dating the formation, or being approximately contemporaneous if the soil developed while sediment slowly accumulated.

Fig. 1. Map showing the locations of the sites mentioned in the text: (1) Bohunice Red Hill sites: 1a–1d are the sites Kejbaly I–IV; 1e Brno-Bohunice 2002; 1f quarry area for Cihelna/Ziegelei/brickyard (shaded area open to E and with a dashed line to W); 1g Družba (about 600–800 m to SW as indicate by arrow); (2) Stránská skała sites.
Table 1
Radiocarbon data for charcoal from all Bohunician sites: First panel Stránská skála Hill sites; second panel Bohunice Red Hill sites of Cihelna and Kejbaly, where Cihelna, Ziegele, and brickyard quarry all denote the same general locality where samples were collected during quarrying activities over several decades; third panel Brno-Bohunice 2002 which is adjacent to the Kejbaly sites (see also Fig. 1). Data from table were used for Fig. 3, except infinite and non-Bohunician ages, as well as charcoal not associated with a Bohunician industry (marked ‘‘). (*More likely to be Larix sp.; ‘‘more likely to be Picea sp. Although the condition of the charcoal was such that the Picea (spruce) and Larix (larch) could not often be distinguished with certainty, the frequent ‘‘rarity of biseriate bordered pits is indicative of Picea’’ – Challinor, pers. comm., 2007; Warden et al., 2005,).

<table>
<thead>
<tr>
<th>Age</th>
<th>Location</th>
<th>Layer</th>
<th>Square ID</th>
<th>Interpleniglacial soil</th>
<th>Species</th>
<th>Lab-number</th>
<th>δ13C Reference</th>
</tr>
</thead>
</table>

**Stránská skála Hill sites**

38,200 ± 1100  Stránska Hill sites III-1 5 Upper soil  Abies alba/C6  Picea/Larix sp.  OxA-14843  −24.3  Valoch, 2008
38,300 ± 1100  Stránska Hill sites III-2 5 Upper soil  Abies alba/C6  Picea/Larix sp.  OxA-14844  −23.2  Valoch, 2008
37,900 ± 1100  Stránska Hill sites IIId 5 Upper soil  Larix/C6  Pinus sp.  OxA-14847  −24.8  Valoch, 2008
37,570 ± 1100  Stránska Hill sites IIId 5 Upper soil  Larix/C6  Pinus sp.  OxA-14848  −23.0  Valoch, 2008
37,270 ± 1100  Stránska Hill sites IIId 5 Upper soil  Larix/C6  Pinus sp.  OxA-14849  −24.4  Mook, 1976

**Bohunice Red Hill sites**

42,900 ± 1700  Cihelna  Soil  Picea/Larix sp.  OxA-14837  −25.2  Mook, 1976
42,100 ± 450  Cihelna  Soil  Larix/C6  Pinus sp.  OxA-14838  −25.0  Valoch, 2008
38,250 ± 550  Cihelna  Soil  Larix/C6  Pinus sp.  OxA-14839  −24.8  Valoch, 2008
41,250 ± 450  Cihelna  Soil  Larix/C6  Pinus sp.  OxA-14840  −24.1  Valoch, 2008
36,000 ± 1100  Cihelna  4a  Larix/C6  Pinus sp.  OxA-14841  −23.9  Valoch, 2008
43,600 ± 550  Kejbaly  Soil  Larix/C6  Pinus sp.  OxA-14842  −23.6  Valoch, 2008
42,750 ± 550  Kejbaly  Soil  Larix/C6  Pinus sp.  OxA-14843  −23.3  Valoch, 2008
41,350 ± 450  Kejbaly  Soil  Larix/C6  Pinus sp.  OxA-14844  −23.1  Valoch, 2008
40,173 ± 1200  Kejbaly  Lower soil  Larix/C6  Pinus sp.  OxA-14845  −22.9  Valoch, 2008
41,400 ± 1400 – 1200  Kejbaly II  Lower soil  Larix/C6  Pinus sp.  OxA-14846  −22.7  Valoch, 2008

**Brno-Bohunice 2002**

29,490 ± 240  2002  3 Area A; C1-3; upper paleosol  Indet. coniferous  OxA-14847  −23.9  This publication
36,050 ± 260  2002  4a Area C; E1-3; lower paleosol  Larix/C6  OxA-14848  −23.9  This publication
38,690 ± 320  2002  4a Area D; D2-76; lower paleosol  Pinus sp.  OxA-14849  −24.2  This publication
38,770 ± 330  2002  4a Area D; D4-53; lower paleosol  Larix/C6  OxA-14850  −22.7  This publication
40,025 ± 340  2002  4a Area A; C4-64; lower paleosol  Larix/C6  OxA-14851  −22.7  This publication
43,470 ± 240  2002  4a Area A; C3-31; lower paleosol  Larix/C6  OxA-14852  −22.5  This publication
38,200 ± 330  2002  4a Area A; E3-43; lower paleosol  Pinus sp.  OxA-14853  −22.9  This publication
36,540 ± 310  2002  4a Area A; C4-48; lower paleosol  Larix/C6  OxA-14854  −23.4  This publication
32,740 ± 530  2002  4a Area A; D2-50; lower paleosol  Picea/Abies  ANU-12024  −24.0  Skrolka and Tostevin, 2005
35,025 ± 730  2002  4a Area A; D2-77; lower paleosol  Picea/Abies  ANU-27214  −24.3  Skrolka and Tostevin, 2005
40,000 ± 0  2002  4a Area A; D2-77; lower paleosol  Abies alba/C6  WIK-17757  −23.18  Richter et al., 2008

4. Typology of dating events

In the present effort to compare the OSL, IRSL, 14C, and TL dating results for one archaeological assemblage, a common theoretical means of evaluating the relationship of results from different dating techniques and the human behavior in question is profitable (Dean, 1978; Dincauze, 2000). Dean’s typology of events in his dating techniques and the human behavior in question is profitable results for one archaeological assemblage, a common theoretical arguments of Waterbolk (1971) which are more specifically misunderstanding and misreading of dating results. This ‘‘typology archaeological dating theory is particularly useful in avoiding the targeted event of Dean’s types) constitute the contextual argument that unites the dated event with the target event or in other words, why does the thing dated have anything to do with the human behavior in question? In the following brief discussion of how target event, dated event, and bridging argument work for each of the dating methods used here, we focus on the bridging arguments rather than the internal assumptions of the dating mechanism.

4.1. Radiocarbon dating of charcoal

The dated event in radiocarbon dating is the time of the death of an organism, which relates to the cessation of carbon uptake of the organism. Inherent to the method of radiocarbon dating (and thus the dated event) is the problem of the fluctuation in atmospheric radiocarbon (e.g. Kitagawa and van der Plicht, 1998), which requires radiocarbon ages to be given in 14C-years rather than the calendric time scale of, for instance, luminescence methods. It should also be mentioned that there is a number of radiocarbon records which indicate the possible presence of extreme and complex variation of radiocarbon levels before 30 ka (e.g. Voelker et al., 2000; Beck et al., 2001; Hughen et al., 2004). If correct, radiocarbon data thus could
underestimate the ‘true’ age by 5–9 ka in the lower range of the
method. Other estimates quote a range of even 10–15 ka (Giacco
et al., 2006). In any case, radiocarbon data beyond 30 ka have to be
viewed with caution and cannot be regarded as always reliable (e.g.
Aitken, 1990; Gamble et al., 2005). But probably even more
important is the lack of a commonly agreed procedure on the
calibration of radiocarbon ages in order to convert the dimen-
sionless radiocarbon data to calendric units which are fundamen-
tally needed for any interpretation of processes in archaeology.
Apart from the difficulty of comparing radiocarbon with chrono-
metric dating results obtained by other methods, any model for
human behavior based on uncalibrated radiocarbon data is flawed
by the conventional use (Stuiver and Polach, 1977) of the Libby half-
life of 5568 a to calculate ages, instead the more recently accepted
5730 a. This leads to an underestimation of, for instance, approxi-
ately 1.1 ka at 40 ka on the calendric time scale, a value which is
larger than uncertainties provided for some AMS radiocarbon data.
Here we use the calibration software CalPal, employing the Hulu
2007 calibration curve as one possibility of converting radiocarbon
data to a linear time scale (Weninger et al., 2007; Weninger and
Jöris, 2008). Comparison of this calibration curve with the proposed
Hulu based Cariaco data set (Hughen et al., 2007) resulted in
discrepancies smaller than the uncertainties quoted for the radio-
carbon data. When such an approach is used, it has to be kept in
mind that the original radiocarbon data always should be reported
(Table 1) in order to allow the calibration with future improved data
sets. This is analogous to the history of the dendrochronological
calibration approach, which received its last major revision in 2004
for IntCal04 (Friedrich et al., 2004). A problem which will not be
solved, however, even with a commonly agreed upon calibration
procedure, is the presence of plateaus in the calibration record,
which lead to difficulties in the interpretation of dates.

Also inherent to the method of radiocarbon dating is the
problem of contamination in the dated sample, where a very small
amount of more recent carbon can lead to erroneous ages (e.g.
Aitken, 1990) and infinite radiocarbon ages can therefore become
finite. It is virtually impossible to prove the absence of contami-
nation and great efforts (e.g. ultrafiltration for bone samples Brown
et al., 1988, but also see (Hüls et al., 2007); or ABOX treatment for
charcoal (Bird et al., 1999)) are undertaken to include only those
parts of samples in the measurement procedure, which relate to the
original carbon of the organism, and not a later contaminant (being
younger or older), or the sample being a mixture of organisms,
which might have ceased to exist at different times. Charcoal
notably takes up humic acids (e.g. Scharpenseel and Schifffman,
1977) which usually percolate down through the sediment column
and therefore bring in younger carbon into the sample, thus causing
an apparently too young age. However, the opposite can also apply
(e.g. Richter et al., in press). It is therefore important to physically
and chemically separate out any contaminants. It must be stressed
that contamination is part of the bridging argument in radiocarbon
dating, i.e., the association argument between the anthropological
question and what is dated (i.e., carbon), rather than the dated event
as with dosimetric issues in luminescence methods.

Bridging assumptions are more difficult for radiocarbon dating
than luminescence techniques since the origin of the sample is
rarely clearly demonstrable as anthropogenic, except for charcoal
found in a distinct hearth feature. The target event is thus often less
closely related to the dated event in such circumstances. For
instance, charcoal fragments are highly mobile in sediments and
similar mechanisms of movement as described below for sediment
grains in luminescence dating apply here as well. Syn- and non-
syndepositional charcoal can be generated by natural fires. But
a syndepositional incorporation of charcoal from a context different
in age (natural or human) is also possible in certain sedimentolog-
ic environments. In comparison with hearth fires, natural fires
should produce a less concentrated spatial distribution. However,
the burning of tree stumps with roots penetrating the archaeolog-
ic layer can leave a pattern very similar to a human fireplace. While
human and other (postdepositional) activities might lead to

Fig. 2. Projection of the vertical distribution a) for area A and b) for areas C and D of lithic material. Open triangles represent lithics attributed to the Upper Paleosol and closed
circles represent lithics attributed to the Lower Paleosol. Refits and conjoins are indicated by lines. Open squares with numbers indicate the positions of radiocarbon samples where
the number refers to the last two digits of the laboratory number given in Table 1. Open squares with capital letters indicate the positions of the OSL samples, with A for the sample
from the overlying loess (UL), B from the archaeological deposit (Lower Paleosol, LP) and C from the underlying loess (LL). Z-axis refers to an arbitrary level.
a horizontal scattering of a formerly discrete patch of charcoal from a fireplace, syndepositional concentrations of charcoal can also result from slope wash into slight surface depressions. It is therefore important to sample material which is most likely in situ, which translates to large pieces for which the species can be identified and verified that it belongs to the appropriate palaeoclimatological context as indicated by other proxy data. Given the above processes, charcoal from roots reflects the age of a post-sedimentation organism (often related to a soil formation at that level or above), whereas other large pieces originate from fallen (or chopped) trees and are therefore pre-sedimentological. Only the latter is therefore directly related to the target event.

The above discussion provides an *a priori* framework for addressing the relationship between the different dating results reported in this paper for the human behavior captured by the archaeological record at Brno-Bohunice. It is within the above framework that the anthropological question is posed, which is in most cases “when did the occupation take place?” The association of each sample’s dated event and the anthropologically relevant target event has to be established through the evaluation of the bridging arguments in order to interpret the dating results for the purpose of reconstructing the prehistorical activities or the palaeoenvironment (Dean, 1978). In many cases the age differences are insignificant with respect to the resolution of the chronometric method used. Nevertheless, the relationships between target event, dated event, and bridging arguments have to be discussed and shown in each individual case.

### 4.2. OSL and IRSL dating of sediment

The actual physical event determined by luminescence dating methods for sediment grains is their last exposure to light. This is thus the dated event. While in principle in luminescence sediment dating the time of the original sedimentation is equivalent to the dated event, the influence of sediment grains which have been moved up and down the sediment column has to be taken into consideration. The dated event, i.e., last exposure to light, is not necessarily identical for all sediment grains sampled and used for dating. This is especially true for bio- and cryoturbated sediments, slope washed sediments (which in itself is datable in principle; see e.g. Lang, 1994), soil formatted sediments, and trampled sediments, most of which are indicated for the sediment containing the archaeological material at Brno-Bohunice in addition to possibly the incorporation of older sediments by sheet flows (Skrdla and Tosfevin, 2005, p. 55; Valoch, 2008). Bioturbation comes along with soil formation and leads to a mixing of sediment grains with different light exposure ages. It is therefore, contrary to Valoch (2008), open for discussion if luminescence ages of soil sediments represent the sediment formation or the possibly more recent event of soil formation, bioturbation, or, more likely, a combination of the above. The reference/bridging event/argument of luminescence dating of sediments thus includes both the assumption of a lack of reexposure to light since the target event (i.e., the human occupation) and an assumption of a temporal association between the human occupation and the sedimentation which shields the sampled grains from light. However, in most cases, luminescence dating of sediment provides ante and post quem age estimates for the target event because of the short time length of a human occupation in relation to a sedimentation which is thick enough to get sampled.

### 4.3. TL dating of heated material

The dated event in thermoluminescence dating of heated material like flint is the time of the last exposure of the stone to fire. The target event here is the discard of the stone artifact and the bridging argument is the temporal association between the last heating of the artifact and its discard. Unlike with the OSL and IRSL techniques, TL dating has the advantage of an almost assured association between the dated event and the target event through the human agency involved in the firing of the artifact. The argument for the bridging in TL dating is thus more straightforward. For while natural fires are common, they are not capable in most cases of heating a large volume of rock to such an extent that the entire piece has experienced temperatures above 400 °C as required for zeroing of TL. Even roots and tree stumps do not produce temperatures high enough to severely burn material located in the ground, except in the very immediate vicinity (Whelan, 1995). Temperatures from grass fires are too low and in any case the expectation would be to find a lot of burnt rocks, charcoal and burnt sediment distributed over a large area, in contrast to localized prehistoric fires and/or sparse occurrence of heated material as a result of such hearths (see e.g. Alpersson-Afly et al., 2007). It is therefore a valid assumption for most Palaeolithic sites to associate the heated flint samples directly to the creation of a fire by prehistoric humans. Thus, while TL dating shares many of the methodological issues involved with OSL and IRSL dating, i.e., the requirement for appropriate assumptions of dose rate parameters like sediment moisture levels or the constancy of the γ-dose rate (Richter, 2007), the bridging argument unifying the dated event with the anthropological target event is more secure for TL dating of heated artifacts than for the other luminescence techniques.

## 5. Chronometric ages for the sites at Brno-Bohunice

Three different dating methods were employed on different materials from the site cluster of Bohunice: Radiocarbon (\(^{14}\)C) dating of charcoal, Thermoluminescence (TL) dating of sediment and heated flint and Optically Stimulated Luminescence (OSL and IRSL) dating of sediment.

### 5.1. Radiocarbon dating

A detailed account and discussion of previous attempts to establish ages for the archaeological occupation(s) at Brno-Bohunice Red Hill is given in Richter et al., (2008). Table 1 and the following discussion provide new radiocarbon data on charcoal samples from the Lower Paleosol and the Upper Paleosol of the Brno-Bohunice 2002 locality. Additional data on samples from the Kejbaly site cluster, which are believed to belong to the same serial occupation (Richter et al., 2008) as the Brno-Bohunice 2002 assemblage, are provided by Valoch (2008). However, the lack of systematic documentation at the time of sample collections makes it difficult to evaluate the association and ‘in situ’ nature of the charcoal lenses sampled. Valoch (2008) also provides three samples from the Cihelna locality, i.e., the quarry wall which ranged from 0 m to ca. 50 m to the east of the Kejbaly localities over the last thirty years of quarrying. While Valoch (2008, p. 226) notes that artifacts were found with these charcoal samples from the Cihelna quarry locality, their association with Bohunician artefacts cannot be unambiguously established. The two other Cihelna charcoal samples published previously derive from the Lower Paleosol but without accompanying artifacts.

All radiocarbon ages for all the sites at Bohunice were obtained on charcoal. Radiocarbon samples from the Brno-Bohunice 2002 excavation are well provenanced and originate from charcoal concentrations within the Lower Paleosol which were interpreted in the field as pedogenically altered hearths. Larger charcoal samples from these concentrations were sampled in a maximum radius of 5 cm together with surrounding sediment. The actual samples for radiocarbon dating were then obtained in the laboratory by sieving and flotation, which was followed by additional cleaning in the laboratories and therefore no sediment was included in the
analysis. For ages from the Oxford laboratory species were identified and the largest piece of charcoal was prepared for radiocarbon dating. The sample at the Waikato laboratory consisted of several pieces which appeared to originate from a single piece which broke up and probably one fragment only was used to obtain the age (F. Petchey and A. Hogg, pers. comm.). For the samples at ANU, it is not possible to reconstruct whether one or several pieces of charcoal were actually analyzed. The samples submitted, however, had each the appearance of a single piece of charcoal which broke into pieces during excavation and handling. The resulting ages for all $^{14}C$ determinations on a single piece of charcoal from Brno-Bohunice 2002 range from 33 to 40 ka $^{14}C$, which is similar to the range for the only other radiocarbon dated Bohunicean assemblages at Strážná skála of 34–41 ka $^{14}C$, indicating that the age of the archaeological layer is probably at the limits of the radiocarbon method (Richter et al., 2008). It should be pointed out that 6 out of 14 radiocarbon dates from the Bohunicean assemblages at Strážná skála (Table 1) were obtained from the IIc site, where a thin, undiagnostic Early Upper Paleolithic occupation was found above the Bohunicean, which is a similar situation to Brno-Bohunice 2002 with its undiagnostic Upper Paleosol assemblage. It could therefore be argued that the young radiocarbon date originate from later human occupations at this site, a scenario which is neither refuted nor distinguished from a later natural source of the charcoal. However, given the low number of artifacts from such later assemblages, they are not expected to relate to occupations long enough to consistently produce such large amounts of charcoal (especially at Brno-Bohunice 2002). One radiocarbon sample from Brno-Bohunice 2002 gave an infinite age estimate and suggests an age older than 40 ka $^{14}C$ (Table 1). This is in accordance with ages obtained by Valoch (2008) on samples from both the Cihelna and Kebjaly I localities, which gave a remarkably tightly clustered set of six AMS samples between 41 and 44 ka $^{14}C$. But the relation of the samples to an identical event which created a charcoal lens (Valoch, 2008; sample 2) can be questioned for the set of OxA-14846 to OxA-14848. The data are in themselves not coherent, which would not be expected from a single event, even if contamination would be an issue. However, the entire data set from Valoch (2008) is in good agreement with radiocarbon data obtained previously (except sample GrN-16920) by beta counting of charcoal at Kebjaly I, II, and Cihelna (Fig. 1), giving ages between 40 and 43 ka $^{14}C$ (Table 1). If these data sets are calibrated with the CalPal Hulu 2007 model, the overall picture of the distributions remains approximately the same, but ages shift towards values a few ka older (see below).

5.2. Thermoluminescence dating

Because the temporal relationship of the dated charcoal and the human occupation cannot be shown without ambiguity, thermoluminescence (TL) dating was carried out on heated flint artifacts from the 2002 excavation. Only a part of the assemblage shows traces of fire, thus making it highly unlikely that a natural fire had caused their heating. Furthermore, no indications for an extensive fire were found in the sediments. The spread in TL ages of artefacts from Brno-Bohunice 2002 is low and the data are normally distributed (Richter et al., 2008). This indicates that the fire event/events took place within a very short period of time, much shorter than the precision of the method, which is in accordance with the archaeological observation of production sequence refits within the Lower Paleosol. The weighted average result on 11 samples of $48.2 \pm 1.9$ ka provides a good estimate of the human occupation of the site because of the unambiguous relationship between the heating of the artifacts (the dated event) and the human activity (the target event) (Richter et al., 2008). A sedimentation age of 47.3 $\pm$ 19 ka for the lower Paleosol was obtained by Zöller (2000) from the stratigraphy of the Cihelna locality, which can safely be assumed to be comparable to the 2002 excavation. The TL age, comparing well with the TL results on heated flint, was obtained on polynuclear material (Zöller, 2000) with the ‘partial bleach longest plateau’ technique (Mejdahl, 1988). However, the validity of the method used has to be questioned and TL dating of sediment is no longer considered to be the method of choice (as it was at the time of sampling by Zöller) for establishing the age of deposits.

5.3. OSL dating

In order to provide a chronometric framework for the stratigraphy at Brno-Bohunice 2002, OSL dating was attempted on sediment from the archaeological layer itself, as well as of the loessic deposits above and below (Fig. 2 and Suppl. Fig. 4). A more detailed account of establishing the sedimentation ages at Brno-Bohunice 2002 by luminescence methods is given in the supplementary to this paper in order to place the new data presented here in context. Four different techniques of luminescence dating of the deposits were attempted at Brno-Bohunice 2002 (Suppl. Tables 2–6).

A Multiple-Aliquot-Additive-Dose (MAAD) on polynuclear fine grains material provided satisfactory results (Suppl. Table 4). Only one sample EVA-LUM-06/20 showed significant fading and has to be regarded as unreliable and considered a minimum age (see Supplementary data), whereas the other results should represent the last exposure to light of the sediment grains analyzed. The resulting IRSL-MAAD ages for sample EVA-LUM-06/19 from the covering loess was calculated to 27.8 $\pm$ 3.3 ka. The sample from the archaeological layer within the Lower Paleosol gave 58.2 $\pm$ 9.9 ka (EVA-LUM-06/20 uncorrected for fading) and the underlying loess deposit 112.6 $\pm$ 12.9 ka (EVA-LUM-06/21).

Analysis of the polynuclear fine grain material by Single-Aliquot-Regeneration (SAR) IRSL analysis of feldspar (Suppl. Table 5) provided only results for lowered quality criteria for the sample above the archaeological horizon (EVA-LUM-07/06), giving an age of $27.7 \pm 3.4$ ka for the last bleaching of this sample. IRSL-SAR analysis of the sample from the archaeological layer (EVA-LUM-07/07) resulted in an age of $58.0 \pm 9.8$ ka while for the lowermost sample (EVA-LUM-07/08) $117.5 \pm 13.2$ ka was obtained. However, this data set has to be regarded as unreliable because of its failure to meet an important quality criteria check (see Supplement for details).

A Double-Single-Aliquot-Regeneration (D-SAR) protocol on polynuclear fine grain material was abandoned because the samples did not meet quality criteria during testing. Feldspar can be also stimulated with green (blue) light (e.g. Duller, 1997) which sheds doubt on the applicability of the double SAR protocol and is likely the cause for the observed failure.

The most reliable data were obtained by Single-Aliquot-Regeneration (SAR) OSL analysis of fine grain quartz extract (Supplement Table 6). Disturbances by bioturbation, trampling, soil formation, etc. are expected for the sample from the archaeological horizon, but not for the one below, as it appeared to be pure loess. It is not possible to decide which one of the various palaeodose populations (Supplement Fig. 8b) might reflect the sedimentation age for sample EVA-LUM-07/02, not to mention how such a sedimentation age is related to the deposition of the artifacts. The resulting OSL dating of fine grain quartz gave 30.9 $\pm$ 3.1 ka for the loess sample EVA-LUM-07/01 located above the archaeological horizon, which itself provided an age of $58.7 \pm 5.8$ ka (EVA-LUM-07/02). The lowest sample gave an estimate of $104.3 \pm 10$ ka (EVA-LUM-07/03). The equivalent dose distributions (Suppl. Fig. 8) display a complex pattern. This is unusual for fine grain quartz and it can be speculated, that the severe chemical treatment might be at least partially responsible. Due to the lack of coarse grain material
no single grain or small aliquot measurements were possible, which would have provided more insight into the properties of the quartz material.

6. Discussion of the new chronometric data for Brno-Bohunice 2002

The new dating results for Brno-Bohunice are discussed within the framework of the typology of events as described by Dean (1978) and placed in relation to the other data previously obtained for the Brno-Bohunice site cluster (Richter et al., 2008; Valoch, 1976, 2008; Tostevin and Škrdla, 2006; Svoboda et al., 1994; Switsur, 1976; Mook, 1976).

6.1. Radiocarbon data

Radiocarbon ages around 40 ka have to be considered to be at the limits of the radiocarbon method, especially in the light of one finite age as is the case for Brno-Bohunice 2002. The discrepancy in ages in well provenanced samples of Brno-Bohunice 2002 (with OxA-18301 as an exception) and those from less well defined contexts at the other Kejbaly and Cihelna localities on Red Hill is not easily explained. Bias by laboratories can be ruled out because some of the new data presented here, as well as the dates from Valoch (2008), were measured in the same laboratory with identical sampling and pretreatment procedures. The ABOX treatment (Bird et al., 1999) was not possible for any of the samples presented here because of their small sizes. Two samples giving finite ages were dated at a different laboratory (ANU) and show a tendency towards younger ages. In addition, radiocarbon age estimates were obtained from charcoal pieces from the same sample (ANU-27214 and OxA-18299). The resulting ages are significantly different, which could be either due to differences in laboratory treatments, or the charcoal pieces dated were spatially closely related, but actually did not originate from an identical tree. Given the mobility of charcoal this cannot be entirely ruled out and different dated events might have been measured here; however, it can neither be determined which of these dates are correct, nor if dated events or laboratory pretreatment procedures are the source of this difference. However, it is unlikely that 2 entirely different events are sampled in a 5 cm spot, and therefore sample treatment is the more likely reason.

It has to be noted that the discrepancy between the laboratories for this particular sample is smaller than the variance obtained for several samples from the same context by the Oxford laboratory. Questions about the reliability of radiocarbon dating in such context have been raised earlier and significant discrepancies have been observed for radiocarbon dating of bone (e.g. Krause et al., 2007). In any case, the apparent older age for the data set from the Kejbaly and Cihelna localities (Valoch, 2008) compared to the well provenanced samples from Brno-Bohunice 2002 (Richter et al., 2008; and herein) needs to be explained and the bridging arguments investigated. While either data set could originate from displaced charcoal accumulations on the slopes, being younger or older, the one from Brno-Bohunice could originate from tree stump burning(s), which were interpreted during excavation as pedogenically altered hearths, these being younger than the artifacts and the charcoal from the other localities at Bohunice. This is less arguable in the case of the Kejbaly and Cihelna localities, because the samples originate from several localities, with only one radiocarbon age being younger than the others (GrN-16920 which lacks associated artifacts). Bioturbation and similar mechanisms could explain the statistical tendency towards younger ages obtained in comparison to the data from the older collections. Theoretically, a localized contamination can be postulated but there are no indications of this, particularly since this would result in less variation in ages than observed. In neither collection can the target event be assumed to be identical to the dated event, i.e., no clear cut association of human occupation and charcoal samples can be firmly established. However, based solely on the archaeological documentation it appears to be fair to assume a priori a likely association to humanly lit fires for many of the samples from all sites. No significant difference in lithic assemblages (except Bohunice II Drobuza) can be observed and the stratigraphic positions appear to be identical for all the sites sampled for radiocarbon dating. However, a significant time difference cannot be excluded a priori either.

No systematic difference in ages can be deduced when taking the wood species into consideration. All genera/taxa identified are consistent with expectations of the local palaeoenvironment within the timeframe of the pleniglacial. Both data sets contain radiocarbon dates from the same species (Picea/Larix) providing different ages, while the age estimates on other species (Pinus) do not differ significantly or show any internal pattern, which could be related to differences in use, site formation or palaeoenvironment.

The method of radiocarbon provides data on a non-linear time scale, and in order to compare this data with other chronometric dating methods, or even to other sites, it needs to be converted. The following discussion is based on a conversion/calibration of radiocarbon data using the CalPal Hulu 2007 data set for data given in Table 1.

Table 1. The calibrated data sets from Brno-Bohunice 2002 are very similar to the one from Stránská skála and provide an almost identical age range between approximately 44 and 35 ka cal BP on the calendric time scale for these Bohunician occupations (Fig. 3). This is in contrast to the data set for the other localities of Bohunice Kejbaly and Cihelna which indicate an age between 48 and 43 ka cal BP. While there certainly is some room for contemporaneity, it appears to be, solely based on radiocarbon data, more like a succession of dates from the Bohunice localities representing earlier occupation(s) followed by the ones from Brno-Bohunice 2002 and Stránská skála. As a result the Bohunice could have lasted from, or took place sometime between, approximately 48 and 35 ka cal BP. However, radiocarbon data from Brno-Bohunice 2002 are neither coherent with the TL data on heated flint from the same excavation (Richter et al., 2008), nor with TL dating of sediment from the Cihelna location (Zöller, 2000), nor the new OSL data presented here. Provided that the charcoal samples were obtained from patches of unevenly distributed small charcoal pieces from a slope which had experienced disturbances by, at least at the base of the Lower Paleosol, sheet floods or similar processes, it has to be suspected that post-occupational charcoal was washed into undefined localized distributions between the vertical artifact distribution. This would imply that the younger radiocarbon ages are more likely associated with the human occupation. However, there is no sedimentological nor any evidence in the assemblage which would indicate a long lasting sedimentological hiatus or heavy mixing at the level of the artifact distributions. The single radiocarbon date (OxA-18320) for one of the very few charcoals from the Upper Paleosol is younger than any of the radiocarbon ages obtained for samples from the Lower Paleosol (Table 1). Assuming that this single date is actually associated with the occupation which has led to the low density of undiagnostic artifacts in the Upper Paleosol, it cannot be used as an argument for postdepositional intrusion of charcoal in such numbers from this occupation into a lower level, that it would dominate the radiocarbon data of the level of the Bohunician. It would indeed provide a terminus post quem for the Lower Paleosol if vertical movement could be ruled out. Alternatively, one or more burnt tree stumps could have been sampled as well, but this as a single origin of the charcoal would have produced a more coherent data set than indicated by the dates.
Contamination, however, is unlikely to be solely responsible, because of the large spread in ages, which would not be expected for a contamination in loess sediment. It appears to be most likely that a mixture of humanly associated charcoal and charcoal from post-occupational tree stump/roots was sampled at Brno-Bohunice 2002. In other words, because of the tenuous association of charcoal with human occupation at the Brno-Bohunice sites, which are considered as one large site cluster. Additionally, such a large spread in radiocarbon data as observed for these sites is not consistent with the archaeological interpretation of a rather limited time span and no evidence is provided to support several occupation events occurring within several millennia, as the radiocarbon data would imply. It is more likely that the association of samples used for dating with the human occupation is not given for all samples, which might be the case for the Stránská skála sites as well. In any case the radiocarbon data could represent the palaeoclimate, indicating when local climate conditions were sufficient for trees to grow in larger numbers, which are of course the times when human occupations are expected to have taken place. According to calibrated radiocarbon data, and under the assumption that the target event equals the dated event for all samples, the Bohunician as a whole took place between Heinrich (HE) 5 and 4 (Fig. 3), roughly between 46 and 38 ka cal BP. Furthermore, assuming that only developed probability peaks are significant, the distribution would end at the same time as the eruption time of the Campanian Ignimbrite (CI or Y5) at 39.28 ± 0.11 at the 2-σ level (De Vivo et al., 2001), which gives a time span of 39.17–39.39 ka (note that another set of 40Ar/39Ar places the main eruption statistically indistinguishable at 41.1 ± 2.1 ka; 39.0–43.2; Ton-That et al., 2001). This eruption is used as a chronological marker at the time of 'transition' from the Middle to Upper Paleolithic and as a source of potential palaeoenvironmental stress on the environment (e.g. Anikovich et al., 2007; Pyle et al., 2006; Giaccio et al., 2006). Taken at face value, this data set would imply the ‘transitional’ industry of the Bohunician to end more or less with the eruption, at a time when palaeoclimatological data indicate harsh conditions. However,
there are contradictions in other data sets (see below) and the coherence of the radiocarbon data as a proxy for human presence has to be questioned, as discussed above.

6.2. OSL data

The results from all three successfully applied OSL protocols agree for all layers each within 1-σ uncertainty. They all yielded results in the correct stratigraphical order and are indicating that the time span evidenced by the sequence in Brno-Bohunice is longer than anticipated. Furthermore, all the luminescence data are giving much older ages than was expected on the basis of the positioning of the two paleosols in the chronostratigraphic framework of the region, as well as by the radiocarbon data, even if calibration is taken into account.

The failure of the IRSL-SAR protocol to recover a dose within reasonable uncertainty (10% of unity, Suppl. Table 5) indicates that this protocol is not appropriate for these particular samples. Furthermore, the systematic lower ages compared to the quartz OSL data indicate the presence of anomalous fading of the IRSL signal which is evidenced by some of the results from the MAAD fading experiment. The failure to detect any fading for the samples from the top and the bottom of the stratigraphy (see Supplement) can be explained by the large uncertainties associated with this type of fading experiment, where data sets of natural and additive doses are compared after different storage times. Therefore the ages obtained by the MAAD protocol (Suppl. Table 4) have to be questioned and would need correction for their potential fading. They gave ages almost identical to the IRSL-SAR results which either indicate that the IRSL-SAR, despite its failure to recover a dose, is not so bad, or they both suffer from an unknown problem in addition to the fading.

In any case, the IRSL data (Suppl. Table 5) statistically agree with the OSL data, (Suppl. Table 6) which are considered to be the best estimate for the sedimentation ages of the sequence because they meet all the criteria for evaluating a luminescence age result and quartz is considered not to fade (e.g. Better-Jensen et al., 2003). The OSL quartz result of 30.9 ± 3.1 ka for the uppermost sample (EVA-LUM-07/01) is in accordance with radiocarbon data and the placement of the underlying Upper Paleosol in the Denekamp. The OSL quartz age of 58.7 ± 5.8 ka (EVA-LUM-07/02) for the Lower Palaeosol is apparently older than any of the radiocarbon estimates, but given the relatively large uncertainty of the OSL data it is statistically compatible with the older radiocarbon estimates when calibration for the latter is taken into account. Agreement is of course obtained when the infinite radiocarbon data are considered as best reflecting the age of the deposit.

Within its 2-σ uncertainties the OSL data are also in agreement with the TL data on heated flint artifacts (Richter et al., 2008). Using the lowest 5% (Olley et al., 1999) approach provides age estimates on that part of the sediment which is believed to have received the most recent exposure to light, which is either directly related to deposition, redeposition, disturbance, bioturbation or soil formation. As discussed above, only in the latter case can a bridging argument be established between the target event of the human occupation and the dated event of the last bleaching of sediment grains if soil formation took place while sediment still accumulated. But the general expectation would be for the OSL age to be younger than the TL data. Because the TL and OSL ages are in agreement, with the OSL data pointing towards a possibly older age, it is more likely that the Bohunice soil at Brno-Bohunice formed while sediment and artefacts were accumulating, and not during a phase of depositional standstill.

The quartz OSL age of 104.3 ± 10.6 ka for the lowermost sample (EVA-LUM-07/03) evidences the accumulation of loess in OIS 5, given the palaeoclimate data most likely in its later half. However, there is no stratigraphic evidence of PK III. Sedimentation rates at Brno-Bohunice 2002 must have been either very slow or major erosions took place which are no longer visible in the profiles.

7. Conclusions

Two data sets of radiocarbon ages on charcoal for adjacent sites on the Red Hill (Červený Kopec) of Bohunice provide significant discrepancies, with the ones from the recent excavation at Brno-Bohunice 2002 on well provenanced samples being younger and showing a much larger spread in results. But the sites are considered to most likely represent a series of human occupations within a time span much less than the differences in chronometric ages suggest. While it is possible to provide reasons for the radiocarbon data set from Brno-Bohunice 2002 being significantly younger (slope wash, cryoturbation, bioturbation, burnt tree stumps or any combination of the above) than the other adjacent sites, there are no a priori arguments to be provided in favour of the radiocarbon data on non-provenanced material from these other localities being correctly associated with the human occupation. However, the AMS samples for Cihelna and Kejbaly were obtained from charcoal lenses (Valoch, 2008) which could have been hearths and therefore their dated events could equal the target event (sensu Dean, 1978). Additionally, this data set provides a more closed set of ages, which, if calibrated, agree with TL data on the sedimentation age from Cihelna and the TL dating results on heated flint artifacts from the recent excavation of Brno-Bohunice 2002. The significant discrepancy of radiocarbon dating of charcoal obtained from what appeared to be a disintegrated piece of charcoal from this site by two different laboratories needs to be addressed, because it additionally casts doubts on the validity of using the method of radiocarbon dating in such context.

The luminescence dating results presented emphasize the general problematic of radiocarbon dating of charcoal pieces from loess deposits, because of significant discrepancies in ages, even when calibration for radiocarbon data is considered. Following Dean’s (1978) typology of events, the bridging argument has to be established, which is very difficult for luminescence dating of sediment and is difficult for radiocarbon dating of charcoal in such contexts. Statistically indistinguishable age results were obtained for OSL dating of sediments, specifically a Multiple-Additive-Dose (MAAD) on polymineral fine grain and Single-Aliquot-Regeneration (SAR) procedures for polymineral Infrared Stimulated Luminescence (IRSL) as well as blue Optically Stimulated Luminescence (OSL) of fine quartz extracts. However, IRSL of feldspar has, again, been shown to suffer from anomalous fading. Interestingly, fading was experimentally detected only for the sample from the level of archaeological occupation which certainly represents some disturbances due to human interference and pedogenesis, and thus alterations of the minerals. Furthermore, the validity of the Single-Aliquot-Regeneration (SAR) protocol for feldspar dominated samples has to be questioned, even though ages obtained by MAAD are identical. The most reliable estimates are provided by OSL of fine grain quartz extract, which gives a coherent data set of 30.9 ± 3.1 ka, 58.7 ± 5.8 ka and 104.3 ± 10.6 ka from top to bottom (samples EVA-LUM-07/01 to -07/03). However, given the large uncertainties which are caused by the large distribution of palaeodoses, the usefulness of luminescence dating of such sediments to tackle very specific questions at the cultural/biological boundary of the Middle to Upper Palaeolithic cannot be shown in this study.

Considering only the two sediments which, in principle, are very well suited for luminescence dating in contrast to the sediment from the archaeological occupation level, the bracketing quartz OSL ages of 30.9 ± 3.1 ka (EVA-LUM-07/01) and 104.3 ± 10.6 ka (EVA-LUM-07/03) for the archaeological layer are in agreement with the
radiocarbon data obtained. While this is not satisfying from the aspect of an archaeological interpretation, the best estimate of the age of the archaeological remains is provided by the TL dating of heated flints (Richter et al., 2008) with 48.2 ± 1.9 ka from Brno-Bohunice 2002, which agrees well with calibrated radiocarbon data from the other Kejbaly sites at Bohunice, but not with the radiocarbon data from the Brno-Bohunice 2002 excavation itself where these flint samples were obtained.

The disagreement between the radiocarbon dates and the luminescence dates (both TL and OSL/IRSL) derived from the Brno-Bohunice 2002 excavation immediately raises the question of a possible scenario with multiple occupation events at the site which were subsequently bioturbated into a single assemblage (see discussion in Tostevin and Skrdla, 2006). With the presence of both diagnostic Bohunician Levalloisian technology and on-site production of leaf points usually associated with the Szeletian, the traditional Palaeolithic systematics in Central Europe (Svoboda et al., 1996) would ascribe one occupation to Bohunician flintknappers and a later one to Szeletian flintknappers, with the latter responsible for the burning of the wood which was sampled. In opposition to this view, however, we note the presence of production refits as well as conjoints in the assemblage, uniting all artefacts from the excavated 3×21 m trench (Skrdla and Tostevin, 2005). By itself, the archaeological evidence of core reduction refits within the Lower Paleosol assemblage and the absence of any vertical or horizontal patterning of raw material, retouch type, dorsal scar direction, or core reduction techniques (Skrdla and Tostevin, 2005) argue for the integrity of the archaeological assemblage. To invalidate the archaeological evidence for the integrity of the assemblage through the emphasis of the younger radiocarbon dates would ignore both the agreement between the TL and the OSL dates as well as the tighter theoretical association between target event and dated event provided by the TL method in comparison with the \(^{14}C\) method at Brno-Bohunice 2002. Given the very high density of charcoal in the 2002 excavation, with over 200 charcoal samples in a 3 m × 5 m area (see Skrdla and Tostevin, 2005, Fig. 7), it is probable that 8 of the 10 dated samples derive from post-occupation tree roots rather than pedogenically altered hearths (a field interpretation now in serious doubt). While two samples (OxA-18301 and WK-17757) match Valoch’s (2008) dates well enough to raise the possibility that they derive from anthropogenic sources that might overlap in age with the fire event dated by TL, the difference in the quality of the bridging arguments between TL and \(^{14}C\) methods, as well as the significant discrepancy of radiocarbon dating of a single charcoal by two different laboratories, lead us to conclude that the weighted TL age of 48.2 ± 1.9 ka on 11 flirt artifacts (Richter et al., 2008) is the more accurate age estimate for the assemblage. Taking the archaeology together with the prerequisites and assumptions of each dating method, we conclude that the TL dating and the archaeology together make the possibility of a post-Bohunian occupation by Szeletian leaf-point manufacturers unlikely.

Taking all the data together the lower soil of the Last Interpleni-glacial paleosols does not seem to represent a stable land surface at the site of Brno-Bohunice and appears not to correlate with the Hengelo interstadial, because of the TL age of its content (48.2 ± 1.9 ka weighted average of 11 samples) and especially its OSL date (58.7 ± 5.8 ka EVA-LUM-07/02). The latter should be considered as maximum age with respect to soil formation, especially in the light of the potential incorporation of older sediments by sheet floods and bioturbation. The top of the sequence consists of loess deposited well before the Last Glacial Maximum which gave an OSL age of 30.9 ± 3.1 ka (EVA-LUM-07/01). The OSL age of 104.3 ± 10.6 ka (EVA-LUM-07/03) for the lower loess provides information on loess deposition before the onset of the last glacial and indicates a low sedimentation rate at Brno-Bohunice. Consequently, the presented luminescence data take the sequence of Brno-Bohunice 2002 out of the chronostatigraphical framework for the region and further chromonometric ages are needed in order to verify the framework. Even when a different average moisture model for the OSL data is assumed (see Supplement) the 2-σ OSL data for the Lower Paleosol do not support the notion of correlating the Lower Paleosol at Bohunice with the Hengelo interstadial. Taken all together, this set of luminescence data provides confirmation of the early chronological position of the type-locality for the Bohunician technocomplex as part of the Early Upper Palaeolithic in the Middle Danube. It also draws into question a 10 ka hiatus observed in the chronometric data for the hominin occupation of Moravia between 53 and 43 ka cal BP (Zilhão, 2006, p. 189; Valladas et al., 2003). With the Neanderthal occupation of Kulina Cave layer 7a dated by ESR (Rink et al., 1996) to 50 ± 5 ka for a linear uptake (LU) model (53 ± 6 ka recent uptake (RU) model) and the Bohunician at Brno-Bohunice 2002 dated to 48.2 ± 1.9 ka (Richter et al., 2008), there is overlap already at the 1-σ probability level which indicates a more or less continuous occupation and makes it difficult to argue for a hiatus, as is clearly observed elsewhere, for instance in the stratigraphies of the Swabian Alb (Conard et al., 2006).

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jas.2008.10.017.

References


