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Fault mechanisms and their frequencies during destructive earthquakes in Iran

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Abstract:

Iran has been affected by the convergence of the Arabian and Eurasia plates. For this reason, it has experienced destructive earthquakes throughout history. In terms of tectonic and seismic properties, Iran can be divided into 5 general seismotectonic provinces; Zagros, Central-East Iran, Alborz-Azerbaijan, Makran, and Kopeh Dagh. One of the facts that best describes the characteristics of earthquakes is their focal mechanism. In this article, the focal mechanisms of these 5 provinces were collected and classified with FMC software. For each zone, the frequency percentage of each group of faults was determined. Most faults are in the reverse class or compression type with the strike-slip component. Most of the faults of the reverse type are related to Zagros province, which includes 58% of its earthquakes and 42% of Iran's earthquakes. Thus, it seems the Zagros has been more affected by the convergence of the Eurasian and Arabian plates than other regions. Normal faults in all provinces have a small frequency so that only about 3% of the total earthquakes in Iran are in this class.

Keywords: Classification, FMC software, Focal mechanism, Seismotectonic provinces, Seismicity of Iran.

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1. Introduction

Iran is located in the Middle East in the range of 25 N to 40 N and 44 E to 63 E. Iran is geologically active due to its location in the Alpine-Himalayan seismic belt and at the junction of the Eurasian-Arabian plates. The convergence of Eurasian-Arabian tectonic plates has caused an active transformation in Iran as one of the most seismic regions in the world. Most of the Iranian plateau is tectonically affected by deformation and shortening due to the collision of continental plates. Meanwhile, only the Makran area in the north of the Oman Sea has different tectonic conditions from other parts of Iran. In this part of Iran, the Oman oceanic crust converges to the north and subduct beneath the Iranian continental crust. The deformation in the Iranian crust is unevenly distributed, mainly at the border of the blocks. Most earthquakes are concentrated in the Zagros, Alborz, Kopeh Dagh or in the direction of strike-slip faults that form the boundary of seismic blocks. Therefore, the margins of the blocks of Central Iran, Azerbaijan, and the Caspian Sea have high seismicity. These seismic parts also have different deformation rates and consequently different seismicity. The difference in seismicity in different parts of the Iranian crust, which is the result of the nature of the crust and the type of deformation and the amount of deformation, has caused the intensity and recurrence periods of earthquakes to be variable.

The convergence of the Arabian plate towards Eurasia is partitioned to the thrusting and strike slip faulting in the Zagros (Talebian and Jackson, 2002; Maggi and Priestley, 2005). The Main Zagros reverse fault is a suture zone between the Arabian and Eurasian plates (Sengor, 1984; Dercourt et al ., 1986). In southeast of Iran and Pakistan, the oceanic crust of Arabian plate is subducted beneath the Makran. The subduction zone of Makran is devided into the west and east parts with different seismicity and tectonic characteristics (Byrne et al. 1992; Zarifi 2006). In the western part of Makran, the subduction is occurring with relatively steeper dips relative to the eastern part (Zarifi 2006, Manaman et al., 2010). Meanwhile, due to the lack of large earthquakes in western Makran, the seismic potential of the region is much debated.

Vernant et al. (2004) estimated the rate of deformation from less than 2 mm/yr in Central Iran to 19.5 mm/yr in the Makran subduction zone, based on the global positioning system (GPS). The fault systems in Central and Eastern Iran region are different from those in other parts of Iran because of the orientation and geometric characteristics of the faults; for instance, they are linear, long and narrow (Hessami and Jamali, 2006; Karimiparidari et al., 2013).

The structure of the crust in the Middle East, especially in Iran, is somewhat heterogeneous and complex; the presence of rifts and the formation of oceanic crust along with the continental crust, erosion, and deep fractures in the mantle have caused some complications. The maximum thickness of the Iranian crust is in Zagros, which is approximately 50 to 55 km, and the minimum in Makran and the coasts

of Oman is 25 km. The thickness of crust in Central Iran is 40 to 45 km and on the southern shores of the Caspian Sea is 35 km (Dehghani and Makris, 1984).

In this paper, the focal mechanisms of Iranian plateau earthquakes are classified using FMC software developed by Álvarez-Gómez (2018). FMC was originally developed on Python 2.7.3 and adapts some of the Gasperini and Vannucci (2003) FORTRAN routines to obtain the different parameters of the earthquake focal mechanisms. The default input and output formats are the same used by the GMT program ‘‘psmeca’’ in order to make the program integration easiest and facilitate the mapping of the data (Álvarez-Gómez, 2018).

2. Data

About 595 focal mechanisms were collected from the CMT catalog (www.globalcmt.org) in Iran. These data are moderate to large, so that their moment magnitude ranges from 4.7 to 7.8; which their distribution is shown in figure 1. The events that were on the border of the provinces were excluded. The number of focal mechanisms in each province is shown in Table 1. Most of the data is related to Zagros, which is about 53% of the events. The pie charts of the percentage of events in the 5 provinces in terms of their depth are shown in Figure 2. A common feature among all provinces is that most events were less than 20 km deep; In other words, most earthquakes occur in the upper crust.

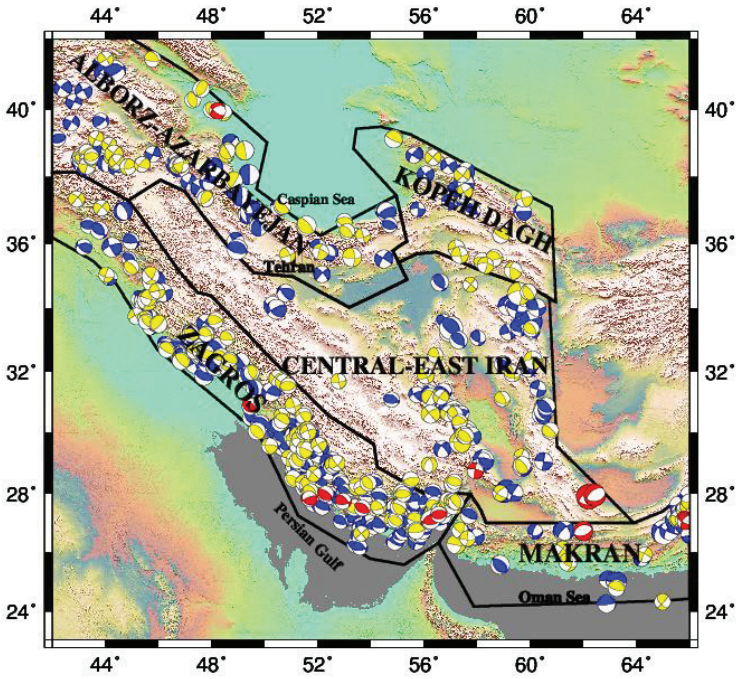


Figure 1. Distribution map of focal mechanisms in Iran from Global CMT Project. Depth of events specified by yellow (0–20 km), blue (21–40 km), and red (> 40 km) . The range of seismotectonic provinces is based on Mirzaei et al. (1998).

Table 1. The number of focal mechanisms for each seismotectonic province suggested by Mirzaei et al. (1998).

Seismotectonic province	Number of focal mechanism	Percentage
Zagros	313	52.6
Alborz-Azarbayejan	100	16.8
Central-east Iran	99	16.6
Makran	54	9.1
Kopeh Dagh	29	4.9

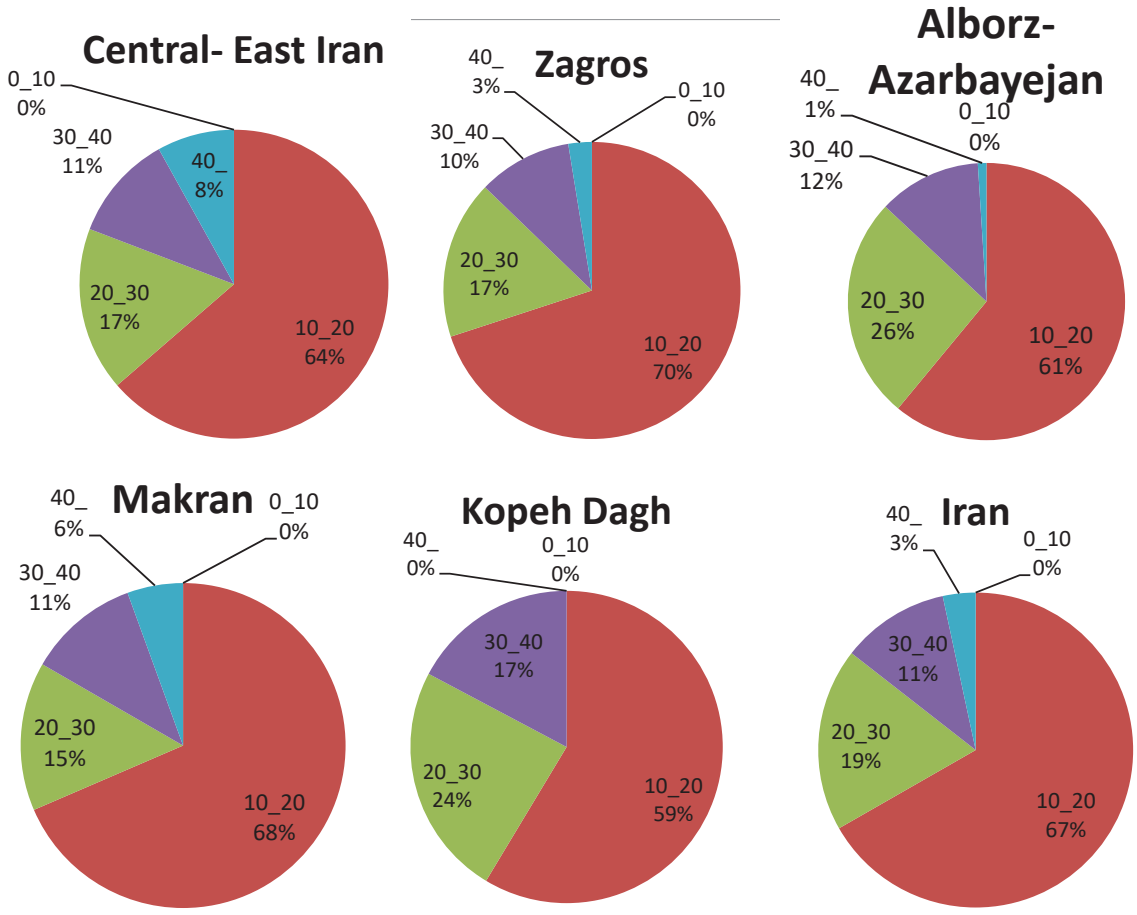


Figure 2. The pie chart of events frequency according to the depth.

3. Classification

In this paper, the tectonic characteristics of Iran have been studied using the focal mechanisms obtained from the earthquakes of study region in a period of more than 50 years (from 1963 to 2020). First, the focal mechanisms were collected from the CMT catalog. Most earthquakes are shallow, so that about 70% of them occurred at a depth of less than 30 km.

In this study, we classify these focal mechanisms so that the type of faulting (reverse, strike-slip and normal) can be determined according to their frequency distribution. We have used the software FMC which has been written in Python. In this software, the focal mechanisms are divided into seven groups: Normal (N), Reverse (R), Strike-slip (SS), Strike-slip – Reverse (SS-R), Strike-slip – Normal (SS-N), Reverse – Strike-slip (R-SS), Normal – Strike-slip (N-SS). The diagrams of these classifications have been shown in Kaverina et al (1996) projection technique (Figure 3). This diagram also is used by Kagan (2005).

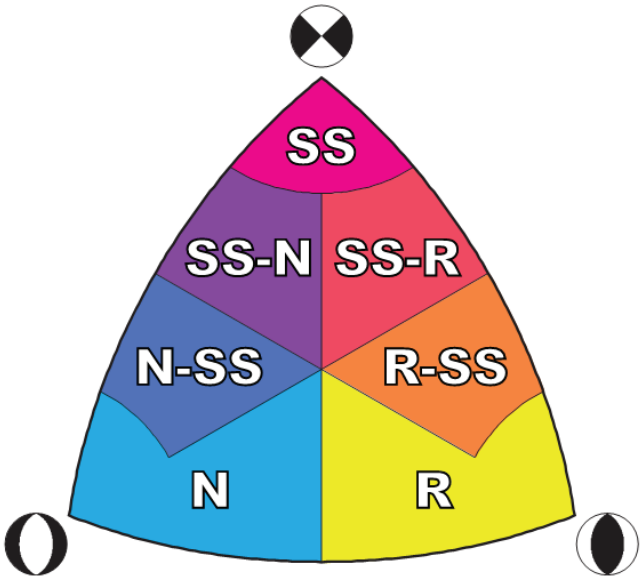


Figure 3. 7 Groups of focal mechanism in the classification diagram (Álvarez-Gómez, 2018). N: Normal; N-SS: Normal - Strike-slip; SS-N: Strike-slip - Normal; SS: Strike-slip; SS-R: Strike-slip - Reverse; R-SS: Reverse - Strike-slip; R: Reverse.

According to the analysis of the eigenvalues and eigenvectors, every moment tensor has three eigenvalues (the maximum value T, the middle value B, the maximum value P) whose directions are determined by eigenvectors. The direction of these three vectors determines the type of faulting is shown by a focal mechanism and to which category of the seven mentioned groups should belong. The flowchart of figure 4 shows the classification based on the direction of the vectors of P, B and T.

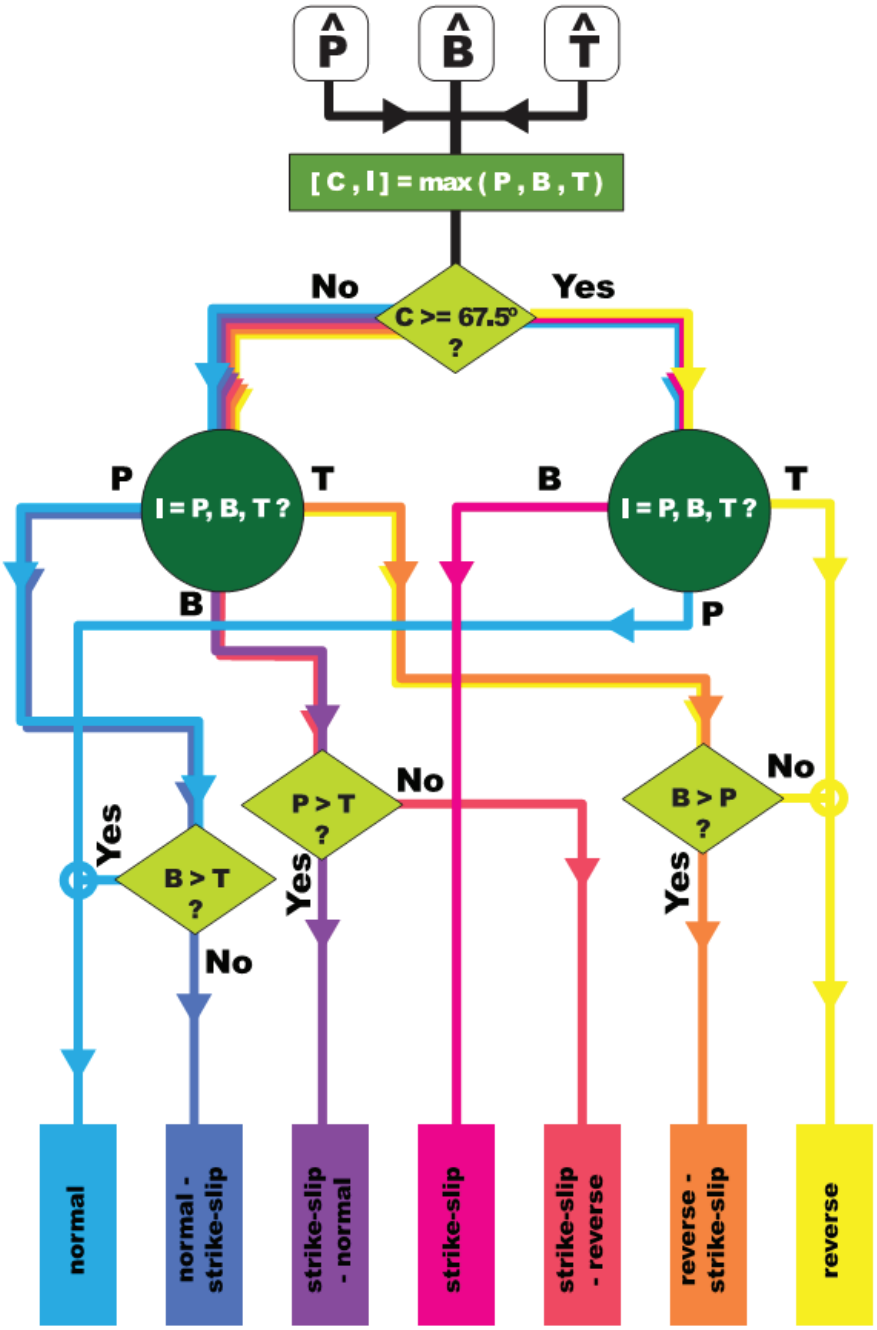


Figure 4. The flow chart of classification based on the maximum value of P, B and T axes (Alvarez-Gómez, 2018).

4. The results of the classification

4.1. Zagros

Considering that more than 50% of the data in this article are related to Zagros, so first they are classified in this region. Their moment magnitude ranges from 4.7 to 7.4. About 94% of the data is smaller than 6, and a small number of them are larger than 6. The classification of Zagros earthquakes is shown in Figure 5. As it is shown in figure 5, most faulting is of reverse and strike-slip type. A few numbers of the normal mechanism are observed.

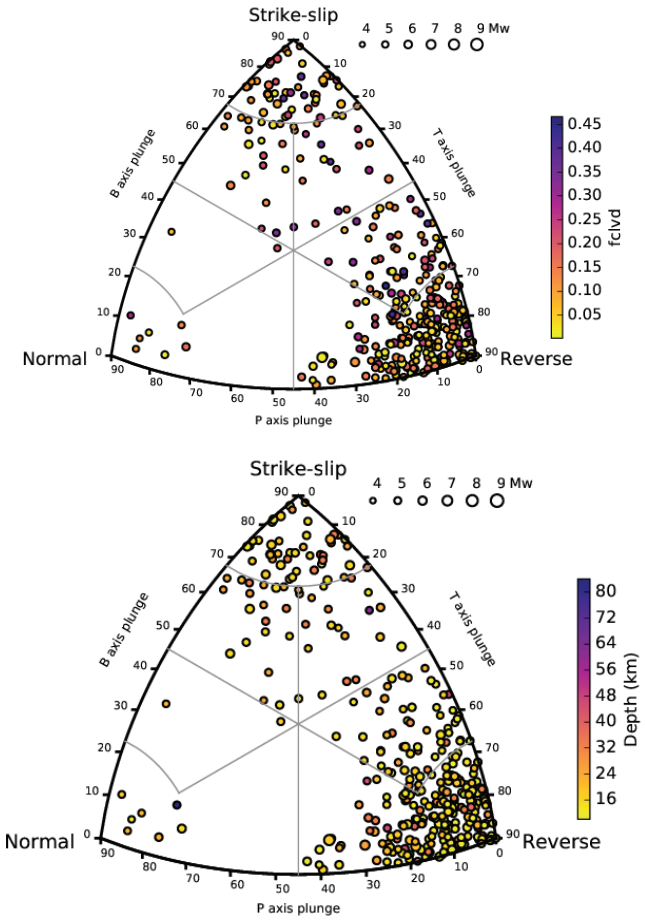
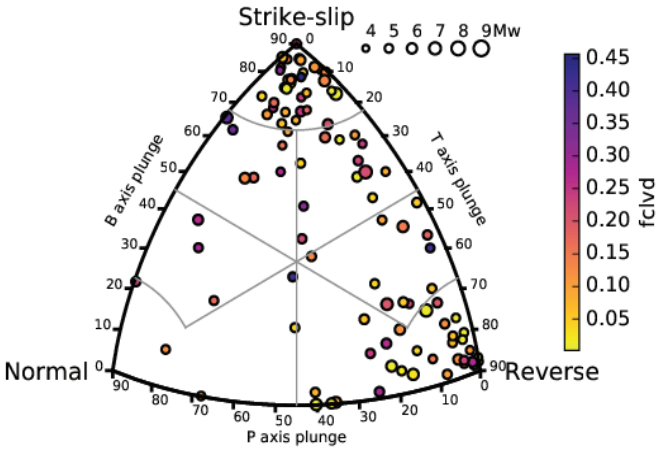


Figure 5. Classification of the Zagros focal mechanism in fclvd scale (top) and depth scale (bottom).

4.2. Alborz-Azerbaijan

In Alborz-Azerbaijan seismotectonic province, 100 focal mechanisms have been recorded, the classification of which is shown in Figure 6. This number is less than the number of focal mechanisms in the Zagros zone. Because other zones, despite their vastness, have less seismicity than the Zagros. Therefore, in the references that record the focal mechanisms, the focal mechanisms of other zones of Iran are low. The strike-slip and reverse faults in the Alborz-Azarbaijan zone are almost equally distributed and with high frequency, while the normal faults are negligible.



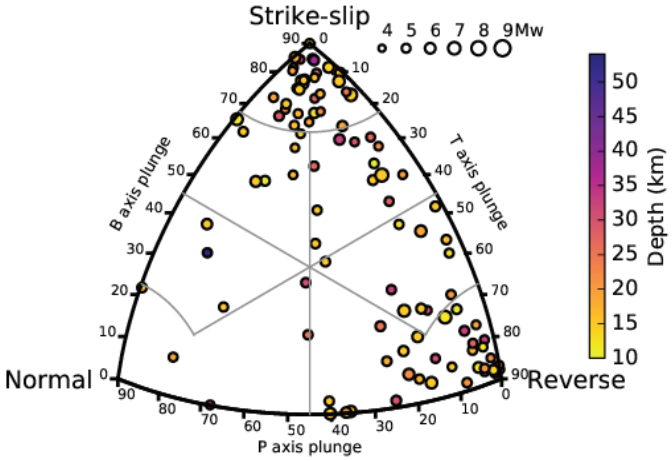


Figure 6. Classification of the Alborz-Azarbayejan focal mechanism in fclvd scale (top) and depth scale (bottom).

4.3. Central-East Iran

Central-East Iran is the largest seismotectonic province. In our catalog, there are 99 focal mechanisms for this region, the classification of which is shown in Figure 7.

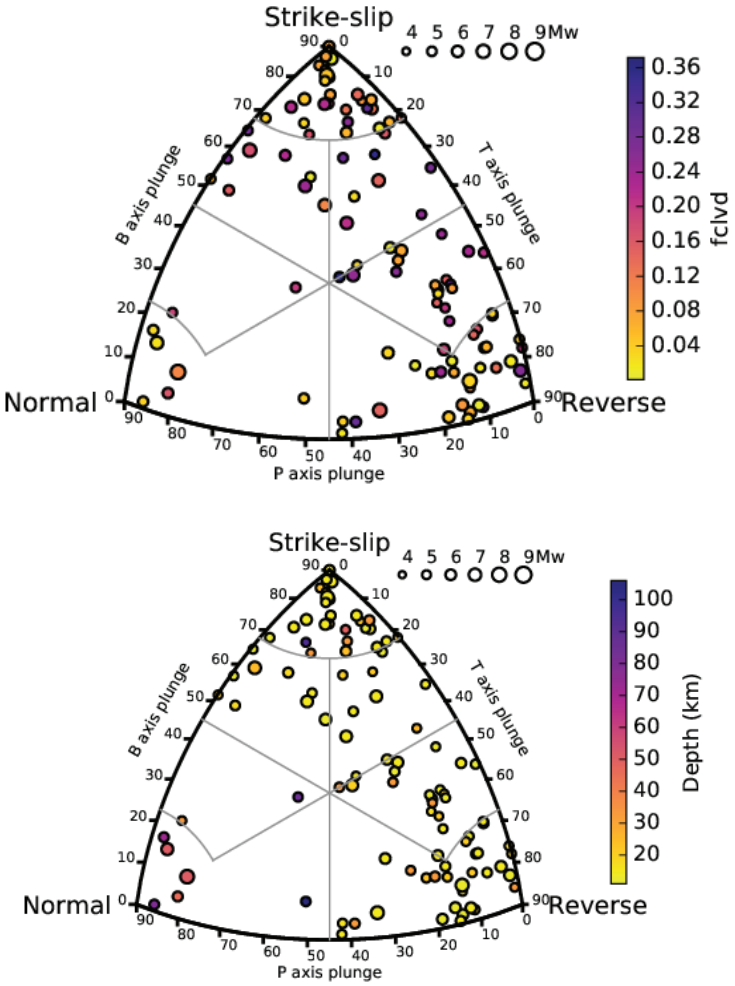


Figure 7. Classification of the Central-East Iran focal mechanism in fclvd scale (top) and depth scale (bottom).

4.4. Makran

The classification of 54 focal mechanisms related to the Makran zone is shown in Figure 8. Normal and reverse faults are negligible in this zone, while strike-slip faults are abundant.

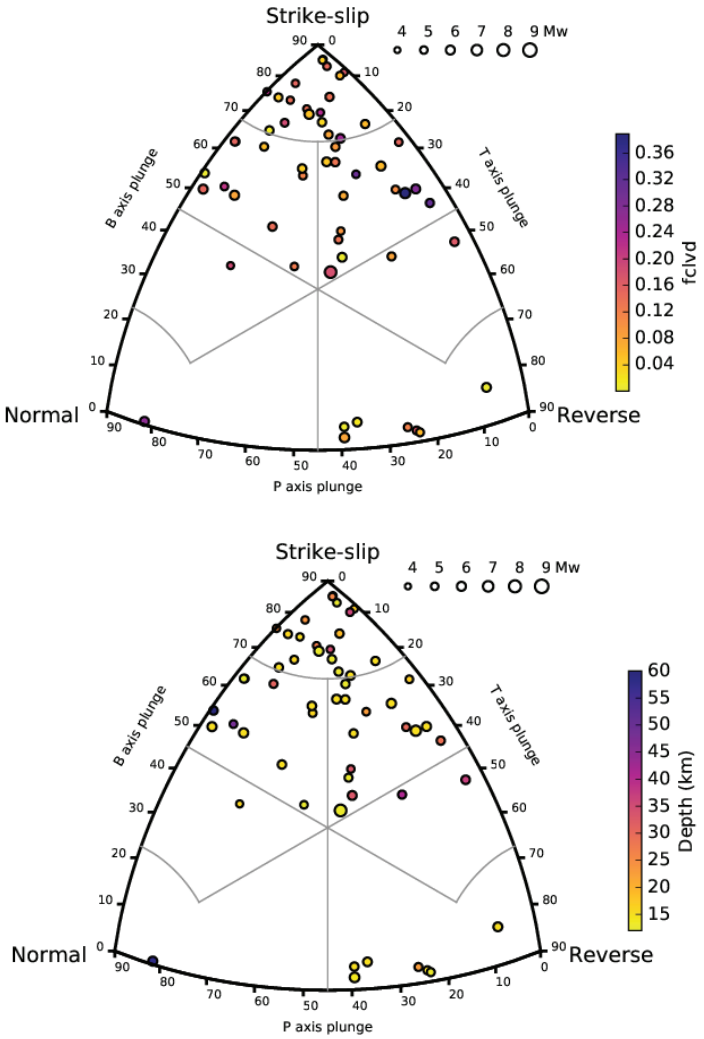


Figure 8. Classification of the Makran focal mechanism in fclvd scale (top) and depth scale (bottom).

4.5. Kopeh Dagh

The lowest number of focal mechanisms (only 29) in our catalog is related to the Kopeh Dagh seismotectonic province, which accounts for less than 5% of the data. No major earthquakes were recorded in this area, so the largest was 6.5. Their classification is shown in Figure 9.

5. Discussion and Conclusion

There is no study on the classification of destructive earthquakes based on the frequency percentage of fault type (focal mechanism) in Iran. In order to better understand the seismic properties of Iran, its focal mechanisms were classified. A pie chart of the percentage frequency of these seven categories has been shown in order to better understand the classification (Figure 10). As expected, most focal mechanisms are reverse (or reverse with a strike-slip component). This is in accordance with the

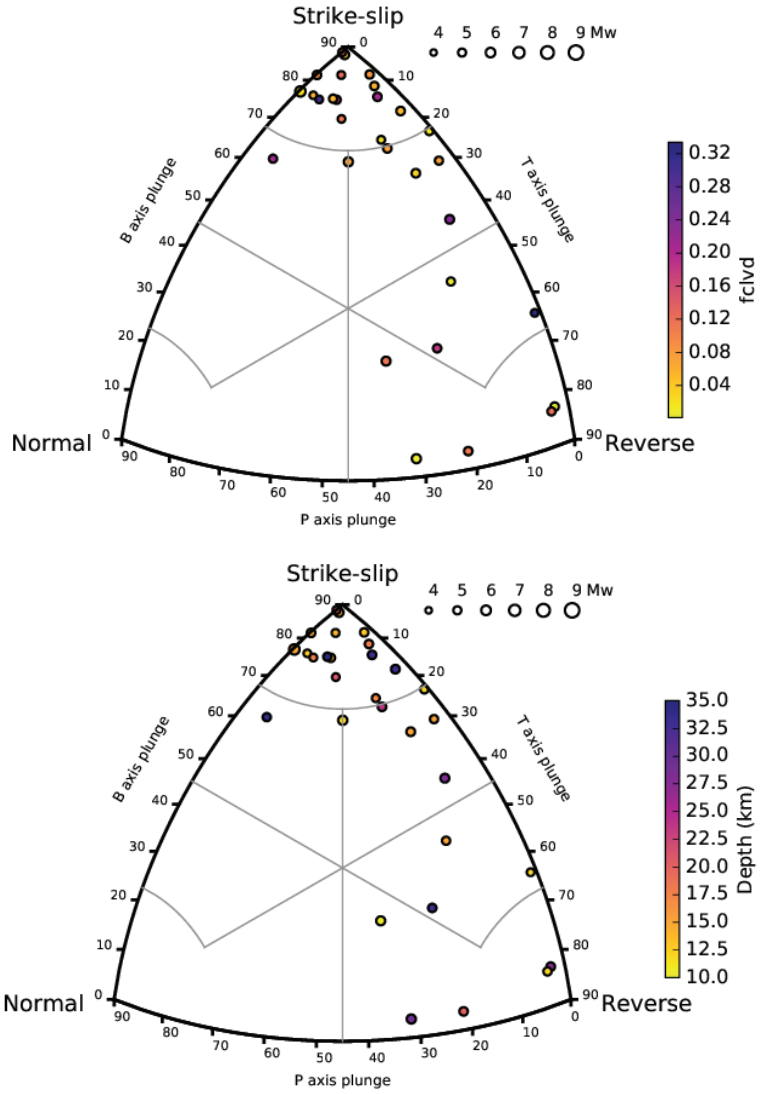


Figure 9. Classification of the Kopeh Dagh focal mechanism in fclvd scale (top) and depth scale (bottom).

convergence of the Arabian plates and Eurasian plates. Zagros province is more affected by this convergence than other provinces; so that more than 75% of its events are of the reverse type (or reverse with the strike-slip component) and a small percentage of events have a normal type mechanism. Among these 5 provinces, the Kopeh Dagh appears to be different from the other; so that about half of its events have a pure strike-slip component, and no normal type (or normal with a strike-slip component) mechanism is observed in it. Most of the faults of the reverse type are related to Zagros province, which includes 58% of its earthquakes and 42% of Iran's earthquakes. The main faulting in Kopeh Dagh is of strike-slip type, so that more than half of its earthquakes are of pure strike-slip type, but other provinces of Iran have a lower percentage of this type of faulting. Normal faults in all provinces have a small frequency, so that only about 3% of the total earthquakes in Iran are of this type. The Alborz-Azerbaijan and Central Iran provinces are most similar in terms of the percentage of fault type.

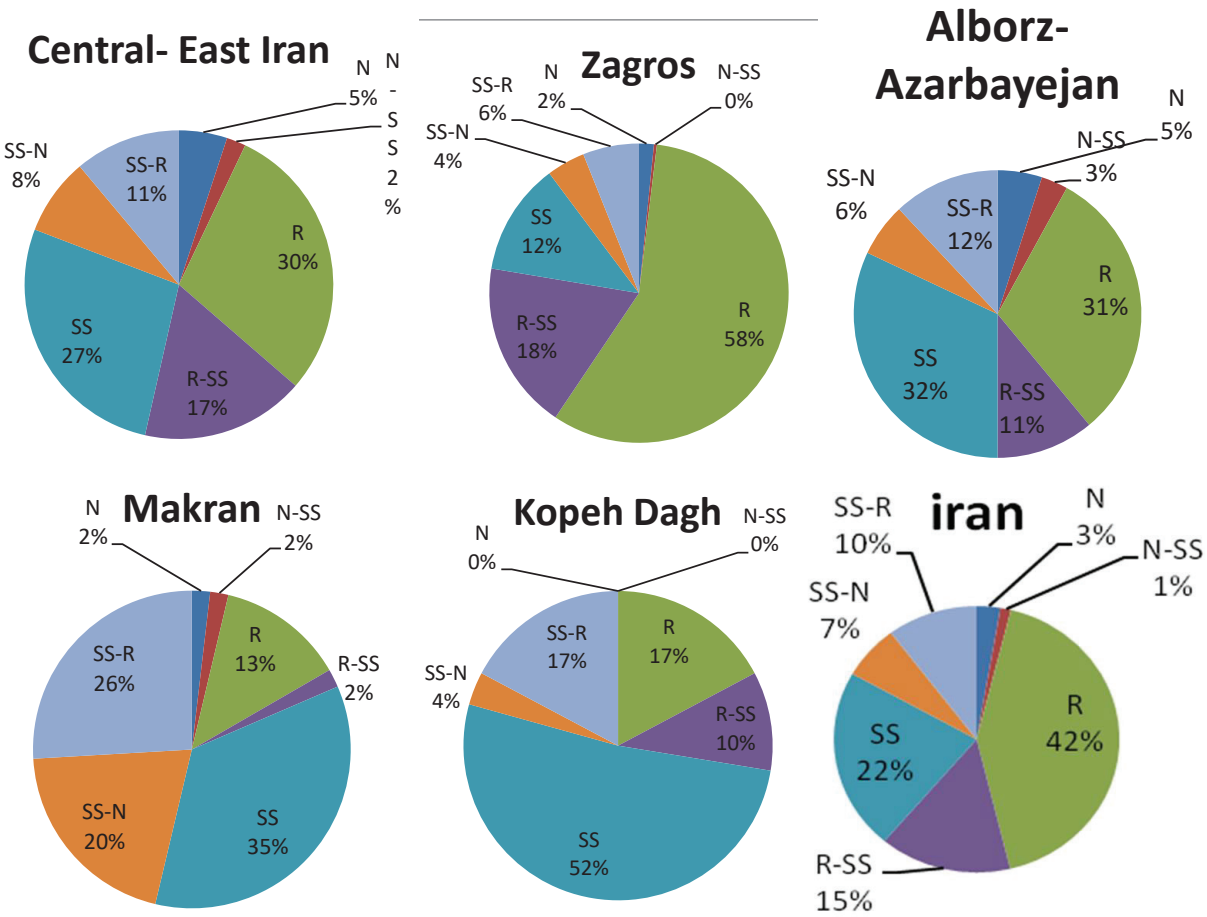


Figure 10. Pie chart of frequency percentage for all 5 seismotectonic provinces. Normal (N), Reverse (R), Strike-slip (SS), Strike-slip – Reverse (SS-R), Strike-slip – Normal (SS-N), Reverse – Strike-slip (R-SS), Normal – Strike-slip (N-SS).

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