The stratigraphic framework for the Upper Pleistocene of the glaciated Russian Arctic: changing paradigms

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Abstract

The development of stratigraphic ideas and terminology for the area of Late Pleistocene glaciation beyond the limit of the Fennoscandian ice sheet is discussed. The original meaning and subsequent distortions of the Siberian stratigraphic terms Zyryanka, Karginsky, Sartan and others are described. Stratigraphic schemes traditionally used in Siberia and in the Russian European Arctic contain similar mistakes due to poor sedimentology obtained from simplistic log descriptions. Indiscriminate use of radiocarbon dating, in disregard to the sedimentological complications, have eroded the value of the old stratigraphic terms and depleted their usefulness. Modern data on widespread glaciotectonic activity and redeposition of organics by shelf-based ice sheets, on retarded melting of buried glacial ice, on ubiquitous permafrost and aeolian processes, coupled with new geochronometric results make it impossible to employ the old framework based on the presumption of undisturbed stratification and slow unperturbed sedimentation. A more structurally complicated model, to which traditional stratigraphic labels are not applicable, is suggested for the uppermost sedimentary formations of arctic plains. It is derived from a wider view of the glacigenic complex by lateral tracing of study objects as a necessary complement to conventional log descriptions. The old Siberian stratigraphic scheme, being obsolete and misleading, is not recommended for further use.

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1. Preface

This paper is inspired by the growing number of Quaternary studies performed in the Russian Arctic by West European scientists, mostly under the aegis of the QUEEN programme. The objective of the paper is twofold: (1) to briefly outline the development of stratigraphic ideas for the Late Pleistocene of the Russian Arctic, responsible for origin of the existing terminology; and (2) to summarize recent results leading to a revision of the conventional stratigraphic wisdom. Such a review seems timely because foreign researchers are not necessarily familiar with the origin or spelling of common names in Siberian stratigraphy, and even less with the ideas behind them. Moreover, many Russian writers, especially those not professionally involved in the northern glacial geology, often misuse traditional labels, thus contributing to the notorious confusion in Quaternary stratigraphy of the Russian Arctic.

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2. Siberia

2.1. Classical stratigraphy

The principal marker horizons of the Arctic Quaternary, first recognised by V.N. Sachs on the Lower Yenissei around Ust-Port (Sachs and Antonov, 1945), were as follows (upwards in the succession):

1. the maximum glaciation bouldery till (only in boreholes);
2. the Messo fluvial sands, named after the river Messo-Yaha;
3. the cold marine sediments of the Sanchugovka Formation: diamictic and stratified clays with poor mollusc fauna with predominance of Portlandia, named after the Sanchugovka creek;
4. the Kazantsevo marine sands with rich boreal fauna, especially Arctica islandica, named after the Kazantsevo village;
5. the Zyryanka till and outwash, deposited by mountain glaciers which spread onto the adjacent lowlands, named after the Zyryanka creek;
6. the Karginsky postglacial terrace 20–30 m a.s.l. named after the Cape Karginsky and consisting of marine sediments with an arcto-boreal mollusc fauna, upstream changing into deltaic and alluvial formations.

Later, the uppermost Sartan horizon was added basing on descriptions of the final generation of alpine moraines overlying high alluvial terraces on the river Sartan, eastern Verkhoyansk Range, more than 2000 km east of Ust-Port area.

The above scheme was extrapolated by Sachs (1953) over the entire Russian Arctic in his grand volume, which contained observations made by early travellers, results of small-scale geological mapping and of stratigraphic studies by the author himself. Sachs thought that the Messo, Sanchugovka and Kazantsevo formations were all deposited during an interglacial analogous to the European Eemian. The last inland (Zyryanka) glaciation occurred in the form of thin ice sheets fed by mountain glaciers. The Karginsky marine and fluvial terraces were never covered by lowland tills and represented a climate warmer than the present one, although colder than the climate of the Kazantsevo transgression. Only in the mountains of northeastern Siberia Late Pleistocene glaciers survived the Karginsky warming and reached their maximum extent during the final, Sartan phase of the last glaciation. Sachs concluded that the Zyryanka lowland glaciation culminated before the last Fennoscandian glacial maximum, probably earlier than 30–35 ka ago, which view was supported by numerous finds of mammoth remains on top of the latest till. He estimated the age of the Sartan alpine phase as between 20 and 10 ka ago. However, without any radiocarbon dates available, he could not decide whether it corresponded to the maximum of the last Fennoscandian glaciation or to its final stages (Sachs, 1953, pp. 510–517). Later, the above events were used for the names of Siberian climatostratigraphic horizons (climatoliths) which, according to the Russian Stratigraphic Code (Bekker et al., 1992), are material representatives of thermochrons and cryochrons in a given region.

What puzzled Sachs and many other geologists was the rare occurrence of diamicts within his Zyryanka horizon, which over the vast expanses of Siberian glaciated flatlands was represented mostly by sands atop of marine Sanchugovka and Kazantsevo deposits. Sachs (1953) tried to explain this phenomenon by a very thin lowland ice, which soon got stagnant producing mostly kames. Strelkov (1965) advocated the idea of passive ice fields over the Siberian plains. Such explanations did not appear very convincing, especially in the view of the implied wide extent of the Zyryanka ice sheets, presumably produced by small mountain glaciers. Therefore, in many publications of the 1960s–1970s, the Zyryanka glaciation shrunk to modest-sized piedmont aprons and alpine glaciers.

2.2. Later revisions

Geologists, who in the 1950s mapped West Siberia south of the Arctic Circle, found no marine formations but only very thick tills separated in places by terrestrial sands. The lowermost till traced south to the drift limit at 60°N was labeled the Samarovo till. The upper till of more limited occurrence was named the Taz till, and intervening sand without distinct palaeontological characteristics was attributed to the so-called Shirta interstadial (or interglacial). This glacigenic sequence, covered by thick loess-like silts, was unanimously related to the Middle Pleistocene.
Late Pleistocene tills, the Sartan label be abandoned, the Zyryanka name should apply to all synchronous with the last ice sheets in Europe and the last inland glaciation of West Siberia was synchronous with the Late Valdai and classical Wisconsin. Since then, in all regional stratigraphic schemes, the Middle/Upper Pleistocene boundary was placed between the Sanchugovka and Kazantsevo formations.

The mortal blow to the scheme of Sachs was dealt by his disciple and malacofauna expert S.L. Troitsky, who studied the Lower Yenissei stratotypes and found that the Karginsky terrace was built of two unrelated formations: the basal marine deposits with arctoboreal fauna, not much different from the Kazantsevo fauna, and overlying terrestrial sediments, till included (Troitsky, 1966). Sachs had to agree with this conclusion. Since the sediments with arctoboreal fauna were related to the Eemian, all record of the Karginsky transgression at its most typical low-altitude sites evaporated. Then, Troitsky found that terrestrial sediments of the ‘Karginsky horizon’ in the parastratotypic section of the same low terrace on river Malaya Heta were again covered by till. Because the sub-till alluvium yielded a couple of finite radiocarbon dates, he suggested that (1) the last inland glaciation of West Siberia was synchronous with the last ice sheets in Europe and America, (2) the Zyryanka name should apply to all Late Pleistocene tills, (3) the Sartan label be abandoned, (4) real ‘Karginsky terraces’ should be looked for outside the limits of the last glaciation and its proglacial reservoirs (Troitsky, 1967). These conclusions actually turned the Sachs’ scheme upside down: a Zyryanka till appeared on top of the Karginsky horizon, and the basic idea of an early glacial culmination in Siberia was replaced by a palaeogeography much different from the European and North American models.

Further application of the radiocarbon method in its conventional form deepened the alienation from the spirit of the classical scheme, though preserving its empty shell in the form of traditional stratigraphic labels. The landmark in this process was the monograph by Kind (1974), who applied radiocarbon geochronometry to the Sachs’ scheme to compose a geochronological scale for Siberia, apparently similar to the North American one. She obtained several old finite dates on shells from the marine strata at the Cape Karginsky stratotype of Sachs (= the Kazantsevo marine formation, according to Troitsky) and at the same time acknowledged their sub-till position. Whereas Troitsky (1967) attributed this till to a late advance of Zyryanka glaciers, Kind (1974), based on finite dates from sub-till beds with palaeontological indicators of a climate by 3–4°C warmer than the present one, suggested a Karginsky interglacial in the interval of 50–22 ka ago, correlative to the Middle Valdai, Middle Wisconsin and isotope stage 3. According to her, it was followed by a large ice sheet synchronous with the Late Valdai and classical Wisconsin. She used the Sartan label for her Late Pleistocene glacial maximum. Kind also maintained that the Younger Dryas event was reflected in the large end moraines of the Norilsk stage at the foot of the Putorana Plateau, treated by Sachs (1953) as a counterpart of the Sartan stage.

It is obvious that the names of the Sachs scheme were applied by Kind (1974) to geochronological stages of quite different palaeogeographical meaning. Unfortunately, this change happened not because the sedimentary events described by Sachs were refuted, but solely on the base of presumed validity of all radiocarbon datings. The main differences of the radiocarbon stratigraphy from the classical scheme was that the second Late Pleistocene (Karginsky) interglacial appeared and that the last ice sheet was rechristened. Because of the wide use of Kind’s scheme by mapping geologists, her geochronological terms stuck and got unwittingly applied to some geological bodies, which Sachs would have never thought as suitable for such labeling. Some geologists even call thick marginal accumulations of tills and glaciectectonised sediments in lowlands ‘Sartan moraines’. This violation of the Stratigraphic Code (Bekker et al., 1992) cannot be excused by the implied geochronological sense because the alpine Sartan moraines s. stricto have never been properly dated and may theoretically belong to quite a different stage, or to any part of that 22–10 ka cold ‘Sartan’ interval by Kind.

Thus, the victorious radiocarbon method turned the classical Upper Quaternary stratigraphy into a double entendre. Since that time, some researchers, especially those who never professionally dealt with glacial geology of the Siberian Arctic, habitually...
employed words Zyryankian, Karginskian, Sartanian for abstract geochronological intervals roughly equivalent to the triple subdivision of the Weichselian/Wisconsinian time, whereas others, mostly northern glacial geologists, used the same terms in their original stratigraphic sense. Unfortunately, the same terms are often loosely applied to much better studied periglacial formations which correlation with the above glaciogenic and marine sediments of the Lower Yenissei is highly questionable. The confusion is so deep-rooted that today there is no easy way out. Though Sachs himself lived to see his original terminology being corrupted and attached to unrelated deposits, he was by then already deeply involved with the Mesozoic research and preferred not to intervene, leaving us to sort out the confusion created by the indiscriminate use of the radiocarbon method coupled with disregard for the Stratigraphic Code.

There was an attempt to ‘escape’ the lowland Sartan glaciation leaving it at the mountains where it rightly belongs. Arkhipov et al. (1977) and Arkhipov (1984) suggested the Zyriankian climatostratigraphic superhorizon consisting of three horizons: the Lower and Upper Zyryankian glacial horizons separated by the Middle Zyryankian interstadial horizon within the radiocarbon brackets 50–22 ka. However, it did not help much because each time the question arose, one had to explain what was actually meant. Later, Arkhipov (1990) returned to the Sartan label for the last inland glaciation. The present official stratigraphic scheme of the West Siberian Plain holds the names of the climatostratigraphic horizons (regional representatives of global climatic events): Upper Zyryankian = Sartanian and Lower Zyryankian = Yermakovian separated by the Karginskian interstadial, all subdivisions of the Zyryankian superhorizon. The Sartanian and Karginskian are accepted without stratotypes (sic!), because the Sartan moraines s. stricto have no relation to the lowland glaciation, and the mentioned marine strata at the Cape Karginsky are dated by ESR to 121.9 ka (Arkhipov, 1990). This terminological mess is further complicated by the geochronological value attached to the Zyriankian superhorizon, which is roughly equivalent to the Wisconsinan (isotope stages 4—2) but not to the West European Weichselian (isotope stages 5d—2) by Mangerud (1989).

### 2.3. Modern data

Apart from the discussion on nomenclature, material foundations of the classical scheme were questioned by reinvestigations of the Sachs sections. The most serious attempt was undertaken by Kaplyanskaya and Tarnogradsky (1975) in the Ust-Port stratotypic area. In laterally extensive sections, they found that the Sanchugovka formation was actually basal till in the form of glaciotectonites with rafts of marine sediments transported from the Kara Sea. In accordance with the Stratigraphic Code, they preserved the geographical name of the Sachs’ sedimentary formations by coining the term Sanchugovka till. They also found boreal fauna of the Kazantsevo type in that till, which further complicated the question, suggesting either another boreal transgression in the Middle Pleistocene or a Late Pleistocene age for the Sanchugovka till. Later, they discovered that the Zyryanka diamicton in many places contained thick bodies of buried glacial ice imperceptibly merging into surrounding ‘primordially frozen till’ (Kaplyanskaya and Tarnogradsky, 1976). The works of the above authors made it clear that in the northern plains with the thick continuous mantle of glaciogenic formations, no good results can be achieved by using only narrow logs or boreholes. Lateral tracing of sedimentary bodies in order to assess their structural position and the governing sedimentary processes is essential for understanding the stratigraphy!

Meanwhile, the very core of the classical palaeogeography of the Siberian Ice Age was shaken, when it was found that the pattern of glaciotectonic ridges and marginal formations together with till petrography conforms with sources of inland ice not in the mountains but on the low coastlands and the shelf of the Kara Sea (Astakhov, 1976, 1977). The would-be Uralian moraines of the last stages of the Zyryanka glaciation (Arkhipov et al., 1977) proved to be marginal features of thick Arctic inland ice that flowed upslope in and around the Polar Urals up to 500–600 m a.s.l. (Astakhov, 1979). These results led to reconstruction of a Late Pleistocene ice sheet more than 2 km thick and to rejection of the classical idea of free northward discharge of Siberian rivers during the maximum of the Late Pleistocene glaciation in favour of large ice-dammed lakes (Volkov et al., 1978; Arkhipov et al., 1980).
The reconstruction of a thick Kara Sea ice sheet helped to get rid of the old puzzle of the Zyryanka glacial horizon. It has become clear that what Sachs and his followers described as the Zyryanka formation were partly piedmont varieties of basal tills, and partly outwash and other ablation sediments deposited in the lowlands, whereas the lowland basal tills and varves, due to the widespread redeposition of mollusc shells by Kara shelf glaciers, were perceived as the Sanchugovka marine formation. This can be easily demonstrated on the Gydan and Yamal peninsulas, where thick clayey diamicts underlain by marine sands contain thick bodies of fossil glacial ice (Astakhov, 1992, 1998). Yet, some researchers still look in vain for Late Pleistocene tills in the overlying sandy outwash of the arctic plains.

In 1980–1981, two special boat trips along the Yenisei river were undertaken by a number of Russian geologists from various institutions to check stratotypes described by Sachs, Troitsky, Arkhipov and Zubakov (Astakhov et al., 1986). They confirmed the conclusions by Kaplyanskaya and Tarnogradsky (1975) and found that most of other Yenisei sequences were also heavily glaciotectonised, the normal superposition in many cases being questionable. The result of this collective inspection was even more disastrous than expected, since it proved almost impossible to directly correlate between basic units of individual sections within the stratotypic area around Ust-Port (Fig. 1). The Kazantsevo marker sand with abundant shells was found only in isolated outcrops, probably as large rafts of the interglacial strata, and could hardly be laterally traced even within the stratotypic area some 40 km wide. The validity of the conventional radiocarbon method in the local conditions of cyclic thawing of the permafrost was also questioned, because several finite dates were obtained from the very base of the Sanchugovka formation (Astakhov et al., 1986).

Another source of stratigraphic mistakes was revealed when studying deposits of fossil glacial ice which were first described by Kaplyanskaya and Tarnogradsky (1976). Buried glacial ice preserved within the long-existing Pleistocene permafrost is apt to accelerated melting during climatic ameliorations, especially in the Holocene, producing thick diamictic sequences with all kinds of radiocarbon datable materials. Such flowtills, characteristic of retarded deglaciation in continental climates, are readily confused with basal tills, leading to erroneous ideas of very young ice advances (Astakhov and Isayeva, 1988). The bona fide basal till of the Lower Yenisei, containing bodies of thick glacial ice, was found to be overlain by alluvial and limnic sediments dated to more than 30,000 radiocarbon years (Astakhov and Isayeva, 1985, 1988).

By that time, sections on the Yamal, Gydan and Taimyr peninsulas, where the thickest part of the last...
ice sheet resided, had already yielded consistent series of old radiocarbon dates derived from post-glacial successions at Cape Sabler, Mongotolyang and Syo-Yaha (Kind and Leonov, 1982; Vasilchuk et al., 1984). A special study of the alleged sediments of a huge ice-dammed lake on the Ob river (Volkov et al., 1978) found only a loessic sequence with lenses of sink-hole deposits yielding finite radiocarbon dates (Astakhov, 1989). Likewise, many silty formations of the Arctic, often related to lacustrine activity, proved to be parts of the ice-rich loess-like mantle not much different from the Yedoma formation of eastern Siberia. For example, the intermittent (if not continuous) growth of long ice wedges through the monotonous silt formation at least 30 m thick at Cape Sabler, Taimyr (Derevyagin et al., 1999), indicates predominantly subaerial and shallow limnic sedimentation for the last 30 ka but hardly a stable lacustrine environment, as was originally suggested (Kind and Leonov, 1982).

From the above and other evidence produced by various investigators, it was concluded that the last invasion of inland glaciers from the Kara Sea shelf onto the Siberian mainland could only have occurred beyond the radiocarbon age limit (Astakhov, 1992, 1998), and therefore, all finite radiocarbon values from beneath the arctic tills must be due to contamination by younger carbon. The indiscriminate use of doubtful radiocarbon dates in previous years coupled with sedimentological misinterpretation is put forward as the main cause of the Siberian geochronological confusion (ibid.).

3. European Russia

3.1. Classical stratigraphy

In the Russian European North, two tills separated by marine strata with warm-water fauna (containing boreal to lusitanian mollusc species) have been known since the turn of the century. Later, Yakovlev (1956) developed a scale with three Neopleistocene glaciations and two interglacial transgressions of warm atlantic water. He related his oldest Neopleistocene glaciation to the Warthe stage and the preceding ‘Northern Transgression’ to an inter-Saalian interglacial. The Boreal Transgression proper, which occurred later, was followed by the Second Neopleistocene glaciation centred on Novaya Zemlya. This ice sheet, correlated to the Early Weichselian, in his opinion occupied the Lower Pechora flatlands but neither reached the Pai-Hoi Range, nor coalesced with the Scandinavian ice. The Second glaciation was followed by the Onega Transgression, which left boreal fauna at present day altitudes up to 220 m in the Kanin Peninsula. Yakovlev and many other geologists saw traces of such a transgression in mollusc shells scattered over the step-like coastal plains. The Third Neopleistocene glaciation took place only in Fennoscandia (Yakovlev, 1956).

3.2. Later revisions

In the 1960s, the deep-rooted ‘Siberian’ inability to distinguish between shelly tills and real marine sediments spread across the Urals and caused the resurrection of drift hypotheses in the form of so-called ‘marinism’. As a result, thick diamicitic sequences along the southeastern low coast of the Barents Sea were mapped by Vorkuta geologists as glacimarine or cold marine strata named the Rogovaya formation, and only Uralian piedmont diamicsts were described as glacial deposits (Popov and Afanasyev, 1963). This Rogovaya formation, presumably of Saalian age, was supposed to represent all clayey surficial sediments, except the staircase of younger marine terraces. The only difference between this scheme and the Siberian one by Sachs (1953) was as regards the Eemian marine formation which in the scheme of Vorkuta geologists (Popov and Afanasyev, 1963; Zarkhidze, 1972a,b) existed only as a terrace about 100 m a.s.l., called the More-Yu formation, whereas similar sands with mollusc shells at higher altitudes were related to the Vashutkiny formation of the final Middle Pleistocene. The Karginsky term was borrowed from Siberia for presumed marine terraces at 40–60 m a.s.l. along the Barents Sea coast. Sands with boreal mollusc fauna underlying the topmost diamicitic formation were regarded as the Padymei formation of Pliocene–Early Pleistocene (Zarkhidze, 1972b).

The above stratigraphy, with varying terminology, is still in use by local exploration and mapping companies, who deal predominantly with drilling logs, but professional glacial geologists do not accept
minist classifications. A team of Moscow geologists led by A.S. Lavrov, who mapped most of the Pechora and Severnaya Dvina catchment areas and were the first to massively employ radiocarbon dating, related all surficial pre-Holocene strata to the Late Weichselian glaciation. The hummocky sand fields with mollusc shells were mapped as kames and other ablation features. Already in the 1970s, they found that the ‘Rogovaya formation’ was an ill-assorted collection of geological objects of various ages, including radiocarbon-dated Middle Weichselian and Holocene sediments (Arslanov et al., 1981a).

The official stratigraphic scheme of the region presently is based on climatostratigraphic subdivisions. The Vychegda (a Middle Pleistocene) till, according to this scheme, is overlain by the Sula marine strata correlated with the Eemian. The Weichselian series north of the Arctic Circle is subdivided into the Laya Lower Valdai horizon represented by periglacial sediments, the Byzovaya (Middle Valdai) interstadial horizon with Palaeolithic artefacts and the Polar Upper Valdai horizon consisting of the surficial tills and stratified glacial drift (Guslitser et al., 1986).

3.3. Modern data

Recent studies by the Russian–Norwegian team (the PECHORA project) discovered that the surficial Markhida till deposited by the last ice advance from the shelf is out of reach for radiocarbon dating. Luminescent dating of beach sediments of the last ice-dammed lake, Lake Komi, yielded values of about 80–100 ka (Mangerud et al., 1999, 2001). Predecessors erroneously ascribed an Early Holocene age to the Markhida ice advance (Grosswald et al., 1974; Arslanov et al., 1987). However, application of the Siberian principle of retarded deglaciation in the Pleistocene permafrost environment (Astakhov and Isayeva, 1988) to the Markhida sequence (Tveranger et al., 1995) helped to differentiate between the genuine basal till of an older ice advance and diamicts of flowtills and solifluction sheets deposited during the Early Holocene warming and melting of Pleistocene permafrost with buried glacial ice, thus getting rid of the strange Holocene glacier surge suggested by Grosswald et al. (1974). In spite of persistent search during six field seasons, no sediments related to interglacial or warm interstadial climate have been found above the Markhida till (Astakhov et al., 1999; Mangerud et al., 1999). Sub-till sediments with forest pollen spectra described by Arslanov et al. (1981a, 1987) and Golbert et al. (1973) as Middle Weichselian most likely belong to the Eemian or even older interglacials. Some sites with old finite dates (35–47 ka), such as Urdyuzhskaya Viska and Lodmashchelye Seyda (Arslanov et al., 1981a, 1987), when resampled and AMS-dated yielded non-finite values. Thus, the situation with the Late Pleistocene of the European Arctic proved to be very similar to that in Siberia, where conventional radiocarbon dating very often gives too young values, especially on shells and driftwood (Astakhov 1992, 1998).

Similarities with West Siberia are not confined to the spurious radiocarbon dates. A special study by the PECHORA project of the Rogovaya, Padymei, Vashutkiny and More-Yu formations, suggested by Vorkuta geologists (Popov and Afanasyev, 1963; Zarkhidze, 1972a,b), at their stratotypic localities, revealed thick heavily glaciotectonised rhytmites and diamictons with shell fragments resembling the Sanchugovka formation of the Yenissei (Fig. 2). Sands with mollusc shells occur any place in the 50–60 m high bluffs. Their normal position is beneath the diamicton, as in Section 9. In logs made by local geologists, the sands in sub-till position are called the ‘Padymei formation’. Overlying the diamic unit, as in Section 11, they are described as the ‘More-Yu formation’ of a 100-m-high Eemian marine terrace (Zarkhidze, 1972a,b). A little digging laterally reveals that the sand with boreal fauna in this section occurs as large blocks within the ‘Rogovaya formation’ diamicton (Fig. 2).

When traced beyond the bluff exposures, the steep-dipping marine sands, as in Section 13, were found protruding as narrow ridges on nearby plateaus at 100–200 m a.s.l. At these altitudes, the marine sands were described as the Middle Pleistocene ‘Vashutkiny formation’ by local geologists. Facies structure, lithology and fossils of the sands are similar in any position and most probably reflect one marine event, which is underlined by very close values of U/Th datings on Tridonta shells (Fig. 2). Various ridge-like heights in arctic tundras east of
Fig. 2. Sections of Upper Pleistocene sediments on the More-Yu river, 67°50’N, 60–60°30’E (results of 1998 by the Russian–Norwegian PECHORA project). Sections are numbered downstream.

The Lower Pechora normally consist of up to 100-m-thick imbricate stackings of the Upper Pleistocene diamicts and sands, as is evident from geological profiles compiled by Lavrushin et al. (1989). The all-pervading glaciotectonism imposed by the Early Weichselian ice sheet on the Eemian marine sediments is the obvious reason for several boreal transgressions to have been described from redeposited shells found on the surface up to 220 m on the Kanin Peninsula and even higher in the Pai-Hoi Range (Yakovlev, 1956).

Thus, modern data from the European Arctic give roughly the same picture as in West Siberia. Again, as in Siberia, log descriptions without lateral tracing in disregard for the heavy glaciotectonism proved to be the main source of stratigraphic errors. The actually observable structure of the Upper Pleistocene on both sides of the Urals reflects deep distortions of the subsurface strata by a thick, upslope moving Early Weichselian ice sheet. In the Polar Urals, imprints of this thick ice is retained in the form of fresh-looking morainic arcs at altitudes up to 560 m,
inserted into the alpine valleys by ice streams that flowed southwards from the Kara Sea shelf (Astakhov et al., 1999).

Large-scale glaciotectonic reworking of the Eemian basement, characteristic for Siberia and the Peri-Uralian Arctic, tends to be less pronounced farther westwards. At least around the Pechora mouth, till-covered Eemian formations, unlike in Siberia, can be traced in many sections (Astakhov et al., 1999; Mangerud et al., 1999). West of the Timan Ridge, no large-scale disturbances of the so-called ‘Boreal Strata’ have been reported (Yakovlev, 1956). This change may be explained by moderate erosive activity of wet-based ice sheets in the west, as opposed to the cold-based ice sheets of Siberian type that heavily excavated the weak substrate in the east (Astakhov et al., 1996).

To complete the comparison with West Siberia: during the field season of 1998 massive glacial ice with pebbles was found at the base of a left-bank bluff built of diamicts on the More-Yu river, 60°E (Astakhov et al., 1999). Although in nearby sections, the overlying sediments of postglacial lakes yield radiocarbon dates not older than 13 ka (Section 9 in Fig. 2), the diamicton containing the fossil glacier ice cannot be Late Weichselian because there are many sections in this area where the topmost member is thick aeolian sand of this age. For example, the cover sand on a right tributary of the More-Yu (Ute-Yaha creek) yielded a consistent series of four luminescence dates in the range 26–21 ka. This is quite compatible with older luminescent datings obtained on sediments deposited during the last glaciation of this region and with numerous radiocarbon values in the range of 37–27 ka from postglacial sediments with mammoth fauna and Palaeolithic artifacts (Mangerud et al., 1999).

Ubiquitous postglacial aeolian and permafrost phenomena, not detected by previous investigators, account for many features of periglacial sedimentation earlier perceived as signatures of a Late Weichselian glaciation (Astakhov et al., 1999). Discontinuous aeolian sheets on top of the uppermost till of the Pechora Basin, indicating very cold and arid Late Weichselian climate, have obvious counterparts in Siberia, where they are intimately associated with syngenetic ice wedges and finds of mammoth fauna (Astakhov, 1992).

4. The Karginsky problem

The Karginsky interglacial suggested by Kind (1974) was readily picked up by micropalaeontologists, who attributed to this event assemblages of foraminifers, sometimes even warmer than the Kazantsevo microfauna. The idea of a warm intra-Weichselian ‘transgression’ quickly spread over the Russian Arctic and even reached the Fennoscandian shores of the Kola Peninsula (Gudina, 1976). However, the Kola geologists falsified it rather promptly by showing that the finite radiocarbon dates were derived from sediments U/Th dated to the Eemian (Arslanov et al., 1981b).

In Siberia, the problem was first dealt with by Troitsky (1966), who showed that mollusc assemblages were basically the same in the Kazantsevo and Karginsky formations. Then, he considered the coastlands of West Siberia and found no postglacial marine terraces except the low Holocene beaches (Troitsky and Kulakov, 1976). All terrace-like surfaces there happened to be either covered by till or built of sediments older than the radiocarbon age limit. The stepped lowland of the Yamal Peninsula in the range of altitudes from 20 to 100 m a.s.l. proved to be composed of glacigenic materials (Astakhov, 1979, 1981; Astakhov et al., 1996; Gataullin, 1988). The only sedimentary body in the Yamal that could be related to a Karginsky marine terrace (Vasilchuk et al., 1984) is loess-like silt with long ice wedges, most probably terrestrial in origin (Astakhov, 1992).

The only postglacial marine formation of Arctic West Siberia, consisting of cold-water clay, sometimes varved, with *Portlandia arctica* (Troitsky and Kulakov, 1976), directly overlies fossil glacier ice (Astakhov, 1992) and has no relation to a transgression of warm Atlantic water.

A similar situation can be seen everywhere along the low coastlands of the Barents Sea. The low coastal platform, which was traditionally mapped as the Karginsky marine terrace, proved to be covered by till and limnic sediments (Arslanov et al., 1987; Lavrushin et al., 1989). Participants of the already noted PECHORA project, which proved an Early Weichselian age of the last ice sheet of the region, have also found no postglacial strandlines. Where the uppermost till is removed by postglacial erosion, the exposed base of the coastal lowland shows a thick
marine formation with interglacial mollusc fauna, sometimes glacially disturbed and not different from the Eemian marine sediments in the sub-till position (Astakhov et al., 1999; Mangerud et al., 1999). Like in Siberia, finite radiocarbon dates are sometimes derived from this basal marine formation. As mentioned above, in places the terrace-like coastal surface is covered by thick aeolian sands of Late Weichselian age (Mangerud et al., 1999). Most serious attempts to pinpoint the Mid-Weichselian interstades (Golbert et al., 1973; Arslanov et al., 1981a,b, 1987) are connected not with this terrace but with sub-till fluvial sediments overlying the Eemian marine strata.

The only area, where the warm-water Weichselian transgression has not yet been disproven by direct geological observations, or falsified by redating, is the Taimyr Peninsula and the arctic islands. However, the suggested Karginsky sedimentary formation there has never been reliably described in terms of sedimentology and structural geology. On the other hand, one cannot exclude the possibility of a deep Mid-Weichselian glacioisostatic trough accommodating Atlantic water (Sachs, 1953). The available evidence is, however, too scanty for any positive conclusion. It boils down to a number of finite radiocarbon dates obtained on shells, driftwood and walrus bones collected on various terrace-like surfaces of Taimyr and Severnaya Zemlya (Kind and Leonov, 1982; Bolshiyanov and Makeyev, 1995). Other authors, who analysed analogous dating results, reject the Mid-Weichselian transgression and conclude that the dated materials originate from Eemian sediments (Fisher et al., 1990). This conclusion seems to be the most reliable for the time being, especially in view of the fact that the ‘Eemian’ U/Th and ESR datings have been already obtained from the allegedly Mid-Weichselian marine formations (Arkhipov, 1990; Arslanov et al., 1981b).

5. Conclusions

The above review purports to demonstrate that the regional stratigraphic schemes of the Russian Arctic cannot accommodate the sedimentological and geochronometric results obtained during the last two decades, the conventional nomenclature being neither adequate, nor unambiguous. The obsolete method of log descriptions in isolated sections used for developing the conventional stratigraphy is a poor tool for deciphering the laterally variable structure of glaciated sedimentary basins. Whereas in marine geology, the log approach, justified by apparently valid presumptions of undisturbed superposition and mostly supported by seismic stratigraphy, may not lead too far away, in terrestrial geology of glaciated plains, the log approach has no such excuses. For terrestrial studies, the best way forward seems to be either by obtaining as wide a view of the glacial complex as possible by mapping the country (e.g., Astakhov et al., 1999) or by measuring lengthy cross-sections with important structures carefully plotted (e.g., Gataullin, 1988).

Fig. 3 illustrates the basic difference between the conventional stratigraphic thinking and results obtained by applying the principle of lateral tracing. The bottom diagram in Fig. 3 shows the basic features of arctic sedimentary sequences that cannot be explained in terms of the traditional stratigraphic nomenclature. The sedimentary complex of the last ice age should not be termed the Zyryankian any more, as follows from comparison of top and bottom sketches in Fig. 3. In the lowlands, the term originally implied only the ablation sediments, i.e. an upper part of what is the last glacial complex in modern understanding. The lowland Upper Pleistocene basal tills, containing marine fossils, were customarily mapped as Sanchugovka, or Rogovaya formations and, what is worse, the same diamict horizons near the uplands were commonly described as the Zyryanka till. The Sartan label, derived from the latest stage of an alpine glaciation, is even less suitable for the lowland glacigenic formations rich in rafts of marine sediments.

Another major source of stratigraphic errors is a disregard for permafrost and aeolian features, often confused with glacial and reservoir sediments, which can lead to the application of radiocarbon time brackets to wrong or non-existent sedimentary events, to glacial stages instead of warming, as is the case with the Markhida and other flowtills, or to inferring lacustrine events instead of arid phases, as has been done for many ice-rich loess-like sequences.

It would thus be wise in the future to refrain from attaching the worn-out Siberian stratigraphic termi-
Fig. 3. The conventional and the author’s models of relations between Pleistocene sedimentary formations exposed on the glaciated plains of Arctic Russia.

The old geological method of applying local geographical names to sedimentary formations is still very much advisable, even if it is not always clear how far such local events can be extrapolated. To avoid the difficulty when alluding to regional objects, this author prefers using such descriptive terms as ‘the last glaciation’, ‘the uppermost glacial complex’, etc. For long-distance correlation and geochronological interpretations, the Siberian scheme is necessary neither. It seems better to compare regional (e.g., North Siberian) sedimentary events with subdivisions of the more reliable European scheme — Late Weichselian, Middle Weichselian, etc.

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References


