Supplementary Material

Supplementary Table 1. Published dates of ice rich deposits in the key sites.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Lab.no | Material dated | Method | Height  (m a.s.l.) | Age  14C yr B.P | Age  yr BP | Reference |
| **Marre-Sale (MS)** | | | | | | |
| Holocene deposits | | | | | | |
| АА-26967 | Betula bark | 14C | 23.7 | 8865 ± 65 | 9960±140 | Forman et al., 2002 |
| GX-23496 | Betula bark | 14C | 24 | 7990 ± 65 | 8840±110 | Forman et al., 2002 |
| АА-26957 | Betula twig | 14C | 18.2 | 8345 ± 60 | 9350±90 | Forman et al., 2002 |
| GX-23495 | Betula bark | 14C | 18.8 | 8050 ± 80 | 8910±140 | Forman et al., 2002 |
| GX-23943 | Betula bark | 14C | 18.9 | 8620 ± 70 | 9620±90 | Forman et al., 2002 |
| GX-23494 | Betula bark | 14C | 19.3 | 8110 ± 90 | 9040±140 | Forman et al., 2002 |
| GX-21801 | Betula bark | 14C | 22 | 8610 ± 150 | 9680±210 | Forman et al., 2002 |
| GIN-5204 | Wood | 14C |  | 8240 ± 70 | 9220±110 | Bolikhovsky, 1987 |
| LU-1266 | Wood | 14C |  | 7820 ± 70 | 8630±120 | Arslanov et al., 1986 |
| P980087121 | Peat plant | 14C | 24.8 | 1153 ± 11 | 1050±50 | Forman et al., 2002 |
| АА-26956 | Peat plant | 14C | 23.7 | 8195 ± 60 | 9160±100 | Forman et al., 2002 |
| АА-26955 | Peat plant | 14C | 24.8 | 1015 ± 40 | 910±60 | Forman et al., 2002 |
| АА-26938 | Peat fragment in IW | 14C | 23.15 | 7165 ± 75 | 7990±80 | Forman et al., 2002 |
| SOAN-7597 | Plants | 14C | 23 | 10930±105 | 12890±100 | Slagoda et al., 2012 |
| SOAN-7940 | Moss | 14C | 22.4 | 7700±120 | 8520±150 | Slagoda et al., 2012 |
| SOAN-7941 | Plants | 14C | 21.5 | 7910±140 | 8780±180 | Slagoda et al., 2012 |
| SOAN-7942 | Plants | 14C | 22 | 5200±110 | 5980±150 | Slagoda et al., 2012 |
| SOAN-7596 | Moss | 14C | 30.4 | 3410±60 | 3660±90 | Slagoda et al., 2012 |
| Ri-362 | Peat | 14C |  | 4640 ± 150 | 5310±200 | Gataullin, 1988 |
| LU-1266 | Peat | 14C |  | 7820 ± 70 | 8630±120 | Arslanov et al., 1986 |
| LU-1267 | Peat | 14C |  | 9010 ± 100 | 10110±160 | Arslanov et al., 1986 |
| LU-1268 | Peat | 14C |  | 6400 ± 250 | 7260±260 | Arslanov et al., 1986 |
| SOAN-7596 | Peat | 14C | 16.7 | 6475±100 | 7380±100 | Slagoda et al., 2012 |
| АА-26954 | Plant | 14C | 24.8 | modern |  | Forman et al., 2002 |
| АА-26953 | Plant | 14C | 24.9 | 80 ± 40 | 130±80 | Forman et al., 2002 |
| Р98-08692А | Plant | 14C | 24 | 620 ± 6 | 610±30 | Forman et al., 2002 |
| Late Pleistocene deposits | | | | | | |
| LU-11 | Wood | 14C |  | > 55500 | >55500 | Zubakov, 1972 |
| GIN-5199 | Wood | 14C |  | 31100 ± 400 | 35490±420 | Bolikhovsky, 1987 |
| GIN-5198 | Wood | 14C |  | 42000 ± 100 | 44710±130 | Bolikhovsky, 1987 |
| LU-1270 | Wood | 14C |  | 43110 ± 1540 | 46410±1820 | Arslanov et al., 1986 |
| NSRL-10307 | Peat plant | 14C | 0.4 | 32800 ± 390 | 37430±650 | Forman et al., 2002 |
| АА-26940 | Plant fragment in IW | 14C | 0.7 | 32700 ± 580 | 37440±830 | Forman et al., 2002 |
| NSRL-10308 | Plant fragment in IW | 14C | 1.9 | 33400 ± 450 | 38210±660 | Forman et al., 2002 |
| NSRL-10309 | Plant fragment in IW | 14C | 3.5 | 32400 ± 440 | 36920±610 | Forman et al., 2002 |
| АА-26939 | Plant fragment in IW | 14C | 4.3 | 32400 ± 500 | 36990±700 | Forman et al., 2002 |
| АА-26937 | Plant fragment in IW | 14C | 0.9 | 29860 ± 720 | 34330±820 | Forman et al., 2002 |
| NSRL-10310 | Peat plant | 14C | 0 | 30100 ± 260 | 34590±260 | Forman et al., 2002 |
| АА-26941 | Plant | 14C | 1 | 27980 ± 380 | 32160±540 | Forman et al., 2002 |
| АА-26942 | Plant | 14C | 2 | 28560 ± 360 | 32800±550 | Forman et al., 2002 |
| АА-26945 | Plant | 14C | 3.3 | 28233 ± 362 | 32450±530 | Forman et al., 2002 |
| АА-26944 | Plant | 14C | 0.2 | 28359 ± 327 | 32570±490 | Forman et al., 2002 |
| NSRL-10312 | Plant | 14C | 2.6 | 25100 ± 560 | 29400±590 | Forman et al., 2002 |
| NSRL-10311 | Plant | 14C | 3.3 | 27300 ± 430 | 31470±450 | Forman et al., 2002 |
| АА-26946 | Plant | 14C | 3.5 | 28280 ± 421 | 32520±590 | Forman et al., 2002 |
| АА-26947 | Plant | 14C | 4.1 | 27450 ± 320 | 31510±300 | Forman et al., 2002 |
| АА-26948 | Plant | 14C | 5.1 | 26230 ± 260 | 30520±260 | Forman et al., 2002 |
| АА-26949 | Plant | 14C | 19.8 | 15025 ± 95 | 18420±150 | Forman et al., 2002 |
| АА-26950 | Moss | 14C | 20.3 | 14280 ± 90 | 17380±180 | Forman et al., 2002 |
| АА-26951 | Moss | 14C | 22.4 | 13225 ± 85 | 15890±130 | Forman et al., 2002 |
| АА-26952 | Moss | 14C | 23.1 | 12220 ± 75 | 14200±190 | Forman et al., 2002 |
| АА-26962 | Moss | 14C | 18.3 | 16360 ± 120 | 19760±150 | Forman et al., 2002 |
| АА-26961 | Moss | 14C | 18.4 | 15020 ± 120 | 18400±160 | Forman et al., 2002 |
| АА-26960 | Moss | 14C | 18.7 | 14140 ± 100 | 17200±120 | Forman et al., 2002 |
| АА-26959 | Moss | 14C | 21 | 13845 ± 80 | 16800±130 | Forman et al., 2002 |
| АА-26958 | Moss | 14C | 22.3 | 12980 ± 80 | 15520±130 | Forman et al., 2002 |
| АА-26965 | Moss | 14C | 21.2 | 13975 ± 95 | 16980±160 | Forman et al., 2002 |
| АА-26964 | Moss | 14C | 13.2 | 13060 ± 100 | 15640±160 | Forman et al., 2002 |
| АА-26966 | Moss | 14C | 13.8 | 13990 ± 100 | 17010±170 | Forman et al., 2002 |
| Tln-1059 | Moss | 14C |  | 13830 ± 260 | 16760±370 | Gataullin, 1988 |
| Tln-1026 | Plant | 14C |  | 13970 ± 140 | 16960±210 | Gataullin, 1988 |
| GIN-5197 | Moss | 14C |  | 13280 ± 140 | 15970±210 | Bolikhovsky, 1987 |
| GIN-5196 | Moss | 14C |  | 13340 ± 200 | 16060±300 | Bolikhovsky, 1987 |
| АА-20496 | Plant | 14C | 19.5 | 14160 ± 120 | 17230±160 | Forman et al., 2002 |
| АА-20495 | Plant | 14C | 20.2 | 13780 ± 190 | 16700±270 | Forman et al., 2002 |
| АА-20494 | Plant | 14C | 21.4 | 13750 ± 110 | 16670±180 | Forman et al., 2002 |
| АА-20493 | Plant | 14C | 22.4 | 13265 ± 150 | 15950±220 | Forman et al., 2002 |
| **Ery-Maretayakha River mouth (EM)** | | | | | | |
| Holocene deposits | | | | | | |
| LU-6534 | Plant root | 14C | 16 | 9100±90 | 10280±130 | Oblogov et al., 2012 |
| LU-6535 | Peat | 14C | 21.2 | 8 500±90 | 9480±90 | Oblogov et al., 2012 |
| GIN-2468 |  | 14C | 9.3 | 3 900 ± 100 | 4320±150 | Vasil’chuk, 1992 |
| Late Pleistocene deposits | | | | | | |
| GIN-2470 |  | 14C | 3.5 | 30200 ± 800 | 34740±870 | Vasil’chuk, 1992 |
| GIN-  2638 |  | 14C | 4.5 | 28600 ± 800 | 32940±900 | Vasil’chuk, 1992 |
| GIN-2471 |  | 14C | 5 | 25100 ± 220 | 29430±270 | Vasil’chuk, 1992 |
| GIN-2469 |  | 14C | 5.9 | 21900 ± 900 | 26280±960 | Vasil’chuk, 1992 |
| LU-6542 | Peat | 14C | 7.8 | 21930±370 | 26300±390 | Oblogov et al., 2012 |
| **Matyuisale trading post (MA)** | | | | | | |
| Holocene deposits | | | | | | |
| GIN-3588 | Peat | 14C | 1.4 | 11400±200 | 13300±190 | Trofimov et al., 1986 |
| GIN-3581 | Detritus | 14C | 12.5 | 11070±150 | 12980±130 | Trofimov et al., 1986 |
| GIN-3583 | Detritus | 14C | 8 | 9940 ±70 | 12980±130 | Trofimov et al., 1986 |
| GIN-3580 | Detritus | 14C | 11.3 | 9570±50 | 10920±120 | Trofimov et al., 1986 |
| LU 6537 | Peat | 14C | 9.1 | 7830±100 | 8690±170 | Streletskaya et al., 2012 |
| LU 6538 | Peat | 14C | 7.7 | 7700±80 | 8500±70 | Streletskaya et al., 2012 |
| GIN-3626 | Detritus | 14C | 9.5 | 8330±60 | 9330±90 | Trofimov et al., 1986 |
| GIN-3624 | Detritus | 14C | 11.9 | 6520±60 | 7420±70 | Trofimov et al., 1986 |
| GIN-3582 | Peat | 14C | 12 | 490±100 | 500±100 | Trofimov et al., 1986 |
| Late Pleistocene deposits | | | | | | |
| LU 6539 | Peat | 14C | 11.5 | 36170±1080 | 41170±1030 | Pismeniuk et al., 2019 |
| GIN -3579 | Detritus | 14C | 7 | 31800±700 | 36380±890 | Trofimov et al., 1986 |
| **Pakha-Sale Cape (PS)** | | | | | | |
| Holocene deposits | | | | | | |
| LU-6541 | Wood | 14C | 4 | 8030 ± 80 | 8880±130 | Oblogov et al., 2012 |
| LU-6540 | Wood | 14C | 7.4 | 5280 ± 160 | 6050±180 | Oblogov et al., 2012 |
| LU-6531 | Wood | 14C | 9.2 | 6630 ± 120 | 7510±100 | Streletskaya et al., 2012 |
| LU-6532 | Peat | 14C | 8.9 | 7850 ± 120 | 8710±170 | Streletskaya et al., 2012 |
| LU-6533 | Peat | 14C | 8.7 | 8030 ± 70 | 8880±120 | Streletskaya et al., 2012 |
| **Sibiryakov Island (SB)** | | | | | | |
| Holocene deposits | | | | | | |
| SOAN-7946 | Peat | 14C | 3 | 11435 ±170 | 13330±160 | Streletskaya et al., 2012 |
| LU-6408 | Peat | 14C | 2.1 | 8920 ±360 | 10 060±450 | Gusev et al., 2013 |
| RLQG-119 | Sand | OSL | 2.0 |  | 8 600±700 | Gusev et al., 2013 |
| LU-6152 | Peat | 14C | 2.2 | 8070±130 | 8 970 ± 210 | Gusev et al., 2013 |
| SOAN-7947 | Peat | 14C | 3.1 | 3480±45 | 3750±70 | Streletskaya et al., 2012 |
| Late Pleistocene deposits | | | | | | |
| RLQG 2072-042 | Sand | OSL | 3 |  | 41 000±3200 | Gusev et al., 2013 |
| RLQG 2073-042 | Sand | OSL | 2.5 |  | 45 800 ±3500 | Gusev et al., 2013 |
| LU-6415 | Peat | 14C | 2.8 | ≥44 700 | ≥47 860 | Gusev et al.,2011 |
| LU-6405 | Peat | 14C | 2 | > 43 500 | ≥46 500 | Gusev et al.,2011 |
| SOAN-7944 | Plants | 14C | 2.2 | 27 285±350 | 31410±310 | Streletskaya et al., 2012 |
| SOAN-7945 | Plants | 14C | 2.2 | 27 085±320 | 31230±270 | Streletskaya et al., 2012 |
| LU-6410 | Peat | 14C | 4.6 | 12 450 ± 250 | 14 670 ± 450 | Gusev et al.,2011 |
| **Dikson (DI)** | | | | | | |
| Holocene deposits | | | | | | |
| LU-6420 | Wood | 14C | 3.2 | 8 670 ± 200 | 9 780 ± 260 | Gusev et al.,2011 |
| SOAN-7587 | Peat | 14C | 3.2 | 3 460±100 | 3730±130 | Streletskaya et al., 2013 |
| SOAN-7588 | Peat | 14C | 3.2 | 4 670±90 | 5390±130 | Streletskaya et al., 2013 |
| **Khrestianka River mouth (KR)** | | | | | | |
| Holocene deposits | | | | | | |
| LU-6418 | Wood | 14C | 2.5 | 8 370 ± 90 | 9350±110 | Gusev et al.,2011 |
| Late Pleistocene deposits | | | | | | |
| RLQG 1948-119 | Sand | OSL | 1.5 |  | 38000±3000 | Gusev et al.,2011 |
| **Sopochnaya Karga (SK)** | | | | | | |
| Holocene deposits | | | | | | |
| LU-6417 | Wood | 14C | 23 | 10560 ± 620 | 12 180 ± 800 | Gusev et al.,2011 |
| АА-75298 | Freshwater mollusk | AMS | 26 | 10282±67 | 11 273±71 | Gusev et al.,2011 |
| LU-6543 | Peat | 14C | 3.5 | 9900 ± 230 | 11 460 ± 400 | Gusev et al.,2011 |
| LU-6545 | Peat | 14C | 3.6 | 9050 ± 70 | 10 210 ± 70 | Gusev et al.,2011 |
| GIN 13055 | Peat | 14C | 3.6 | 8 050±60 | 8910±120 | Gusev et al.,2011 |
| GIN 13056 | Peat | 14C | 3.7 | 7320 ± 130 | 8140±130 | Gusev et al.,2011 |
| Late Pleistocene deposits | | | | | | |
| RLQG  1770-107 | Sand | OSL | 8 |  | 117 700 ± 10 000 | Gusev et al.,2011 |
| RLQG 1769-107 | Sand | OSL | 7 |  | 112 500 ± 9 600 | Gusev et al.,2011 |
| RLQG 2248-034 | Sand | OSL | 5.0 |  | 28 000 ± 2100 | Gusev et al., 2015 |
| RLQG 2249-034 | Sand | OSL | 4.4 |  | 28 800 ± 2200 | Gusev et al., 2015 |
| RLQG 2250-034 | Sand | OSL | 4.0 |  | 29 500 ± 2300 | Gusev et al., 2015 |
| LU-6403 | Wood | 14C | 16 | ≥43700 | ≥46 700 | Gusev et al., 2011 |
| GrA-57723 | Carcass of a woolly mammoth | 14C | 6 | 44750±950 | 47300±1080 | Mashchenko et al., 2015 |
| LU-6547 | Peat | 14C | 5.5 | ≥39 600 | ≥43 800 | Gusev et al., 2011 |
| LU-6546 | Peat | 14C | 6.5 | ≥37 200 | ≥42 260 | Gusev et al., 2011 |
| UGAMS-12565 | Carcass of a woolly mammoth | 14C | 6 | 37830± 160 | 42210±80 | Mashchenko et al., 2015 |
| LU-6548 | Peat | 14C | 6 | ≥37 200 | ≥42 260 | Gusev et al., 2011 |
| LU-6412 | Wood | 14C | 19 | ≥38 300 | ≥42370 | Streletskaya et al., 2013 |
| AA-115962 | Wood | AMS | 18 | ≥52 800 | ≥52800 | Streletskaya et al., 2013 |

**Supplementary Table 2.** Main characteristics of different ground ice in the key sites.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | δ18O  ‰ | δD  ‰ | dexc | Mineralization mg/l | Сomposition of water-soluble salts | | Methane  content (ppmV) |
| Cations | Anions |
| **Holocene ice wedges** | | | | | | | |
| MS | -22.8/  -16.9/  -11.0 (49)1 | -170.8/  -127.7/  -89.8  (49) | -1.5/  8.2/  11.9  (49) | 37/84.0/218  (4) |  |  | 2/  146/  927 (20) |
| EM | -23.6/  -20.6/  -18.1  (6) | -179.9/  -154.6/  -133.6  (6) | 8.1/  10.2/  11.9  (6) | 212  (1) |  |  | - |
| MA | -19.2/  -18.3/  -17.2/  (6) | -143.5/  -137.2/  -127.9  (6) | 6.6/  9.3/  10.4  (6) | 37 (1) |  |  | - |
| PS | -19.1/  -19.2  (2) | -146.2  -146.7  (2) | 6.8  7.3  (2) | 17 (1) |  |  | - |
| SB | -22.2/  -19.9/  -16.0  (22) | -167.5/  -149.2/  -120.1  (22) | 7/  9.6/  11.7  (22) | 29/58/109 (7) |  |  | - |
| DI | -21.1/  -20.1/  -14.7  (31) | -158.8/  -150.4/  -107.8  (31) | 7.3/  10.6/  13.0  (31) | 26/88/360 (8) |  |  | - |
| SK | -23.3/  -19.7/  -17.1  (25) | -175/  -145.8/  -122  (25) | 7.6/  11.6/  15.6  (25) | 22 (1)- |  |  | 7/74/207/  (8) |
| **Late Pleistocene ice wedges** | | | | | | | |
| MS | -27/  -24/  -16.6  (170) | -208/  -183/  -123.7  (170) | 3/  7.8/  12.2  (170) | 25/70/104  (13) |  |  | 2/40/357  (28) |
| EM | -24.7/  -24/  -22.6  (4) | -193.1/  -186.3/  -176.5  (4) | 4.2/  5.2/  6.7  (4) | 126  (1) |  |  |  |
| KR | -23.5/  -22.7/  -22  (17) | -179.7/  -172.6/  -167.7  (17) | 8.2  9.1  10.2  (17) |  |  |  |  |
| DI | -26.6/  -24.2/  -22.9  (10) | -204.3/  -185.5/  -175.13  (10) | 6.97  8.5  10.3  (10) | 47/52/60  (3) |  |  | - |
| SK | -26.9/  -24/  -21.7  (56) | -204.8/  -184.8/  -164.8  (56) | -0.4  7.229  10.9  (56) | 57/128/266  (8) |  |  | 24/55/90  (5) |
| **MTGI (I type)** | | | | | | | |
| MS | -21.5/  -19.4/  -17.2  (33) | -165/  -147/  -129 (33) | 5.19/ 7.9/ 10.3  (33) | 23/103/260  (8) |  |  | 2/1413/9182  (18) |
| SK | -24.2/  -22.9/  -17.2  (29) | -185.6/ -173.2/ -128.7  (29) | 2/  5.8/  8.9  (29) | 311/772/1068  (4) |  |  | 6/301/1177  (12) |
| **MTGI (II type)** | | | | | | | |
| MS | -21.9/  -15.4/  -7.5  (50) | -163.7/ - 126.1/ -67.9  (50) | -1.1/  6.4/  11.9  (50) | 32/100/218  (4) |  |  | 12/558/4663  (16) |

1Maximum / mean / minimum values (number of the samples)

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