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West Siberian Plain as a late glacial desert

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A R T I C L E I N F O

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A B S T R A C T

The paper presents results of morphoscopic studies of quartz grains recovered from sands underlying surficial peat over the West Siberian Plain. The field materials were collected in the course of the Russian–American expedition in 1999–2001. The data obtained proved the existence of a vast area in West Siberia similar to cold deserts in appearance at the late glacial time (and probably even as early as the Last Glacial Maximum – 18–20 ka BP). The desert was confined to the arctic and temperate belts, the southernmost part of the plain being an area of loess accumulation.

1. Introduction

At the present stage of the geosphere evolution, West Siberia is the largest area of wetlands (including bogs, marshes and peatlands in the Northern Hemisphere, just as Amazonia is in the Southern Hemisphere). Dynamics of the wetland ecosystems exerts an essential influence over the global carbon budget and proportion of greenhouse gases (carbon dioxide and methane) in the atmosphere (Budyko, 1984; Kobak, 1988; Izrael, 2004; Smith et al., 2004).

On the map of Northern Eurasia, vast wetlands seem to be quite naturally dominant over West Siberia which is mostly low-lying plain belonging to the drainage basins of the Ob and Yenisey – the largest rivers in Northern Hemisphere. It has not been always, however, that West Siberia looked like as it does at present. The data obtained in the recent decades and supported by numerous radiocarbon dates confirm the previous conclusion that West Siberia was actively waterlogged only since the Early Holocene (Karavaeva, 1982; Bleuten and Lapshina, 2001; Vasiliev, 2001; Kremenetski et al., 2003; Smith et al., 2004). Results of joint Russian–American field works and laboratory studies in 1999–2001 showed, in particular, that environments of the pre-Holocene – Sartanian – glacial time were not favorable for wetland formation. Numerous boreholes drilled within the limits of wetland systems revealed mostly sandy sediments directly underlying the peat. Such a sequence was observed everywhere, no matter which landforms and topographic elements were drilled or studied in exposures. The field route survey, in full agreement with literature data, has shown presence (or even dominance) of sandy varieties to be the most typical feature of surficial deposits in West Siberia, at least in its northern and central regions; sands are found not only in fluvial (terrace) sequences, but also on higher levels including the main divide, the ridge of Siberian Uvals. As the sands occur at the base of peats, it was of particular interest to study more fully their genetic properties, to reconstruct environments at the time immediately preceding the onset of waterlogging processes.

Analysis of sand grain morphoscopy (surface texture and roundness) was used. The results thus obtained provided support for the notion of the late glacial environments in West Siberia being drastically different from (almost diametrically opposite to) those of today.

2. Study area

Bog and peatland systems were studied mostly north of 60°N (Fig. 1) within the limits of the taiga zone (north and middle taiga subzones). At the latitude of the Arctic Circle the latter passes through the forest-tundra ecotone into tundra zone. Temperatures of January vary between −21 °C in the south of the considered area and −28 °C in the north, those of July – between +18 and +4 °C respectively; annual precipitation is 600–400 mm (Myachkova, 1983).

2.1. Topography

Though West Siberia as a whole is termed a “plain”, its surface, tilted in general towards the Arctic Ocean, displays essential spatial differentiation (Nikolayev, 1970a). There are slightly elevated areas at its periphery adjoining the Urals in the west, the Central Siberian Plateau (with Near-Yenisei Upland) in the east and the Sayan-Altai piedmonts in the south.

The interior regions are not uniform, either. The hilly ridge of the Siberian Uvals extending approximately along 62°N divides the

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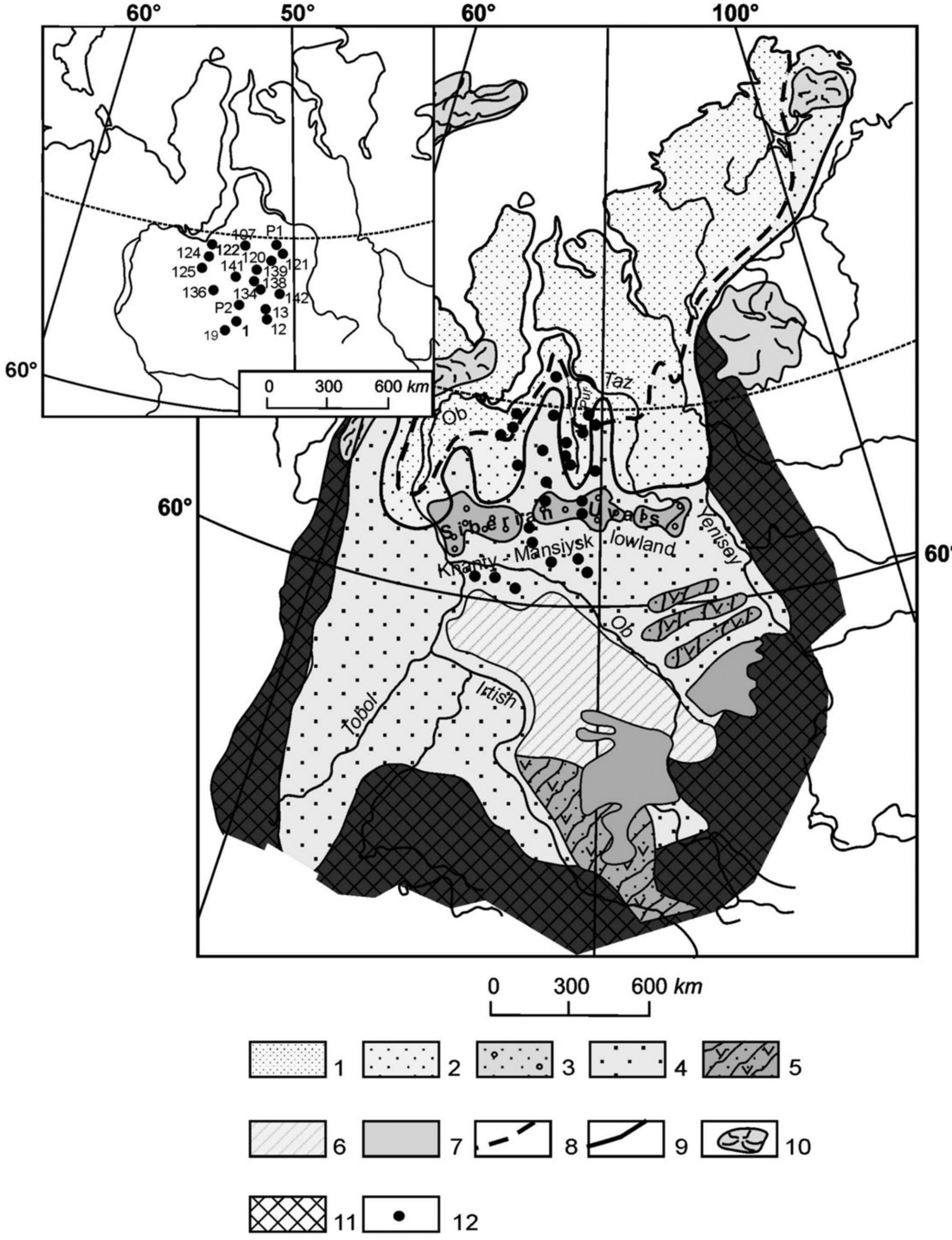

Fig. 1. Late Pleistocene aeolian processes in the West Siberian Plain. (Insert map shows location of the studied cores). 1 – sands deposited by Kazantsevo transgression and reworked by wind; 2 – sands deposited by Tobolsk transgression; 3 – aeolian sands and sandy clays in the Siberian Uvals zone; 4 – sandy and silty sediments of lacustrine-alluvial plains and depressions reworked by wind in the upper part of the sequence; 5 – flat and undulating plains with low elongated hills ("grivas") modeled by aeolian processes; 6 – areas of discontinuous loess cover and isolated patches of loess; 7 – continuous loess cover; 8 – limit of Kazantsevo transgression; 9 – limit of Tobolsk transgression; 10 –area of Sartanian glaciation; 11 – mountains and plateaus; 12 – sites of sampling.

plain into northern and southern parts. The ridge itself varies in elevation from 120 to 150 m a.s.l. in its western and eastern parts to 80–90 m at the center. A genetic differentiation of the Siberian Uvals was emphasized by S.A. Arkhipov (1970).

Directly south of the Siberian Uvals is the lowermost portion of the plain – heavily waterlogged latitudinally oriented depression (including Khanty-Mansiysk and Surgut lowlands) elevated no more than 50–60 m a.s.l. in its central part. Another low area, the Konda lowland, joins it on the west. The entire sublatitudinal low area south of the Siberian Uvals may be considered the main topographic depression of the West Siberian Plain. On the south it is bordered by Tobolski Materik upland and Vasyugan plain, both elevated up to 100–150 m a.s.l.

2.2. Geological setting

Both modern topographic features and lithology of sediments (including those underlying the peatlands) were predetermined by geological evolution of the region. Consequently, it seems useful to enlarge on the main points of its history during Meso- and Cenozoic.

As early as Late Paleozoic (about 300 Ma) as a result of the Hercynian orogenesis the area of West Siberia presented a mountain terrain. The continental regime existed until the mid-Jurassic, planation processes and development of lacustrine-fluvial systems taking place during that time (Vdovin, 1970). Since mid-Cretaceous to the middle of the Cenozoic, the plate experienced intensive subsidence, and marine environments prevailed all over the region. A vast Turtass lake-sea existed in the region up to the end of Oligocene, and outflowed to the south through the Turgai Strait. The deep Khanty-Mansiysk depression was formed in the middle part of the plate where the subsidence amplitude reached its maximum. A series of sands up to 79 m thick accumulated (Nikolayev, 1970b). The Neogene (beginning about 24 Ma) was marked by dominance of lacustrine and fluvial sedimentation. At the same time, according to Nikolayev, erosion activities began at the Siberian Uvals as early as Neogene. In all probability, erosion processes were activated by development of the main latitudinal system of arched Ob-Yenisei uplifts dated back to early Oligocene.

In Early Pleistocene (about 1 Ma BP) the Siberian Uvals were already well pronounced in topography as a low range of hills. In the north it bordered on elevated denudational plain, and on the south on lacustrine and alluvial lowlands; the latter showed a tendency for tectonic subsidence (Arkhipov, 1970), probably of compensatory nature related to arched uplifts in the Siberian Uvals zone.

Since Middle Pleistocene (about 0.4 Ma BP), the northern portion of West Siberia experienced mostly tectonic subsidence and was repeatedly flooded by marine transgressions. Opinions differ as to the number of transgressions. Lazukov (1970) recognized only the Yamal transgression spanning the period from Tobolsk (Likhvinian, Holsteinian in European stratigraphy) Interglacial to the second part of Samarovo (Dnieper, Saalian) glacial epoch ($\sim$0.25 Ma BP). Arkhipov et al. (1999) distinguished two transgressions within this interval, the Tobolsk and Shirtinsk. The beginning of Late Pleistocene (dated at about 0.135–0.140 Ma BP) was marked by the Kazanstevo transgression (synchronous to Mikulino and Eemian in Europe) (Lazukov, 1970; Troitsky, 1979; Arkhipov et al., 1999).

Numerous questions of glaciations in West Siberia and their correlation with glaciolacustrine events and marine transgressions are still the object of discussions. In the opinion of Arkhipov et al. (1999), an ice-dammed basin developed as far back as early Pleistocene glacial epochs (Shaitanka glaciation, for example). That implies the ice sheets descending from the Urals and central Siberia, and probably those coming from the northern shelf, joined and formed a continuous glacial front which prevented free river discharge to the north. Similar ice-dammed lakes were reconstructed by Arkhipov for the middle Pleistocene (Samarovo and Taz) glaciations when the ice sheets presumably expanded over the Siberian Uvals. When reconstructing Late Pleistocene ice sheets, Arkhipov emphasized an importance of the ice sheet originated from the Kara shelf. However, even this author noticed the rather fragmentary distribution of glacial deposits on the Siberian Uvals and north of them; he attributed such discontinuity to erosion processes.

The authors of the present paper have observed mid-Pleistocene till on the eastern and western margins of the West Siberian Plain. On the central part of the plain, field survey has not revealed glacial till either on the Siberian Uvals, or north of them. The data available on the central part of the Siberian Uvals suggest ice-rafted or brought by icebergs material in the deposits (termed glaciomarine by Lazukov, 1970), which could be left by the maximum mid-Pleistocene transgression when the sea penetrated into the lower parts of the Siberian Uvals.

The Late Pleistocene sequences of central West Siberia consist mostly of marine deposits, primarily sands, associated with fluvial-lacustrine sands and sandy loams. They contain gravel and pebbles brought either by fluvioglacial streams, or by icebergs. It has been proved beyond any doubt that no ice sheet existed there at the Sartanian time (Velichko et al., 1997; Svendsen et al., 2004). There is no evidence of extensive ice cover in the north of the plain at the Zyryanian time. In the spatial reconstruction by Mizerov (1970), ice sheets of that time are shown to expand only onto the peripheral parts of the plain adjoining the Urals and Central Siberia. The remainder of the West Siberian North is shown to be an area of thin local ice sheets of intermittent occurrence, no evidence of a continuous ice sheet having been known.

It follows from the above that the peatlands studied in the course of joint Russian–American works belong to three distinct geomorphic regions different in geological setting and history:

1) Northern group of peatlands initiated on flatlands slightly tilted towards the ocean; the area was repeatedly flooded by marine transgressions during the Middle and Late Pleistocene and influenced to a certain extent by glaciers coming onto the lowland from the east and west.
2) Peatlands located within the limits of hilly ridge of the Siberian Uvals – geomorphologically distinct belt extending from east to west across the middle part of the plain.
3) Southern group of peatlands concentrated within the main Khanty-Mansiysk depression south of the Siberian Uvals. The depression was an area of lacustrine and fluvial deposition since the end of Paleogene or beginning of the second half of Oligocene.

Typical for the Cenozoic, and particularly for the Quaternary, in all three regions was the dominance of sand fractions in the sediments.

As follows from the results of peatland drilling in all the three regions, no evidence of sedimentation gap or unconformity has been recorded between peat and underlying sands or sandy loam (Fig. 2). Towards its base the peat gradually passes into a layer consisting of fine organic and mineral particles with abundance of plant remains; proportion of organic material gradually decreases downward while that of sand grains increases. Further down there is a gradual transition to a layer of basically sandy composition.

The established lithological sequence and a gradual transition from peat to underlying layers suggest the peat accumulated (after a short initial phase of lacustrine inundation) over vast areas composed mostly of sandy material. The earlier phases of peat formation were radiocarbon dated to the interval of 10–11 ka BP (uncalibrated), or 12–11.5 ka BP (calibrated) (Kremenetski et al., 2003).

3. Methods

Sandy layers underlying the peat in boreholes were sampled for analysis of the sand grain morphoscopy. In laboratory the samples were washed and sieved into two groups (fractions): grain size of 1–2 mm and 0.5–1 mm. Previous investigations, including experimental ones, have shown this grain size to be most informative for the purposes of diagnostics. Fifty quartz sand grains were randomly chosen from each fraction and analyzed using a binocular microscope with magnification range of $\times 16$ to $\times 50$. The roundness of quartz grains was estimated using the five-grade scale of Khabakov (1946) and patterns of Rukhin (1969). A roundness coefficient (Q) was then calculated following the Russel and Taylor (1937) equation:

$$Q = \frac{0n_0 + 1n_1 + 2n_2 + 3n_3 + 4n_4}{n_0 + n_1 + n_2 + n_3 + n_4} \times 25\%,$$

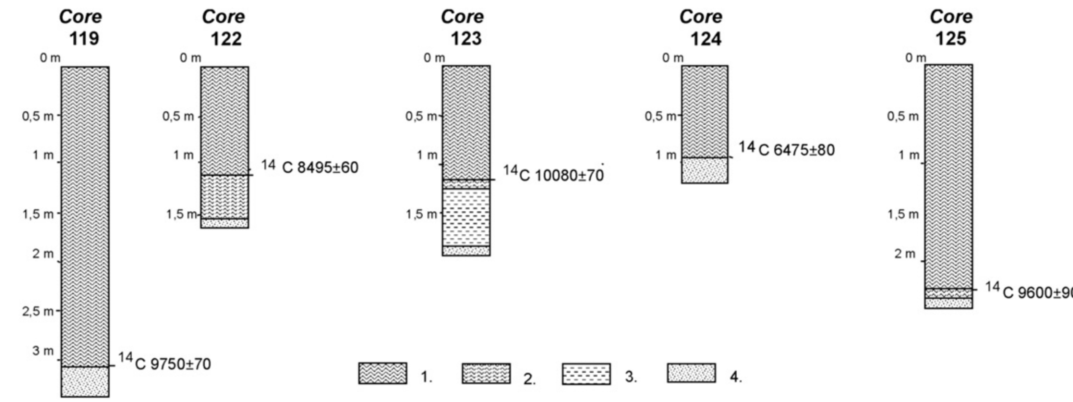

Fig. 2. Ages of the peat accumulation onset inferred from dated cores of peatlands. 1 – peat; 2 – gyttja with sand; 3 – clay; 4 – sand.

where n_0, n_1, n_2, n_3, n_4 are grain number of 0 to 4th classes of roundness.

The grain surface type – degree of the surface dullness – (glossy to matted) was estimated using the modified method of T.A. Salova (Kuzmina et al., 1969). Quantitative characteristics were calculated as follows:

$$C_m = \frac{0G + 0,25QM + 0,5HM + 1M}{G + QM + HM + M} \times 100\%,$$

where G is number of glossy grains, QM, HM and M – those of grains with quarter-mat, half-mat and mat surface respectively.

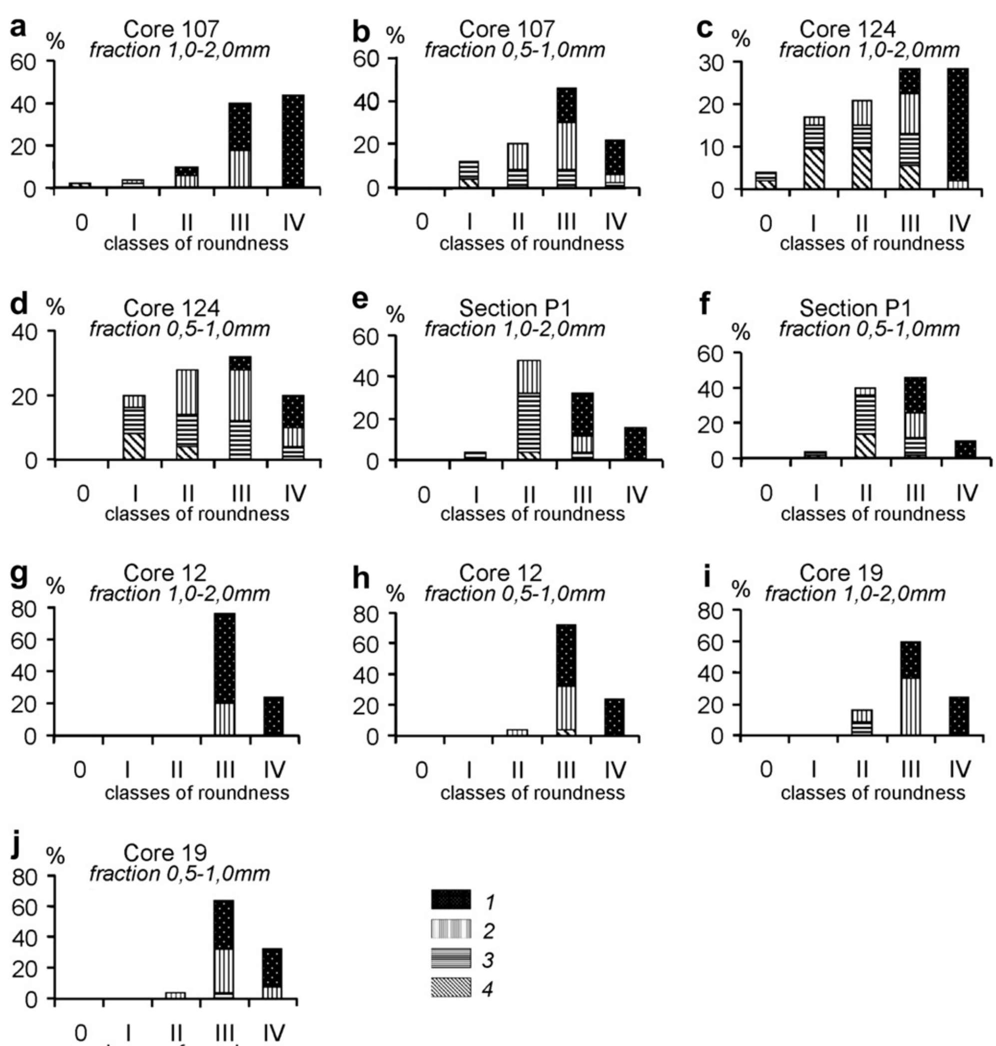

Fig. 3. Average distribution of sand grains from cores over roundness classes. Types of surface texture: 1 – matted, 2 – half-matted, 3 – quarter-matted, 4 – glossy.

Special attention was paid to the texture of the grain surface. It has been described using a genetic classification developed when studying grains from different environments subaerial and subaqual (Cailleux, 1942; Chichagov, 1959; Doornkamp and Krinsley, 1973; Velichko and Timireva, 2002). Both surface texture and roundness of every studied grain were recorded in a special matrix.

4. Regional differentiation in characteristics of the quartz sand grain surface texture

4.1. Northern marine flatlands

Twelve cores were obtained by drilling boreholes on the interfluves of the Pur and Nadym rivers. Samples for analysis of morphoscopy were taken from sediments underlying the peat and bog series. The sampled flatlands can be subdivided into two groups by elevation. The first group includes wetland systems on interfluves less than 80 m a.s.l. (cores 107, 120, 121, 136, 138, 139, 141, 142). This level corresponds to the level of Kazantsevo transgression which penetrated into the Pur and Nadym drainage basins. Typically, this group of samples displays well enough rounded sand grains (III and IV classes are prevalent), while less rounded ones (mostly II class) are infrequent (Fig. 3a and b). Sand grains 0.5–1.0 mm in diameter have roundness coefficients ranging from 69.5% to 92%. Fraction 1.0–2.0 mm shows slightly lower values, from 56.8% to 80% (Fig. 4-Ia). The degree of surface matting is rather high, from 51% to 72.5%. Grains are mostly matted and half-matted, proportion of glossy grains does not exceed 10%. Grains with spherical and ellipsoidal shape dominate (Fig. 5a). Most of quartz grains bear traces of strong aeolian activity on their surface, such as micro-pits resulting from sand grain collisions in the air (Doornkamp and Krinsley, 1973). Such micro-pits are found both on convex and concave areas on the sand grain surface. Besides the micro-pits marking points of grain collisions, there are traces of grain traction in the form of linear furrows. Some grains display older elements, probably preserved from earlier epochs and different environments. For example, crescent-shaped furrows were likely left by marine abrasion processes (Krinsley and Doornkamp, 1973).

Some sand grains have young textural features on their surface, such as conchoidal fractures or depressions of various shapes. They could have resulted from frost-induced desquamation subsequent to the major stage of aeolian processes.

On the whole, all the grains from this group seem to indicate subaerial formation, actively reworked by aeolian processes at the final stage. No grains of obvious glacial or glaciofluvial origins were found.

The second group of samples taken from sites (cores 122, 124, 125) located on interfluvial surfaces elevated more than 90–100 m a.s.l.; the elevation corresponds to the levels of Middle Pleistocene transgressions. The studied areas are confined to the southwestern

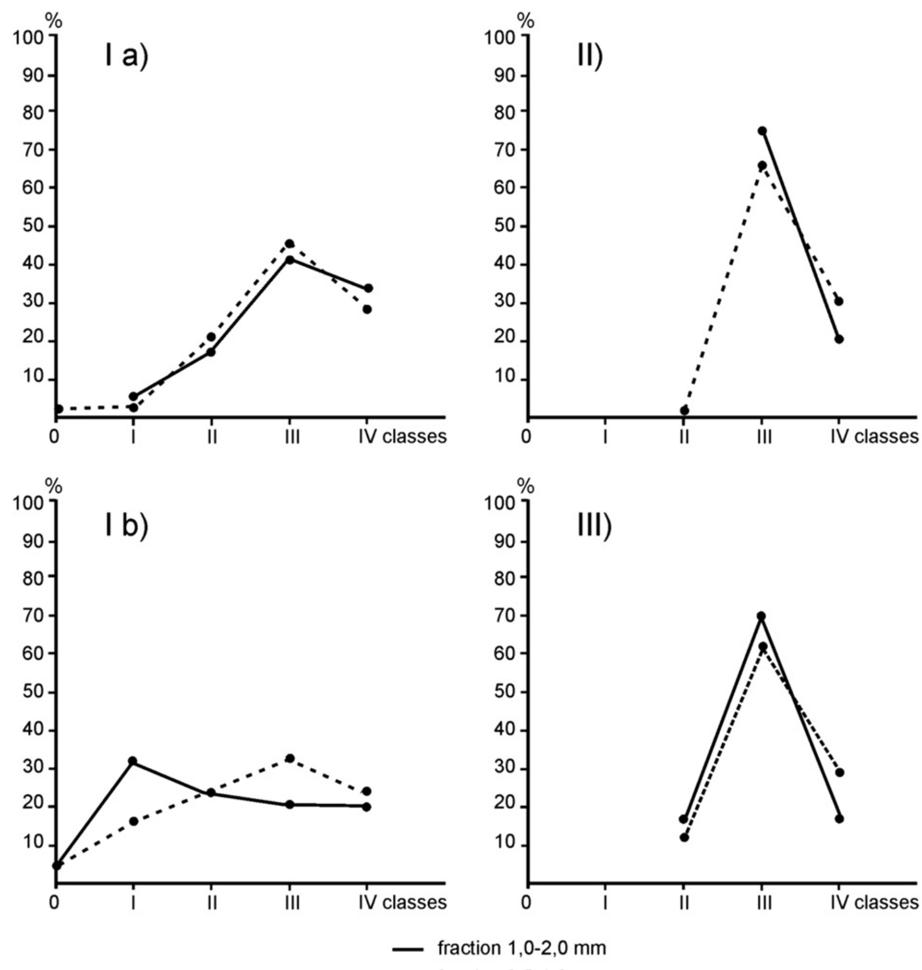

Fig. 4. Averaged distribution of sand grains over classes of roundness in: Ia – northern marine flatlands in the Pur and Nadym R. drainage basins, elevations less than 80 m a.s.l. (cores 107, 120, 121, 136, 138, 139, 141, 142); Ib – marine flatlands in the Nadym R. drainage basin at elevations 90–100 m a.s.l. (cores 122, 124, 125); II – Siberian Uvals hills (cores 1, 12, 13, 15); III – the main geomorphic depression (core 19). Dashed line – fraction 0.5–1.0 mm, solid line – fraction 1.0–2.0 mm.

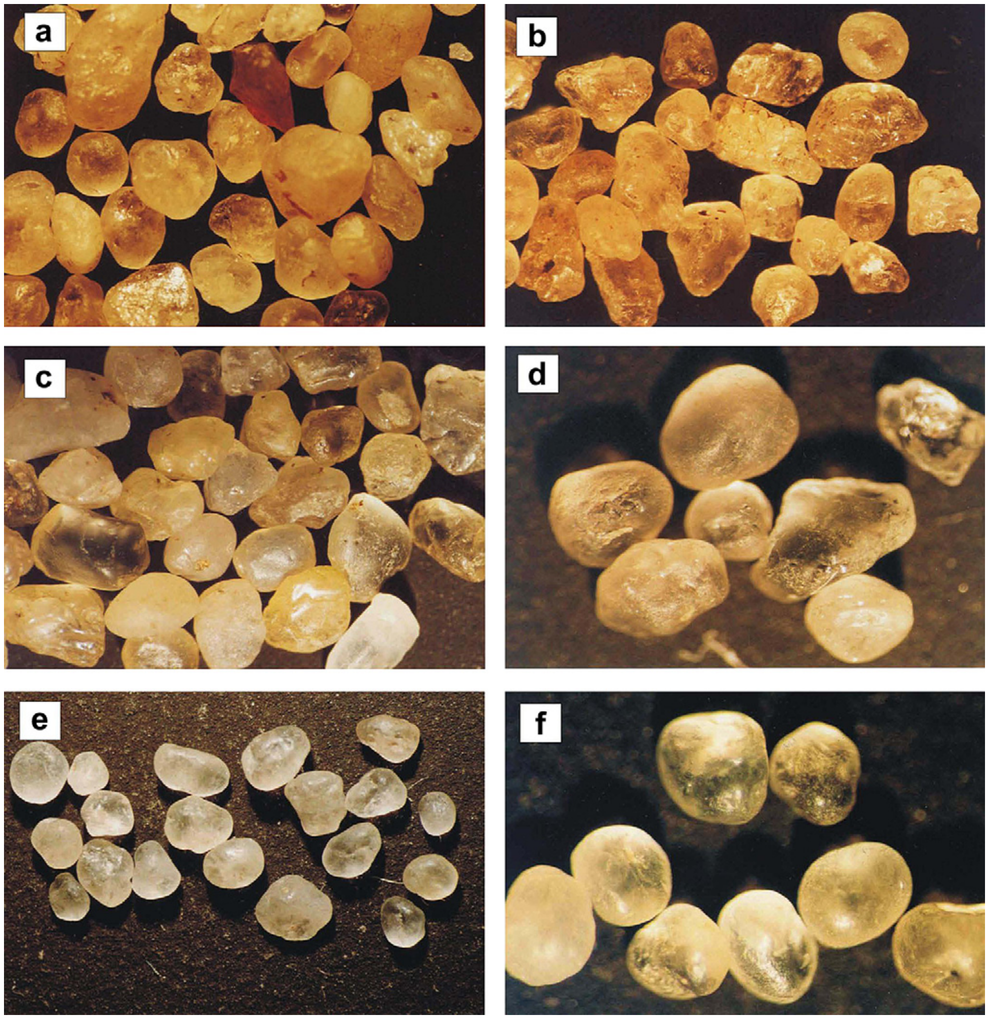

Fig. 5. Quartz grains morphology: a – fraction 0.5–1.0 mm, core 107, at magnification 6.25×; b – fraction 1.0–2.0 mm, core 124, at magnification 6.25×; c – fraction 1.0–2.0 mm, from section PI, magnification 6.25×; d – fraction 1.0–2.0 mm, core 12, magnification 10×; e – fraction 1.0–2.0 mm, core 19, magnification 4×; f – fraction 1.0–2.0 mm, core 19, magnification 10×.

Nadym drainage basin. Unlike the grains described in the first group (recovered from sediments attributed to the Kazantsevo transgression), those in the second group of samples show slightly lower indexes of roundness (not exceeding 67%), though round or oval grains occur frequently (Fig. 5b). The grain surface often bears large depression, conchoidal fractures, small-size crescent-like furrows, etc. Noteworthy is the surface matting, varying from 35.5% to 49.5% (Fig. 4-Ib), although grains of class IV roundness are mostly matted. On the whole, the grains in the 2nd group of samples are more “rough” as compared with the 1st group (Fig. 3c and d).

The grain surface texture indicates prevalence of subaerial processes. The aeolian factor, however, seems to have been of secondary importance and probably controlled the primary grain configuration to a lesser extent than in the first group. This conclusion is supported by the data on one of the exposures described on the high right bank of the Bolshaya Khadyryakha River (Pur R. drainage basin).

Sand grains found in that section are highly diversified in the appearance and surface texture (Fig. 3e and f, Fig. 5c). Grains with all types of surfaces are found, from glossy to matted, but the glossy grain percentage is low. Many grains have crescent-shaped furrows – traces of processing in the aquatic environments, and micro-pits resulted from aeolian transportation. The degree of grains matting varies from 47.5% to 64%. It is likely that these sediments have aquatic origins (possibly beach sands) and have subsequently been slightly reworked by aeolian processes.

4.2. Siberian Uval hills

At the hilly terrain of the Siberian Uvals, sand samples were studied in cores 1, 12, 13, and 15. The great majority of grains, both in the 1.0–2.0 mm and in 0.5–1.0 mm fractions, display excellent roundness (the roundness coefficient is 77–84%) and a high degree of matting (the coefficient varies from 72% to 97%). Dominant are grains of class III roundness, although grains of class IV are present in a considerable number (20–38%) (Fig. 3g and h). Noteworthy is the absolute dominance of high roundness classes, typical shape being close to spherical (Fig. 5d). Poorly rounded and non-rounded (angular) grains are practically absent, with the exception of core 12 where a very small amount of medium rounded grains were recorded in fraction 0.5–1.0 mm (Fig. 4-II). Matted grain surfaces are dominant (in some samples up to 95–97% of grains are perfectly matted). Characteristically, the best rounded (quasi-spherical, class IV) grains are also highly matted. On the whole, there is a noticeable prevalence of rounded grains marked by well pronounced traces of aeolian processing, namely micro-pits and depressions traceable over the entire grain surface; those features could only result from a long-term aeolian activities. Judging from the grain shape and surface texture, they were repeatedly subject to aeolian processes, not only during their final deposition, but also at previous stages. According to Møller (1986), the wind velocity sufficient to detach and to move particles of that size would be >10 m/sec. There are also some fresh microforms on the grain surface, such as small pits, conchoidal fractures, and cracks which are likely to result from frost weathering. Crescent-shaped furrows are present on some grains recovered from boreholes located at elevations less than 100 m. They are probably inherited from the marine stages of the area's evolution.

These characteristics differ radically from those of the grains in samples collected from a quarry near Noyabrsk, at the northern margin of the Siberian Uvals (Fig. 1, P2). The sand grains are mostly of medium to poor roundness (classes II and I, with occasional zero roundness), both in 1.0–2.0 mm and in 0.5–1.0 mm fractions. Only a very small proportion (less than 5%) of grains falls into roundness classes III and IV. Grains with glossy or slightly matted surfaces are dominant.

When compared with histograms from other regions, the grains from that quarry show the greater morphological resemblance to those from the middle Pur and Nadym drainage basins. The localities are also similar in geomorphic position. The Noyabrsk quarry exposes the sediments underlying the lower surface (100 and less m a.s.l.) belonging to the upper reaches of the Pur R., while the boreholes penetrating sands under peatlands on the Siberian Uvals hills are located at about 140–150 m a.s.l. The morphological characteristics of the sand grains suggest a genetic similarity between the Noyabrsk site and the lower sites north of Siberian Uvals. Thisprovides supporting evidence for earlier suggestions of Arkhipov (1970) and Lazukov (1970) that ingressions of middle Pleistocene marine transgression could penetrate the hilly ridge along lower hollows.

4.3. Region of the main geomorphic depression

Samples of sands taken from under peat layer (core 19) are distinguished for a good roundness and high matting degree of grains in both fractions (0.5–1.0 mm and 1.0–2.0 mm) (Fig. 5e and f). The roundness coefficient varies from 77% to 82% (Fig. 4-III). Proportion of class III roundness may be as high as to 60%. Grains of class IV are found in large numbers, up to 32% in fraction 0.5–1.0 mm and 24% in fraction 1.0–2.0 mm (Fig. 3i and j). Only a small number of grains (less than 16%) are medium rounded. Degree of matting is considerable, 72% in fraction 1.0–2.0 mm and up to 77% in fraction 0.5–1.0 mm. Well rounded grains are mostly spherical, with evidence of active aeolian processing, their surface being almost entirely covered with micro-pits.

5. Discussion

An analysis of surface texture performed on quartz sand grains from sediments lying directly under wetland deposits (peat) revealed a stable proportion of matted grains in all the three regions, and a high percentage of completely matted (dull) grains. A predominance of completely matted grains has been recorded in roundness class IV, i.e. among perfectly rounded grains close to spherical in shape. Such a combination of grain features suggests subaerial environments at the final stages of grain processing, the aeolian factor leading in the process (Cailleux, 1952; Krinsley and Doornkamp, 1973; Pye, 1984). The importance of sand transport by wind is indicated by small pits (stippling) on the grain surface resulting from the grains collision in air, as well as by the prevailing dullness of surfaces.

Along with the grain surface features common to all the considered regions, there are certain differences. Thus, in the northern region there are weakly matted or glossy and poorly rounded grains found together with grains of aeolian (matted) appearance. Such a combination may be attributed to sand deposition under conditions of marine transgression with noticeable glaciomarine sedimentation or deposition of ice-rafted material (as the glaciers expanded onto the flooded area from east and west). Such sediments have been studied in the sections at Noyabrsk and in cores obtained in the Pur R. basin.

Sand grains extracted from boreholes drilled in the middle region, on higher surfaces of the Siberian Uvals, differ noticeably in morphology from those described in the northern flatlands. Well rounded grains with matted surface are dominant. Some details of the grain surface texture positively indicate the action of strong winds blowing at a speed of more than 10 m/s. The high degree of the grain roundness (close to spherical) may be attributed to specific features of the regional geological history. The sands were deposited mostly in marine environments through the Mesozoic to mid-Paleogene. During the subsequent stage of the Cenozoic, ridges in the middle part of the Siberian Uvals remained subaerial and were subjected to erosion, aeolian processes being of considerable importance. In the Pleistocene, those processes evidently dominated over glacial ones. The latter, however, left distinct traces in the depressions between the ridges, where marine transgressions penetrated and brought ice-rafted gravel and pebble material of glacial origin.

Characteristics of sand grain morphoscopy in the southern region (Khanty-Mansyisk depression) are based on limited data at present. Matted well rounded grains appear to be dominant in the deposits attributable to the considered time interval, though some medium rounded slightly matted and glossy grains are also present. Such a distribution of the sand grains features may be related to the regional topographic setting. The area belongs to the zone of deep depressions where fluvial and lacustrine processes were dominant since mid-Paleogene, occasionally giving way to arid phases (Zykin, 1982).

It follows from the above that the morphology and surface texture of quartz grains reflect differences in geological history of individual regions. The differences, however, do not conceal the morphological characteristics of grains the three studied areas have in common. Those general features provide direct evidence of intensive aeolian activities at the final stages of the sediment formation. The sand grains are comparable in morphology to those described in sand deserts (Cailleux and Tricart, 1956).

Radiocarbon dates obtained in the regions permit to put the upper chronological limit of the considered stage of eolisation at the Younger Dryas cold stage, immediately before the peatland initiation in the Early Holocene. Volkova and Kulkova (1999) date the peat bog onset to 10.5–8 ka BP.

Aridity in West Siberia at the late glacial stage aroused a considerable interest among investigators. The notion of desertification of the area at the end of the Pleistocene is not inconsistent with paleobotanical material. The latter indicate the complete disappearance of forest assemblages and wide occurrence of *Ephedra* (Arkhipov et al., 1999; Volkova and Kulkova, 1999). Long-term works provided convincing evidence of aeolian processes in southern West Siberia, such as loess mantle, dunes, and linear ridges (Kes, 1935; Arkhipov, 1970; Volkov, 1971; Zykina, 1986). As for origin of the linear ridges, there is some disagreement between the specialists, but even supporters of erosional genesis of the ridges acknowledge the importance of aeolian action (Nikolayev, 1970a).

Aeolian processes in northern West Siberia gained considerably in importance towards the end of the Pleistocene. In all probability, they increased in intensity not only in the late glacial, but as early as the Last Glacial (Sartanian) Maximum. No ice-dammed lake or continuous ice sheet existed in the north of the plain at that time. Open flatlands extended 300–400 km and more northward, due to the ocean regression.

Fig. 6. Loess and deserts of Northern Eurasia at the last glacial time. 1 – deserts; 2 – areas of loess accumulation; 3 – boundaries of the Valday (Weichselian) glaciation.

Highly arid conditions and intensified aeolian processes were favored by the presence of pack ice not only in the Arctic Ocean, but also in the North Atlantic. That resulted in reduced evaporation and decrease in precipitation, in Northern Siberia in particular. Simultaneously, the Siberian High expanded considerably and was amplified at the time of the dramatic global cooling in the Late Pleistocene. Permafrost area also reached its maximum and included the entire West Siberian Plain (Velichko, 1984; Baulin, 1985).

Under those climatic conditions, West Siberia appeared to fall into the zone of extreme aridity. In the northern and central portions of the plain, mostly on sandy ground, the environments were highly favorable for activation of aeolian processes, as indicated by the morphoscopic studies. On the basis of those data and taking into consideration climatic conditions, in the late glacial (and probably since the LGM) in the temperate–arctic zone of the Northern Hemisphere there existed a vast area similar to cold deserts in appearance. Judging from the paleobotanical results, a part of the landscape could be semidesert, while relicts of arboreal vegetation could persist in large river valleys. Therefore, the term "cold desert" is used in reference to an intricate combination of arid environments.

In the southern part of the plain the cold desert landscapes gave way to the areas of loess accumulation (Zykin et al., 1998). In all probability, the desert area was one of important sources on the silt brought by air into the loess regions (much like the present-day interrelation between deserts and loess areas in China). A similar "couple" could exist also in Europe: a vast sandy desert as reconstructed by Tutkovsky (1909) in the Polessje lowland in the upper Dnieper basin and a loess area bordering it on the south (Fig. 6). However, the stated idea about the correlation between desertification and loess accumulation in the period from the LGM to the end of late glacial is just a hypothesis and should be considered as such, until it has a solid geochronological basis.

Radiocarbon dated samples from the base of peat sequence in West Siberia suggest the earliest phases of paludification (probably after a short lacustrine stage) fall on a narrow time interval between the end of Younger Dryas and beginning of Preboreal, that is about 10 700–10 300 BP. In other words, the landscape system would have rapidly shifted from one extreme state (cryoarid desertification) to another, opposite to the first in many characteristics (active paludification). The cause of such a dramatic change is to be looked for in the drastic decay of marine ice in the North Atlantic and western Arctic seas (off the European coasts). Under conditions of initiated warming, sea ice (as a constituent characterized by the minimum response rate in fluctuations of seasonal boundaries) retreated rapidly northward (McIntyre et al., 1972) thus providing favorable conditions for active influx of precipitation into inner regions of temperate and arctic belts of Eurasia. Low elevations in central West Siberia, along with gentle slopes and vast flatlands, hindered the drainage and facilitated waterlogging in the Siberian North. A certain role in the paludification could belong to permafrost. Another important factor was the low potential evaporation due to cold air masses invading the region from the north in summer.

6. Conclusion

An analysis of sand grains morphoscopy performed on samples from deposits lying immediately under peat in northern and central West Siberia revealed a noticeable proportion, and in some cores predominance, of perfectly rounded matted grains with surface texture indicative of highly active aeolian processes. Radiocarbon dating of the lowermost peat layers permitted attribution of the final phase of desertification to the end of the late glacial stage, and more precisely, to Younger Dryas.

The data obtained provide evidence of a vast cold desert (locally including semidesert landscapes) that existed at the late glacial time in the northern half of West Siberia and gave way to areas of loess and wind-blown sands farther south. Cryoarid environments in the region were favored, on one hand, by the land mass expansion northwards, and on the other by enlargement of sea ice area in the North Atlantic resulting in drastically reduced moisture supply. Instrumental in the climate cooling and drying were perennial pack ice cover in the Arctic Ocean and the Siberian High gaining in size and strength.

Rapid sea ice decay in the North Atlantic due to the Early Holocene warming led to increase in precipitation. In the territory (low elevations, flattened topography, insufficient drainage, low potential evaporation and melting of ground ice) the landscape system changed abruptly from cold desert (semidesert) to over-moistened lands and widespread wetlands.

The described sequence of natural events is of considerable theoretical importance. It provides a basis for a notion of the landscape sphere being able to transform rapidly into a new state, sometimes quite opposite to the former one. The transformation may occur on global scale, as follows from the case of West Siberia, which undoubtedly falls into this category.

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