Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2023.2.09

Research Article

An earthquake swarm on the Malta Graben, Central Mediterranean, September–November 2020

P. Galea[*1], **M. R. Agius**[1], **D. Farrugia**[1] **and S. D'Amico**[1]
[1] *Department of Geosciences, University of Malta, Msida, Malta*

Abstract. The seafloor of the Sicily Channel is characterised by an extensional regime, governed by a network of normal and strike-slip fault systems. These faults generate a background level of seismicity that rarely exceeds magnitude 5.0. A number of these faults pass close to the Maltese islands. In particular the Malta graben lies less than 15 km to the south of Malta at its closest point, and the islands have been shaken a number of times by earthquakes originating on this, and other fault systems. In this study we describe the occurrence of a seismic sequence, that started in September 2020 and lasted for several weeks, the largest event having a local magnitude of 4.5 and being strongly felt throughout the archipelago. The sequence was located at a distance of around 23 km south of the eastern tip of Malta. We have used single-station polarization analysis at seismic station WDD to estimate epicentral location for all events, down to magnitude 1.2. For the largest events, we have also used conventional network location, utilising phase picks at stations of the Malta Seismic Network and in Southern Sicily. We describe the time evolution of the sequence, felt effects, the public response and the implications for seismic hazard.

Keywords: Sicily Channel, earthquake swarm, Malta graben, felt reports.

1 Introduction and geological background

The Sicily Channel Rift Zone (SCRZ) appears as the main bathymetric feature on the shallow platform joining Sicily to Tunisia in the Central Mediterranean Sea (Figure 1). It features three main grabens that interrupt the seabed in a NW–SE trend. The Pantelleria graben, an approximately 100 km long trough that contains the volcanic island of Pantelleria, branches out into two other parallel troughs—the Linosa graben to the south and the Malta graben to the north. The latter runs for about 180 km, passing less than 15 km south of the Maltese coastline at the nearest point. The whole graben system spans a distance of about 300 km, and the sea depth exceeds 1500 m at the deepest point within the Malta graben (Dart et al., 1993; Pedley & Clarke, 2002). Since the Pliocene, the SCRZ has been undergoing NE–SW directed extension, a process superposed on the general NW directed compressional regime of Africa converging on to Europe. Details of the tectonic history and proposed models of present behaviour are given in, for example, Agius et al. (2022), Civile et al. (2010), Corti et al. (2006) and Faccenna et al. (2001).

Geophysical studies confirm that extension across the grabens, themselves bounded by normal faults and interlinked by a network of strike-slip faults (Catalano et al., 2008; Grasso et al., 1986; Reuther et al., 1993), has been recently active, and GPS measurements reveal that it is still ongoing (Agius et al., 2022; Serpelloni et al., 2007). Such processes are expected to be accompanied by seismicity, which, however, is only observed as sparse and ill-defined on most maps, owing primarily to difficulties in instrumental coverage of the region. Agius et al. (2020) have recently compiled an earthquake catalogue spanning the period 1994–2014 for the offshore region around the Maltese islands. The earthquakes in this catalogue were located using a single-station, WDD, in the south of Malta. The map indicates a clear clustering of seismicity along a lineament at 35°N, as well as at the southeastern end of the Malta graben (Figure 1).

Since 2014, seismic monitoring in Malta has gradually developed into the Malta Seismic Network (MSN, FDSN code ML), currently consisting of eight broadband stations covering the whole archipelago of Malta, Gozo and Comino (Galea et al., 2021). The MSN (Figure 1), inset) is managed by the Seismic Monitoring and Research Group (SMRG) within the Department of Geosciences,

*Correspondence to: P. Galea (pauline.galea@um.edu.mt)

University of Malta. The network represents an important development in the assessment of seismic activity occurring all around the islands, especially at close distances, or even on land. The situation still exists, however, where a considerable number of small magnitude events, particularly to the south of Malta, are well recorded on only one or two of the closest stations. In these cases, the use of conventional hypocentral location, using network first arrivals, may be limited, and the single-station polarisation algorithm LESSLA (Local Earthquake Single Station Location Analyser) developed locally (Agius & Galea, 2011) presents a valuable alternative, allowing a quantitative assessment of seismicity and approximate source location of events. For local and regional earthquakes, LESSLA computes event distance and origin time from measured S-P times against a calibrated regional travel time graph, while event azimuth is measured from the 3-component polarisation at the first P-wave arrival, using the algorithm of Roberts et al. (1989).

In this paper we present a first description of an intense episode of seismic activity whose most active phase lasted for around 2 months. The activity occurred at around 23 km south of Malta during September–November 2020, then continued sporadically even to the present day. Most of the events were of magnitude below 3.0, but the largest event reached a local magnitude of 4.5 and was strongly felt on the islands. The earthquake swarm is important not only because it provides insight onto ongoing geological processes, and the SCRZ in general, but also because it represents an important contribution towards assessing the sources of seismic hazard to the islands. To this end, further studies will concentrate more deeply on its seismological characteristics and geodynamical interpretation.

2 The Seismic Sequence

Except for a few larger events, as described later in this section, this work reports the earthquake locations as obtained by the use of single station location, using broadband station WDD. The first identified earthquake of the sequence occurred on the 8^{th} September 2020 at 04:49 UTC, at a distance of 22.7 km from station WDD, and having a local magnitude of 2.3. This was followed in the next days by a number of similar events during September, most of them with magnitudes smaller than 2.0. Then on the 30^{th} September 2020, a magnitude 4.5 event, at 22.9 km from WDD, occurred at 01:01 UTC (03:01 local time), producing strong shaking on the Maltese islands and waking up most of the residents of the southeastern region of Malta. This event was preceded by a magnitude 3.4 event on the previous day, 29^{th} September, at 18:24 UTC (20:24 local time) which was also felt by residents. The magnitude 4.5 event was followed by more than 15 events on the same day, 30^{th} September (Figure 2). The inset of figure 2 shows the 3-component recording of the magnitude 4.5 event on station WDD.

Figure 3 shows the magnitude–time development of the sequence over a 70-day period. We clarify here that the local magnitudes shown in this figure are the ones estimated by the single station algorithm, however when referring to the largest event, we choose to assign the magnitude computed by SeisComP (see later in this Section). The whole sequence continued till the middle of November 2020, with some events also being felt, notably the ones on the 1^{st} October at 09:00 UTC with magnitude 3.1 and on the 20th October, at 07:36 UTC with magnitude 3.4. In all, the SMRG located 116 swarm events during this period. Figure 3 shows the sequence to be composed of 2 phases, lasting between 8^{th} September–4^{th} October, and 19^{th} October–11^{th} November respectively. The largest event was the one of 30th September. After this swarm, other sporadic events from the same source region, were recorded, up till the time of writing. The smallest detectable event of the sequence had a local magnitude of 1.2. Figure 4 shows the location of those events which had a good enough signal quality to allow reliable location by the single-station method, applied at station WDD.

All events in the sequence had an S-P time of around 3.0 s. The local/regional distance calibration used in LESSLA translates this to a distance of 23 km, while the polarization analysis of all events gave a mean back-azimuth of 177° with a standard deviation of 24°. The back-azimuth calculation in LESSLA represents the largest uncertainty in the location, especially when the signal-to-noise ratio at the P-onset is low, as in the weakest events. It is observed in figure 4 that the events are located along a circular arc centred at WDD. This reflects the constant epicentral distance coupled with the uncertainty in the back-azimuth calculation inherent in the single-station location.

The mainshock of the swarm was large enough to be recorded on all operating stations of the Malta Seismic Network at the time, and on a number of stations in Southern Sicily. This triggered an earthquake location by SeisComP (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences and gempa GmbH, 2008) which is used at SMRG for routine seismic monitoring. SeisComP employs Hypo71PC (Lee & Valdes, 1985) for earthquake location. The first epicentre calculation was automatically communicated one minute after the earthquake origin time, and after manual verification, a standard report was sent to the Civil Protection Department (CPD) after 9 minutes. Using 24 stations, with the furthest at a distance of around 400 km, a manual relocation using SeisComP placed the hypocentre at 35.63°N,

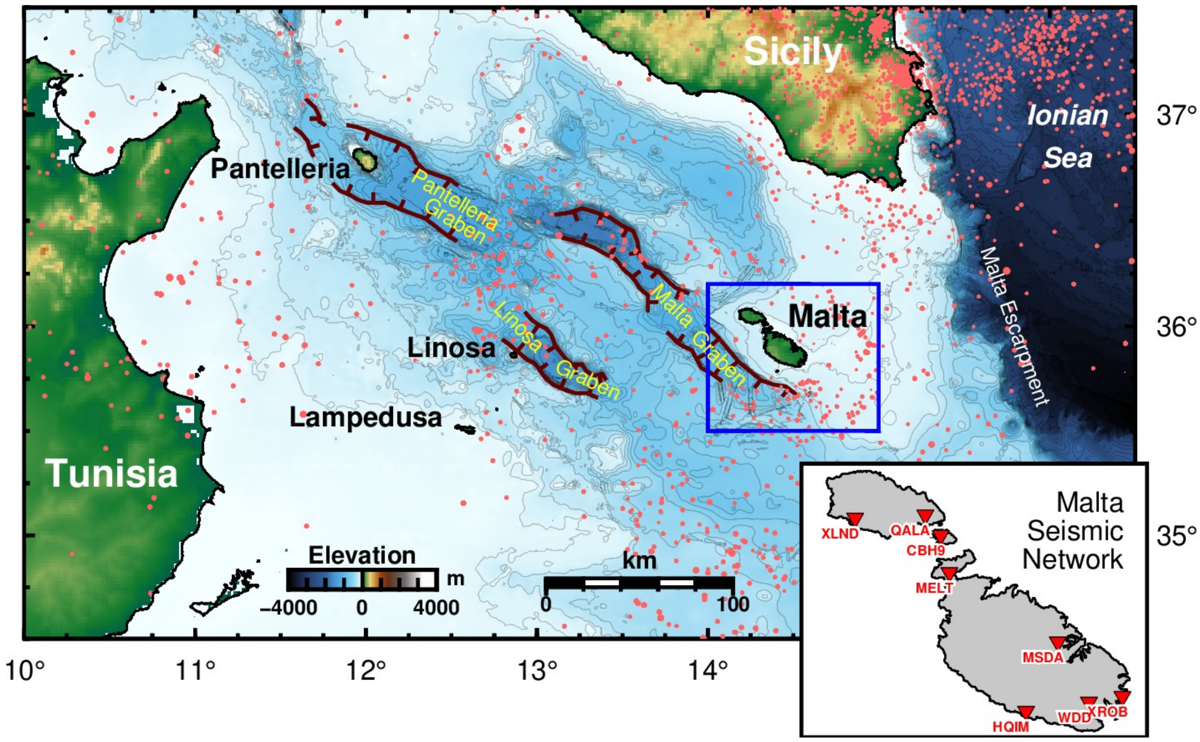

Figure 1: Location of the Maltese islands (blue box), bathymetry of the Sicily Channel and the three main grabens, and the seismicity of the region between 1995 and 2014, with maximum magnitude of 5.4 from Agius et al. (2020) (scaled red dots). Inset shows the stations of the Malta Seismic Network.

14.56°E, 4 km depth and magnitude 4.5. The SeisComP location is shown as a large black star on figure 4. The smaller stars represent the SeisComP location, using all available recordings, of three smaller events on the 29^{th} and 30^{th} September, and 1st October, having magnitudes 3.3, 3.7 and 3.4 respectively. SeisComP locates these events at depths ranging between 1 km and 6 km.

Figure 5 shows a number of filtered P-waveforms all recorded on station WDD from events taking place during the 30^{th} September, including the M4.5 event, showing the first 3 seconds after the P-onset. The strong waveform similarity is evident and implies an origin on the same fault.

3 Felt Reports

The magnitude 4.5 event of the 30^{th} September was felt all over the archipelago, and especially in the eastern half of Malta. Close to 2000 felt reports were submitted to the "Did you Feel It?" form on the SMRG website (https://seismic.research.um.edu.mt/) (Figure 6). 282 reports were also submitted on the website of the Euro-Mediterranean Seismological Centre (EMSC) (https://www.emsc-csem.org/) (Figure 7). For this event, the absolute majority of reports were from the island of Malta. In total, only five reports were received from the island of Gozo. In addition, around 30 reports were submitted for each of the felt events on the 29^{th} September and 20^{th} October. Figure 6a shows the geographical distribution of the felt reports over the islands while figure 6b shows the timeline of website hits and questionnaire submissions on the 29^{th}–30^{th} September, including the preceding event at 20:24 local time on 29^{th} September. Around 1000 website hits were registered during the first few minutes following the largest event, right after 3am local time, with another peak of reporting during the following morning. Close to the epicentre, the reports indicate strong shaking with 78% of respondents being woken from their sleep by the shaking. Approximately half the respondents reported rattling doors and windows, and a minority reported falling small objects. 74% of respondents reported that some kind of sound (mostly a roaring sound) accompanied the shaking. Overall, the distribution and intensity reported through SMRG and EMSC websites show very similar patterns (figure 6a, and figure 7). These reports allow us to assign an intensity of IV–V on the European Macroseismic Scale (EMS-98) (Grünthal & Levret, 2001) over the island of Malta. The short form of the EMS-98 scale describes intensity IV as "Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.", whereas intensity V is

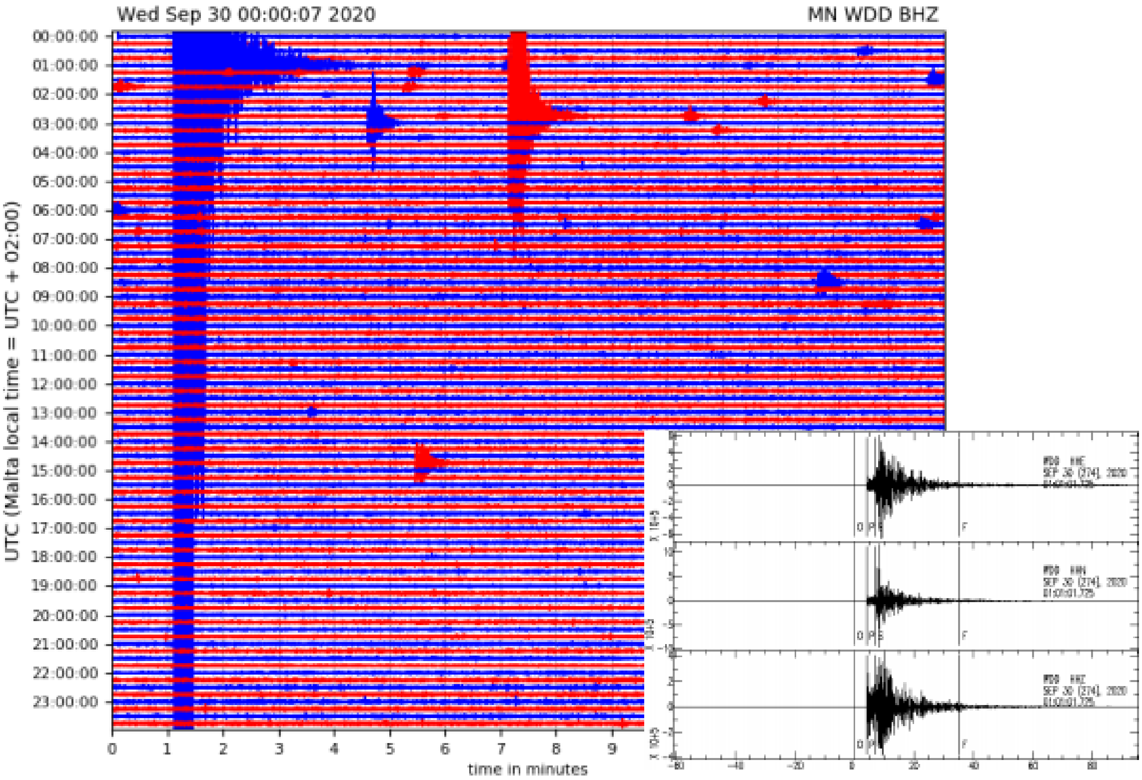

Figure 2: 24-hour plot from station WDD on the 30th September 2020. Inset shows the 3-component trace of the largest event record on broadband station WDD. O, P, S, F mark the origin time, *P* and *S* picks, and *fini* of the event, respectively.

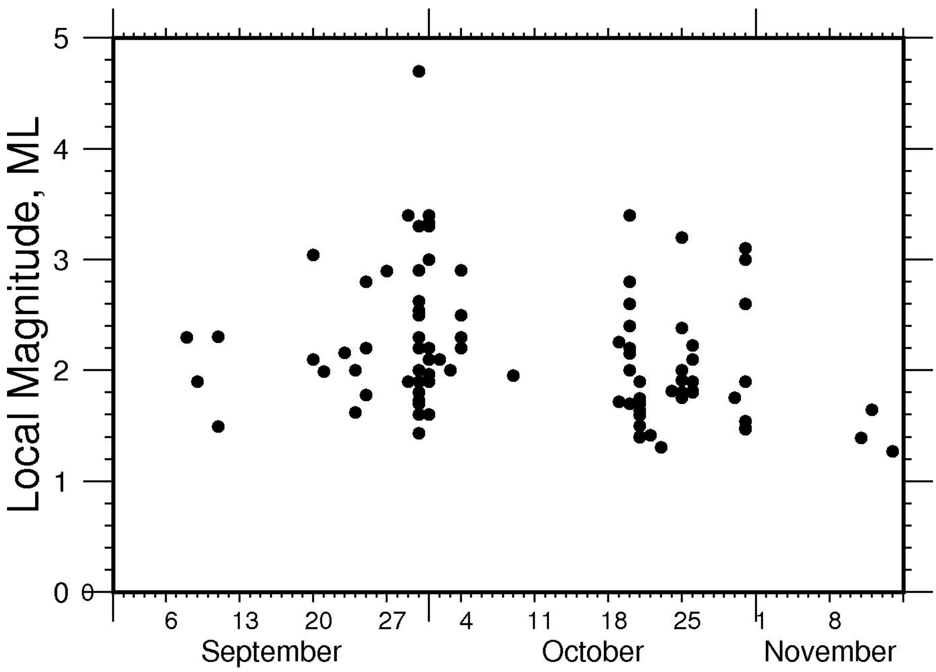

Figure 3: Magnitude-time plot of the earthquake sequence September–November 2020.

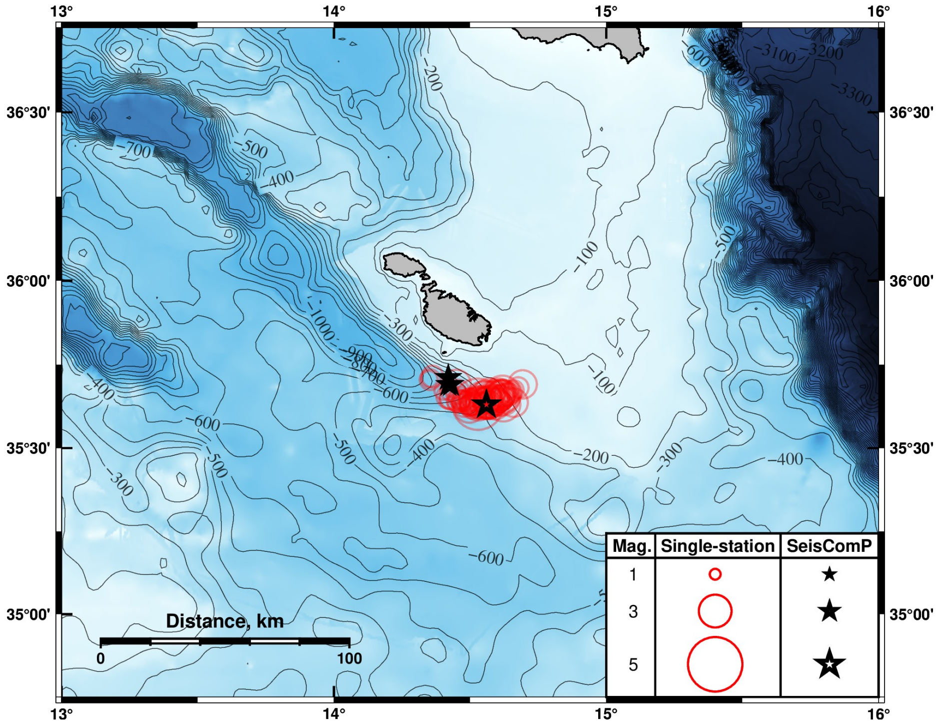

Figure 4: Epicentre locations of the earthquake swarm from 08/09/2020 to 14/11/2020 Red circles are epicentres using single-station location at station WDD. The black stars indicate SeisComP locations.

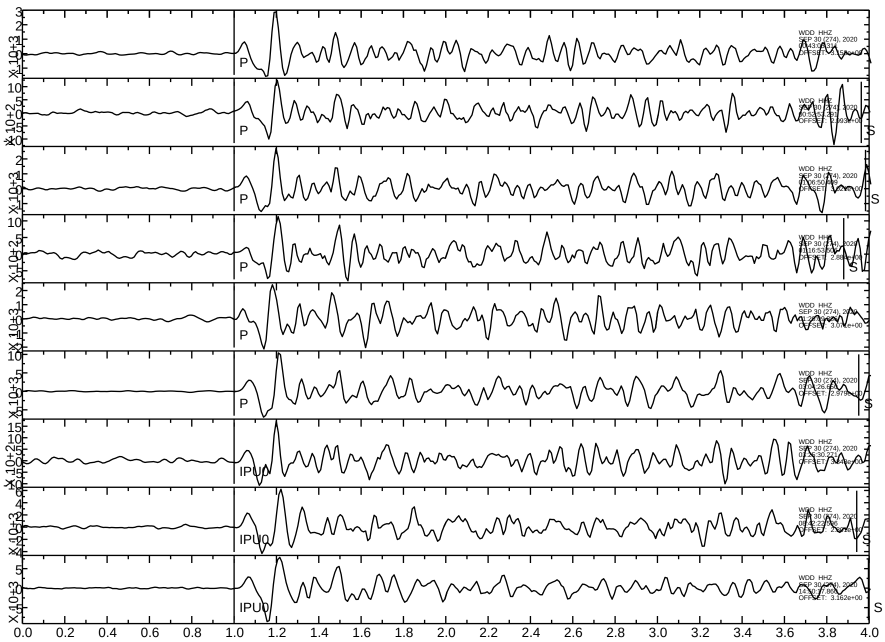

Figure 5: Seismograms showing an example of the similar P phase arrivals of 9 different events from the swarm sequence recorded on station WDD on the 30th September.

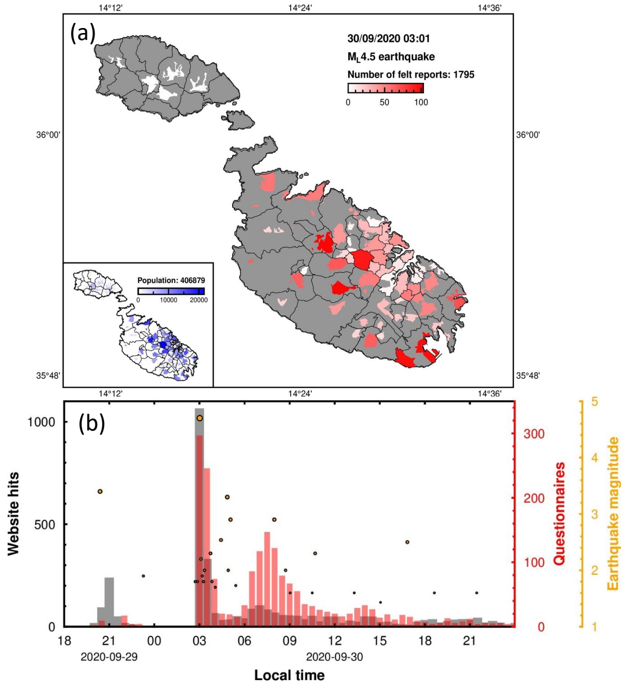

Figure 6: (a) Geographical distribution of felt reports on Malta (red shade). Internal boundaries delineate local council areas. Inset shows the population distribution across the Maltese islands based on the national census (National Statistics Office 2011). (b) Website hits (grey bars) and number of questionnaires (red bars) submitted between the 29th and 30th September 2020, binned every thirty minutes. Orange circles represent the earthquakes time and magnitude.

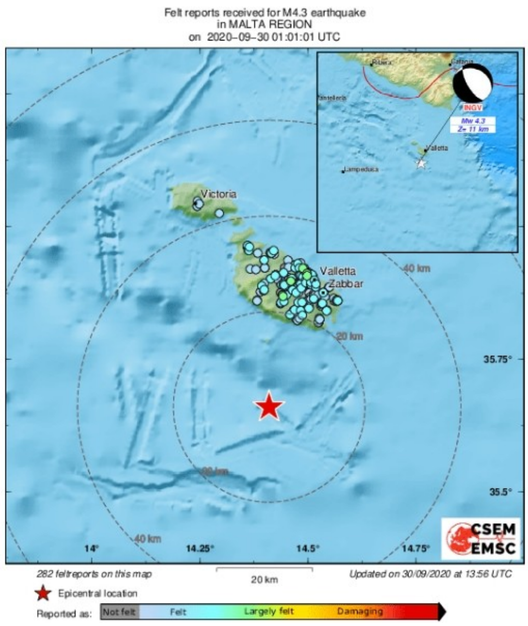

Figure 7: Felt reports and earthquake solution reported by the Euro-Mediterranean Seismological Centre (EMSC). Coloured dots represent the felt/damaging intensity reported. Red star shows the epicentre solution by EMSC. Inset shows the earthquake focal mechanism as reported by INGV.

described as "Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut."

4 Discussion and Concluding Remarks

An earthquake sequence whose main activity lasted close to 3 months has been successfully identified and monitored to the south of the Maltese islands. The sequence consisted of more than 100 events, the largest one having a local magnitude of 4.5. The majority of the events had a magnitude smaller than 3.0, and were consequently reliably recorded on only a few stations of the Malta Seismic Network. The use of a single-station location algorithm, LESSLA, was therefore employed in this study, using the recordings from station WDD, approximately 23 km away. For the magnitude 4.5 event, on the 30th September, as well as three other events, sufficient recordings were available from Sicilian stations, together with four available stations of the MSN, to allow us to carry out conventional location using SeisComP, which is routinely used at the University of Malta for earthquake monitoring. The SeisComP location of the main event, with a location error of ± 4 km, is very close to the single station location for this event, giving us confidence about the LESSLA location at the southern extremity of the Malta graben. The azimuthal uncertainty from single-station location results in an arc-like distribution of epicentres, which therefore has no geological significance related to the causative structure or the spatio-temporal evolution of the sequence. Nonetheless, a more thorough analysis of the earthquake recordings from all available stations shall be carried out to investigate whether a conventional least squares epicentral location methodology will yield different results. This, possibly together with a moment tensor inversion of the mainshock, will enable us to give a better geodynamical interpretation of these events. At the time of writing, the only moment tensor solution available is one by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), reported on the EMSC website (Figure 7), which shows a normal faulting mechanism, with strike oriented parallel to the Malta graben, possibly implying that the events occurred on the graben bounding faults.

Seismicity around the Maltese islands has often been observed to occur in swarm episodes (Agius et al., 2020), although the swarm reported here is one of the largest to be recorded instrumentally, both in terms of duration as well as in the number of events. A swarm of around 15 events, lasting 4 days was experienced on 24^{th} April 2011 and located around 40 km east of Malta (Agius et al., 2016). The largest event in that swarm, having magnitude 4.1, was also strongly felt on the islands. Other, less significant, swarms were also recorded on WDD in previous years, originating south of Malta (Agius et al., 2020). Historical documents contain several reports of episodes of felt tremors lasting several days (Galea, 2007). One such example occurred between the 14^{th} and 27^{th} August 1886, when no less than 15 tremors were reported in local newspapers to have been felt by the population, 6 of them on the same day, Sunday 15^{th} August. Of these, the largest event, at 03:45am (local time) on Sunday, was large enough to cause most of the residents of Valletta and nearby cities to flee outside, and was accompanied by rumbling sounds. These events were reported not to have been felt in any nearby countries. It is therefore likely that such historical earthquake sequences had similar origins and characteristics as the 2020 sequence.

Finally, the close proximity of this swarm to the southern Maltese coastline makes it important to understand as well as the possible characteristics of this fault system and its contribution to the seismic hazard assessment of the Maltese islands, especially considering the ongoing rapid increase in the urban and population densities of the archipelago, particularly in the southeastern region of Malta.

References

Agius, M. R., D'Amico, S., & Galea, P. (2016). The Easter Sunday 2011 earthquake swarm offshore Malta: Analysis on felt reports. In *Earthquakes and their impact on society* (pp. 631–645). Springer.

Agius, M. R., & Galea, P. (2011). A single-station automated earthquake location system at Wied Dalam station, Malta. *Seismological Research Letters*, *82*(4), 545–559.

Agius, M. R., Galea, P., Farrugia, D., & D'Amico, S. (2020). An instrumental earthquake catalogue for the offshore Maltese islands region, 1995–2014. *Annals of Geophysics*, *63*(6), SE658–SE658.

Agius, M. R., Magrini, F., Diaferia, G., K"astle, E. D., Cammarano, F., Faccenna, C., Funiciello, F., & van der Meijde, M. (2022). Shear-velocity structure and dynamics beneath the Sicily channel and surrounding regions of the central Mediterranean inferred from seismic surface waves. *Geochemistry, Geophysics, Geosystems*, *G*(3).

Catalano, S., De Guidi, G., Romagnoli, G., Torrisi, S., Tortorici, G., & Tortorici, L. (2008). The migration of plate boundaries in SE Sicily: Influence on the large-scale kinematic model of the African promontory in southern Italy. *Tectonophysics*, *449*(1–4), 41–62.

Civile, D., Lodolo, E., Accettella, D., Geletti, R., Ben-Avraham, Z., Deponte, M., Facchin, L., Ramella, R., & Romeo, R. (2010). The Pantelleria graben (Sicily Channel, Central Mediterranean): An example of intraplate 'passive' rift. *Tectonophysics*, *490*(3–4), 173–183.

Corti, G., Cuffaro, M., Doglioni, C., Innocenti, F., & Manetti, P. (2006). Coexisting geodynamic processes in the Sicily channel. *Special Papers-Geological Society of America*, *409*, 83.

Dart, C. J., Bosence, D. W. J., & McClay, K. R. (1993). Stratigraphy and structure of the Maltese graben system. *Journal of the Geological Society*, *150*(6), 1153–1166.

Faccenna, C., Becker, T. W., Lucente, F. P., Jolivet, L., & Rossetti, F. (2001). History of subduction and back arc extension in the central Mediterranean. *Geophysical Journal International*, *145*(3), 809–820.

Galea, P. (2007). *Seismic history of the Maltese islands and considerations on seismic risk*. Annals of geophysics.

Galea, P., Agius, M. R., Bozionelos, G., D'Amico, S., & Farrugia, D. (2021). A first national seismic network for the Maltese islands—the Malta seismic network. *Seismological Society of America*, *92*(3), 1817–1831.

Grasso, M. A., Reuther, C.-D., Baumann, H. O., & Becker, A. R. (1986). Shallow crustal stress and neotectonic framework of the Malta platform and the Southeastern Pantelleria Rift (central Mediterranean). *Geologica Romana*, *25*, 191–212.

Grünthal, G., & Levret, A. (2001). L'echelle macrosismique européenne = european macroseismic scale 1998. (EMS-98).

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences and gempa GmbH. (2008). *The SeisComP seismological software package.* GFZ Data Services.

Lee, W. H. K., & Valdes, C. M. (1985). *HYPO71PC: A personal computer version of the HYPO71 earthquake location program* (Vol. 85). US Geological Survey.

Pedley, M., & Clarke, M. H. (2002). *Limestone isles in a crystal sea: The geology of the Maltese islands*. Publishers Enterprises Group, Malta.

Reuther, C. D., Ben-Avraham, Z., & Grasso, M. (1993). Origin and role of major strike-slip transfers during plate collision in the central Mediterranean. *Terra Nova*, *5*(3), 249–257.

Roberts, R. G., Christoffersson, A., & Cassidy, F. (1989). Real-time event detection, phase identification and source location estimation using single station three-component seismic data. *Geophysical Journal International*, *97*(3), 471–480.

Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., Baldi, P., & Gasperini, P. (2007). Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data. *Geophysical Journal International*, *169*(3), 1180–1200.