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An Eruption of the Veer Cone As a Volcanic Event during the Increase of Volcanic Activity in Kamchatka at the Beginning of the Christian Era

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Abstract—Tephrochronologic studies conducted in the Levaya Avacha River valley helped determine the true age of the Veer cinder cone, which formed approximately in 470 AD (1600 ^{14}C BP). These data refute the existing idea that it was generated in 1856. The monogenetic Veer cone should be cancelled from the catalogs of historical eruptions and active volcanoes in Kamchatka. The eruption of this cone was a reflection of the all-Kamchatkan increase in the activity of endogenous processes that occurred in 0–650 AD.

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INTRODUCTION

The problem of dating volcanic occurrences is one of the most urgent when reconstructing the history of eruptive activity for individual volcanoes and major volcanic centers. Special significance for long-term prediction of volcanic activity and assessment of volcanic hazard attaches to reliable data on historical eruptions.

We conducted detailed tephrochronologic studies in a zone of horst uplifts in the Avacha River basin; we found and described 19 Holocene eruptive centers (cinder cones with lava flows and maars). We determined the times of generation for most of these, identified some patterns in the space–time distribution of eruptive events, and reconstructed the eruptive history for some cinder cones [6]. The present paper supplements these studies and is concerned with results for the Veer cone, which is one of the last unstudied monogenetic centers in the area.

The current literature dates the generation of the Veer cone to 1856 [8, 9, 12, etc.]. When the Volcanoes of the World catalog appeared [12], the Veer cone began to be represented in some publications and on web pages as one of the youngest cinder cones (or even active volcanoes) in Kamchatka. The results we obtained contradict these data and deserve a separate publication.

A study of soil–pyroclastic cover (SPC) sections near the cone yielded a composite section of Holocene pyroclastic deposits; this was the basis for our reconstructions, along with the detailed tephrochronologic scale developed for this area of Kamchatka [4]. An analysis of the composite section revealed that the SPC found in the Levaya Avacha River basin involves transit ashes from many major Holocene explosive eruptions of Kamchatka. However, only one of the tephra horizons deposited there during the past 10000 years comes from a near local source; this is a cinder layer of considerable thickness and grain size lying around the Veer cone.

The Veer cone was dated using two regional marker horizons, viz., the Baranii Amfiteatr tephra (OP) in the caldera of Opala Volcano (Fig. 1) whose age is 1478 ± 18 ^{14}C years and the tephra of the caldera-generating eruption on Ksudach Volcano (KS_1) whose age is 1806 ± 16 ^{14}C years [5, 10]. The ashes involve several typical features (Table 1) that permit unambiguous identification when encountered in sections and provide easy discrimination from the other transit ashes found in the area of study. The ash of Avacha Volcano (AV_{1600}) was an additional age marker.

THE VEER CONE AND ITS EJECTA

The Veer cone is situated on the right bank of the Levaya Avacha River, 13 km upstream from its confluence with the Vershinskaya River and 75 km NNW of Petropavlovsk-Kamchatskii (Fig. 1). It is a small cinder cone that measures 350 m across at the base and stands about 80 m above its immediate surroundings; its southern sector has been damaged by a lava flow that contains large blocks (Fig. 2). The lavas correspond compositionally to moderate-potassium basalts (Table 2). Nearly no cinder has been found on the surface of the flow, indicating that the lava flow was discharged at the terminal phase of this eruption. The flow was about 1 km long and has an area of 3.65×10^5 m^3. The lava volume is estimated to be 1.46×10^7 m^3, assuming a mean thickness of ~40 m (based on our reconstruction). The cone has a volume of 3.8×10^6 m^3 based on a 1 : 50000 map. The total volume of pyroclastics (~9×10^6 m^3) was obtained as a crude estimate using the technique we employed previously to estimate the pyroclastic volume in the Tolbachinskii Dol cones [3]. The total volume of erupted material when converted to solid rock (DRE) with a mean density of 2.6 g/cm^3 is about 1.8×10^7 m^3.

The Veer tephra was followed for as far as 15 km from the source. The tephra thickness varies from over 80 m as measured at a distance of 1 km from the cone (Fig. 2) to 0.5–1 cm at distances of 11–12 km south and north of it. The most detailed description of this tephra is available for that found 5 km south of the Veer cone, in a terrace on the right bank of the Levaya Avacha River. The tephra is found at this location as a stratified sequence (Fig. 3) of mostly poorly sorted volcanic sand with varying grain sizes, with fine sand interbeds (which dominate the section) alternating with ones of coarse volcanic sand, frequently with an admixture of cinder gravel as large as 5 mm across. Fine ashes are generally enriched in accretionary lapilli as large as 3–5 mm across, and their cores are occasionally found to contain fine cinder gravel. In the bottom of this sequence we identified an interbed 2–3 cm thick that, nearly all of it, consists of accretionary lapilli (Fig. 3, trace 2). The coarse sand interbeds are frequently found to contain intermittent, subhorizontal and, less often, cross bedding. The tephra is typically a dirty-grey color, it being only toward the top of the sequence that one finds an interbed of black, well sorted coarse sand (Fig. 3, trace 1). The sequence has a total thickness of ~35–40 cm.

The character of these deposits suggests that the Veer eruption was mostly phreatomagmatic. The prevalence of fine fractions in the tephra, even near the source, indicates a high degree of disintegration for the erupted magma; when this circumstance is combined with overall poor sorting, the combination is one that distinguishes such eruptions. The presence of accretionary lapilli also provides evidence of a substantial involvement of the phreatomagmatic component. The rising magma came in contact with water, most likely, in shallow water-saturated horizons of the alluvial and proluvial deposits that fill the Levaya Avacha River valley (Fig. 2). However, that contact came to an end during the terminal phase of the eruption, which became Strombolian in character as indicated by an interbed of well-sorted cinder in the top of the deposits. It was during this phase that the lava flow formed on the cone.

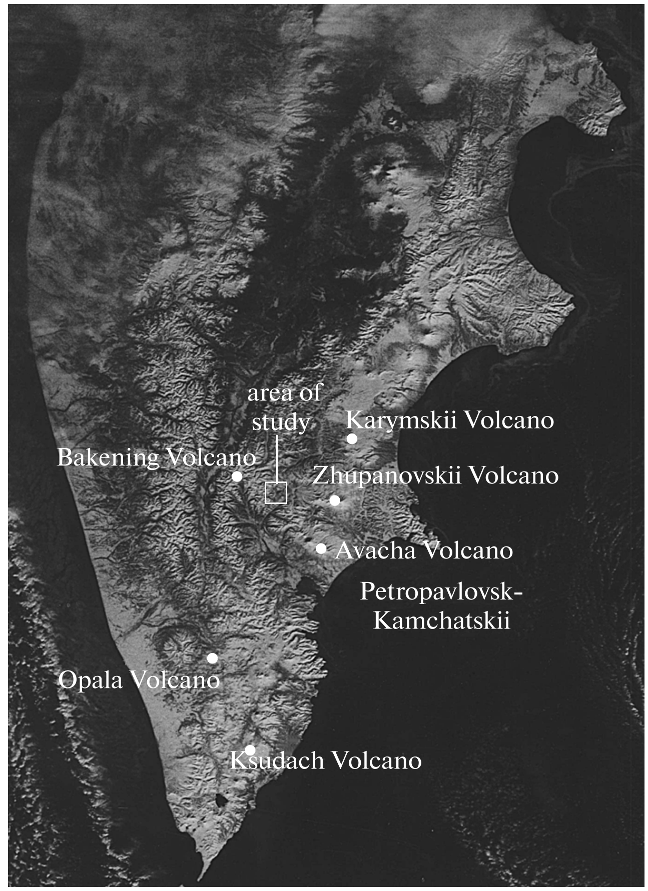

Fig. 1. The area of study and nearest Holocene volcanoes.

DATING THE VEER CONE

The block surface of the lava flow prevented the normal formation of the SPC, and it was only in a few low points among the lava blocks that strongly reduced fragments of the soil cover were found in pits. The lava flow is everywhere overlain by an OP tephra horizon (Table 1),

Table 1. Diagnostic characteristics of OP and KS_1 ashes

Tephra index	OP	KS_1
Age, ^{14}C BP	1478 ± 18	1806 ± 16
Thickness, cm	1–4 (2)*	3–10 (4)* cm
Color	yellowish–white	yellow, light grey
Grain size	fine-grained sand	fine- to coarse-grained sand
Sorting	well sorted	moderately sorted
Mineral composition	Pl+Amf+Bi	Pl+Px
Chemical composition	rhyodacite–rhyolite	dacite–rhyodacite
Other features		two-member horizon: the lower part is yellow, the upper light grey

Note: The ash indices, age, and composition are given after [5, 10].

* Parentheses enclose the average tephra thickness in the area of study.

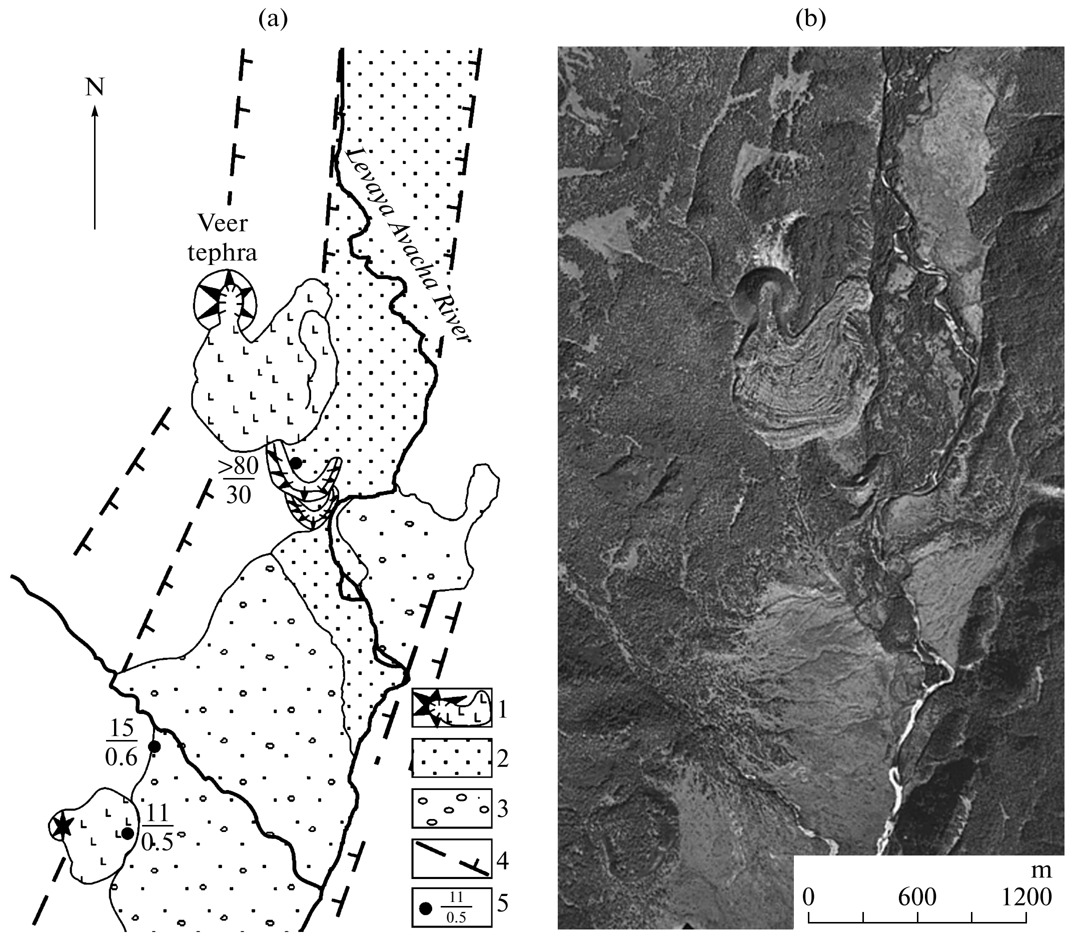

Fig. 2. A geological–geomorphologic map (a) and an aerial photograph (b) of a part of the Levaya Avacha River valley around the Veer cone: (1) monogenetic centers and their lava flows, (2) alluvial deposits, (3) diluvial–proluvial fan deposits, (4) tectonic faults, short transverse dashes indicating the downthrown side, (5) observation sites for which the Veer tephra and its characteristics are described: the numerator denotes thickness in cm, the denominator the greatest size of fragments in cm.

while no KS_1 ash has been discovered. The thin (not thicker than 0.5 cm) interbed of poorly humified sandy loam underlying the OP ash suggests that the lava flow was discharged about 1500–1600 ^{14}C years BP.

In addition, we have described SPC sections in pits beyond the limits of the lava flow, both near and far from the cone, in order to date its cinders. A total of four sections have been described within 5 km of the cone and more than ten within 15 km. In all these sections the Veer tephra can be followed in the top of the SPC between the OP and KS_1 marker ash horizons, which define the time limits of cone deposits: 1478 ± 18 to 1806 ± 16 ^{14}C BP.

However, some SPC sections involve a thin horizon of grey, fine and very fine, volcanic sand just under the Veer

Table 2. Chemical composition of Veer lavas (wt %)

Row #	Sample identification number	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
1	D117	51.64	0.73	17.02	5.46	4.52	0.12	7.69	8.90	2.60	1.31	0.00	100.00
2	D120	52.38	1.01	17.57	3.77	5.11	0.16	7.26	7.95	3.38	1.15	0.26	100.00

Note: The analyses were carried out by A.B. Perepelov, Vinogradov Institute of Geochemistry, Siberian Branch, Russian Academy of Sciences, Irkutsk and are here converted to dry residue.

tephra (Fig. 4a), with no more than 1 cm of poorly humified sandy loam between the two. It follows that the identification of this ash is of exceptional importance for refining and shortening the above age interval, provided we know the age of that ash. The clearly defined stratigraphic place and the narrow time range (slightly over 300 ^{14}C years) considerably simplified the problem. We firmly believe that the "unknown" ash came from the AV_{1600} eruption on Avacha Volcano, which was identified and dated by reconstructing the volcano's Holocene eruptive activity [1]. The eruption age is 1622 ± 45 ^{14}C BP. Calibration with the help of the Calib 4.2 program [13] gave a calendar age, AD 264(424)541. The ash was identified by direct correlation to the well-studied tephra horizons due to AV_{1600} which were previously followed from the foot of Avacha Volcano to the upper reaches of the Vershinskaya and Gavanka rivers (Fig. 5). The ashfall from this eruption also involved the environs of Bakening Volcano [4]. Analysis of the map of lines of equal thickness for AV_{1600} tephra revealed that the area of study is within the zone of that ashfall; thus one can well expect to encounter 1–2 cm of the ash, which tallies with the measured values near the Veer cone (Figs. 4, 5).

Our inferences are corroborated by the revised and correlated SPC sections that were previously described for the extensive area between Avacha Volcano in the south, as far as Karymskii Volcano in the north, and the Central Kamchatka depression in the west, as well as borne out by data on the eruptive activity of other volcanoes close to the area of study (Fig. 1). For example, the time interval of interest (1500–1800 ^{14}C BP) falls in a repose period for Karymskii Volcano, one of the most active volcanoes for several last 100 years [2]. The history of Zhupanovskii is still poorly known, but the available data suggest the absence of any significant eruptions during this interval of time. The Bakening and Koryakskii volcanoes also did not erupt during this time period.

We thus find it firmly established that the Veer tephra lies in the section in the immediate vicinity of the AV_{1600} horizon (Fig. 4). The small thickness of the interash layer allows us to estimate the age of the cone as ~1610–1600 ^{14}C years. A more accurate calendar age was derived by using calculations of the rate of soil deposition between the time markers. To do this, we selected those sections that involve well-pronounced tephra horizons: the Veer cone, Avacha Volcano (AV_{1600}), and Ksudach Volcano (KS_1). The age values found by this method vary in the range AD 462–AD 482. The mean value of this range, viz., AD 470, was assumed here as the date the Veer cone formed.

The age as determined here differs substantially (by nearly 1400 years) from the date 1856, which figures in various publications as the time of generation for the Veer cone. As well, the SPC sections were not found to contain any traces of later eruptions at this cone, which corroborates our characterization of it as a young monogenetic center that was produced by a single eruption and did not renew its activities. For this reason the Veer cone should be eliminated from the catalogs of active volcanoes and from the lists of historical eruptions and the youngest cinder cones in the Avacha River basin. Although it remains one of the youngest monogenetic centers in the area of study, the eruptive centers in the Kostakan valley formed somewhat later, in the range 600–1200 ^{14}C BP, and are the youngest volcanic formations to be found there [6].

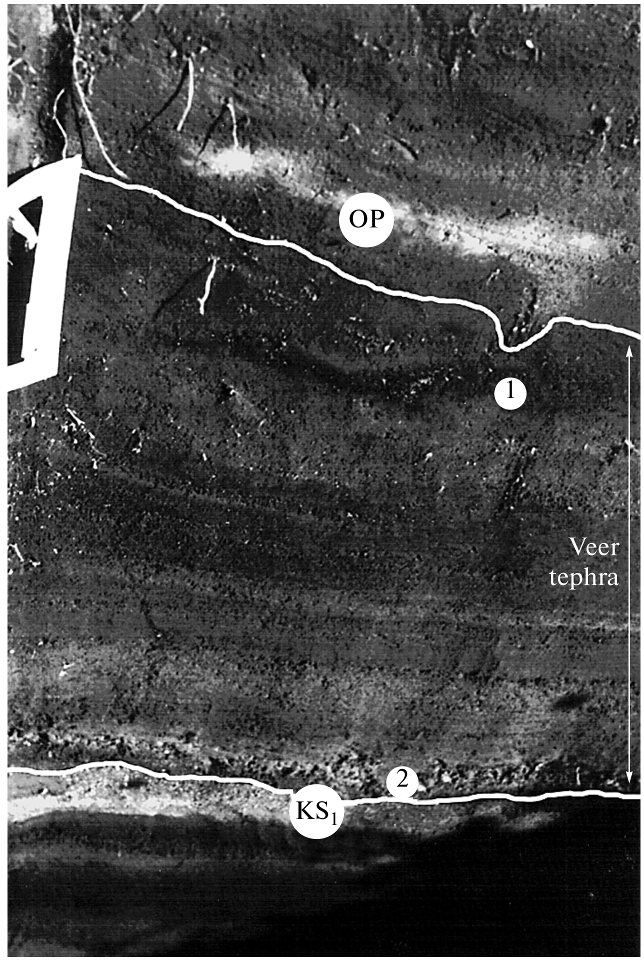

Fig. 3. A fragment of soil–pyroclastic cover section showing the location of the Veer tephra and marker transit ashes. The ruler length is 15 cm. Tephra of the following volcanoes: OP (Opala (Baranii Amfiteatr), KS_1 Ksudach. Interbeds 1 and 2—see text.

Eruptions of cinder cones in the upper reaches of the Avacha River and its tributaries occurring on the larger tectonic faults in the area were episodically recurring during all Holocene time. According to [6], these eruptions can be grouped into at least three time intervals: stage I 12000–8000 ^{14}C BP, stage II 3000–2500 ^{14}C BP, and stage III (the youngest) 1200–600 ^{14}C BP (Fig. 4b). This dating of the Veer cone fits well into these periods of volcanic activity. It may be hypothesized that the Veer erup-

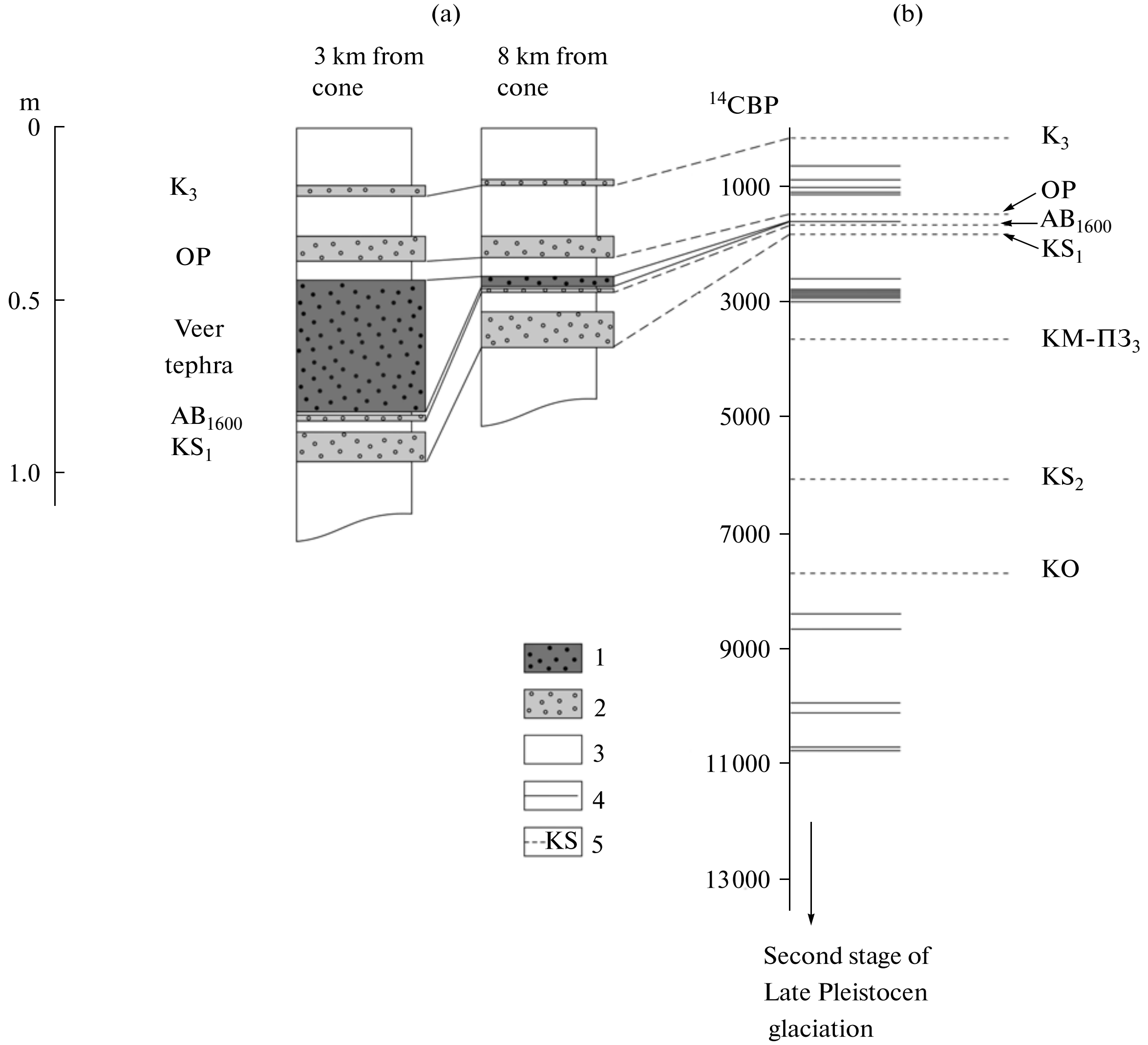

Fig. 4. Fragments of sections of the soil–pyroclastic covers near the Veer cone (a) and the time distribution of areal centers in the basins of the Levaya Avacha and Srednyaya Avacha rivers (b): (1) Veer tephra, (2) marker ashes, (3) interash humified sandy loam, (4) locations of monogenetic centers on the time axis, (5) locations of marker ash beds on the time axis and their indices after [1, 4, 5]. The ages of marker ashes are given after [1, 4].

tion started the third and, until recently, the last stage of areal volcanic activity in the area. The youngest known eruptions during this stage occurred in the Kostakan valley, 30 km toward the west–northwest; the last to occur was that around 600 ^{14}C BP.

It should also be noted that the time of generation of the Veer cone corresponds to a period of dramatic increase in the activity of endogenous processes throughout Kamchatka. Melekestsev et al. [7] define the time interval 0–650 AD as the stage of the most powerful endogenous catastrophism of our time. At least 24 volcanoes erupted during that time period, of the 30 active and potentially active, multiply erupting Kamchatka volcanoes, and a violent spike of activity occurred within the Tolbachik regional zone of cinder cones. It was during that period as well that nearly all of Kamchatka experienced a dramatic tectonic uplift. Although the chief "theater of operations" was in southern Kamchatka, the East Volcanic Zone, and the volcanoes in northern Kamchatka, considerable events were also occurring in the area of study. The all-Kamchatka uplift is also identified from the presence of series of alluvial river terraces 1–3 m high in the basins of the Levaya Avacha and Srednyaya Avacha [11]. In its turn, the Veer eruption was the first in the series of eruptions occurring at monogenetic cinder cones in the area [6].

The periodicity of volcanic occurrences and ongoing seismic activity as identified in the area (see the website www.emsd.iks.ru) suggest that this period of increased activity seems to be still going on, so that new eruptive centers are likely to arise there in the future.

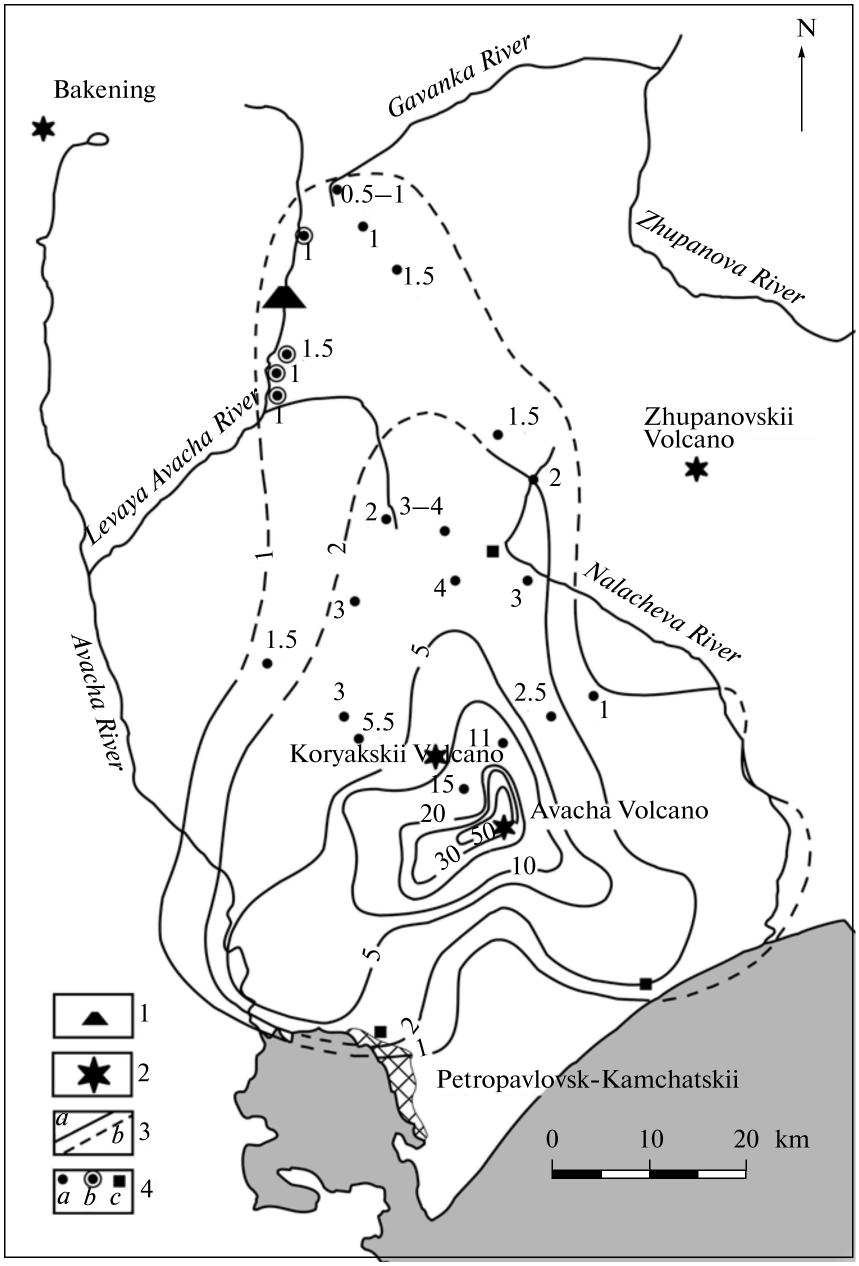

Fig. 5. A map showing the distribution of AV_{600} tephra: (1) Veer cone, (2) Holocene volcanoes, (3) lines of equal thickness in cm (*a* certain, *b* hypothetical), (4) observation sites (not exhaustive) and ash thickness in cm (*a* those used previously to construct lines of equal thickness north and northwest of Avacha Volcano, *b* those acquired near the Veer cone, *c* sections in which the radio carbon age of AV_{600} ash was determined).

CONCLUSIONS

(1) The Veer cone is a monogenetic center that formed around 1600 ^{14}C BP or approximately in 470 AD in calendar scale. The idea that the cone formed in 1856 is not supported by our studies. For this reason both the Veer cone and the erroneous date should be eliminated from the catalogs of active volcanoes.

(2) The eruption of the Veer cone was largely phreatomagmatic thanks to the contact between the rising magma and the unconsolidated water-saturated deposits that fill the Levaya Avacha River valley. It was only during the terminal phase, when the lava flow was being discharged, that the explosions became Strombolian.

(3) About 9×10^6 m^3 pyroclastics were ejected during the eruption, along with about 1.46×10^7 m^3 of lava. The total volume of erupted material when converted to solid rock was 1.8×10^7 m^3.

(4) The eruption can be regarded as a manifestation, in the Levaya Avacha River basin, of the all-Kamchatkan

increase in the activity of endogenous processes that occurred in 0–650 AD.

(5) The periodicity of areal volcanism and the relationship between the volcanism and tectonic movements in the area of study suggest that volcanic eruptions are very likely to occur there in the future.

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