

# Climate History and Early Peopling of Siberia

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## 1. Introduction

Siberia is an extensive territory of 13.1 mil km<sup>2</sup> encompassing the northern part of Asia east of the Ural Mountains to the Pacific coast. The geographic diversity with vegetation zonation including the southern steppes and semi-deserts, vast boreal taiga forests and the northern Arctic tundra illustrates the variety of the present as well as past environments, with the most extreme seasonal temperature deviations in the World ranging from +45°C to -80°C. The major physiographical units – the continental basins of the Western Siberian Lowland, the Lena and Kolyma Basin; the southern depressions (the Kuznetsk, Minusinsk, Irkutsk and Transbaikal Basin); the Central Siberian Plateau; the mountain ranges in the South (Altai, Sayan, Baikal and Yablonovyy Range) and in the NE (Stavonoy, Verkhoyanskyy, Suntar-Hajata, Cherskego, Kolymskyy Range) constitute the relief of Siberia. The World-major rivers (the Ob, Yenisei, Lena, Kolyma River) drain the territory into the Arctic Ocean. Siberia has major significance for understanding the evolutionary processes of past climates and climate change in the boreal and (circum-)polar regions of the Northern Hemisphere. Particularly the central continental areas in the transitional sub-Arctic zone between the northern Siberian lowlands south of the Arctic Ocean and the southern Siberian mountain system north of the Gobi Desert characterized by a strongly continental climate regime have been in the focus of most intensive multidisciplinary Quaternary (palaeoclimate, environmental and geoarchaeological) investigations during the last decades. Siberia is also the principal area for trans-continental correlations of climate proxy records across Eurasia following the East-West and South-North geographic transects (Fig. 1). Among the terrestrial geological archives, loess (fine aeolian dust) represents the most significant source of palaeoclimatic and palaeoenvironmental data, together with Lake Baikal limnological records, with bearing for reconstruction of the past global climate history. The Siberian loess, being a part of the Eurasian loess-belt, has provided chronologically the most complete evidence of past climate change in the north-central Asia (Chlachula, 2003).

The Cenozoic neo-tectonic activity with the Pleistocene glaciations and interglacial geomorphic processes modeled the configuration of the present relief of Siberia and the adjoining Ural Mountains. During the cold Pleistocene periods, the vast extra-glacial regions of West Siberia south of the NW Arctic ice-sheet were transformed into a large periglacial super zone (Arkhipov, 1998), which became a major sedimentation area of aeolian (silty) deposits cyclically derived by winds from the continental ice-front ablation surfaces. Main palaeoenvironmental records, spanning over several hundred thousand years, have been preserved in deeply stratified sections within the major basins (Ob, Yenisei, Angara and

Lena River) exposed after progressive erosion triggered by constructions of large dams (Drozdov et al., 1990; Medvedev et al., 1990). Equally important sources of the Quaternary (geological and biotic) palaeoclimate proxy data originate from open-coalmines and other modern industrial surface disturbances (Zudin et al., 1982; Foronova, 1999).

Studies of Quaternary climates in Siberia, encompassing the last 2.5 million years, have advanced considerably in recent years, mainly because of increased awareness of the value of reconstructing geological and natural histories for understanding of the present-day ecosystems, and applied as a means of predicting the probable extent and consequences of future climatic changes. Because of the multi-factorial nature of a long-term climatic and environmental evolution, Siberian palaeoclimate-oriented studies have become increasingly interdisciplinary, integrating Quaternary geology and palaeogeography, palaeopedology, palaeontology, palaeobotany, Palaeolithic archaeology and other fields (Chlachula, 2001a-c, 2010a-b). Reconstructions of past environments in specific regions and time periods have been used to assess the effects of orbital variations on seasonal and latitudinal distribution of solar radiation and atmospheric circulation patterns, and the consequential changes in regional temperatures, precipitation and moisture balance. Some long-term models provide means of predicting future climatic evolution in the context of the global climate history and help in the assessment of the modern human factor in environmental change. Because of the pronounced climatic continentality of the territory, even minor variations in atmospheric humidity and temperature led to major transformations in local ecosystems, particularly in the open southern Siberian continental sedimentary basins and the upland depressions.

Principal information on past climates and climate change comes from the southern Siberian loess regions that have been intensively studied since the 1990's, following the initial field investigations and chronological interpretations of long-term sub-aerial sequences. The most recent studies have gradually shifted to more detailed and high-resolution Late Quaternary records and refinement of the regional loess-palaeosol chronostratigraphies, illustrating the landscape development and biota evolution particularly for the last 130 000 years by using advanced chronometric, geo-chemical and biostratigraphic marker analyses. The most complete Late Pleistocene palaeoclimate archives include four main stages (the Kazantsevo Interglacial, the Ermakovo /early Zyriansk/ Glacial, the Karginsk Interpleniglacial, and the Sartan /late Zyriansk/ Glacial) correlated with the Marine Isotope Stages (MIS) 5-2.

The broad Siberia also has the key relevance for elucidation of timing and conditions of environmental adaptation of the prehistoric and early historic people to high latitudes of Eurasia, as well as the initial colonization of the Pleistocene Beringia, including the north-western part of the American continent. The particular geographic location and the diversity in topographic configuration of regional landscape reliefs together with changing Quaternary environments governed by the past global climate change played the key role in this long and complex process. The spatial and contextual distribution of the documented archaeological sites reflects a climatic instability and a timely discontinuous inhabitability of particular geographical areas of Siberia delimited by the Central Asian mountain system in the south and the Arctic Ocean in the north. The cyclic nature of the glacial and interglacial stages led to periodic geomorphic transformations and generation of specific ecosystems adjusted to particular topographic settings and responding to acting atmospheric variations. Diversity of the present relief and environments (Fig. 1B), reflecting the past climate change, played the key role in the process of the initial peopling of the immense Siberian territory. Palaeoenvironmental databases (palynological, palaeontological as well as early cultural

records) provide unique evidence of strongly fluctuating Pleistocene glacial and interglacial climates, corroborating the geological stratigraphic archives.

The human occupation of Siberia used to be traditionally associated with the Late Palaeolithic cultures. Systematic ge archaeology investigations during the last 20 years across the entire Siberia (with the key research loci in the Tran-Ural region of West Siberia, the Altai region, the Upper Yenisei, Angara and Lena Basins, as well as at the easternmost margins of the Russian Far East in Primoriye and on the Sakhalin Island) revealed several hundred of Palaeolithic and Mesolithic sites (Serikov, 2007; Chlachula et al., 2003, 2004b; Derevianko & Markin, 1999; Derevianko & Shunkov, 2009; Medvedev et al., 1990; Mochanov, 1992; Vasilevsky, 2008; Zenin, 2002). Particularly the discoveries of numerous Palaeolithic sites, some of potentially great antiquity (> 0.5 Ma), located in large-scale surface exposures (river erosions and open-pit mines) followed by systematic archaeological investigations within the major river basins of south and central Siberia between the Irtysh River in the west and the Lena River / Lake Baikal in the east (Fig. 1A), have provided overwhelming evidence of a much greater antiquity of human presence in broader Siberia and capability of early people to adjust to changing Pleistocene environments. Cultural remains are located in diverse geomorphic settings (i.e., lowland plains, mountain valleys, upland plateaus) and geological contexts (aeolian, fluvial, lacustrine, palustrine, alluvial, glacial and karstic), with the highest concentrations in the Pleistocene periglacial parkland steppe and the boreal tundra-forest foothill zone. Particularly the geographically extensive and deeply stratified loess-palaeosol sections in the southern Siberian open parklands have revealed a long and chronologically well-documented cultural sequence of human occupation. The variety of cultural finds provides witness to several principal stages of inhabitation of the Pleistocene Siberia, possibly encompassing the time interval close to 1 Ma with the earliest (Early and Middle Pleistocene stages) represented by typical "pebble tool" industries, followed by the Middle Palaeolithic complexes, including the (Neanderthal) traditions with the Levallois prepared-core stone-flaking technology, and the regionally diverse Late/Final Palaeolithic blade complexes eventually replaced by the microlithic Mesolithic cultural facies that developed in response to major natural transformations during the final Pleistocene.

A further northern geographic expansion of humans into the Arctic regions reflects a progressive cultural adaptation to extreme climatic conditions of (sub)polar Pleistocene environments (e.g., Mochanov & Fedoseeva, 1996, 2001). The occupation sites in the Polar Urals and North Siberia (Svendsen & Pavlov, 2003; Pitulko et al., 2004) provide eloquent evidence that people reached the Arctic coast already before the Last Glacial (>24 000 years ago). All these discoveries logically lead to revision of the traditional perceptions on a late peopling of northern Asia as well as the "late chronology" models of the initial human migrations across the exposed land-bridge of Beringia to the North American continent (Chlachula, 2003b). Ge archaeology studies, particularly in the poorly explored and marginal geographic regions of northern and eastern Siberia (Pitulko et al., 2004; Vasilevsky, 2008), are of utmost importance for reconstruction of past climate change as well as the early human history in north Eurasia. Evolutionary processes in natural environments, and specific behavioral Palaeolithic adaptation patterns and material-technological conditions, as well as documentation of sequenced climatic events stored in geological records are the principal objectives of the current multidisciplinary Quaternary investigations in Siberia.

This contribution summarizes in a general overview the present evidence on the Quaternary climates and climate development in western, southern and eastern Siberia in respect to associated environmental transformation and the stages of early peopling of particular geographic areas of this extensive and fascinating territory.



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Fig. 1. A: Geographic map of Siberia. 1. Trans-Urals and West Siberia, 2. Altai, SW Siberia, 3. upper Yenisei Basin, 4. East Siberia (Lake Baikal, Lena Basin); B: Landscapes & ecosystems 1. parkland-steppe (West Siberian Lowland), 2. the Altai Mountain tundra; 3. semi-desert (Chuya Basin, southern Altai); 4. northern taiga with thermo-karst lakes (central Yakutia).

## 2. Pleistocene climates and natural environments of Siberia

Because of its vast territory and the geographical isolation between the major Central Asian (Himalayan) mountain systems and the Arctic Ocean, Siberia represents a unique place that is of major potential for mapping the climatic history of northern Eurasia, but also general pathways and rates of global change in the Northern Hemisphere. Tectonic uplift in the Miocene, continuing through to the late Pliocene, initiated formation of the present relief. Breaking up the original pre-Cenozoic continental Siberian Platform significantly influenced the Pleistocene atmospheric circulation by blocking a free influx of warm and humid air masses from the southeast. The dominance of the arctic atmospheric streams gradually led to the present strongly continental climatic regime, with dry winters with little snow cover, and warm to hot summers, of mean annual temperatures  $-0.5$  to  $-3^{\circ}\text{C}$  (with the recorded minimum  $-71.2^{\circ}\text{C}$  at Oymyakon in central Yakutia). Permafrost underlies most of north and central Siberia (Fig. 1B-4), while perennial mountain ground ice is locally distributed on the upland plateaus north of Mongolia. Glaciers occur above 3000 m altitude in the Altai and Sayan Mountains. The NW-SE oriented southern Siberian mountain ranges (Fig. 1B-2) form a barrier between the northern sub-arctic uplands and Arctic lowlands, and the southern steppes and rocky deserts of Mongolia and north-west China. The regional geography and relief shape the pronounced latitudinal and altitudinal vegetation zonation, with (parkland)-steppe, taiga forest, alpine tundra, polar tundra-steppe and mountain semi-deserts (Fig. 1B). Steppe chernozems with thick humic (Ah) horizons, cryogenically distorted by frost wedges, are distributed in the southern loess zone, while podzols with brown forest soils and gleyed tundra soils prevail in the mountains and the northern regions, respectively.

The pre-Quaternary ( $>2.5$  Ma) geology of the southern and eastern Siberian areas was controlled by a series of tectonic events. Both relief and the geological structure contributed to intensive geomorphic processes in the past. The Middle and Late Palaeozoic orogenesis formed uplands separated by isolated continental depressions. Later Hercynian and Oligocene tectonics modified the original configuration of the upper Lena, Angara, Kuznetsk, Minusinsk and other basins north of the Altai-Sayan Mountains and the Northern Baikal-Yablonovyy Mountain Range. Accumulation of extensive proluvial near the mountain fronts and lacustrine /alluvial formations in the principal sedimentary basins continued throughout the Miocene and Pliocene. During the Late Pliocene and Early Pleistocene, early fluvial systems were established, accompanied by a progressive regional uplift. In response to climate change in conjunction with orogenic activity, a series of river terraces gradually developed in the climatically most favorable and first inhabited basins of southern Siberia, with the earliest, Early and Middle Pleistocene (70-90 m, 110-130 m, 150-170 m-high) terraces preserved mostly in relics and buried by 10-50 m loess deposits. The Siberian river valleys (Fig. 1A) served as main migrations corridors of both Pleistocene fauna and early humans.

During glacial periods, the northward drainage of the Ob and Yenisei Rivers was diverted by the ice barrier of the northern inland ice-sheet southwest into the Aral and Caspian Sea (Arkhipov, 1998). The relief of southern Siberia with deep intermountain depressions preconditioned formation of major river dams blocked by mountain glaciers that periodically caused high-magnitude floods (Rudoy & Baker, 1993). These large-scale catastrophic events undoubtedly had a dramatic impact on the early human habitat. The geographical position close to the geographical centre of Asia also contributed to extreme continental climatic conditions with widespread permafrost developed during cold stadials. Siberia is thus of bearing significance for mapping Pleistocene changes in Arctic air-mass circulation above the central and eastern Eurasia, as reflected in textural and compositional

variations in the aeolian deposits. Among the continental sediments used as climatically significant palaeo-archives, loess (fine aeolian dust) has attracted most attention because of its high environmental sensitivity and the long-term stratigraphic records it often provides. Increased rates of loess accumulation correspond to cold and dry (glacial) stages followed by soil development during warm (interglacial and interstadial) intervals. The Siberian loess and the associated palaeoclimate proxies contribute to the trans-Eurasian palaeoclimatic correlation, linking the European, Central Asian and Chinese loess provinces (Rutter et al., 2003; Bábek et al., 2011). Ultimately, the Siberian loess-palaeosol sections, rich in fossil micro- and macro-fauna and early cultural remains, provide a contextual and chronological framework for documentation of timing, natural conditions and processes acting during the early human peopling of northern Asia and the Pleistocene Beringia.

The principal distribution zone of loess and loess-like deposits lies in the southern part of the Siberian territory (50°-60° N and 66°-104° E) west of the Ural Mountains within a broad belt 500-1500 km wide (N to S), encompassing ca. 800 000 km<sup>2</sup> between the Ob and Angara River basins along the Altai, Salair and Sayan Mountains (Fig. 2A). The Siberian loess provides a detailed, high-resolution record of climatic shifts that may not be detectable in more uniform loess-palaeosol formations elsewhere on the Eurasian continent. Thickness of loess sections is from a few meters in the Lake Baikal area to 40 m in the Yenisei River valley and up to 150 m on the Ob River (Priobie) loess plateau and the North Altai Plains. The regional loess-palaeosol record spans throughout the Quaternary, yet it may be locally fragmentary, partly re-deposited, or may be completely absent for the earlier stages. The geomorphological setting of southern Siberia with the extensive open lowlands in the west and depressions towards the east, combined with dominantly westerly (NW-SW) winds, points to location of the major deflation surfaces (loess source areas) on the eastern/steppe Altai Plains between the Irtysh and Ob Rivers with accumulations of fine aeolian dust eastwards on the plains north of Altai-Sayan Mountains. Ice-sheet marginal areas, large alluvial floodplains, exposed valley floors and margins of (glacio-) lacustrine basins were important sources of the silty sediment. Local geological sources in the southern intramontane basins (Kuznetsk, Minusinsk, Irkutsk Basin), with aeolian dust discharge from the glaciated Altai and Sayan Mountains, the Kuznetskiy Alatau and the Baikal Range, played an important role in the regional input of wind-blown sediment in the adjacent river basins. The present westerly (SW/NW) winds likely prevailed throughout the Quaternary Period with several Late Pleistocene stages of sub-aerial deflation and sediment deposition.

The most continuous and high-resolution sections of aeolian aerosol dust deposits, interbedded with variously developed fossil soils from the Priobie Loess Plateau, the North Altai Plains, the upper Yenisei and Angara River basins, produced a consistent and unique evidence of the Late Quaternary climate evolution and the corresponding landscape development in parkland-steppe of southern Siberia. The temporarily preceding Early and Middle Pleistocene loess records are less complete with regional climatostratigraphic hiatuses. Climate-indicative proxy data (magnetic susceptibility, grain-size, % CaCO<sub>3</sub>, % TOC mineral color parameters) supplemented by pedological, including thin-section studies from the most continuous loess-palaeosol reference sites (i.e., Iskitim, Biysk, Kurtak and Krasnogorskoye ) (Fig. 2A, 2D) show marked and cyclic climatic variations spanning the last ca. 250 000 years (250 ka) corresponding to Marine Oxygen Isotope Stages (MIS) 7-1, most pronounced during the last interglacial-glacial cycle in congruence with the Lake Baikal detrital records and the globally indicative deep-sea isotope records (Fig. 2B) (Chlachula, 2003a; Evans et al., 2003; Bábek et al., 2011; Grygar et al., 2006; Prokopenko et al., 2006).

The loess stratigraphy shows aeolian dust deposition during dry and cold stages, and soil formation during warm intervals with surface stabilization and a subsequent cryogenic distortion by frost actions followed by colluviation due to climatic warming. The massive (late) Middle Pleistocene loess accumulation in the southern periglacial tundra-steppe zone is linked with a major Pleistocene glaciation of the Altai and Sayan Mountains during the penultimate glacial (MIS 6, 170-130 ka BP). An intensified pedogenic activity indicates a rapid onset of the last interglacial (MIS 5, 130-74 ka BP) (Fig. 2D) with a strongly continental warm climate during the interglacial climate optimum (MIS 5e, 125 ka BP). The palaeo-temperature data indicate an increase of temperature during the last interglacial peak in average by ca +3°C in the southern part of Siberia and up to +6°C in the arctic regions. This was succeeded by a dramatic interglacial cooling (MIS 5d) with a temperature minimum at ca. 115 ka BP evidenced by a major cryogenic event (with deformation of the MIS 5e chernozem by 1-3 m deep frost-wedges blanked by a thin loess cover) in congruence with the Lake Baikal stratigraphic record. Permafrost remained widely distributed in east Siberia. Cooler conditions during the following interglacial sub-stages (MIS 5c and 5a) correspond to the zonal vegetation shifts, with a gradual replacement of parkland-steppe and mixed southern taiga by boreal forests, interspersed by periglacial tundra-steppe (MIS 5d and 5b). The progressing cooling climatic trend of the early Last Glacial (MIS 4, 74-59 ka BP) culminated in several hyper-arid and cold stadials (MAT by ca. 10°C under present values) interrupted by intervals of climatic amelioration with (gleyed) periglacial forest-tundra soils formation and isolated brush and tree communities (*Betula nana*, *Salix polaris*, *Pinus sibirica*). The following cycle with relatively short warm as well as very cold climate variations characterizes the mid-last glacial interstadial stage (MIS 3, 59-24 ka BP) with cryogenically distorted chernozemic soils, pointing to the existence of a high permafrost table for most of this (Karginsk) interstadial. This was ensued by a new stage of a massive loess accumulation during the late Last Glacial (MIS 2, 24-12 ka BP) with incipient (forest/steppe)-tundra gleysols formed in response to warming oscillations prior to the present Holocene surface stabilization (MIS 1, 12-0 ka BP). A marked drop in MAT by about 8°C (to -9/-10°C) and a decline of precipitation by 250 mm is assumed for the last glacial maximum (22-19 ka BP) (Velichko, 1993). The highest loess accumulation rates recorded during the Late Pleistocene glacial stages (Ermakovo / MIS 4 and Sartan / MIS 2) on the Altai Plains and in the upper Yenisei Basin indicate the most intensive aeolian dust deposition after the glacial maxima, with the most recent interval dated to ca. 19-15 ka BP (Chlachula, 2003a; Evans et al., 2003).

The interglacial and interstadial palaeosol markers in the loess series, characterized by an intensive syndeositional pedogenesis, attest to a strongly fluctuating climate evolution and the corresponding landscape development with major biotic transformations in north-central Asia during the Late Quaternary. The past continental atmospheric shifts reflected by changes in the main vegetation zones display a cyclic pattern of interglacial/interstadial parkland-steppe and mixed taiga ecosystems replaced by boreal tundra-forest and arid periglacial tundra-steppe during cold stadial stages. The northern expansion of parkland-steppes during warm periods as well as periglacial steppes undoubtedly promoted a geographical enlargement of the Palaeolithic oikumene. Cold climatic stages furthermore stimulated human biological and cultural adaptation in the process of peopling of Siberia.

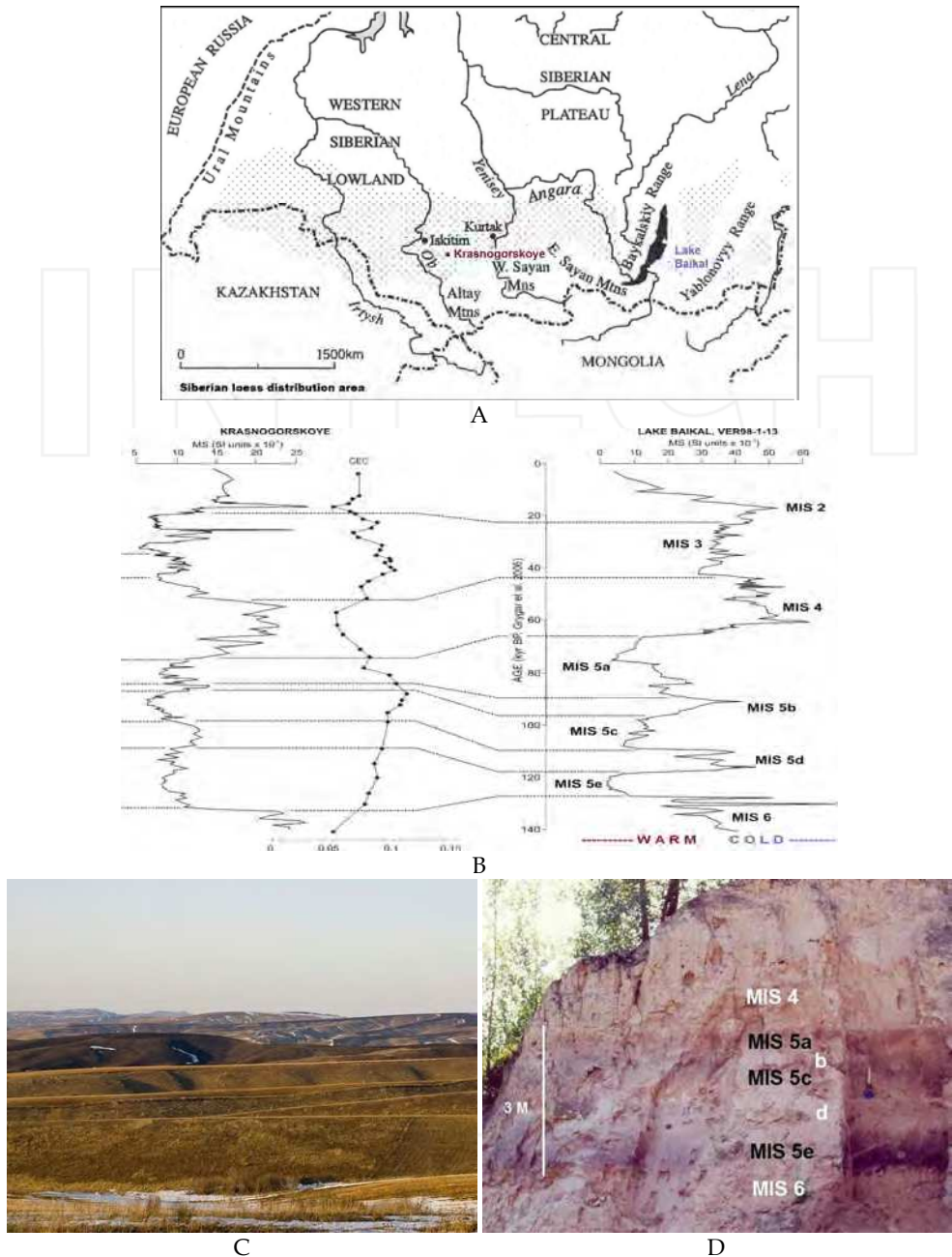


Fig. 2. A: Loess distribution in Siberia; B: Late Quaternary climate evolution in Siberia based on loess-palaeosol and Lake Baikal proxy records; C: the Altai loess landscape; D: the last interglacial (MIS 5) pedocomplex (130-74 ka BP) at Iskitim, with three parkland chernozems.



### 3. Early human occupation and environmental adaptations

The vast territory of Siberia and the adjacent Trans-Ural region has principal bearing for elucidating the historical processes and environmental contexts of the Pleistocene expansion of people from the south-eastern parts of Europe into West-Central Siberia and the northern Russian Arctic areas. Interactions of past climate change and the regional relief modeling triggered by the neotectonic activity and reflected by natural transformations of ecosystems attest to the complexity of the Quaternary landscape development, ultimately affecting timing, intensity and adaptations of the earliest human occupation of north-central Asia.

The contextual geology, palaeoecology and paleontology records from the investigated archaeological sites and stratified geological sections provide evidence of pronounced (palaeo)environmental and biotic shifts triggered by the global climate evolution as well as the associated glacial and interglacial geomorphic processes. Quaternary climatic cycles regulated spatial and temporal movements of prehistoric people into the high latitudes of Eurasia. Integrated ecology multi-proxy databases document trajectories of the complex and long occupation history of this extensive, but still marginally known part of the World.

#### 3.1 The Urals and the Trans-Ural regions of West Siberia

The Urals with the adjoining regions of the West Siberian Plain (*Zauralye* – the Trans-Urals) are of key relevance for multi-disciplinary Quaternary studies focusing on initial peopling of northern Eurasia in respect to the strategic geographical location of this mountain chain, forming the natural borderline between Europe and North Asia. Except for documenting the Pleistocene and Holocene climate evolution and related environmental transformations, the territory of the Urals has a major bearing for mapping the main time intervals of migrations of Pleistocene hominids / early humans into the high latitudes / sub-polar and polar regions of Eurasia, and reconstruction of adaptation strategies to past climate variations.

##### 3.1.1 Geography and natural setting

The Urals, the principal mountain range separating the East European Plains and the West Siberian Lowland as the geographical milestone between Europe and Asia, extends for over 2000 km from the Arctic coast in the north to the arid steppes of western Kazakhstan in the south (Fig. 1A). It is characterized by a pronounced vegetation zonation with polar tundra-forest, taiga and open steppe being the dominant biotopes. The archaeologically most productive Central Urals (56-59°N) is one of the five physiogeographic zones of the Ural mountain range (1895 m asl.), connecting the Southern Urals with the Northern, Sub-polar and Polar Urals (Fig. 3A). Most of the regional hilly relief (700-1500 m asl.) is transected by mountain valleys with the principal E-W oriented fluvial drainage discharge following the continental topo-gradient (Fig. 3C). The adjoining geographical area in the west (*Priuralye* / Fore-Urals) includes the loess plateau of the upper Kama River basin. The Trans-Ural region is delimited by the southern limits of the Sverdlovsk District, and the Tobol and Ob River basins from the (South-)East with the tributary valleys (Severnaya Sosva, Sosva, Tura, Tagil', Neiva, Pyshma) draining the eastern Ural foothills (Fig. 3D). Its western part is formed by small hills (300-400 m asl.) separated by shallow river valleys, lakes and bogs, extending east into the West Siberian Lowland. The present soil cover is characterized by well-developed parkland-steppe chernozems, mixed / coniferous taiga forest brunisols / gleysols and forest-tundra regosols, all with fossil analogues in the Quaternary pedostratigraphic record.

### 3.1.2 Palaeogeography and climate history

The topographically and biotically diverse territory of the broader Ural area attests to the complex palaeogeography and palaeoecology history reflecting large-scale landscape restructurings affected by orogenesis, and the Arctic and northern mountain glaciations (Arkhipov et al., 1986; Astakhov, 1997; 2001; Velichko, 1993; Mangerud et al., 2002). The regional Quaternary stratigraphy is based on geological, palaeontological, bio-stratigraphic and palaeomagnetic records related to the continental basin transgressions and regressions, and stages of loess deposition (Arkhipov et al., 2000; Vereshagina, 2001; Stefanovskiy, 2006). The pre-Quaternary history of the broader Urals is closely linked with formation of the main hydrological systems, particularly in the Fore-Urals area, connected to the Pechora and Caspian Basins. This process was triggered by past global climatic change in conjunction with the re-activated orogenesis of the Eurasian Plate, with dynamic sea-transgressions and prolonged periods of stands and regressions, shaping the continental relief and resulting in formation of the present northern (Pechora) and southern (Kama-Volga) drainage systems. In warm climatic stages, the basins were filled by alluvial and lake deposits superimposed by periglacial alluvial formations (Yakhimovich et al., 1987). The original N-S oriented drainage of the Oligocene-Miocene basins persisted until Pliocene. A new tectonic phase contributed to a palaeo-relief restructuring with shallow river basins. The Early Pleistocene interglacial biotic records document a forest-steppe habitat with presence of arboreal taxa absent in the area today (*Fagus*, *Acer*, *Fraxinus*, *Ulmus*, *Tilia*, *Castanea*) and brackish settings inhabited by *Archidiscodon meridionalis*, *Hipparion* sp., *Coelodonta* sp. (Stefanovskiy, 2006). Climatic cooling at the end of the Early Pleistocene (ca. 740 ka BP) is manifested by glacial deposits distributed in the Pechora and Upper Kama basins, with regressions of the Caspian and Arctic seas. The reactivated tectonics at the beginning of the Middle Pleistocene in the broader Urals-Caucasus area accelerated restructuring of the former drainage system. Increased aridity put up to an intensified weathering in the mountain regions of the Urals. A reduced fluvial activity in the eastern (Trans-Ural) West Siberian lowlands contributed to genesis of closed lake and boggy basins. Floral and faunal communities indicate dry steppe environments replacing former woodlands with the Mediterranean vegetation (*Pterocarya fraxinifolia*, *Rhododendron* sp., *Taxus baccata*, *Castanea sativa*) (Stefanovskiy, 2006). The new hydrological network of the Tobol (MIS 9) Interglacial (390-270 ka) correlates with the 60 m-terrace, with the Tiraspol Fauna Complex of large herbivorous species (*Paleoloxodont* sp., *Mammuthus primigenius* Blum., *Bison priscus gigas*, *Alces alces*, *Megaloceros giganteus*, *Cervus elaphus*, *Equus hemionus*, *Equus caballus*, *Camelus* sp. and *Ovis amon* sp.) indicative of warm semi-arid parklands. The following Samarovo (MIS 8) Glacial (270-244 ka) correlates with the maximum expansion of the Arctic ice to ca. the present line Perm-Nizhny Tagil, blocking the northern Ob / Irtysh River drainage of the West Siberian glacial waters diverted south into the Aral-Caspian Basin. Temperate parklands characterized the following the Shirta (MIS 7) Interglacial (244-170 ka). Recession of the ice-masses is assumed for the final Middle Pleistocene Tazov (MIS 6) Glacial (160-130 ka) with mountain glaciers confined to the Northern - Polar Urals (Arkhipov et al., 1986). The late Middle Pleistocene in the south-central Ural basins is associated with 20-30 m thick fluvial deposits with fossil fauna of the Khozarian Complex (*Mammuthus primigenius*, *Coelodonta antiquitatis*, *Bison priscus longicornis*, *Megaloceros giganteus* and *Equus caballus chosaricus*) indicative of a moderately cold climate. A final Middle Pleistocene neotectonic stage accentuated the regional geomorphological relief restructuring triggered by continuing uplifts of the Central and Southern Ural ranges.

The beginning of the Late Pleistocene brought up a reduced regional topographic differentiation associated with lateral planation processes in the Trans-Ural area and the initial last interglacial (MIS 5e, 130-120 ka BP) transgression. The Ural foothills were covered by a mixed spruce and pine-dominated taiga; open parklands occupied lowlands inhabited by the "Mammoth Fauna Complex" (Bolikhovskaya & Molodkov, 2006).

The Late Pleistocene stratigraphy and glacial geomorphology reflects reducing geographical limits of the continental ice-masses during the Zyriansk (MIS 4) and the Sartan (MIS 2) glacial stages. Predisposed by the territorial topography, most of the present West Siberian Lowland was inundated by a large ice-dammed lake formed between the northern Arctic ice-sheet and the southern continental water divides during the early Last Glacial (ca. 90 ka BP) (Mangerud et al., 2001). Moraines in the Pechora Basin on the NE European Plains point to the expanding Arctic glaciations from the Kara and Barents Sea ice lobes, presumably reaching their Late Pleistocene maximum extent (Mangerud et al., 1999) in corroboration with the West Siberian glacial records (Astakhov, 1997, 2001). Dynamic climatic fluctuations of the second half of the glacial stage are linked with a gradual recession of the continental ice limits in the Northern Urals and activation of intensive periglacial and gravity-slope processes resulting in massive accumulations of up to 80 m thick polygenic colluvia in the Trans-Ural foothills. An intensified loess deposition formed a 20-25 m thick cover on the Fore-Ural plateaus, overlying periglacial alluvia of the Upper Kama, reflects the prevailing dry and cold climatic conditions of periglacial tundra-steppe.

The subsequent mid-last glacial (MIS 3) interstadial warming (59-24 ka) promoted expansion of spruce- and pine-dominated taiga. The new stage of glacial advance during the late Last Glacial /Sartan (MIS 2), probably confined to the Polar and Northern Urals with localized ice-caps, led to expansion of tundra-steppe and tundra-forests in the southern lowland and mountain areas, respectively (Velichko et al., 1997). Most of north-central Siberia presumably remained ice-free (Zemtsov, 1976, Mangerud et al., 2008), opposing the model of a more extensive ice-cover in the Russian Arctic (Grosswald & Hughes, 2002). The geographic distribution of glacial landforms and glacial deposits provides evidence of the Arctic ice expanding from the Kara Sea basin along the western slopes of the Urals, likely merging with the piedmont glaciers (Mangerud et al., 2002). Most of the eastern slopes of the Urals likely hosted ice-free environment possibly due to a rapid disintegration of the early Last Glacial (MIS 4) ice and dry climate. Accelerated loess accumulation in the Fore-Ural area marks onset of the full last glacial conditions associated with remains of large Pleistocene fauna (*Mammuthus primigenius*, *Coelodonta antiquitatis*, *Equus* sp., *Bison priscus*) and small species typical of periglacial tundra-steppe (Yakhimovich et al., 1987).

The late Pleistocene ecosystems in the Trans-Ural region are linked to alluvial formations of the fluvial basins draining the eastern slopes of the Urals, and incorporating the typical large and small periglacial fauna of periglacial tundra-steppe (mammoth, woolly rhinoceros, horse, bison, reindeer, elk, saiga) with smaller open-steppe and semi-desert taxa such as wolf, fox, hare, marmot, as well as of rodents and other small mammals indicative of mixed polar tundra – steppe biotopes (Stefanovskiy, 2006). Permafrost limits at the end of the Pleistocene (the Allerød warming) were still located at 55°N in the Trans-Urals / West Siberia (Velichko et al., 2002). Precipitation values during the late Last Glacial and the early Holocene (15-10 ka BP) amounted to ca. 60-65% on the East European Plains and ca. 80% in West Siberia comparing to the present-day values. The present geographic distribution of particular biotopes in the broader Ural territory reflects the Holocene climate development.

### 3.1.3 Pleistocene environments and early human peopling

The importance of the Trans-Urals lies in its specific geographic location at the westernmost limits of Siberia adjacent to the Ural Mountains in terms of study of prehistoric migration processes, adaptation strategies and cultural exchanges between Eastern Europe and Siberia. Interaction of the Pleistocene climatic variations with the regional relief modeling by the northern Arctic glaciations, interglacial sea-transgressions, and stages of river erosion and sediment weathering attest to the complexity of the Quaternary history of the broader Ural area. During most of the Pleistocene, the North and Central Trans-Urals, sloping east from the central mountain range, were ice-free. The bordering foothills and plains of West Siberia constituted parts of the periglacial super zone (Arkhipov, 1999) and the place of mass accumulation of aeolian deposits transported from the ablation zone of the NE European-Siberian ice-sheets. The geographic and topographic configuration of the Urals predisposed a long history of human occupation in this area, forming a natural gateway for the early human infiltration further east into the vast parklands and forest lowlands of West Siberia.

The initial peopling of the territory, presumably from the East European Plain and the northern Caucasus region, was a complex process governed by changing palaeoecology conditions in response to the Pleistocene climate variations. Warm and humid Middle Pleistocene interglacial, with rich biotic resources of forest-parklands, undoubtedly enabled early human migrations further north and east along the Ural range particularly through the major river systems (Volga, Kama, Pechora) draining the East European Plains. Mixed coniferous and broad-leaved forests with *Pinus silvestris*, *Betula pubescens*, *Quercus robur*, *Tilia cordata*, *Ulmus laevis* formed a mosaic vegetation cover during the late Middle Pleistocene (MIS 9 and MIS 7) interglacials (Bolikhovskaya & Molodkov, 2006). The oldest recorded (Early Palaeolithic) sites are mostly exposed along active river banks of the Kama reservoir by erosion of loess and loessic sediments overlying relics of the Middle Pleistocene (35-60 m) river terraces. The cultural material is represented by archaic and simply flaked core-and-flake stone industries (cores, retouched flakes, scrapers and other tools, partly bifacially worked) produced on cobbles from old river alluvia. Numerous fragmented animal bones with the anthropogenic working and use attributes (flaking, splitting, retouching) (Fig. 2B) indicate productive natural occupation habitats and complex behavioral activities. The formal technological uniformity of these Palaeolithic finds and their geological contexts related to the Middle Pleistocene alluvia suggests an intensive expansion of the Old Stone Age people across the middle latitudes of Eurasia prior to the last interglacial. (>130 ka BP) (Matyushin, 1994; Velichko et al., 1997; Chlachula, 2010a). Periglacial sub-Arctic tundra-steppe and open forest-tundra correlated with the late Middle Pleistocene (MIS 8 and MIS 6) glacial advances in the north-eastern part of Europe (the Pechora Urals) covered most of the non-glaciated territories occupied by periglacial fauna (*Mammuthus primigenius*, *Coelodonta antiquitatis* Blum., *Rangifer tarandus*, *Bison* sp., etc.). These prominent Middle Pleistocene glacial stages brought a major geographical reduction of the early human occupation areas.

The pronounced climatic warming at the beginning of the Last Interglacial (MIS 5), recorded in the loess-palaeosol sections from the East European Plain to southern Siberia (Little et al., 2002; Chlachula, 2003), may have created inundations and ground saturation of the formerly glaciated areas and thus temporarily impeded free movements of early people. Increased continentality and MAT led to expansion of parkland-steppe also facilitating new migrations of the Middle Palaeolithic (Neanderthal/early *Homo sapiens*?) communities. High summer temperature (increased by ca. 4-5°C in respect to present values) and mean annual

precipitation (by ca. 100 mm) led to the northward distribution of southern taiga along both sides of the Urals by 500-700 km beyond the present limits (Velichko et al., 1992; Velichko, 1993). Pine-spruce-birch forests with oak, hornbeam, lime, hazel and elm characterized the prevailing mosaic vegetation of the warm last interglacial climate sub-stages (MIS 5e, 5c).

Recession of human occupation is linked with the onset of the early Last Glacial stage (MIS 4, 74-59 ka BP) reducing the formerly inhabited areas of the periglacial steppe zone around the Southern Urals and repeatedly during the late Last Glacial stage (MIS 2, 24-12 ka BP). The most intensive late Middle / early Upper Palaeolithic geographic expansion occurred during the mid-Last Glacial interstadial interval (MIS 3, 59-24 ka BP) reaching the northernmost regions of the Urals and the adjacent territories of northern Europe and NW Siberia (Pavlov, 1986; Pavlov et al., 2001, 2004). The progressive biological and cultural adaptation enabled to retain the new lands prior and shortly after the LGM. The Central Urals forming the free geographic passage connecting the East European Plain with the vast West Siberian territories most likely played a key role in this historical evolutionary process. The last glacial peopling of north-central Urals is principally associated with the cave complex in the Chusovaya River valley cutting E-W through the Ural mountain range. The multi-layer sites (e.g., Bezmyannaya Cave, Kotel Cave, Kamen Dyrovatyy, Bolshoy Glukhoy) distributed in a karstic formation over a 200 km distance encompass a long record spanning from the Late Pleistocene (Middle Palaeolithic) till the Iron Age (Fig, 3C). Apart of the main valley, the upper Chusovaya River tributaries (Koiva, Sylvitsa, Serebryanka) likely encompassed rich biotic niches even in glacial stages. A unique cultural record from the Kamen Dyrovatyy Cave treasured over 18,000 arrowheads made of various materials (stone, bone and metal) dating since the Late Pleistocene to Holocene, with the Late Palaeolithic level, dated to  $13,757 \pm 250$  yr BP (Serikov 2001). Other central Ural cave sites interpreted as cultic in view to archaeological inventories (Kumyshanskaya Cave, Ignatievskaya Cave, Grot Zotinskyy, Kotel Cave) as well as those in the southern Urals (Kapova Cave) (Bader, 1965; Matyushin, 1994) suggest a high socio-cultural and behavioral complexity. In the latter mountain zone, spruce and pine taiga forests persisted until the onset of the Last Glacial, ca. 22-21 ka BP (Danukalova & Yakovlev, 2006). A certain regional cultural non-uniformity across the Urals manifested in the lithic industry composition may indicate differences in environmental adaptations. The taxonomic diversity of hunted fauna is particularly evident at other Final Palaeolithic / Mesolithic sites, including reindeer- and mammoth-dominated sites in the Trans-Ural foothills and the eastern lowlands, respectively (Serikov, 1999; 2000). A multifunctional character and a variety of particular activities are well evident in the broad repertoire of stone and bone tools, including "hacking" instruments, barbed harpoons and arrowheads. A micro-lithization and stone tool polishing in the Mesolithic complexes distributed across the Urals and West Siberia indicate an adaptive adjustment and diversification of exploitation of the final Pleistocene/early Holocene environments.

Opposite to taiga forest of the Ural mountain valleys, the eastern Trans-Urals and the adjacent West Siberian Lowlands hosted a diversity of environments and settings related to seasonally water-saturated taiga forests with braided river streams, lakes and bogs. This vast and biotically diverse territory underwent a palaeogeographical and palaeoecological evolution reflecting large-scale environmental shifts, partly affected by the Arctic as well as mountain Pleistocene glaciations. The stratigraphic position of the mapped Pleistocene sites is determined by past geomorphic processes and biotic shifts of both the lowland and foothill areas with absence of thick loess deposits present on the eastern slopes of the Urals.



Fig. 3. (Trans-)Urals. A: the Pleistocene glacial mountain topography of the Northern Urals; B: humanly flaked bones and ivory of the Middle Pleistocene fauna (the upper Kama basin); C: karstic formations of the Chusovaya River valley with multilayer prehistoric cave sites; D: open parkland taiga of the Sosva River valley, Trans-Urals of West Siberia. E: frost-wedge casts incorporating fossil wood and charcoal of the last glacial landscape diagnostic of low MAT and a periglacial setting. F: Gari Site 1, Late Palaeolithic occupation with concentration of mammoth bones indicating cultural exploitations of the last glacial Siberian ecosystem.

The Palaeolithic in the Trans-Ural regions, predating the mid-Last Glacial, is poorly known contrary to the western regions of the Urals (Pavlov et al., 1995). The archaic character of lithic implements from the local Pleistocene occupation sites must not imply antiquity and may reflect a time-transgressive character of expedient stone industries of the Palaeolithic and Mesolithic complexes pre-determined by local raw material sources (e.g. sandstone and siltstones at Gorbunovskiy Torfianik; quartzite tuffs at Golyy Kamen) (Serikov, 1999; 2000). Geoarchaeology studies from the easternmost limits of the Trans-Ural area provide multiple lines of evidence of Palaeolithic peopling of this geographically marginal and still poorly explored territory of West Siberia following the mid-last glacial warming (35-24 ka). A specific cultural entity represents the Late Palaeolithic complex of open-air sites in the Sosva River basin on the periphery of the West Siberian Lowland contextually associated with massive concentrations of large Pleistocene fauna remains, previously interpreted as natural "mammoth cemeteries" known since the 19th century (Fig. 3D, F). Other fossil fauna with woolly rhinoceros, bison, horse, reindeer and other animals characteristic of periglacial tundra-steppe together with small (bird and fish) species indicate a diversity of exploitation of the local Late Pleistocene natural resources and adaptation to the last glacial sub-polar environments (Chlachula & Serikov, 2011). The skeletal remains from the main occupation localities suggest both active hunting and anthropogenic scavenging practices during the Last Glacial (with radiocarbon dates of ca. 25-12 ka BP). Human behavioral activities at the key Gari I site are also indicated by circular concentrations of mammoth and rhinoceros bones (including complete skulls, large bones and tusk fragments), some of them artificially modified, reminding primitive dwelling structures known in the Late Palaeolithic from the East European Plains (Pidoplichko, 1998; Iakovleva & Djindjian, 2005). The geological context of the well-preserved fossil records, sealed in cryogenically distorted alluvial deposits of the meandering Sosva River, indicates complex taphonomic histories of the occupation sites buried in cold periglacial swampy-riverine settings. The palaeontological records show an extraordinary biotic potential of the Pleistocene periglacial West Siberian steppe marginally interspersed by the eastern Ural foothill ecosystems. The dominant exploitation of mammoth (98.5%) corroborates the faunal compositions from other Late Palaeolithic sites on both sides of the Urals (Byzovaya Cave, Mamontova Kurya in the Pechora basin, Volchiya Griva in west Siberia (Pavlov, 1996; Petrin, 1986; Savel'eva, 1997, Svendsen & Pavlov, 2003). Due to the extreme environmental conditions (the high climate-continentiality, surface saturation and natural water/stream barriers), the adjacent West Siberian Lowland is assumed to have been colonized rather late only after the Last Glacial Maximum at about 17-16 ka BP (Petrin, 1986). The Trans-Urals and probably the north Siberian Arctic regions remained largely ice-free even during the LGM and except for water-saturated and frozen boggy lands there were no major natural obstacles for free movement of Palaeolithic groups further east into NW Siberia prior and after that time interval. Fossil fauna displays a major biotic potential in the central northern Trans-Urals. The latitudinal zonal differentiation of the last glacial ecosystems of the broader Urals from the Arctic coast in the north to the Black/Caspian Sea was likely more uniform, largely covered by periglacial tundra-steppe in contrast to more mosaic interglacial parkland landscapes (Markova, 2007), facilitating a free migration of fauna as well as the Late Palaeolithic peoples particularly within the foothill corridors. Regional palaeoenvironmental deviations, differing from the overall territorial bio-geographic and climatic pattern (Panova et al., 2003), may have played a significant role in the process of early prehistoric peopling of the northern regions of Eurasia.

### 3.2 South-west Siberia (the Altai region and the Kuznetsk Basin)

The territory of SW Siberia shows a complex Quaternary history spanning the last 2.5 million years governed by climate changes leading to the present pronounced continentality of inner Eurasia in association with a regional Cenozoic orogenic activity. Dynamics of these processes is evident in formation of the relief of the southern Siberian mountain system. It is also witnessed in preserved geological records that may have a global relevance in view to the geographic location (such as deeply stratified loess-palaeosol sections indicative to high-resolution Pleistocene and Holocene atmospheric variations in the Northern Hemisphere). Reconstruction of the past climate dynamics that shaped the configuration of SW Siberian topography and local ecosystems is essential for understanding timing and adaptation of the initial peopling of the territory of northern Asia. Geoarchaeological investigations of the Palaeolithic and Mesolithic occupation have a long tradition particularly in the Altai region. The spatial distribution of the transitional geographic areas along the margin of SW Siberia believed to be the main gateway for early human migrations from the southern regions of Central Asia into Siberia is of utmost significance of multidisciplinary Quaternary studies.

#### 3.2.1 Geography and natural setting

The territory of SW Siberia, including the Altai and the Kuzbass regions, is characterized by a rather diverse physiography with high mountain massifs in the south and east, and open lowlands in the north and west (Fig. 1A). The Altai Mountains (maximum elevation 4506 m asl.) and the Kuznetskiy Alatau (2171 m asl.) form a natural barrier from the South and East, respectively, connected by the Gornaya Shoria Mountains (1560 m asl.). The Salair Range (590 m) separates the adjacent continental depression in the north from the upper Ob Basin and the Kuznetsk Basin (150-300 m), representing the marginal parts of the Western Siberian Lowland. Hydrologically, the area belongs to the Ob River drainage system with the Katun', Biya, Irtysh and Tom' River being the main tributaries. The lower relief zone (>1200 m asl.) includes more than 50% of the mountain area and constitutes relics of old denudation surfaces covered by more recent Pleistocene deposits derived during past glaciations. The present climate is strongly continental with major seasonal temperature deviations between the northern lowlands and the southern mountains (Fig. 1B). In winter, climatic conditions in the montane zone are generally less severe than in the open northern steppes, and microclimate prevails throughout the year in some protected locations in the Altai and West Sayan central valleys. Annual temperatures as well as the precipitation rate vary greatly according to particular topographic settings. Most of the precipitation falls on the W/NW slopes in the northern and central Altai, whereas the southern regions are more arid and increasingly continental with average July temperature +25°C. The average January temperature -33°C may drop to -60°C. Most of the area is underlain by perennial permafrost with the active thaw layer only 30-70 m thick. Vegetation is characterized by open steppe-parkland dominated by birch and pine. Mixed southern taiga (larch, spruce, pine, Siberian pine, fir and birch) is replaced by the alpine vegetation (with pine, larch and dwarf birch) at higher elevations. Semi-desert communities with admixture of taxa characteristic of the Mongolian steppes are established in upland depressions and on plateaus of the southern Altai. The present soil cover corresponds with the zonal vegetation distribution, with steppe chernozems in the northern lowland basins and plains, luvisolic soils at humid valley locations, brunisols and podzolic soils in the lower taiga forest zone, tundra regosols in the (sub)-alpine zone; and calcareous soils and solonets in the semi-desertic mountain basins.



## 3.2.2 Palaeogeography and climate history of SW Siberia

### 3.2.2.1 Southern mountain areas

Geological history of the broader territory of SW Siberia is linked with the formation of the southern Siberian mountain system initiated by the Miocene uplift of the Transbaikal region and reaching the Sayan-Altai area during the late Pliocene (ca. 3 Ma). This major orogenic period that continued until the early Middle Pleistocene constructed a system of mountain ranges separated by deep depressions filled by large lakes (Fig. 1B-2). Following warm climatic conditions with landscape stability encompassing most of the Pliocene (5.3-2.5 Ma), the beginning of the Pleistocene period brought a major modification of the former relief as a result of dramatic climatic changes with progressive intra-continental cooling and aridity. The Pleistocene glaciations caused a regional topographic restructuring with intensive erosion in the glaciated alpine zones and accumulation of (pro)glacial, alluvial, proluvial, lacustrine and aeolian deposits in the intramontane depressions. Little is known about the earliest glacial events of the Altai, with evidence largely obliterated by erosional processes of subsequent glaciations. The earliest Quaternary (Early Pleistocene) non-glacial records are documented by gravelly alluvia and lacustrine sands in the Teleckoye Lake formation with pollen indicating a mixed taiga forest with warm broadleaf arboreal communities. A high-mountain forest-steppe stretched over the major southern Altai intermountain basins (the Chuya and Kuray Depressions) witnessed by pollen records with *Ephedra* and a large fossil fauna represented by *Hipparion* sp., *Coelodonta* sp., Elephantidae, Bovidae (Deviatkin, 1965). The Middle Pleistocene glacial periods are evidenced by two glacial moraines correlated with the Kuyuss Glaciation and buried in the middle Katun' River basin. The pollen data from the lower till bear witness of a cold steppe environment (Markin, 1996). Warm interglacial conditions during the Middle Pleistocene from the Anui River valley, NW Altai, are evidenced by mixed pollen of pine, birch, oak, lime, maple and other arboreal taxa (Derevianko et al., 1992c). An analogous climatic development in the northern lowlands is documented in the Kuzbass Basin with a series of basal red soils indicative of warm and relatively humid forest-steppe followed by brown soils of cold tundra steppe (Zudin et al., 1982). Tectonic movements during the late Middle Pleistocene (0.3-0.2 Ma) initiated uplift of the mountain ranges to about the 1500-2000 m elevation, triggering intensive denudation processes of former unconsolidated deposits. The renewed orogenic activity caused a restructuring of the regional drainage system, with a dominant N-S oriented river-flow direction and a further deepening of the mountain river valleys by up to 100 m in the marginal areas (Anui, Charysh) and > 200 m in the central Katun River valley.

The regional climatic variations are documented by thick alluvial-proluvial sandy gravels of the Tobol (MIS 9) Interglacial separated by glacial till deposits (MIS 8) from the following Shirta (MIS 7) Interglacial (Markin, 1996). The warm periods are characterized by expansion of mixed taiga forests, and brown forest and forest-steppe soils in the Kuznetsk Basin (Zudin et al., 1982). The final Middle Pleistocene (MIS 6) glacial stage (Eshtykholskoye Glaciation) is believed to be the most extensive Pleistocene glacial event in the Altai and West Sayan area (Deviatkin, 1981) corroborated by the evidence from the Eastern Sayan Mountains (Nemchinov et al., 1999). The alpine glaciers presumably formed extensive coalescent ice fields supporting large glacial lakes in the central basins (Fig. 4A). Massive proglacial, ice-marginal deposits accumulated in the Chuya Basin with up to 50 m thick alluvial fans along the eastern flanks at the Kuray Range (4000 m asl.). In the foothills and the adjacent continental depressions, this climatic cooling is linked with appearance of

forest-tundra soils (Zykina, 1999). Cold and dry climatic conditions in the extra-glacial areas are indicated by accumulation of loess, incorporating the typical loessic mollusc fauna (*Succinea oblonga*, *Pupilla muscorum*, *Vallonia tenuilabris*, *Columella columella*, *Vertigo alpestris*) and rodent species characteristic of tundra-steppe. An extensive geographic expansion of southern taiga forests dominated by spruce and the Siberian pine into the former steppe and upland region characterizes the Last Interglacial (MIS 5) (Shunkov & Agadzhanian, 2000).

During the Late Pleistocene, the Altai, as well as other southern Siberian mountain ranges experienced two glaciation events (MIS 4 and 2) represented by two moraines and tills separated by non-glacial interstadial deposits. The first (Ermakovo/Chibit) glaciation followed the same topographic ice-expansion pattern as the previous Middle Pleistocene glaciation (MIS 6). Large glaciofluvial ice-marginal lakes repeatedly filled the upper reaches of the Chuya and Kuray Basins, with icebergs released from the surging glaciers (Deviatkin, 1965). Accumulation of coarse and massive glacial sediments and formation of erosional surfaces in the lower reaches at relative elevations of 200 m, 80-100 m, 50 m, 30-40 m, 4-6 m and 1-1.5 m followed the glacial lake drainage cycles (Fig. 4B), indicating periodicity of these processes during the two glacial events (Rudoy et al., 2000). Pollen from the lower Katun River terraces dominated by dwarf birch (*Betula nana*) documents very cold conditions with tundra-steppe expanded within the northern lowlands and depressions of SW Siberia.

The mid-last glacial (MIS 3) warming (59-24 ka BP) is associated with accumulation of gravelly alluvial sediment facies in the mountains, resulting from the former ice ablation, and river sands and lacustrine clays in the upper Ob and the Kuznetsk Basins (the Bachatsk Formation) (Markin, 1996; Zudin et al., 1982). Geological records display a wide range of environments and climates. Pollen from the 30 m Katun River terrace shows expansion of taiga forests with appearance of warm broadleaf flora (*Quercus*, *Tilia*, *Ulmus*, *Juglans*) whose distribution range is well south beyond the present Altai limits. A gradual transformation to forest steppe and tundra steppe characterizes the later part of this stage (the Ust'-Karakol section), reflecting cooling of the Konoshelskoye Stadial (33-30/29 ka BP). Analogous climatic trends are indicated by pollen records from the pre-Altai Plain.

The second (MIS 2) Late Pleistocene (Sartan/Akkem) glaciation (24-17 ka BP) was less extensive than the preceding two (MIS 6 and 4) glaciations. In the Altai, it is associated with terminal moraines at the >2000 m elevations. Glacial basins formed in the intramontane depressions of the Biya, Chulyshman, Bashkaus, Katun, Chuya and Argut River basins with the synchronous glacier expansion followed by cataclysmic flooding (Butvilovskiy 1985, Okishev, 1982; Baker et al., 1993; Chlachula, 2001a, 2011b), with the latest around 13 ka BP. Large alluvial fans overlying or laterally merging with the highest alluvial terraces attest to dramatic geomorphic processes during the Last Glacial. Periglacial conditions with cold-adapted fauna prevailed in the northern extra-glacial zone. Pollen data illustrate distribution of cold periglacial steppe in the Altai foothills and on the adjacent plains with isolated tree (birch, pine, spruce, willow) communities in more humid settings (Zudin et al., 1982). The broken mountain relief differentiated the regional climatic pattern during the Last Glacial, with microclimate conditions in the protected locations along the northern Altai foothills and the central Katun basin allowing survival of warm Pleistocene flora and other biota until the Holocene. Large periglacial stony polygons on the Plateau Ukok, formed as a result of permafrost dynamics, attest to very severe post-glacial climatic variations. Dramatically wasting mountain glaciers in the southern Altai (the Tabon Bogdo Ula Range, 4120 m) are linked with a progressing global warming despite very low MAT (-10°C) (Rudoy et al. 2000).

### 3.2.2.2 Northern lowland areas

The Pleistocene climatic evolution in the lowland extra-glacial areas of SW Siberia and the continental depressions north of the Altai-West Sayans are characterized by accumulation of aeolian (silty and sandy) deposits during glacial periods and surface stabilization with soil formation during interglacial periods (Arkhipov et al., 2000). Particularly the loess-palaeosol formations widely distributed in southern Siberia provide the most detailed multi-proxy chronostratigraphic correlation of past climatic cycles (Chlachula, 2003; Bábek et al., 2011).

In the Kuznetsk Depression, being a major tectonic basin of SW Siberia bordered by the Salair Range and the Kuznetskiy Alatau Mountains, the Quaternary climate evolution is evidenced by the unique 30-60 m thick stratigraphic sequence of loess and lacustrine deposits intercalated by up to 16 Early, Middle and Late Pleistocene palaeosols above the Pliocene red soils (Zudin et al., 1982). The contextually associated fossil fauna, illustrates diversity of the local ecosystems (open steppe and parkland-forest environments) in terms of the regional climatic evolution and the geographic relief configuration (Foronova, 1999). Intensive aeolian dynamics over the south-west Siberian parkland-steppe, being a part of the Eurasian loess belt, is eloquently documented by up to 150 m high loess sections on the Priobie (Ob River) Loess Plateau, with a series of prominent interglacial pedocomplexes of chernozemic steppe soils and luvisolic / brown forest soils, spanning from the Early to Late Pleistocene. The stages of aeolian reactivation of silty dust derived from up to 100 m deep deflation surfaces in the lowland areas of SW Siberia (Zykina, 1999) correlate with the main glacial cycles in the mountain regions. Because of earlier stratigraphic hiatuses, best-documented are the Late Quaternary palaeoclimate loess archives spanning over the last ca. 300 000 years.

The prominent last interglacial (MIS 5) pedocomplex (Fig. 2D), with three parkland-steppe chernozems disturbed by cryogenesis under humid and cold conditions, shows complexity of the interglacial climate evolution (130-74 ka BP) (Chlachula & Little, 2011). The MAT during the interglacial climatic optimum (MIS 5e, 125 ka BP) in SW Siberia was by 1-3°C higher than at present, with about a 100 mm increase in annual precipitation. Environmental conditions were broadly similar to the present ones during the following interstadials. Increased precipitation and annual temperature contributed to a northward expansion of southern taiga forests by about 500-700 km beyond their present distribution limits due to raised summer temperature by 4-5°C relative to the present values (Velichko et al., 1992). Climate during the mid-last glacial (Karginsk/MIS 3) interstadial optimum was likely warmer than at the present as witnessed by chernozemic soils dated to 35-31 ka BP. The overlying podzolic forest soils (26-22 ka BP) show a gradual cooling towards the early last glacial stage (MIS 2) succeeded by a cold periglacial tundra-steppe with humic gleysols analogous to the modern soils of central Yakutia (with January temperatures below -27°C). Following the LGM, pronounced aridization at the western margin of southern Siberia correlates with loess accumulation (19-14 ka BP) and the time-equivalent formation of large, ice-marginal glaciolacustrine basins in the Irtysh and Ob River valleys (Arkhipov, 1980).

In sum, both glacial and sub-aerial formations provide evidence of cyclic nature of the Pleistocene climates of south-western Siberia with pronounced shifts in past ecosystems. The Early Pleistocene interglacials, characterized by a higher heat balance and atmospheric humidity, promoted distribution of meadow-forests and mixed parklands. The progressing climatic continentality during the Middle and particularly Late Pleistocene led to establishment of the present-type forest-steppe vegetation zones during interglacial periods and periglacial steppe during cold stages correlated with the Altai mountain glaciations.

### 3.2.3 Pleistocene environments and early human peopling

The Quaternary climatic changes and transformations in natural environments in south-western Siberia are well manifested by geological, biotic, but also the early cultural records. The past glacial dynamics, controlled by the regional atmospheric air-mass circulation flows in conjunction with the neotectonic activity and river erosion, shaped the relief to form biotically productive river valleys and depressions. The cyclic nature of the glacial and interglacial stages led to a restructuring of landscapes and generation of specific ecosystems adjusted to particular topographic settings and responding to ongoing climatic variations.

The spatial distribution of the Palaeolithic sites on the territory of SW Siberia shows a location of most sites within the transitional zone between the southern mountain ranges and the northern lowlands. These geomorphological zones, about 75-150 km wide, form a topographic relief belt of the 300-1000 m altitude, narrowing or expanding in respect to the particular physiographic conditions and the configuration of the relief (Baryshnikov, 1992). Particularly the Altai region shows the high density of Pleistocene occupation localities. This pattern of the (palaeo)geographic site location, reflecting specific environmental adaptation strategies to local settings, applies for both open-air localities buried in alluvial, colluvial or aeolian deposits, as well as cave sites concentrated in the NW Altai (the Anui valley) (Fig. 4E). Formation of the latter relates to a progressive down-cutting by fluvial erosion through the Devonian-Carboniferous limestone bedrock during the late Middle Pleistocene.

The periodic Palaeolithic migrations in the broader SW Siberia were principally dependent of the Pleistocene climatic development. Intensified orogenic uplifts, triggering large-scale erosions in the river valleys, re-shaped natural occupation habitats. Relatively stable environmental conditions seem to have persisted in the central and northern Altai due to increased regional precipitation and a tempering atmospheric effect of the mountain ranges. Limestone caves excavated by a fluvial bedrock erosion provided shelters for a more permanent human inhabitation of the Altai area, particularly in the northern foothills and the central intramontane depressions (Derevianko & Markin, 1992) characterized by warmer microclimate conditions. Cataclysmic drainage of glacier waters, periodically dammed by the mountain glaciers during glacial stages, had temporarily a dramatic impact to the local Pleistocene ecosystems. Enormous erosion processes associated with these major events significantly reduced the visibility potential of occupation sites in the flooded areas, with localities preserved only at high topographic elevations above the glacial basin waterlines.

The initial peopling of the Altai - West Sayan region likely occurred in some of the early Middle Pleistocene interglacials in the process of the northern expansion of warm biotic communities. Mixed coniferous and broadleaf forests became established in the tectonically active mountain areas with maximum elevations about 1500-2000 m. Parklands covered most of the adjacent plains of West Siberia with continental depressions filled by lakes and drained by meandering rivers. Rudimentary core and flake ("pebble tool") stone collections scattered on high river terraces and the former lakeshore margins of the present arid basins (Kuznetsk and Zaisan Basin) attest to several stages of early human inhabitation and a relative environmental stability (Chlachula 2001a, 2010b). There is limited evidence on persistence of the Early Palaeolithic occupation during glacial stages on the territory of SW Siberia, although some intermittent semi-continuity in the southernmost areas is assumed in view to finds of weathered lithic artifacts from the old periglacial alluvia in association with cold-adapted megafauna. Mastering the technique of fire making was clearly the main precondition for early human survival in cold tundra-steppe and tundra-forest habitats.

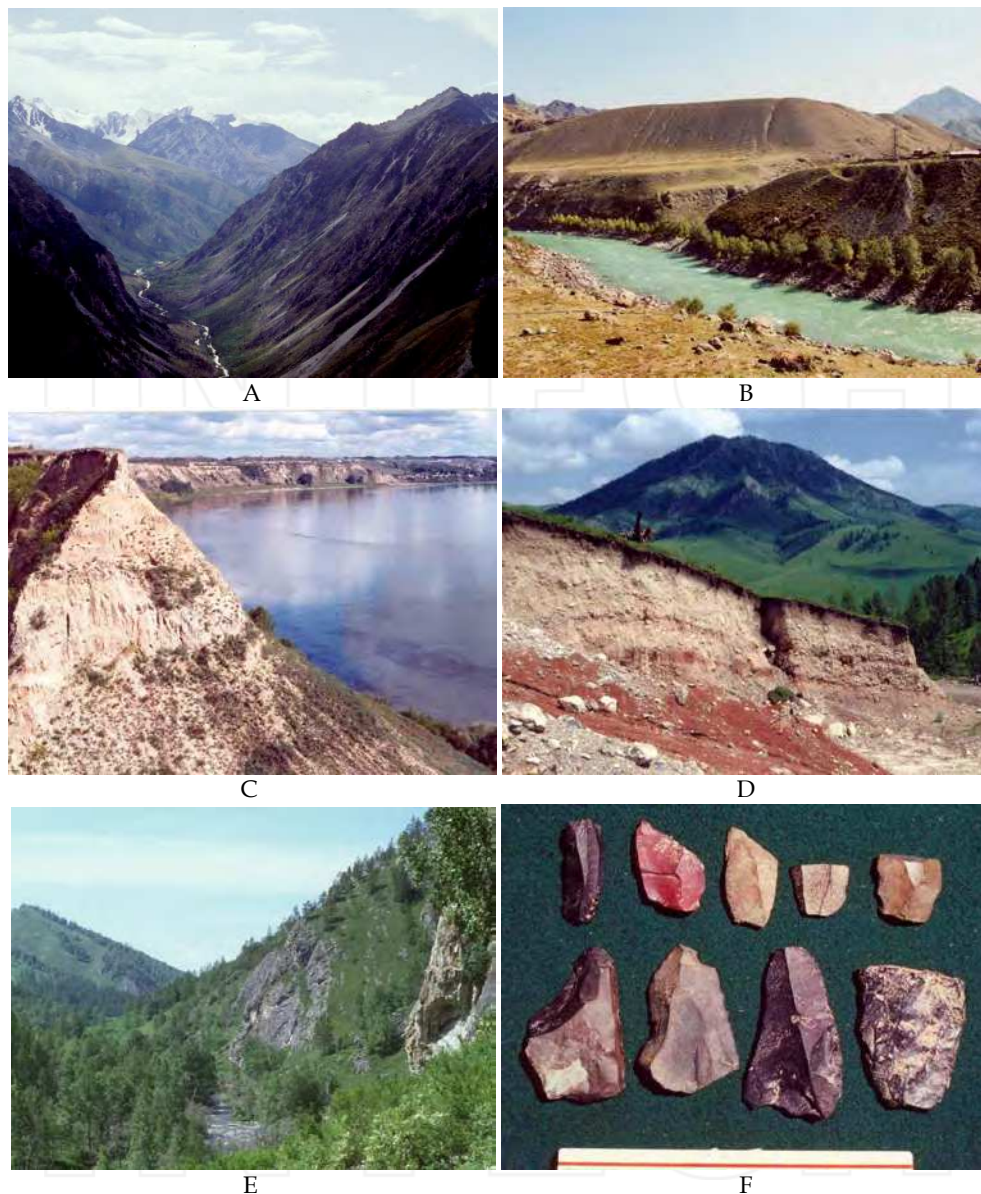


Fig. 4. Altai, SW Siberia. A: former glacial valleys of central Altai; B: glacio-fluvial terraces (up to 200 m high) in the Chuya River basin formed by cataclysmic releases of glacial lakes dammed by valley glaciers; C: thick loess deposits along the Biya River, North Altai Plains; D: colluviated redsoils in NW Altai attesting to warm Middle Pleistocene climate conditions; E: the Anui River valley, NW Altai, with the Middle-Late Palaeolithic occupation cave sites; F: Denisova Cave, Anui valley. Mousterian (Neanderthal) tools of the Levallois tradition.

The last interglacial warming (130 ka BP), associated with the re-colonization of southern Siberia by coniferous taiga forests, is linked with the appearance of the Mousterian tradition. Changes in the relief configuration influenced a regional climate regime and opened new ranges of habitats for the Middle Palaeolithic population concentrated in the transitional zones (500-1000 m asl) in the karstic area of the NW Altai foothills (e.g., Ust'-Kanskaya, Strashnaya, Denisova, Okladnikova, Kaminnaya Caves) as well as at open-air sites in the central valleys (e.g., Kara-Bom, Ust'-Karakol, Tyumechin I and II) (Derevianko & Markin, 1999). The Middle Palaeolithic horizon, encompassing a time span of up to 140 000 years (180-40 ka BP), represents a marked cultural phenomenon in the Altai. Isolated teeth (2) from the Denisova Cave dated to MIS 5 and identified as *Homo neanderthalensis* support the model of biological evolution of pre-modern humans in Siberia (Derevianko & Shunkov, 2009). Major cooling during the early Last Glacial (MIS 4) led to establishment of full glacial conditions in the central and southern Altai, and a zonal geographic replacement of boreal forest by periglacial tundra-forest in the northern Altai and by arid tundra-steppe in the adjacent lowlands (the Ob River basin and the Kuznetsk Basin). Accentuated moderate climate fluctuations between cold stadials are evidenced by embryonic regosolic soils in the loess formations on the North Altai Plains and sparse cultural records in protected locations in the Altai foothills. Human occupation of the central and southern Altai during the early Last Glacial was impeded by harsh, ice-marginal environments and expansion of glaciers in the upper reaches of the Katun - Chuya valleys subsequently filled by large proglacial lakes. Progressive warming during the early mid-last glacial interstadial interval (MIS 3, 59-35 ka BP) caused a dramatic wasting of the ice fields accompanied by cataclysmic releases of ice-dammed lakes and large-scale mass-flow and slope erosional processes. The former valley glaciers either completely disappeared or receded to the highest elevations where they persisted as corrie glaciers. The periodic outbursts of the glacial basins had a dramatic impact on the regional ecosystems, but also obliterating most of the earlier cultural records. Mixed forests dominated by birch, pine, spruce and fir invaded the former periglacial and ice-marginal landscape. The presence of broadleaf arboreal taxa (oak, lime, chestnut, maple) indicates a climate warmer than at the present time. Increased humidity and cooling during the later stage of the mid-last glacial interstadial interval (35-24 ka BP) initiated mass gravity slope processes and cryogenic deformations related to the Konoshelskoye Stadial (33-30 ka BP) followed by warmer oscillations with formation of podzolic forest gleysols. Appearance of the transitional early Late Palaeolithic cultural facies reflects human adaptation to mosaic interstadial habitats, including sub-alpine taiga, dark coniferous forest, mixed parklands and steppe with mixed non-analogue biotic communities. The identical geographical distribution of the Middle - Late Palaeolithic sites and the time-transgressive lithic technologies suggest a regional cultural (and biological?) continuity in the Altai area during the Late Pleistocene (Derevianko, 2010). A phalanx fragment from Denisova Cave dated to 40 000 years and interpreted on basis of DNA as an extinct human species (Dalton, 2010) reinforces this scenario. Re-establishment of cold tundra-steppe habitats correlates with dispersal of the developed Late Palaeolithic with blade-flaking techniques in stone tool production and associated with a periglacial megafauna that possibly survived in protected and milder microclimate locations in the northern Altai throughout the LGM (20-18 ka BP). Emergence of the microlithic stone tool assemblages with wedge-shape cores is linked with a new cultural adjustment in the final stage of the Palaeolithic development responding to natural transformations of the former periglacial ecosystems towards the end of Pleistocene.

### 3.3 South-central Siberia (the Yenisei Basin)

The upper Yenisei basin in the southern part of the Krasnoyarsk Region, south-central Siberia, is rather unique in view to its location near the geographical centre of Asia (Fig. 1A). It has been together with the upper Angara basin in the Irkutsk Region the key area of Quaternary stratigraphic studies mapping the Pleistocene climate evolution. The extensive loess cover with a suite of buried palaeosols from the Northern Minusinsk Basin, being a continuation of the southern Siberian loess belt, have provided the most complete, high-resolution Late Quaternary palaeoclimate record in the north-central Eurasia (Chlachula et al., 1997, 1998). Coupled with the pollen evidence, the continuous loess-palaeosol sequences document periglacial steppe-tundra established during cold stadial intervals, replaced by boreal forest and parkland steppe during the warm interstadials and interglacial stages. The associated Pleistocene landscape transformations, governed by marked climatic variations, are reflected by large diversity of fossil faunal species, including non-analogue communities to modern biota. Geoarchaeological investigations in the stratigraphic sections in the upper reaches of the Yenisei River basin, initiated after progressive erosion of the unconsolidated aeolian deposits, revealed a rich series of Early, Middle and Late Palaeolithic stone tools (industries) associated with an abundant Pleistocene fossil fauna (Drozdov et al., 1990, 1999; Chlachula, 2001b) (Fig.5). The main focus of the current studies is reconstruction of the Pleistocene ecology and chronology of the early human occupation of south-central Siberia. The unique loess-palaeosol records have a fundamental bearing for better understanding the past global climate and environmental history well beyond the limits of north-central Asia.

#### 3.3.1 Geography and natural setting

The south-central Siberia, bordered by the western Mongolia from the South and the Central Siberian Plateau along the eastern margin of the West Siberian Lowland in the North, is a geographically extensive, and topographically and biotically diverse territory encompassing lowlands, high ranges of the Sayan Mountains and the transitional foothill areas transected by river valleys largely draining water discharge from the southern mountain massive. The broader southern Siberian continental basin is built by a system of regional tectonic depressions structured by the Hercynian orogenesis related to the formation of the central Asian mountain system. The upper Yenisei area, including the Northern and Southern Minusinsk Depression and the adjacent slopes of the Eastern and Western Sayan Mountains, lies in the southern Siberian loess zone along the upper reaches of the Yenisei River (52-56°N and 89-94°E). The central part of the Minusinsk Basin is structurally defined by a zone of tectonic breaks running in the north-south direction across the Batenevskiy Range (900 m asl.) in the north. From the east, it is bordered by ridges of the Eastern Sayan Mountains (1778 m), from the west by the Kuznetskiy Alatau (2178 m) and from the south by foothills of the Western Sayan Mountains (2735 m). In the northwest, the Yenisei basin broadens and joins a system of palaeo-valleys merging with the Nazarovskaya Depression of the West Siberian Lowland. The present continental climate (with MAT -0.4°C), with cold and dry winters with little snow cover and warm to hot summers, corresponds to the particular geographical location of the territory. Open steppe stretches over most of southern Central Siberia, with isolated mosaic mixed parkland forest-steppe communities dominated by birch and pine. A chernozemic soil cover underlies parklands, whereas brown forest and podzolic soils are developed under mixed and coniferous taiga forests, respectively. Sandy semi-deserts with saline lakes such as in Khakasia illustrate the marked regional climate diversity.

### 3.3.2 Palaeogeography and climate history of south-central Siberia

Pre-Quaternary geology of the broader southern Siberian territory was controlled by a series of tectonic events. Both relief and the geological structure encouraged intensive geomorphic processes in the past. The Cambrian and Proterozoic volcanism disturbed and subsequently dislocated the south Siberian pre-Cambrian crust composed of igneous and metamorphic rocks. The Middle and Late Palaeozoic orogenesis formed a system of high mountain ranges separated by deep intra-continental depressions. Later Hercynian and Oligocene tectonics in southern Siberia modified the original configuration of the Angara, Kuznetsk, Minusinsk and other basins north of the Altai, Salair and Sayan Mountains, which were filled by Devonian, Carboniferous, Jurassic and Palaeogene volcanic, lacustrine and alluvial deposits. Accumulation of extensive proluvia near the mountain fronts and lacustrine / alluvial formations in the main sedimentary basins continued throughout the Miocene and Pliocene. During the Late Pliocene and Early Pleistocene (ca. 3-1 Ma), an early fluvial system of the palaeo-Yenisei was established with relics old river terraces about 200 m above the present river level. A neotectonic movement during the early Middle Pleistocene divided the Minusinsk Basin into the northern and the southern parts. In response to climatic change in conjunction with the orogenic activity, a system of terraces gradually developed with the earlier, Early and Middle Pleistocene (70-90 m, 110-130 m, 150-170 m) preserved mostly in relics and buried by 10-50 m of aeolian loess as well as colluviated loessic deposits. The Late Pleistocene terraces (8-12 m, 15-20 m, 30-45 m) formed above river plains (Chlachula, 1999). During glacial periods, the northward drainage of the Yenisei and the Ob River was diverted by the ice barrier of the northern inland (Arctic) ice-sheet to the southwest into the Aral and Caspian Sea (Arkhipov, 1998). The regional (palaeo)relief of southern Siberia with intermountain depressions preconditioned formation of large river dams blocked by glaciers periodically causing high-magnitude floods. These dramatic events resulted in an intensive syndepositional accumulation of alluvial and alluvio-lacustrine sediments in the river valleys adjacent to the Altai and Sayan Mountains (Rudoy & Baker, 1993; Yamskikh, 1996). Loess and loessic deposits, in average 10-20 m thick and derived from local alluvial plains during glacial periods, are distributed over most of the landscape, but mainly on the western, lee-side slopes where they reach up to 40 m (Chlachula, 2001b) (Fig. 5A). During warm interglacial and interstadial stages, the formation of alluvia as well as the aeolian sediment accumulation was interrupted by palaeo-surface stabilisation with formation of chernozemic and brunisolic palaeosols (Chlachula et al., 2004a). The geographical location of the Yenisei area close to the geographical centre of Eurasia contributed to extreme continental climatic conditions with widespread permafrost that developed during cold stadials. Permafrost was not preserved during the Last Interglacial (130-74 ka BP) in the southern part of Siberia, whereas it remained widely distributed farther north and east. Detailed stratigraphic records of the last two glacial-interglacial cycles have been documented in the Kurtak area in the Northern Minusinsk Basin (Drozdov et al., 1990). Erosion of the Quaternary sedimentary cover overlying old terraces and igneous bedrock exposed the most complete loess - palaeosol sequences with a chronostratigraphic archive encompassing ca. the last 300 000 years. The unique geological record indicates pronounced and cyclic climatic variations during the Late Quaternary, displaying consistent correlation regularities with the deep-sea oxygen isotope records (Marine Oxygen Isotope Stages / MIS 7-1) also reflected by the corresponding patterned changes in the natural environments. Magnetic susceptibility of the fine aeolian dust has proven to be a very sensitive and useful proxy indicator of past climate change in this part of Siberia (Chlachula et al. 1997, 1998). A



prolonged period of a relative environmental stability during the late Middle Pleistocene is manifested by a basal prominent chernozemic palaeosol (Kurtak 29 type-section) correlated with MIS 7a. The following cold period (MIS 6) experienced significant warm-cold climate fluctuations, expressed by an intensively colluviated loess unit traced across southern Siberia between two main cold and arid intervals defined by aeolian dust sedimentation. The last interglacial / (MIS 5) *sensu lato* (130-74 ka BP) is evidenced by a new period of landscape stabilization with intensified soil formation processes disrupted by intervals of loess deposition and periglacial surface deformation (Fig. 5B). The loess-palaeosol sequence attests to several relatively short, warm as well as very cold intervals (MIS 5e-5a), with a gradual shift from a strongly continental climate during the first half of the interglacial (130-100 ka BP) to cooler and more humid conditions. Reactivated loess sedimentation reflects a progressive cooling during the early stage of the last glacial (MIS 4), culminating in several cold and hyperarid stadials. Climatic amelioration during the early mid-last glacial (Karginsk) interval (MIS 3) is evidenced by the appearance of (gleyed) brunisolic soils. The interpleniglacial climatic optimum associated with the well-developed duplicate chernozem dated to ca. 31 ka BP was likely as warm, but more humid than the present (Holocene) interglacial. The secondary cryoturbation of the fossil chernozem shows a major drop of temperature and formation of underground permafrost. Gradual cooling leading to formation of gleyed brunisolic and later to regosolic horizons found in the upper Yenisei loess sections indicates that the transition towards the last glacial stage (MIS 2) was less dramatic than during the previous glacial interval (Chlachula, 1999). A further drop of annual temperatures associated with an intensive loess deposition marks the time around the Last Glacial Maximum / LGM (20 000 - 18 000 years BP). A progressive warming with several climatic oscillations expressed by an initial pedogenesis characterizes the Final Pleistocene climate development, eventually leading to establishment of the present (MIS 1) interglacial conditions. Frost wedges, filled with humus-rich sediments in the present chernozem, reflect cold winters with little snow cover and seasonally frozen ground. Pleistocene faunal remains are abundant in the larger southern Siberia and provide a significant line of proxy evidence on past natural habitats and biodiversity composition related to climate change. The most prolific and taxonomically rich large fauna collections originate from the Kuznetsk and Yenisei Basins (Fig. 5D). Taxonomically, more than 32 large fossil fauna species have been documented, with the evolutionary (Middle-Late Pleistocene) *Mammuthus/Elephas* lineage being the best-represented. Most frequent megafauna species include woolly rhinoceros (*Coelodonta antiquitatis* Blum.), mammoth (*Mammuthus chosaricus*), horse (*Equus hemionus* Pall. and *Equus mosbachensis - germanicus*), bison (*Bison priscus* Boj.), roe deer *Capreolus capreolus* L., giant deer (*Megaloceros giganteus* Blum.), reindeer (*Rangifer tarandus*), saiga (*Saiga tatarica*) and sheep (*Ovis* sp.) among other animals (Foronova, 1999). Malacofaunal (fossil mollusc) assemblages represent one of most abundant and indicative biotic records in the loess-palaeosols formations with both interglacial and glacial taxa.

In sum, the diversity of the Pleistocene faunal communities in the Minusinsk and Kuzbass Basins documents particular evolutionary stages reflecting regional environmental transformations and zonal biotic shifts triggered by climate change during Late Quaternary. The presence of cold-adapted species in the fossiliferous sedimentary beds indicates a very high biotic potential of periglacial steppe that expanded during the stadial intervals and was replaced by parklands and mixed forests during the warmer interglacial/interstadial stages.

### 3.3.3 Pleistocene environments and early human peopling

Until the 1980s, Siberia was generally believed to have been colonized by the Late Palaeolithic people (Tseitlin, 1979). Systematic geoarchaeological investigations particularly in the Yenisei valley revealed much earlier traces of human peopling. Progressing erosion of the Krasnoyarsk Lake have exposed the nearly complete stratigraphic Late Quaternary geological stratigraphic record, enclosing a series of various Palaeolithic stone industries accompanied by a rich Middle and Late Pleistocene fauna (Drozdov et al., 1999). Abundant archaeological finds represented by simply flaked, but diagnostic stone artifacts originate, together with the taxonomically diverse fossil fauna remains, from basal alluvial gravels of the 60-70 m terrace beneath 20-40 m thick loess deposits (Chlachula, 2001b) (Fig. 5C).

The archaeological and palaeontological records incorporated in the fluvial and sub-aerial formations provide new insights on timing, processes and conditions of the initial peopling of this territory, as well as on biodiversity of the particular Pleistocene habitats. Abundant "pebble tool" assemblages bear witness of human occupation of the Yenisei area prior to the last interglacial (>130 ka BP) in agreement with other regions of southern and eastern Siberia (Fig. 1A). These earliest cultural records, classified on the basis of stone flaking technological attributes as the Early Palaeolithic, are age-corroborated by the contextual geological position (the Kamenny Log, Sukhoy Log, Verkhnyy Kamen and Razlog sites). These archaic stone implements were largely redeposited by erosional processes, but are also documented *in situ* in the original geological context of the Middle Pleistocene alluvia. The formal variability of the Early Palaeolithic industries, displaying a differential degree of patination and aeolian abrasion, indicates several stages of the initial peopling of this area. These cultural finds, in conjunction with the Middle Pleistocene cold-adapted fossil fauna, suggest an early human adjustment to local periglacial environments. The archaeological records from the Minusinsk Basin, supported by analogous finds from the Kuzbass and the upper Angara River basins (Medvedev et al., 1990), show that parts of southern Siberia were occupied repeatedly at several stages during the Middle Pleistocene.

Evidence on the Middle Palaeolithic peopling of central Siberia is principally from the foothill areas of the Altai and Sayan Mountains and the local tributary river valleys (Derevianko & Markin, 1999). In the Minusinsk Basins, the Middle Palaeolithic is found in the Late Pleistocene loess strata and the interbedded soils, particularly of the last interglacial pedocomplex, but may be exposed on the present surface in low-sedimentation-rate areas of Khakhasia, Tuva, Gorno Altai, East Kazakhstan (Astakhov, 1986; Chlachula, 2001b, 2010b). Favorable climatic conditions promoted expansion of the Mousterian (Levallois) tradition during the Last Interglacial (MIS 5) that persisted until the early last glacial stage (MIS 4).

An exceptional Middle Palaeolithic site producing a unique archaeological as well as palaeontological locality is Ust'-Izhul' exposed by erosion at the Krasnoyarsk lakeshore (Chlachula et al., 2003). Numerous concentrated fossil skeletal remains were incorporated *in situ* on top of the last interglacial chernozem IRSL dated of 125 ka±5 ka (Sib-1) and overlying the 65 m Middle Pleistocene Yenisei terrace (Fig. 5E) The fauna included an early form of mammoth (*Mammuthus primigenius* Blum.), woolly rhinoceros (*Coelodonta antiquitatis*), bison (*Bison priscus*), horse (*Equus mosbachensis*), elk (*Cervus elaphus*), as well as small mammals such as marmot (*Marmota cf. baibacina*), beaver (*Castor sp.*) and badger (*Meles meles*). The most abundant species -- mammoth -- was represented by several hundreds bone fragments and 42 molar teeth of at least 12 individuals, mostly juveniles, parts of which were recorded in anatomical position. The associated mollusc fauna shows a xerotheric grassland setting. A perfectly preserved stone tool assemblage (ca. 200 pcs) was found in association with the



Fig. 5. Central Siberia. A: eroded late Quaternary loess sections along the Krasnoyarsk Lake; B: the key section (Kurtak 29) with the interglacial (MIS 7, 244-170 ka; MIS 5, 130-74 ka BP) and interstadial (MIS 3 59-24 ka BP) pedocomplexes; C: exposed gravel alluvia of the Middle Pleistocene (65 m) Yenisei River terrace incorporating fossil fauna and archaic pebble-tools; D: Kuznetsk Basin, mammoth teeth (left: *M. trogonterii*, *M. sp.*, *M. primigenius*); E: the Middle Palaeolithic site Ust'-Izhul' with remains of early *Mammuthus primigenius* and stone artifacts (F) c. 125 000 year old, representing a most unique and complete early occupation in Siberia.

fossil fauna and three fireplaces with a fir-wood charcoal radiocarbon dated to >40 ka BP. The stone artifacts mostly represented by simple flakes (Fig. 5F) were used for processing the slaughtered animals. Human activity is also manifested by flaked and cut bones of mammoth, rhinoceros, bison and elk, and mammoth tusk fragments. The palaeogeographic site configuration with the concentrations of the skeletal remains suggest that the game was hunted by people in the nearby area across the 100-110 m terrace over a cliff onto the present 65-70 m terrace (which formed the floodplain) and transported in dissected pieces to the habitation place. The composition of the inventories reinforces the interpretation that it was a short-term occupation / processing campsite. In respect to the high age and the contextual completeness, the Ust'-Izhul' locality is at present without parallel in Siberia. Together with other Pleistocene megafaunal assemblages from the Minusinsk Basin, the associated fauna record bears witness to the rich biological potential of the area for early human occupation. There is no consensus if the Middle Palaeolithic tradition in southern Siberia can be associated with the European and Near Eastern cultural milieu, although some "classical" Mousterian influences in the Altai cave sites are evident (Derevianko & Markin 1992) (Fig. 4F). The Middle Palaeolithic stone flaking technology, especially the Levallois technique, is still reminiscent in the Late Palaeolithic traditions, suggesting a certain continuity of the cultural and possibly biological human evolution in Siberia during the Late Pleistocene. The Late Palaeolithic occupation in the southern Central Siberia is documented at both open-air and cave sites. Warming during the mid-last glacial interstadial stage (MIS 3) accelerated formation of the Late Palaeolithic cultures characterized by the developed blade flaking techniques. The upper Yenisei basin is one of the major loci of the Late Palaeolithic sites in Siberia (the Krasnoyarsk - Kanskaya forest-steppe, the Northern and Southern Minusinsk Basin, and the Western Sayan foothills) (Astaknov, 1986; Drozdov et al., 1990; Larichev et al., 1990; Vasiliev, 1992; Yamskikh, 1990). The earliest occupation sites have been found buried in the Karginsk (MIS 3) Pedocomplex (31-20 ka BP), in the early Sartan loess and the intercalated, weakly developed, humic loamy interstadial forest-tundra soils (dated to 25-22 ka BP). Intervals of significant climatic deterioration and onset of full glacial (MIS 2) conditions are manifested by the absence of any archaeological record except for biotic refugia in the northern foothills of the Western Sayan Mountains. During the LGM (22 000 - 19 000 yr BP), the Yenisei area, as most of southern Central Siberia, seems to have been vacated due to very cold and arid environmental conditions with the biologically productive mid-last glacial parkland-steppe gradually replaced by a harsh and inhospitable steppe-tundra. More recent Final Palaeolithic finds from the steppe and foothill areas (Abramova, 1979a, 1979b; Drozdov et al., 1990; Vasiliev et al., 1999) provide evidence of re-colonization of the upper Yenisei region during warm climatic oscillations at the end of the Pleistocene. A pre-dominant smaller fauna (reindeer, red deer, argali sheep) hunting, composite bone tools (spears/harpoons) and a micro-blade stone flaking illustrate major shifts in adaptation strategies in response to changing environments during the warm interstadial (16-13 ka BP), preceding the last cold climatic interval of the Final Pleistocene (Younger Dryas, 12.9 ka BP). In sum, the present archaeological records from the larger southern Central Siberia provide eloquent evidence that this territory was occupied repeatedly by early people at several stages during the Pleistocene, including glacial stages with harsh periglacial natural conditions. Human occupation may have persisted throughout the Last Glacial in protected southernmost locations despite severe hyperarid climates over most of the northern plains.

### 3.4 East Siberia (the Angara, Lake Baikal and the Lena Basin)

The palaeogeographical and palaeoenvironmental evolution over East Siberia during the Quaternary Period is characterized by a dynamic interaction of past global climatic changes and a regional neotectonic relief modeling. Sub-rifting orogenic regimes of the Mongolian-Siberian mountain zone gave rise to a diversity of geomorphic settings throughout the Pleistocene. The Cenozoic tectonics in conjunction with mountain glaciations continuously shaped the topography of Eastern Siberia structured by a system of mountain ranges (North Baikalsky, Verkhoyansky, Cherskego, Kolymsky) separated by the major (Angara, Lena, Viluy, Aldan, Indigirka, Yana, Kolyma) river valleys and their tributaries. The geographical isolation with a partly reduced atmospheric circulation regime contributed to a pronounced climatic continentality of this vast territory. Pleistocene glaciations over the East Siberian mountain ranges, though largely localized to isolated ice-caps, played a significant role in the landscape development and related environmental shifts in the extraglacial depressions. Increased accumulation rates of sub-aerial (sandy and loessic) sediments and periglacial palaeosol surface deformations point to a gradually progressing climate cooling during the Late Quaternary. Fossil pollen, fauna and early cultural records from stratified geological contexts provide evidence of pronounced palaeoecology changes in natural habitats. Study of the palaeogeographical processes is essential for reconstruction of the Quaternary climate history, geomorphic and biotic transformations of ecosystems as well as human occupation. The key regions for the Quaternary studies are located in the southern part of East Siberia.

#### 3.4.1 Geography and natural setting

The south-eastern Siberia (Fig. 1A), encompassing the Pribaikal area (the upper Angara and Lena basins) and the SE Transbaikal area (the Selenga River basin), is a territory of contact of the major tectonic structures of the Siberian Platform and the adjacent mountain massifs. The southern part of the territory is formed by the Irkutsk Depression (800-1200 m asl.), geographically confined by the Eastern Sayan Mts. and the Baikal Range (2500-3000 m asl.). Lake Baikal (-1620 m max. depth) occupies a tectonic basin of 636 x 26-79 km or 31,500 km<sup>2</sup>. A system of palaeolakes existed in this area since the late Oligocene (25 Ma ago), although formation of the present lake (Fig. 6A) relates to a major orogenic activity initiated during the Pliocene/Pleistocene (the Baikal Tectonic Phase spanning for the last 3.5 Ma). The Baikal rift zone, 150 km wide in average, extends for about 2,500 km from Lake Khubsugul in Mongolia to the upper Aldan River in south-east Yakutia, and includes a series of tectonic depressions (Khubsugul, Tunkin, Baikal, Barzugin, and the upper Angara depression). Most of the relief is shaped by smooth mountain ranges (800-1300 m asl.) separated by river valleys and shallow basins. Taiga forests occupy the northern lowland areas, while open steppe grasslands (Pribaikalnye) and semi-deserts (Transbaikalnye) broadly extend in the southern regions. Present climate is strongly continental, reflecting the geomorphological configuration of East Siberia, forming an orographic atmospheric barrier strengthening the influence of the Siberian Anticyclone. Average temperatures -20°C (January) and +23°C (July), and low annual precipitation values (250 mm) characterize most of the territory. Maximum precipitation falls on the north-exposed slopes (700-800 mm), covered by coniferous (mostly pine) forests. More humid regional climate prevails along the margins of the Irkutsk and upper Lena basins due to a warming effect of the Lake Baikal (350-450 mm). Mixed southern taiga is largely represented by spruce, larch and birch. Most arid interior valleys (250-300 mm *per year*) include xenotheric steppe and mosaic parkland communities.

### 3.4.2 Palaeogeography and climate history of East Siberia

Both orogenesis and climate have shaped the present relief of East Siberia. The pre-Cenozoic geological formations are represented by relics of the Palaeogene palaeo-relief preserved on plateaus tectonically raised to 300-500 m asl above the basal igneous and metamorphic rocks and sedimentary, partly lithified deposits. The Oligocene and Miocene uplift of the marginal regions of the Irkutsk Basin (including the upper Lena area) initiated formation of the united morphostructural province of the broader Baikal region. Tectonic processes, significantly reactivated during the Cenozoic Period, generated massive colluvial deposits that filled the former riverine basins and shallow depressions originating by the Late Miocene pre-rifting (Rezanov, 1988). The orogenic movement around the Pliocene/Pleistocene boundary (2.5 Ma ago), opened the Baikal rift zone and caused a major uplift of the Pribaikal and West Transbaikalian regions. The raised topographic gradient led to intensive river erosion followed by the establishment of the present drainage of the major East Siberian rivers (Angara, Lena, Selenga). Formation of the surrounding mountain ranges precipitated the accumulation of fluvial deposits and a gradual filling of the Pliocene rift graben (Bazarov, 1986). In the Lake Baikal surrounding, the geomorphic dynamics is evidenced by 6-10 raised lake terraces related to the former lake water-stands and elevated up to 200 m above the present lake level. During the Early-Middle Pleistocene, the Lake Baikal discharge followed a passage through the Irkut River valley into the former Yenisei basin. The present regime was established during the Late Pleistocene as a result of a new tectonic movement opening an outlet into the present Angara River drainage system (Fig. 6B).

The neotectonic movements during the early Middle Pleistocene (after 750 ka BP) contributed to an accumulation of thick deltaic, fluvio-lacustrine and slope deposits filling the major river valleys and intermountain depressions, particularly in the Selenga River basin (Rezanov, 1988, 1995). A reactivation of the orogenic activity during the initial stage of the late Middle Pleistocene resulted in the Lake Baikal transgression. A system of 40-50 m-high river and lake terraces and adjacent alluvial fans formed during the Tobol (MIS 9) interglacial and continued in the following Samarovo (MIS 8) glacial period. During this maximum Middle Pleistocene glaciation, initiated by global climate cooling coupled by a regional uplift, mountain glaciers extended to 1000-1300 m elevation with terminal moraines along the foothills of the Baikal, Barguzin and Angarsk Ridges (Rezanov & Kalmikov, 1999). A renewed regional tectonic activity of the Baikal rift at the beginning of the Late Pleistocene (130 ka BP) triggered an accelerated erosion of the Selenga River, and the upper Angara and Lena River (Bazarov, 1986). Marked climatic shifts characterize the last glacial-interglacial cycle, with ice-cap formations in the East Siberian mountains during the cold stages (MIS 4 and 2). The Ermakovo (MIS 4) glacial stage, with a major glaciation in the Baikal Range and the East Sayans, is evidenced by moraine ridges and altiplanation terraces at >1000 m elevations (Nemchinov et al., 1999). Increased aridity and decrease of annual temperatures during the cold stadials together with strong NW winds stimulated formation of deflation and drifting sandy surfaces on top of the Early and Middle Pleistocene terraces, and aeolian dust deposition in main river valleys and depressions (Medvedev et al., 1990). Climate fluctuations of the early Last Glacial (MIS 4) caused intensive solifluction processes. The mid-last glacial (MIS 3) optimum (dated to ca. 31 ka BP) was thermally approaching the last interglacial (MIS 5e) climate conditions. A reduction of the glaciated areas is observed for the following Sartan (MIS 2) glacial stage. The present geomorphological configuration and a regional environmental zonation became gradually established during the Holocene.

### 3.4.2.1 Quaternary climate change and environments of the glacial mountain areas

Pleistocene glaciations in the East Siberian mountains, bordering the Angara and Lena basin from the south and east played a major role in the landscape development and related shifts in ecosystems of the extra-glacial depressions (Fig. 6E). The main glacial events documented in the Eastern Sayan Mountains occurred during the late Middle Pleistocene and Late Pleistocene, with the penultimate (Ermakovo, MIS 4) glaciation (74-50 ka) been the most extensive (Nemchinov et al., 1999). This evidence corroborates the glacial records from the northern part of the Baikal Depression and the Baikal Range as witnessed by relics of terminal moraines assigned to the Samarovo (MIS 8) glacial stage (Bazarov, 1986; Rezanov & Kalmikov, 1999). Warmer interglacial / interstadial periods correlate with a mountain ice retreat and expansion of thermophilous biotic communities over large geographical areas.

The Late Pleistocene climate variations caused a major landscape restructuring with a deep bedrock frost weathering, sediment deposition, solifluction and cryogenesis during cold stages, and pedogenic development during warm interstadials, particularly in the loess area of the Irkutsk Basin. Renewed tectonic activity contributed to intensive river incision, leading to formation of the present river valleys, but also of passages for the last glacial ice expansion. The initial Late Pleistocene interglacial (MIS 5) promoted spread of pine-birch forests including some warm arboreal broad-leaved taxa (*Tsuga*, *Tilia*, *Corylus*). A progressing climatic cooling at the beginning of the early Last Glacial (Zyriansk Glaciation, MIS 4) gave rise to major montane glaciers in the Baikal Range and the most intensive Pleistocene glaciation in the Sayan and Altai Mountains. Mountain valley glaciers, expanding from the north-eastern slopes of the Bolshoy Sayan Ridge, formed mighty piedmont glaciers penetrating up to 100 km north into the extra-glacial zone. Accumulation of massive colluvia (up to 20 m thick) was apparently triggered by the reactivated regional neotectonic movements towards the end of the early last glacial stage. A climatic warming during the following (Karginsk) mid-last glacial interval (MIS 3) is evidenced by pollen records from alluvial and lacustrine sedimentary formations. Apart of coniferous species (*Pinus silvestris*, *Pinus sibirica*, *Abies*, *Picea* and *Tsuga*), deciduous trees (*Quercus*, *Ulmus*, *Corylus* and *Alnus*) and shrubs (*Salix*, *Alnaster*) were present. The East Siberian mountain glaciers largely wasted or retreated into high topographic locations to form isolated ice-caps. The late Last Glacial (Sartan Glaciations, MIS 2) in the Eastern Sayan Mountains was largely confined to active corrie glaciers above the 2700 m elevation (Nemchinov et al., 1999). On the contrary, the Pribaikal Highlands likely experienced the most extensive Pleistocene glaciation during the LGM (22-19 ka BP), with piedmont glaciers advancing far down into the foothill valleys (Rezanov & Kalmikov, 1999). Only isolated ice-caps formed on the NE Siberian mountain ranges (Verkhoyanskyy, Cherskogo, Kolymskyy) despite very low temperature, but due to a very high aridity and a lack of winter precipitations. Cold Late Pleistocene climatic intervals are also documented by cryogenic surface deformations, with the most prominent (up to 5 m deep) at the contact of the Pleistocene/Holocene formations assigned to Younger Dryas (12.9-11.5 ka BP). Cold periglacial tundra with isolated shrub and dwarf trees occupied the adjacent northern foothills until the warm climatic oscillations sparked off a complete zonal vegetation rearrangement with the approaching end of the last glacial stage. Cold and strongly continental climatic conditions prevail in the East Siberian mountain region at the present time, with MAT of -4°C. A considerable part of the territory is covered by mountain tundra with larch (*Larix* sp.), Siberian pine (*Pinus sibirica*) and dwarf birch (*Betula nana*). Most of the area is underlain by active perennial permafrost.

### 3.4.2.2 Quaternary climate change and environments of the extra-glacial areas

Quaternary geology of the extra-glacial areas of the Baikal territory (the Irkutsk Depression, the Transbaikal and upper Lena River areas) shows a complex structure resulting from the interaction of past climatic changes and a topographic modeling by the neotectonic activity. This encouraged mass deposition of alluvial, aeolian, colluvial and other clastic materials. The iron-stained gravels and reddish strongly weathered lacustrine clays attest to warm climatic conditions during the late Pliocene in corroboration with the incorporated pollen of thermophilous taxa (*Quercus*, *Carya*, *Tsuga*) of mixed coniferous-broadleaved forests.

The Pliocene/Pleistocene transition around 2.5 Ma BP defines the first major cooling evidenced by prominent cryogenic features. The Early Pleistocene climate trend of progressing continentality caused a complete zonal palaeogeographic rearrangement (Medvedev et al., 1990). The Early and Middle Pleistocene climatic variations are witnessed by a wide range of palaeosols (kastanozems, chernozems, luvisols, brunisols, gleysols), indicating a mosaic vegetation and relief zonation. Stages of climatic deterioration correlate with weakly developed initial soils (regosols), solifluction horizons, cryogenic deformations and relic periglacial landforms. A seasonal strengthening of temperate and humid climate promoted a latitudinal zonal vegetation distribution. The Middle Pleistocene interglacial periods were warm and humid, allowing a northern expansion of a mixed pine-spruce-fir taiga with broad-leaved species (*Quercus*, *Fagus*, *Ulmus*, *Corylus*, *Pterocarya*, *Juglans* and *Tilia amurensis*) with up to a 50% increase in precipitation in the warmest Tobol Interglacial (MIS 9) (Rezanov & Kalmikov, 1999). The following climate deterioration during the late Middle Pleistocene is manifested by progressive fossil fauna forms of open periglacial parklands.

Diversity of soils developed during the Last Interglacial on alluvial and aeolian deposits (tundra gleysols, gleyed podzolic soils of northern taiga, podzols of central taiga, brown soils of southern taiga and chernozems of parkland-steppe). Polygons with up to 3-4 m deep frost wedges on top of the last interglacial (MIS 5e) chernozem indicate a dramatic cooling during the following stage (MIS 5d) with temperature minimum around ca. 115 ka BP, suggesting a major glaciation in eastern Siberia corroborated by the record from Lake Baikal and the loess-palaeosol sequences from other parts of southern Siberia (Karabanov et al., 1998; 2000; Prokopenko et al., 1999, Chlachula 2003, Chlachula et al., 2004b) (Fig. 2B).

Onset of the early Last Glacial stage (Ermakovo Glaciation) is associated with an intensive erosion of the exposed land surfaces leading to a massive transfer of sediments, particularly fine sands from the major denudation areas / deflation surfaces along the margin of the Irkutsk Depression. Solifluction of loessic deposits underwent during the following time intervals as a result of a moderate warming. The mid-last glacial Karginik interstadial stage (MIS 3, 59-24 ka BP) included an earlier (cold and arid) phase of loessic sediment deposition succeeded by a later (warm and humid) phase of progressive soil formation (the Osinsk Pedocomplex in the Angara - upper Lena region). The first phase of the late Last Glacial (MIS 2), radiocarbon dated to 24-17 ka BP, is linked with marked climatic oscillations evidenced by solifluction and cryoturbation of the preceding (MIS 3) soils, succeeded by loess sedimentation with the approaching Last Glacial Maximum (22 ka BP). Cold climates corroborate appearance of cold-adapted fauna characteristic of periglacial steppe (*Saiga tatarica*, *Alces alces*, *Equus hemionus*). A warming interval after the LGM (17-16 ka BP) is manifested by an intensified gleying and degradation of permafrost in the southern part of the territory due to a global climatic amelioration also reflected by the expansion of coniferous taiga forests, and by the Palaeolithic re-colonization of south-eastern Siberia.



### 3.4.3 Pleistocene environments and early human peopling

Present cultural evidence attest to several stages of human occupation of Eastern Siberia during the Pleistocene, with the oldest represented by the Early (?) and Middle Pleistocene records, implying very early hominid migrations into the mid- and high-latitudes of Asia. Systematic investigations at the occupation sites in the upper Angara, Lena, Aldan, Viluy and Selenga River basins, along the Baikal Range and Eastern Sayan foothills, contextually associated with diverse palaeo-geomorphic zones and geological (alluvial, colluvial, aeolian, karstic) settings, deliver detailed multi-proxy information on the Pleistocene climate change and associated palaeoenvironmental processes in the particular areas (e.g., Medvedev et al., 1990; Konstantinov, 1994; Mochanov, 1992; Mochanov & Fedoseeva, 2002; Chlachula, 2001c). Principal Quaternary research in the Pribaikal and Trensbaikal regions (the upper Angara, Lena and Selenga basins and their tributary valleys) reflects a limited transport accessibility of the north-eastern territories. Archaeological sites may be partly obliterated or poorly preserved around the Lake Baikal due to neotectonic activity triggering erosional processes. The cultural finds, chronologically defined by the stratigraphic geological position and diagnostic technological attributes of stone flaking, include: 1) the Early Palaeolithic from Early(?) / Middle Pleistocene alluvial deposits (>130 ka BP) (Fig. 6B); 2) the Middle Palaeolithic buried in the last interglacial (MIS 5) pedocomplex and the early last glacial (MIS 4) gleysol horizons; 3) the early Late Palaeolithic (42-30 ka BP) from the mid-last glacial (MIS 3) soils; 4) the "classical" Late Palaeolithic from the late mid- and early last glacial (MIS 2) gleyed soil horizons (30-17 ka BP); 5) the final Palaeolithic (17-12 ka); and f) Mesolithic (12-8 ka BP) from diverse geo-contexts (Medvedev et al., 1990; Chlachula et al., 2004b).

The earliest Pleistocene sites with definite cultural occurrences are associated with old alluvial formations in the Lena and Angara River basins. Presently one of the oldest sites in East Siberia was found at the Diring Uriah within coarse sandy deposits of a 200 m-high terrace of the Lena River near Yakutsk. Despite its unclear chronological assignment ranging from 2.5 Ma to 400 ka and the postulated model of the extra-tropical origin of humans in NE Siberia (Mochanov, 1992) this site eloquently demonstrates a very early Pleistocene peopling of northern parts of Asia in the principal river valleys much earlier than previously believed probably during some of the Early or Middle Pleistocene interglacials (Waters et al., 1995). Temperate and drier conditions of the late Middle Pleistocene interglacial interval (MIS 7) promoted expansion of mixed taiga (*Pinus*, *Picea*, *Alnus*, *Salix*, *Betula*) and open parklands. A Middle Palaeolithic occupation is documented at the Mungkharyma site (64°N) located on the 70 m alluvial terrace of the middle Viluy River with a diagnostic stone industry, including elaborated bifaces, bifacial knives and side-scrapers, found in association with Pleistocene fauna (mammoth, woolly rhinoceros). Luminescence dates 150±38 ka BP (RTL-958) in the overlying sandy-silt layer and 600±150 ka BP (RTL-957) in the basal part suggest a (late) Middle Pleistocene age of this unique locality (Mochanov & Fedoseeva, 2001) (Fig. 6C-D). These as well as other pre-last glacial (>74 ka BP) sites from the central and southern Lena basin and its major tributaries (Viluy, Aldan) also have the principal implications in respect to the initial prehistoric colonization of the American continent (Chlachula, 2003b).

The archaeological records from the upper Lena and Angara River areas dated to the Middle Pleistocene, represented by analogous stone artifacts made on quartz / quartzite cobbles with the typical archaic tool forms (choppers, bifaces, scrapers on flakes, polyhedral cores), display strongly abraded surfaces as a result of aeolian weathering. The age of these earliest cultural assemblages from the Angara region exposed along the Bratsk Lake (Igetei locality),

referred to as of the Acheulian-Mousterian tradition, is estimated to ca. 200 ka BP, corresponding to the Shirta Interglacial /MIS 7 (244-170 ka BP) (Medvedev et al., 1990). Climatic cooling, leading to expansion of mosaic steppe and pine-larch parklands, is linked with the onset of the Samarovo (270-244 ka BP) glacial period. A drop of annual temperature and increase in aridity during the Tazov Glacial (170-130 ka BP) hastened a degradation of interglacial forests and extension of open periglacial tundra landscapes in the broader Baikal region (Nemchinov et al., 1999). Human survival in south-east Siberia during the Samarovo (MIS 8) and Tazov (MIS 6) glacial stages presumes knowledge of fire-making. The marked final Middle Pleistocene environmental deterioration is indicated by records of cold-adapted fossil fauna from river terrace formations, including more progressive taxa typical of open periglacial landscapes, such as mammoth, woolly rhinoceros, bison, horse, kulan, giant deer, argali, and some species specific to the Trans-Baikal area - Kiakhta antelope (*Spirocerus kiakthensis*), the Baikal yak (*Poephagus baikalensis*), dzeren/gazelle (*Procapra gutturosa*), camel (*Camelus* sp.) (Kalmikov, 1990), in congruence with the preserved glacial landscape relics in the Northern Baikal Range and the Eastern Sayan Mountains (Rezanov & Nemchinov, 1999). During the Last Interglacial (MIS 5), mixed taiga forests with Siberian pine (*Pinus sibirica*), spruce, larch, birch, willow and hemlock were widely distributed in the mountain areas, indicating a temperate continental climate similar to the present one (Nemchinov et al., 1999). Brown fossil chernozems at the Mal'ta and Igetei Middle Palaeolithic sites (dated to MIS 5e and 5c, respectively) illustrate open parkland-steppe settings of the Angara basin. Marked cooling, increased aridity accompanied by a strong aeolian activity contributed to accumulations of extensive sandy deposits derived from drying up river beds in the Irkutsk Depression and Lena Basin during the early last glacial (MIS 4), also witnessed by an intense abrasion of the contextually associated stone industries. In the western Baikal region, this stimulated drifting sandy surfaces and accumulation of fine, aeolian dust on lee slopes in the form of a loess-like series at the eastern margin of the Eurasian loess belt. Cold intervals with increased atmospheric humidity correlate with cryoturbation processes, solifluction horizons and pollen records of invading periglacial grasslands and open pine-birch tundra. A local Middle Palaeolithic (Mousterian?) occupation may have survived under such harsh environmental conditions in the upper Angara at the Igetei Site III (Medvedev et al., 1990). The mid-last glacial interstadial interval (MIS 3), with an early cold and arid loess sedimentation phase (59-40 ka BP) followed by a warm and humid pedogenic phase (40-24 ka BP) brought a major change in the distribution of vegetation zones in East Siberia, with a northern expansion of mixed taiga forests and pine-birch dominated parklands. Broad-leaved arboreal taxa (oak, beech, elm, hazel) distributed in more humid river valleys of the Baikal region testify to mosaic habitats with climate conditions possibly warmer than today (Rezanov & Kalmikov, 1999). The pedogenic record in the Transbaikal region (the lower hor. Kamenka site) indicates very high MAT of +8/10°C, thus considerably exceeding the present day temperature values (Dergachova et al., 1995). This warming correlates with a transgression of Lake Baikal, triggering deposition of thick deltaic and estuarine sediments. Cultural finds from the principal occupation sites (Ust'-Kova in the Angara basin, Mezin in the Kana valley, Kamenka in the Selenga basin, the Aldan River complex) dated to 30-24 ka BP display a poor preservation due to cryogenesis and solifluction processes persisting until the onset of late Last Glacial (Sartan) stage (MIS 2). Remains of exploited Pleistocene fauna (horse, antelope, woolly rhinoceros, mammoth, bison, sheep-argali and camel) similarly as rodent taxa are indicative of an open steppe and parkland habitat. At the Kamenka site in

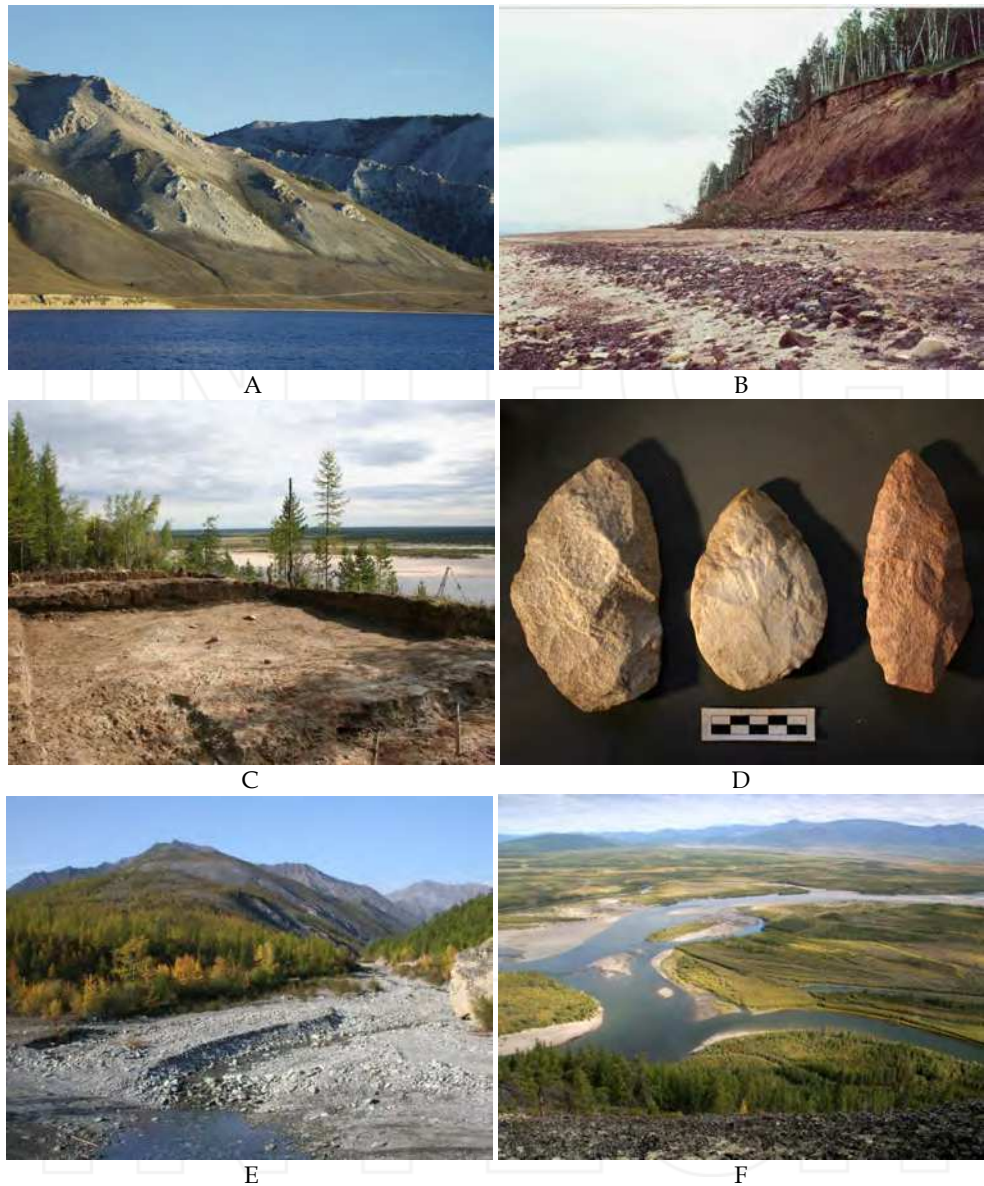


Fig. 6. East-Central Siberia. A: the central west coast of Lake Baikal with marked orogenic structures; B: Upper Angara Basin (Igetei Site), eroded fossiliferous Late Quaternary loess-palaeosol sections overlying a Middle Pleistocene alluvium incorporating cultural remains; C: the Mungkharyma Site (64°N) on the 70 m Viluy River terrace, east-central Yakutia; D: Middle Palaeolithic quartzite tools (Mungkharyma II Site; courtesy Yu. A. Mochanov); E: coarse gravelly alluvial fans in the formerly glaciated Verkhoyansky Range, NE Yakutia; F: the meandering Yana River valley was one of corridors for peopling of the Arctic Siberia.

southern Buryatia, the most represented animal species, Mongolian gazelle (*Procapra gutturosa*), lives today in dry grassland steppes and semi-deserts in eastern Altai, Mongolia and Inner Mongolia in gently rolling landscapes with a reduced snowfall. Several specific site functional complexes related to game processing, woodworking, stone and bone tool production and manufacturing of mineral paints, and other behavioral cultural (ritual) activities were documented (Lbova 1996). The taxonomic fossil fauna variety from different (mountain) ecotones shows a wide (>100km) mobility range of the local Palaeolithic hunters. Expansion of the Late Palaeolithic occupation ambit into the extreme parts of the East Siberian Arctic is documented at the Yana RHS site located 100 km south of the Laptev Sea coast (70°43'N, 123°25'E) (Pitulko et al., 2004). The cultural evidence (stone and bone industry and fossil fauna), sealed in frozen and cryogenically distorted silt blocs on a 18 m Yana River terrace radiocarbon dated to ca. 28-26 ka BP, illustrates warm interstadial (MIS 3) climates and a relative environmental stability of floodplain meadows of the Yana River delta (Fig. 6F). This exceptional site provides eloquent evidence of humans migrating along the ice-free northern coast of Siberia (the exposed continental Arctic shelf) across the exposed Bering land-bridge during the mid-last glacial interstadial (50-24 ka BP), opposing the model of "initial" peopling of Alaska by the East Siberian Diyuktai Culture at 12 ka BP. The late Last Glacial stage (MIS 2) - the Sartan Glaciation (24-12 ka BP) - is the best-studied Pleistocene time interval in eastern Siberia in view to contextual cultural records. Tundra-steppe covered most of the territory occupied by the Late / Final Palaeolithic people with the famous sites Mal'ta and Buret' in the upper Angara basin (Tseitlin, 1979). Climate deterioration with sparse Arctic vegetation and progressive loess accumulation around the LGM (18 ka BP) caused a major decline in the population density in East Siberia, although some adaptation to extreme periglacial environments was suggested at the Krasnyy Yar Site, with animal bones and fossil coal used as fuel (Medvedev et al., 1990). A periglacial fauna (horse, woolly rhinoceros, mammoth, bison, giant deer, elk, saiga) implies cold periglacial tundra steppe across vast areas across the Angara, upper Lena and the Trans-Baikal basins. Climate amelioration after the LGM (18 ka BP) is best-evidenced by micro-mammal (rodent) faunas from the Baikal-Angara-Lena Palaeolithic sites (Buret', Krasnyy Yar, Igetei, Mal'ta, Bolshoi Jakor) that indicate a gradual transition from tundra-steppe and meadow-steppe to forest-steppe landscapes corresponding to shifts from a cool and dry climate to milder and humid conditions (Medvedev et al., 1990, Khenzykhenova, 1999). This warming trend fostered dispersal of the Final Palaeolithic complexes with micro-blade stone and bone technologies during the late Last Glacial (18-12 ka BP). Re-colonization of broad areas of East Siberia regions reached the marginal sub-polar regions of the NE Russian Arctic (e.g. Berelekh site in northern Yakutia at 70°N, dated to 14-13 ka BP) (Vereshagin, 1977; Vasil'ev, 2001). The broad geographical distribution of new technologies to the most distant parts of NE Siberia and the Russian Far East Islands (Vasilevskyy, 2008) documents a successful prehistoric adaptation to the Final Pleistocene environments. This process culminated in a spatial spreading and presumably a major population increase by the end of the Pleistocene, represented by the early Mesolithic (11,000-10,000 yr BP) hunters and gatherers. In sum, palaeoenvironmental (geological and biotic) proxy records document well the evolutionary development of Quaternary climate change in East Siberia as reflected in the gradual cultural adaptation of people and the geographic expansion of occupied areas. A great diversity of the early Quaternary biotic communities became reduced as a result of climatic cooling, leading to a relative taxonomic faunal uniformity in the Late Pleistocene.

#### 4. Conclusion

Geological and palaeoecological evidence across western, south-central and eastern Siberia, including the Ob, Irtysh, Kuznetsk, Yenisei, Angara and upper Lena basins and the adjacent mountain regions of the Trans-Urals, Altai, Western and Eastern Sayans Mountains, Baikal Range and the NE Siberian mountains, shows patterned cyclic climatic changes during the Quaternary leading to establishment of the present natural conditions. A progressing global trend towards a strongly continental climate, with increased aridity and high seasonal temperature fluctuations, can be traced since the late Pliocene. At that time, northern and north-eastern Siberia experienced the first major regional glaciations (Laukhin et al., 1999) in response to changes in solar radiation and atmospheric circulation over high latitudes of the northern Hemisphere. The subsequent development during the Quaternary Period (last 2.5 Ma) is evidenced by zonal geographic shifts in the vegetation distribution, with expansion of boreal (taiga) forests northward during the interglacial periods and warmer interstadials, succeeded by sub-arctic periglacial forest-steppe, and tundra-steppe during cold glacial intervals, when the tree cover became much reduced and spatially limited to biotic refugia in the southernmost portions of central Siberia (the Altai and Sayan Mountain foothills). Complex palaeoenvironmental evolution archives are stored in the high-resolution loess-palaeosol sequences, pollen records and fossil fauna remains from deeply stratified alluvial and loessic formations. The loess-palaeosol sections on the Northern Altai Plains and in the upper Yenisei basin have provided most complete information on the past climatic variations, the landscape development and the associated changes in the Pleistocene biotic communities on the territory of southern Siberia. The high-resolution stratigraphic records coupled with pollen and palaeontology data indicate marked Pleistocene ecosystem transformations, with arctic tundra and forest-tundra during cold stadial intervals, being replaced by boreal forest and later by parkland - steppe during warm interstadial intervals. The Early and Middle Pleistocene climates brought a major modification of natural habitats, facilitating the northward dispersal of Palaeolithic people from the southern areas of Central Asia and Mongolia, and their environmental adaptation to the Siberian habitats and regional settings. The earliest unequivocally documented Middle Pleistocene (Early Palaeolithic) occupation centered in the southern continental basins and river valleys north of the Altai-Sayan Mountains. The human dispersal into East Siberia is assumed to have principally occurred during warm interglacials in the processes of the northern expansion of mixed parkland forests and associated fauna communities, whereas only local movements of early human groups are envisaged during cold stages. The Tobol (MIS 9) Interglacial (390-270 ka BP), when the MAT was by ca. 3-4°C higher than at present, is likely to have been (one of) the most favorable time period for the main initial migration to northern Asia through the major Siberian river valleys, reaching as far north as 60°N latitude. The Early and Middle Palaeolithic finds bear witness of repeated inhabitation of the Irtysh, Ob, upper Yenisei, Angara, Viluy, Aldan and the upper Lena River basins prior to the Last Interglacial. During the Middle Pleistocene glacial periods, glaciers in the Western and Eastern Sayan ranges expanded into the foothills to about 300-400 m altitude preceded by a down-slope retreat of dark coniferous taiga forests. In the Northern and Southern Minusinsk Depression, in the Kuznetsk Basin and some extraglacial locations in the northern Altai valleys protected by mountains from the west and east, and separated by high ranges from the frigid arctic tundra in the north, propitious (although periglacial) conditions with great biomass concentrations of steppe-parklands are likely to have persisted during the glacial

stages. This is evidenced by the abundant fossil remains from the old (60-80 m) Yenisei and Angara alluvia, as well as the colluvial reworking of the older (late Middle Pleistocene) loess cover, indicative of a relatively humid, moderately cold and fluctuating climate regime. Within the Last Interglacial (MIS 5; 130-74 ka BP), most of Siberia was covered by coniferous or mixed forests, with forest-steppe distributed at lower elevations and in river valleys. At that time, the Middle Palaeolithic (Neanderthal or early *Homo sapiens*) people entered the territory from Central Asia and/or the East European Plains. Expansion of the occupation habitat into the mountain areas, following the last interglacial climatic optimum, likely occurred in the later (MIS 5c and 5a) interstadials. During the early Last Glacial (Zyriansk) stage (MIS 4; 74-59 ka BP), cold periglacial tundra or tundra-steppe expanded across Siberia. The approaching glacial maximum disrupted human occupation, although this may have persisted in some protected southern locations. Following the interval of intensive loess deposition at the end of the glacial, renewed warm climate pulses during the mid-glacial (Karginsk) interval (MIS 3; 59-24 ka) preconditioned formation of zonal soils contextually associated with the transitional Middle/early Late Palaeolithic stone industries, suggesting a certain regional cultural (and possibly biological) evolutionary continuity in the Late Pleistocene Siberia. Moderately cold and stable environments during the second half of the interstadial interval (30-24 ka BP) promoted a major enlargement of habitats marking a climax of the Palaeolithic peopling in Siberia associated with the emergence of the "classical" Late Palaeolithic cultures. Productive interstadial ecosystems with mixed parkland-forest vegetation were gradually transformed into periglacial tundra with the approaching last (Sartan) glacial stage (MIS 2; 24-12 ka BP). A reduced population density is assumed around the LGM (22-19 ka BP) hindered by extremely harsh climate conditions. Some occupation continuity persisting until the end of the Pleistocene may have applied just for biotic refugia in the protected southernmost locations along the Altai-Sayan foothills. Overall, the spatial and temporal distribution of the cultural records documents climatic instability over large parts of Siberia during the Quaternary Period (the last 2.5 Ma). Specific geographical and contextual locations of early sites indicate that environmental conditions during the earlier periods were generally more stable and favorable for peopling than during the later periods. On the other hand, increased continentality and gradual shifts towards cold and arid conditions accelerated adaptation of Palaeolithic populations to harsh periglacial climates promoting progressive development of sophisticated survival strategies. Timing and evolutionary processes related to the initial colonization of northern Asia are still insufficiently mapped, although ongoing archaeological investigations supply new and often surprising evidence about particularities and general trajectories of this evolutionary process. The traditional views, assuming only a Late Pleistocene inhabitation of Siberia and Beringia, have been definitely challenged. The archaeological discoveries disprove the long-held assumption of a late penetration (by Late Palaeolithic people) into the middle and high latitudes of northern Asia. Instead, glacial-interglacial and stadial-interstadial climate cycles regulated a geographic movement of early people northwards, predetermining the inhabitability of particular geographical areas. During glacial maxima, most of Siberia seems to have been vacated, especially during the earlier periods, because of the expansion of continental glaciers in the north, and harsh and inhospitable environments in the southern extra-glacial regions. Gradual adaptation to cold natural habitats accelerated during the Late Pleistocene in connection with the advanced cultural and biological adjustment, enabling people to establish permanently in the vast and geographically diverse Siberian territory.

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We are increasingly faced with environmental problems and required to make important decisions. In many cases an understanding of one or more geologic processes is essential to finding the appropriate solution. Earth and Environmental Sciences are by their very nature a dynamic field in which new issues continue to arise and old ones often evolve. The principal aim of this book is to present the reader with a broad overview of Earth and Environmental Sciences. Hopefully, this recent research will provide the reader with a useful foundation for discussing and evaluating specific environmental issues, as well as for developing ideas for problem solving. The book has been divided into nine sections; Geology, Geochemistry, Seismology, Hydrology, Hydrogeology, Mineralogy, Soil, Remote Sensing and Environmental Sciences.

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