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Paleoseismological multi-theme study of seismically induced geological effects at Vendicari (south-eastern Sicily).

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Strong earthquakes can produce direct and permanent geological effects on the earth surface. Beyond surface faulting, other effects, such as landslides, liquefactions and ground deformations (seismites), take place in the epicentral area as a consequence of the seismic wave propagation in the sediments. Since the last three decades only, these features have been considered indicators of seismicity and their analysis (paleoseismological off-fault study) has been used as an useful tool for obtaining crucial information on the causative earthquake parameters. Such analyses are especially useful in areas where earthquakes occurred before the seismic instrument development or without clear evidence of surface faulting. Since paleoseismology is a youth discipline, the integration of innovative and multidisciplinary techniques and the updating of the case studies on seismites is of fundamental importance.

During historical time south-eastern Sicily has been hit by strong earthquakes (M up to 7), such as the 1169, 1542 and 1693 events. Given the lack of surface faulting evidence, the real source location of these earthquakes is a still open question and represents the main gap of the Sicilian seismogenic framework, therefore paleosismological off-fault study can contribute to identify seismogenic sources.

Along the NNE-SSW trending rocky coast of Vendicari, we detected a singular association of deformational structures affecting terrains up to Quaternary age. These structures are both soft sediment deformations (autoclastic breccias, diapyr-like injections, dikes and thyxotropic wedges), probably linked to liquefaction mechanisms, and fragile deformations, consisting of opened fractures generally filled by sediment (Neptunian dykes). With the aim to define the deformation mechanisms that affected the deposits at Vendicari, we studied in detail the local stratigraphic sequence and the deformational structures, performing a mesostructural study of the fractures and the analysis of the microscopic characteristic of the filling materials, as well.

The systematic and paleostress analyses of the fractures highlighted a high variability in the architectural style and a high dispersion of the plane direction. This is probably linked to more than one deformative mechanism concurring in their development and masking the stress field. A coseismic brittle deformation, linked to the shaking and to the seismic wave propagation, and a lateral spreading and settlement mechanism with fissuring parallel to the coastline (driven by gravity under a moderate topographic gradients), are proposed as probable causes of the fracture development together with the tectonic stress field. However, the analysis of the fractures, filtered and cleaned up from the contribute of the disturb mechanisms, shows a stress field characterized by a probable NW-SE-trending $\sigma_{1,}$which iscompatible with the active regional stress. The occurrence of violent coseismic deformation should be also testified by the development of the liquefaction-driven soft sediment deformations, observed in the area, that reveals the application of an horizontal shear stress and of a sudden high hydraulic pressure.

The overall analysis of seismites at Vendicari highlights the occurrence of at least three triggering events, occurred after the Pleistocene age. They could be tentatively associate with the historical 1169, 1542 and 1693 earthquakes ($I_0 \geq$X) or with similar or strongest paleoevents, considering the minimum epicentral distances and the minimum intensity at a site ($I_s \geq$ IX) for which an earthquake is capable to induce these association of seismites. The paleoseismological study at Vendicari allowed us to upgrade the paleoseimological off-fault techniques and to increase the study cases in Sicily. Moreover, this study provides, if integrated with similar studies at regional scale, new and useful information on ancient earthquakes in a high-seismicity area like eastern Sicily, for a better characterization of the seismogenic sources.