PALEOTSUNAMI DEPOSITS AND BURIED EROSIONAL SCARPS FROM CO-SEISMIC SUBSIDENCE ALONG AVACHINSKY BAY COAST (KAMCHATKA)

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The distance from the Kamchatka coast to the axis of the Kuril-Kamchatka Trench varies from about 80 to 200 km, which has an important impact on onshore co-seismic crustal deformation. Only the strongest subduction-type earthquakes with a source width on the order of 150 km or more can cause noticeable coseismic subsidence on the broadly recessive parts of the Kamchatka coast such as Avachinsky Bay (Pinegina, 2014, Lander, Pinegina, 2017). In the case of Avachinsky Bay, these prehistoric widest ruptures are recorded by buried scarps - the result of post-seismic coastal retreat/erosion - as well as by tsunami deposits. The marker tephra at Avachinsky Bay are abundant enough that buried scarps can be well dated, and specific tsunami deposits can be correlated with them.

During field investigations along about 70 km of Avachinsky Bay (Fig. 1) we measured 9 topographic profiles perpendicular to the coastline and described ~150 soil and peat sections. Along each profile, we dug excavations through the soil-pyroclastic sequence down to clean beach/storm sand, typically not deeper than to 2.5-3 m. In excavations, we made general descriptions of the geological sections and identified, described and sampled volcanic ashes (tephra) and tsunami deposits.

Fig. 1. Field area on the coast of the Avachinsky Bay where we studied the tsunami deposits and cosmetic deformations. The position of the measured topographic profiles showed by black lines.

On the central and north coast of Avachinsky Bay, most of the tephra horizons in the soil belong to active Avachinsky volcano, a few tephra layers related to Ksudach and Opala volcanoes (and Zhupanovsky at the north part of the studied coast). Using both the chemical analyses and radiocarbon dates, we could correlate these tephra to previously studied and mapped ashfall layers (Pinegina et al., 2018).

During our study, we determined the age of each beach ridge (and related swale). The age of the lowermost tephra in the section roughly corresponds to the time when the active beach ridge passes into the inactive stage, and the soil-pyroclastic sequence begins to accumulate above the beach storm deposits (Pinegina et al., 2013). After dating each beach ridge we find such places along profiles, where the nearest ridges have a quite significant difference in age (we can see this difference from the numbers of tephra layers in excavations). We supposed that between this excavations should be buried erosional scarps.

Therefore we did here GPR sounding, and according to the radargrams, we chose a place for trenching. We used the Russian GPR “Oko” and shielded aerial units with a center frequency of 250 and 700 MHz and measured GPR profiles perpendicular to the shoreline and beach-ridge orientation (strike) (as in Meyers et al., 1996). Buried erosional scarps on GPR profiles look like a boundaries corresponding to an angular unconformity, dipping seaward at an angle greater than prograding shoreline surfaces (Fig. 2).

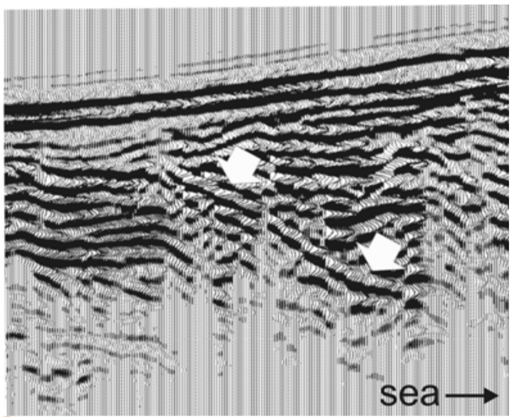

Fig. 2. The fragment of GPR profile with buried erosional scarp (white arrows).

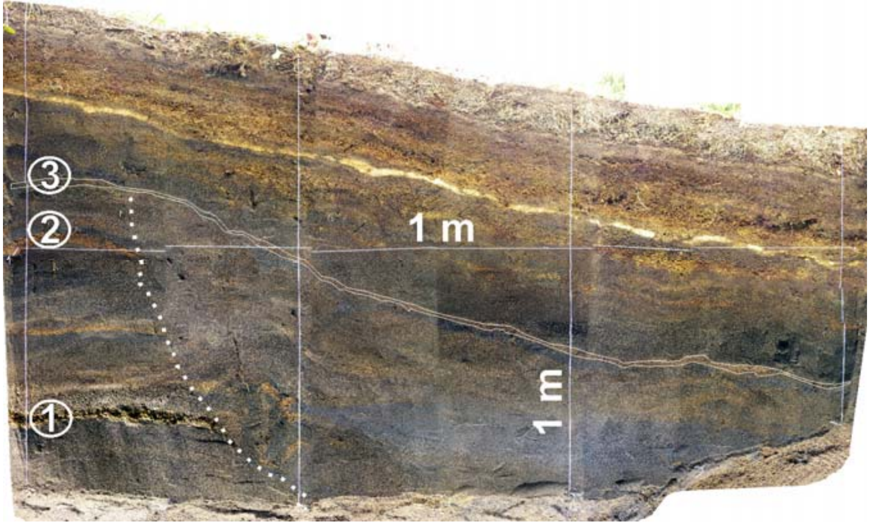

Fig. 3. The wall of the trench with opened buried scarp (dotted line). The coastline is to the right. Numbers 1, 2, 3 correspond to the horizons of tephra at the age of 2650 ^{14}C, 2500 ^{14}C and 2400 ^{14}C years BP accordingly. The white line shows the horizon of tephra 3 overlapping the scarp. Age of this buried scarp (from co-seismic subsidence) is 2450 ± 50 ^{14}C years BP.

We opened buried scarps in trenches (Fig. 3), make descriptions, photos, and take samples of tephras and tsunami deposits. In the excavations located landward from the buried scarp, we identified and described the tsunami deposits which had a similar age, and thus we confirmed the cosmetic nature of the scarp. To reconstruct paleoshoreline horizontal and vertical positions and determine paleotsunami runup back in time, we use tephra stratigraphy and tephra mapping along measured topographic profiles (Pinegina et al., 2013). The frequency of significant ashfalls (which left visible layers in the soil profiles) in our field area is from the first tens to the few hundreds of years, so the method is accurate enough to correlate and date sediments and forms of relief (Pinegina et al., 2018).

In the southern part of the field area (Khalaktyrsky Beach), the age of oldest beach ridges, dated by tephrochronology are ~ 3300 ^{14}C years (Pinegina et al., 2002). In the middle part of the studied area (near Kotel'noe Lake and Right Kotel'naya River) the oldest preserved beach ridges were formed ~3700-3800 ^{14}C years ago (Pinegina et al., 2018). In the northern part of the field area (Ostrovnaya and Vakhil' Rivers), the oldest poorly preserved beach ridges have age ~5200 ^{14}C years, and ridges pronounced in modern relief have age ~3500 ^{14}C years (Pinegina et al., 2017).

In study area we reconstruct the vertical runup and horizontal inundation for 33 big tsunamis recorded over the past ~4200 years (Pinegina et al., 2018), 5 of which are historical events − 1737, 1792, 1841, 1923 (Feb) and 1952. The runup heights for all tsunamis in Kotelnoe site (Fig. 1) range from ~2 to ~6 m, and inundation distances from 40 to 460 m. At Khalaktyrsky Beach (Fig 1) the historical and paleotsunamis runup were some higher – up to 6-8 m, with about the same inundation distances up to ~450 m (Pinegina et al., 2018). In Ostrovnaya – Vakhil' site the runup heights of Holocene tsunamis range from ~1 to ~6 m and inundation distances up to 500 - 700 m.

The average recurrence for historical tsunamis is ~56 years and for the entire study period ~133 years. The obtained data make it possible to calculate frequencies of tsunamis by size, using reconstructed runup and inundation, which is crucial for tsunami hazard assessment and long-term tsunami forecasting.

For the same period of time, in total, three buried erosion scarps were discovered and studied (Fig. 3, 4; Pinegina et al., 2015, 2017). With the help of the tephrochronology method, we determined that the scarp #1 was formed 1150 - 1250 ^{14}C years BP, scarp #2 - 2400-2500 ^{14}C years BP, and scarp #3 - 3300 - 3500 ^{14}C years BP, the amplitude of subsidence for each event was ~ 1 ± 0.5 m. Not every identified buried erosional scarp in the body (sediments) of the marine terrace can be associated with the co-seismic subsidence of the coast. For example, the tsunami also can make not a space-regular scours or scarps. The criteria's for the separation of particularly co-seismic scarps from other are their same age along a large part of the coast (tens to hundreds of km), its age coincidence with deposits of the tsunami, which accompanied the earthquake.

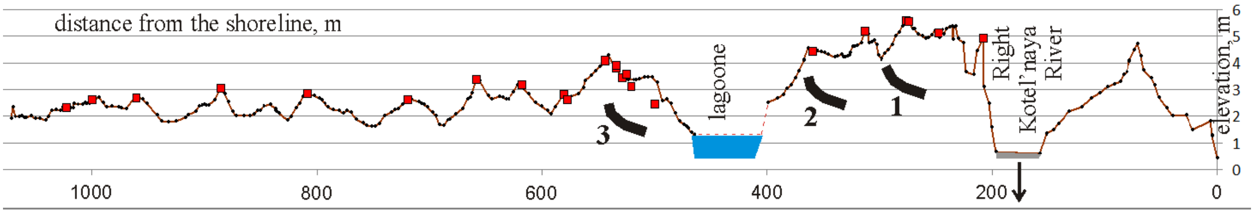

Fig. 4. One of the topographic profiles measured across the marine terrace. The elevation of the profile is relative to the Point of the State Geodetic Network (sea level at the moment of measurement was +0.5 m). The excavations position is shown by red squares. The position of the buried erosional scarps #1-3 is shown by bold black lines.

We fined that the difference in runup and inundation between typical tsunamis and tsunamis which accompanied by co-seismic subsidence at the central-northern part of Avachinsky Bay are not significant to separate events by this parameters. Study of geological traces of the coastal vertical co-seismic deformations along the subduction zones makes it possible to detect the strongest (mega) earthquakes from the other (typical) tsunamigenic events.

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This work was supported by grants from RFBR #18-05-00407 & FEB RAS #18-5-003 (to Pinegina), Russian Ministry of Education and Science (grant #14.W03.31.0033 to Shapiro); Expeditionary studies partly supported by grant RFBR #16-05-00090 (to Kozhurin).