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STUDIES OF SECULAR PALEOMAGNETIC VARIATIONS IN KAMCHATKA USING HOLOCENE TEPHRA

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Analysis of paleomagnetic variations along parallel sections across the Holocene soil-pyroclastic cover of Malyĭ Semyachek Volcano in Kamchatka has shown that directions of magnetization were similar during a period of 350–6000 B.P. This proves that magnetization is primary and applicable for reconstruction of the history of the Earth's magnetic field. Paleomagnetic variations that occurred in the interval of 1000–4000 B.P. have been investigated in the contemporaneous tephra section of Klyuchevskoĭ Volcano 240 km to the north.

It is known that since some of the tephra horizons may be missing in this section owing to specific conditions of tephra deposition, a more detailed knowledge of paleomagnetic variations requires the study of two or more parallel sections.

Holocene soil-pyroclastic deposits, widespread in areas of young volcanism in Kamchatka, consist mainly of tephra. Sections commonly exhibit here a rapid alternation of unaltered tephra of different granulometric composition (ash, volcanic sand, lapilli, scoriae) and humic sandy loams and buried soils of a variable organic content. Attaining 15–20 m in thickness and being well preserved in the interfluve areas, this rock succession presents a detailed record of the history of the nearby volcanic activity. The presence of humic layers and horizons with buried wood and coals in the sequence allows their radiometric dating over a sufficiently closely spaced grid. Along with some other properties, the above-mentioned features of the soil-pyroclastic deposits make them a favorable target for the study of paleosecular variations of the geomagnetic field [3].

Deposits of this kind had hardly been used at all for paleomagnetic investigations until recently, when new evidence indicated that fine-clastic tephra (less than 1 mm in particle size) was suitable for paleomagnetic reconstructions and studies of paleomagnetic variations in the Holocene [1]. The early results, however, had not been verified in parallel sections. Verification was extremely important since the subject of study was new, and all previous judgments were more or less indirect. And only confirmation that paleomagnetic variations recorded in tephra extend along the strike could demonstrate the suitability of these rocks for reconstructing the history of the geomagnetic field. For this purpose a comparative study was carried out in parallel sections of the soil-pyroclastic cover of Malyĭ Semyachik Volcano and, partly, Klyuchevskoĭ.

The studied sections, situated at a distance of 3 to 5 km from Malyĭ Semyachik, are 5 to 7 m in thickness. The dominant constitutent is fined-grained material suitable for paleomagnetic sampling. The collection of oriented specimens, measurement of their magnetic properties, magnetic cleaning, and data processing were performed independently by paleomagnetic teams from the Institute of Volcanology, Far East Scientific Center, USSR Academy of Sciences, and from the Academy's Institute of Physics of the Earth.

The section studied by the Institute of Volcanology team consisted of two parts, upper (section 8) and lower (section 3). They were sampled using a continuous, locally overlapping grid. The sampling localities were chosen according to the results obtained by Braĭtseva et al. [2] so that the deposits would be sufficiently complete and representative in each of them. Section 5 studied by the Institute of Physics of the Earth covered the stratigraphic range of both sections and was situated at about 3 km from each of them. A good tephrostratigraphic knowledge and reliable mutual correlation of these sections on a sufficiently large number of marker horizons made it possible to identify strictly synchronous intervals in them. The chronological dating of these intervals was facilitated by the availability of about 30 radiometric datings obtained for different horizons of the soil-pyroclasticc cover of the Malyĭ Semyachik area [2].

Analysis of the geochronological data available points to a great irregularity in the rate of accumulation of the studied deposits. The lowest rates of 15–20 cm per 1000 years are typical of the soil horizons formed in the episodes of weak volcanic (explosive) activity. At the same time, volcanic scoriae reaching several meters in thickness could be deposited during one eruption. This excludes the possibility, applicable to other types of sedimentary rocks, of interpolating and extrapolating the age of horizons which cannot be directly dated.

Another special feature of tephra successions essential for their understanding should be mentioned. It concerns the fact that the deposition area of volcaniclastic ejecta changes from eruption to eruption. The factors that determine it may be the height of volcanic ejections, their granulometric and mineralogical composition, and the direction and velocity of the prevailing winds. The preservation of the ejecta varies from place to place depending on the topography, vegetation, and other factors. Because of this, successions of tephra beds may differ from one another even in two nearby sections, and, as a consequence, some layers in the sections may be missing, and, accordingly, there may be breaks in the paleomagnetic record. Therefore, in correlating the paleomagnetic data on parallel sections, an important task is to complete the paleomagnetic record by adding information on the missed layers.

The initial data on each of the sections were sets of the mean directions of natural remanent magnetization (after magnetic cleaning) for each of the sampled horizons (four to eight oriented samples were collected from each horizon). In the subsequent data processing, the directions were averaged for two or more adjacent horizons so that the distance of each direction thus obtained from the adjacent ones was not less than the corresponding radius for the cone of confidence at $P = 0.05$.

Let us now consider the results of correlating variations in the remanent magnetization vector obtained for simultaneously deposited intervals of the sections. The first of the intervals embraces a time gap of 300 to about 1000 years B.P. In Figure 1 a the solid curve shows variation in magnetization in section 8, and the dash curve in section 5. In both cases an almost closed variation loop is observed. Similar variations of the vector direction in the two sections favor the supposition that the magnetization revealed in the rocks is primary and that the studied geomagnetic variations are realistic. It follows from Figure 1 a that, for one of the above-mentioned reasons, the directions corresponding to horizon 5 of section 8 have not been recorded in section 5 and the directions corresponding to horizons 7 and 8 of section 5 have not been detected in section 5. By complementing each other, the mentioned directions substantially improve the trajectory of the vector over the time interval. This is seen from Figure 1 b which demonstrates a paleovariation loop derived by generalizing the data on both sections. The directions of some points on this trajectory have been averaged from the data of the two sections. Averaging has been performed for the horizons whose ages, judging by the tephrostratigraphical data, are close, and the directions of magnetization coincide within the limits of the measurement error (the cones of confidence are considerably overlapping).

The next (downward) interval of the section covers a time range of about 1000 to 3000 years B.P. The data obtained for this interval are illustrated in Figure 2 a. In this case, apart from the apparent resemblance of the trajectories, we can see a pronounced

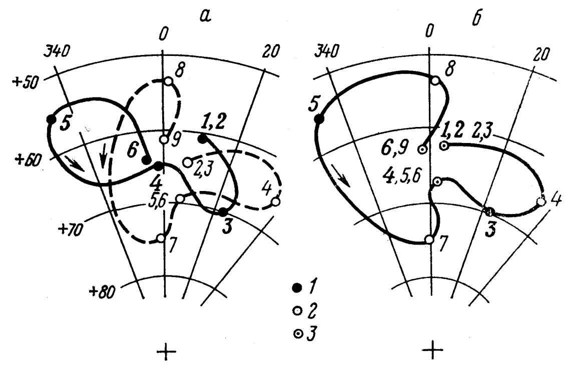

FIGURE 1 Variations of paleomagnetic field 300–1000 years B.P.: a – data on parallel sections; b – summary trajectory of remanent magnetization vector; 1 – section (designated in Figures 4 through 6 as section 3); 2 – section 5; 3 – directions averaged from two sections; arrows indicate changes in directions from young to old geomagnetic fields.

difference in their orientation. The figure pattern suggests that the rocks of one of the sections are turned almost by 90° around the axis with an azimuth of 355° and a dip of about 65°. However, the tectonic and geomorphological situation at the sampling site rules out this suggestion. Nor is there any evidence for a mechanism of remagnetization of these rocks, which could lead to such a result. Therefore, the only explanation is that the paleomagnetic record is incomplete in the studied sections, which somewhat distorts the geomagnetic variations. Figure 2b demonstrates the reconstruction of these variations based on the data from both sections. The validity of the presented 8-shaped loop of paleovariations taking place 1000–3000 years ago is confirmed by the study of paleovariations in the tephra deposits of Klyuchevskoĭ Volcano which is 240 km north of Malyĭ Semyachik. A fairly similar paleovariation loop has been obtained there for this time interval (Figure 2 c).

Uninterrupted layered tephra deposits 3000–4000 years in age are missing in sections 3 and 8 (this is another striking example of missed tephra horizons). Because of this, the directions of magnetization in this interval of section 5 can only be compared with the data from the area of Klyuchevskoi Volcano. This comparison, demonstrated in Figure 3, reveals a similarity in variations of remanent magnetization at both fairly far spaced observation points.

The next interval of the section embraces the rocks deposited approximately 4100–4600 years B.P. These rocks have been studied in section 5 and 3, and the results are shown in Figure 4 a. As seen from the Figure, the position of three points of the variation loop obtained for section 5 agrees with the initial segment of the trajectory obtained in section 8. The supposition that the upper horizons of this time interval are missing is supported by the analysis of the lithology in both sections: soil horizons which are readily recognizable in section 8 are either absent or very thin in section 5. Moreover,

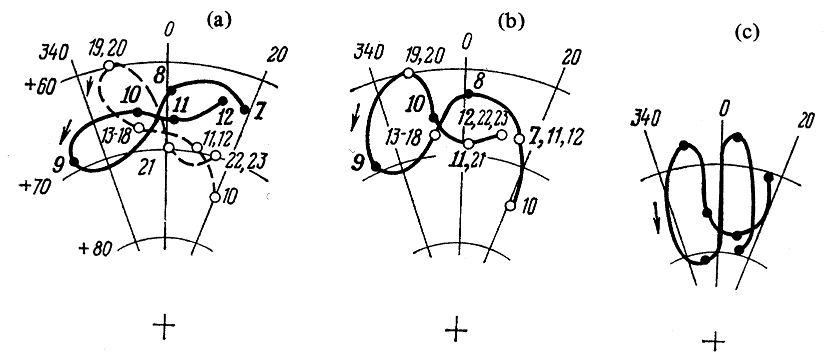

FIGURE 2 Variations of paleomagnetic field 1000–3000 years B.P.: a, b – same as in Figure 1; c – data on section of Klyuchevskoĭ Volcano.

in section 8, which is in general somewhat thicker, peleomagnetic sampling of this stratigraphic interval was carried out with overlapping, whereas in section 5 sampling was performed by a conventional layer-by-layer technique. Thus, in the magnetization vector trajectory generalized for the data of the two sections (Figure 4 b), only the initial segment has been confirmed; the part of the trajectory denoted by the dash line has to be verified.

When reconstructing the generalized trajectory a correction for a dip of 4° was introduced into the direction of magnetization in section 8. The necessity for this correction

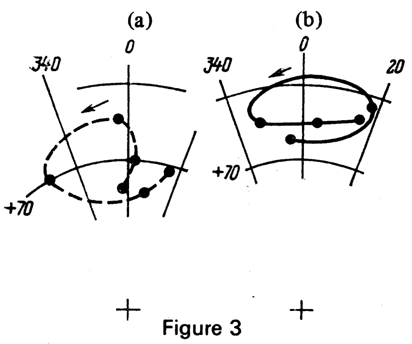

Figure 3

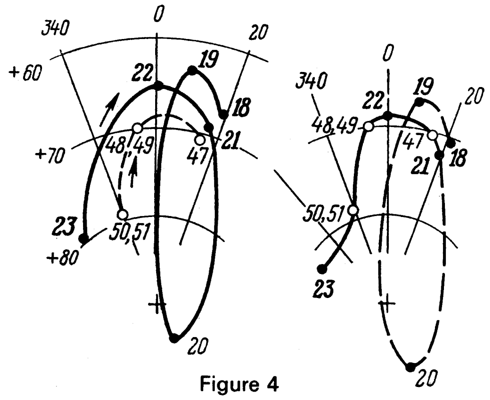

Figure 4

FIGURE 3 Variations of paleomagnetic field 3000–4000 years B.P.: a – data on section 5; b – data on section of Klyuchevskoĭ Volcano.

FIGURE 4 Variations of paleomagnetic field 4100–4600 years B.P. See Figure 1 for explanations.

followed from the displacement of two trajectories (Figure 4 a). It is assumed that the displacement was caused by a change in the dip of the tephra layers in section 8, owing to a landslide or slumping (this section was sampled in steep cliffs of a creek). At the same time, in section 5, which was sampled in a pit dug in a comparatively flat site, the possibility of any secondary dip of the tephra layers can practially be ruled out.

The secondary geomorphological dip of the tephra layers, which increases with depth, is distinctly traceable in all the subjacent horizons of section 8. Its identification and quantitative estimation became possible only after correlating the data on parallel sections.

An interval of 4600--5000 years B. P. has been studied in the same two sections, 5 and 8. The result obtained is shown in Figure 5 a. The similarity of the vector trajectories in both sections is obvious. The above-mentioned displacement of the trajectory points of section 8 is here almost 5°. The generalized trajectory obtained after applying this correction is shown in Figure 5 b. In this case, the position of horizons 50 and 51 of section 5 between horizons 26 and 27 of section 8 is confirmed by the stratigraphic data. As seen from Figure 5, a distinctly abnormal direction of the vector in horizon 27 has not been verified in the parallel section, and consequently this part of the trajectory is indicated by a dash line. In our opinion, it is premature to discard from further consideration this abnormal direction as well as the direction of magnetization in horizon 20 of the previous age interval, since they may reflect the geomagnetic variations that were too short to be fixed in the sedimentary sections. If realistic, these paleofield directions could provide good chronological and stratigraphic markers, and hence these age intervals should be studied in greater detail in future on several other parallel sections.

The results obtained from sections 5 and 8 for the next age interval – from 5000 to 6000 years B. P' – are shown in Figure 6 a. At first glance, the two demonstrated trajectories are essentially different. Yet, after applying a correction for a dip of the tephra layers in section 8 (as large as 7.5°) their common features become clearer, enabling us to reconstruct, with a certain degree of probability, the variations of the geomagnetic field in this time interval. This reconstruction (Figure 6 b) shows that a variation loop with the directions corresponding to magnetization in horizons 57, 58, and 59 of section 5 has not been reflected in section 8. Obviously, more parallel sections need to be studied to confirm these directions and to refine the geomagnetic variations in this age interval.

In the section below, we failed to find any similarity between the magnetic variations in the synchronously deposited layers. This can possibly be explained by a different

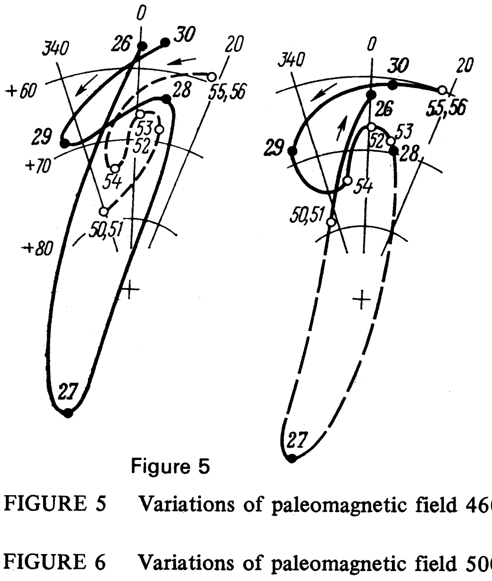

Figure 5

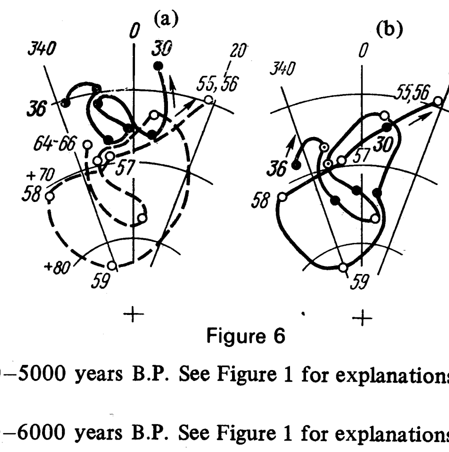

Figure 6

FIGURE 5 Variations of paleomagnetic field 4600–5000 years B.P. See Figure 1 for explanations.

FIGURE 6 Variations of paleomagnetic field 5000–6000 years B.P. See Figure 1 for explanations.

regime of explosive activity of Malyĭ Semyachik Volcano. While the upper part of the section is a frequent alternation of numerous thin tephra interlayers, which is favorable for a detailed record of the geomagnetic history, the lower part consists of a comparatively fewer number of thicker interbeds deposited as a result of single explosions. Another explanation may be that the amplitude of variation in the preceding time interval was lower and comparable with the error of our estimates. According to the preliminary data, such a decrease in the amplitude of paleovariations 4000 and more years ago is observed in the tephra deposits of Klyuchevskoĭ Volcano, too. And, finally, a possibility cannot be ruled out that the directions of the ancient geomagnetic field were not stable enough. This problem, however, requires particular consideration and more field and laboratory study.

CONCLUSIONS

1. Parallel sections of soil-pyroclastic deposits of Malyĭ Semyachik display identical changes in the directions of remanent magnetization for a time interval of 300 to 6000 years B. P. The same picture has been observed for an interval of 1000–4000 years B. P. in the contemporaneous successions of Malyĭ Semyachik and Klyuchevskoĭ volcanoes, situated 240 km apart. This confirms that tephra carries primary synchronous magnetization that reflects the directions of the ancient geomagnetic field.

2. Because the studied objects are complex owing to their specific origin (lithologic diversity, the discrete nature of the age, and the extremely irregular rate of accumulation of individual horizons), the study of two or more parallel sections is required to obtain a detailed picture of paleovariations.

3. The results obtained indicate that paleovariations can be applied in the differentiation and very detailed regional correlation of Holocene deposits.

REFERNCES

1. V. A. Alekseeva, A. G. Zubov, and V. V. Kochegura, in: *Problemy izucheniya paleovekovykh variatsiĭ magnitnogo polya Zemli* (Problems of study of secular paleomagnetic variations) (Vladivostok, 1979): 36–51 (in Russian).
2. O. A. Braĭtseva, I. A. Egorova, I. A. Nesmachnyĭ, O. B. Selyangin, and L. D. Sulerzhitskiĭ, *Byull. Vulkanol. St*. No. 54: 41–52 (1978) (in Russian).
3. O. A. Braĭtseva and I. V. Melekestsev, in: *Problemy izucheniya peleovekovykh variatsiĭ magnitnogo polya Zemli* (Problems of study of secular paleomagnetic variations) (Vladivostok, 1979): 27–35 (in Russian).