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RADIOCARBON DATING AND PALYNOLOGICAL STUDY OF SOIL-PYROCLASTIC DEPOSITS AT THE FOOT OF KARYMSKII AND MALYI SEMYACHIK VOLCANOES

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This paper presents radiocarbon dates obtained at the Institute of Volcanology and the Geological Institute, USSR Academy of Sciences, from 77 samples of coal, wood, and buried soil collected during a tephrochronological study of soil-pyroclastic deposits at the foot of Karymskii and Malyi Semyachik. The radiocarbon dates arc tabulated with references to major events in the eruptive history of the volcanoes and are also indicated on the geologic columns which show the location of the samples used for dating. The accuracy of the dates is discussed. A spore and pollen diagram is presented for the soil-pyroclastic deposits at the foot of Malyi Semyachik. It is considered to be a reference for the East-Kamchatka volcanic zone. Spore and pollen assemblages were identified, dated and tied to the time intervals of the Blytt-Sernander climatic classification.

This paper is a current report on radiometric dating in a series of publications initiated by the Institute of Volcanology in 1984 [6]. The results of radiocarbon age determination for the eruptive products of Karymskii and Malyi Semyachik Volcanoes, as well as tephrochronological data, were published in [2], [3], [8], and [9], where they were used to determine the age and reconstruct the eruptive histories of the volcanoes. Since then, a large number of new radiocarbon dates have been obtained and we deem it reasonable to summarize the data collected during this stage of the work.

Karymskii and Malyi Semyachik Volcanoes are situated in the East-Kamchatka volcanic zone at a distance of 20 km from each other. The Karymskii volcanic structure is a normal cone located in a young Holocene caldera. Malyi Semyachik is a volcanic ridge consisting of three stratovolcanic cones connected at the base: Paleozoic, Mesozoic and Cenozoic Semyachik cones.

The geologic materials used for radiocarbon dating were pyroclastic-soil deposits at the foot of the volcanoes which record a sequence of explosive events. The pyroclastic-soil deposits consist of tephra beds with sandy loams and buried soils in-between. Dating was undertaken to determine the time of the volcanic events recorded by the tephra. We also determined the age of the pyroclastic flows which had been related to the formation of the Karymskii caldera and to the eruptive activity of Cenozoic Semyachik.

The source materials for carbon-14 dating were buried wood, coals, and soils. Samples were collected in different years by O.A. Braitseva, I.A. Egorova, S.N. Litasova, and L.D. Sulerzhitskii. A sample of carbon extracted from organic matter buried in volcanic ash (Sample GIN-1066 in Table I) was made available to us by G.N. Kovalev. Radiocarbon dating was performed at the Geological Institute, USSR Academy of Sciences (samples labeled GIN), and at the Institute of Volcanology, Far East Division, USSR Academy of Sciences (samples labeled IV AN).

Most of the samples were buried soils. Their ages were determined using successive alkali extracts from one and the same sample, which contained organic remains of different ages and gave an idea of the beginning and end of soil formation. This technique, however, could only be employed with carbon-rich samples. Besides, use was made of wood buried in soil or in tephra above it. Also, coal samples were collected from the material deposited by pyroclastic flows.

Figures 1 and 2 demonstrate the geologic columns of soil-pyroclastic deposits from which samples were collected for dating, and Figure 3 shows their location. On the columns of Figure 2 the radiocarbon dates are tied to particular soil horizons. The materials used for dating (coal, wood, or buried soil) are marked by symbols. The scale plotted on the left indicates the depth of sampling. The boxed figures are the maximum and minimum ages obtained from the successive alkali extracts from one sample (all ages between these limits are presented in Tables I and II). The constant of 5568 years was used and no corrections were applied. To make correlation easier, the radiocarbon ages are plotted in Figure 1 on the composite sections of the soil-pyroclastic deposits at the foot of Karymskii (I) and Malyi Semyachik (II).

Before considering the results of radiocarbon dating it is worth dwelling on the technique of their interpretation. The normal sequence of dates obtained from buried soils, as they gradually become older downward, and the absence of significant outliers and reversals indicate that these dates are close to the actual radiocarbon age. On this basis, soils from soil-pyroclastic deposits can be recognized as a material suitable for radiocarbon dating, because they were safely conserved under the pyroclastics and some of their horizons had a very short life. Another evidence supporting the supposition that the dating was accurate enough is a satisfactory agreement between the dates for the samples collected from the same soil at several sites located along the strike, sometimes at large intervals between them. This is clearly demonstrated by the dates for the soil horizon between a transit ash bed (3) and a cinder layer at the foot of Karymskii and for soils 4, 6, and 7 at the foot of Malyi Semyachik.

At the same time, one can see that for a sequence of humus horizons in a thick soil the age from the youngest extract for the lowermost horizon is frequently younger than the age from the oldest extract for the uppermost horizon. Examples are the lower horizons of soils 3 and 4 in the Malyi Semyachik column and the soils above and below unit PT_6 and the soils under pyroclastic unit K in the Karymskii column. Obviously, this situation may be the result of the downward migration of young humus, which might be quite significant where humus horizons are separated by a small number of thin ash layers and constitute one fairly thick unit (soils 3 and 4 on Malyi Semyachik and soils in the upper and lower part of the Karymskii column). At the same time, one can see that the dates obtained

Table I Radiocarbon Dates for Soil-Pyroclastic Cover at Karymskiĭ Base

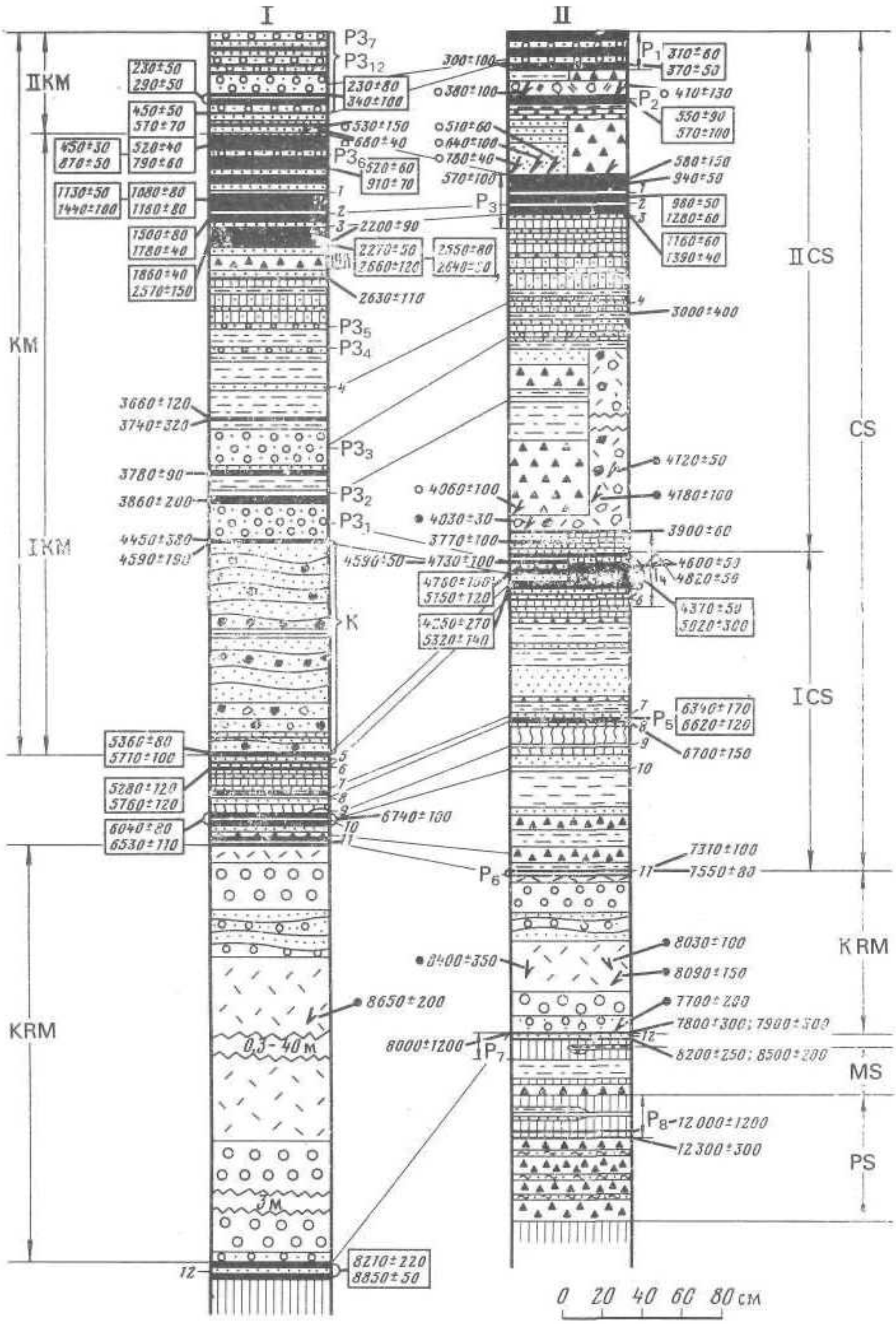
Stratigraphic unit and material sampled for dating	*Dated event*	*Sampling depth*	*Radiocarbon age, years ago*	*Sample number*	*Sampling site number*
Humus horizon under pumiceous tephra PT_{11}	Short breaks	0.08	Recent	IV AN-197	336
Humus horizon under pumiceous tephra PT_{8-9}	between eruptions during II KM active period	0.14	$230\pm80_{I}$	IV AN-199a	336
			$290\pm50_{II}$	IV AN-199b	
			$340\pm100_{III}$	IV AN-199c	
		0.04	$230\pm50_{II}$	IV AN-209a	357
			$290\pm50_{III}$	IV AN-209b	
Humus horizon under pumiceous tephra PT_7		0.60	$450\pm50_{I}$	IV AN-181a	283
			$570\pm70_{II+III}$	IV AN-181b	
Wood from soil between pumiceous tephra PT_6 and gray-black volcanic sand	Onset of Karymskii activity	0.80	530 ± 50	IV AN-66	283
		0.90	680 ± 40	IV AN-206	349
Soil between pumiceous tephra PT_6 and gray-black volcanic sand	Period of subdued activity between IKM and IIKM active periods	0.90	$450\pm30_{II}$	GIN-1850	283, sampled in 1972
			$770\pm90_{I}$	GIN-1849	
			$870\pm50_{III}$	IV AN-35	283, sampled in 1978
		0.86	$520\pm40_{III}$	IV AN-185	
			$630\pm40_{II}$	IV AN-186	
			$790\pm60_{I}$	IV AN-184	
Soil under pumiceous tephra PT_6		1.00	$620\pm60_{II}$	IV AII-188a	283
			$680\pm100_{III}$	IV AII-188b	
			$910\pm70_{I}$	IV AII-188c	
Coal in soil containing transit ash bed 1		0.64	1500 ± 120	IV AII-208	361
Soil between transit ash beds 1 and 2		1.24	$1080\pm80_{II}$	IV AH-33	283, sampled in 1976
			$1160\pm80_{III}$	IV AH-32	
		1.24	$1130\pm50_{III}$	IV AH-190	283, sampled in 1978
			$1210\pm40_{I}$	IV AH-189a	
			$1440\pm100_{II}$	IV AH-189b	
		0.26	1200 ± 30	GIH-1167	28
Soil between transit ash beds 2 and 3		1.34	$1500\pm80_{I}$	IV AH-191a	283
			$1760\pm40_{II}$	IV AH-191b	

Table I contd

			$1780\pm40_{III}$	IV AH-191c	
Soil between transit ash bed 3 and cinder layer CL		1.40	$1860\pm40_{II}$ $2160\pm60_{I}$ $2570\pm150_{III}$	IV AH-193a IV AH-191b IV AH-191c	283, sampled in 1978
		1.40	$2090\pm60_{I}$ $2290\pm110_{III}$ $2990\pm60_{II}$	GIH-1847 IV AH-34 GIH-1848	283, sampled in 1975
		1.46	$2270\pm50_{III}$ $2660\pm120_{I+II}$	IV AH-5a IV AH-5b	283
		1.44	$2200\pm90_{I}$	GIH-1853	278
		1.30	$2550\pm80_{II}$ $2640\pm80_{III}$	IV AH-177a IV AH-177b	285–286
Humus horizon below cinder layer CL	Short repose period before violent eruption	1.52	2630±110	IV AH-203	343
Soil above pumiceous tephra PT_3	Repose period after violent eruption which ejected PT_3	3.00 1.06	3660±120 3740±320	IV AH-476 IV AH-194	285 336
Soil between PT_3 and PT_2	Repose period between eruptions which ejected PT_3 and PT_2	0.70	3780±90	IV AH-480	25
Soil between PT_1 and PT_2	Repose period between eruptions which ejected PT_1 and PT_2	1.28	3860±200	GI H-1852	278

Soil below PT_1		Repose period before eruption which ejected PT_1	1.42 1.68	4450 ± 380 4590 ± 190	IV AH-195 IV AH-283	336 342
Buried soil between Karymskiĭ Volcano (KM) and caldera (KRM) deposits	Humus horizon below pyroclastics ejected at Karymskiĭ birth	End of repose period before Karymskiĭ birth	6.90	$5360\pm80_{II}$ $5710\pm100_{III}$	IV AH-178a IV AH-178b	286
	Humus horizon below transit tephra 6		6.96	$5280\pm120_{I}$ $5760\pm120_{II}$	IV AH-179a IV AH-179b	286
	Humus horizon enclosing transit ash beds 9 and 10	Repose period between caldera formation and Karymskiĭ birth	7.06 3.70	$6040\pm80_{I}$ $6280\pm100_{II}$ $6530\pm110_{III}$ 6740 ± 100	IV AH-180a IV AH-180b IV AH-180c GIH-1709	286 278
Coals from pyroclastic flow produced during Karymskii caldera formation		Caldera formation	9.00	8650 ± 200	IV AH-519	319
Soil buried under caldera-related deposits (KRM)		Period preceding onset of caldera-forming eruptions	25, 36	$8210\pm220_{I}$ $8280\pm180_{III}$ $8850\pm50_{II}$	IV AH-1a IV AH-1b IV AH-1c	319

Note. I, II, III in Column 5 are successive alkali extracts from the same soil sample. For location and explanation of symbols see Figure 1.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230±50
290±50
230±80
340±100
450±50
570±70
450±30
870±50
520±40
790±60
530±150
680±40
520±60
910±70
1130±50
1440±100
1080±80
1160±80
1500±80
1780±40
2200±90
2270±50
2660±120
2550±80
2640±50
1860±40
2570±150
2630±110
3660±120
3740±320
3780±90
3860±200
4450±380
4590±190
4590±50
5360±80
5710±100
5280±120
5760±120
6740±100
6040±80
6530±110
8650±200
0,3–40 м
3 м
8210±220
8850±50
310±60
370±50
300±100
380±100
410±130
550±90
570±100
510±60
640±100
780±40
580±150
940±50
570±100
980±50
1280±60
1160±60
1390±40
3000±400
4120±50
4060±100
4180±100
4030±30
3900±60
3770±100
4730±100
4600±50
4820±50
4760±100
5150±120
4370±50
5020±300
4250±270
5320±140
6340±170
6620±120
6700±150
7310±100
7550±80
8030±100
8400±350
8090±150
7700±200
7800±300; 7900±300
8000±1200
8200±250; 8500±200
12 000±1200
12 300±300
0 20 40 60 80 см
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19
230±50

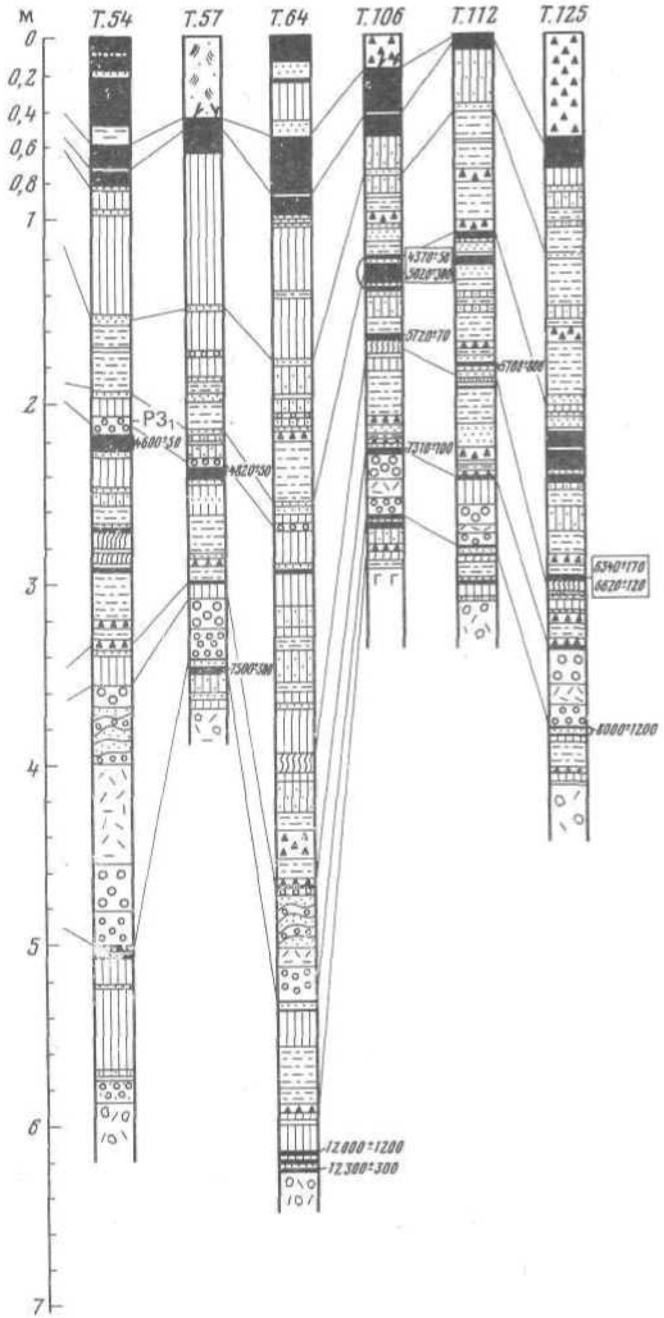
from the oldest extracts for the same humus horizons tend to be definitely older for each successively lower horizon, i.e. the ages of the soil horizons determined from the oldest extracts become progressively older downward.

In some instances, the dates obtained for one and the same soil horizons vary essentially from place to place. For example, two dates of about 5700 years ago and one date of 6700 years ago were obtained earlier [8], [9] for soil 5 at Malyi Semyachik. The age of 5700 years was preferred because it was given by two datings. However, the new data (Sample IV AN-281, Table II) obtained for the same soil after a particularly careful resampling procedure yielded an age close to 6500 years ago. The age of 5700 years seems to have been underestimated because soil 5 was contaminated with young humus. Earlier [9], a date of 21600±500 years ago was reported for the soil at the base of the Malyi Semyachik pyroclastic cover at Site 125, but no geological interpretation was offered. Later this soil was resampled and dated approximately 8000 years ago. This age agrees with the dates obtained for the same soil from the other localities.

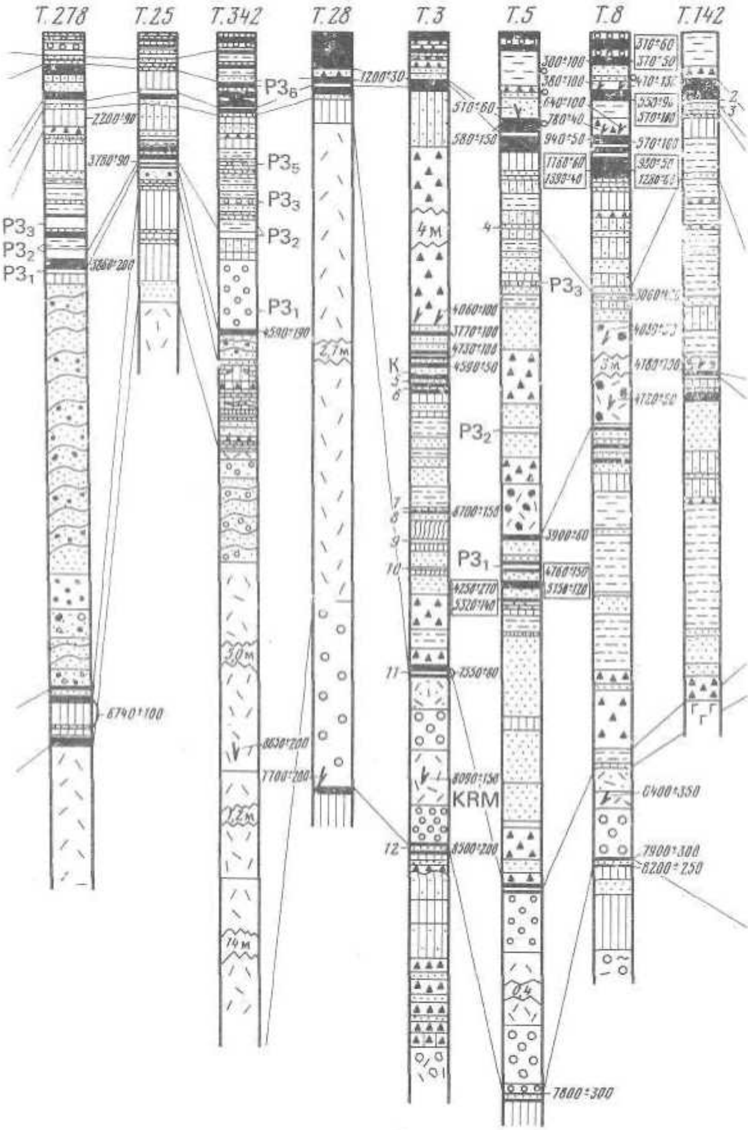
Consistent dates were obtained from different wood samples, where the soil from which they were recovered was thin enough (e.g. soil 2 at Malyi Semyachik). The wood samples collected from thick soils (e.g. soil 3 at Malyi Semyachik and the soil including pumiceous tephra unit PT_6 at Karymskil) yielded ages with a spread of 100-300 years. Yet, they fall within the age range obtained for the upper horizon of the soils under consideration (above transit ash unit 1 and pumiceous tephra unit PT_6).

A normal sequence of dates along the column and a good agreement of dates for the same horizons sampled at different sites indicate that the dating was accurate enough and the ages obtained do not differ much from the true radiocarbon ages thanks to the "dead" CO_2 effect of active volcanoes. However, where coals were sampled from pyroclastic flows, dating yielded ages older than those of the underlying soil horizons. Examples are the coals from the pyroclastic flows of the Karymskii caldera dated 8400 and 8600 years with the underlying soil dated 7800-7900 years and the coals from a pyroclastic flow at Cenozoic Semyachik dated 4120 and 4180 years with the underlying soil of 3900 years. Obviously, the overestimated ages resulted from the effect of various amounts of juvenile volcanic carbon entrapped from the carbon dioxide of the gas-rich material of the pyroclastic flows. The age of 7700 years obtained for the coals sampled from the cold-

Figure 1 Composite sections of soil-pyroclastic deposits at the foot of Karymskii (I) and Malyi Semyachik (II). 1 — bombs, lapilli, volcanic gravel; 2 — bombs lapilli, pumice gravel; 3 — pumiceous lapilli and coarse volcanic gravel; 4 — stratified pumiceous tephra, lapilli, coarse ash; 5 — coarse ash; 6 — stratified coarse ash; 7 — stratified coarse ash with bombs, lapilli, and resurgent material (pyroclastics ejected by early Karymskii eruptions); 8 — "ochreous" bed of oxidized gray and yellow coarse ash; 9 — thin-bedded fine and coarse ash; 10 — fine ash; 11 — pyroclastic flow deposits and fine ash produced by Karymskii eruption responsible for caldera formation; 12 — sandy loam; 13 — sandy loam with coarse ash; 14 — buried soil; 15 — deposits of Cenozoic Semyachik pyroclastic flow; 16 — deposits of explosive origin; 17 — redeposited coarse ash; 18 — wood; 19 — radiocarbon dates: (a) from coal samples, (b) from wood, and remaining — from buried soil. Code: KRM — deposits produced by Karymskii eruptions responsible for caldera formation; KM — deposits ejected by Karymskii eruptions; PS — Paleozoic Semyachik deposits; MS — Mesozoic Semyachik deposits; CS — Cenozoic Semyachik deposits; I KM, 1! KM and I CS, П CS — deposits of major events in Karymskii and Cenozoic Semyachik activity, respectively. Marker beds: PT] to PT_{i2} — Karymskii Pumiceous tephra units; K — early Karymskii pyroclastics; CL — Karymskii cinder layer; 1 to 12 — transit ash beds; Si to S« — buried soils in Malyi Semyachik deposits.



fallen lapilli at the base of the caldera pyroclastic unit is close to the carbon-14 age for the underlying soil horizon. Here, wood was probably coalified when the soil was covered by a thick pyroclastic flow, though heating was not strong enough for



the adsorption of volcanic carbon. It is quite likely that the age of 1500±200 years (see IV AN-202 in Table I) for the coals in the upper soil containing transit ash unit 1 of about 1000 years was overestimated due to the entrapment of "dead" carbon dioxide by the wood as it was coalified.

The tephrostratigraphic correlation of the geologic sections served as a valuable means of checking the accuracy of dating by correlating the ages for the same horizons in many separated areas at the foot of Karymskil and Malyl Semyachik Volcanoes. The soil horizons which were used for dating were identified in the field by tracing ash beds along a profile between the volcanoes. An important

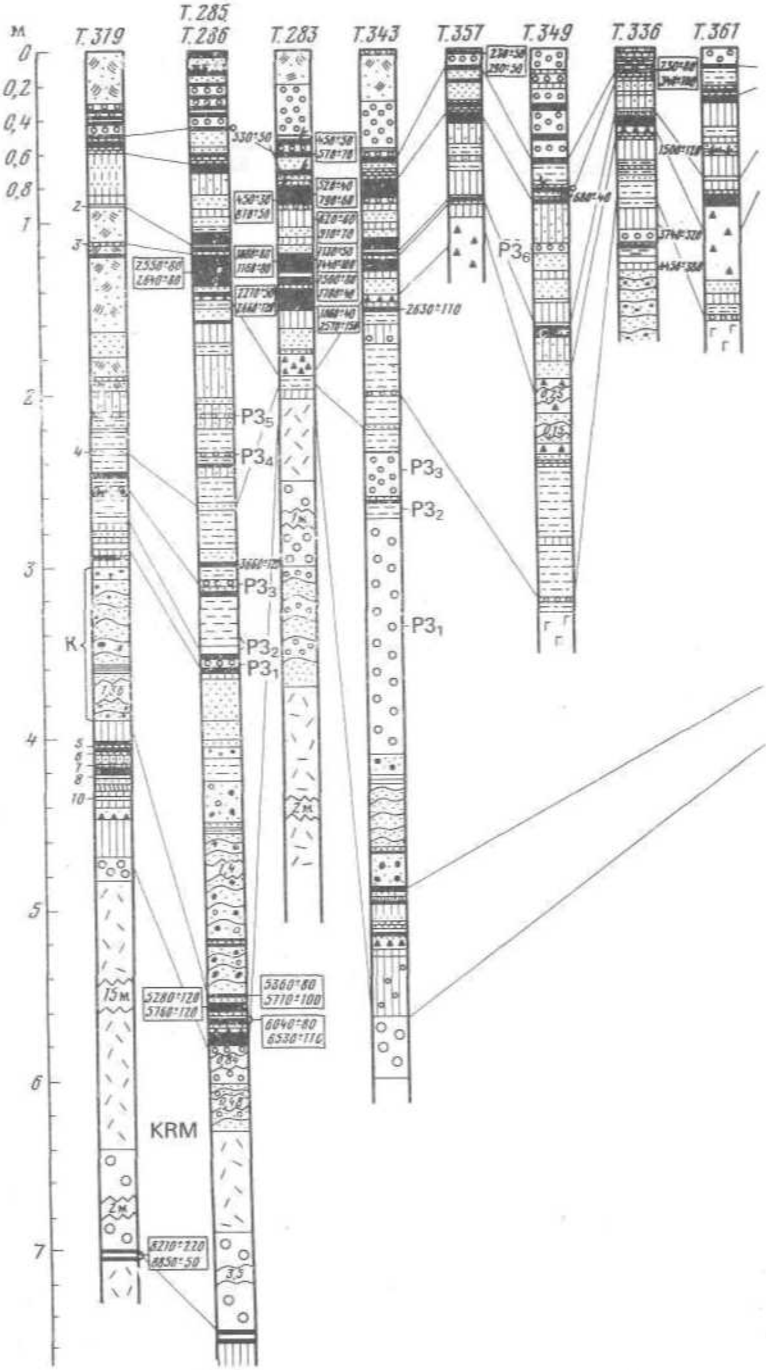


Figure 2 Soil-pyroclastic columns from the base of Karymskil and Malyi Semyachik. For legend and code see Figure 1.T.54 — sampling site.

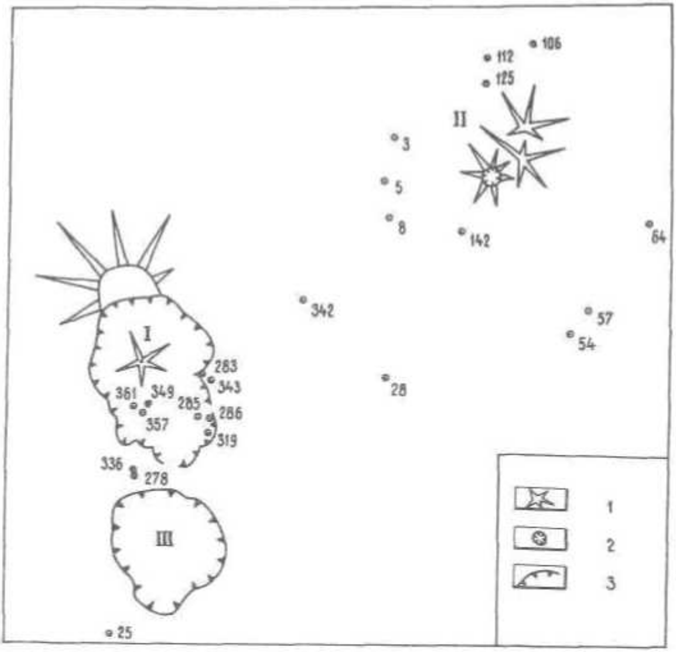


Figure 3 Location of soil-pyroclastic sections sampled for dating. 1 — stratovolcano; 2 — caldcra; 3 — caldera wall; I — Karymskil; II — Malyl Semyachik; Ш — Karymskii caldera lake

feature on which the stratigraphic correlation was based was a sequence of ash beds which could be discriminated by color, thickness, grain size, and chemical and mineral composition. Figure 1 shows correlation of major markers which are present in the tephra of both columns. The markers are transit ash beds and some of the pumiceous tephra horizons at Karymskii and cinders at Malyi Semyachik. The correlation of the dates obtained for the soil horizons mutually correspondent in stratigraphic position (i.e. for the same horizons in two separated areas) showed their fairly good agreement. Examples are the top of soil 3 at Malyi Semyachik and the soil including the PT_6 pumiceous tephra unit at Karymskii, trie wood from these horizons, the soil between transit ash beds 1 and 2, the soil under pumiceous tephra unit PT_b the soil under pyroclastic unit K, and the soil horizons under the pyroclastic material produced by the explosion responsible for the formation of the Karymskii caldera.

In some cases, the same soil horizons at Karymskii and Malyi Semyachik yielded different ages, e.g. the soil between transit ash beds 2 and 3. The date obtained from the Karymskii soil seems to be closer to the true age because dates of the order of 1400—1500 years were obtained for the soil under transit ash bed 2 (ash from Opala Volcano) elsewhere in the East-Kamchatka volcanic zone [5], [7], [10].

The results of the carbon-14 dating suggest the following ages for some of the transit tephra beds: about 1000 years for bed 1, approximately 1400—1500 years for bed 2 (ash of Opala Volcano), about 1800 years for bed 3 (Ksudach ash),

Table II Radiocarbon Dates for Soil-Pyroclastic Cover at Malyĭ Semyachik Base

Stratigraphic unit and material sampled for dating	*Dated event*	*Sampling depth*	*Radiocarbon date, years ago*	*Sample number*	*Sampling site number*
Soil 1, lower humus horizon	Onset of relatively subdued activity of Cenozoic Semyachik	0.14 0.14	300 ± 100 $310\pm60_{I}$ $370\pm50_{II+III}$	GIN-1160 IV AH-268a IV AH-268b	8, sampled in 1973 8, sampled in 1978
Wood from black volcanic sand above soil 2	Strong eruption of Cenozoic Semyachik	0.32 0.34	380 ± 100 410 ± 130	GIN-1039 GIN-1052	8 8
Soil 2	Repose period between two strong eruptions	0.36	$550\pm90_{I}$ $570\pm100_{III}$ IV AH-269a IV AH-269b	IV AH-269a IV AH-269b	8
Wood from soil 3 and overlying volcanic sand	Strong eruption of Cenozoic Semyachik	0.50 0.60	510 ± 60 640 ± 100	IV AH-275 GIN-1041	5 8
Soil 3, upper humus horizon above transit ash 1		0.62 0.62 0.52 0.60	780 ± 40 940 ± 50 580 ± 150 570 ± 100	IV AH-270a IV AH-270b GIN-1368 IV AH-270	8 8 13 8
Soil 3, middle humus horizon between transit ash beds 1 and 2	Repose period in Cenozoic Semyachik activity	0.65 0.67	$1260\pm70_{I}$ $1250\pm60_{III}$ $980\pm50_{II}$ $1060\pm60_{III}$ $1280\pm60_{I}$	IV AH-272a IV AH-272b IV AH-273a IV AH-273b IV AH-273c	8 8
Soil 3, lower humus horizon between transit ash beds 2 and 3		0.70	$1160\pm60_{III}$ $1300\pm80_{II}$ $1390\pm40_{I}$	IV AH-274a IV AH-274b IV AH-274c	8
Plant remains in black volcanic sand	Sequence of	1.46	3000 ± 400	GIN-1066	8

	minor eruptions during relatively subdued Cenozoic Semyachik activity				
Coals from pyroclastic flow	Strong eruptions of Cenozoic Semyachik which produced a pyroclastic flow and cinder ejections in early II CS period	1.7	4030 ± 30	GIN-1040	8
		5.0	4120 ± 50	GIN-1053	9
		1.84	4180 ± 100	GIN-1051	142
Wood from cinder above soil 4		5.6	4060 ± 100	GIN-1042	3
Soil 4, sequence of humus horizons	Repose period and subdued activity of Cenozoic Semyachik in late ICS period	2.80	3900 ± 60	IV AH-276	5
		5.70	3770 ± 100	GIN-1043	3
		5.82	4730 ± 100	GIN-1044	3
		5.86	4590 ± 50	GIN-1045	3
		3.06	$4760\pm150_{I}$	IV AH-279a	5
			$4830\pm120_{III}$	IV AH-279b	
			$5150\pm120_{II}$	IV AH-279c	
		2.24	4600 ± 50	GIN-1168	54
		2.44	4820 ± 50	GIN-1170	57
		1.30	$4370\pm50_{I}$	GIN-1050a	106
			$4800\pm140_{II}$	GIN-1050b	
			$5020\pm300_{III}$	GIN-1050c	
		3.16	$4250\pm270_{I}$	IV AH-281a	5
			$5320\pm140_{II+III}$	IV AH-281b	
Soil 5	Short repose period in the middle of ICS period	1.70	5720 ± 80	GIN-1054	106
		1.88	5700 ± 800	GIN-1374	112
		3.04	$6340\pm170_{I}$	IV AH-281a	125
			$6420\pm140_{II}$	IV AH-281b	

Table II contd

		6.68	6620±120$_{III}$ 6700±150	IV AH-281c GIN-1046	3
Soil 6	End of repose period prior to birth of Cenozoic Semyachik	2.32 7.58	7310±100 7550±80	GIN-1055 GIN-1047	106 3
Coals from lower KRM lapillic horizon	Eruption responsible for formation of Karymskiĭ caldera	28.0	7700±200	GIN-844	28
Coals from KRM pyroclastic flows		 8.10	8030±100 8090±150	GIN-1171 GIN-1162a	146 3
Soil 7, humus horizon above transit ash 12 Soil 7, humus horizon below transit ash 12	Repose period preceding formation of Karymskiĭ caldera after Mesozoic Semyachik ceased its activity	6.26 7.56 7.60 8.54 3.88	7800±300 7900±300 8200±250 8500±200 8000±1200	GIN-1049 GIN-1163 GIN-1164 GIN-1048 GIN-1371	13 8 8 3 125
Soil 8, basal humus horizons	Period of subdued activity before Paleozoic Semyachik ceased to erupt	6.20 6.30	12000±1200 12300±300	GIN-1376 GIN-1375	64 64

Note. I, II, III are successive alkali extracts from the same sample. For location and explanation of symbols see Figure 1.

about 3000 years for bed 4 (Avacha ash), 5500-5600 years for bed 5 (Avacha ash) and bed 6, about 7400 years for bed 11, and approximately 8000 years for bed 12. Bed 10 is the ash produced by Khangar Volcano and has an age older than 6700 years in the Malyl Semyachik column. On Krasheninnikov Volcano this ash was dated approximately 6900 years [10]. The presence of these markers in the sections of the neighboring areas enables us to use them as time-stratigraphic units for the dating and correlation of different geologic formations and relief forms.

In this paper we report the carbon-14 dates obtained for the sections at the foot of Karymskil and MalyT Semyachik Volcanoes and for the major eruptive events and repose periods in the activity of these volcanoes dated accordingly on the basis of these ages. As mentioned above, the application of carbon-14 ages for more detailed reconstructions of volcanic histories, such as the determination of the ages of volcanoes and the duration of their active eruptive and repose periods, the dating of most violent eruptions, etc., was discussed earlier in [2], [3], [8], and [9]. To reconstruct the volcanic histories and compare the carbon-14 ages with paleogeographic, paleoclimatic and other data available on the Holocene period, they were calibrated in a conventional manner [1], [12].

Along with the tephrochronological work, we undertook a palynological analysis [4], [9]. We studied pollen and spores in every layer of the soil-pyroclastic cover and found that pollen and spores were present in almost all horizons with the exception of thick interbeds of volcanic sand and lapilli which had been deposited as the result of strong and short-term ejections during volcanic eruptions. The spore and pollen spectra of each horizon are synchronous with the time of its deposition and reflect both the local and regional features of vegetation. Variations in the spore and pollen spectra are associated primarily with climatic changes.

Having analyzed the palynological data, we identified five phases in the evolution of the Holocene vegetation in eastern Kamchatka and, using a great number of radiocarbon dates, determined their age ranges and tied them to the periods of the Blytt-Sernander climatic classification* (Figure 4). These phases are: phase I — the growth of grass and bush communities with the local distribution of brushwoods 10300—9200 years ago; phase II — the growth of creeping alder with minor birch forests 9200-6000 years ago; phase III — the Holocene peak of birch forest development with the general predominance of bush communities of creeping alder and Japanese stone pine 6000-4500 years ago: phase IV — the dominant development of bush communities of creeping alder and Japanese stone pine 4500-2500 years ago; and phase V — the growth of birch forests with the general predominance of bush communities of creeping alder and Japanese stone pine 2500 years ago to the present time.

The identified phases of the vegetation evolution are characterized by certain spore and pollen assemblages and served as the basis for differentiating the eastern Kamchatka Holocene deposits into five stratigraphic units each of which was tied to the absolute time scale. The characteristic features of the spore and pollen assemblages are: an insignificant content of bush pollen and a predominance of the *Lycopodiaceae* spores in the cold periods of the late glacial stage and the

* We referred to the Holocene subunits of the Blytt-Sernander classification as modified by Khotinskii for North Eurasia [11].

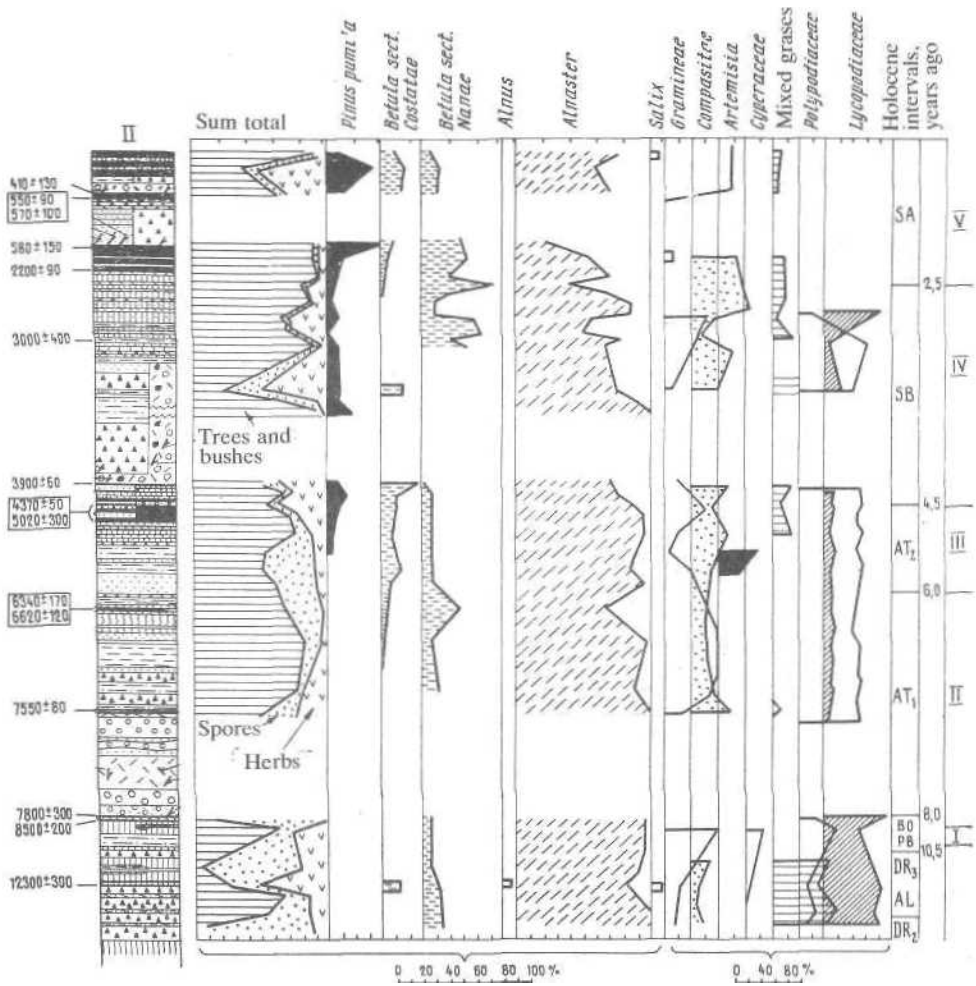


Figure 4 Composite spore and pollen diagram for soil-pyroclastic deposits at Malyl Semyachik base. SA - Subatlantic; SB - Subboreal; AT - Atlantic; BO - Boreal: PB - Preboreal; AL - Allerod; DR — Dryas. I to V — phases of vegetation evolution

early Holocene; an absolute domination of creeping alder pollen *(Alnaster)* during the Boreal interval (BO) and the first half of the Atlantic (AT_t); the appearance of birch tree pollen *(Betula sect. Costatae)* and Japanese stone pine pollen *(Pinus pumila)* in the second half of the Atlantic (AT_2); a decrease and disappearance of birch tree pollen during the Subboreal climatic deterioration (SB); and a new increase in the content of birch tree pollen in the spectra of the Subatlantic interval (SA).

The most prominent stratigraphic unit corresponds to the Holocene climatic optimum which occurred 4500-6000 years ago and was characterized by an abundance of birch forests.

The lower Holocene boundary was determined by the beginning of bush growth after a climatic deterioration at the end of the postglacial interval (Dryas-3). It was placed at 10.3—10.5 thousand years, which agrees with the universally adopted time. The stratigraphic and pollen data indicated a climatic amelioration of late-glacial time corresponding to the Allerod (12000 years ago).

The dated spore and pollen diagram (see Figure 4) for the foot of Malyi Semyachik Volcano is a reference for the extensive region of the East-Kamchatka volcanic zone. The pollen assemblages identified in this research and tied to the time scale can be used as a basis to correlate geologic sections in the region and solve an inverse problem — date the soil-pyroclastic covers where carbon-14 dating is precluded by the absence of organic matter [3]. Also, the palynological data will be instrumental in reconstructing the paleogeographic environments that existed during the birth of the volcanoes.

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