The long-lasting earthquake swarm leading up to the 2024 M7.6 Noto earthquake, Japan

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An intense earthquake swarm has persisted for over three years within a 20 km ×20 km area beneath the northeastern tip of the Noto Peninsula, central Japan, since November 2020. On January 1st, 2024, an M7.6 earthquake rupture nucleated within the swarm area and propagated bilaterally toward ENE and WSW directions along multiple faults over 100 km. Globally, it is rare that a long-lasting seismic swarm preceded such a large event. We have analyzed the continuous seismic waveforms to create a more precise earthquake catalog associated with this earthquake sequence. Based on this catalog, we have explored the spatial-temporal evolution of the seismicity before and after the M7.6 event by applying a machine-learning phase picker and template-matching technique. Note that localized swarm-like seismicity started about 1.5 hours before the M7.6 rupture at the deeper part of the southeast-dipping fault that hosted the 2023 M6.5 event. After the M5.5 foreshock 4 minutes before the mainshock rupture, the foreshock area expanded along strike and dip directions. The mainshock rupture nucleated near the southern edge of the foreshock zone. The swarm-like expanded foreshock sequence indicates the involvement of fluid-driven slow slip transient during the foreshock stage and facilitates stress loading on the mainshock nucleation point.

Previous studies using seismic and geodetic data suggest that the long-lasting earthquake swarm has been driven by upward fluid flow along pre-existing cracks/faults in the crust (e.g., Nishimura et al. 2023). Especially, Kato (2024, doi:1029/2023GL106444) found out a rapid upward migration of the immediate aftershocks following the 2023 M6.5 and M5.9 events and implied fault-valve behavior that might be driven by upwelling of crustal fluids along the intensely fractured and permeable fault zones via the dynamic ruptures. If fluids could migrate along pre-existing faults, fault strength would be reduced by lubrication. In addition, the long-lasting intense seismicity and slow deformations detected by GNSS network have partially released the accumulated elastic stress in the swarm area, resulting in stress loading onto nearby surrounding fault segments. The strength of the faults had gradually decreased, and the stress had been partially released over three years, which may have triggered the powerful M7.6 earthquake.

After the M7.6 rupture, the seismicity spread over 150 km along the fault-strike. Although the northwest-dipping fault planes are recognized in the northeastern part of the aftershock zone, most aftershocks show the southeast-dipping fault planes. Along the several profiles where seismic stations are relatively dense, lithtric fault structures (stepper dip angle near the surface and shallower with increased depth.) can be recognized, indicating reactivation of pre-existing normal faults created during the opening of the Japan Sea. At the down-dip extension of the hypocenter of the M7.6 mainshock, a localized cluster activated after the mainshock rupture, showing a swarm-like feature that tends to become shallower over time gradually. Since this localized swarm implies an upwelling of crustal fluid, it is important to monitor the evolution of the seismicity for a while.