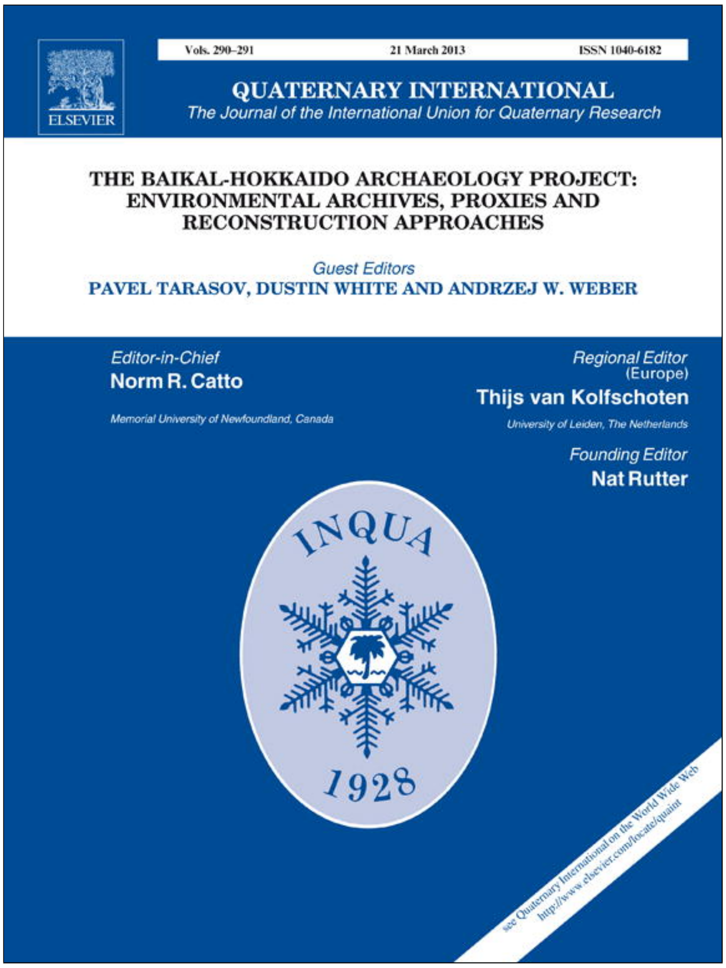
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Late Glacial and Holocene environmental change reconstructed from floodplain and aeolian sediments near Burdukovo, lower Selenga River Valley (Lake Baikal region), Siberia

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ABSTRACT

Floodplain and aeolian sediments near Burdukovo reveal a detailed record of Holocene environmental change in the lower Selenga River Valley (Lake Baikal region, Siberia). During the late Pleistocene and early Holocene fine-grained alluvium accumulated on the floodplain followed by a period of increased landform stability and subsequent pedogenic formation. This part of the stratigraphical sequence yielded rich assemblages of terrestrial molluscs, which increase in species diversity from early pioneer communities with about ten taxa to levels containing over twice that number. The land snail assemblages also record an episode of relatively drier local habitats prior to ~9.2 ka BP with subsequent wetter conditions lasting until ~8.0 ka BP. This was followed by an abrupt and sustained change in floodplain deposition, shifting from overbank alluvium to aeolian sedimentation, within which a series of weakly developed soil horizons formed during the middle and late Holocene periods. The onset of aeolian processes and relatively drier conditions in the middle Holocene at Burdukovo coincides with major changes observed both in other regional palaeoenvironmental proxy records and in local archaeological sequences, although it is still not clear how the two are linked.

1. Introduction

Investigation of late glacial and Holocene climate and environmental change in the Lake Baikal area of southern Siberia has increased significantly over the past decade, revealing important shifts in temperature, moisture and vegetation dynamics across the region. Palaeoecological data derived from sediments from Lake Baikal (Karabanov et al., 2000; Kataoka et al., 2003; Demske et al., 2005; Mackay et al., 2011) and adjacent small lakes and peat bogs (Bezrukova et al., 2005a, 2005b, 2008, 2011) provide increasingly high resolution proxy records of Holocene environmental change, and important new palaeoclimate studies have also recently been reported for the adjacent northern Mongolian Plateau (Wang et al., 2011; Zhang et al., 2012). These data, combined with quantitative biome reconstructions (Tarasov et al., 2007, 2009) and numerical climate simulations (Bush, 2005; White and Bush, 2010), allow the development of more robust local and regional-scale frameworks with which to view shifting landscape conditions and the changing environmental contexts of local hunter-gatherer groups during the Holocene. Such studies are particularly relevant to the aims of the Baikal Archaeology Project, whose research over the last decade has sought to understand long-term patterns of culture change among Neolithic and Bronze Age populations inhabiting the Lake Baikal area (Weber et al., 2002, 2010 and chapters therein), and their possible links to variations in local palaeoecology.

Despite the growing number of studies relating to Holocene environmental change across the Baikal region, evidence from the surrounding river valleys is comparatively sparse. Only recently have more detailed investigations been reported on the formation of Holocene floodplain sequences in the large valleys immediately northwest of Lake Baikal, along the upper Lena (White et al., 2008) and middle Kirenga (Preece and White, 2008) rivers, respectively. In addition to shifts in palaeohydrological regimes, depositional patterns and pedogenic cycles, many such stratified floodplain sequences also contain abundant shells of land and freshwater molluscs, which can provide important records of local environmental history, especially periods of increased wetness or aridity. However, information is scant regarding the Holocene floodplain

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and terrestrial molluscan successions in the river valleys of the Trans-Baikal region to the east of Lake Baikal. The present work addresses this deficiency by reporting new data from a site near Burdukovo in the lower Selenga River Valley.

This paper has three principal aims: (1) to describe the geological and stratigraphical context of the Burdukovo site; (2) to present results from a detailed study of an early–middle Holocene molluscan succession; and (3) to integrate these new data with key local and regional multi-proxy Holocene climate and environmental records. These results also provide further insights into the possible relationship between coeval changes documented in climatic archives and local archaeological sequences.

2. Site background

The Burdukovo site (52°07′13.2″N, 107°29′29.3″E; elevation 490 m a.s.l.) is located ~90 km east of the Selenga Delta area of Lake Baikal near the junction of the Eastern Khamar-Daban (1100–2400 m a.s.l.) and Ulan-Burgasy (1100–1800 m a.s.l.) mountain ranges (Figs. 1 and 2a). These SW–NE oriented uplifts and intermontane depressions are part of the eastern mountain chain of the Baikal Rift Zone, which is cut by the Selenga River near Tataurovo. Maximum elevations of local topography reach 1300–1400 m a.s.l., with ridge lines averaging c. 900 m a.s.l. Geological formations are part of the early Palaeozoic Barguzin intrusive complex composed of biotite, biotite–hornblende and gneissic granites, as well as syenites, granodiorites, pegmatites and diorite porphyrites (Bazarov, 1968). Exposures of carbonate cemented boulder-pebble conglomerates of the Cambrian Tataurovo suite and conglomerates with sandstone interlayers of the Jurassic Baikal suite are also present in the area (Preobrazhenskiy et al., 1959). Quaternary deposits occur as thin mantles of colluvial sediments along valley slopes, as alluvial deposits of the Selenga River terrace complex and its tributaries, and as sandy aeolian sediments overprinted by multiple buried soils. Today valley bottoms support sandy loam and loamy meadow soils characteristic of Gleyed Cumulic and Gleyed Cumulic Humic Regosols (Mollic Fluvisols), with Eutric Brunisols (Eutric Cambisols) covering valley slopes and upland plateaus (Dobrovolsky and Urusevskaya, 1984).

Meteorological data recorded at Tataurovo (~4 km northwest of the Burdukovo site) indicate that average annual air temperature is −1.7 °C, with average minimum and maximum temperatures of −8.3 °C and 4.8 °C, respectively (Chita hydro-meteorological observatory reports, 1966). Annual precipitation at higher elevations (>1000 m a.s.l.) averages about 300–350 mm, exceeding levels in the river valley by approximately 100 mm. The seasonal humidity regime is marked by moderate precipitation totals from June to August (about 2/3 of annual total), with minimum levels during February and March (Chita hydro-meteorological observatory reports, 1974). Snow-cover and river freeze-up occurs in mid-November and lasts until the beginning of the melting period in early April. Spring flooding starts during the first half of April (when ice-jamming is common), reaches a maximum in early May, and typically ends during the second half of May. River discharge between April and September constitutes about 83.4% of the annual total, with 12.5% occurring between October and November and 4.1% between December and March (Zhukov, 1960). Annual discharge rates near Burdukovo average 935 m^3/sec, reach 5350 m^3/sec during the spring flood season, and increase to about 7700 m^3/sec during flooding brought on by rain events. The annual range of river water level oscillation in the area averages 0.60 m,

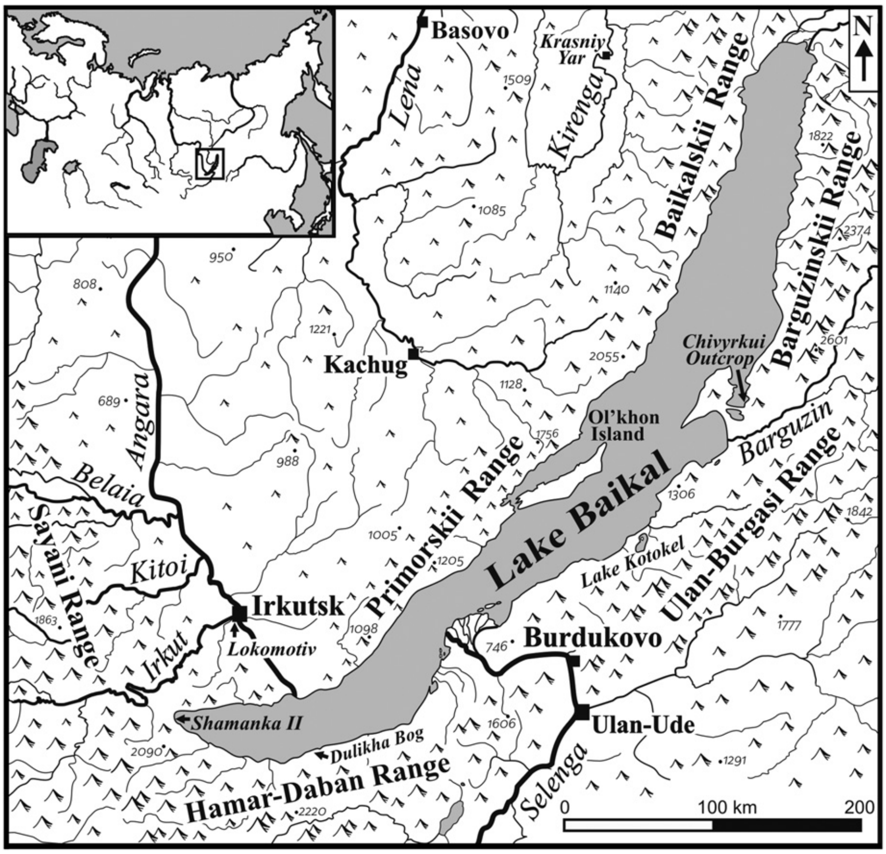

Fig. 1. Geographical setting of the study area showing location of sites mentioned in the text. Spot heights in metres.

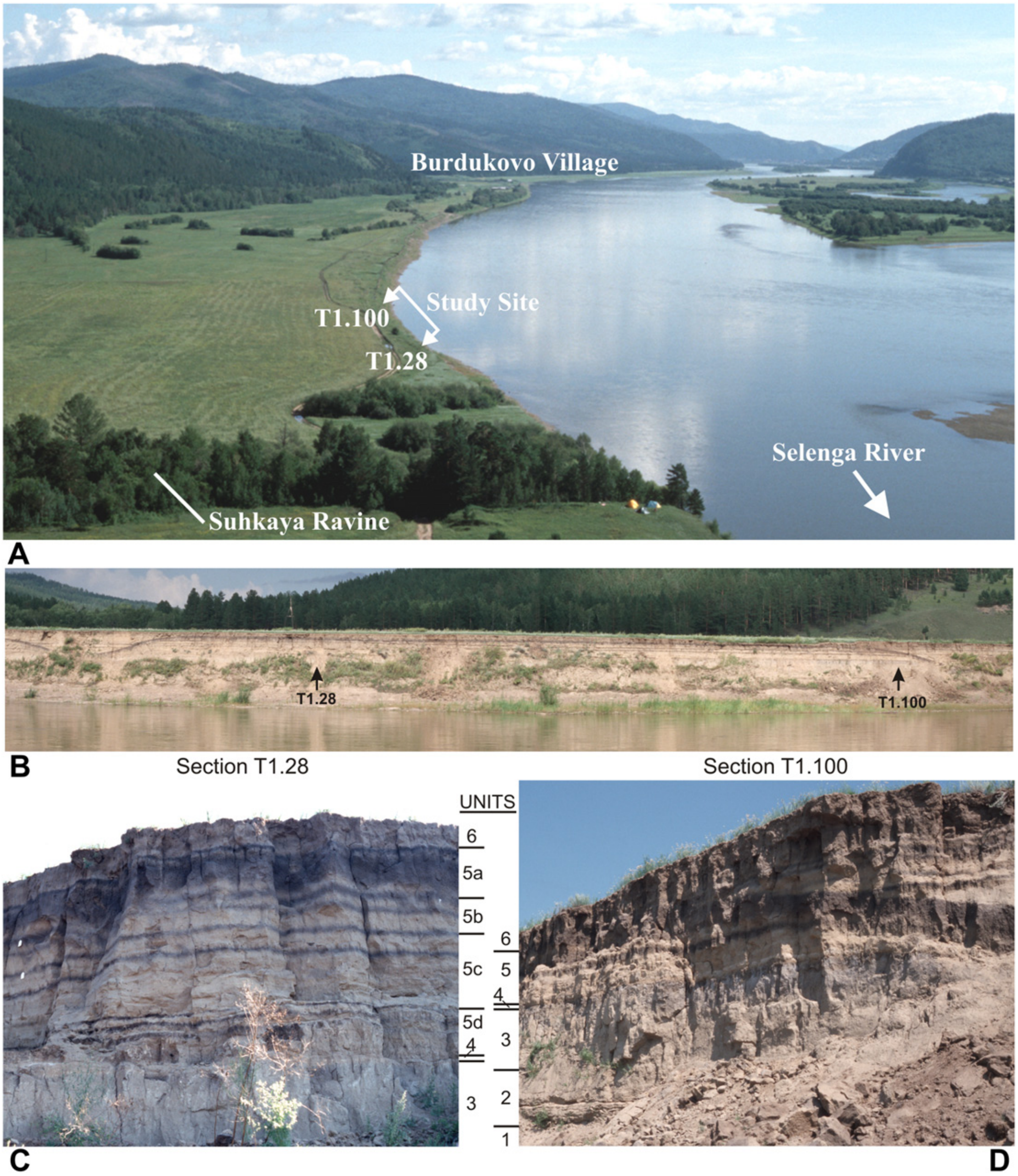

Fig. 2. (A) view looking south over the lower Selenga River Valley, showing the location of Burdukovo village and the stratigraphic sections presented in this study; (B) view from the Selenga River looking east towards the Burdukovo floodplain/terrace section under study. Note the palaeodepressions at the margins of the photo; (C) section T1.28; and (D) section T1.100.

with the highest recorded level reaching 6.45 m during an ice-jamming event in 1968 (Snitsarenko, 1983).

Forest–steppe and steppe vegetation is common throughout the lower Selenga River valley and the intermontane depressions of its tributaries. Vegetation complexes along the valley bottoms near Burdukovo are composed of halophyte meadows, which include *Puccinellia tenuiflora*, *Hordeum macilentum* and *Alopecurus brachystachys*, together with stands of willow (*Salix* sp.), bird cherry (*Padus avium*) and blood-red *Crataegus sanguinea*. Forested valley slopes in the surrounding area are dominated by pine (*Pinus sylvestris*) and larch (*Larix sibirica*, *Larix dahurica*) mixed with birch (*Betula pubescens*) and herbaceous underbrush of *Pulsatilla flavescens*, *Anemone crinita* and *Carex pediformis*. Local treeline elevations vary depending on topography and slope orientation, but generally range between 1300 and 1800 m a.s.l.

3. Materials and methods

3.1. Fieldwork and sedimentology

Fieldwork for this study took place during several short visits to the lower Selenga River Valley beginning in 2001. During an initial brief reconnaissance near the settlements of Tataurovo and Burdukovo, stratified alluvial deposits rich in terrestrial and fluvial molluscs and an overlying sequence of non-shelly aeolian sediments with multiple cycles of pedogenic development were identified in the first terrace of the Selenga River, approximately 3 km downstream from Burdukovo village (Figs. 1 and 2). Subsequent visits to the site in 2002, 2004 and 2007 completed the field investigations upon which this study is based.

Following field descriptions, bulk samples were collected from excavated sections at consecutive and contiguous 10 cm intervals,

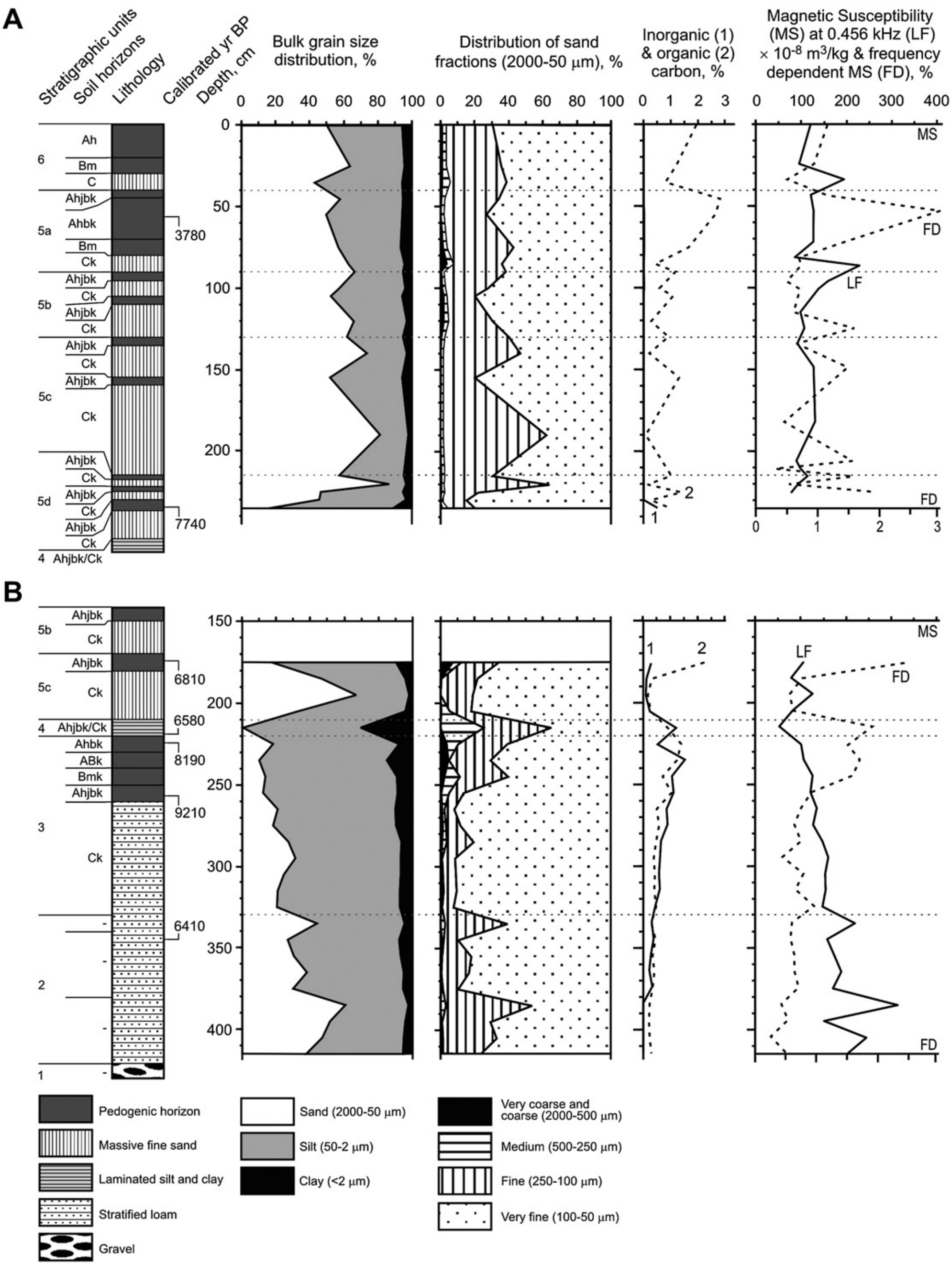

Fig. 3. Lithology of the Burdukovo profiles, (A) T1.28 and (B) T1.100, showing grain-size, carbon content, and magnetic susceptibility data. Soil horizon nomenclature follows the Canadian System of Soil Classification (1998).

respecting natural stratigraphic levels, from depths reaching 4.0 m up to the modern surface. Finer sampling intervals were used for thinner horizons and/or near stratigraphic boundaries and occasionally larger intervals were used for more homogeneous deposits. Samples varied between 150 and 250 g dry sediment weight. For granulometric analyses dried sediment was passed through a 2000 μm-diameter sieve to separate the fine fraction from larger particles, followed by hydrometer measurements of the sand (2000–50 μm), silt (50–2 μm) and clay (<2 μm) fractions (Sheldrick and Wang, 1993). Subsequent analyses included ultrasonic sieving of the sand fraction into very coarse (2000–1000 μm), coarse (1000–500 μm), medium (500–250 μm), fine (250–100 μm) and very fine (100–50 μm) components (Gee and Bauder, 1986). For graphical presentation the 2000–500 μm sand fractions were combined due to the limited occurrence of coarse sediments. Carbon content was measured by wet-oxidation digestion using a Carlo-Erba NA 1500 CNS Elemental Analyzer to determine total and total organic carbon, with the inorganic component derived by subtraction (Ellert and Jansen, 1996). Samples were also measured for mass specific high frequency

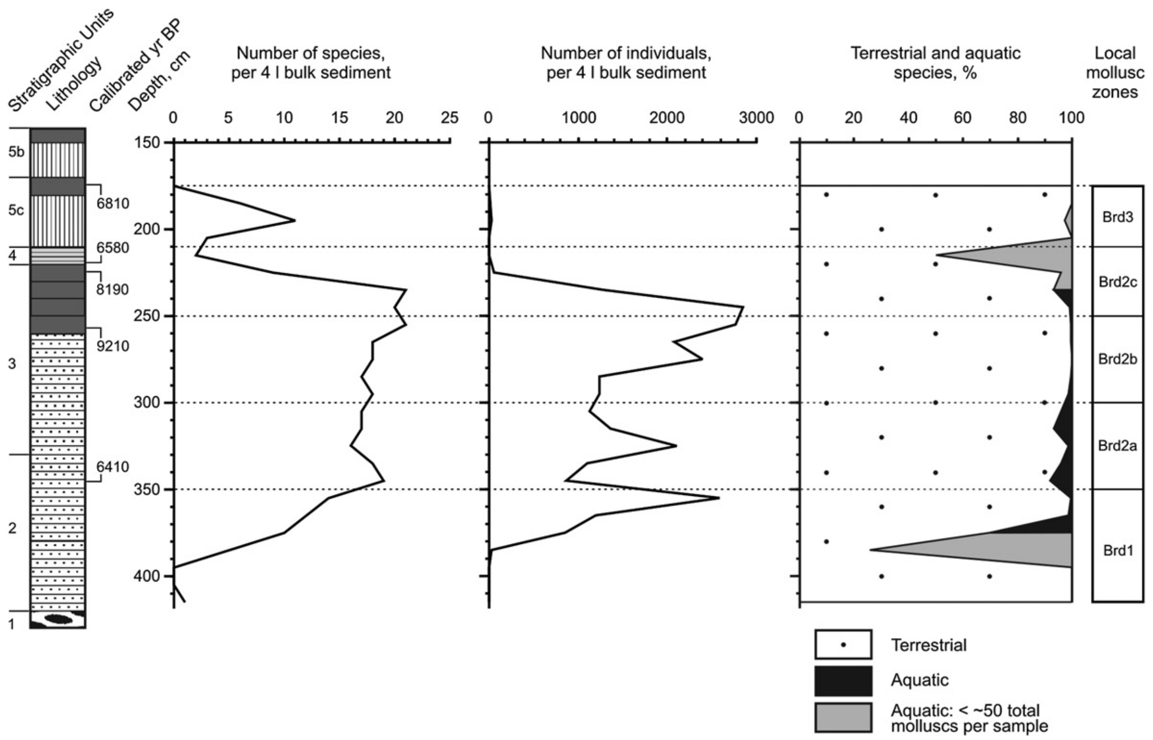

Fig. 4. Ecological profile of the Burdukovo molluscan succession showing the number of species and individuals/4 l of sediment, together with the percentage of land and freshwater species and their zonation.

magnetic susceptibility (4.65 kHz) and low frequency magnetic susceptibility (0.465 kHz) using a Bartington MS2 meter and a Bartington MS2B dual-frequency sensor on disaggregated bulk sub-samples placed into 1 cm^3 plastic containers. Frequency dependency of magnetic susceptibility (FD) was calculated to determine possible production of ultrafine superparamagnetic minerals by pedogenic processes (Evans and Heller, 2003). The delineation of stratigraphic units follows the North American Commission on Stratigraphic North American Code of Stratigraphic Nomenclature (1983) and Morrison (1998). Textural classes and soil descriptions are based on the Canadian System of Soil Classification (Soil Classification Working Group, 1998), with the WRB international classification equivalents provided in brackets (International Society of Soil Science, 1998).

3.2. Molluscs

Molluscan analyses were undertaken on 25 contiguous 10 cm samples of moist bulk sediment (each measuring 4.0 L) from the Burdukovo terrace profile between 4.10 and 1.70 m in depth below the modern surface. Each sample was wet-screened through a 500 μm sieve and air-dried and examined under binocular-microscope (×6–×50) to extract all identifiable fossils (Ložek, 1986). Specimens were sorted by taxa and minimum totals for each species assessed by counting every apex or apical fragment (or hinge fragments in the case of bivalves). In samples where diagnostic apertural fragments outnumbered apices for a given taxa (e.g. *Pupilla* and *Vertigo*), counts were then based on these non-apical fragments. Quantified molluscan results are presented as plots of number of species, individuals and terrestrial/aquatic ratio, and as frequency histograms. For the latter, all samples with more than 200 terrestrial specimens are plotted as a percentage of the total terrestrial sum. In those samples containing less than 200 individuals, percentage calculations were not deemed statistically adequate, so counts are plotted as absolute values. Zonation of the molluscan assemblage was performed by Two-Way Indicator Species Analysis (TWINSPAN; Hill, 1979). In addition, living land and freshwater molluscs and information about modern species–habitat associations were collected at several locations near Burdukovo and in the Selenga Delta area near Lake Baikal. Modern faunal samples were collected by hand from plant debris, overturned logs and stones and by 'thrashing' vegetation into nested sieves (2000 μm and 500 μm) and sorted with fine forceps. Many samples also include preserved soft tissue specimens.

3.2.1. Identification and taxonomic issues

A number of issues were encountered in the identification of certain molluscan taxa. Some resulted from practical difficulties in assigning fragmentary or juvenile specimens to particular species, whereas others related to nomenclatural issues concerning the correct use of names. These are discussed briefly below. For additional information and more detailed discussion of these and other issues see White et al. (2008) and Supplementary Table 1.

Vallonia. This was the most abundant genus of land snail, represented by five species. Adults of most could be distinguished relatively easily but the juveniles, except those of *Vallonia tenuilabris* (which are larger) and *Vallonia pulchella* (which are smooth), were impossible to differentiate. These are listed as *Vallonia* spp. in Supplementary Information Table 2, but for graphical presentation they have been divided in proportion to the number of securely identified adult shells. The separation of *Vallonia kamtschatica* from *Vallonia* cf. *chinensis* was especially troublesome and the counts are based on identifications made by Jochen Gerber, who has made a detailed study of this genus (Gerber, 1996).

Vertigo extima. The validity of this species was demonstrated by Waldén (1986) but in Russian literature it is likely to be recorded as a form of *Vertigo modesta*. *V. extima* still lives near Burdukovo in damp grassland habitats bordering birch woodland with larch and pine.

Vertigo microsphaera. The modern distribution of this species was originally thought to be restricted to the North Pacific region (Schileyko, 1984) but White et al. (2008) demonstrated its presence both living and as a fossil in the upper Lena River Valley and living populations have recently been found in the Altai Mountains (Pokryszko and Horsák, 2007). This species was also found living along the southeast coast of Lake Baikal and in the vicinity of Burdukovo village, and as a fossil at the Burdukovo site. Its presence here demonstrates the widespread Holocene occurrence of this species in the Baikal region.

Succineidae. At least three species appear to be represented. *Succinella oblonga* can be distinguished by its slender shell with a relatively tall spire. The two other species can be separated on the size of the apical whorls, which is bulbous in one but not the other (see White et al., 2008, Fig. 8). Further work is needed to attribute these to particular species, and they are here recorded as *Oxyloma/Succinea* in Fig. 5 and Supplementary Information Tables 1 and 2.

Discus ruderatus. This boreo-montane species lives in coniferous woods, marshes and moist grassland. It has an enormous range extending east from central Europe and Scandinavia right across the Palaearctic region as far as the Pacific coast. Forms in North America may be conspecific, so its range may eventually prove to be Holarctic. Throughout much of the western part of its range, *D. ruderatus* shows little variation in shell form but in the east it becomes extremely variable, particularly with respect to the height of the spire and the extent of angulation of the periphery. This has resulted in the description of a number of sub-species, the validity of which has still to be satisfactorily resolved. One of these, *Discus ruderatus pauper*, is particularly distinctive in possessing a more flattened shell with a keel. This sub-species was originally described by Gould (1858) from Petropavlovsk, Kamchatka and from the Japanese island of Yeso, but subsequently was found to encompass much of the south-eastern part of the range of *D. ruderatus*. According to Uminski (1962, Map 1), the western distributional limit of *D. ruderatus pauper* lies just west of Lake Baikal. However, he points out that the variation in shell form within a single site is often greater than that observed from sites separated by enormous distances. Anatomical differences between *Discus ruderatus ruderatus* and *D. ruderatus pauper* were also variable but not marked. He concluded that the most typical examples of *D. ruderatus pauper* come from the Amur Basin, whereas more or less transitional forms occur in Kamchatka, the Kuril Islands, Japan, Korea, northern China and the vicinity of Lake Baikal. At Burdukovo most of the *Discus* shells have strong angulation and also possess a distinct apical microsculpture of transverse riblets crossed by an irregular series of spirally oblique striations (see Fig. 6). These characteristics have been used to assign this form to *D. ruderatus pauper*.

3.3. Chronology

Seven radiocarbon dates derived from either individual wood charcoal fragments, plant remains or bulk soil samples establish the chronology for the sections presented in this study (Table 1). Wood charcoal and plant specimens were either hand-picked *in situ* or collected from screened bulk macrofossil samples. Derived humic acids from bulk soil samples represent either a 5 or 10 cm composite of a single pedogenic horizon. All materials for radiocarbon dating were pre-treated and analyzed by ISOTRACE laboratories in Toronto, Canada, and calibrated using the Intcal09 radiocarbon calibration curve (Reimer et al., 2009) and OxCal software ver. 4.1.7 (Bronk Ramsey, 2009). All radiocarbon dates provided in the text and figures are listed in calibrated years BP.

Table 1
Details of the Burdukovo radiocarbon chronology.

Location/ Unit	Depth (cm)	^{14}C yr BP	Calibrated yr BP 95.5% c.i. (2σ)	Calibrated yr BP 68.2% c.i. (1σ)	Calibrated mid-point yr BP 68.2% c.i. (1σ)	Sample material	Lab #
T1.100/5a	150–155	3500 ± 70	3590–3971	3690–3866	3780	Bulk soil	TO-10972
T1.100/5c	170–180	5970 ± 60	6668–6949	6737–6887	6810	Bulk soil	TO-11669
T1.28/5d	245	6890 ± 80	7590–7925	7660–7826	7740	Charcoal	TO-10552
T1.100/4	219	5720 ± 430	5655–7473	6019–7149	6580	Plant remains	TO-10551
T1.100/3	220–230	7370 ± 70	8026–8342	8056–8315	8190	Bulk soil	TO-11668
T1.100/3	258	8230 ± 120	8790–9517	9031–9397	9210	Charcoal	TO-10550
T1.100/2	340–350	5560 ± 650	4880–7790	5667–7157	6410	Plant remains	TO-11666

4. Results

4.1. Stratigraphy

Site investigations were conducted along an exposed terrace cross-section of the lower Selenga River ~3 km downstream from Burdukovo village (Figs. 1 and 2a). In this area, the Selenga Valley is up to 2.5 km wide within which there are as many as three terrace levels and a modern gravelly floodplain (Bazarov, 1968). The 18–22 m terrace (T-3) was not clearly visible at the site, but a remnant of the 10–12 m terrace (T-2) is present where Suhkaya Ravine emerges from hilly terrain to join the Selenga River. Here sediments are exposed in a steep (up to 30°) 5–6 m scarp composed of fine sandy loam with weakly defined horizontal bedding. The modern soil is a Eutric Brunisol (Eutric Cambisol). Buried soils and macrofossils were absent in the exposed section of this 10–12 m terrace.

Near the outlet of Suhkaya Ravine the first terrace (T-1) of the Selenga River reaches 4–6 m in height and extends gently upstream for over 2 km towards Burdukovo village, reaching up to 350 m at its widest point (Fig. 2a and b). Closer to the village, the terrace is composed primarily of gravel and coarse sand. Nearer to Suhkaya Ravine (i.e. downstream), the height of the terrace increases noticeably and the sediments are much finer and overprinted by numerous buried, weakly developed pedogenic horizons (Fig. 2b–d).

Two profiles of the first terrace were described and sampled at composite sections located 72 m apart, designated as T1.100 and T1.28 (Fig. 2a–d). Depositional units include (i) basal gravel and fossiliferous (i.e. mollusc-rich) fine-grained alluvium, (ii) a laminated silty clay loam, and (iii) overlying fine sandy beds of aeolian

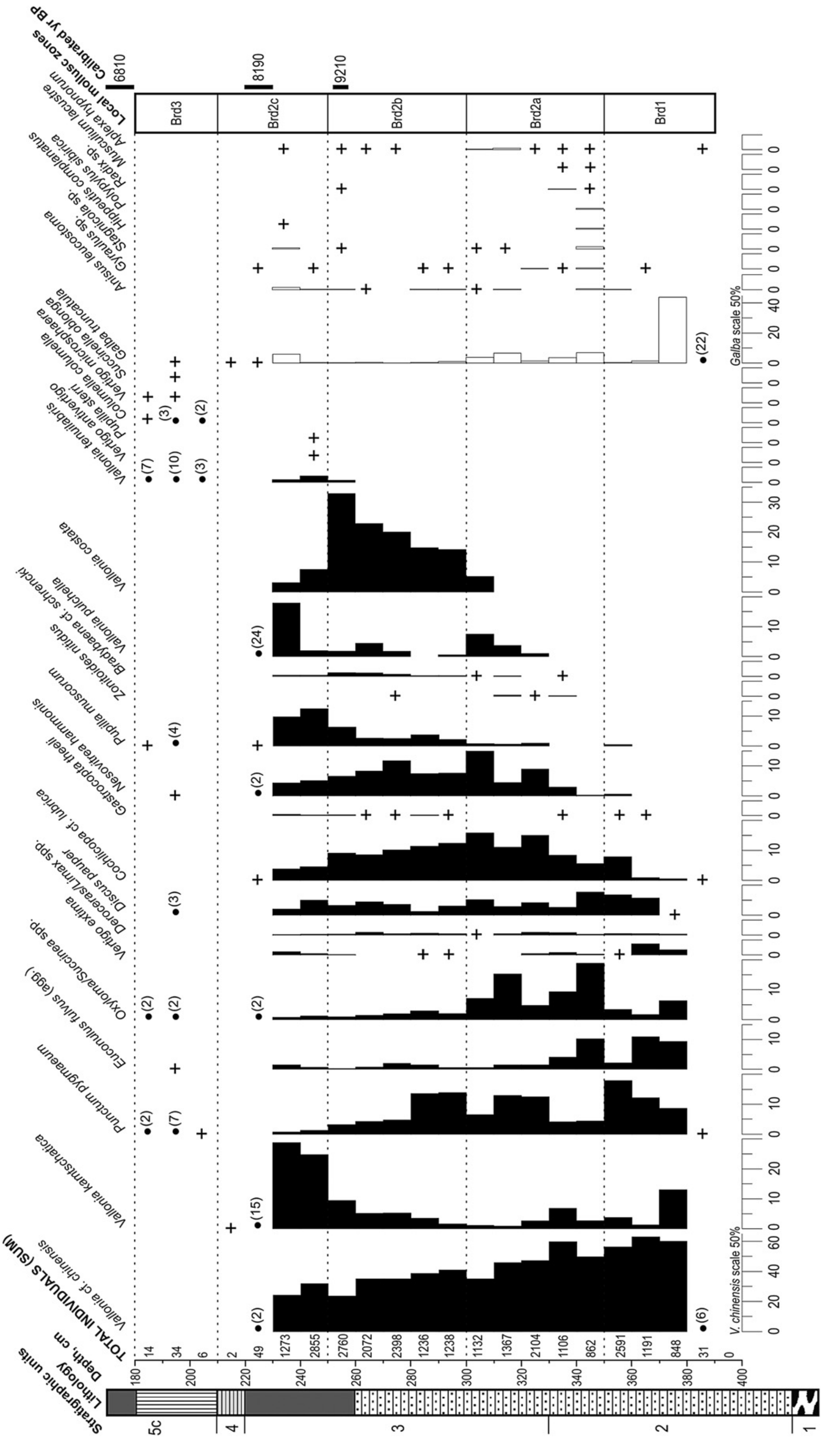

Fig. 5. Mollusc diagram plotting the frequency of terrestrial (closed bars) and aquatic (open bars) taxa at Burdukovo. All values expressed as percentages of total land snails. Note that the scales for *Vallonia* cf. *chinensis* and *Galba truncatula* have been reduced by 50%. The symbol (+) indicates single shells and •(#) indicates number of shells in samples with less than 50 individuals.

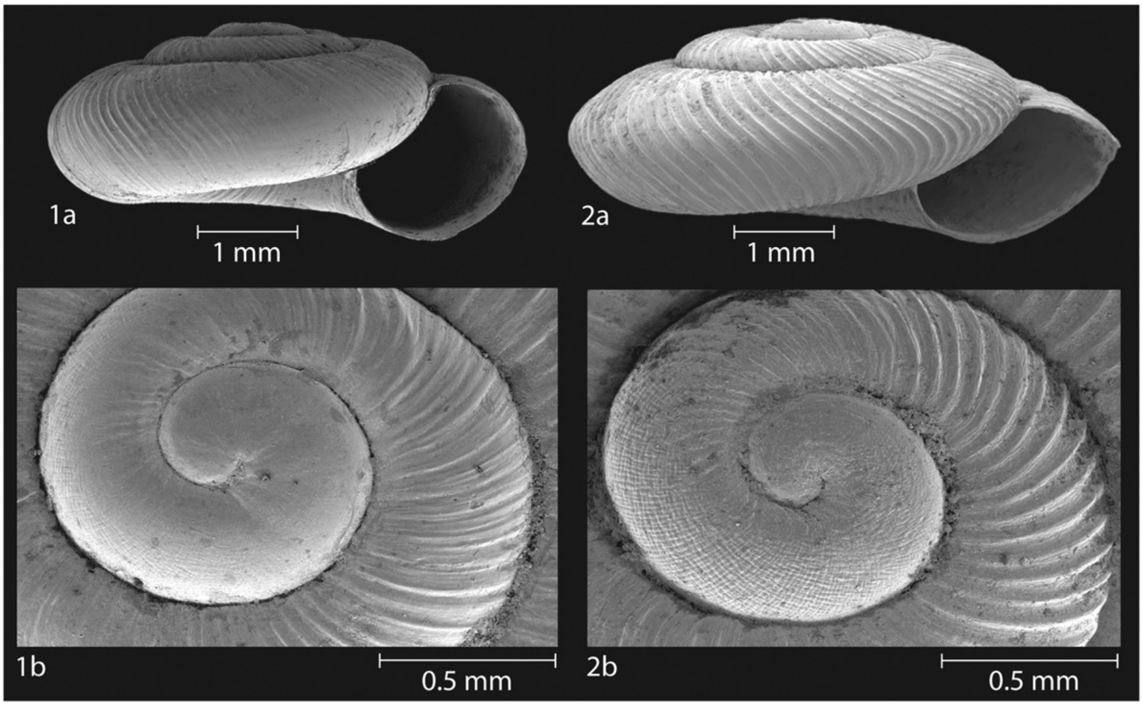

Fig. 6. 1a and 1b: *Discus ruderatus* from Basovo (Upper Lena Valley); 2a and 2b: *Discus ruderatus pauper* from Burdukovo. Note differences in the angulation of the periphery and apical microsculpture.

origin. Soil formation (Cumulic Humic Regosols and Cumulic Regosols [Mollic Fluvisols and Cumulic Arenosols]) has occurred repeatedly at the site during periods of greater landform stability. These composite study sections are situated between two buried palaeo-depressions (in-filled tributary channels) measuring approximately 25 m wide by 2.8 m in depth and 40 m wide by 2.5 m in depth, to the west and east respectively (Fig. 2b). Site stratigraphy is described in detail below and illustrated in Fig. 3.

Unit 1 – a non-fossiliferous (non-shelly), bedded sandy gravel with clast-supported pebbles and cobbles of variable size, colour and mineralogy. Clasts generally fall within the range of 5–10 cm in long-axis diameter and are predominately well-rounded. This unit occurs at ~4.20 m below the modern surface and has a sharp boundary with overlying sandy sediments.

Interpretation: Unit 1 occurs at the base of the entire sequence under study and formed in a high-energy fluvial environment characteristic of a gravel bar. Age is unknown although presumed to be late Pleistocene.

Unit 2 – dark brown to brown (10 YR 4/3–5/3) stratified loam with thin lenses (1–3 cm thick) of very fine to medium sand. This unit is 90 cm thick at T1.100 and is generally coarser with more frequent sandy lenses in the non-fossiliferous lower portion, where weak cross-bedding is observed. Deposits are highly calcareous and have very low carbon content (<0.8%). Fe–Mn nodules (up to 2.0 mm in diameter) and Fe-mottles (up to 8.0 mm in diameter) are most abundant in the lower half of this unit, and carbonate coatings are common around matrix pore spaces. Frequency dependency of magnetic susceptibility (or FD value) is low and relatively stable. The boundary with underlying coarse gravel (Unit 1) is sharp to abrupt and wavy. Molluscs become abundant in the upper part of Unit 2. Plant remains recovered from bulk sediments at 3.4–3.5 m from this unit returned an age of ~6.4 ka BP.

Interpretation: Unit 2 is a stratified sequence of low-energy loamy alluvial sediments, which episodically accumulated along the bank of the Selenga River during the late Pleistocene–early Holocene. Given the stratigraphic context, very high error margin and age of overlying radiocarbon samples, the plant remains dated from this unit are considered to be intrusive root material.

Unit 3 – consists primarily of silty loam overprinted by pedogenic development in its upper half, indicated by darker colours, high organic carbon content, weak granular to subangular blocky macrostructure, high FD values and the presence of krotovina (burrows). The lower part is predominantly dark greyish brown (10 YR 4/2), darkening upward (10 YR 3/2–3/1) due to increased organic carbon content, which ranges from 0.4% at the base of the unit to 1.4% at the upper boundary. At T1.100, this unit is 1.10 m thick. The textural composition of the lower, non-pedogenic portion is generally more homogeneous than Unit 2 below, although occasional sandier lenses are evidence of limited fluvial sorting in the otherwise weakly stratified horizontal bedding. Weak Fe-mottling and common Fe–Mn nodules (up to 2.0 mm in diameter) are also present. FD values are relatively stable at this level before increasing sharply under the apparent influence of soil formation processes nearer the top of the unit. This pedogenic sequence occurs between 2.20 and 2.60 m below the modern surface and has a relatively uniform thickness across the 100 m Burdukovo cross-section under study. Limited deposition of sand during pedogenesis is also indicated. Soil horizon boundaries are generally clear to gradual and wavy. Poorly preserved plant macrofossils are present and mollusc frequency and species richness reach maximum levels. Charcoal collected *in situ* from 2.58 m at T1.100 returned an age of ~9.2 ka BP, and bulk soil from the uppermost 10 cm (2.20–2.30 m below surface) of this unit was dated to ~8.2 ka BP.

Interpretation: Unit 3 formed during the early Holocene as increasingly fine alluvium continued to aggrade onto the floodplain reaching elevations above active water levels. This resulted in relative surface stability and soil formation at the site for the first time since the onset of the Holocene. The upper boundary of the pedogenic sequence is very sharp, an indication of a relatively abrupt cessation of soil-forming processes and a rapid depositional shift on the floodplain.

Unit 4 – laminated dark yellowish brown (10 YR 4/4) silty clay loam between 5 and 10 cm in thickness. At T1.100 this unit occurs between 2.10 and 2.20 m below surface, although in horizontal profile along the terrace it is somewhat arched, sloping gently downward into each of the buried depressions that truncate it. Sediments from Unit 4 contain ~30% clay and are almost entirely devoid of sand or larger particles. Micromorphology shows that the platy laminations within this unit are overprinted with subangular and angular blocky microstructure. FD values remain high, whereas low values of low frequency magnetic susceptibility may reflect gleyic processes. The upper boundary of Unit 4 is less sharp than the lower, suggesting a more gradual change in the environmental conditions that followed. Mollusc shells are not common. Plant remains occasionally cluster together, and material from one such cluster at 2.19 m below surface returned an age of ~6.6 ka BP.

Interpretation: The sedimentary features of Unit 4 display characteristics partly indicative of formation from higher water levels and subsequent suspension fallout after a period of localized ponding on the floodplain. The deposition of suspended fines accounts for the generally laminated structure and silty clay-rich texture. Blocky microstructure is attributed to repeated wetting–drying and freeze–thaw cycles rather than strong soil-forming processes, although weak pedogenic features are apparent at the top of this unit. The date obtained on plant remains from this unit is again considered suspect given the stratigraphic context, high error margin and age inversion. This material is also similar in age to the plant remains dated from Unit 2, which may point to a similar intrusive origin, perhaps from pioneering riverine vegetation rooting along the steep and unstable terrace face. Taking these factors into consideration and the more secure associated bracketing ages, Unit 4 is estimated to have formed, perhaps during a relative brief period of time, ~8.0 ka BP. This unit is an important stratigraphical marker horizon in the sequence separating underlying alluvial from overlying aeolian sediments.

Unit 5 – these deposits are between 2.0 and 2.3 m thick and can be divided into at least four sub-units (5d–5a), each representing cycles of aeolian sedimentation and weak pedogenesis. Boundaries between pedogenic and non-pedogenic horizons are generally clear and wavy, and the sediments are distinctly sandier than those beneath. These sub-units also slope gently downward into each of the buried depressions exposed in the terrace cross-section.

Sub-unit 5d – is present only near T1.28 where it directly overlies clay-rich Unit 4, consisting of a 40 cm thick wedge of massive brown to light yellowish brown (10 YR 5/3–6/4) very fine to fine sandy loam and loamy sand with three thin (3–5 cm), intervening (i.e. compounded or multi-story) very dark grey (10 YR 3/1) incipient soil horizons. Pedogenic features are indicated by dark colours and high organic carbon contents, weak subangular blocky structure and high FD values. Molluscs were absent. Radiocarbon dating of *in situ* charcoal recovered at T1.28 from 2.45 m (lowermost pedogenic horizon from this sub-unit) returned an age of ~7.7 ka BP.

Sub-unit 5c – is laterally extensive and occurs in the entire terrace section under study, but its stratigraphic expression varies somewhat. At T1.28 it is 85 cm thick and consists of massive brown to light yellowish brown (10 YR 5/3–6/4) very fine to fine loamy sand within which two very dark grey (10 YR 3/1) sandy loam pedogenic horizons, each approximately 5 cm thick, have developed. Pedogenic horizons are indicated by darker colours, high organic carbon content, weak subangular blocky structure and high FD values. At T1.100, this sub-unit is 40 cm thick where it directly overlies clay-rich Unit 4, but unlike its occurrence at T1.28, only a single pedogenic horizon (10 cm thick) is present. Few molluscs were recovered from this sub-unit, and no shells were found in overlying sediments. Radiocarbon dating of bulk soil from this sub-unit (1.70–1.80 m depth at T1.100) returned an age of ~6.8 ka BP.

Sub-unit 5b – is another sequence of brown to light yellowish brown (10 YR 5/3–6/4) very fine to fine sandy loam with at least two very dark grey (10 YR 3/1) incipient soil horizons. It is 40 cm and 45 cm thick at sections T1.28 and T1.100, respectively, with lithological and pedogenic properties similar to those of Sub-unit 5c.

Sub-unit 5a – includes the most distinct pedogenic sequence in the first terrace. At T1.28, it is 50 cm thick and consists of brown to light yellowish brown (10 YR 5/3–6/4) very fine to fine sandy loam overprinted by a moderately developed soil profile. Pedogenesis is indicated by a predominantly very dark grey (10 YR 3/1) colour, high organic carbon content, subangular blocky structure and very high FD values. The upper boundary of this buried soil varies in its relative position below the modern surface, reaching depths >2.5 m within the infilled palaeochannels but is only 20 cm beneath the modern surface near the middle of the terrace exposure. Dating of bulk soil from Sub-unit 5a from 1.50 to 1.55 m at T1.100 returned an age of ~3.8 ka BP.

Interpretation: Unit 5 is composed predominantly of very fine and fine, massive, wind-blown sand, with multiple incipient pedogenic horizons formed during periods of increased surface stability and moisture availability. These aeolian sediments are thought to have originated from the deflation of exposed floodplain surfaces during periods of relatively lower water levels in the Selenga River Valley and from the poorly vegetated slopes of surrounding hilly terrain. Boundaries between pedogenic horizons and wind-blown sediments are relatively sharp, suggesting both relatively rapid and frequent changes in landform stability. Microtopography appears to have influenced local pedogenic processes, accounting for the predominance of 'compounded' or 'multi-storied' soil horizons near T1.28. Charcoal from near the base of Unit 5 was radiocarbon dated to ~7.7 ka BP. This provides an approximate minimum age for the onset of aeolian deposition at the site, possibly related to increased middle Holocene aridity, which may reflect the initiation of a broader regional trend prevailing across the upper Selenga River basin (i.e. northern Mongolian Plateau) and the Lake Baikal area.

Unit 6 – includes all aeolian sediments and soil horizons which formed at the site since the cessation of pedogenic processes of Unit 5, including the infilling of the two buried palaeochannels within the terrace. Unit 6 is 40 cm thick at T1.28 and consists of brown to light yellowish brown (10 YR 5/3–6/4) fine sandy loam overprinted by two very dark grey (10 YR 3/1) pedogenic horizons, the last of which represents the modern terrace surface. Approximately 50 m to the south (i.e. upstream), this unit occurs as a thin (20 cm) sandy surface soil directly overlying the uppermost pedogenic horizon of Unit 5. Unit 6 also includes the sedimentary infill of each of the buried palaeochannels, reaching depths over 2.50 m below the modern surface. These infillings consist of high temporal frequency couplets of massive, very fine sand and organic-rich incipient pedogenic horizons. As many as eight aeolian-soil cycles are present in the two buried depressions, each ranging from 10 to 50 cm in thickness. Boundaries separating pedogenic sequences are sharp. Molluscs are absent in this unit.

Interpretation: Unit 6 is only broadly divided in this study and represents high temporal variability in aeolian deposition and incipient pedogenic development during the late Holocene (<3.8 ka BP). This pattern may reflect a continuation of oscillating conditions of comparatively greater aridity facilitating wind-blown sedimentation and periods of relatively increased moisture availability and landform stability suitable for weak soil formation. The emplacement of this unit had the effect of levelling the previously undulating palaeosurface of the Burdukovo first terrace, where distinct erosional features left by intermittent tributary shifts on the floodplain were infilled by active aeolian processes.

4.2. Molluscs

The molluscan record from Burdukovo consists primarily of an early–middle Holocene succession of land species. Of the 25 bulk (4 L) samples collected and processed, over 25,000 specimens representing at least 24 terrestrial and nine aquatic taxa make up the assemblage (Figs. 4 and 5). Fifteen of the samples contained >800 shells (the most abundant >2800 specimens), whereas seven samples produced <50 shells and three samples were non-fossiliferous. Zonation of the molluscan data by Two-Way Indicator Species Analysis (TWINSPAN; Hill, 1979) derived three principal mollusc zones, two of which correspond to those designated as Brd1 and Brd3. Zones designated Brd2a, Brd2b and Brd2c were further sub-divided from a single TWINSPAN zone based on the successional trends of several key species. The genus *Vallonia* dominates the assemblage, represented by over 15,000 specimens or about 60% of the total shells recovered. Molluscs were found in great abundance throughout much of the stratified alluvial sediments but occur in very low frequencies or are absent in the overlying aeolian sediments. The following local assemblage zones can be distinguished:

4.2.1. Zone Brd1: 350–390 cm

Zone Brd1, the earliest mollusc assemblage within the first terrace landform at Burdukovo, exhibits increasingly high abundance and species richness (up to 15 taxa at the upper boundary). The zone is dominated by the terrestrial species *V.* cf. *chinensis* (c. 60%) and *Punctum pygmaeum* (up to 20%), together with the amphibious species *Galba truncatula* (up to 40%). Other land snails present in relatively high frequency (5–10%) include *V. kamtschatica*, *Euconulus fulvus* agg., *Oxyloma/Succinea* spp., *V. extima*, *D. ruderatus pauper* and *Cochlicopa* cf. *lubrica*. *Deroceras/Limax* spp., *Nesovitrea hammonis*, *Pupilla muscorum* and *Gastrocopta theeli* are also present, each comprising <5% of the assemblage. True aquatic taxa are rare. Given the distinctive alluvial context of this sedimentary unit, it is likely that some shells from this zone have been transported to the site. The molluscan assemblage is interpreted as a 'pioneering community' rather than one reflecting site-specific floodplain ecological conditions. No radiocarbon dates are available from this zone, although it is presumed to date to the late Pleistocene.

4.2.2. Zone Brd2a: 300–350 cm

The assemblage of Zone Brd2a marks a trend towards greater species diversity. Shell abundance shows a peak in the centre of the zone with fewer specimens near both its lower and upper boundaries. Greater species richness is accounted for by the increased, although still relatively limited, presence of aquatic fauna and a few additional terrestrial taxa. The assemblage is again dominated by *V.* cf. *chinensis* (40–60%), although *Oxyloma/Succinea* spp., *C.* cf. *lubrica*, *N. hammonis* and *P. pygmaeum* each comprise up to 15%. New records include the terrestrial species *Bradybaena* cf. *schrencki*, *Zonitoides nitidus* and *V. pulchella*. These last two taxa are characteristic of wet meadow and marsh environments, as is *Oxyloma/Succinea* spp. Aquatic species also become more diverse and include *Anisus leucostoma*, *Hippeutis complanatus*, *Polypylus sibirica*, *Aplexa hypnorum*, *Gyraulus* sp., *Stagnicola* sp., *Radix* sp., and *Musculium lacustre*. Again, some of the shells from this zone may have been transported to the site with the deposition of alluvial sediments during periodic flood events. The data suggest both generally wet conditions and a continuation of relative floodplain instability at the site during the late Pleistocene–early Holocene.

4.2.3. Zone Brd2b: 250–300 cm

Both mollusc abundance and species richness (>20 taxa) reach maximum values in this zone with terrestrial taxa again dominant. *V.* cf. *chinensis* maintains high although decreasing relative frequencies (falling from 40 to 25%), whereas *Vallonia costata* appears and steadily increases from 15 to 35% of the assemblage. The presence of *V. costata* is significant in that it suggests relatively drier habitats at the site. Decreasing frequencies of hygrophilous taxa, such as *Oxyloma/Succinea* spp., *V. pulchella*, *V. extima* and *G. truncatula*, also indicate increased localised desiccation of the floodplain. Other taxa include *P. pygmaeum* (5–15%), *C.* cf. *lubrica* and *N. hammonis* (each up to 10%), and there are progressively higher frequencies of both *V. kamtschatica* (up to 10%) and *P. muscorum* (up to 7%) as well as the first sustained occurrence of *B.* cf. *schrencki*. Aquatic taxa are again rare, and apart from *G. truncatula* and *A. leucostoma*, species are represented by single specimens only. Charcoal from the upper boundary of this zone returned an age of ~9.2 ka BP.

4.2.4. Zone Brd2c: 210–250 cm

Initially shell abundance and species richness remain high in this zone but both decline sharply during deposition of clay-rich Unit 4, which appears to have temporarily interrupted the malacological succession at the site. The most significant features of this zone are the increases in *V. kamtschatica* (up to 30%), *V. pulchella* (up to 20%), *P. muscorum* (up to 10%) and *G. truncatula* (up to 10%), together with the abrupt decline in *V. costata* (falling from 35 to <10%). These trends suggest wetter conditions at the site, a conclusion supported by the reappearance of *V. extima*. *V.* cf. *chinensis* continues its decline in relative frequency but still comprises up to 30% of the assemblage. Of particular significance are the first appearances of the terrestrial taxa *V. tenuilabris*, *Pupilla sterri* and *Vertigo antivertigo*. The last two species inhabit very different habitats, *P. sterri* lives in dry open environments and *V. antivertigo* is a species typical of wet meadows and marshes. Their unique occurrence in this level indicates some mixing and/or the contemporary proximity of these contrasting local communities. Apart from *G. truncatula*, *A. leucostoma* and *Stagnicola* sp., aquatic taxa are scarce. The upper boundary of this zone is radiocarbon dated to ~8.2 ka BP.

4.2.5. Zone Brd3: 180–210 cm

The uppermost division is distinguished on the basis of both low shell abundance (<50 shells) and species diversity, but the limited assemblage hints at having a markedly different faunal composition. Of those present in underlying zones, only *V. tenuilabris*, *P. pygmaeum*, *P. muscorum*, *D. ruderatus pauper*, *Oxyloma/Succinea* spp., *E. fulvus* agg., *N. hammonis* and *G. truncatula* are represented. Significantly, three species appear in the record for the first time, including *Columella columella*, *S. oblonga* and *V. microsphaera*, an apparently under-reported and/or rare species in continental East Asia (White, 2006; White et al., 2008). In general, the species composition and associated onset of aeolian sedimentation suggests increasing aridity at the site. The upper boundary of Zone Brd3 is dated to ~6.8 ka BP.

5. Discussion

5.1. Palaeoenvironmental significance of the Burdukovo site

The Burdukovo record exhibits a dynamic sequence of floodplain alluvial deposition spanning the late Pleistocene and early Holocene with subsequent well-defined cycles of aeolian sedimentation and weak pedogenesis throughout the middle and late Holocene periods. Whilst the site lies near the present forest–steppe boundary and is likely to be sensitive to Holocene environmental change, this part of the lower Selenga River Valley has received limited study to date. This research therefore represents an important contribution to our understanding of the changing environmental conditions in the valley corridor linking Lake Baikal to Mongolia, which is one of only two main natural passages (the other being the Tunka Valley) for the movement of prehistoric populations between these two regions.

Floodplain development at the site began at the end of the late Pleistocene with the deposition of coarse fluvial gravels (Unit 1) and fine loamy alluvium (Unit 2). The instability of this aggrading landform is indicated by differentially sorted sandy beds and the absence of buried soils. The associated molluscan assemblage (Zone Brd1) is therefore likely to include some redeposited elements but the fauna nevertheless appear to represent an early 'pioneering community', probably typical for this period in the lower Selenga River Valley. Dominant taxa include *V.* cf. *chinensis*, *P. pygmaeum* and *G. truncatula*.

Subsequent sedimentation of increasingly fine alluvium (Unit 3) was followed by the initiation of pedogenic development on the floodplain after ~9.2 ka BP. Molluscan communities begin to show greater species richness in this stratigraphic sequence, initially represented in Zone Brd2a by taxa indicative of generally moist conditions, including *Oxyloma/Succinea* spp., *P. pygmaeum*, *V. extima*, *Z. nitidus*, *V. pulchella* and *G. truncatula*. However, the association of these and other species in alluvially-derived sediments suggests that some faunal mixing may have occurred. The overlying molluscan sequence of Zone Brd2b indicates a distinct change in floodplain habitats with the arrival of *V. costata*, a species which commonly occurs in moderately dry environments. *V. costata* appears as more hygrophilous taxa, such as *Oxyloma/Succinea* spp., *P. pygmaeum*, *V. extima*, *V. pulchella* and *G. truncatula*, begin to decline. After ~9.2 ka BP, coincident with generally increased floodplain surface stability and soil formation, wetter habitats are indicated by the abrupt decline in *V. costata* in Zone Brd2c, accompanied by increases in *V. pulchella*, *V. kamtschatica*, *P. muscorum*, *V. extima* and *G. truncatula*, and the first occurrence of *V. antivertigo*. After ~8.2 ka BP, conditions at the site were rapidly altered by the sedimentation of Unit 4, which consists of laminated silty clay loam deposited during an apparently short episode of ponding on the floodplain surface. This wetter interval lasted until sometime before ~7.7 ka BP. The molluscan assemblage associated with Unit 4 is extremely limited.

Unit 4 represents an important stratigraphic and temporal marker horizon within the first terrace landform. Overlying sediments (Units 5 and 6) consist of very fine to fine wind-blown sands with multiple intervening pedogenic horizons. Unit 5 can be broadly divided into four general sub-units (d-a), each of which varies somewhat in thickness and arrangement within the terrace exposure due to the effects of local palaeotopography on sedimentation and pedogenic processes. As many as eight incipient soil horizons are represented in Unit 5, ranging in age between ~7.7 ka BP at the base of the unit and ~3.8 ka BP near the upper boundary. Each of these pedogenic intervals is separated by very fine and fine sandy aeolian beds, which result from the deflation of poorly vegetated slope exposures and floodplain surfaces of the Selenga River Valley during periods of lower water levels. This cycle of stability and instability at the site may represent alternating periods of relatively wetter conditions fostering pedogenesis, and drier and windier intervals facilitating aeolian sedimentation. The palaeoecological significance of this part of the sequence may extend far beyond that of the Burdukovo area, as the water levels of the lower Selenga River are directly related to moisture regimes prevailing in the upper watershed, which includes much of the northern Mongolian Plateau. Molluscan assemblages are poorly represented in the wind-blown sediments, and were only recovered in very low numbers in the lower (Sub-unit 5c) portion of the aeolian sequence, designated as Zone Brd3. Despite their scarcity, drier conditions are nevertheless indicated by the occurrence of several xerophilous species. By ~6.8 ka BP, molluscs virtually vanish from the sections under study.

The overlying Unit 6, not subdivided in detail here, includes the wind-blown sediments and cycles of incipient pedogenesis which infill the palaeochannels exposed within the first terrace. These sediments provide a detailed archive of local landscape changes in western Trans-Baikal during the late Holocene (<3.8 ka BP) and document frequent oscillations between aeolian sedimentation, perhaps during drier intervals, and weak pedogenesis during periods of greater effective moisture and landform stability. The effects of increased pastoralist activities and land use changes may have also contributed to sedimentation patterns during this period.

5.2. The Burdukovo record in context with other regional palaeoenvironmental archives

Results from the Burdukovo site allow reconstruction of changing local environmental conditions in the lower Selenga River Valley and enable potential correlation of these shifts to other climate proxy records both in the Lake Baikal region and the northern Mongolian Plateau. Over the last decade or so the Baikal area and adjacent regions have been the focus of considerable palaeoclimate research that has included various lake and peat bog drilling projects, which have recovered increasingly high resolution records. These data have shed light on the vegetational history and other environmental proxies in relation to changing climatic conditions through the Holocene. Collectively, these results provide new insights into the development of the regional climate system and the chronological framework in which Holocene events can be evaluated and interpreted.

The early Holocene is widely documented as a period of increasing temperature and precipitation across central Asia. In the Baikal area, one of the most important palaeoenvironmental archives for this period is Lake Kotokel, located ~80 km north of Burdukovo (Fig. 1). Several recent studies have now been reported for the site outlining climate and environmental data derived from different methodological approaches (Bezrukova et al., 2008, 2010, 2011; Shichi et al., 2009; Tarasov et al., 2009; Kostrova et al., 2013). Tarasov et al. (2009) used a pollen-based quantitative climate reconstruction model to illustrate late glacial and Holocene vegetation dynamics near Lake Kotokel. This indicated that increasing temperatures and precipitation resulted in the expansion of boreal (taiga) forest at the start of the Holocene (~11.5 ka BP), culminating in its maximum extent between ~10.8 and 7.3 ka BP. Results from a number of other studies in the Baikal region show a broadly similar early Holocene trend (Kataoka et al., 2003; Demske et al., 2005; Bezrukova et al., 2005a, 2005b; Tarasov et al., 2007). On the northern Mongolian Plateau, significantly wetter conditions are recorded between ~10.3 and 7.0 ka BP at Lake Gun (Zhang et al., 2012), located ~200 km south of Burdukovo, and isotopic evidence from Lake Baikal itself also suggested increased fluvial input from the Selenga River between ~10.1 and 8.6 ka BP (Mackay et al., 2011). Simulated humidity parameters based on regional General Circulation Models (GCM) indicate that the early Holocene was the wettest period of the last 12 ka BP (Bush, 2005; White and Bush, 2010). Evidence from Burdukovo of an aggrading alluvial floodplain at the onset of the Holocene followed by increased landform stability and pedogenic development is consistent with the prevailing regional early Holocene pattern of generally increasing precipitation and temperature.

The transition from the early to middle Holocene (~7.5–6.5 ka BP) is one of marked change across central Asia with a general trend of significantly increased aridity, although the timing of this appears to be asynchronous (Wang et al., 2010). Evidence from Lake Kotokel shows decreasing percentages of woody vegetation by ~7.0–6.5 ka BP in response to both reduced precipitation and temperature (Tarasov et al., 2009). Palaeoecological data derived from sediments from Lake Baikal (Demske et al., 2005; Tarasov et al., 2007) and from peat bogs along the lake's eastern coastline (Kataoka et al., 2003; Bezrukova et al., 2005a, 2005b) also indicate increasing aridity during the early–middle Holocene transition. Isotopic data from Lake Baikal may also indicate a reduction in the discharge of rivers entering from the south (i.e. Selenga) between ~8.6 and 7.0 ka BP (Mackay et al., 2011). A similar trend is evident across the northern Mongolian Plateau where proxy records for more arid conditions are registered by ~7.0 ka BP at Lake Gun (Zhang et al., 2012), by ~7.1 ka BP at Lake Ugii (Wang et al., 2011), and by ~7.0 ka BP at Lake Telmen (Peck et al., 2002; Fowell et al., 2003). Further south, increasing aridity is recorded in Inner Mongolia at Lake Eastern Juyanze by ~7.5 ka BP (Hartmann and Wünnemann, 2009). GCM results of simulated humidity parameters also show a relatively abrupt transition to more arid conditions by ~7.0–6.5 ka BP (Bush, 2005; White and Bush, 2010). At Burdukovo, evidence for greater aridity after ~8.0 ka BP is indicated by a shift in depositional patterns as wind-blown sediments begin to dominate. Initially aeolian processes are localised (Sub-unit 5d), but by ~6.8 ka BP laterally extensive sand layers (Sub-unit 5c; ~0.5–1.0 m thick) have already been deposited across the floodplain/terrace under study. The Burdukovo data therefore correlate well with other evidence for a shift to more arid conditions during the early–middle Holocene transition.

The middle and late Holocene periods at Burdukovo, although still poorly dated, are characterised by repeated cycles of surface stability and instability with comparatively wetter intervals promoting weak pedogenesis on the floodplain/terrace and more arid periods facilitating aeolian sedimentation. Other proxy records of local climatic conditions in the Baikal area show mixed signals during the second half of the Holocene, some indicating increasing stability as reflected in the subdued nature of the vegetation dynamics seen in pollen records (Demske et al., 2005; Bezrukova et al., 2005a, 2005b, 2008; Tarasov et al., 2009), whereas others indicate greater variability (Bezrukova et al., 2013). Evidence from the northern Mongolian Plateau also suggests more variable conditions during this time. Middle Holocene aridity persisted from ~7.0 to 5.7 ka BP at Lake Gun resulting in low lake levels and the input of aeolian material from ~4.1 to 3.6 ka BP and ~3.0–2.5 ka BP. These arid episodes were interspersed with periods of relatively high lake levels, freshwater conditions and increased moisture availability (Zhang et al., 2012). At Lake Telmen aridity is registered from ~7.0 to 4.5 ka BP and ~1.6–1.2 ka BP with more humid conditions from ~4.5–1.6 and from ~1.2 to the present day (Fowell et al., 2003), whereas at Lake Ugii increased aridity is indicated from ~7.1 to 2.3 ka BP with drought conditions peaking between ~6.6 and 3.3 ka BP (Wang et al., 2011). Isotopic evidence also suggests a possible reduction in fluvial input into Lake Baikal from the Selenga River by ~5.7 ka BP (Mackay et al., 2011). On an even broader scale, a general pattern of variability and asynchronous climatic conditions is reported across central Asia during the middle and late Holocene periods (Rudaya et al., 2009; Wang et al., 2010).

6. Conclusions

The Burdukovo sequence provides an important new record of Holocene environmental change in the lower Selenga River Valley southeast of Lake Baikal. The site has yielded the first detailed Holocene land snail succession from the area, which also contains a number of species of broader biogeographical interest. These results add to the growing list of sites in the Baikal region where similar molluscan studies have been undertaken (Preece and White, 2008; White et al., 2008) and illustrate the potential value of malacological data in the reconstruction of local palaeoenvironments. Such information is relevant to the interpretation of molluscan assemblages from cold stages in Europe, which contained several species that now live only in the eastern Palaearctic (Pokryszko and Horsák, 2007; Horsák et al., 2010). The floodplain/terrace sequence also exhibits sedimentological and pedogenic evidence that document distinct shifts in local habitats and regional environmental and climatic conditions. Of particular significance is the change in depositional processes after ~8.0 ka BP as aeolian sedimentation assumed greater prominence mantling older floodplain deposits. Chronologically these data correlate well with other climate proxy records both in the Baikal area and the Northern Mongolian Plateau showing increased regional aridity during the early–middle Holocene transition.

Collectively these palaeoenvironmental records, although variable in resolution, provide the spatial and temporal framework available for investigating potential relationships between shifting climatic conditions and changes in local archaeological sequences. Over the last decade the Baikal Archaeology Project has been investigating long-term patterns of culture change and continuity among hunter-gatherer populations inhabiting the Lake Baikal region (Weber et al., 2002, 2010 and chapters therein). Archaeological data demonstrate two distinct phases of increased population size, use of large formal cemeteries, and greater social differentiation during the Early Neolithic and Late Neolithic–Early Bronze Age, with an apparent intervening ~1000 year Middle Neolithic period (beginning ~6.8 ka BP) during which large mortuary sites are absent in the region. Evidence also suggests that the cultural groups on either side of the Middle Neolithic differed in their subsistence, diet, mobility, and genetic affiliation. The factors resulting in this 'biocultural discontinuity' remain elusive, but interestingly the seeming abandonment of the Early Neolithic mortuary tradition (e.g. at the Kitoi sites of Shamanka II and Lokomotiv) is broadly coeval with sharply increasing aridity across the region. Others have speculated that the influence of changing climatic and environmental conditions on hunter-gatherer subsistence resources and adaptation strategies may have played a critical role in the reconstitution of Neolithic populations in the Baikal area (White and Bush, 2010). More integrated and high resolution palaeoecological studies with robust chronologies are needed across the region (cf. Weber et al., 2013), including further assessment of potential old carbon effects on the human skeletal materials used to construct the temporal boundaries of the proposed Cis-Baikal culture history model (cf. Nomokonova et al., 2013). Only then will it be possible to more clearly establish whether the documented shifts in middle Holocene climatic conditions could be related to the cultural changes observed in the archaeological record.

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Appendix A. Supplementary material

Supplementary material associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.quaint.2012.11.007.

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