Numerical analyses of tsunamis generated by caldera collapse and pyroclastic flow entering sea during the 6.5 ka Kikai eruption

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Tsunami generation, propagation, and inundation during the 6.5 ka caldera-forming eruption at Kikai volcano, Japan, were investigated numerically in order to limit them to the source conditions, using two models; a caldera collapse model and a pyroclastic flow entering sea model. Non-linear long wave equations were used with variable initial conditions, which were controlled by some physical parameters effecting on wave characteristics.

Caldera collapse models describe the difference in geometry between pre- and post-collapse and the duration of collapse. With all models, the computed tsunami heights just outside the caldera were largest when dimensionless collapse speeds (Vs/(gh)ˆ1/2) were about 0.01, and the height substantially decreased with slower speeds. In some locations along the coasts of the Kyushu mainland, the maximum height, run-up height, and run-up distance of tsunamis were calculated for all models. When the collapse speed was low, the tsunami height was just a few meters and it did not produce in most coastal areas. The approximate boundaries whether inundations occur or not at the studied outcrops are 0.003 at Ei, 50 km from the caldera, and 0.01 at Nejime, 65 km from one, respectively.

Pyroclastic flow models describe the difference in volume flux of a debris component of pyroclastic flow entering sea, using a two-layers model, which is valid when the source size is much larger than water depth. Flux was controlled, using a sine function, and the maximum one was set to be 106, 107, and 108 m3/s. Results of numerical computations calculated from the relationship between maximum flux and total volume of pyroclastic flow with each model showed that the maximum height of the tsunami varied, and was largest when the dimensionless volume flux (q/h(gh)ˆ1/2) was about 0.22 for all models. The first positive waves in the larger volume flux models produced run-up on land, but when the volume flux was lower, the tsunami height was drastically decreased to just a few meters and it did not produce in most coastal areas. The approximate boundary whether inundation occurs or not is 0.1 in Satsuma Peninsula (Makurazaki and Ei). In Nejime, inundation does not occur in all models.

Geological evidence of tsunami generation during the 6.5 ka eruption is indicated by submarine sediments, composed of reworked sand layers, in Tachibana Bay, Nagasaki, and 220 km from the source (Okamura et al., 2005, J027-P025). The approximate source conditions of the tsunami, which can stir granule-to-pebble size particles on the sea floor, were investigated in the computed area, using the Shields-Bagnold non-dimensional boundary shear stress. As a result, it is suggested that tsunamis generated by caldera collapse could easily achieve the shear stress to the threshold values for the particles, but ones generated by pyroclastic flow entering sea could not sufficiently. On the other hand, at Nejime, a complete sequence of eruptive deposits was found at 20 m above sea level suggesting no tsunami inundation at this location, indicating that tsunamis were less than 20 m in height. Comparisons with geological and numerical results can lead the source condition of the 6.5 ka eruption: the range of dimensionless caldera collapse speed, 0.001-0.01, corresponding with durations from 40 minutes to 6 hours (deepest collapse model), or ones from 20 minutes to 2 hours (shallowest collapse model), which can explain traces of tsunami in all locations. A dimensionless volume flux of a climactic pyroclastic flow cannot be sufficiently limited, but it should be about 0.1, when tsunami inundate at coasts in Satsuma Peninsula.