



Multiple severe typhoons in recent history revealed by coral boulders of northwestern Luzon, Philippines

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Meter-sized coral boulders occurred on Holocene reef flat at Pasuquin, Ilocos Norte and Cabugao, Ilocos Sur, Philippines. Boulders larger than 3 meters were located and measured by field survey and UAV photogrammetry. Boulders now distributed 45-140 m away from edge of Holocene reef flat, and above highest high tide. The lithology of those boulders is the same as the underlying Holocene coral reef at the sites, hence believed to be broken from reef edge locally. Fossil corals in those boulders mostly appear not in upward-growing attitude but overturned or tilted. Several tens of photos were taken around selected boulders from different angles, and 3D models were established from the photos. Dimension and volumes were calculated from 3D models. Boulder volumes can be estimated much more accurately this way than simply multiple X, Y, and Z as many previous studies did. The volumes of boulders larger than 3 m in length vary from 10-52.6 m³. Assuming 2.1 g/cm³ for wet density, weights of boulders are estimated to range from 21-110 metric tons. Boulders of such size and weight obviously can't be moved by normal waves, and likely dislodged by Extreme Wave Event (EWE). Small and well-preserved corals were found in depressions on boulder surface and interpreted to represent timing of final displacement. Corals found on seven boulders at Pasuquin were ²³⁰Th dated to be 1782, 1904, 1946, 1957, 1978 and 2003 AD respectively. No tsunami was reported in historical records in northern Luzon for those years, but several documented typhoons could be responsible for displacement of each of those boulders. Another Porites boulder at Cabugao was dated to be tilted five times from 673-838 AD, averaging one EWE every 33 years. Such frequent occurrence of EWE is unlikely resulted from tsunami. Therefore, those coral boulders at Pasuquin and Cabugao are interpreted to be displaced by severe typhoons.