River terraces of the Vltava and Labe (Elbe) system, Czech Republic, and their implications for the uplift history of the Bohemian Massif

Jaroslav Tyráček[1], Rob Westaway[2] & David Bridgland[3]

TYRÁČEK, J., WESTAWAY, R. & BRIDGLAND, D. 2004. River terraces of the Vltava and Labe (Elbe) system, Czech Republic, and their implications for the uplift history of the Bohemian Massif. *Proceedings of the Geologists' Association*, **115**, 101–124. The record of river terraces and related fluvial deposits from the Vltava and Labe (Elbe) rivers in the Czech Republic is reassessed. Field relations between the Labe terraces and sediments derived from Scandinavian ice sheets, together with biostratigraphy, provide the basis for correlation with the oxygen isotope record from the oceans. The resulting scheme allows an internally consistent correlation of these terraces with their more fragmentary counterparts downstream in Germany. It is also possible to use the terraces to estimate Late Cenozoic uplift in this region, which appears to have followed a similar pattern to other parts of Europe, in particular with a marked increase in uplift rates after ~0.9 Ma. Previous schemes may, thus, have overestimated the ages of earlier parts of this Middle Pleistocene fluvial sequence in the Bohemian Massif. Analysis of the biostratigraphy reveals many similarities between interglacial faunas from southern England and the Czech Republic and raises questions about some of the previously published correlations.

Key words: Vltava, fluvial deposits, Quaternary, Pleistocene, Pliocene

[1]*Czech Geological Survey, Klárov 3, 11821 Prague, Czech Republic (email: tyracek@cgu.cz)*
[2]*16 Neville Square, Durham DH1 3PY, UK (email: r.w.c.westaway@ncl.ac.uk)*
[3]*Department of Geography, University of Durham, Durham DH1 3LE, UK (email: d.r.bridgland@durham.ac.uk)*

1. INTRODUCTION

The southernmost headwaters of the Elbe system are in the Bohemian Massif, Czech Republic, where the main river is known as the Labe (Fig. 1). The main tributary of the Labe is the Vltava, which flows through Prague, the Czech capital. The Labe/Vltava catchment, upstream of its northward course across Germany to the North Sea (Fig. 1a), covers most of the western Czech Republic. As the limit of the advance of Scandinavian ice sheets is near the German border (Fig. 1a), most of this upper catchment has never been glaciated, which has allowed the preservation of extensive river terrace sequences. These terraces are described in a substantial local literature, including attempts at dating them using magnetostratigraphy, mammalian and molluscan biostratigraphy, analyses of overlying loess/palaeosol sequences, relations with glaciogenic sediments and correlations with other river terrace systems across Europe (see below). Terrace chronologies for this region were, indeed, established by the 1970s (e.g. Záruba *et al.*, 1977; Kukla, 1978), at a time when few believed the matching of river terrace records to global oxygen isotope stages (OIS) to be feasible.

Re-assessment of the Czech terrace sequences has been prompted by a number of factors. First, high-resolution marine OIS records indicate additional Middle Pleistocene climatic fluctuations, which were unknown when the existing chronologies were established (see below). In particular, the concept of a 'Cromerian Complex', representing a series of at least five early Middle Pleistocene interglacials, has replaced the old notion of a single Cromerian stage and has itself seen a number of revisions (e.g. Zagwijn, 1986, 1996; Preece & Parfitt, 2000; Stuart & Lister, 2001). Second, it is now realized that the terrace staircases that are widespread along major rivers in Europe and elsewhere have developed this form only because the Earth's surface in onshore regions is typically uplifting (e.g. Maddy, 1997; Maddy *et al.*, 2001; van den Berg & van Hoof, 2001; Westaway *et al.*, 2002). This paper attempts reappraisal of the Vltava/Labe terrace sequences in the light of this new thinking.

2. THE VLTAVA AND LABE TERRACE SEQUENCE

The terrace sequence of the Vltava and its downstream continuation into the Labe (Fig. 1b) has been documented in many studies, notably by Záruba (1942), Balatka & Sládek (1962), Šibrava (1972) and Záruba

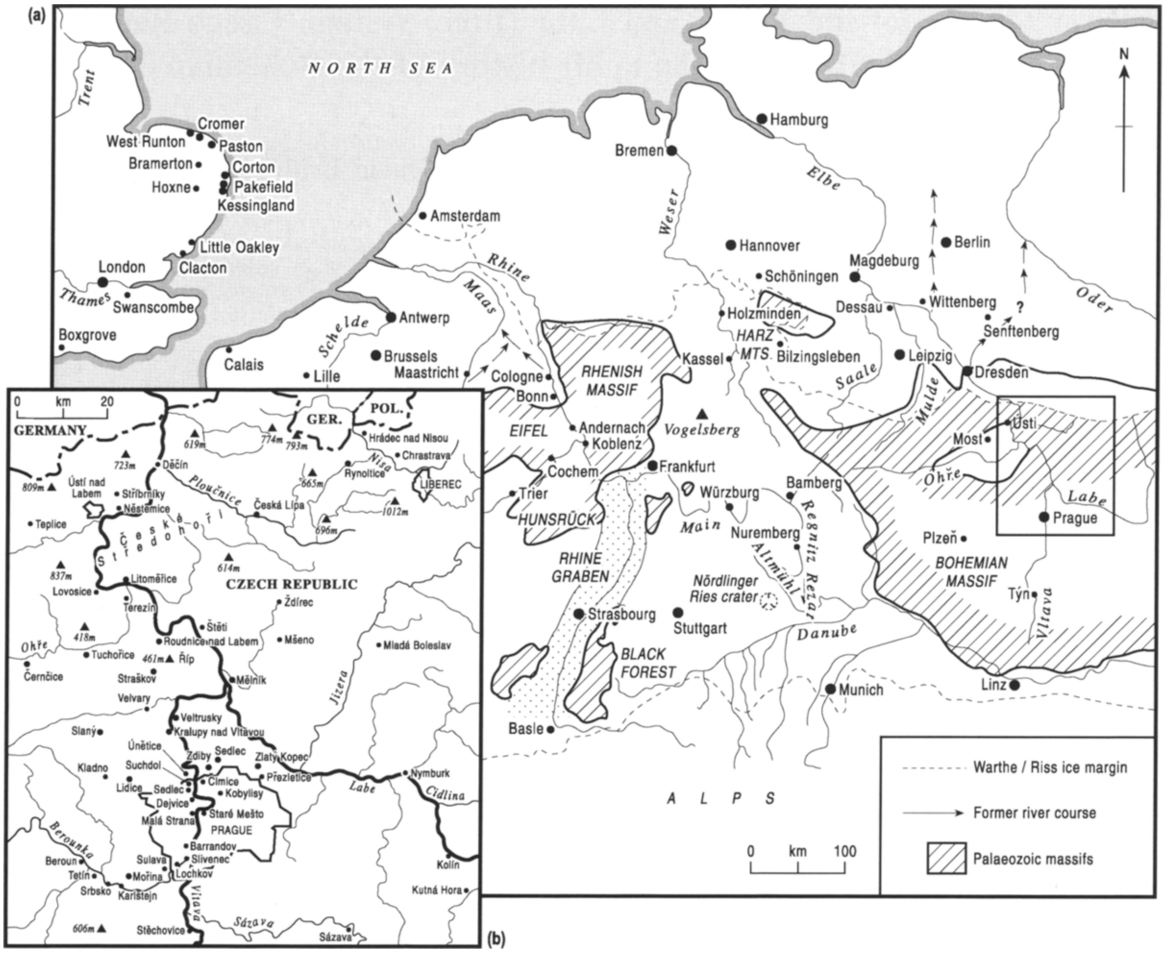

Fig. 1. (**a**) Map of central Europe showing the study region and other localities discussed in the text. (**b**) Location map for the study region, showing the Vltava and Labe rivers between the Prague area and the Czech–German border, selected spot heights and localities named in the text.

et al. (1977). Although extensive and well developed (Figs 2, 3), this sequence is virtually isolated from its surroundings, making it difficult to correlate with any other river system (Tyráček, 2001a). Near Litoměřice, downstream of its Vltava confluence, the Labe enters a ~30 km long gorge, the Bohemian Gate or Porta Bohemica, through the České Středohoří mountains (Fig. 1b). Terrace evidence is locally fragmentary and often non-existent, although key age-control evidence has been found near Děčín (see below). Downstream of Děčín, the Labe enters Germany (becoming the Elbe) via another gorge, up to ~380 m deep, through the Cretaceous sandstones within the Krušne Hory or Erzgebirge mountains. During the Elster glaciation, the Scandinavian ice sheet reached the outlet of this gorge, ~10 km inside Germany (e.g. Šibrava, 1972), obliterating any older terrace evidence. Further downstream the Elbe has been repeatedly diverted and its terrace sequence disrupted as a result of interactions with Scandinavian ice sheets. Several studies (e.g. Grahmann, 1933; Šibrava, 1964, 1966, 1972, 1986; Präger, 1966; Záruba *et al.*, 1977) have attempted correlation of the Vltava terraces with the Elbe terraces around Dresden, across the two intervening gorge reaches, but no agreement has emerged.

The Vltava terrace sequence can be subdivided longitudinally into two reaches. Downstream of its confluence with the Sázava (km 166; Fig. 2b), the terraces are subparallel to each other and to the modern channel gradient of ~0.4 m km^{-1}. Further upstream, the channel gradient is more variable, but typically steeper than the terraces, which thus converge upstream with the river. Tyráček (2001a) has discussed the correlation of terraces between the lower and upper reaches of the Vltava. This review will concentrate instead on the evidence around Děčín, Mělník and Prague.

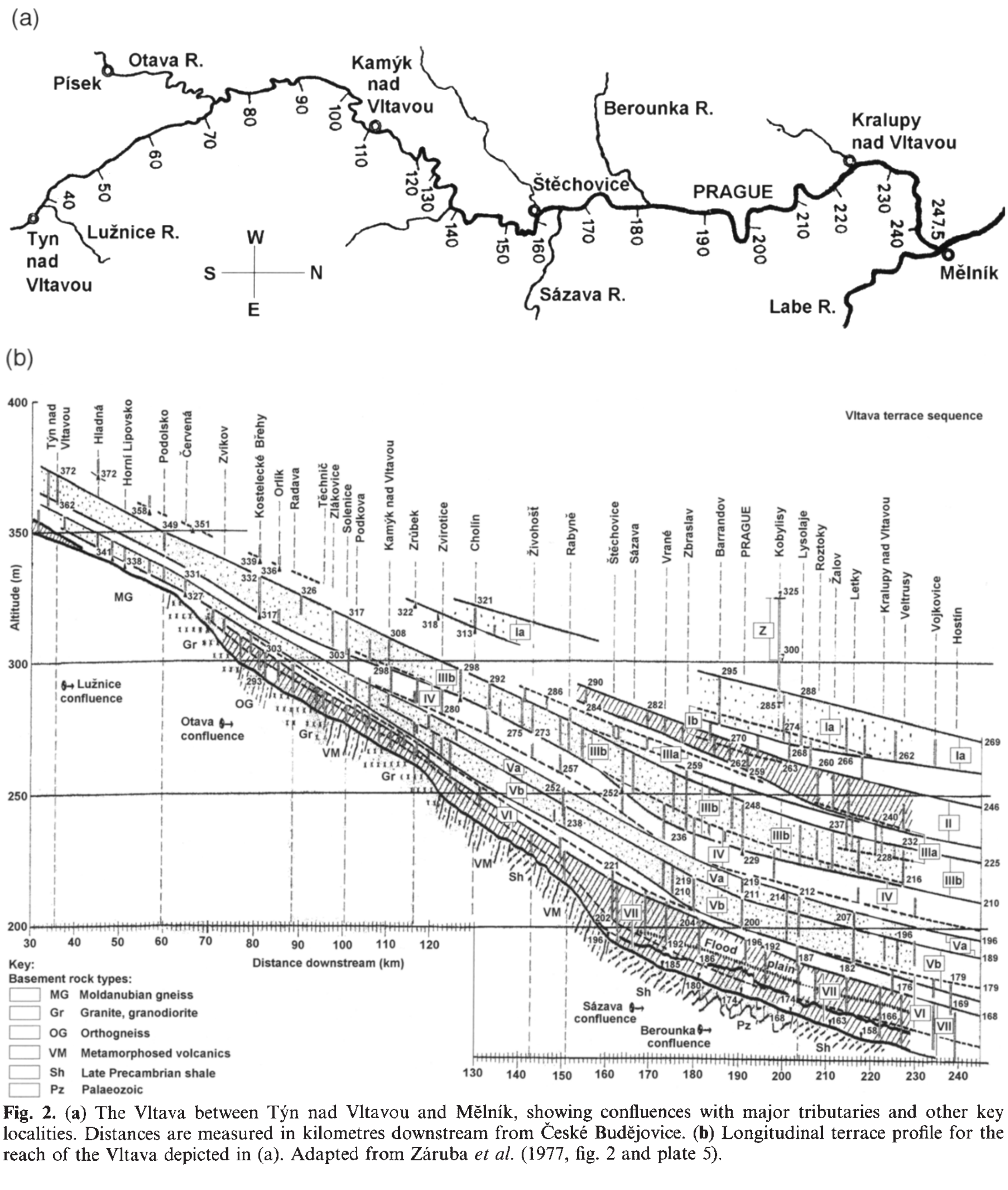

Fig. 2. (**a**) The Vltava between Týn nad Vltavou and Mělník, showing confluences with major tributaries and other key localities. Distances are measured in kilometres downstream from České Budějovice. (**b**) Longitudinal terrace profile for the reach of the Vltava depicted in (a). Adapted from Záruba *et al.* (1977, fig. 2 and plate 5).

Děčín area

Focksche Höhe

Děčín marks the confluence of the Labe with the Ploučnice, which flows southwestward from the Czech–Polish border region (Fig. 1). As previously described (e.g. Grahmann, 1933; Šibrava, 1966, 1967, 1972), in this area fluvioglacial and glaciolacustrine sediments of Elster I age are overlain by Ploučnice gravel of Elster II age (Fig. 3), which, as the Bohatice terrace, can be traced upstream along the Ploučnice to the Elster II ice margin. During the Elster II glaciation, the Ploučnice thus carried meltwater from the Scandinavian ice sheet southwestward to the Labe, which then channelled it northward back to the ice

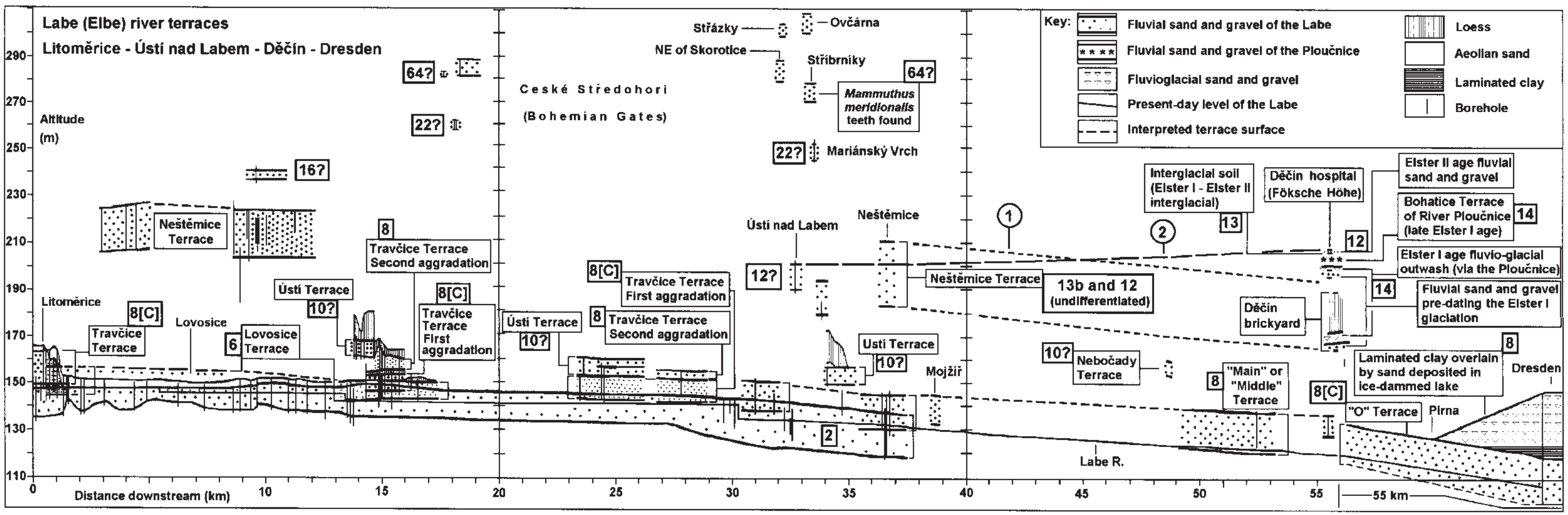

Fig. 3. Longitudinal terrace profile for the reach of the Labe between Litoměřice and the Czech–German border, adapted from Šibrava (1972, fig. V). Inset shows the terraces in the Dresden–Pirna area of Germany, further downstream, including information from Präger (1966, fig. 3).

margin in the Dresden area. Šibrava (1986) correlated the Elster I glaciation with OIS 14 and the Elster II with OIS 12. At Focksche Höhe, the top of the fluvial gravel of the Bohatice terrace is at 208 m, 85 m above the present-day level of the Labe (Fig. 3). The proximity of this site to the Labe–Ploučnice confluence means that it provides a good indication of the level of the Labe at this time.

At Neštěmice, ~20 km upstream of Děčín and near the outlet from the Bohemian Gate, a body of gravel ~30 m thick reaches 78 m above the Labe (Fig. 3). This Neštěmice 'terrace' is also found around Litoměřice, upstream of the Bohemian Gate, ~30 km from Neštěmice, where it reaches the same relative level and a similar thickness (Fig. 3). This Neštěmice gravel has generally been regarded as marking at least part of the Elster stage (e.g. Šibrava, 1972; Záruba *et al.*, 1977).

Ústí nad Labem

The vicinity of Ústí nad Labem preserves the most complete Labe terrace record north of the Bohemian Gate, with terraces up to ~180 m above river level (Fig. 3). The main local age constraint is the discovery at Stříbrníky, in the ~280 m terrace (~150 m above the Labe), of molar teeth of the ancient mammoth *Mammuthus* (*Archidiskodon*) *meridionalis* (Liebus, 1929; Šibrava, 1972). This constrains the age to between ~2.5 Ma and ~1.5 Ma (e.g. Stuart, 1982). Šibrava (1972) regarded this Stříbrníky terrace as anomalously high and suggested that the land surface around the Bohemian Gate has uplifted faster than in the surrounding area during the Quaternary. This interpretation is not, however, supported by the younger terraces, which, although fragmentary, remain subparallel with the Labe throughout this reach (Fig. 3), seemingly precluding differential uplift.

Mělník area

Between Kralupy nad Vltavou and the Labe confluence at Mělník (Fig. 4), the Vltava terrace system has developed largely within a low-relief landscape formed in Late Cretaceous marine sediments. Individual terrace gravels along this reach are up to ~5 km wide and typically >10 m thick (Fig. 5).

Vraňany

The area around Vraňany station (A in Fig. 4) on the Prague–Berlin railway provides good exposures of the gravels of Balatka and Sládek's (1962) Veltrusy (VI) terrace group of the Vltava. This railway runs along the surface of terrace VIb, ~20 m above the river. Further west, the land surface rises abruptly to terrace VIa at ~25 m and immediately east of the railway it drops to the surface of terrace VIc at ~16 m. Gravel of terrace VIb is exposed in the cutting of the branch line from Vraňany to Lužec nad Vltavou, as it descends to terrace VIc from the northern end of Vraňany station.

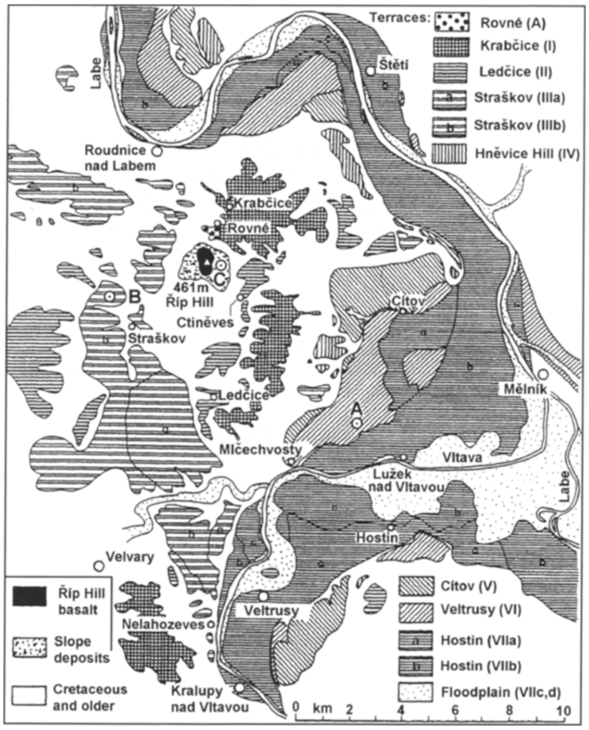

Fig. 4. Map of the Mělník area, adapted from Tyráček (2001b, fig. 1).

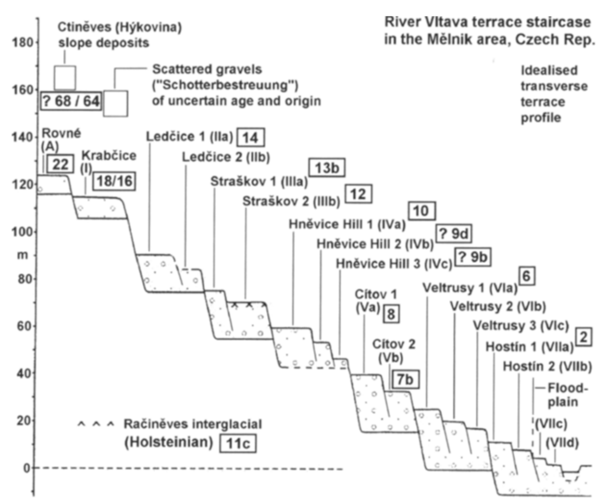

Fig. 5. Schematic transverse profile across the Vltava terrace sequence in the Mělník area. Adapted from Tyráček (2001b, fig. 2).

Terrace VIc was formerly well exposed in a gravel pit adjacent to this branch line (Záruba *et al.*, 1977, plate IV-2), where ~15 m of terrace gravel, typically comprising medium-sized rounded clasts of Bohemian Massif metamorphic rocks, was overlain by a ~0.7 m thick chernozem palaeosol, thought to comprise two distinct soil horizons, then ~1.5 m of loess beneath a

~0.5 m thick chernozem attributed to the Holocene. These two fossil soils are tentatively designated PK2 and PK3 in the Czech soil classification scheme. In this scheme, PK1 and PK2 mark interstadials in the last climate cycle and PK3 is attributed to the Eemian (OIS 5e). PK4 and PK5, which are forest soils, and PK6, which is a braunlehmic parabraunerde, mark the three preceding interglacials (i.e. OIS 7, 9 and 11); PK7 and older, which are plastosols, formed during earlier interglacials. The evidence from Vraňany, therefore, suggests that terrace VIc formed at the end of OIS 6.

Račiněves

A section through the Straškov (IIIb) terrace of Balatka & Sládek (1962), ~70 m above the Vltava (here called the Straškov 2 terrace), is exposed in a gravel quarry at Račiněves (B in Fig. 4). As described by Tyráček (2001b) and Tyráček *et al.* (2001), the fluvial deposits here comprise a coarse lower unit and a finer upper unit and are overlain by loess and slope deposits containing palaeosol fragments that may represent two distinct warm stages. During aggradation of the Straškov 2 terrace, the Vltava flowed west of the Říp Oligocene–Miocene volcanic neck (Fig. 4), subsequently diverting to its present-day position east of Říp. The Vinohrady terrace is the equivalent of this terrace further upstream (e.g. Záruba *et al.*, 1977).

The ~12–14 m thick lower fluvial unit, consisting of stratified sands and gravels, is thought to indicate a cold-climate braided-channel environment. The ~0.5–2 m thick upper fluvial unit is mainly composed of sand and fine sandy gravel, disturbed by cryoturbation. It has yielded thermophilous mammals (Table 1), interglacial molluscs and archaeological material.

The rich molluscan fauna comprises 22 taxa, the most important of which are the woodland species *Drobacia banatica* and *Aegopis verticillus* which, with *Helicodonta obvoluta*, *Ena montana*, *Cochlodina laminata* and *Discus ruderatus*, indicate interglacial conditions. Tyráček *et al.* (2001) also reported *Lithoglyphus pyramidatus*, known from the Holsteinian of Germany. The archaeological evidence includes cores, notches, knives, scrapers, wedges and hammerstones, made of Proterozoic lydite; some are in fresh condition, indicating a primary or near-primary context. Mammal bones with cut marks provide further evidence of human occupation, indicating hunting and butchery activities.

The Račiněves mammal fauna (Table 1) has strong similarities with those from northwest European sites, such as Swanscombe in southeast England (Bridgland & Schreve, 2001) and Bilzingsleben I in central Germany (e.g. Mania, 1995), which are dated to OIS 11 (Holsteinian *sensu stricto*). The absence of the mollusc species *Helicigona capeki* and *Granaria frumentum*, considered diagnostic of Cromerian Complex interglacials in the Czech Republic (cf. Záruba *et al.*, 1977), supports this correlation, suggesting that the underlying gravels aggraded late in OIS 12.

Tyráček *et al.* (2001) noted that the Račiněves interglacial fluvial deposits have yielded the water vole *Arvicola terrestris cantiana* (or *A. mosbachensis*, its synonym), which points to an age no older than latest Cromerian Complex (e.g. Preece & Parfitt, 2000; Stuart & Lister, 2001) or OIS 13 (e.g. Westaway *et al.*, 2002). Tyráček *et al.* (2001) indeed noted that *A. t. cantiana* teeth from Račiněves have a characteristic Holsteinian morphology. They postulated a wider range of possible ages, however, influenced by the occurrence above the fluvial sediments of a fragmentary braunlehmic parabraunerde palaeosol that they correlated with pedocomplex PK6, which is normally assigned to the Holsteinian and could, therefore, point to a late Cromerian Complex age for the interglacial deposits.

Ctiněves

At Hýkovina quarry near Ctiněves, just east of the Říp volcanic neck (C in Fig. 4), a ~10 m section is exposed through slope deposits, ~160–170 m above the Vltava. This section consists of loess, loam and palaeosol layers interbedded with scree material (Ložek, 1964; Horáček & Ložek, 1988, photo 3; Tyráček, 2001b). From its molluscan and mammalian assemblages, this site has been assigned to mammal zone MN17 (e.g. Fejfar, 1989), the Late Villanyian, which is dated to ~2.4–1.9 Ma by Fejfar *et al.* (1997) (but see also below). It has yielded the mollusc *Gastrocopta serotina*, an MN17 index fossil, and the rodents *Mimomys pitymyoides*, *M. reidi*, *Beremendia fissidens* and *Borsodia* sp. (Ložek, 1964; Fejfar & Horáček, 1983). Younger species such as *Mimomys savini*, *Microtus* (*Allophaiomys*) *deucalion* and *Microtus* (*Allophaiomys*) *pliocaenicus* are notable absentees.

This site is on a hillslope – just above a subhorizontal bench ~160 m above the Vltava – capped by scattered fluvial gravel or 'Schotterbestreuung' of indeterminate age and origin (Fig. 5). There is no stratigraphic contact to determine whether the slope deposits overlie these gravels or not, but the biostratigraphy provides a clear minimum age for fluvial incision to this level.

Prague area

In the Prague area, the Vltava occupies a steep-sided valley incised into Palaeozoic and Precambrian metamorphic rocks (Fig. 6). Flanking this valley is a low-relief landscape in Cretaceous marine sediments, similar, apart from its higher level, to the modern valley further north in the Mělník area. Although the Pleistocene river terraces in the Prague area (Fig. 7) are all deposited on metamorphic basement, spreads of higher-level Miocene and Pliocene fluvial sands and gravels have been deposited on the Cretaceous cover. To the north, the older terraces form broad continuous spreads (Figs 8e, f), indicative of a much lower-relief landscape than at present. For example, terrace Ia sediments are ~20 m thick and ~1 km wide at Lysolaje (Záruba *et al.*, 1977, plate I-1; Fig. 8e).

Table 1. Comparison of significant mammal taxa from selected pre- and post-Elsterian sites, including those in the present study region.

Sites[a] / Species[c]		Račiněves	Bilzingsleben II[b]	Bilzingsleben I[b]	Schöningen[d]	Swanscombe	Clacton	Hoxne Upper[e]	Hoxne Lower[e]	Boxgrove	Chlum 4 C	Westbury Upper[f]	Westbury Lower[f]	Únětice[g]	Chlum 4 B[h]	Zlatý Kopec	Little Oakley	Pakefield [i]	Kessingland [i]	Corton [i]	West Runton
Insectivora																					
Macroneomys brachygnathus Fejfar	extinct shrew																				x
Sorex savini Hinton	extinct shrew									x	x	x	x		x	x	cf.				x
Sorex runtonensis Hinton	extinct shrew									x	x	x	x	x	x	x	cf.				x
Talpa minor Freudenberg	extinct small mole					x		x		x		x	x			x					x
Sorex minutus Linné	pygmy shrew				x			cf.		x	x		x	x	x	x					
Carnivora																					
Ursus deningeri von Reichenau	extinct bear									x											x
Ursus spelaeus Rosenmüller & Heinroth	extinct cave bear		x			x															
Crocuta crocuta Erxleben	spotted hyena									x								x	x	x	x
Rodentia																					
Microtus gregalis (Pallas)	extinct vole[j]									x				aff.	cf.[j]						
Pliomys episcopalis Mehely	extinct vole									x	x	x	x		x	x					x
Microtus gregaloides Hinton	extinct vole										x	x	x		x	x	cf.				x
Mimomys savini Hinton	extinct water vole													x	x	x	x	x			x
Arvicola terrestris cantiana (Hinton)	water vole	x	x	x	x	x	x	x		x	x	x	x								
Microtus subterraneus de Sely-Longchamps	extinct pine vole		x		x	x		x		x	x		x	x	x						cf.
Trogontherium cuvieri Fischer	extinct giant beaver		x	x	x		x	x	x							x		x			x
Microtus arvalis (Pallas)	common vole		x		x	x	x	x		x	x	x	x		x	x	x				cf.
Apodemus sylvaticus (L.)	wood mouse							x		x		x	x				[k]				x
Apodemus maastrichtensis van Kolfschoten	wood mouse									x							[k]				
Clethrionomys glareolus (Schreber)	bank vole	cf.	x		x		x	x		x	x	x	x		cf.		x				x
Microtus oeconomus (Pallas)	northern vole				x	x				x							x				x
Microtus agrestis L.	field vole		x		x			x		x											
Proboscidea																					
Mammuthus trogontherii Pohlig	steppe mammoth	[l]														x		x	x	x	x
Mammuthus primigenus Blumenbach	woolly mammoth	[l]																			
Palaeoloxodon antiquus Falconer & Cautley	straight-tusked elephant		x	x	x	x	x	x	x			[m]	[m]						x		

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Sites[a] / Species[c]		Račiněves	Bilzingsleben II[b]	Bilzingsleben I[b]	Schöningen[d]	Swanscombe	Clacton	Hoxne Upper[e]	Hoxne Lower[e]	Boxgrove	Chlum 4 C	Westbury Upper[f]	Westbury Lower[f]	Únětice[g]	Chlum 4 B[h]	Zlatý Kopec	Little Oakley	Pakefield[i]	Kessingland[i]	Corton[i]	West Runton
Perissodactyla																					
Equus caballus Reichenau	caballine horse													x		cf.	[n]				
Equus hydruntinus Ragalia	extinct donkey													x							
Equus mosbachensis von Reichenau	horse		x		x																
Equus ferus Boddaert	horse					x	x	x		x											
Equus altidens von Reichenau	horse																[n]	x	x		x
Stephanorhinus hundsheimensis Toula	small rhinoceros[o]									x						x		x	x	x	x
Stephanorhinus hemitoechus Falconer	small rhinoceros[o]	x	x			x	x	cf.													
Stephanorhinus kirchbergensis Jäger	large rhinoceros[o]	x	x	x	x	x	x														
Artiodactyla																					
Hippopotamus amphibius L.	hippopotamus																	x	x		
Megalogeros verticornis Dawkins	extinct giant deer									x								x	x	x	x
Megalogeros savini Dawkins	extinct giant deer																	x	x	x	x
Megalogeros dawkinsi Newton	extinct giant deer									x							cf.		x		
Megaloceros giganteus Blumenbach	extinct giant deer					x		x													
Sus scrofa L.	wild boar		x		x	x	x			x							[p]	x	x	x	x
Cervus elaphus L.	red deer	cf.	x		x	x	x	x	x	x						cf.	cf.	x	x		x
Dama dama (L.)	fallow deer	x				x	x	x		x								x			
Bos primigenius Bojanus	aurochs	x	x			x	x	ind.	ind.												
Primates																					
Homo sp.	human	x	x	x		x	x	x	x	x		x	x								

Species identifications are from: Račiněves, Tyráček (2001b), Tyráček *et al.* (2001); Bilzingsleben I, Bilzingsleben II and Schöningen, Mania (1995); Swanscombe, Stuart (1982); Clacton, Bridgland *et al.* (1999); Hoxne, Schreve (2000) (data for these three British sites are also compiled by Bridgland & Schreve, 2001); Chlum 4 C, Horáček & Ložek (1988); Westbury-sub-Mendip (Calcareous Member), Stringer *et al.* (1996) and Preece & Parfitt (2000); Únětice and Chlum 4 B, Horáček & Ložek (1988); Zlatý Kopec, Fejfar (1969) and Šibrava *et al.* (1979) (with precedence given to the latter); Little Oakley, Lister *et al.* (1990); Kessingland, Pakefield, and Corton, Stuart & Lister (2000) and Stuart (1996); and West Runton, Preece & Parfitt (2000). Large mammals are not documented at Únětice and Chlum 4.

Abbreviations: cf., species identification is not definitive; aff., specimen has an affinity for the named species but the identification is not certain; ind., specimen is identified to species level, but its stratigraphical level at the specified site is indeterminate.

[a]Site groupings. Each grouping of sites is thought by us to represent a particular age within the Middle Pleistocene. From left to right, these groupings are: Račiněves to Hoxne, OIS 11 (Hoxnian/Holsteinian); Boxgrove, Chlum 4C and Westbury-sub-Mendip, OIS 13 (latest Cromerian Complex); Únětice, Chlum 4 B, Zlatý Kopec and Little Oakley, late OIS 15 (OIS 15a); Pakefield, Kessingland and Corton, earlier OIS 15 (OIS 15c or possibly OIS 15e); West Runton, OIS 17 or possibly earliest OIS 15 (OIS 15e). See e.g., Preece & Parfitt (2000), Westaway *et al.* (2002), or Bridgland *et al.* (2004) for further details on the resolution of different ages between these sites and their assignment to oxygen isotope stages.

[b]Bilzingsleben. Both Bilzingsleben I and II have prevoiusly been assigned to the Holsteininan, being thought to possibly represent OIS 11c and 11a (e.g. Schreve & Bridgland, 2002). Bridgland *et al.* (2004) suggest an alternative possibility, in which Bilzingsleben II may be Holsteinian with Bilzingsleben I being from the latest Cromerian Complex stage (OIS 13a). The limited fauna from Bilzingsleben I prevents a definitive conclusion being reached.

[c]Species synonyms: *Macroneomys brachygnathus* at West Runton was listed as *Beremendia fissidens* (Petenyi) by Stuart (1996), but reinterpreted by Preece & Parfitt (2000). '*Sorex* sp. 1' of Lister *et al.* (1990) at Little Oakley is assumed here from its size and other characteristics to probably be *Sorex runtonensis*. '*Sorex* sp. 2' of Lister *et al.* (1990) at Little Oakley is assumed here from its larger size and other characteristics to probably be *Sorex savini*. *Ursus spelaeus* at Bilzingsleben 2 was listed as *Ursus deningeri-spelaeus* by Mania (1995). *Microtus gregaloides* is a synonym for *Pitymys gregaloides*. *Arvicola terrestris cantiana* at Račiněves and Chlum 4 C is listed as *Arvicola mosbachensis* Schmidtgen. *Microtus subterraneus* has synonyms *Pitymys arvaloides* or *Microtus arvaloides*. It is listed as *Microtus arvaloides* at Chlum 4 C and *Pitymys arvaloides/subterraneus* or *Microtus* (*Terricola*) *subterraneus* at Westbury-sub-Mendip. *Trogontherium cuvieri* at Zlatý Kopec is listed by Šibrava *et al.* (1979) as *Trogontherium schmerlingi* Pomel. *Microtus arvalis* is listed as *Microtus arvalidens* Kretzoi at Chlum 4 C, Chlum 4 B, and Zlatý Kopec. The identification at Zlatý Kopec, of *M. arvalidens* Kretzoi, is described as 'essentially the same as *Microtus arvalis* L. but a little smaller and differing in the morphology of the lower first molar' (Fejfar, 1969). *Equus caballus* Reichenau is recorded as *Equus mosbachensis* Reichenau by Fejfar (1969) and as *Equus caballus mosbachensis* Reichenau by Šibrava *et al.* (1979). *Equus hydruntinus* is a synonym for *Asinus hydruntinus* Ragalia. *Equus mosbachensis* at Bilzingsleben 2 is listed as *Equus mosbachensis-taubachensis* (Mania, 1995). *Stephanorhinus hundsheimensis* is considered a synonym for *Dicerorhinus etruscus* Falconer (see note o below). Fejfar (1969) highlighted the absence of *Stephanorhinus hundsheimensis* from Zlatý Kopec. Šibrava *et al.* (1979) listed its synonym *Dicerorhinus etruscus* as present. Valoch (1995) also listed it as present. *Dama dama* is of the subspecies *Dama dama clactoniana* at Račiněves. The subspecies at Hoxne is indeterminate.

[d]Schöningen. The designation Schöningen includes Reinsdorf.

[e]Hoxne. Hoxne, Upper means stratum C, beds 4 and 5. Hoxne, Lower means strata F and E.

[f]Westbury. Designates the Westbury-sub-Mendip cave sequence, for which we follow the stratigraphic scheme of Preece & Parfitt (2000) and others in correlating the cold-climate deposits forming unit 18 in the main chamber and unit 15/8 in the side chamber. The 'Upper' (U.) sequence means the temperate units above this level; the 'Lower' (L.) sequence means the units below this level.

[g]Únětice. Designates Holý Vrch, near Únětice.

[h]Chlum 4 B. Chlum 4 B is designated as the interglacial deposits in beds B8 to B14 and K3, which Horáček & Ložek (1988) regarded as from the same warm stage.

[i]Pakefield, Kessingland, Corton. Pakefield means the Pakefield Rootlet Bed. Kessingland means Pakefield/Kessingland gravel. Corton means the Corton rootlet bed.

[j]*Microtus gregalis* (*gregaloides* morphotype) is believed (e.g. Preece & Parfitt, 2000) to uniquely mark the very latest Cromerian Complex time, as evidenced for instance by the Boxgrove site, corresponding to OIS 13a (Westaway *et al.*, 2002). The specimens from Únětice are listed as *Microtus* aff. *gregalis/conjugens*. This species is not present at Chlum 4 B but as noted by Horáček & Ložek (1988) it is present at Chlum 4 K (bed 7) where it is listed as *Microtus* cf. *gregalis*. Our definition of Chlum 4 B includes Chlum 4 K down to bed 3 (see footnote e), so if this species was not present during the interglacial represented by this site it was present shortly beforehand (see main text).

[k]Specimens were identified as *Apodemus maastrichensis* by Preece & Parfitt (2000) amongst material identified as *Apodemus sylvaticus* by Lister *et al.* (1990).

[l]The mammoth remains from Račiněves, of indeterminate species, are presumed to represent an early form of *M. primigenus*.

[m]Not known at Westbury-sub-Mendip but identified at sites believed synchronous, notably Ostend and Waverley Wood (Preece & Parfitt, 2000).

[n]Lister *et al.* (1990) discussed at length the significance of the horse remains from Little Oakley. They concluded that they are probably of a caballine species, which may be *Equus mosbachensis*, although of unusually small size for that species. Preece & Parfitt (2000) interpreted the species present, recorded by Lister *et al.* (1990) as '*Equus* sp. (caballine)', as *Equus altidens*.

[o]*Stephanorhinus hundsheimensis* and *S. hemitoechus* are regarded as members of an evolutionary lineage of small rhinoceroses (e.g. van der Made, 2000), this species transition occurring during the mid Middle Pleistocene (cf. Bridgland *et al.* 2004). Classification is made primarily on the basis of dimensions of teeth, which show a systematic variation throughout the Middle Pleistocene. Van der Made (2000) placed this transition at the point between the forms observed at Süssenborn (OIS 15) and Mosbach (OIS 13), in central Germany. However, the form found at Boxgrove, southern England (late OIS 13), has been attributed to *Stephanorhinus hundsheimensis* (e.g. Parfitt, 1998; Preece & Parfitt, 2000). *Stephanorhinus kirchbergensis* denotes a separate lineage of larger rhinoceroses, for which the dimensions of teeth also varied systematically during the Middle Pleistocene. Classification of *S. kirchbergensis* is complicated by the existence of synonyms, notably *Dicerorhinus mercki* and possibly also *S. brachycephalus* (e.g. van der Made, 2000). Van der Made (2000) considered that *S. hundsheimensis* and *S. kirchbergensis* both entered Europe around the Early–Middle Pleistocene boundary or during the early Middle Pleistocene, and superseded the Early Pleistocene *S. etruscus*, which was, thus, not their direct ancestor; he, thus, regarded the many reports in the literature of *S. etruscus* (or *D. etruscus*) at Cromerian Complex age sites as mis-classifications of other species, notably *S. hundsheimensis*.

[p]Species found in material collected at Little Oakley by Warren in the 1950s but regarded as from modern spoil (Preece & Parfitt, 2000).

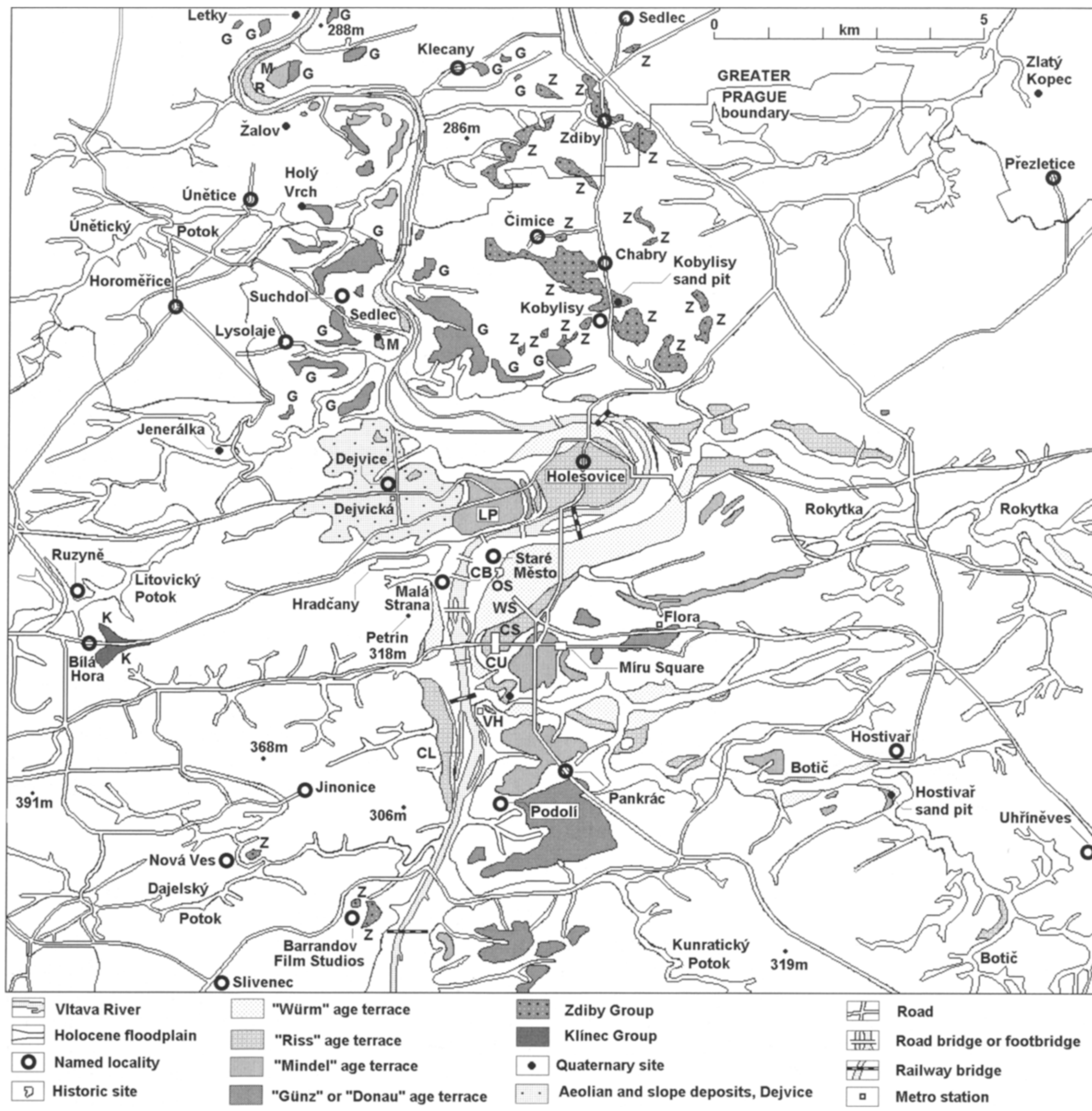


Fig. 6. Map of the Prague area, adapted from Kovanda (1995). Abbreviations denote: CB, Charles Bridge (Karlův Most); CL, Císařská Louka (island in Vltava); CS, Charles Square (Karlovo náměstí); CU, Charles University (Univerzíta Karlova); LP, Letná Park (Letenské Sady); OS, Old Town Square (Staroměstské náměstí); VH, Vyšehrad (site of ancient fortification on interfluve); WS, Wenceslas Square (Václavské náměstí). Aeolian and slope deposits are omitted, except where covering the Dejvice abandoned meander. Kovanda (1995) assigned the terraces of the Vltava and its tributaries to the classic Alpine glacial stages. His 'Donau/Günz' terraces, or High Terrace group, comprise Ia, Ib and II, which are assigned here to OIS 18, 16 and 14. His 'Mindel' terraces comprise IIIa, IIIb and IV, which are assigned here to OIS 13b, 12 and 10. His 'Riss' terraces, or Main Terrace group, comprise Va, Vb and VI, which are assigned here to OIS 8, 7b and 6. His 'Würm' terraces or Valley Terrace group comprises the various levels within terrace VII that formed during the last glacial cycle culminating in OIS 2. See text for discussion.

Preservation within the gorge is poor and generally restricted to the younger terraces (see Figs 8a, b). At some localities, notably Sedlec, Letky and Únětice (Fig. 6), overlying interglacial deposits provide biostratigraphical age constraints and evidence for environmental conditions (see below).

The city of Prague (Fig. 6) is built on terraces of the Vltava. The flat land surface ($\sim$5 m above river level)

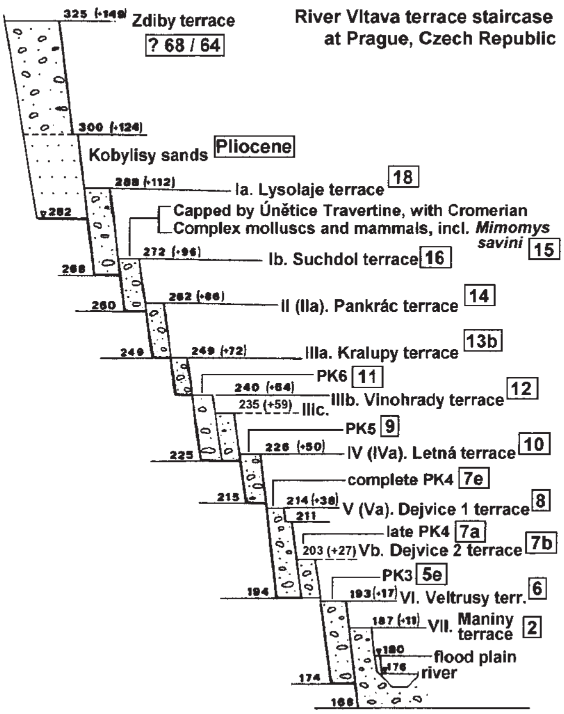


Fig. 7. Schematic transverse profile across the Vltava terrace sequence in the Prague area. Absolute altitudes correspond to km 204 (see Fig. 8e). Adapted from Záruba *et al.* (1977, fig. 1).

on the right bank of the Vltava in the Staré Město (Old Town) district is part of terrace VII (Fig. 8c), in the core of a dextral meander. Moving southeast, Wenceslas Square (Václavské náměstí) is underlain by gravels of the older terrace VI capped by a thin layer that is correlated with the younger terrace VII. At the SE end of this square, near the National Museum, the land surface rises abruptly to the level of older terraces (Fig. 8c). The core of the subsequent sinistral meander (Fig. 6) preserves a ~1.5 km wide flat expanse of gravel of terrace VI, ~15 m above river level, now largely covered by the suburb of Holešovice. In the same meander core, ~45 m above the river, a flat expanse of gravel of terrace IV (the Letná terrace) underlies Letná Park (LP in Fig. 6, also Fig. 8c). Further downstream, at Dejvice, on the outside of a second dextral meander, is preserved a ~700 m wide buried channel, filled with deposits of terrace V (Fig. 8d), that has since been cut off and abandoned.

The Vltava terrace sequence in Prague was first mapped systematically by Záruba (1942). His original terrace scheme was illustrated by Tyráček (2001a, fig. 3) and so is not repeated here. Záruba *et al.* (1977) revised the terrace nomenclature, introducing the notation used in this study, and subdivided several of the original terraces into multiple levels (Fig. 7). One important difference between the schemes concerns the Charles Square (Karlovo náměsti) terrace (base 18 m and top 27 m above the Vltava), recognized by Záruba (1942) but not by Záruba *et al.* (1977), who regarded the lower level of the 'Charles Square' terrace as a result of partial erosion of the Dejvice terrace. Nonetheless, separate higher and lower base as well as surface levels are identifiable within the Dejvice terrace of Záruba *et al.* (1977). They labelled these divisions Va and Vb (see Figs 8b and 8d), the lower one being present at Charles Square (Figs 8b, d; Fig. 6); here they are labelled the Dejvice 1 and Dejvice 2 terraces.

Sedlec

The former brick clay quarry at Sedlec u Prahy (Fig. 6) has yielded information on the relative ages of loess layers and palaeosol complexes that overlie Vltava terraces IIIb to VI (e.g. Záruba *et al.*, 1977) (Fig. 9). As already noted (see Vraňany, above), palaeosol PK3 overlies terrace VI. The complete sequence of palaeosol PK4 (two layers of parabraunerde followed by chernozem horizons) overlies terrace Va, but only its upper part (the chernozem) is present on the younger Vb (Fig. 9). Palaeosol PK5 overlies terrace IV and, nearby, PK6 overlies terrace IIIb. The relationship between terraces Va and Vb (or Dejvice 1 and 2) and palaeosol PK4 suggests that Va aggraded at the warming limb preceding the OIS 7 interglacial, which included two separate optima (when the parabraunerde soils developed). These were followed by a cold stadial when Vb aggraded, then a third warm episode when the upper part of PK4, covering both terraces, was formed.

Letky

A similar sequence of fluvial gravels, loess beds and interglacial palaeosols has been documented at the abandoned brick clay quarry at Letky (Záruba *et al.*, 1977, plates III-2 and IV-1; Fig. 6). Both Sedlec and Letky have yielded interglacial molluscs from both PK3 and PK4. The evidence from both sites indicates that the species most strongly indicative of warm humid climates, notably *Aegopinella ressmanni*, *Aegopis verticillus*, *Helicigona banatica*, *Soosia diodonta*, *Cepaea nemoralis* and *Gastrocopta theeli*, are found in association with PK3 but not PK4 (Záruba *et al.*, 1977). Overall, the evidence from Sedlec and Letky supports the association of PK3 with OIS 5e, the Eemian, both from stratigraphical position and the thermophilous nature of the fauna. The combination of two distinct climatic minima and three optima suggests that PK4 marks OIS 7 (7e–7a), with aggradation of the Dejvice 1 (Va) terrace during OIS 8 and the warming limb preceding OIS 7, and of the Dejvice 2 (Vb) terrace during OIS 7b.

Únětice

At Holý Vrch, near Únětice (Figs 6 and 10), calcareous tufa overlies the Suchdol (Ib) terrace, which has a base of 88 m and top of 97 m above the Vltava (Fig. 7). This tufa has yielded molluscs, including *Granaria*

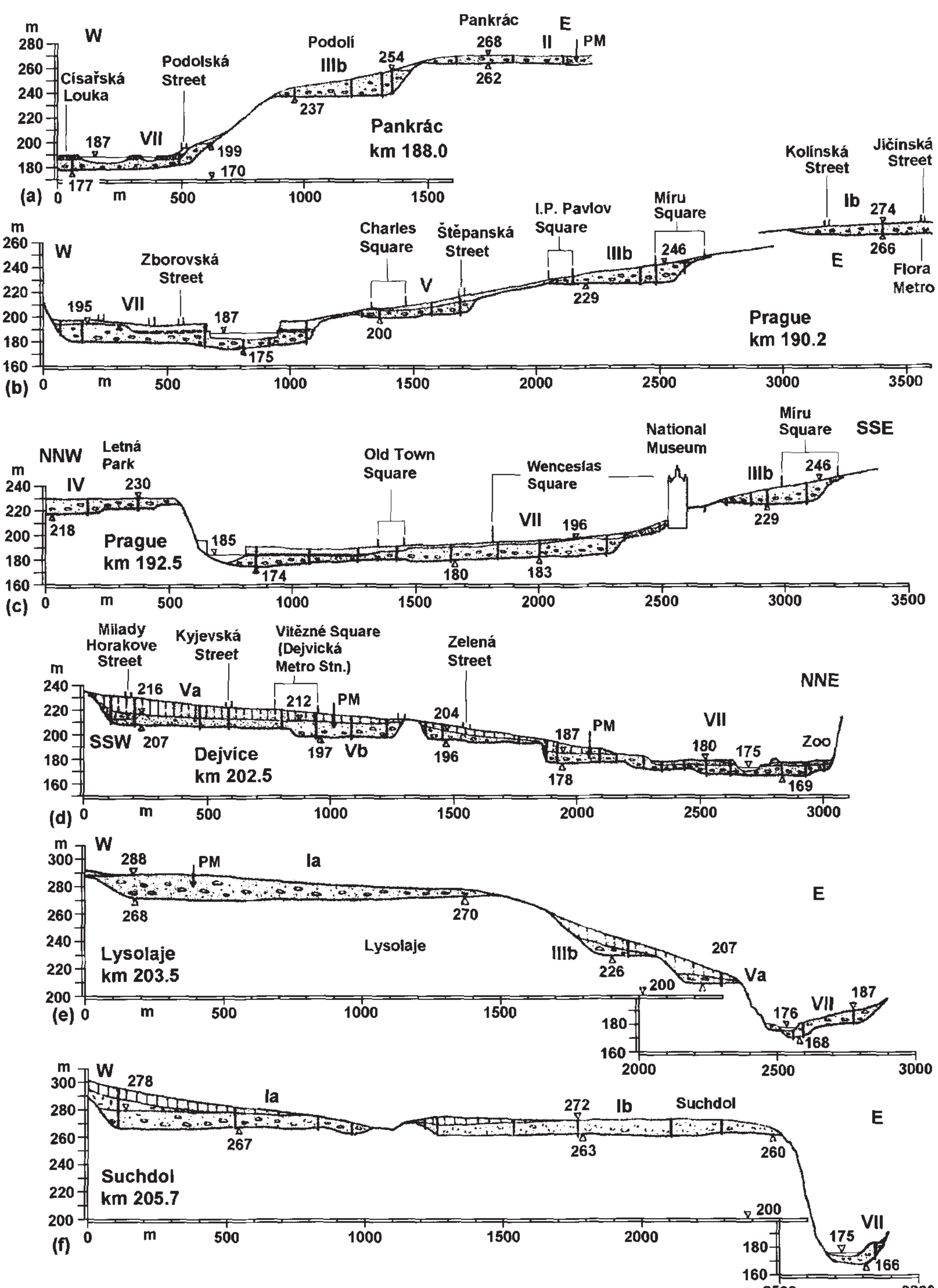


Fig. 8. Selected transverse profiles showing the younger part of the Vltava terrace sequence in the Prague area: (**a**) at Pankrác in the southern outskirts of Prague; (**b**) at the southern edge of the city centre; (**c**) through the city centre; (**d**) at Dejvice, north of the city centre; (**e**) at Lysolaje; (**f**) at Suchdol. Adapted from parts of Záruba *et al.* (1977, figs 7 and 8).

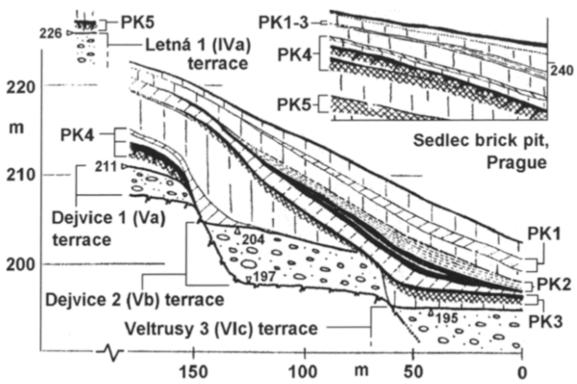


Fig. 9. Cross-section through Vltava terraces IV, Va, Vb and VI at Sedlec brick pit near Prague, showing the overlying interglacial soil complexes. The inset shows (at the same scale) the development of soil complex PK4 elsewhere at the site, showing its structure comprising two layers of parabraunerde overlain by chernozem. Adapted from Záruba *et al.* (1977, fig. 10).

frumentum and *Heliciqonia capeki* (see Fig. 10 caption), characteristic of interglacials within the Cromerian Complex (cf. Záruba *et al.*, 1977). The sedimentary and biostratigraphical evidence (Fig. 10) indicates that a single interglacial is represented.

Záruba *et al.* (1977) have claimed, following magnetostratigraphic investigations, that the Matuyama–Brunhes transition occurs in a ~4 m section within this tufa (Fig. 10), which would constrain the interglacial to OIS 19 and the aggradation of the Suchdol terrace to OIS 20. However, inspection of this dataset (Fig. 10, inset) raises several questions. First, the interpretation (from Záruba *et al.*, 1977) spans several complete climate cycles, not a single interglacial. Second, many data are not internally consistent; for instance, much of what is interpreted as reverse-magnetized from its upward inclination has a northward declination. Third, according to Záruba *et al.* (1977), the data were analysed using a spinner magnetometer using alternating field demagnetization. Given

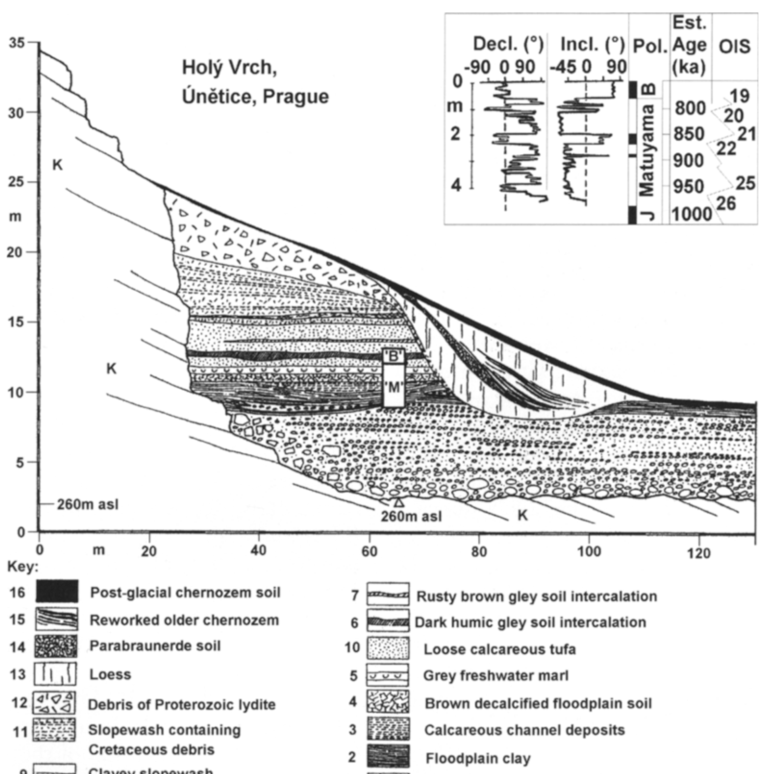


Fig. 10. Cross-section through the calcareous tufa overlying the Suchdol terrace, ~90 m above the Vltava, at Únětice (Holý Vrch) (Fig. 6): adapted from Záruba *et al.* (1977, fig. 9); based originally on Ložek (1969, fig. 5). Quaternary sedimentary unit numbers (in key) correspond with usage by Záruba *et al.* (1977). Unit 3 contains freshwater molluscs (*Sphaerium*, Planorbidae, *Bithynia leachi*); Unit 5 contains early interglacial molluscs (abundant *Chondrula tridens* and *Granaria frumentum*). Unit 10 contains a fully interglacial mollusc fauna (e.g. *Helicigona capeki*, *Discus perspectivus*, *Ruthenica filograna*, *Ena montana*, *Discus ruderatus* and *Carychium tridentatum*). Units 13–15 form the infill of an erosional depression. 'M' and 'B' denote the position where the Matuyama and Brunhes chrons have previously been magnetostratigraphically interpreted within the stratigraphical section, using the data in the inset. See text for discussion.

that tufa is typically extremely weakly magnetized, it is questionable whether such equipment (as opposed to a cryogenic SQUID magnetometer) could have produced a reliable analysis. Furthermore, samples used by Záruba *et al.* (1977) to illustrate demagnetization do not show the magnetization direction tending to a stable limit, making it impossible to tell whether the true primary magnetization has been revealed.

Despite doubts about the value of the magnetostratigraphy, biostratigraphical evidence for a Cromerian Complex interglacial is clear. The small mammal evidence from Únětice (Table 1) includes *Mimomys savini* and other species characteristic of the Late Biharian. Indeed, the absence of older species such as *Beremendia fissidens* led Horáček & Ložek (1988) to assign this site to their biozone Q2-3, the latest of the three Late Biharian stages that they recognized, although the magnetostratigraphic evidence of a Matuyama age led them to place the lower part of this site in their biozone Q2-2. If the magnetostratigraphy is ignored, a date in the mid Cromerian Complex seems most likely.

Zdiby Group

Fluvial deposits of the Zdiby Group, conventionally assigned to the Pliocene, are documented at several localities around Prague, relating to an infilled and abandoned early fluvial course (Fig. 6). Small exposures are identified to the SW (e.g. at Lochkov, Slivenec and Barrandov; Fig. 6), whereas thicker and more extensive deposits are documented to the NE (at Čimice–Kobylisy–Chabry and Zdiby–Sedlec). In the latter area, these deposits can be subdivided into two units. Morphologically higher, at 299–323 m altitude, are coarse sandy gravels, whereas at lower levels (265–301 m) there are ferruginous sands with lenses of clayey silt (Kobylisy Sands), up to ~40 m thick, indicative of fluvial and fluvio-lacustrine environments. The literature is not clear about the stratigraphical relations of these two units, although the placing, by Záruba *et al.* (1977), of the 'Zdiby terrace' at the top of the Kobylisy Sands suggests that they regarded the higher sandy gravels as older, with the sands incised into them. Dating of the Zdiby Group is problematic. Magnetostratigraphic evidence from the Kobylisy Sands, claimed to record a normal to reverse transition around the time of the Réunion subchrons (Záruba *et al.*, 1977), is probably no less problematic than that from the Únětice tufa (see above).

The plant species *Taxodium dubium* and *Salvinia formosa*, from the Kobylisy sands, have been interpreted as Pliocene (Králík, 1984). However, because these are not index fossils and have a much wider stratigraphical range, a greater age cannot be excluded. Pebbles of 'moldavite', a tektite related to the Nördlinger Ries meteorite impact crater (Fig. 1a) in Bavaria (which is Ar–Ar dated to 15.21 ± 0.15 Ma – Staudacher *et al.*, 1982) have been found in the upper part of the Kobylisy Sands and would seem to date them to the Middle Miocene (Žebera, 1972). Analogous sands occur in the Vltava valley near Zbraslav and Kamýk, ~5 km and ~75 km upstream from Prague.

Localities along the 'Little Labe'

Upstream of the Labe–Vltava confluence at Mělník (Fig. 1, inset), the 'Little Labe' (Malé Labe) has a much smaller drainage catchment than the Vltava and, over a relatively short distance upstream, the separation between terraces decreases (e.g. Balatka *et al.*, 1966; Balatka, 1992), as in the headwaters of the Vltava (Fig. 2). Several significant localities are known along the ~73 km reach of the Little Labe between Mělník and Kolín (Fig. 1).

Zlatý Kopec

At Zlatý Kopec, near Přezletice ~18 km upstream of the confluence (Fig. 1), an interglacial mammalian fauna, assigned to a Cromerian Complex interglacial (cf. Fejfar, 1976), occurs in lacustrine sediments and palaeosol, in association with molluscs and chipped clasts that have been interpreted as primitive artefacts (e.g. Záruba & Roth, 1946; Ložek, 1964, 1969; Šibrava *et al.*, 1979). This locality (Fig. 6) is at ~250 m altitude, ~75 m above the Labe, which flows ~5 km to the northeast (Fejfar, 1969; Šibrava *et al.*, 1979). The lacustrine deposits at this site, at ~244–247 m altitude, record a complete cold–temperate–cold climatic cycle. Although these are not river terrace deposits, Šibrava *et al.* (1979) suggested that they accumulated just beyond the southern margin of a Labe terrace that had previously aggraded to the ~244 m level. Their altitude also invites comparison with localities on the Vltava in Prague, ~10 km to the southwest. On this basis, the Zlatý Kopec site has been regarded (e.g. by Záruba *et al.*, 1977) as younger than the Cromerian Complex interglacial site at Únětice, which caps Vltava terrace Ib.

Šibrava (1972) proposed that the small mammals from Zlatý Kopec indicate the latest part of the Biharian stage (MQ1) and that the associated palaeosol is PK8. The end of the Biharian is marked by the last appearance of the water vole *Mimomys savini*, which, in northwestern Europe, is thought to have been replaced by its descendent, *Arvicola cantiana*, following OIS 15 (e.g. Preece & Parfitt, 2000; Westaway *et al.*, 2002). This timing would make OIS 15 the youngest feasible age for Zlatý Kopec, which would fit an extrapolation of the palaeosol chronology that correlates PK7 with OIS 13 and PK8 with OIS 15. Furthermore, this site has many faunal similarities with Little Oakley (Table 1), the youngest Biharian-equivalent site known in southeast England (Preece & Parfitt, 2000; Stuart & Lister, 2001), attributed by Westaway *et al.* (2002) to OIS 15a.

From the 1940s onwards, Zlatý Kopec was thought to be the oldest human occupation site in central Europe and the only place in this region where humans co-existed with *Mimomys*. Reported archaeological

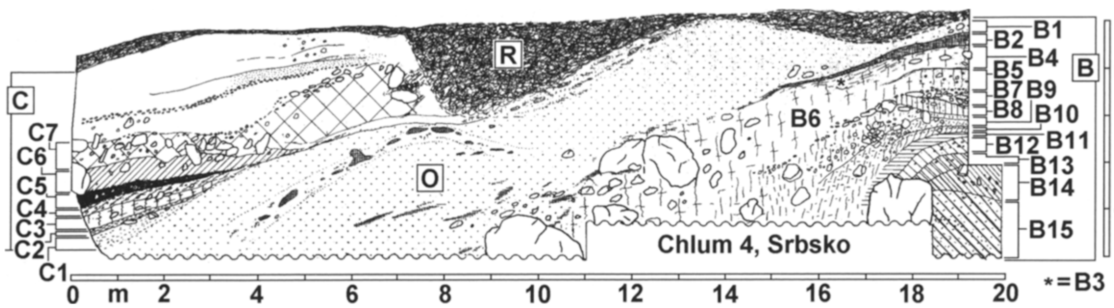


Fig. 11. Cross-section through the upper part of the sediment that covers the 85 m terrace of the Berounka river at locality Chlum 4 near Srbsko (Fig. 1), adapted from Horáček & Ložek (1988, fig. 7). A thick bed (O) of blown sand – containing carbonate encrustations (shaded) – separates sequences B and C, which belong to two distinct climate cycles, given that B contains *Mimomys savini* and C contains *Arvicola mosbachensis* (i.e. *Arvicola terrestris cantiana*) (see text). Sequence R overlying C is younger infill. Beds C1 and C2 are sandy loam (C1 is greyish-yellow; C2 is greyish-brown); C3 and C4 are loess loam (C4 containing coarse angular clasts); C5 is dark brown humic soil; C6 is reddish-brown loam, infilling between angular rock fragments; C7 is fine infill between boulders. The coarse material in sequence C resulted from the collapse of a former cave mouth. B1 is blown sand; B2 is a localized carbonate encrustation; B3 to B6 are loess layers; B7 to B10 are layers of tufa, which accumulated in a former cave mouth; B11 to B14 are loam; B15 is sandy loam, passing downward into loess loam and loess.

evidence (e.g. Fejfar, 1969; Fridrich, 1987; Valoch, 1995) was, however, subsequently dismissed by Roebroeks & van Kolfschoten (1995).

Čílec
Čílec, near Nymburk (~52 km upstream of the Labe–Vltava confluence; Fig. 1), is the only locality in the Czech Republic where the thermophilous bivalve *Corbicula fluminalis* has been reported (e.g. Smetana, 1935). Záruba *et al.* (1977) mentioned that the Čílec terrace, where *Corbicula* is found, occupies roughly the same altitudinal range above the Labe as the Vb or Dejvice 2 terrace above the Vltava at Prague (i.e. ~18 m to ~27 m). They implied that the *Corbicula* bed is at the base of this terrace, indicating that it marks the preceding warm stage. If this correlation and the suggested ages of the sequence at Prague (see above) are correct, this occurrence of *Corbicula* would date from OIS 7, an interglacial during which this bivalve was common in NW Europe (Keen, 1990; Bridgland 1994; Meijer & Preece, 2000; see below).

Localities upstream of Prague

As already noted, the Vltava terraces gradually converge upstream of its confluences with the Sázava and Berounka (Fig. 2b). The lower Berounka (Fig. 1) also has its own terrace sequence (Balatka & Loučková, 1991, 1992), including biostratigraphically significant localities.

Karlštejn
At Altán, near Karlštejn, terrace Va, 34 m above the Berounka, is overlain by a thick soil complex (e.g. Záruba *et al.*, 1977; Horáček & Ložek, 1988). This consists of a basal interglacial soil, including colluvium containing the interglacial mollusc *Ruthenica filograna*, and is overlain unconformably by other interglacial deposits, also containing thermophilous molluscs. This suggests that the underlying 34 m of terrace pre-dates the last two interglacials, suggesting a correlation with the Dejvice 1 (Va) terrace at Prague, as would also be expected from its altitude above river level. This is, thus, a likely analogue of Sedlec and Letky, already discussed.

Srbsko
Several karstic fossiliferous localities are documented from Chlum Hill near Srbsko. The most significant is Chlum 4 (Fig. 11), where the fossiliferous sediments (designated as sequences K, B and C) cover terrace Ib, which has a surface ~85 m above the Berounka (e.g. Záruba *et al.*, 1977; Horáček & Ložek, 1988). Sequence K consists of loess with a cold-climate small mammal fauna, dominated by *Microtus gregaloides*. The overlying sequence B (Fig. 11) consists of loam and tufa with a diverse temperate fauna including *Mimomys*, passing upwards into loess that is again dominated by *Microtus gregaloides*. The overlying sequence C consists of temperate-climate slope deposits containing *Arvicola*. Nearby, beneath sequence K, cave infill (sequence S), again with a diverse temperate-climate fauna containing most of the species in the temperate part of sequence B, is presumed also to post-date the aggradation of the 85 m terrace. Horáček & Ložek (1988) assigned sequence C to their biozone Q3-1 and to Kukla's (1978) climate cycle G (which probably equates with OIS 13), sequence B to biozone Q2-3 and to climate cycle H (OIS 15), and sequences S and K to climate cycle I (OIS 17), with S tentatively assigned to the earlier biozone Q2-2, even though its fauna is very similar to that of sequence B.

This site, thus, straddles the *Mimomys–Arvicola* transition, something known from a very few sites in

Table 2. The Vltava terrace chronology of Záruba *et al.* (1977).

Terrace sequence		Interglacial sequence	Age (ka)	Classification	
		Holocene, PK0			
VII	Maniny		70–30	Weichselian	Würm
		Eemian, PK3			
VI	Veltrusy		170–130	Warthe	Riss 2
		Rügen (i.e. Treene), PK4			
V	Dejvice		260–220	Drenthe (Saalian)	Riss 1
		Dömnitz (Holsteinian 2), PK5			
IV	Letná		370–340	Fuhne (Late Elster)	Mindel 2
		Holsteinian 1, PK 6			
IIIb	Vinohrady		540–440	Elster (Elster 2)	Mindel 1
		Voigtstedt			
IIIa	Kralupy		640–600	Helme (Elster 1)	Günz 2
		Cromerian (Únětice)			
II	Pankrác		780–750	Menapian	Günz 1
		Ctiněves			
Ib	Suchdol		880–820	Eburonian	Donau 2
Ia	Lysolaje		980–940	Brüggen	Donau 1
Z	Zdiby		2050–2100	Pliocene	

Age estimates are from magnetostratigraphy. The Matuyama–Brunhes boundary was assigned to 690 ka at this time and regarded as occurring within the Únětice tufa deposits (Fig. 10).

Europe and none in the UK. The temperate-climate fauna from sequence B is similar to that from Little Oakley (Table 1), the youngest known site in England with *Mimomys* (e.g. Preece & Parfitt, 2000; Westaway *et al.*, 2002). The temperate fauna from sequence C is similar to that from the calcareous member at Westbury-sub-Mendip (Table 1), the only karstic site in a (British) group considered to directly post-date the *Mimomys–Arvicola* transition (e.g. Preece & Parfitt, 2000). With this extinction assigned to OIS 14 (see above), sequences B and C fall into OIS 15a–14 and 13c–13b. The faunal similarity between sequences S and B indicates that no great interval of time separates them, so that sequences S and K may have formed in OIS 15c–15b and the underlying gravel of the 85 m Berounka terrace (Ib) in OIS 16.

Beroun

An exposure through the Quaternary sequence of the Berounka gorge, in a ~20 m deep motorway cutting at Beroun, has been studied in detail (e.g. Kovanda *et al.*, 1988; Tyráček & Kovanda, 1991; Tyráček, 1991, 2001a). The oldest fluvial deposit exposed here, the Vráž 'terrace', is aggraded to 85 m above the river. It is overlain by gravel of the considerably younger Beroun terrace (Ib), aggraded to 90 m above the river. At lower levels, two more terraces are evident, at 50 m and 42 m, with the 'Main' terrace at 10 m and the 'Valley Bottom' terrace at 2 m. Between deposition of the Vráž and Beroun terraces, the Vráž gravel was covered by ~20 m of loess, aeolian sand and slope deposits interbedded with five interglacial brownearth palaeosols, indicating a considerable hiatus at this point in the fluvial sequence, with no valley rejuvenation. The river incised into the loess/soils sequence prior to aggradation of the Beroun terrace sediments, however.

According to Valoch (1995), the youngest feasible correlation for the youngest of these five palaeosols is with PK7 (OIS 13), although Balatka & Loučková (1991, 1992) have regarded the whole sequence as older. These different interpretations mean that the Vráž gravel could have been deposited as early as OIS 36 or as late as OIS 22. Irrespective of this, it seems most likely that the 50 m and 42 m terraces represent OIS 12 and 10 respectively, the 'Main' terrace OIS 6, and the 'Valley Bottom' terrace OIS 2. It is apparent that this locality experienced relative stability in the late Early Pleistocene, followed by rapid incision beginning after formation of the youngest palaeosol; the longer-time-scale interpretation, which places the latter in OIS 19 or 17 and suggests aggradation of the Beroun Terrace in OIS 16 (Balatka & Loučková, 1991, 1992), fits better with the proposed interpretation of the Prague area.

Clasts from both the Vráž and Berounka terraces, and from the second-oldest palaeosol in the loess sequence, have been interpreted as artefacts (e.g. Fridrich, 1991; Valoch, 1995) but, as with those from Zlatý Kopec, these were dismissed by Roebroeks & van Kolfschoten (1995) as resulting from natural processes.

Above the level of the river terraces, outliers of up to 30 m of Miocene fluvial sediment, designated as the Klínec Group, are evident at several points beside the lower Berounka, at altitudes of up to ~380 m asl or ~165 m above the river (e.g. Balatka & Loučková, 1991, 1992; Balatka, 1992; Kovanda, 1995). An example is at Sulava, near the Vltava confluence (Fig. 1), where a former sand quarry provided exposures of fluvial sands interbedded with clays containing leaf imprints. Other outliers occur at Mořina, Slivenec and Lochkov along the Berounka (Fig. 1), and at Bílá Hora in the western suburbs of Prague (Fig. 6). The precise palaeogeography at the time these Miocene fluvial deposits accumulated is unknown. However, as palaeo-coastlines roughly followed the northern and southern margins of the Bohemian Massif for much of the Miocene (e.g. Ziegler, 1982; Steininger & Rögl, 1984), with the North European Plain and Vienna Basin inundated, valley floor levels in this area may well have been only a few tens of metres above contemporaneous sea-level. In the absence of evidence for sufficient global sea-level lowering to explain it, the ~400 km of net downstream channel lengthening between the Miocene and Early Pleistocene requires uplift dramatically exceeding the ~80 m of net incision during that interval. Assuming a distance of ~100 km between the Prague area and the Miocene coastline, and a mean river gradient of ~0.3 m km^{-1} (less than at present, given the proximity of the palaeo-coastline), the minimum feasible palaeo-altitude of the depositional surface in the Prague area can be estimated as ~30 m above contemporaneous sea-level. The total net uplift of this region since the Miocene fluvial sedimentation could, thus, be as much as 350 m, with maybe ~110 m of incision during the Middle–Late Pleistocene (from the top of the loess sequence overlying the Vráž terrace). For comparison, south of the Czech Republic, in the Vienna Basin, shallow-marine deposits of the Paratethys Sea, dated to the late Middle Miocene/early Late Miocene (Sarmatian) era, are now found at altitudes of up to ~500 m (e.g. Šibrava, 1972), implying rather more (~50%) post-Miocene uplift than in the lower Berounka/Prague area.

Near Tetín (Fig. 1), fluvial and lacustrine sediments, which resemble the Klínec Group, underlie the gravels of the ~75 m terrace (of presumed 'Günz' age – probably OIS 16) that flanks the Berounka gorge through the limestone of the Bohemian Karst belt (Petrbok, 1950). Calcareous colluvial loams and sands, also underlying the 75 m terrace gravel, contain the molluscs *Platyla* sp., *Negalus* sp., *Argna* sp., *Palaeoglandina* sp., *Strobilops* sp., *Plioptychia* aff. *vulgata*, *Laminifera* sp., cf. *Monachoides* sp. and *Helicodonta* sp., indicating an Early Miocene age (Kukla & Ložek, 1993). At this time, the river flowed westward, opposite to its present course (Žák *et al.*, 2001), and drained into a freshwater lake in the Most Basin (Fig. 1) (Tyráček, 2001a). Broadly contemporaneous travertines and lacustrine limestones of the Most Basin, interbedded with its main lignite seam, also contain rich floras and mollusc and mammal faunas, which are indicative of early Miocene biozone MN3 (early Orleanian; early Burdigalian; ~19–21 Ma), for instance at Tuchořice (e.g. Fejfar, 1989).

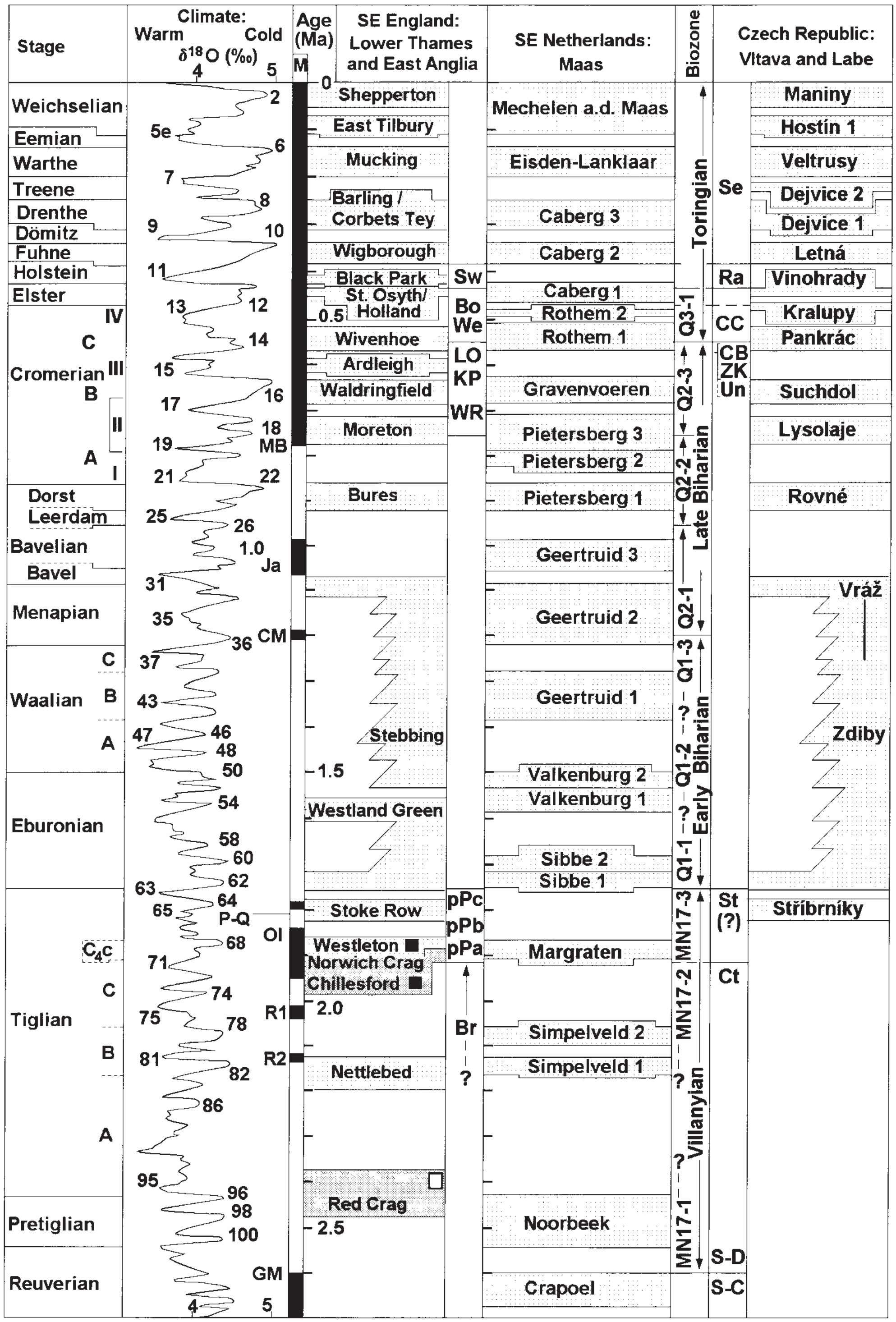
3. DISCUSSION

The well-established notation for the Vltava/Labe terraces, using Roman numerals (Balatka & Sládek, 1962; Záruba *et al.*, 1977; Tyráček *et al.*, 2001), is retained here alongside geographical names for the key terrace levels (Figs 3, 5, 7). The dating of the sequence requires reconsideration in the light of the greater range of climato-stratigraphic stages now recognized from the Quaternary, thanks to research on deep ocean sediments (e.g. Shackleton *et al.*, 1990; Bassinot *et al.*, 1994). Evidence for the ages of sediments and soils at key localities has already been presented and, where controversy exists, has been discussed. The extent to which this can be combined to form a viable Vltava terrace chronology can now be examined.

It is worth noting that, although much more is now known about the Quaternary than was available to Záruba *et al.* (1977), much of their chronology (Table 2), especially that part post-dating the Cromerian Complex, is broadly confirmed. Indeed, correlation of the Cromerian, Elsterian, Holsteinian and Saalian 'complexes' with the oxygen isotope record remains controversial, with a number of unresolved conflicts, pivotal amongst which is whether the main Elsterian glaciation (Elster II) should be correlated with OIS 12, as is favoured in Britain (Bowen *et al.*, 1986, 1989; Bridgland, 1994, 2000; Bowen, 1999; Rowe *et al.*, 1999; Scourse *et al.*, 1999) or with OIS 10, as favoured by Dutch and some German workers (De Jong, 1988; Roebroeks & van Kolfschoten, 1995; Urban, 1995; Zagwijn, 1996). Upon this latter dispute rests the attribution of the Holsteinian *sensu stricto* to OIS 11 or OIS 9 (Sarnthein *et al.*, 1986; Schreve, 2001). The scheme of Šibrava (1986), which favours the Anglo-French (Elsterian=OIS 12, Holsteinian=OIS 11) 'longer' chronology, is advocated here for central Europe.

Miocene–Early Pleistocene

The oldest level within the Vltava–Labe sequence for which a reliable age estimate can be suggested is the Middle Miocene Kobylisy Sands, dated with reference to a meteorite impact event (see above). These deposits do not, however, belong to the present drainage pattern, but instead follow a separate, infilled and abandoned early fluvial course. The considerable antiquity of the Kobylisy Sands suggests that their top does not represent a terrace, as implied by Záruba *et al.* (1977); instead they presumably underlie the coarse sandy gravels of the Zdiby Group, which aggraded to altitudes of around 300 m, compatible with levels of post-Miocene uplift discussed above. The upper level of these Zdiby Group gravels at Prague, 149 m above the Vltava (Fig. 7), is similar to that of the scattered gravels or 'Schotterbestreuung' around Ctiněves (~160 m; Fig. 5). The minimum age estimate of ~1.9 Ma for the slope deposits at Ctiněves can be


Stage
Climate: Warm Cold
δ18O (‰)
Age (Ma)
SE England: Lower Thames and East Anglia
SE Netherlands: Maas
Biozone
Czech Republic: Vltava and Labe
Weichselian
Eemian
Warthe
Treene
Drenthe
Dömitz
Fuhne
Holstein
Elster
Cromerian
Dorst
Leerdam
Bavelian
Bavel
Menapian
Waalian
Eburonian
Tiglian
Pretiglian
Reuverian
Shepperton
East Tilbury
Mucking
Barling / Corbets Tey
Wigborough
Black Park
St. Osyth/ Holland
Wivenhoe
Ardleigh
Waldringfield
Moreton
Bures
Stebbing
Westland Green
Stoke Row
Westleton
Norwich Crag
Chillesford
Nettlebed
Red Crag
Mechelen a.d. Maas
Eisden-Lanklaar
Caberg 3
Caberg 2
Caberg 1
Rothem 2
Rothem 1
Gravenvoeren
Pietersberg 3
Pietersberg 2
Pietersberg 1
Geertruid 3
Geertruid 2
Geertruid 1
Valkenburg 2
Valkenburg 1
Sibbe 2
Sibbe 1
Margraten
Simpelveld 2
Simpelveld 1
Noorbeek
Crapoel
Toringian
Late Biharian
Early Biharian
Villanyian
Maniny
Hostín 1
Veltrusy
Dejvice 2
Dejvice 1
Letná
Vinohrady
Kralupy
Pankrác
Suchdol
Lysolaje
Rovné
Vráž
Zdiby
Stříbrníky

taken as a broad indication of the age of these fluvial deposits, which probably represent the combined effects of deposition during many cold climate cycles from ~2 Ma onward. However, the low incision rate and the large number of cold climate cycles resulting from the characteristic ~40 ka Milankovitch forcing at that time prevent further resolution.

The correlation scheme proposed here places all the terraces, from the Lysolaje (Ia) onwards and representing ~110 m of incision, in the Middle Pleistocene, assigning each to a specific OIS (see below). Age assignments and correlations for the older terraces and mammal assemblages are more tentative. The similarity in height between the top of the Kobylisy Sands and the Rovné terrace near Mělník, both ~124 m above the Vltava, is thought to be coincidental. The Rovné terrace is, thus, likely to be significantly younger than the Kobylisy Sands and is tentatively assigned to OIS 22 (Fig. 12). The ~150 m Stříbrníky terrace of the Labe can be regarded, from the presence of *Mammuthus meridionalis* molars (see above), as no younger than ~1.5 Ma and, thus, significantly older than the Rovné terrace.

As already noted, the Ctiněves slope deposits can be assigned to the Villanyian mammal stage (biozone MN17). In the scheme of Horáček & Ložek (1988), their age has been further refined to substage MN17-2. They are excluded from the succeeding substage MN17-3 as they lack *Microtus* (*Allophaiomys*) *deucalion* and also from the preceding substage MN17-1 as they lack *Mimomys stenokorys*, a predecessor of *M. pitymyoides*. Attribution to MN17-2 implies an age no younger than ~1.9 Ma (e.g. Fejfar *et al.*, 1997). The Stríbrníky terrace is ~10 m lower, relative to the river, than the Ctineves deposits, suggesting a slightly younger age (estimated as ~1.8 Ma; Fig. 12).

Middle Pleistocene

The early Middle Pleistocene, prior to the Elsterian, is broadly synonymous with the Cromerian Complex as originally defined in the Netherlands (e.g. de Jong, 1988; Zagwijn, 1996). The Dutch Cromerian I interglacial is, however, reverse magnetized and, therefore, falls in the latest Early Pleistocene (OIS 21(?)–19). Recent revisions of the normally magnetized Cromerian Complex, based on mammalian and molluscan biostratigraphy (Preece & Parfitt, 2000; Stuart & Lister, 2000, 2001), envisage up to four temperate episodes characterized by the presence of *Mimomys savini* and, thus, effectively equivalent to biozone Q2-3 of Horáček & Ložek (1988), the latest Late Biharian. Westaway *et al.* (2002) proposed that these three episodes represent OIS 17 (West Runton), 15c (Pakefield/Kessingland/Corton) and 15a (Little Oakley) (Fig. 12). Biostratigraphy is of some value in the Vltava–Labe. A correlation between Zlatý Kopec, in the Little Labe (see above), and the latest of the three 'Late Biharian' episodes (Little Oakley) is suggested by the high proportion of unrooted molar teeth of *Mimomys savini* (Fejfar, 1969), a late evolutionary development that also characterizes the Little Oakley assemblage (e.g. Preece & Parfitt, 2000). This suggestion gains support from the absence at the Czech site of taxa considered characteristic of the Pakefield/Kessingland/Corton group (Stuart & Lister, 2000, 2001), notably *Hippopotamus amphibius*, *Palaeoloxodon antiquus*, *Megaloceros dawkinsi* and *Equus altidens*. Similarly, the Zlatý Kopec assemblage also lacks *Macroneomys brachygnathus*, a warm-adapted shrew that characterizes the West Runton episode.

The small-mammal fauna from the Chlum 4B sediments, which overlie terrace Ib (see above), has many similarities with that from Zlatý Kopec. The 4B deposits are overlain by post-Biharian Cromerian Complex sediments, Chlum 4C, with *Arvicola*. It is suggested here, based on similarities in mammal biostratigraphy, that the Chlum 4C sequence correlates with the Calcareous Member at Westbury-sub-Mendip, SW England, and represents OIS 13c (cf. Preece & Parfitt, 2000; Westaway *et al.*, 2002).

Precise biostratigraphical correlation of Únětice, the third Cromerian Complex interglacial site in the Vltava system, is more problematic, given its sparser assemblage. The interglacial sediments here, which overlie the Suchdol (Ib) terrace of the Vltava, contain *Mimomys*, suggesting a minimum age in OIS 15 (see above; Fig. 12).

The mammalian fauna at Račiněves provides an important potential marker within the early part of the

Fig. 12. Summary diagram showing the proposed ages of Vltava/Labe sequence, its correlation with European Quaternary stratigraphic stages (cf. Šibrava, 1986), the oxygen isotope record from the deep oceans (Shackleton *et al.*, 1990) and, for comparison, the terraces of the Thames as interpreted by Westaway *et al.* (2002) and the Maas, as interpreted by Westaway (2001, 2002a). Global magnetostratigraphy is also shown in the column headed 'M' within the chrons and subchrons are indicated as follows: GM = Gauss-Matuyama; R2 = Réunion 2; R1 = Réunion 1; Ol = Olduvai; CM = Cobb Mountain; Ja = Jaramillo; MB = Matuyama-Brunhes. Mammal stages and substages proposed by Horáček & Ložek (1988) are also indicated, in the Biozone column. The diagram shows tentative correlations between the Bramertonian and pre-Pastonian stages in East Anglia, the Tiglian Stage in the Netherlands and the Villanyian mammal stage, based on Freudenthal *et al.* (1976), Stuart (1982), Mayhew & Stuart (1986) and Horáček & Ložek (1988). Abbreviations for the Czech Republic are: Se, Sedlec (with Letky and Karlštejn); Ra, Račiněves; CC, Chlum 4 C; CB, Chlum 4 B; ZK, Zlatý Kopec; Un, Únětice; St, Stříbrníky; Ct, Ctiněves; plus S-C and S-D, Stranzendorf C and D. For southeast England they are: Sw, Swanscombe (with Hoxne and Clacton); Bo, Boxgrove; We, Westbury-sub-Mendip; LO, Little Oakley; KP, Kesslingland/Pakefield/Corton; WR, West Runton (with Sugworth); pPa, pPb, pPc, sites of pre-Pastonian A, B and C age; Br, sites of Bramertonian age.

Toringian mammal stage. The occurrence of *Arvicola* suggests that this interglacial post-dates OIS 14 (see above), that being the oldest likely age for the underlying Vinohrady (IIIb) terrace gravel, given the indication that no significant hiatus exists between the two (Tyráček *et al.*, 2001). This would indicate a minimum time-averaged incision rate in the Prague area of ~ 0.12 mm a^{-1} (~ 64 m/540 ka) since the Middle Pleistocene.

However, the mammalian assemblage at Račiněves has strong similarities with others, over a wide area of NW Europe, attributed to OIS 11 (=Holsteinian/Hoxnian), at sites such as Bilzingsleben, in central Germany (Mania, 1995) and Swanscombe, Clacton and Hoxne in the UK (Schreve, 2001; Table 1). A Holsteinian age for Račiněves, although seemingly in conflict with the palaeosol evidence (Tyráček *et al.*, 2001; see above), would imply a faster incision rate of ~ 0.15 mm a^{-1} (~ 64 m/440 ka). Extrapolating this rate suggests that the Kralupy (IIIa) terrace aggraded during OIS 13b (~ 470 ka), the Pankrác (II) terrace during OIS 14, the Suchdol (Ib) terrace during OIS 16 and the Lysolaje (Ia) terrace during OIS 18; this is consistent with the tentative assignment of the Rovné terrace in the Mělník area to OIS 22. In contrast, extrapolating the lower of the two incision rates further back into the Pleistocene would suggest, from their height above the modern river, that the Kralupy (IIIa) terrace aggraded during OIS 15b (~ 600 ka) and the Pankrác (II) terrace during OIS 20 (~ 810 ka) or earlier. There would, thus, no longer be a one-to-one match between terraces and climate cycles for this part of the record.

The most easily traceable datum within the Vltava–Labe sequence is Vltava terrace IIIb (Fig. 2), the Straškov terrace in the Mělník area (Balatka & Sládek, 1962) and the Vinohrady terrace at Prague (Záruba *et al.*, 1977), the terrace overlain by the Račiněves fossiliferous sediments. According to Šibrava (1972), this can be traced downstream along the Labe as the Neštěmice terrace (1 in Fig. 3). However, this is ~ 15 m higher above the Labe near Děčín than above the Vltava in the Prague area (~ 80 m against ~ 65 m; see above); the Elster II gravels of the Ploučnice are even higher, ~ 85 m above the river (see above; Fig. 3). The implication of the Záruba *et al.* (1977) interpretation would appear to be, therefore, that despite its apparent continuity, this terrace is diachronous; around Děčín it corresponds to the Helme/Elster 1 glacial, which Záruba *et al.* (1977) thought marked the formation of the Kralupy terrace in the Prague area.

A possible alternative explanation of the evidence is that Vltava terrace IIIb and the Neštěmice terrace sediments near Děčín both formed in OIS 12 (Elster II), a suggestion that requires the Račiněves fossiliferous sediments to be of OIS 11 age, rather than older. Around Děčín, deposition was adjacent to the OIS 12 Scandinavian ice margin, so that glacio-isostatic depression of the crust might have caused aggradation to take place at a ~ 20 m higher relative level than would have occurred otherwise. After deglaciation the crust would have rebounded, raising the terrace to its higher-than-expected modern level (2 in Fig. 3). Indeed, Záruba *et al.* (1977) noted dramatic incision in the Děčín area following aggradation of the Neštěmice terrace, which is not observed around Prague and which might, therefore, be a response to this post-Elsterian isostatic rebound. A similar explanation accounts for anomalously high altitudes of Anglian terraces of the Thames that aggraded in parts of SE England near the Anglian (OIS 12) ice sheet (Maddy & Bridgland, 2000).

In the Mělník area, the Straškov (IIIb) terrace reaches a relative altitude ~ 5 m higher than the Vinohrady (IIIb) terrace at Prague: ~ 70 m against ~ 65 m above the river. This ~ 5 m difference may represent the southward tapering in the post-Elster isostatic rebound, from its ~ 20 m maximum around Děčín to zero around Prague. As Děčín is ~ 45 km north of the Mělník area, the geometry of the rebound would have reduced the Vltava–Labe gradient by ~ 0.3 m km^{-1}, from ~ 0.4 m km^{-1} to ~ 0.1 m km^{-1}. This disruption may explain why the Vltava abandoned its pre-Elster course west of Říp Hill at this time, adopting the modern course further east.

Late Middle and Late Pleistocene

As noted above, the chronological scheme proposed by Záruba *et al.* (1977) for the post Elsterian appears robust, in that it fits with the interpretations of the earlier parts of the sequence, discussed above, and with modelling of terrace formation as a response to climatic fluctuation in the context of modern understanding of the palaeoclimatic record. Corroborative biostratigraphical or geochronological evidence from the fluvial sediments is scanty, however, the primary evidence coming from palaeosols and molluscan faunas within loessic overburden (e.g. Ložek, 1969).

Záruba *et al.* (1977) proposed that the Letná (IV) terrace group formed during the 'Late Elster (Fuhne)' or Mindel 2 glacial. Using Šibrava's (1986) scheme, this would imply correlation with OIS 10, which fits well with the correlation scheme proposed here (Fig. 12). Záruba *et al.* (1977) also proposed that the Dejvice (V) terrace group aggraded during the 'Saale' or Riss 1 (i.e. 'Drenthe') glacial, which equates with OIS 8, according to Šibrava (1986). The evidence from Sedlec (Fig. 9), discussed above, supports an OIS 8 age for the older Dejvice 1 (Va) terrace, although it is likely that the Dejvice 2 (Vb) terrace aggraded later, during OIS 7b (see above; Fig. 12).

One potential difficulty concerns the occurrence at Čílec of *Corbicula fluminalis* at the level of terrace V of the little Labe (~ 18 m above river level), which is considered the local equivalent of Vltava terrace V (e.g. Balatka *et al.*, 1966). Along the Elbe and its tributaries in Germany, *C. fluminalis* has long been regarded as characteristic of the Holsteinian interglacial *sensu lato*, being absent in younger deposits (e.g. Mertin, 1940; Cepek, 1968), although it is present in OIS 11, 9 and 7 in Britain (see above). More recently, Mania (1995) has proposed that this species occurs in central Germany only in the interglacial represented by Bilzingsleben II (OIS 11). This would seem to conflict with the suggestion, above, that the Čílec site represents OIS 7.

Like the different levels of terrace V, the youngest terraces are dated using their stratigraphical relations with overlying palaeosols. For instance, the palaeosol evidence from Vraňany, where gravel of terrace VIc has been shown to be overlain by palaeosol PK3 of Eemian age, thus dating the gravel to the end of OIS 6, has already been discussed.

Correlation with the sequence downstream in Germany

Establishing a definitive correlation between the Labe in the Czech Republic and the Elbe in Germany has proved difficult. In Germany, following Grahmann (1933), Engelmann (1938) and others, a letter notation has been devised, applied alphabetically from higher (older) to lower. The clearest terraces are those designated E, I, O and U. Around Pirna, upstream of Dresden, the tops of the E, I and O terraces are, respectively, at ~130 m, ~70 m and 12 m above the Elbe (e.g. Präger, 1966). The younger U terrace has three surface levels, 8 m (U1), 6 m (U2) and 3 m (U3) above the river. Präger (1966) estimated that the E terrace pre-dates the Cromerian, the I terrace aggraded between the Elster I and Elster II glacials, the O terrace formed during the cooling limb before the OIS 8 glaciation (it is covered by deposits related to the Early Saalian ice advance (e.g. Präger, 1966; Lüttig & Meyer, 1975; Fig. 3)), the U1 terrace aggraded before or during the Warthe glaciation, the U2 is Weichselian and the U3 Holocene. From its altitude, the E terrace can be tentatively correlated with the Rovné terrace (Fig. 5) and other terrace fragments along the Labe (Fig. 3), for which an age around the Lower–Middle Pleistocene boundary is suggested in Figure 12.

Šibrava (1964, 1966) proposed that the ~20 m terrace of the Labe/Vltava in the Czech Republic (i.e. the Veltrusy (VI) terrace) pre-dates the Drenthe glaciation and, thus, correlates with the O terrace in Germany, and that the ~12 m (i.e. VIIa or Hostin 1 terrace) is of Warthe age. However, Šibrava (1972) suggested instead that the ~27 m Charles Square terrace of the Vltava is the correct correlative of the O terrace. The separate existence of this particular terrace was disputed by Záruba *et al.* (1977), but it is taken here to be equivalent to the Dejvice 2 terrace (see above). Later, Šibrava (1986) reverted to his earlier correlation of the ~20 m Vltava terrace with the 'Drenthe' glaciation, which is supported by the interpretation proposed in this paper.

Implications for uplift history

The interpretation favoured here regards the bulk of the Vltava terrace staircase as dating from the Middle–Late Pleistocene, starting in OIS 18 with the aggradation of the Lysolaje (Ia) terrace. The typical incision rate on this time-scale has been estimated as ~0.15 mm a^{-1}, which is interpreted as representing the rate of surface uplift in this region. The incision (and, thus, uplift) rate along the Vltava and Labe in the Early Pleistocene was, in contrast, much lower; it can be estimated as ~0.04 mm a^{-1} time-averaged between ~ 1.7 Ma and ~ 0.9 Ma from the ages and relative altitudes (~150 m and ~120 m) of the Stříbrníky and Rovné terraces. The evidence along the Berounka indicates an even greater contrast, with no net incision on this time-scale (see above).

Terrace sequences of other European rivers, notably the Maas, Rhine and Thames (van den Berg & van Hoof, 2001; Westaway, 2001; Westaway *et al.*, 2002), indicate that uplift rates of the surrounding land areas increased abruptly around or shortly after 0.9 Ma (i.e. OIS 22) (see also Westaway, 2002a, b). This event is now thought to mark the start of increased forcing of flow in the lower continental crust by cyclic loading effects of the larger-magnitude sea-level and ice volume fluctuations that began at this time (e.g. Westaway 2001, 2002a, b; Westaway *et al.*, 2002). It was preceded by a period (roughly coincident with the Early Pleistocene) with slow uplift, itself preceded by an earlier phase (starting at ~ 3 Ma) with relatively high uplift rates and with minimal vertical crustal motions before that. The Vltava terrace dataset fits this pattern well for the Pleistocene. As already noted, the altitude of the Kobylisy Sands and Klinec Group sediments may indicate an earlier phase of uplift, but this was accompanied by downstream channel lengthening and so the river probably maintained an equilibrium gradient without incision equalling the amount of uplift. However, further investigation is needed to establish this point.

4. CONCLUSIONS

The record of fluvial terraces and related interglacial sediments along the Vltava and Labe rivers constitutes an important Quaternary archive. Using key biostratigraphigraphical pinning points, a correlation with the oceanic oxygen isotope record can be suggested (Fig. 12). This scheme also allows an internally consistent correlation of these terraces with their more fragmentary counterparts downstream in Germany.

These terrace sequences indicate an increase in uplift rates following OIS 22 (~870 ka). The terrace record from OIS 18 (~710 ka) onwards indicates ~110 m of uplift at a time-averaged rate of ~0.15 mm a^{-1}, preceded by an interval spanning most of the Early Pleistocene with much slower uplift at ~0.04 mm a^{-1} or less. The altitudes of fragmentary remnants of

Mio-Pliocene fluvial sediments suggest the possibility of an earlier phase of faster uplift. The overall pattern indicated, involving two phases of uplift, is similar to what is observed along other European rivers with long-time-scale terrace records.

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