RADIOCARBON DATING OF THE KURILE LAKE CALDERA ERUPTION (SOUTH KAMCHATKA, RUSSIA)

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Key words: RADIOCARBON DATING, KAMCHATKA, KURILE LAKE CALDERA ERUPTION, PYROCLASTIC DEPOSITS, KO KEY-MARKER ASH

Abstract: In this paper the set of radiocarbon dates obtained for the caldera-forming early-Holocene Kurile Lake eruption, which deposited a very important key-marker ash (KO) and formed the isochronous benchmark, is analyzed. Previous 12 dates derived from samples collected mostly far from caldera, and fall into the significant time interval (7890-7530 BP). In 1996-98 we performed the extensive sampling of organic matter related to pyroclastic flow and fall KO deposits, and 17 new dates were obtained. We selected the valid dates from both data sets analyzing the sample types and taphonomy, to estimate the accurate age of the KO eruption, and sharpened the time-span (7690-7530 BP) where the reliable dates fall. The estimated age is 7618±14 BP (Cal. 6455 BC).

1. INTRODUCTION

Radiocarbon dating is often used to provide age estimates for various geological events. Unfortunately, many deposits do not contain organic matter by themselves, and we can estimate their ages only by dating various types of organic material associated with them. This material can form during long period of time and thus contains heterogeneous organic matter of different ages. Therefore, to get an accurate age of non-organic deposits, it is necessary to obtain series of radiocarbon dates instead of one or a few (Braitseva, *et al*., 1993). This provides the self-control of the method and allows receiving representative data. However, in some cases, such dates show widely discrepant values, and it is necessary to carefully consider each date to derive the definite radiocarbon age of the event. We are going to analyze the sources of radiocarbon date deviations and evaluate the data set for the case of repeated dating of a single strong volcanic eruption on various types of organic matter, and to estimate its age.

2. THE KURILE LAKE CALDERA ERUPTION, AND ITS DEPOSITS

This research was carried out for catastrophic Kurile Lake caldera eruption which took place in Early Holocene in South Kamchatka. Ejection of 140-170 km^3 of pyroclastic material resulted in formation of a collapse caldera *ca* 14 km in diameter (Melekestsev *et al.*, 1998). The total volume of tephra was 7-8 times larger than that of Krakatoa eruption (20 km^3) and was close to that of Tambora eruption, the largest one on historical record. The Kurile Lake caldera eruption produced rhyodacitic tephra fallout, voluminous ignimbrite and surge deposits. Thick flow deposits filled valleys and covered an area of about 1500 km^2 around the caldera. The ash-cloud moved through the southern half of the Kamchatka peninsula, across the Sea of Okhotsk to the Magadan region (northeastern Russia) and deposited an ash layer (**Fig. 1**), which is an important marker and isochronous stratigraphic benchmark for South Kamchatka and northern Kurile Islands (Braitseva *et al.*, 1997b). This was the strongest Holocene event of Kurile-Kamchatka volcanic belt, and its environmental impact was significant (Melekestsev *et al.*, 1998). Thus, it is very important to know its accurate age.

Therefore, the main purpose of the paper is to analyze and evaluate all the radiocarbon dates obtained for this eruption, and to present the radiocarbon and calibrated ages of this important event, which formed the key marker ash (KO).

3. PREVIOUS DATING

A few attempts were made earlier to estimate the age of the eruption. The earliest were undertaken in early 60-ies, in the Kurile Lake area. Two radiocarbon dates of 8000-8300 BP were obtained from charred wood and bedded soil samples from the deposits underlying the Kurile Lake ignimbrites (Kraevaia, 1967), and thus the early Holocene age of this event was set up. The next effort was performed at the beginning of 70-ies in the same region, when five dates of 8000-9500 BP were derived from charcoal samples (Masurenkov, 1980), but in most cases the exact stratigraphic position of the samples was unknown. Other two dates: 7860±100 (GIN-1062) and 7620±50 (GIN-1063), obtained from underlying peat and enclosed wood, were excluded from the analysis as too young. Thus, the age of the eruption was considered to be about 8350-8400 BP (Masurenkov, 1980). After that, the radiocarbon data related to the Kurile Lake eruption ash layer were collected farther from the caldera, mostly northwards and northwestwards. The dates were obtained on peat and soil samples, collected from under and above Kurile Lake ash layer. The most distant samples were collected in 1988 at the Magadan area (the northeast of Russia, **Fig. 1**), about 1000 km from the vent. In that case peat and humificated sandy-loams were collected from under and above the Kurile Lake ash. The dates show essential discrepancies, and the sample ages range from 6190 to 8770 BP (Melekestsev *et al.*, 1991).

The analysis of all these dates was performed by Braitseva *et al.* (1995). Two groups of dates were organized. The first group of reliable data consists of dates 7890-7530 BP, obtained on peat and soil samples, which under- and overlie the Kurile Lake ash (far from the vent), and two dates of charcoal and soil samples from the pyroclastic flow deposits and from beneath them (northwards from the caldera). Both dates showed good concordance and they are marked with (*) in **Table 1**. Nevertheless, these dates showed a significant range, about 360 years between the oldest and the youngest ones. The dates of the second group, 7980-8400 BP, seemed to be too old (Braitseva *et al.*, 1995), and were considered as outliers. The dates from the first data set (n=12) were used to calculate the mean age of the eruption, which was calibrated using Calib 3.0 (Stuiver and Reimer, 1993): 7666±12 BP and 6530 (6459) 6422 BC respectively (Braitseva *et al.*, 1997a). Two acid peaks of 6470 BC and 6476 BC were identified in the Greenland Ice sheet, probably matching with the Kurile Lake eruption.

However, most of the dates used for calculation have been obtained in distant localities. That is why, in 1996-98, when we conducted the detailed study of the Kurile Lake caldera deposits, we decided to get proximal samples to confirm the age determination.

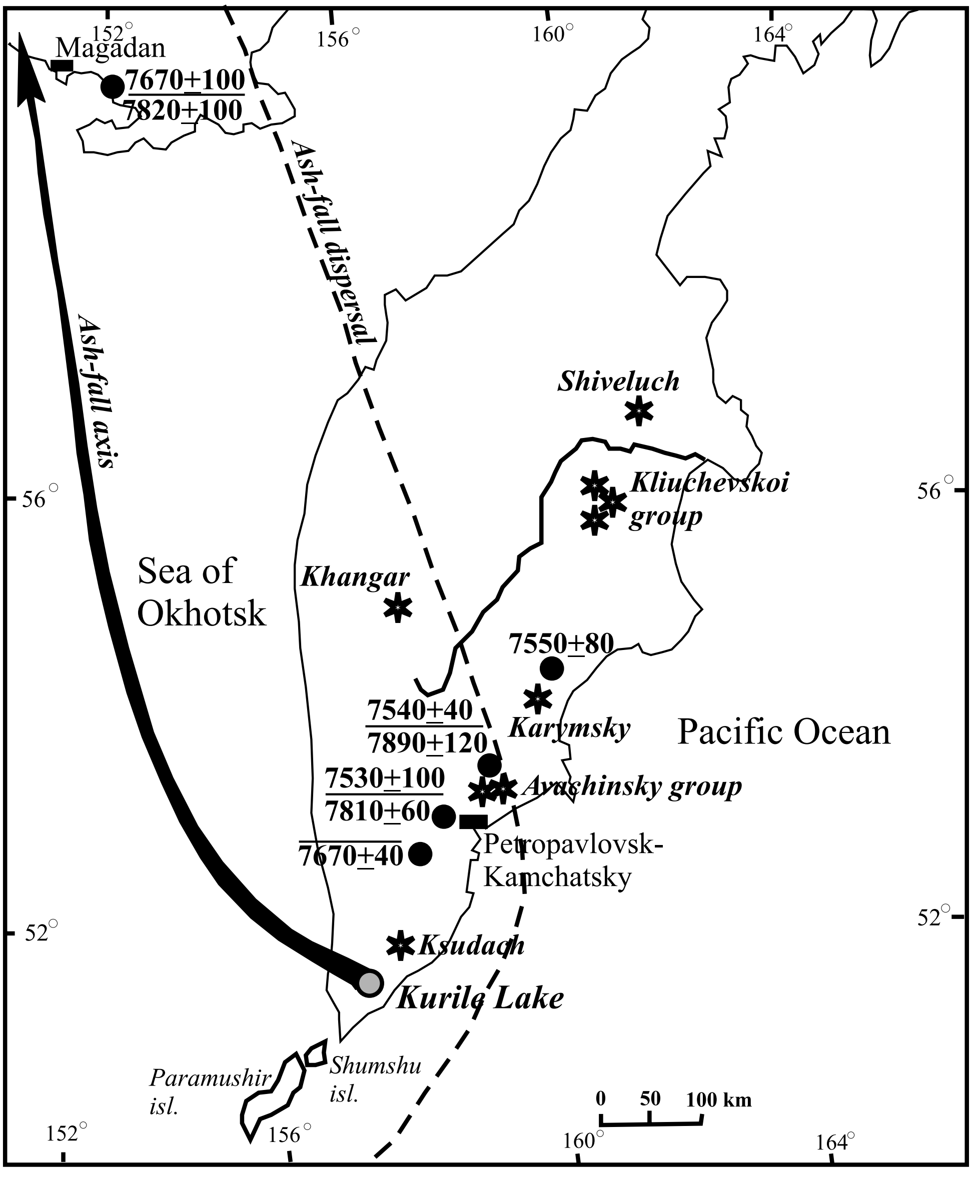

Fig. 1. Ash-fall axis and area of ash dispersal (1-cm isopach) for the Kurile Lake caldera eruption (from Braitseva et al., 1997); dates obtained from under and above Kurile Lake ash (Braitseva et al., 1995) beyond the area covered by pyroclastic flow deposits are presented.

4. NEW SAMPLES AND THE RADIOCARBON DATING

In 1996-1998 we performed extensive and accurate sampling of different types of organic matter, associated with the Kurile Lake deposits, in the vicinity of caldera. New samples included various charcoals and wood from within and under 50-200 m thick ignimbrite, charred soil layers and compressed peat buried by the eruption deposits, from many sites all around the caldera (**Fig. 2**).

Charcoals (7 samples) were collected mostly from the pyroclastic flow deposits. These are logs, branches or twigs, charred during the eruption under the thermal or chemical effect. Charcoal samples were pretreated using A-A-A procedure: after the sample cleansing in hot 5% HCl dilution it was washed with distilled water and then boiled for 20 minutes in 2% dilution of NaOH. Then the charcoal pieces were once more pretreated in hot 5% HCl dilution and washed with distilled water.

To evaluate the possibility of sample contamination by volcanic CO_2 in the gas-saturated pyroclastic flow (Braitseva *et al.*, 1993) we divided two log samples from the flow deposits into the 10-years tree-rings segments. The all dates are significantly the same (**Table 1**), which indicates lack of sample contamination by CO_2.

Sometimes, charcoal dates could be older then the eruption age due to inbuilt age of samples (in case of big logs and trunks), or due to capture of dead wood pieces by cooling flow (in any case). These possibilities are analyzed later on.

2 wood samples were collected form under the Kurile Lake tephra fall and pyroclastic flow deposits. These are logs and twigs from peat deposits, buried by ignimbrite, sometimes strongly compressed. For the wood samples we used the same procedure as for charcoals. Soil samples (2 samples, sometimes carbonized) were collected from under the tephra deposits. We received humic alkaline extractions for each soil sample (Braitseva *et al.*, 1993).

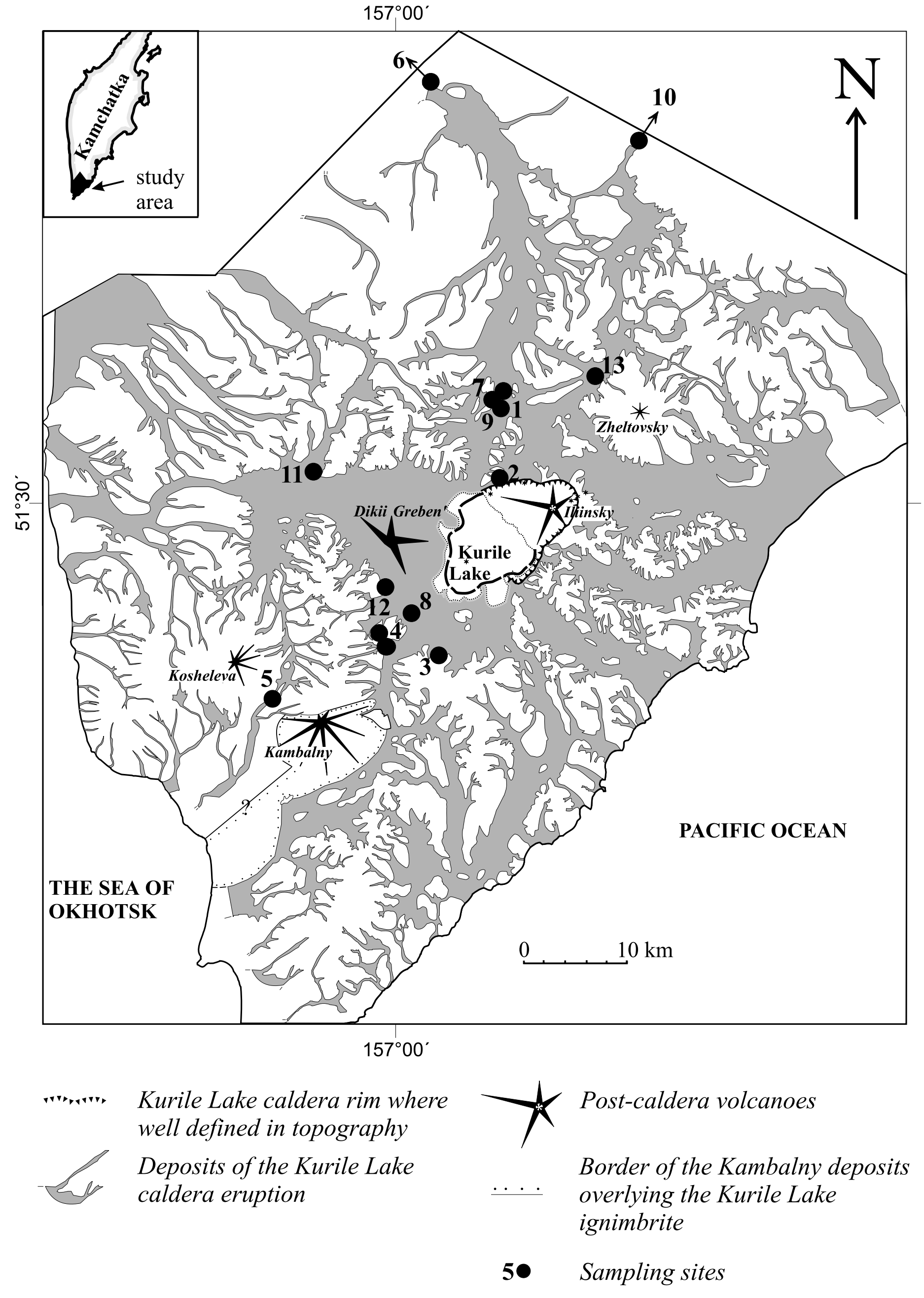

Fig. 2. *Sketch-map of the Kurile Lake pyroclastic flow deposits, composed by Ivan M. Melekestsev; sampling sites close to the the caldera are shown.*

3 peat samples under the pyroclastic flow and tephra deposits are strongly compressed, and they looked like very solid parts of "burned books". It was very difficult to sample such a peat and extract humic fraction from the samples. Thus, we applied the A-A-A pretreatment procedure, as for wood samples, and then dated the alkali insoluble fraction (small pieces).

All the pretreated samples (alkaline extractions, wood, charcoals and peat) were charred before the benzene synthesis. ^{14}C activity was measured using liquid scintillation counting method, according to the procedure described by Braitseva *et al.* (1993). We did not measured the $\delta^{13}C$ value, and all ages are not corrected for carbon isotopic fractionation.

5. DISCUSSION OF RADIOCARBON DATES

New data set consists of 29 dates, including earlier published reliable dates (Braitseva *et al.*, 1995) and 17 new dates obtained in 1996-1998. They are presented in **Fig. 3** and **Table 1**.

We analyzed all the obtained dates from the point of view of sample taphonomy and ways of carbon accumulation and conservation in them. The first data set is obtained on the samples from under the KO deposits. The dates are derived from compressed wood fragments (log and branches), buried soils, sand with organic matter and peat (normal peat far from the vent and compressed one under the ignimbrite deposits). Ages range from 8100±80 to 7540±40 BP, with the time-span (interval) between consecutive dates of 10-80 years.

Wood log date (GIN-8768, 7880±50 BP) is significantly older (200-300 years) than the branches date (GIN-8769, 7540±40 BP) from the same peat, and than the date GIN-1062 (7620±40 BP), probably due to the high rate of inbuilt age, thus we may consider the log date as too old (outlier). Dates of buried soils show good agreement with those obtained on branches, except the older GIN-8766 (7730±60 BP), probably due to inbuilt age of the soil layer.

Two samples consist of sand with organic matter (or charred sandy loams), GIN-6079 and 9197, both showing significant standard deviation rate (7820±100 and

***Table 1.** Results of ^{14}C dating of samples under the KO deposits.*

No.	Lab. No. GIN-	Sample type and stratigraphic position	Location	^{14}C Age [BP]
1	8769	Branches from 8770	Unkanovich river (1)	7540±40
2	IV-828*	Charred soil	Northwest foot of Zheltovsky volcano (13)	7570±100
3	1062*	Wood from 1063	Kuril Lake area	7620±40
4	8770	Charred peat	Unkanovich river (1)	7660±40
5	5252*	Peat	Apacha village	7670±40
6	8766	Charred soil	Maar, northwest foot of Iliinsky volcano (2)	7730±60
7	IV-822*	Peat	Petropavlovsk-Kamchatski	7810±60
8	6079*	Sand with organic matter	Magadan, Tanon Lake	7820±100
9	9197	Sand with organic matter	Hakytsyn river, right bank (3)	7840±140
10	1063*	Peat	Kuril Lake area	7860±100
11	8768	Wood from 8770	Unkanovich river (1)	7880±50
12	9192	Charred peat	Lower Hakytsyn river (4)	7940±60
13	6340*	Peat	Avachinsky volcano, Sedlovinskie lakes	7890±120
14	9220	Charred peat	Saddle between Kosheleva and Kambalny volcanoes (5)	8100±80
15	1047*	Soil enclosing the KO ash	Maly Semiachik volcano, western foot	7550±80
		Charcoals inside the KO deposits		
16	9673	Upper part of ignimbrite layer	Kuzaniok river (6)	7590±40
17	8772a-outer 8772b-inner 8772c-middle	Lower part of ignimbrite layer	Unkanovich river (7)	a: 7660±50 b: 7640±50 c: 7650±50
18	9198	Middle of ignimbrite layer	Etamink river (8)	7680±160
19	8771	Middle of ignimbrite layer	Unkanovich river (9)	7690±50
20	5689*	Middle of ignimbrite layer	foot of Ksudach volcano (10)	7770±40
21	9136	Middle of ignimbrite layer	Kaiuk river (11)	7770±60
22	9153	Middle of ignimbrite layer	To the south of Dikii Greben' volcano (12)	7800±40
23	9189a-outer 9189b-inner	Upper part of ignimbrite layer	Lower Khakitsin river (4)	a: 7840±40 b: 7880±40
		Samples above the KO deposits		
24	IV-812*	Peat above the KO ash	Petropavlovsk-Kamchatsky	7530±100
25	6338*	Peat above the KO ash	Avachinsky volcano, Sedlovinskie lakes	7540±40
26	6085*	Peat above the KO ash	Magadan, northern coast of Gertner Bay	7670±100

Notes: * = valid dates from Braitseva *et al.* (1995). Site numbers shown in Fig.2 are in parentheses.

7840±140 BP respectively). We suppose that these dates reflect the sum concentration of organic matter, which accumulated during long time (several hundred years or more), and these ages are older than the eruption age.

The most interesting group of dates was obtained on peat samples underlying the Kurile Lake deposits. Dates from nearby of the caldera derived from the uppermost thin layers of that organic horizon. Despite this fact, due to high rate of peat compression, these layers could record the long period of peat accumulation, and we consider these dates older than the eruption age. Thus, we are unable to use them for the accurate age estimation. Exception is GIN-8770 (7660±40 BP), enclosing the youngest woody sample – the very thin peat layer right below the fall deposits. Dates obtained on samples far from the caldera: GIN-6340 (7890±120 BP), 5252 (7670±40 BP) and IVAN-822 (7810±60 BP) resulted from total alkaline extraction but also reflect the time-span of peat accumulation. We consider these dates as outliers, except GIN-5252 (7670±40 BP), which is in concordance with the youngest wood and soil dates.

The second data set is obtained on various charcoal samples (thick logs, branches, twigs and destroyed wood fragments) from the KO ignimbrite and one date is obtained on soil enclosing the KO ash. This data set consists of dates with ages ranging from 7880 to 7550 BP, despite the mostly unified sample type, with the time interval between consecutive dates of 10-80 years. Thus, these dates fall into the same range as those obtained on underlying samples. The analysis of the charcoal data set has shown that:

1. The ages of charcoal samples do not depend on the diameter of charred trunk (branch, twig): we obtained older dates (7770-7880 BP) on logs (GIN-9136, 9189a and 9189b) as well as on twigs (GIN-9153). The same is for younger dates: 7540-7690 BP (9673 and 8772 are logs and 9198 is a small twig).

2. The ages of charcoal samples do not depend on the sample position in the lower, middle or upper part of the pyroclastic flow deposits (**Table 1**).

3. The ages of charcoal samples do not depend on the distance from the caldera (**Fig. 2**).

The third data set is obtained on peat samples above the Kurile Lake deposits, far from the caldera. The age range inside this group is 7670-7530 BP, the dates fall into the same range as those from inside and under the KO

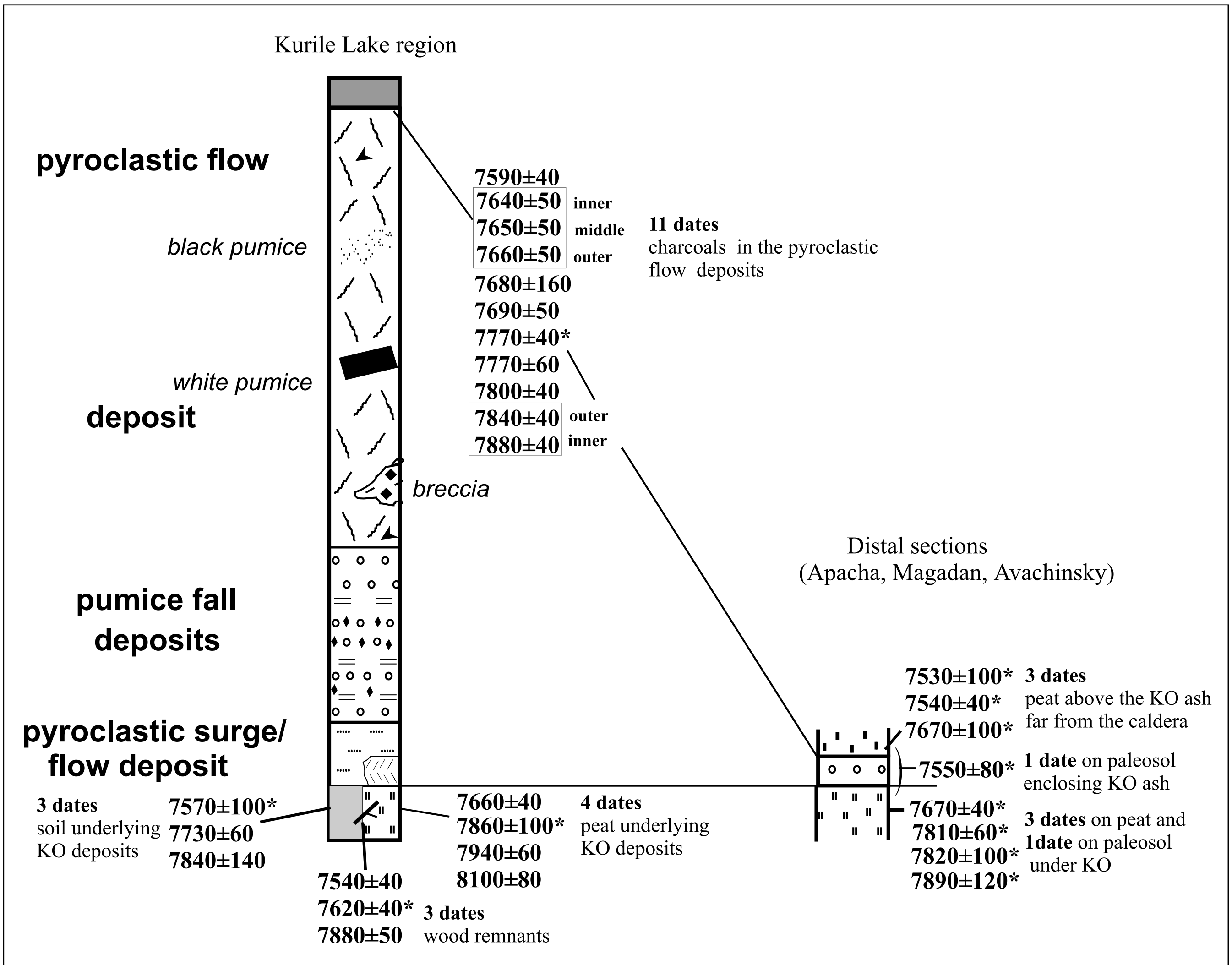

*Fig. 3. Summary section through the Kurile Lake caldera deposits with radiocarbon dates on various types of organic matter; * - dates averaged in Braitseva et al., 1995*

deposits, but the average age of this group is younger. The dates contain no outliers and are similar within standard deviations, showing good agreement with the youngest dates obtained from inside and under the Kurile Lake deposits in the vicinity of caldera and far from it.

6. ESTIMATION OF KO AGE

We analyzed all types of organic matter used for radiocarbon dating of the Kurile Lake eruption, and the resulted dates. Nevertheless, the ages of selected dates range from 7880 to 7530 BP, and we think it is unreliable to estimate the accurate age using all the data set. The test statistic *t'* is 61.02, and the dates are significantly different at 95% level (Stuiver *et al.*, 1998). Thus, we performed the procedure of date selection, to sharpen the time interval where the dates lie.

First of all, we proceed from the assumption that the samples (organic matter) from under the thick pyroclastic flow and fall deposits in the area close to the vent are not susceptible to contamination effects from the above organic horizons. We can exclude the impact of modern roots, or any biological migrations of young organic matter throughout thick pyroclastic strata. Thus, we consider the youngest dates obtained on the organic matter under the Kurile Lake deposits as the most reliable for the accurate radiocarbon age estimations. These are IVAN-828 (7570±100 BP), derived from the charred thin (short-lived) soil horizon, GIN-8769 and GIN-1062 (7540±40 and 7620±40 BP respectively), obtained on branches from the compressed peat underlying the fall deposits, with minimal inbuilt age, buried apparently during the eruption, and GIN-8770 (7660±40 BP), which is obtained from the compressed peat right below the thick KO section. The date GIN-5252 (7670±40 BP) from a peat sample (Apacha peat-bog) does not contradict this sequence. Other dates, derived from underlying organic deposits, are significantly older, possibly due to long rate of peat/soil accumulation, and they reflect the age of organic matter which could form over a long period before the eruption (in case of soils or peat), or reflect the inbuilt age, or time span between the death of a tree and the eruption (in the case of a wood sample).

The ages of underlying organic deposits, selected as valid, may be considered as references for further analysis of other dates. Next, we select the GIN-9673 (7590±40 BP), GIN-8772a-c (7660±50, 7640±50 and 7650±50), GIN-9198 (7680±160 BP) and GIN-8771 (7690±50 BP) from the "in-deposit" charcoal data set for the KO age estimation, which are in agreement with the youngest "underlying" dates and may have minimum inbuilt age (time-span between the inner and outer sample of 8772 is only 20 years). The date GIN-9198 (7680±160 BP) shows the significant deviation rate due to small sample size, and we do not use it for the KO age estimation. Also, GIN-1047 (7550±80 BP) is obtained on soil enclosing the Kurile Lake ash, and may be used as reliable date for the age estimation. Other charcoal dates seem to be too old: the youngest of them steps apart from the oldest accepted charcoal date by 80 years (**Fig. 3**). This probably can be caused by redeposition (capture) of dead wood by the pyroclastic flow. The overlying dates are in good agreement with the selected ones derived from inside and under the Kurile Lake caldera deposits.

Finally, we received the set of dates, reliable for the estimation of accurate age of the Kurile Lake caldera eruption (**Table 2**). This data set contains all the types of dated samples, from all possible stratigraphic positions. The test statistc *t'* for this data set is 14.8, samples are significantly same at 95% level (Stuiver *et al.*, 1998). This allows us to average the sample radiocarbon ages and use the data for the estimation of KO eruption age.

Table 2. *Results of ^{14}C dating of the Kurile Lake caldera eruption*

No.	Lab. No.	^{14}C Age [BP]
	GIN- (IVAN-)	
1	IV-812*	7530±100
2	6338*	7540±40
3	8769	7540±40
4	1047*	7550±80
5	IV-828*	7570±100
6	9673	7590±40
7	1062*	7620±40
8	8770	7660±40
9	8772a-outer	a: 7660±50
	8772b-inner	b: 7640±50
	8772c-middle	c: 7650±50
10	5252*	7670±40
11	6085*	7670±100
12	8771	7690±50

Thus, the final radiocarbon age of the Kurile eruption is **7618±16 BP**. Calibration of this age value, using the Calib 4.3 programme (Stuiver *et al.*, 1998), give the calendar age of 6463 (6455) 6435 BC.

7. SUMMARY

The extensive radiocarbon dating of the Kurile Lake caldera eruption– the strongest volcanic Holocene event of Kurile-Kamchatka volcanic belt – was provided. We sampled all kinds of organic matter related to ignimbrite and fall deposits nearby the caldera, and analyzed previous data obtained far from the vent. New data consists of dates derived from charcoals, wood, soils and compressed peat, and shows wide discrepancy of ages. We analyzed the sample taphonomy and other properties to sharpen the time span into which the eruption age falls, and tested the obtained data statistically. We consider the estimated radiocarbon age of the Kurile eruption as 7618±14 BP, the calendar age 6463 (6455) 6435 BC.

ACKNOWLEDGEMENTS

This research was possible thanks to field grants No. 5663-96, 5926-97 and 6215-98 from the National Geographic Society and grants from the Russian Foundation for Basic Research.

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