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Damavand Earthquake of 2020 the Mainshock or an Alarm for Disaster for the Capital of Iran

[1]Milad Baftipour [2]Hadi Jarahi, [3]Gulten Polat and [4]Sedigheh Seifilaleh

[1]*Department of Civil Engineering, Taft Branch, Islamic Azad University (IAU), Taft, Iran*
[2]*Department of Geosciences, North Tehran Branch, Islamic Azad University (IAU), Tehran, Iran*
[3]*Department of Civil Engineering, Yeditepe University, 26 Ağustos, Yerleskesi, Kavisdagi cad. 34755, Istanbul, Turkey*
[4]*Geophysics Ms.C, Tehran University, Tehran, Iran*

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Corresponding Author:
Hadi Jarahi
Department of Geosciences, North Tehran Branch, Islamic Azad University (IAU),
Tehran, Iran
Email: hadijarahi@gmail.com

Abstract: On 7 May 2020, the Damavand earthquake with a magnitude of 5.1 occurred 55 km east of Tehran city, which has a population of over 15 million people. This earthquake caused a seismic hazard for the capital of Iran. In this study, this earthquake was assessed to understand whether it will cause any seismic disaster. There is a doubt about the dip of the earthquake fault because the hypocenter position, as well as the aftershocks, correspond to the surface outcrop of the Mosha fault. However, according to the declared slope for this fault, the epicenter of the earthquake should be located in a belt parallel to the fault and at a distance of 3 to 10 km. The significant observation of this study is that the Damavand earthquake was produced by the Mosha fault according to the information of the focal mechanism. The slope of the fault in this study was estimated to be 90 degrees. By the findings of this study, the seismic hazard of the city of Tehran was thus investigated. The results exhibit that the city is under seismic risk. Therefore, we can suggest that we should take precautions against a possible devastating earthquake.

Keywords: Damavand Earthquake, Tehran City, Hypocenter, Disaster

Introduction

Previous studies (Ritz *et al*., 2003; Assereto, 1966) indicate that the city of Tehran was surrounded by several of the most active faults in the world. One of these significant faults is the Mosha fault which is more than 140 km in length the northeast of Tehran. Throughout history, this fault caused important earthquakes such as in 1665 (5.5) and 1830 (7.1) (Ambraseys and Melville, 1982). The last earthquake of this fault was the Damavand earthquake with a magnitude of 5.1 at 20:18:21 UTC on 7 May 2020. More than 30 million people felt this shock. But the question is: "Was this the main earthquake?" or a foreshock of a large earthquake? This study aims to investigate the Damavand 2020 earthquake's seismic properties. The study area (Fig. 1) is located in the central Alborz Mountains which are associated with active faults. Studying the seismicity and the hazard of Tehran earthquakes has a long history (Tchalenko *et al*., 1974; Berberian, 1976a; Jackson *et al*., 2002; Berberian, 2014). But most of these studies tell us about a coming disaster in this city with a population of more than 15 million (Jarahi 2021, Jarahi *et al*., 2011a; 2011b; Zamanfashami *et al*., 2012; Pourkermani *et al*., 2012; Jarahi *et al*., 2013; Honarvar *et al*., 2014; Jarahi *et al*., 2015; Jarahi, 2016; Jarahi *et al*., 2016; Jarahi and Seifilaleh, 2016; Jarahi, 2016a; Nazari *et al*., 2011). Paleo seismological studies of Mosha (Ritz *et al*., 2003), Firuzkuh (Nazari *et al*., 2014; Ritz *et al*., 2009), North-Tehran (Ritz *et al*., 2012), Taleghan (Nazari *et al*., 2009) faults show that this area has witnessed more than 10 earthquakes with magnitude >7.0 over the past 30.000 years. The Morphological and stratigraphic study of the Kahrizak, the North Ray, and the South Ray scarps was done in the south of Tehran (Nazari *et al*., 2010). This study suggested these scarps correspond most likely to Paleo shorelines and are not fault scarps. Therefore, these morphological scarps are no more the earthquake fault of the historical earthquake of southern Tehran (Berberian, 2014). Subsequent studies (Jarahi, 2019) have shown that by ignoring the southern faults (morphological scarps), the seismic contribution of the northern faults of Tehran city is higher than before. Due to this reason, the potential risk of a catastrophic event in Tehran is higher than ever.

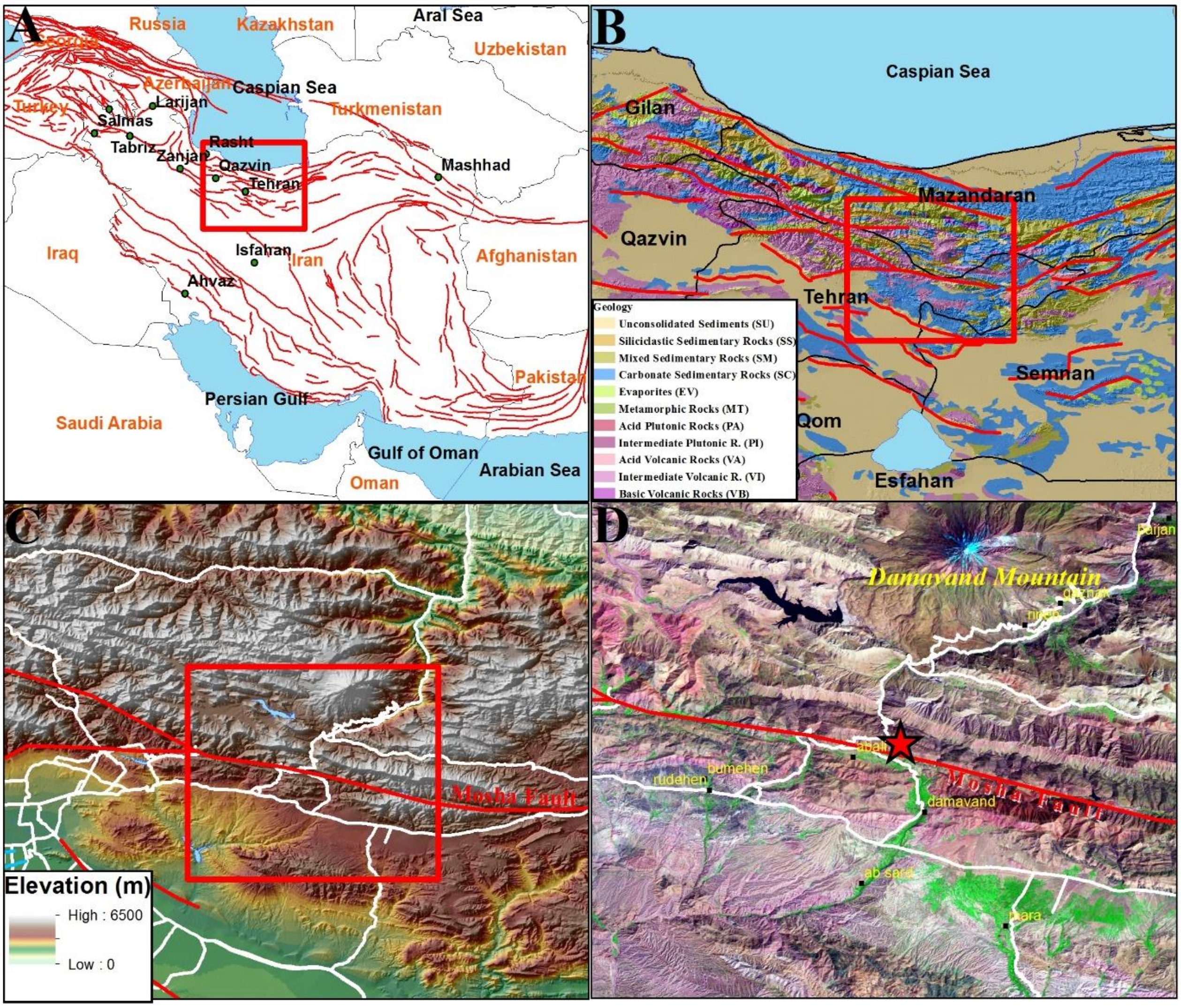

Fig. 1: Study area. (A) location of the study area in the middle east fault map (Danciu *et al*., 2018), (B) geological map (Jens and Nils, 2012), and (C) morphology (Jarvis *et al*., 2008), (D) Landsat natural color. The red star shows the Damavand earthquake

Also, the occurrence of a relatively small earthquake, such as the 5.1 Damavand earthquake, is very significant in terms of natural hazards. This earthquake gives us valuable information about the unknown fault parameters of this area. On the other hand, it should be noted that the Masha fault, in its western part, is connected to the fault north of Tehran (Solaymani *et al*., 2011).

Tectonic Setting

The evolution of Alborz is the result of the Assyntic, early Cimmerian, and the Alpine orogenic activities (Tchalenko *et al*., 1974). The folding of Assyntic is present as an alteration in Alborz which leads to the lithification of Precambrian rocks (Tchalenko, 1975). However, the general conformity and even the gradual boundary of the Kahar formation to the younger Neo-Proterozoic deposits (Soltanieh formation) indicate that there is no clear representative of the Assyntic orogenic activities in Alborz (Alavi, 1996). The lack of the stratigraphic units before the Permian and Devonian are related to the orogenic movements or Caledonian and Hercynian uplifts although there is no representative of orogenic and folding movements of the Paleozoic present in the area. The distribution of the limy deposits of the hanging wall of the faults in the Cretaceous is representative of these activities. From the Tertiary, as a result, the opening of the Red Sea (Ambraseys, 2009) and the movements to the north of the Arabic plate from Eurasia resulted in the change in the tensional to the compressive regime in Alborz. Thus, the major faults in central Alborz converted to compressive from tensional and as a result, this led to the reverse plate tectonic in Oligo-Miocene. The dating of the neomorphic of Alborz and Talesh mountains certifies the effect of this orogenic activity as the major plate tectonic activity in the north of Iran (Zanchi *et al*., 2006). This neomorphic resulted in the uplift of the Alborz Mountains in the direction of the major faults (such as Mosha and Kandevan) and deposition of the terrigenous sediments in the basins among the mountains (the Hezardareh conglomerates of Pliocene). From the Pliocene (Allen *et al*., 2003) or the Pleistocene (Ritz *et al*., 2006) the major faults of Alborz, which have had reverse and compressional activities, changed their activity partially to the oblique-slip with left-lateral component faults with the change in the motions of the southern Khazar crust to the southwest. This variation in the movements of the southern Khazar crust also resulted in the further movements of the faults of the basement of Alborz, which lead to the sinistral and dextral faults in the central Alborz (Ballato *et al*., 2008). The rifting of the Red Sea and its consequent movements of the Arabic plate to the north and northeast and the Iran plateau has continued to the present time and as a result, the Alborz Mountains like other parts of the Iran plateau are subjected to shortening, uplift, and frequent earthquakes. The rifting of the Red Sea is about 20 mm annually and half of it is consumed for the shortening of central Iran and Alborz (Vernant *et al*., 2004). Recent studies based on GPS data show that central Alborz was subjected to shortening of about 5±2 mm/yr which resulted in a 30 km decrease in the plateau from the Pliocene (5 million years ago) (Vernant *et al*., 2004). Mosha (Delenbach 1964), Firuzkuh (Nazari *et al*., 2014), North Tehran (Tchalenko, 1975; Tchalenko *et al*., 1974), Ipak (Berberian, 1976b), Taleghan are active faults surrounding the city of Tehran. The Mosha fault is the closest active structure to the epicenter of the Damavand earthquake. The Mosha fault is one of the primary structures in the southern margin of central Alborz which is important in the evolution of Alborz. The thrust of Precambrian-Paleozoic deposits on the Cenozoic formations (Karaj) is the result of its activity before the Quaternary. Based on the seismotectonic map of the north of Iran (Ritz *et al*., 2006) and the provided list from the rate of the slips of the Alborz faults (Maggi *et al*., 2000), this is an active fault with an annual slip rate of 2.3 mm/yr.

Hypocenter Characteristics

Regarding data prepared by the Building and Housing Research Center (BHRC), the focal depth of the Damavand earthquake is 10 km. The focal mechanism of this earthquake follows a right-lateral strike-slip fault. As is shown in Fig. 2, the focal depth of the Damavand earthquake and its aftershocks are about 9 to 12 km and are classified as shallow crustal earthquakes (Kuyuk and Susumu, 2018). The seismogenic layer in this part of Iran is from 8 to 12 km (Engdahl *et al*., 2006). Based on Fig. 3, we can see that the aftershocks of the Damavand earthquake have migrated from east to west. Moreover, the focal depths of the earthquakes remarkably increased. Since the Damavand earthquake occurred in the eastern part of the Mosha fault and the aftershocks migrated to the west (and a bit in depth), it can be expected that the focal of looked energy, for the future earthquake (Jarahi, 2017) can be at the west part of the Mosha fault.

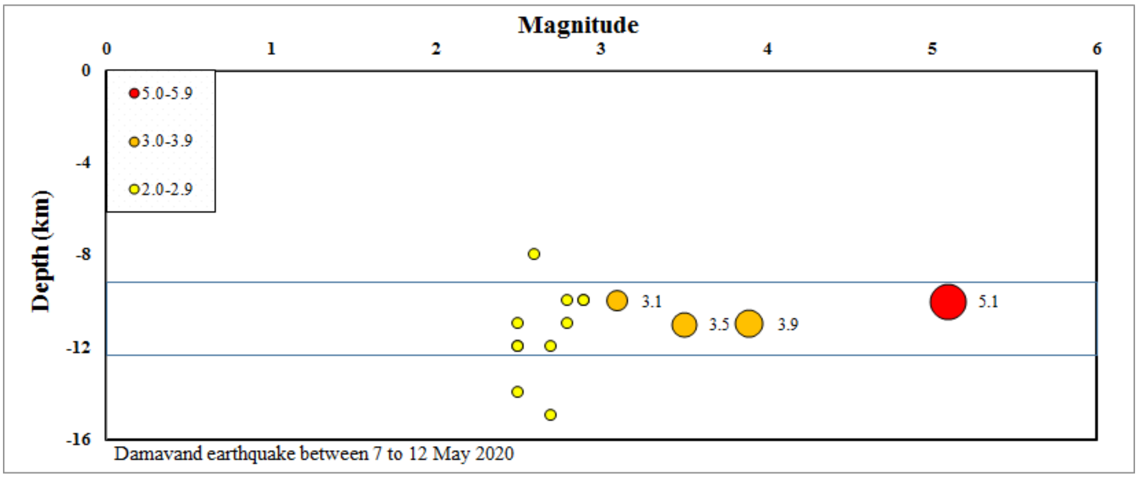

Fig. 2: The focal depth propagation of the Damavand earthquake

Earthquake Fault

The depth of the seismogenic layer in the study area is around 12±2 km (Maggi *et al.*, 2000). The reported slip of the Mosha fault is about 50-70 degrees to the North (Moinabadi and Yassaghi, 2007; Solaymani Azad *et al.*, 2003). A seismotectonic section was created to show the expected epicenter of earthquakes (Fig. 4). Areas A, B, and C are the horizontal projection of the rupture zone for dip 90, 70, and 50 degrees of the Mosha fault. It is shown, that whether the dip of fault is low, the epicenter area is farther away from the fault trace. It is expected that the epicenter of the Mosha earthquakes should be located in the hanging wall and 3 to 10 km distant from fault surface exposure. However, as shown in Fig. 4, the propagation of the Damavand earthquake and its aftershocks, are located in the area. In Fig. 5, a seismotectonic map of the study area is also provided.

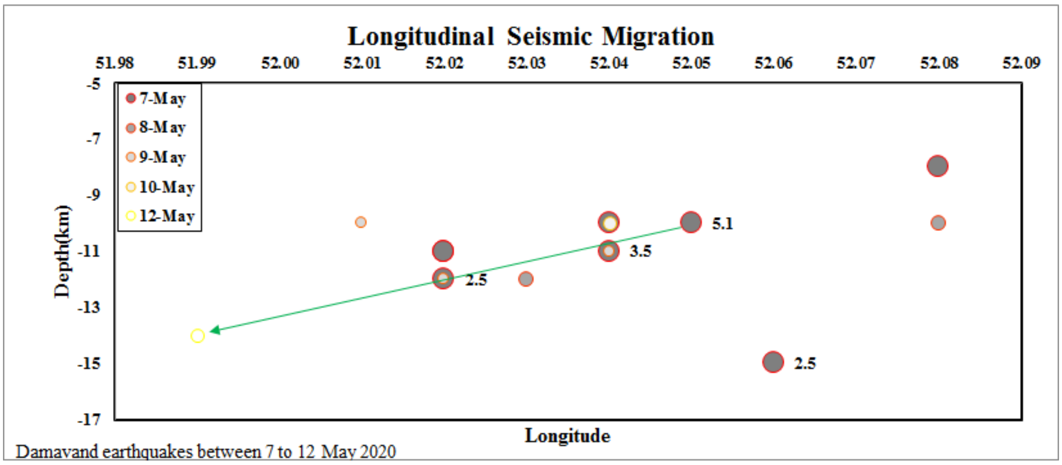

Fig. 3: Longitudinal profile across the Mosha fault. Aftershocks of the Damavand earthquake show a migration from the east to the west

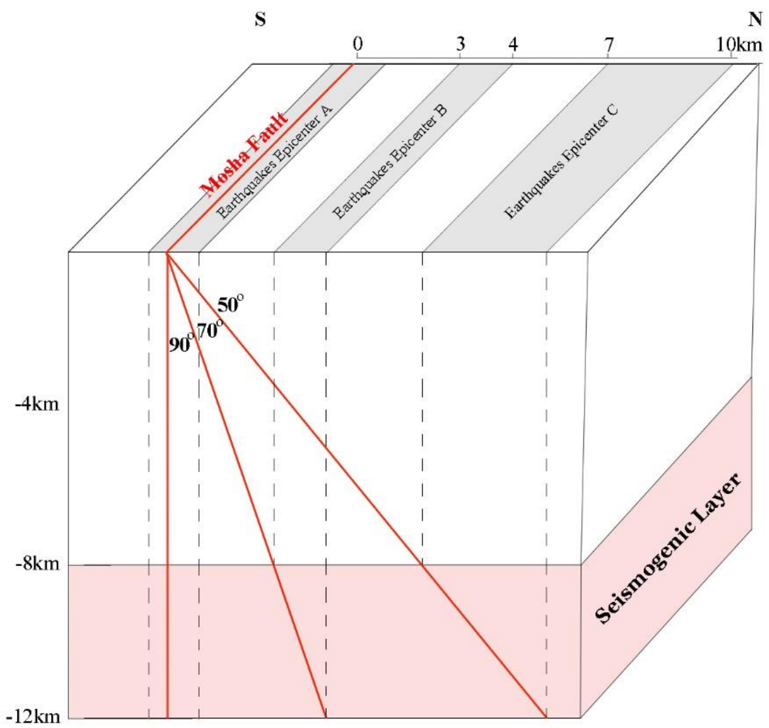

Fig. 4: A Schematic model of the Mosha fault profile. The profile is from South to North. The location of the expected earthquake epicenter is shown by gray bands over the hanging wall

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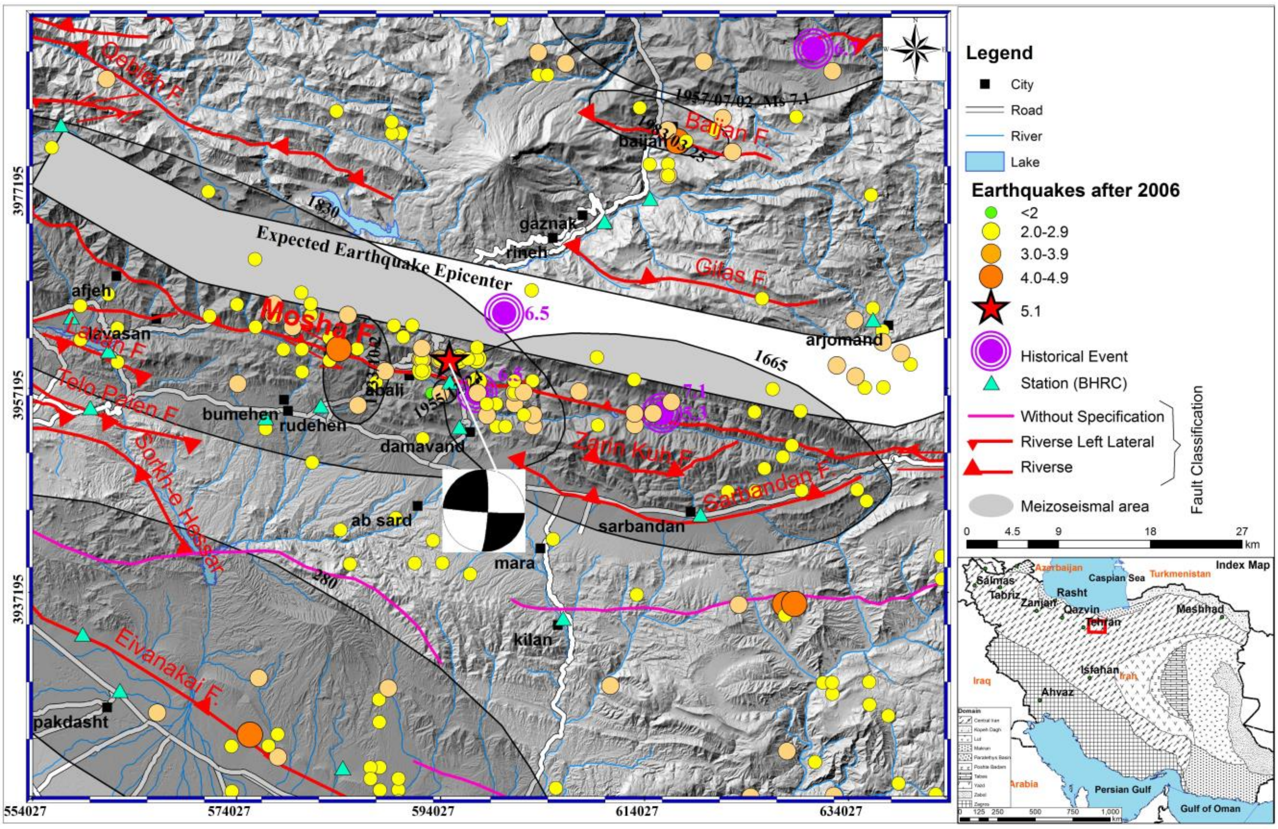

Fig. 5: Seismotectonic map of the Damavand 2020 earthquake. The white band shows the expected earthquake epicenter for the Mosha fault based on a dip angle between 50 to 70 degrees and 8 to 12 km depth of the seismogenic layer

The combination of areas B and C in Fig. 3 is indicated as a white band in the hanging wall of the Mosha fault. Despite the expected, most of the earthquakes occurred out of this band. A high-density earthquake can be observed close to the fault trace. If the Mosha fault is considered to be the cause of the Damavand earthquake, we must accept that the dip of this fault is 90 degrees. There is other evidence to prove this statement. The focal depth batch ball which is shown in Fig. 5, demonstrates an E-W fault with a vertical dip.

Results

The results from the analyzed data acquired from the BHRC indicate that the focal depth of the Damavand earthquake is 10 km and its focal mechanism solution follows a right-lateral strike-slip fault. Also, the depths of aftershocks with a magnitude greater than 2 caused by this earthquake varied from 9 to 12 km. The main shock and all the aftershocks occurred in the seismogenic zone of the region. This observation is quite consistent with the depth of the determined seismogenic layer of the region (Maggi *et al*., 2000). Based on all the observations, all the occurred earthquakes in this region may be classified as shallow crustal earthquakes (Kuyuk and Susumu, 2018). The aftershocks also migrated from east to west and their focal depths gradually increased.

Discussion

The Damavand earthquake most likely released a part of stored energy in the eastern part of the Mosha fault. Releasing the energy in the eastern part of the Mosha fault and its connection with north Tehran's fault raises concerns about what will happen next. A seismic event occurred on 31 Aug 1968 in Dasht-E Bayaz with a magnitude of 7.1. After about 20hr, an earthquake with a magnitude of 6.1 was produced by the Ferdows fault that is connected to the Dasht-E Bayaz fault. As a result, this case shows that it is possible that after a significant earthquake is produced by an active fault, this earthquake can trigger another fault to be seismically active if there is a tectonic connection between both faults. This earthquake was followed 3 days later by the second event of Mw 5.5, with a reverse fault focal mechanism in the Ferdows town region (Gheitanchi *et al*., 1993; Crampin, 1969; McEvilly and Niazi, 1975; Tchalenko and Ambraseys, 1970; Tchalenko and Berberian, 1975). There is a junction between the Mosha and the North Tehran active faults (Solaymani *et al*., 2011). Three dip angles comprised of 50, 70, and 90 degrees were suggested for the rupture zone of the Mosha fault. As shown in Fig. 4, while the dip angle of the fault was small, the epicenter region of the earthquakes was quite away from the fault trace. However, looking at the seismic activity of the region, most of the earthquakes were clustered only in the fault trace. This suggests that the dip of this fault is 90 degrees. Following all these findings, it may be suggested that the Damavand earthquake was produced by the Mosha fault. Therefore, stress changes in the Mosha fault can also be effective in the North Tehran fault activity. This suggests that the next significant seismic event may occur in the west part of the Mosha fault (Jarahi, 2017).

Conclusion

The Damavand earthquake with a magnitude of 5.1 occurred 55 km east of Tehran city on 7 May 2020. This seismic event caused a significant seismic risk to a population of over 15 million people living in this city. Hence, this earthquake in this study was evaluated as to whether it will cause any disaster for the capital of Iran. A significant part of stored energy in the eastern part of the Mosha fault was released due to the Damavand earthquake produced by this fault. There is an important connection between the Mosha fault in its western part and the North Tehran fault. Therefore, stress changes in the Mosha fault may considerably influence the seismic activity of the North Tehran fault. It is expected that a similar event like the Ferdows and Dasht-E Bayaz earthquakes in this region may be observed. Therefore, the Damavand earthquake is not just an earthquake. It is a seismic trigger for this region. Finally, it may be said that based on considering all the findings, this fault has an important potential to trigger devastating earthquakes in this region.

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Author’s Contributions

This section should state the contributions made by each author in the preparation, development, and publication of this manuscript.

Milad Baftipour, Hadi Jarahi, and Gulten Polat: Developed the conceptual idea, designed the study, collected data, and interpreted.

Sedigheh Seifilaleh: Edited the manuscript.

Ethics

This article is original and contains unpublished materials. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

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