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FIRST ^{230}Th/U DATE OF MIDDLE PLEISTOCENE PEAT BOG IN SIBERIA (KEY SECTION KRIVOSHEINO, WESTERN SIBERIA)

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Abstract: A ^{14}C date older than 53900 yrs BP was obtained for the uppermost part of the buried peat bog in Krivosheino section (Middle Pleistocene of Western Siberia). These sediments also yielded ^{230}Th/U dates of $195^{+10.8}_{-9.1}$ ka using the leachate alone (L/L) and 204^{+17}_{-13} ka using total sample dissolution (TSD) models. Peculiarities of ^{230}Th/U dating are discussed. Palynological investigation of the buried peat bog together with underlying and overlaying sediments, and comparison with palynological data from Baikal and Elgygytgyn lakes revealed that the peat layer in Krivosheino section was formed at the end of Shirta Interglacial (Marine Isotopic-Oxygenous stages MIS-7), when climate conditions at all studied sites were more severe compared to the modern ones.

Keywords: ^{230}Th/U dating, palynological data, palaeoclimates, Middle Pleistocene, Western Siberia.

1. INTRODUCTION

Only a few absolute dates are available for Siberian Middle Pleistocene deposits, which makes the perspective of obtaining new geochronological and palaeogeographical data a very important task. Recently, the use of uranium-thorium (^{230}Th/U) dating method has become increasingly common, for it allows to estimate the absolute age of buried continental organic interglacial and interstadial deposits that are younger than 300-350 ka but beyond the limits of radiocarbon dating and has been applied in Siberia to estimate the age of the Late Pleistocene deposits (Geyh, 2001; Kuznetsov and Maksimov, 2003; Arslanov *et al*., 2004; Maksimov *et al*., 2006; Kuznetsov, 2008; Laukhin *et al*., 2008a, b).

In 2008, a buried peat bog suitable for ^{230}Th/U-dating was found on the left bank of the Ob' River, near the village of Krivosheino (57°18'51"N and 83°56'42"E – **Fig. 1**), which is the reference section of the Middle Pleistocene deposits in Western Siberia. This section has been continuously studied for about 80 years (Grichuk, 1957, 1961, 1966, 1970; Bogdashev *et al*., 1961; Mizerov, 1961; Strizova, 1962; Strizova and Mizerov, 1962; Feniksova, 1968; Nikitin, 1970; Grichuk *et al*., 1971; Arkhipov and Volkova, 1994 and others).

In previous studies, findings of buried peat were referred to the end of the Middle Pleistocene in age. The aim of our study is to determine the absolute age of the buried peat bog and to perform a high-resolution palynological investigation of this layer together with the underlying and overlying deposits, to obtain a more precise

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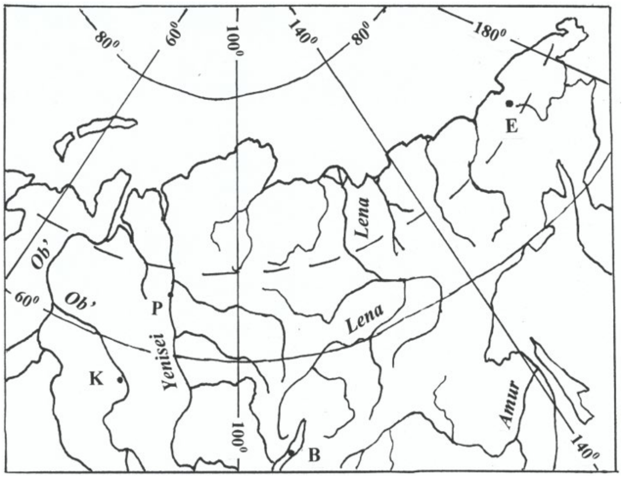

Fig. 1. *Location of sections discussed in the paper. K – Krivosheino, P – Popkovo, B – Baikal-Lake, E – Elgygytgyn-Lake.*

picture of the changing palaeoclimatic events in the second half of the Middle Pleistocene.

2. STRUCTURE OF KRIVOSHEINO SECTION

The 2.5 km long outcrop reveals the structure of a 50 m high watershed accumulative plain, with the height of the edge varying between 50 and 44-40 m. The northern part of the outcrop is covered by a talus, therefore similarly to earlier researchers, we studied only its southern, better exposed part. The northern part is distinguished from the southern by its predominantly sandy composition (Feniksova, 1968). Description of the Krivosheino outcrop has been published previously (e.g., Feniksova, 1968; Grichuk, 1970; Nikitin, 1970; Grichuk *et al*., 1971; see **Fig. 2**).

The sequence of layers is close to that described in (Grichuk *et al*., 1971), that is why we did not change the

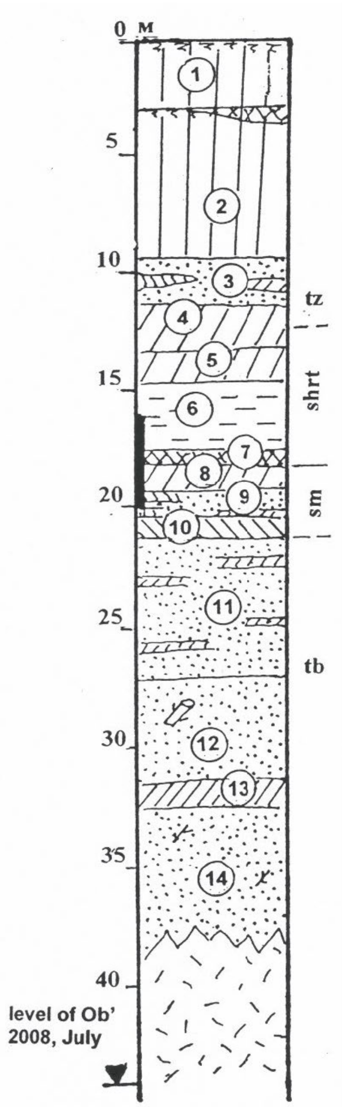

Fig. 2. *Outcrop of 2008, which was uncovered section of watershed accumulative plain on left bank of the Ob' River near Krivosheino. In circles are number of layers: 1) 0-3.0 m brownish-yellow sandy loam loess-like; 2) 3.0-9.2 m pale yellow sandy loam loess-like, with peat lenses and buried soil at the top; 3) 9.2-11.5 m yellow sand heterogranular with diagonal bedding; 4) 11.5-13.1 m laminated yellowish-gray loam; 5) 13.1-14.6 m laminated, dense bluish-gray loam; 6) 14.6-17.3 m bluish-gray clay, extending laterally into dove-gray loam, unstratified, ferruginous. The basal, up to 20 cm thick, layer represents an intercalation of grayish-yellow silt and rusty-brown loam sandy loam, in bottom layers interlayers are 0.5 to 2 cm thick; 7) 17.3-18.0 m peat with a lens of gyttja in upper half of the layer. Brownish peat, dense, finely laminated, with horizontal layers carrying grass and seeds along laminae, with wood debris and thin (1-2 mm) discontinuous seams of dove-gray sandy loam. Grayish-brownish gyttja with wavy horizontal laminae, lamination is indistinct and emphasized by the horizontal orientation of wood debris. At the base of the gyttja there is a 5-6 cm thick lens of dove-gray loam. Both, the top and the bottom contacts are well-pronounced, the bottom contact is erosional; 8) 18.0-19.0 m bluish-gray to dove-gray loam, light to medium, with indistinct lamination, the upper part with small-size fragments, the basal part plastic with conchoidal fracture; 9) 19.0-20.2 m finely laminated sediment with intermittent layers of grey, light sandy loam, loam and pale-yellow silt, well washed and sorted. Interlayers are 1-2 mm thick and less. Lamination is wavy and horizontal. At the top of the layer there is a dense ferriferous crust (1-5 cm) which locally is divided into four rusty-black layers of sandy loam and sand 2-4 mm thick; 10) 20.2-21.0 m gray sandy loam thin laminated; 11) 21.0-27.0 m light gray sand fine-grained, horizontally layered with thin layers of loam; 12) 27.0-31.2 m yellow sand, obliquely-laminated, heterogranular with gravel and wood debris in the upper part; 13) 31.2-32.4 m gray loam coarse-laminar; 14) 32.4-38.4 m gray sand with plant debris. Below this horizon there is talus and beach.*
The black bar on the left indicates the interval where samples on spore-and-pollen analyses were collected (see spore-and-pollen diagram on ***Fig. 6****); stratigraphical indexes see on* ***Table 1****.*

numeration of the layers, although their thickness and sometimes composition change over short distances. The following layers were previously dated according to their stratigraphical position and palaeobotanical data (Grichuk *et al.*, 1971): layers 14-11 – were referred to the first half of the Middle Pleistocene, Tobol Regiostage (**Table 1**), locally the underlying deposits of the Lower Pleistocene age are exposed. This part of the section together with the remains of macroflora in it were of greatest interest to previous researchers. The first palynologocal data were obtained from this interval of the section (Grichuk, 1957). Layers 10-8 were referred to the Samarovo Glacial, layer 7 and the basal part of layer 4 to the Shirta Interglacial (?), the upper part of layer 4 and layer 3 to the Taz Glacial Regiostage; layers 2 and 1 to the Upper Pleistocene. V.P. Nikitin identified 19 macrofloral taxa from layer 7, these identifications do not contradict the palynological data but also do not provide any additional information. Nevertheless, the presence of the remains of *Betula humilis, B. nana, Larix sibirica, Pinus silvesris* and abundance of *Picea abovata* in the macroflora is noteworthy.

We discovered the buried peat bog in the southern part of the outcrop at 17.3-18 m below the edge (layer 7). We studied the depth interval of approximately 16-20 m in detail. Peat samples for ^{230}Th/U dating were collected, as well as samples from the entire interval for spore and pollen analysis. Shortly before we conducted the ^{230}Th/U dating of the buried peat (layer 7), an infinite ^{14}C date (≥53.9 ka, LU-6024) was obtained (Maksimov *et al.*, 2009) for a sample from the top of the peat (0-2 cm).

3. ^{230}Th/U-DATING OF THE BURIED PEAT BOG

The ideal model of ^{230}Th/U-dating method of Pleistocene deposits is based on two assumptions: 1) in the moment of its formation sediments include only uranium, from which as a result of its radioactive decay accumulate the daughter isotope of ^{230}Th, called radiogenic; 2) in post-sedimentary time the deposits to be dated should behave like a closed radiometric system with regard to U and Th. The buried organic deposits are not a completely ideal system, because at the moment of its formation they could have been contaminated by varying amounts of mineral detrital material containing thorium isotopes, including ^{230}Th, named primary thorium (or "nonradiogenic" thorium). In this case, the quantitative contribution of primary ^{230}Th, partially decayed for the present moment, should be taken into account (deducted) for determining ^{230}Th age. Primary thorium contamination is characterized by concrete value of the ^{230}Th/^{232}Th activity ratio (AR). It is decreased during a time (t) from the moment of formation of deposits on the following relationship:

$$\left(\frac{^{230}Th}{^{232}Th}\right)_t = \left(\frac{^{230}Th}{^{232}Th}\right)_0 \cdot e^{-\lambda_0 t} \tag{3.1}$$

where $\left(\frac{^{230}Th}{^{232}Th}\right)_0$ – the value of the initial thorium contamination at the time of formation of deposits (time t is equal to zero); $\left(\frac{^{230}Th}{^{232}Th}\right)_t$ – the value of the thorium contamination at present time t; λ_0 – radioactive decay constant of ^{230}Th.

In reality, the variable parameter in **Eq. 3.1** is the activity of primary ^{230}Th only which decreases in time. The ^{232}Th activity during the time interval available for ^{230}Th/U method up to 300-350 thousand years remains practically unchanged because of its great half-life time about $1.3 \cdot 10^{10}$ years. As a rule, this radionuclide is found in measurable contents in peat samples. It allows to assess the activity of primary ^{230}Th in some way and make a correction of age calculations. The most promising way in this respect is the isochronous approach, which implies the quantitative determination the U and Th isotopes in several coeval peat samples. The isochronous approach can be applied if the following two assumptions are fulfilled: 1) the primary thorium contamination in selected coeval samples must be the same as well as the correction factor; 2) samples form a closed radiometric systems relative to the uranium and thorium isotopes.

From our point of view the objective criteria of selection of experimental points for calculation of a reliable age are absent till now. Therefore, we used the new version of isochronous approximation, successfully applied before (Maksimov *et al.*, 2006, 2007; Laukhin *et al.*, 2008a, b). Its basic requirement is the agreement of the isochronously corrected ages for a set of the same coeval samples obtained applying both, the "leachate alone" (L/L) and the „total sample dissolution" (TSD) models. The U and Th specific activities of 8 samples (**Table 2**) selected in 34-55 cm layer from the roof of peat bog was determined. The radionuclides were extracted applying both L/L (by "aqua regia" as the extracting agent) and TSD models (Laukhin *et al.*, 2008b). Analytical data of four samples from depths 34-37, 40-43, 49-52, 52-55 cm were suitable for the calculation of a reliable age estimate. Age calculations were produced separately for both L/L and TSD models by several stages applying technique proposed by M. Geyh, F. Maksimov *et al*. Geyh, 2001; Maksimov *et al.*, 2007; Laukhin *et al.*, 2008b. With

Table 1. *Correlation Pleistocene regiostages of Western Siberia and marine isotopic-oxygenous stages (MIS) of part of Middle and beginning Upper part Pleistocene.*

Pleistocene	Regiostage (index)	MIS
Upper	Kazantsevo (kz)	5
Middle	Taz (tz)	6
	Shirta (shrt)	7
	Samarovo (sm)	8
	Tobol (tb)	9

Table 2. *Results of radiochemical determination of U and Th isotopes in peat samples from the Krivosheino section.*

Depth (cm)	Ash (%)	^{238}U (dpm/g)	^{234}U (dpm/g)	^{230}Th (dpm/g)	^{232}Th (dpm/g)	^{230}Th/^{234}U	^{234}U/^{238}U
L/L-model							
34-37	81.12	2.365±0.085	3.33±0.11	2.981±0.056	0.731±0.026	0.895±0.034	1.408±0.051
40-43	35.89	4.765±0.14	6.77±0.20	5.920±0.065	0.566±0.015	0.874±0.027	1.425±0.028
43-45	26.33	4.75±0.14	6.94±0.19	5.181±0.093	0.458±0.021	0.746±0.024	1.462±0.039
45-46	28.2	2.860±0.078	3.813±0.098	4.853±0.051	0.253±0.010	1.273±0.035	1.333±0.032
46-47	29.3	2.999±0.066	4.252±0.088	3.967±0.040	0.266±0.009	0.933±0.022	1.418±0.027
47-49	30.45	8.65±0.21	11.63±0.28	8.92±0.13	0.377±0.015	0.767±0.021	1.345±0.015
49-52	42.28	7.72±0.18	10.71±0.24	9.63±0.11	0.556±0.019	0.899±0.023	1.388±0.018
52-55	63.96	5.22±0.15	7.09±0.20	6.278±0.077	0.391±0.015	0.886±0.027	1.358±0.030
TSD-model							
34-37	81.12	8.77±0.28	12.22±0.37	12.14±0.20	3.382±0.084	0.993±0.034	1.394±0.035
40-43	35.89	8.72±0.26	12.29±0.36	11.42±0.17	1.424±0.040	0.930±0.030	1.409±0.025
43-45	26.33	7.73±0.20	10.65±0.27	9.65±0.12	0.953±0.024	0.906±0.025	1.379±0.019
45-46	28.2	13.14±0.25	18.22±0.34	17.21±0.13	1.153±0.028	0.945±0.019	1.387±0.016
46-47	29.3	15.27±0.26	20.46±0.34	16.81±0.11	1.163±0.023	0.822±0.014	1.340±0.013
47-49	30.45	16.05±0.36	21.97±0.48	17.96±0.26	1.031±0.025	0.818±0.022	1.368±0.013
49-52	42.28	15.71±0.36	21.49±0.49	19.96±0.22	1.554±0.032	0.929±0.023	1.368±0.015
52-55	63.96	18.70±0.79	24.80±1.02	22.24±0.30	2.344±0.066	0.897±0.039	1.327±0.031

the use of analytical data the linear dependences, so called isochrones, are built using the least squares method (York, 1966) and correction factors f are defined as intersection of the isochrone on the Y axis (**Fig. 3**).

The correction factor f for TSD-model directly equals the value of primary thorium contamination at the present time according to **Eq. 3.1**. The value f for L/L- model depends on the value of primary thorium contamination as well as on the conditions of experiment, i.e., from that, in which relationship the uranium and thorium isotopes leach from the mineral fraction. The analytical data obtained by both chemical techniques for each individual sample was corrected according to **Eq. 3.2**:

$$\frac{^{230}Th^*}{^{234}U} = \frac{^{230}Th - f \cdot {}^{232}Th}{^{234}U} \tag{3.2}$$

where ^{230}Th, ^{232}Th, ^{234}U – experimental activities in a sample for L/L (or TSD)-model (**Table 2**); f – correction factor for L/L (or TSD)-model (**Fig. 3**); ^{230}Th* – activity of radiogenic thorium in a sample for L/L (or TSD)-

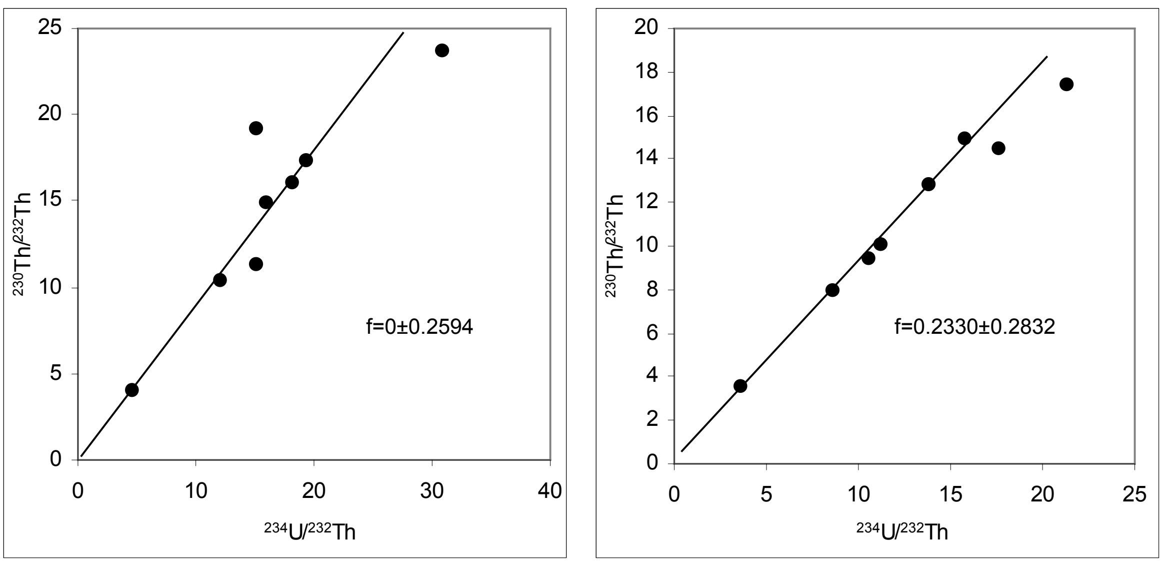

Fig. 3. *Linear dependences in the isochronous coordinates built on analytical data of peat from the Krivosheino section (correlation coefficients >0.99). Correction factors f characterize the value of the primary thorium contamination of peat for the selected set of samples for the two different chemical treatment techniques.*

model ($^{230}Th^* = {}^{230}Th$ for L/L-model from f=0); $^{230}Th^*/^{234}U$ – corrected activity ratio in a sample for L/L (or TSD)-model.

Detritally-corrected L/L (or TSD) sample age is calculated from corrected $^{230}Th^*/^{234}U$ AR and analytical value of $^{234}U/^{238}U$ AR according to the equation by Kauffmann and Broker (Kaufman and Broecker, 1965). The four detritally-corrected dates are calculated with the use of analytical data obtained for the L/L-model as well as for the TSD-model. Their mean weighted value is accepted as the value of L/L (or TSD) isochronously-corrected age of peat samples.

In this way the well agreeing isochronously-corrected ages of $195.2^{+10.8}_{-9.1}$ kyr and 204.1^{+17}_{-13} kyr were obtained for the L/L- and TSD-models, respectively.

The peat bog is covered by clays and underlain by loams. Probably, it can ensure that the radiometric system of peat behaves as a more or less closed system in respect to U and Th isotopes. However, the two points for each of both models are located on the right side of the straight line in **Fig. 3** and correspond to the underestimated age of ≤160 kyr. In contrast, the other points are fitted on or near the isochrones and give approximately 200 kyr of age (**Fig. 4**). The samples corresponded to these points are selected from inner sub-layers of vertical peat profile in the range of 43-49 cm depth.

It can be assumed that groundwater could penetrate into the sub-layers of peat in this depth interval during postsedimentary time. Other words, an additional uranium uptake had the lateral direction and could lead to underestimation of the $^{230}Th/U$ age of the inner part of the peat bog and did not affect the neighboring upper and lower sub-layers.

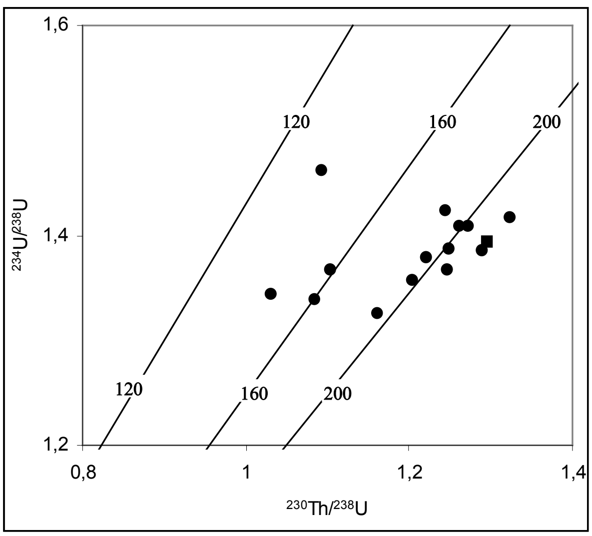

Fig. 4. *Corrected isotope data in $^{234}U/^{238}U$ – $^{230}U/^{238}U$ AR coordinates. Straight lines are the isochrones with 120, 160, 200 kyr age.*

Now the Krivosheino section is located much farther south of the southern boundary even of island permafrost (**Fig. 5**). In the Tazovian (MIS-6) time, it was located in the zone of continuous permafrost. In the Kazantsevian interglacial (MIS-5), suprapermafrost groundwater could penetrate into the peat layer during the thawing permafrost. This process could occur here in Holocene again during the degradation of the permafrost of Sartan cryo-arid time. In spite of some possible rejuvenation the isochronously-corrected ages obtained are in a good agreement with each other and fit in frames of MIS-7 (186-242 kyr ago; Bassinot *et al.*, 1994) and reflect the late stage of Middle Pleistocene warming up.

4. LANDSCAPE-CLIMATIC CONDITIONS IN THE SECOND HALF OF THE MIDDLE PLEISTOCENE BASED ON PALYNOLOGICAL STUDY OF KRIVOSHEINO SECTION AND COMPARISON WITH THE ADJACENT TERRITORIES

As a result of the complex structure of the section, especially of its upper, post-Tobol part, as well as its poor exposure, the palynological study was difficult and took a very long time. Already in the mid-1950s, M.P. Grichuk (1957) revealed the transition from the northern spruce taiga to the birch open woodlands and then its further replacement during the Samarovo time by grasslands with shrubs and polar birch. In the beginning of the 1960s, this section was studied by M.B. Sadikova and A.I. Strizhova (Grichuk, 1961; Bogdashev *et al.*, 1961; Strizova, 1962; Strizova and Mizerov, 1962; Feniksova, 1968), who arrived at similar conclusions (Grichuk, 1957, 1961). Later, in the mid-1960s M.P. Grichuk (1966) studied pollen spectra of Shirta age in the layers overlying Samarovo beds. As a result, by the beginning of the 1970s she summarized the results in a diagram based on the data from eight different sites of the outcrop which showed the sequence of palynological spectra from the Tobol to the beginning of the Taz epochs (Grichuk *et al.*, 1971). However, even with this complete spore-and-pollen diagram (comprised of the data from several sampling sites), she could only give a schematic overview of the transition from the Samarovo Glacial to Shirta Interglacial (?). We studied this transition at one site in more detail.

We sampled the buried peat bog (layer 7) in 5 cm intervals, and the over- and underlying deposits in 10 cm intervals. The diagram clearly displays a hiatus in sedimentation at the boundary between the bluish-gray loam of layer 8 and peat of layer 7. In the section we observe an erosional contact (**Figs. 2** and **5**) at this boundary, which had been mentioned earlier (Mizerov, 1961; Grichuk *et al.*, 1971 and others). In our spore-and-pollen diagram (**Fig. 5**) it coincides with the sharp increase (70-88%) in the percentage of pollen of arboreal and shrub taxa together with the similarly sharp decrease in the percentage of grasses and small shrubs 7-14 to 26.4%) and almost complete absence of spores (1-5%). At the

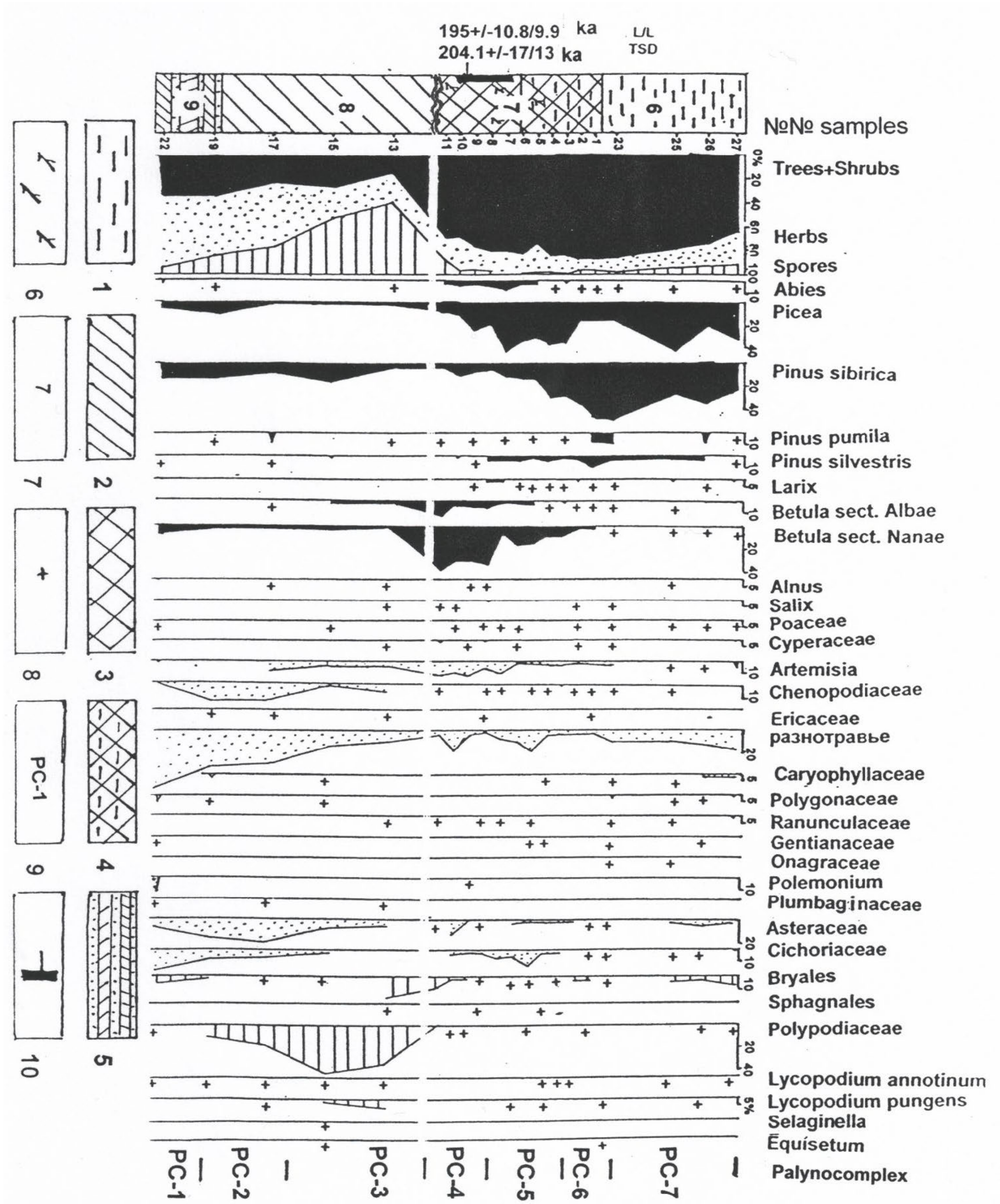

Fig. 5. *Fragment of Middle Pleistocene section in Krivosheino outcrop and spore-and-pollen diagram of this part section. 1 – clays, 2 – loams, 3 – peat, 4 – loam with peat, clayey peat, gyttja, 5 – interbedding of sands, sandy loams and loams, 6 – debris of wood, 7 – number of layers (see Fig. 2 and text), 8 – quantity of spore or pollen less 2%, 9 – disposition of palynocomplexes, 10 – interval of sample collected on* ^{230}*Th/U-dating.*

same time, in layers 8 and 9 the correlation is the opposite: arboreal and shrub pollen reaches up to 15-35%, grasses and small shrubs comprise 22-59%, and spores – 7-62%. Accordingly, there is a redistribution of taxa within these groups. Seven palynological complexes (PC 1-7) were distinguished on the spore-and-pollen diagram.

Forbs pollen is abundant (53%) in layer 9 (PC 1), represented by the meadow taxa (*Liliaceae, Polygonaceae,Rosacee*), plants from moist and swampy areas (*Polymonium, Polygonum amphibium*), steppe grasses (*Asteraceae*), together with *Cichoriaceae*. Xerophytes are rare. Meadows with forbs and *Gramineae* together with swampy sparse woodlands with dwarf birch and spruce were wide spread under cold and humid climate conditions. A variety of vegetation ranged from swampy sparse woodlands with spruce and dwarf birch to larger woodless open areas with xerophytes and spores of cold-resistant *Lycopodium*. During accumulation of layer 8 (PC 2 and PC 3), in first the percentage of forbs drops down to 26-31%, while the share of xerophytes reaches up to 25%, the latter include *Chenopodiaceae* (represented by seven taxa) and *Artemisia, Plumbogenaceae.* Single findings of birch pollen, including dwarf birch, Siberian dwarf pine and spruce are noteworthy. Open woodless areas with xerophytes occupy larger territories, the following taxa are introduced: birch, Siberian dwarf pine and cold-resistant *Lycopodium.* Climate was cold and dry. In palynological complex (PC 3) the spores of *Polypodiaceae* (37-43%) become dominant. Green and *Sphagnum* mosses are present, together with cold-resistant and woodland-inhabiting type of *Lycopodium*, as well as *Selaginella* and *Equisetum*. Sparsely growing birch trees become more widespread together with spruce, dwarf birch, ferns, brushwoods of alder and *Salix* growing along rivers, xerophytic formations, all of which indicate cold and humid conditions. According to M.P.Grichuk (Grichuk, 1970, Grichuk *et al.*, 1971 and others). PC 1-3 fall into the section interval accumulated during the Samarovo Glacial, when in the periglacial area of the Ob' lowland meadows and swampy sparse woodlands were replaced by tundra-forest-steppe and later by swampy birch woodlands with spruce and ferns. Over the last 50 years different authors agree about the boundary of the maximum expansion of the Samarovo Glaciation (Astakhov, 2009, Mizerov, 1961 and many others). Accordingly, at that time the site of Krivosheino section was located 400 km to the south of the Samarovo ice sheet, that is in the periglacial area, which has been confirmed by the composition of the vegetation reflected by PC 1-3. The hiatus in the sedimentation, falling in between PC 3 and 4 (**Fig. 5**) does not allow to conclude which particular part of the Samarovo epoch does the vegetation of PC 1-3 correspond to. Below we discuss which interval of the Shirta period do we observe in PC 4-7.

Arboreal and shrubby pollen predominates in the basal part of the peat from layer 7. Pollen of dwarf and birch is very abundant as treelike (4-14%) and shrubs (31-38%), while spruce and cedar pine pollen is less abundant. At about 200 ka, birch forests were widespread, sometimes together with larch, spruce and fir, as well as various forbs, *Gramineae*, and ferns. Upward the section, in PC 5, spruce pollen is abundant, while cedar pine, fir trees and birch including dwarf birch become less abundant. Among grasses, *Cichoriaceae* and *Artemisia* predominate. Spruce and fir woodlands with larch and birch prevailed. In PC 6, cedar pine 38-50% pollen is very abundant, unlike spruce, Siberian dwarf pine and fir. Spruce-cedar woodlands were widespread, similar to the modern middle taiga subzone when conditions are warm and humid. At present Krivosheino section is situated close to the southern boundary of the southern taiga subzone (**Fig. 6**).

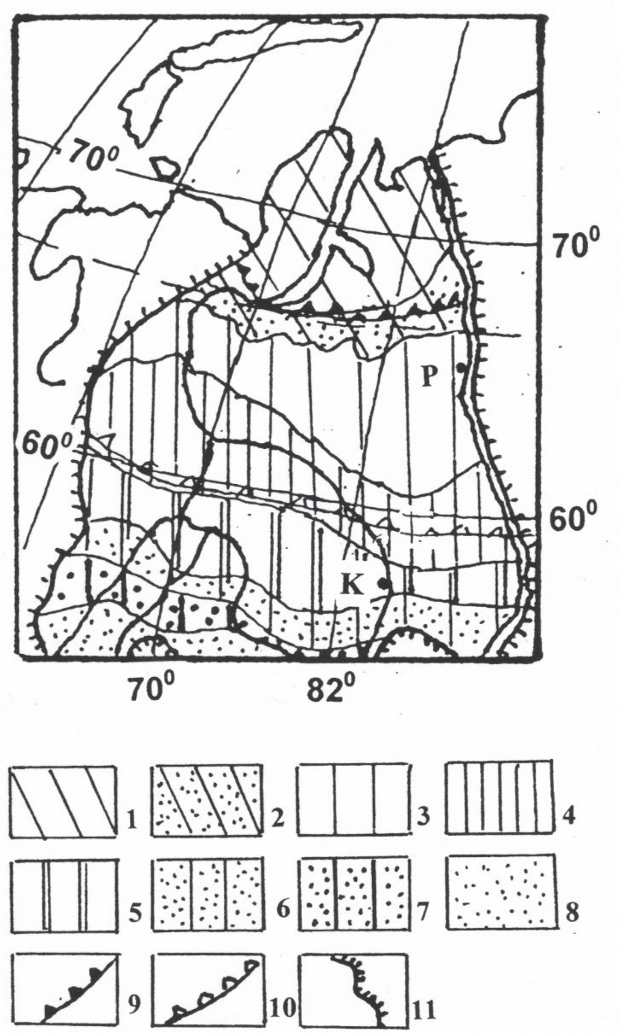

Fig. 6. *Scheme of vegetation zonality of Western Siberian plain. 1 – tundra, 2 – forest-tundra, 3 – northern taiga, 4 – middle taiga, 5 – southern taiga, 6 – open woodland, 7 – woodland-steppe, 8 – steppe, 9 – southern boundary of continuous permafrost, 10 – southern boundary of discontinuous and islands permafrost, 11 – boundaries of Western Siberian plain. K – Krivosheino, P – Popkovo.*

In the bottom of layer 6 (PC 7) pollen of Siberian dwarf pine and spruce are almost equally abundant. Spruce-cedar woodlands with admixture of fir trees and Siberian dwarf pine, as well as heather, ferns and *Lycopodium* predominated. Areas with sparsely growing birch and larch were less common. To conclude, based on the analysis of the vegetation in the interval of PC 4-7 (**Fig. 5**), environmental conditions were cooler and more humid than the modern ones. The entire interval covered by L/L and TSD ^{230}Th/U-datings is quite long in duration and includes, according to the marine oceanographic scale (Bassinot *et al.*, 1994), substages MIS 7.0-7.3 (**Fig. 7**).

If we consider that the L/L dating is more precise (with narrower confidence interval), then we see it in the "warm" substage MIS-7.1 of layer 7. Previously, palynospectra from this interval were characterized by the most thermophilic (for layers 7 and 6) vegetation PC 6 (**Figs. 5** and **7**). Later (PC 7) and earlier (PC 4 and 5) the vegetation was less thermophilic, which corresponds to the substages MIS-7.0 and MIS-7.2. The confidence interval of the L/L dating up and down from the sampling point is limited to the interval between MIS-7.0 and MIS-7.2. Most likely, layer 7 and the basal part of layer 6 of Krivosheino section were accumulated during the last third of the Shirta period (MIS-7), and the hiatus in sedimentation includes part of the Shirta epoch, together with substage MIS 7.3. In **Fig. 7**, the upper interval of this substage is shown schematically in order to display the entire confidence interval of the dating obtained with the TSD model.

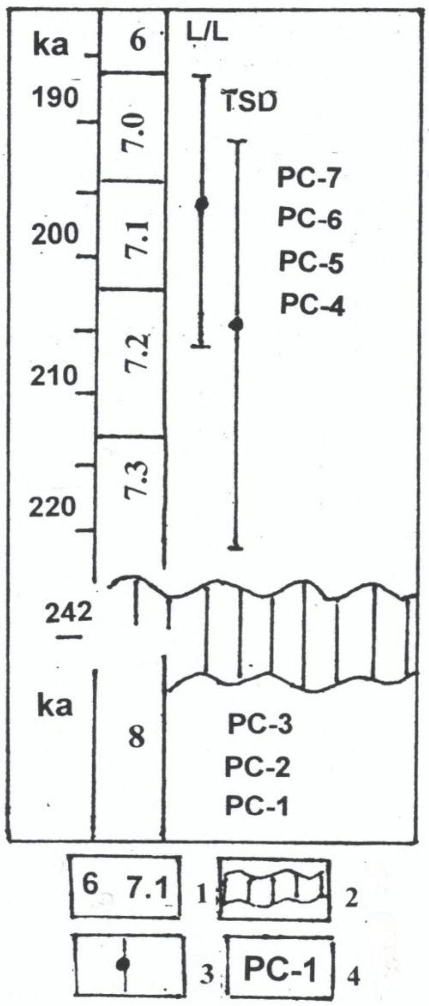

Fig. 7. *Disposition of palynocomplexes (see **Fig. 6**) concerning MIS scale. 1 – stages and substages of MIS, 2 – washout and nondeposition hiatus, 3 – ^{230}Th/U date and confiding interval of this date, 4 – disposition of palynocomplexes (see **Fig. 6**) concerning of stages and substages of MIS.*

Shirta beds were first distinguished in the 1950s and immediately became the matter of a dispute for their climatic interpretation, whether they represented interglacial (Grichuk, 1961; Bogdashev *et al.*, 1961; Zemtsov and Shatskyy, 1961 and others) or interstadial (Bogdashev *et al.*, 1961; Mizerov, 1957, 1961; Strelkov *et al.*, 1965 and others) deposits. This question is still open. In the recent summary reports on the Cenozoic in northern Asia (Cenozoic of climate 2005) and West Siberia (Volkova *et al.*, 2002), one can find both interpretations of the Shirta time. There are scattered thermoluminescence age determinations covering the time interval between approximately 210-180 ka (Arkhipov *et al*., 1997; Zubakov, 1986; Astakhov, 2009 and others) obtained on the West Siberian Plain between moraines of the Samarovo and Taz glaciations in the Ob' and Irtysh basins. Broad confidence intervals of these dates, fragmentariness of the sections within the Shirta Regiostage, multiple sedimentation hiatuses in the continental deposits and uncertainty in precise dating of the Middle Pleistocene paleoclimate events make the reconstruction of the vegetation development during the Shirta time very difficult. Most of these fragmentary sections from the northern West Siberian lowland were studied for palynospectra of the northern taiga. It was suggested that on the Belogorskyy Materik, at about 63ºN, the middle subzone of taiga expanded during the Shirta time, and the climate was modern-like (Arkhipov and Volkova, 1994). The uranium-ionium date of 233±10 ka (Zubakov, 1974) yielded from shells of marine mollusks is of particular interest. The material was obtained from near the Village of Popkovo, at about 65º N on the Yenisei River, from layers with southern-taiga palynospectra (Astakhov, 2009). Popkovo beds have been repeatedly compared with MIS 7 (Zubakov, 1986; Astakhov, 2009 and others), and the above mentioned date corresponds to MIS 7.5. Northward migration of the southern taiga subzone by 475-500 km from its present location suggests that the Shirta time for West Siberia can be considered an Interglacial, with an optimum centered at the early warming of that time.

Westward from the West Siberian Plain, in northeastern Europe from Lithuania to the Pechora River basin, MIS 7 was correlated with the Cherepet' Interglacial based on the ESR-dates of about 220 ka BP (Molodkov and Bolikhovskaya, 2006). To the south, interglacial deposits were traced to the upper reaches of the Oka River, where during the interglacial optimum hornbeam-oak and cedar-pine-broadleaved forests predominated (Molodkov and Bolikhovskaya, 2006). Recently, deposits of the second half of the Middle Pleistocene have also been studied in detail from the territory to the east of West Siberia.

Lacustrine sections are considered to be the best, most complete and continuous continental records. Within the last years in North Asia the most detailed studied lacustrine sections of the Middle Pleistocene age come from Lake Baikal in the southern Siberia and Elgygytgyn Lake from northern Chukotka (**Fig. 8**).

In Lake Baikal, the deep-water sediments recovered from borehole BDP-96-2 and dated at about 180-236 ka (MIS-7) correspond to interglacial deposits. This interval is characterized by three distinct peaks and two minima in organic silica content, reflecting three warmings and two coolings (Kuzmin *et al*., 2008). The middle peak dated at about 215 ka has the maximum range. The amplitude of this peak is approximately the same as the one corresponding to MIS-5e. But the total abundance of diatoms reaches maxima in the lower peak, which is smaller than the MIS-5e peak. Based on palynological data (Bezrukova *et al*., 2009), the interglacial optimum falls into the lower half of the Shirta time when fir taiga was widespread. Siberian cedar forests with fir and spruce, analogous to PC 6 in Krivosheino section, are more characteristic for the final stage of MIS-7 in Baikal area. However, during MIS-7, at about 200 ka, ridges in the Lake Baikal area reached the hionosphere level (Kuzmin *et al*., 2008). The altitudinal zonation of vegetation could average the composition of palynospectra in deep water sediments. The seismicity of the Baikal region could also influence the composition of deep water sediments in Lake Baikal. We do not find any of these factors complicating climatic paleoreconstructions when studying sediments of Lake Elgygytgyn.

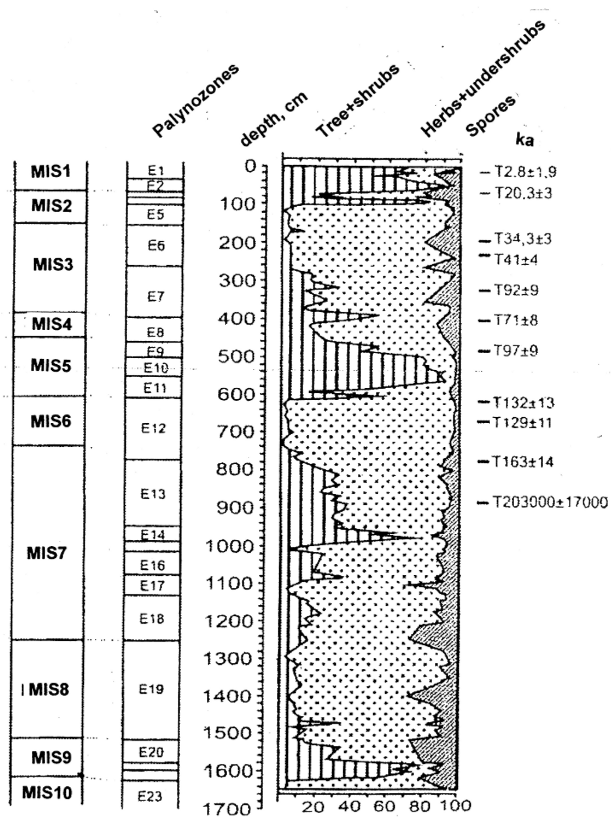

Fig. 8. *Correlation of palynozones of core of LZ-1024 bore hole of Elgygytgyn Lake sediments with stages of MIS (according T.V. Matrosova, 2009). T- thermolumeniscence dates (according Juschus* et al.*, 2007).*

A continuous section of the second half of the Middle Pleistocene was studied from sediments of Lake Elgygytgyn (**Fig. 8**) in the Anadyr' Plateau (Matrosova, 2009). The lake is located at about 67° 30' N in the hypo-Arctic herbaceous tundra. Shrublands (low osier-beds and dwarf birch) are only found in protected parts of the valleys. Light-coniferous forest with larch starts at 150 km and its main massif at 300 km to the south of the lake. In general, during MIS-7 climate in Elgygytgyn Lake area was cooler than modern. Although, in borehole LZ-1024 a sharp increase in the percentage of arboreal and shrub pollen is observed in palynozone E-14 (MIS-7 corresponds to palynozones E-18 - E-13). Larch migrated northward to the coast of the lake. Palynozone E-14 reflects climatic optimum of the Shirta Interglacial. For palynozone E-13 we have the thermoluminescence date of 203±17 ka (Juschus *et al*., 2007). The ^{230}Th/U date allows comparison of the peat from Krivosheino section with palynozone E-13 from the bottom sediments of Lake Elgygytgyn. Similar to palynozone E-13, peat from Krivosheino section was formed at the end of the Late Shirta time, after its climatic optimum.

5. CONCLUSIONS

Recently obtained data confirm the interglacial nature of the Shirta time interval. The climatic optimum was the most pronounced on the Yenisei River, where a northward shift of 475-500 km of the southern taiga subzone was accompanied by the marine transgression, which penetrated along the Yenisei Valley for more than 850 km to the south of the modern sea coast. Here the optimum occurred during the beginning of the interglacial. In the deep water sediments of Lake Baikal the optimum of the Shirta Interglacial is less pronounced, as indicated by the admixture of palynomorphs originating from the upper mountain belts. However, we can be certain, that the optimum did not take place in the very beginning of the interglacial. In the sediments of Lake Elgygytgyn the optimum of the Shirta Interglacial coincided with the middle warming, and the northward shift of vegetation zones most likely did not reach 300 km. Peat from Krivosheino section was formed at the end of the Shirta Interglacial, when climate was more severe compared to the modern at all the studied sites.

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