# Double-couple troubles

by

**Davide Zaccagnino e Carlo Doglioni**

in

**Communications Earth Environment, Nature Group**

The Earth's crust is constantly undergoing the tectonic forces that tend to deform it. In the presence of excessive load conditions, rocks can break causing an earthquake, produced by the sudden movement of crustal masses, accompanied by the release of stress and nucleation of elastic waves. Dislocations occur along complex fractures called "faults". The classical seismological models used for the study of earthquakes assume that the rupture takes place over planes with friction under the action of a double-couple of forces orthogonal to each other and oriented to reproduce the wave radiation pattern recorded by seismic networks. Although restrictive, the assumptions of flatness and elastic rebound can explain the most important seismological observables and provide some first-order information about the seismic event, such as its magnitude and the kinematics of the fault. However, the same hypotheses and other simplifications are too rigid for an advanced description of seismicity, which, on the one hand, allow simplistic interpretations of seismological processes to thrive, and on the other, introduces bias in the estimates derived from the source parameters. The development of seismic networks and the development of the techniques and technologies used in the characterization of seismicity finally allow us to analyse its properties. In the study "The impact of faulting complexity and type on earthquake rupture dynamics" just published in Communications Earth & Environment, it is shown that the composition of the moment tensor, the matrix describing the average dynamics of the seismic event, changes according to the complexity of the fault that generated it, the geological setting in which it was nucleated, and several other reasons related to the seismic signal processing and analysis techniques. Earthquakes are different: the seismic signal in terms of the percentage of double couple in the composition of the tensor moment varies as a function of the structure of the rupture; the latter, in turn, is influenced by the fact that the crustal volumes tend to overlap, move away, or slip parallel to each other. In the first case, the dislocation occurs along a particularly thin and concentrated fracture, while in the other cases it tends to spread and to activate several fault planes. The higher the double-couple, the greater the concentration of effort on a single and thin plane, while a slip on several planes results in a lower double-couple percentage. Therefore, the work demonstrates that on faults associated with compressive environments, i.e., thrusts, earthquakes have a double-couple larger than strike-slip and normal fault-related events. Furthermore, it is highlighted that the estimate of the double-couple component is positively correlated to the magnitude of the events in a significant way only for the compressive events and negatively correlated to the scale exponent of the frequency-magnitude distribution of the seismic events (b-value), usually used in forecasting models. The research shows the existence of a dependence between the structure of the seismogenic source, statistical properties of seismicity and stress patterns within the lithosphere, a relationship that current seismological models, designed to study the dynamics of single earthquakes within a certain resolution, are unable to explain. The results of the research show that to understand the relationship between dynamics of single earthquakes, seismicity, and tectonics, it is necessary to make further theoretical and modelling efforts and to systematically continue the analysis of increasingly abundant and reliable data. Specifically, the role of the various energetic contributions to the mobilization of crustal volumes should be better clarified: while thrust-faulting and strike-slip events are mainly driven by elastic relaxation, normal-faulting ones are dominantly fuelled by gravitational energy; it is then desirable to analyse the impact of the complexity of the seismogenic source on the efficiency of the stress dissipation process in the brittle lithosphere and, consequently, on the spatial and temporal evolution of seismicity (as already discussed in Zaccagnino et al., 2022). This will allow the development of an integrate framework for seismological dynamics and a more advanced and complete understanding of the processes affecting the fragile lithosphere. Furthermore, the study suggests a possible systematic and significant underestimation of the magnitude of earthquakes in the presence of low double-couple values not justified by physical processes. This hypothesis seems to be consistent with the most recent results in the field of 3D modelling of seismic wave propagation (see for example Sawade et al., 2022). Therefore, at least for large events characterized by high non-double-couple components (for instance, the Norcia earthquake 30/10/2016, Mw 6.5 and the Great Kaikoura earthquake, New Zealand, 13/11/2016, Mw 7.8) the need to estimate its magnitude with innovative techniques should be considered, especially due to the impact that an underestimation of the seismic moment can imply on the reliability of the procedures used in the context of seismic forecasting.

References:

Sawade, L., Beller, S., Lei, W. & Tromp, J. Global centroid moment tensor solutions in a heterogeneous earth: the CMT3D catalogue. Geophys. J. Int., 231(3), 1727-1738 (2022).

Zaccagnino, D., Telesca, L., & Doglioni, C. Scaling properties of seismicity and faulting. Earth Planet. Sci. Lett., 584, 117511 (2022).

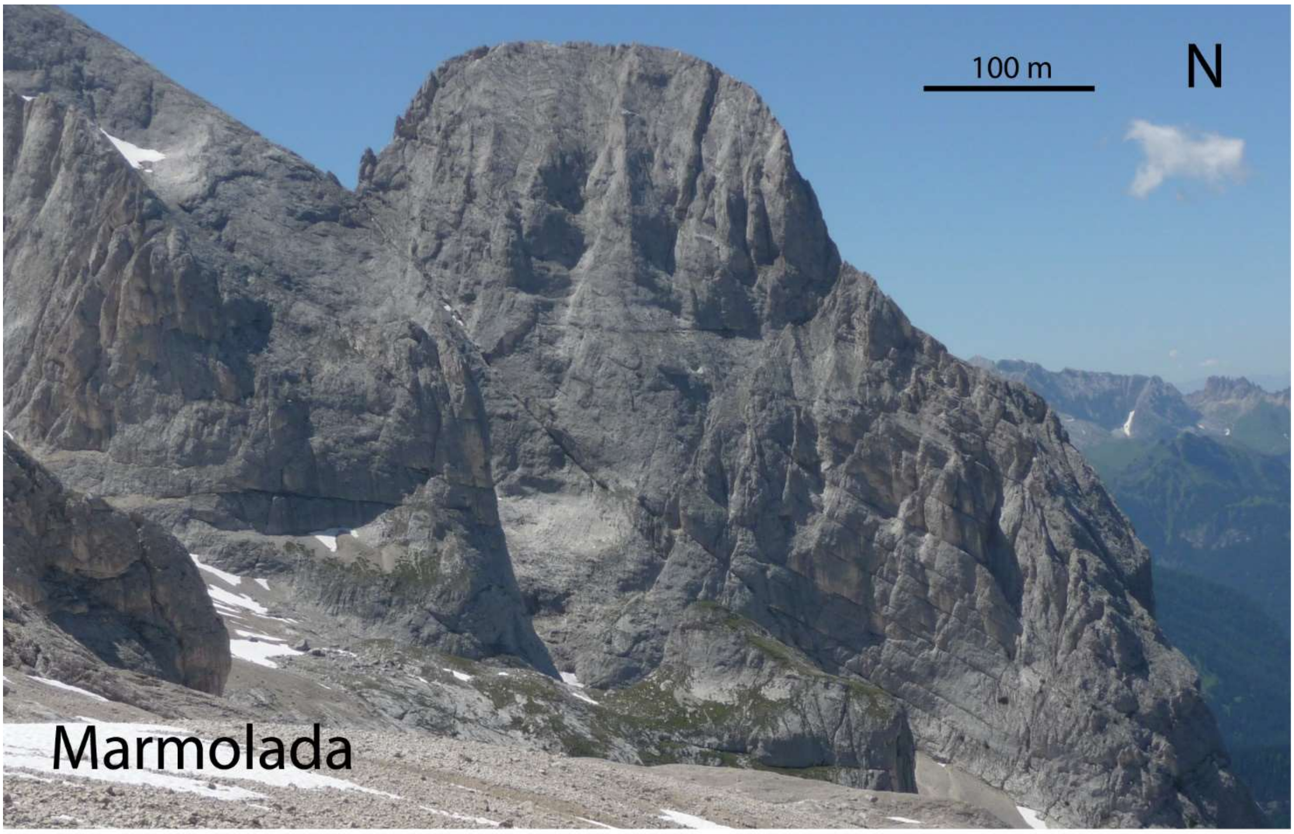
Authors at the *Department of Earth Science, Sapienza University of Rome and ^National Institute of Geophysics and Volcanology:
Davide Zaccagnino* and Carlo Doglioni*^

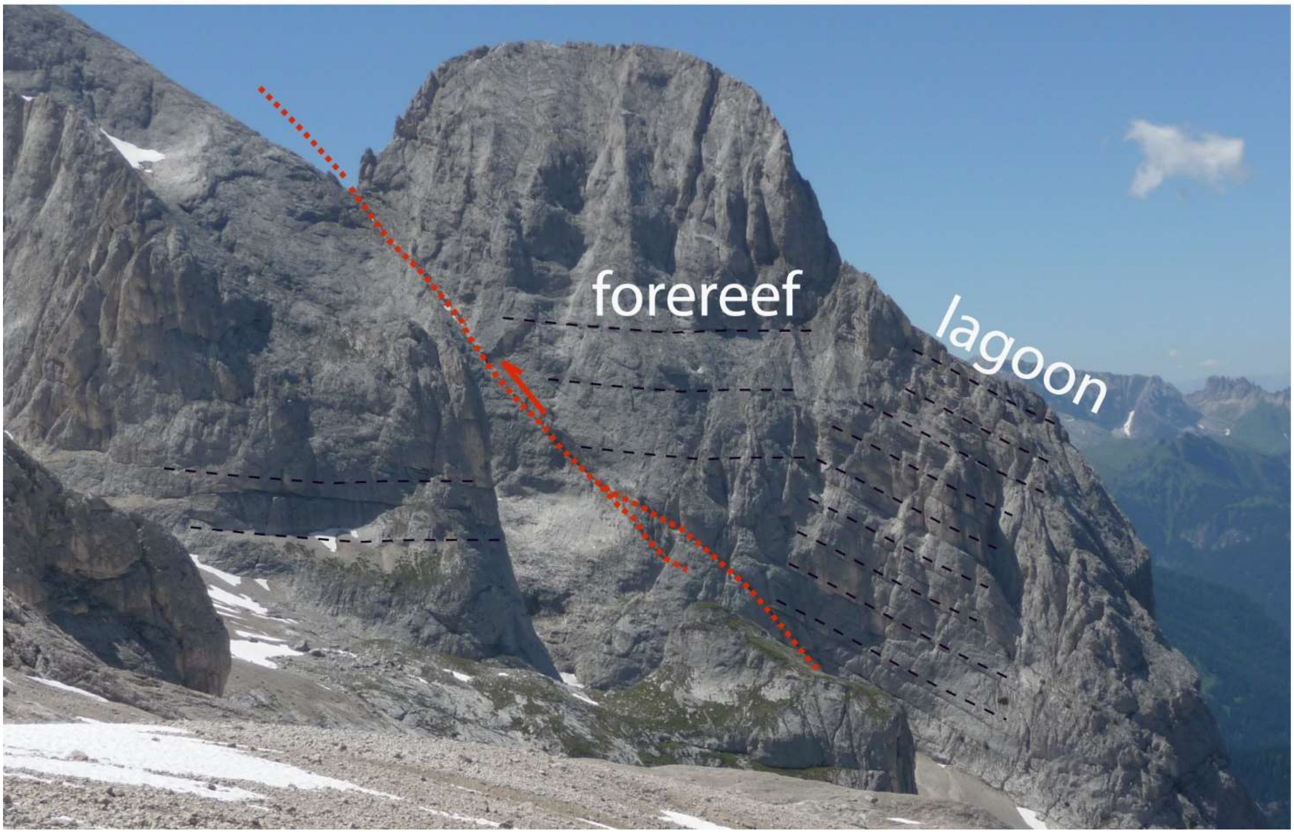
Info: Davide Zaccagnino: davide.zaccagnino@uniroma1.it

Link to the article: https://www.nature.com/articles/s43247-022-00593-5

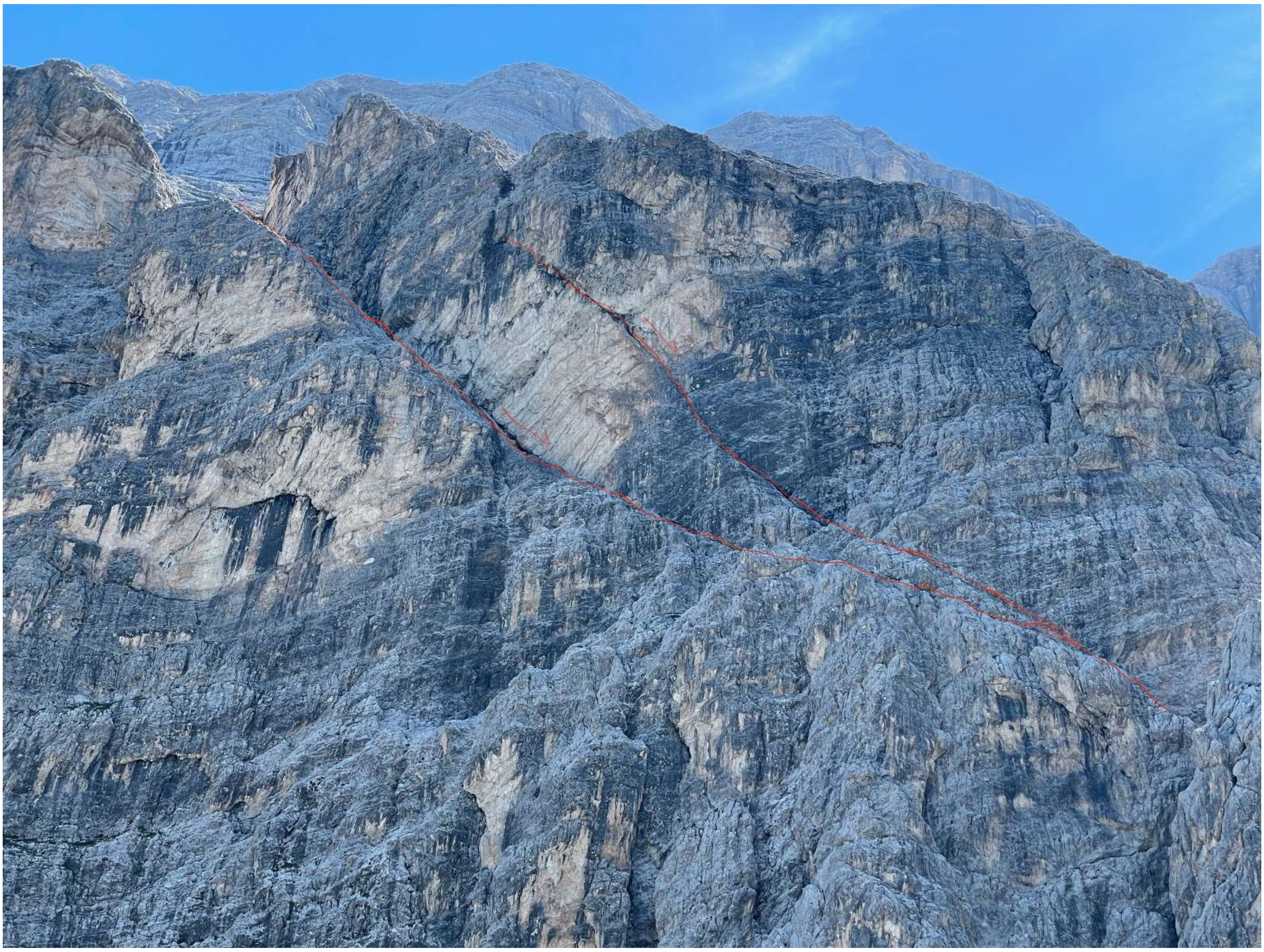
Rome, 30th October 2022 Davide Zaccagnino & Carlo Doglioni

**Alpine S-verging thrust in Middle Triassic carbonate platform, Marmolada Massif in the Dolomites. Note there is a sharp, thin and concentrated damage zone.**



**Branching of two Mesozoic normal faults in the tidal Norian Dolomia Principale of the Conturines Massif in the Dolomites, northern Italy. The offset is only few tens of meters, but the deformation is spread into different segments of a large hanging-wall volume.**



**Damage zone of a left-lateral N-S-trending strike-slip fault. The cataclastic core affects upper Triassic dolomites (SettSass massif, Dolomites, northern Italy) in both wall sides. Note the width of the fault zone that is about 2 m and the horizontal displacement is only 50 m apart, i.e., quite a large damage zone in spite of a small offset.**

Panoramic view of the Campo Imperatore intramountain basin, Gran Sasso Range, Central Apennines, Italy. The along strike white damage zone of the normal/transtensional Tre-Selle and Vado di Corno faults is clearly visible in the left of the image, with mostly Mesozoic limestones and dolostones breccias. The width of the cataclastic core is larger than 300 m accommodating about 1-2 km vertical throw. Holocene alluvial deposits cover the plain to the right. North to the left.

Mesozoic carbonates override the Neogene flysch in the footwall along the Gran Sasso range (Apennines, central Italy). The total shortening is of several (10?) km and the damage zone in the forest at the bottom of the cliff is only few ten of m thick.  West to the left.