Temporal Relationships between Vertical-CLVD Earthquakes and Volcanic Unrest

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Although most volcanic earthquakes are small, occasionally volcanoes generate earthquakes that can be detected globally. Some of the largest and most unusual volcanic earthquakes are vertical-CLVD events, for which deviatoric moment tensors have large non-double-couple components dominated by vertical extension or compression. Well-studied examples include M_W >5 earthquakes associated with fissure eruptions at Bárdarbunga and Nyiragongo volcanoes, as well as the Tori Shima earthquake, which is associated with a volcanogenic tsunami. To assess the link between the occurrence of these anomalous earthquakes and volcanic unrest, we performed a systematic global search for vertical-CLVD earthquakes located near volcanoes that erupted in the last ~100 years. We identified 101 vertical-CLVD earthquakes with magnitudes $4.3 \geq M_W \geq 5.8$, and found that approximately 70% are associated with documented episodes of volcanic unrest at a nearby volcano. The vertical-CLVD earthquakes in our data set are linked to many different types of eruptive activity including volcanic earthquake swarms at submarine volcanoes, and effusive and explosive eruptions and caldera collapse at subaerial volcanoes. Vertical-CLVD earthquakes are predominantly located in subduction zones, although a small number of events are located in continental rifts and regions of hotspot volcanism. Most source volcanoes have caldera structures and erupt magmas with low silica contents. A source model consisting of dip-slip motion on volcano ring faults can explain the seismic radiation patterns and source durations of vertical-CLVD earthquakes, as well as their relationship to volcanoes in specific geodynamic environments. A particularly important result of our global study is the observation that one type of vertical-CLVD earthquake, those with dominant tension axes, generally precedes volcanic eruptions. These vertical-T earthquakes are likely generated by slip on curved reverse faults triggered by the inflation of shallow magma chambers. Similarly, the other type of vertical-CLVD earthquake, those with dominant pressure axes, generally occurs after the start of eruptive activity at a source volcano. These vertical-P earthquakes are likely generated by slip on curved normal faults triggered by the deflation of shallow magma chambers. Our work clearly indicates that vertical-CLVD earthquakes are causally related to dynamic physical processes occurring inside the edifices and magmatic plumbing systems of active volcanoes, and suggests that the occurrence of these events may be useful for identifying volcanoes that have recently erupted and volcanoes that are likely to erupt in the future.

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