Notable Events

The mb=5.4 Katav-Ivanovsk Earthquake (Urals) on 04 September 2018

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Excerpt from the
Summary of the Bulletin of the International Seismological Centre:

Dyagilev, R.A. , Verkholantsev, F.G., Varlashova, Y.V. and Shulakov, D.Y. (2021), The mb=5.4 Katav-Ivanovsk Earthquake (Urals) on 04 September 2018, *Summ. Bull. Internatl. Seismol. Cent.*, July - December 2018, *55*(II), pp. 56-–63, https://doi.org/10.31905/JSWK1WM4.

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7.1 The mb=5.4 Katav-Ivanovsk Earthquake (Urals) on 04 September 2018

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The article summarises the instrumental and macroseismic data of the Katav-Ivanovsk earthquake, which occurred on September 4, 2018, in the Chelyabinsk region, Russia. The earthquake was the strongest instrumentally recorded earthquake in the Urals (mb=5.4) and at the same time, it had the most seismic intensity compared to other earthquakes in Russia in 2018 (I0=6 points). For the first time in the Urals the aftershock process was recorded, the active stage of which lasted more than 1 year. Like the mainshock, some aftershocks had a significant macroseismic effect.

7.1.1 Introduction

The earthquake in the area of Katav-Ivanovsk, Chelyabinsk region, which occurred on September 4, 2018, was an unexpected and unusual natural phenomenon for the South Urals. In 2018, this earthquake in Russia became the event with the greatest macroseismic effect. Seismicity in this area is not properly studied, the nature of seismic events that previously occurred here is controversial, since the available instrumental data are unrepresentative. Data on the focal mechanisms in this area are almost completely lacking. Studies carried out in the source area after the Katav-Ivanovsk earthquake made it possible to obtain a large amount of information in a relatively short period of time and to remove many questions about the nature of the seismicity of the area. Macroseismic data on the main shock and its three strongest aftershocks are collected. The significant magnitude of the earthquake made it possible to use

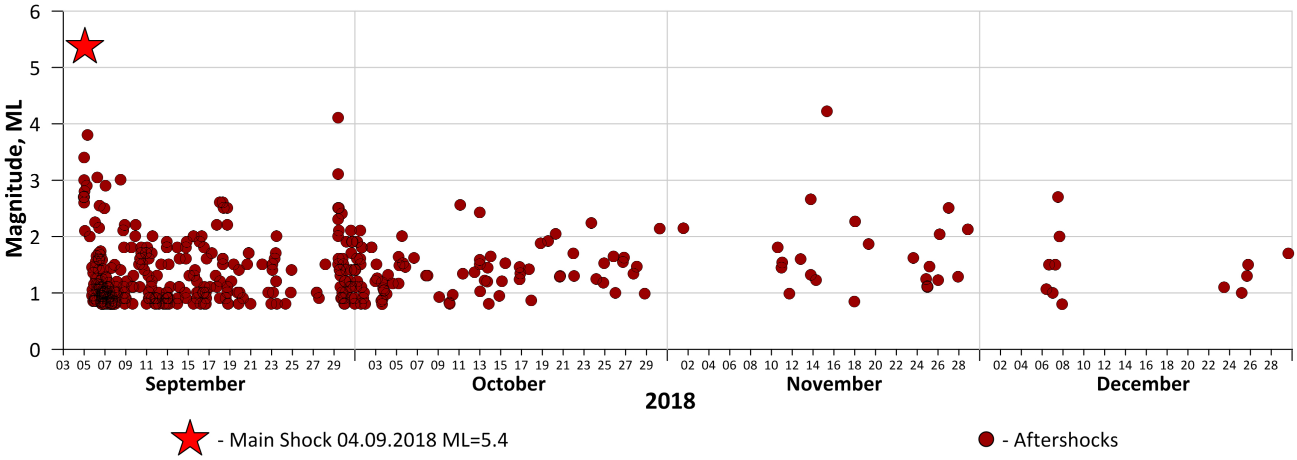

Figure 7.1: *Temporal distribution of aftershocks of the Katav-Ivanovsk earthquake*

data from dozens of teleseismic stations to determine the depth and the mechanism of the earthquake source.

The Katav-Ivanovsk earthquake of 2018 is one of the three strongest (M≥5.0) earthquakes known in the Urals. The first two occurred quite a long time ago (1798 – Perm-Kungur, 1914 – Bilimbai), the primary information about them consists mainly of macroseismic descriptions. These, with a small amount of instrumental data (only concerns the Bilimbai earthquake), became the basis for determining the events main parameters (*Godzikovskaya*, 2016; *Malovichko et al.*, 2020). To study the conditions for the occurrence of the Katav-Ivanovsk earthquake, the amount of instrumental data obtained in 2018 was significantly larger and supplemented by the same information received from the local network of temporary stations deployed in the epicentral zone a day after the main shock. The local network made it possible to obtain a fairly complete picture of the focal area, due to the fact that for the first time in the Urals a powerful aftershock process was recorded.

7.1.2 Instrumental Data

In total, more than 1200 seismic events were recorded and processed in the epicentral zone. Their temporal dynamics are shown in Figure 7.1, and a map of those earthquakes recorded by at least three stations is shown in Figure 7.2. It can also be seen in the map that the local network changed its spatial configuration, however, events with magnitudes of M0.8 and above were registered at all times (see Fig. 7.3).

The calculation of the coordinates of the epicenter, based on the data from teleseismic stations and the regional network (57 stations in total), indicates the position of the source in the area of the Karaulovka village (Fig. 7.2). However, the cloud of aftershocks obtained from the data of the temporary network indicates that this epicenter was determined with a large error (about 10 km). The subsequent recalculation using the relative location procedure of *Spence* (1980), where the aftershock of November 15, 2018 which could be more accurately located (location error of less than 0.5 km) because of the additional stations from the temporary network was used as the master event, showed that the main event occurred near the western outskirts of Katav-Ivanovsk. The same procedure was performed for two other strong aftershocks that occurred on the first day, while the temporary network was not yet functioning. The

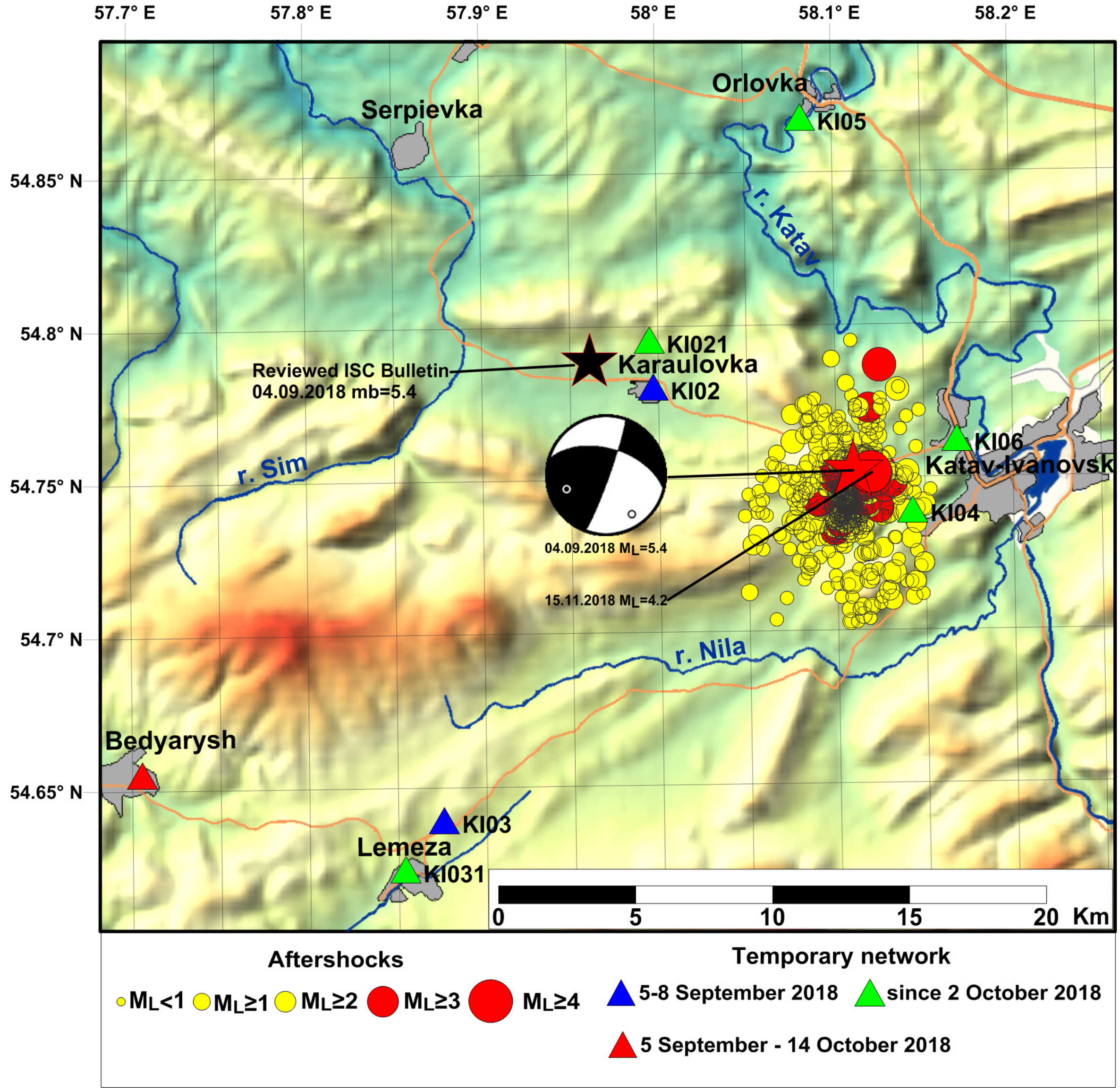

Figure 7.2: *Map of aftershocks of the Katav-Ivanovsk earthquake. Orange lines = roads.*

Date	Orig. time	Hypocentre							Magnitude
		Lat/deg	Lon/deg	a/km	b/km	Az/deg	h/km	δ/km	
04/09/2018	22:58:19	54.752	58.110	2.25	1.35	137	5.9	1.0	mb=5.4, ML=5.4, MS=4.8
05/09/2018	07:27:15	54.757	58.106	2.95	0.82	101	3.2f	–	mb=4.7, ML=3.8
29/09/2018	09:06:46	54.757	58.099	2.00	0.65	110	3.2f	–	mb=4.4, ML=4.1
15/11/2018	07:48:24	54.752	58.119	0.44	0.44	-	3.15	0.30	mb=4.4, ML=4.2

Table 7.1: *Parameter of the Katav-Ivanovsk earthquake and its three strongest aftershocks according to instrumental data. f - fixed depth; a, b – axes of error ellipse; Az – azimuth of longest axis.*

refined parameters of the hypocenters for all three relocated events and the master event are presented in Table 7.1.

The focal mechanism was calculated based on the polarity of the first arrivals of P-waves at 42 stations, of which compression motion (positive polarity) was recorded at 20 stations, and tension (negative polarity) at 22 stations. The stations are located between 1.5 and 94.6° epicentral distance and in the azimuthal range of AZ=12–355°. Data on the focal mechanism are given in Table 7.2. The nodal plane NP1 corresponds to the right-hand strike slip with elements of uplift, the plane NP2 corresponds to

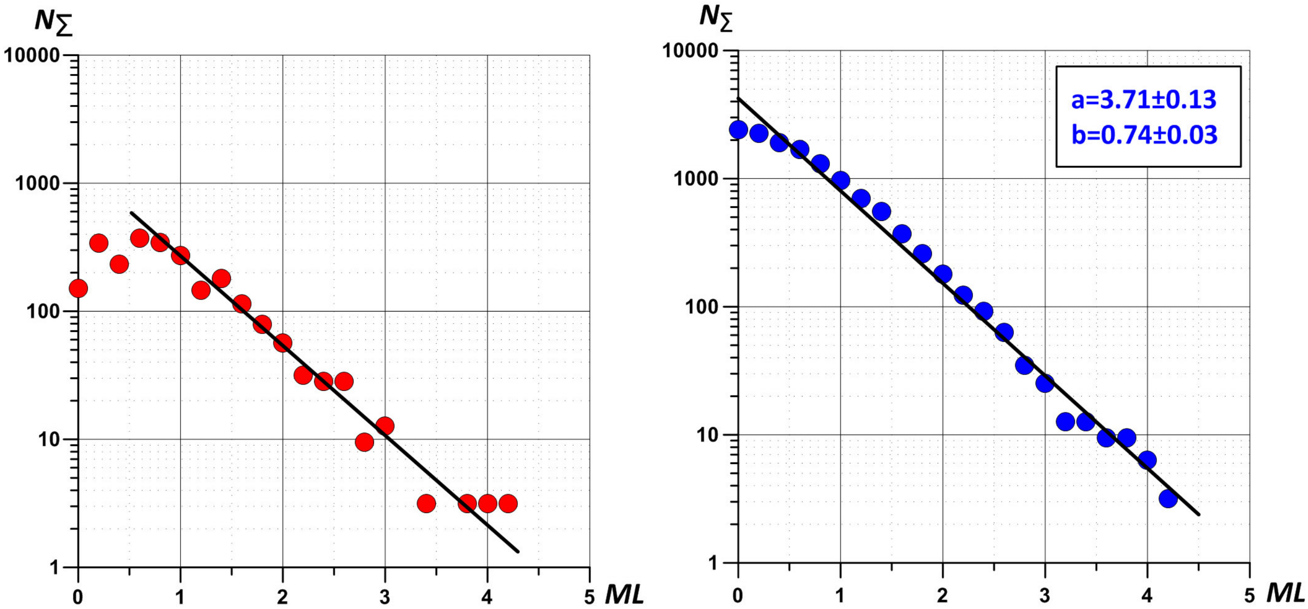

Figure 7.3: *Frequency (left) and cumulative frequency (right) magnitude distribution for the aftershock sequence of the Katav-Ivanovsk earthquake.*

Principal stress axes					
T		P		N	
Plunge/deg	Azimuth/deg	Plunge/deg	Azimuth/deg	Plunge/deg	Azimuth/deg
29	249	21	147	27	53

Nodal planes					
NP1			NP2		
Strike/deg	Dip/deg	Rake/deg	Strike/deg	Dip/deg	Rake/deg
285	54	173	19	85	37

Table 7.2: *Focal mechanism solution of the Katav-Ivanovsk earthquake.*

the left-hand reverse strike slip. Taking into account the orientation of the cloud of aftershocks, the NP2 plane is seen as the most probable variant of movement. The same decision is in good agreement with the tectonic condition of the area. The stress direction in the source actually coincides with the stresses obtained by alternative methods in the area (*Tevelev et al.*, 2019), and the rupture along the NP2 plane coincides in strike and slip pattern with the ruptures of the Bakal-Satka fault zone in the nearby Chelyabinsk Region.

7.1.3 Macroseismic Data

The earthquake in Katav-Ivanovsk had a significant macroseismic effect. Most of the macroseismic information was collected during the first week after the event as a result of a survey of the population in the settlements closest to the epicenter. Also, data collection was carried out through a survey of the population via the Internet. Due to the vastness of the survey geography (the radius of the earthquake sensibility zone was 200–300 km), the questionnaires in social media networks were partially filled out by specialists when replies were shared in posts rather than put into the questionnaires. In particular, the latter method made it possible to collect representative data on shaking in the nearest regional centres: Chelyabinsk, Ufa, Yekaterinburg and Perm. Systematization of macroseismic data was carried

Figure 7.4: *Damages to the hospital in Katav-Ivanovsk.*

out according to the new seismic intensity scale – SIS-2017 (*GOST R 57546-2017*, 2017), which is fully compatible with MSK-64, but allows for more objective assessments of seismic intensity in settlements based on people's feelings, reactions of household items and damage to buildings.

The strongest shaking (up to 6 points), according to the collected data, was observed in an area with a radius of 30 km from the epicenter, which included three cities – Katav-Ivanovsk, Ust'-Katav and Yuryuzan and several small settlements. Since the event took place at night, people woke up, experienced a strong fright and sometimes ran out of their houses. In houses, light household items reacted strongly – they swayed, shifted and fell while heavy objects reacted less frequently and more weakly. The largest amount of damage to buildings was noted in the city of Katav-Ivanovsk and the village Orlovka. The building of the city hospital in Katav-Ivanovsk suffered the worst damage, where there were cracks in the partitions, cracks in the load-bearing walls and large pieces of plaster falling off (Fig. 7.4). After the incident, the activities of the institution were suspended. In total, 454 cases of damage to private houses were officially registered in the city. Most of the damage was done to the interior decoration of the premises, although sometimes cracks in the foundation were noted, and in some cases collapsed stoves and chimneys.

Also, strong shaking caused a landslide on the eastern slope of Peschanaya Mountain, located directly

Figure 7.5: *Landslide on the eastern slope of Peschanaya Mountain triggered by the main shock.*

above the main shock (Fig. 7.5). The landslide was noticed in the forest by local residents on September 25, 2018, when the viscous water saturated soil, along with the trees growing on it, began to slowly slide down a slope with a dip angle of 5°. In the most intense phase of movement, the mud flowed with a width of 10 to 30 m and moved at a speed of about 1 m/s. As a result, a large volume of soil moved down the slope for about 0.5 km leaving a 3-5 m deep ditch behind along its path. The entire volume of the removed soil (about 5000 m^3) stopped on the slope below, forming piles up to 3 m high. The presence of such a landslide, according to the SIS-2017 classification, confirms the intensity of shaking at the epicenter up to 6 points.

After collecting the macroseismic data, they were geographically grouped and processed. These results served as the basis for constructing a map of the macroseismic field, which is shown in Figure 7.6.

Isoseismal lines on the map were constructed using the approach described in *Kul'chitskii* (2014), allowing for the azimuthal heterogeneity of the distribution of the macroseismic effect under conditions of low spatial coverage of the initial data, which is especially important in sparsely populated areas of the Urals. The macroseismic epicenter (maximum of macroseismic field) is located in the Orlovka village and has the coordinates: 54.877°N, 58.110°E, which is 14 km north of the instrumental epicenter. The macroseismic field is oriented to the Northwest, which is in good agreement with the results of macroseismic surveys of other strong earthquakes in the Urals (*Dyagilev et al.*, 2018).

It should be noted that in 2004 and 2006 five smaller earthquakes of magnitudes $2.3 \leq M \leq 3.0$ were recorded in the same area. One of them had a macroseismic effect with an intensity of up to 4 points. Doublet earthquakes were observed twice, which were separated from each other in time by several minutes. Due to the low density of the stationary seismic network in this area, it was difficult to conclude anything about the nature of these events, because for the South Urals, due to the active development of deposits, induced seismicity is also typical. For the induced seismicity, aftershocks over a short period in time were also noted at the nearby mining facilities. Now, after detailed observations of the epicentral zone, it has become quite obvious that technogenic sources in the vicinity of Katav-Ivanovsk do not occur, and the events of 2004-2006 are weak tectonic earthquakes with aftershocks, of which only the strongest ones were observed instrumentally.

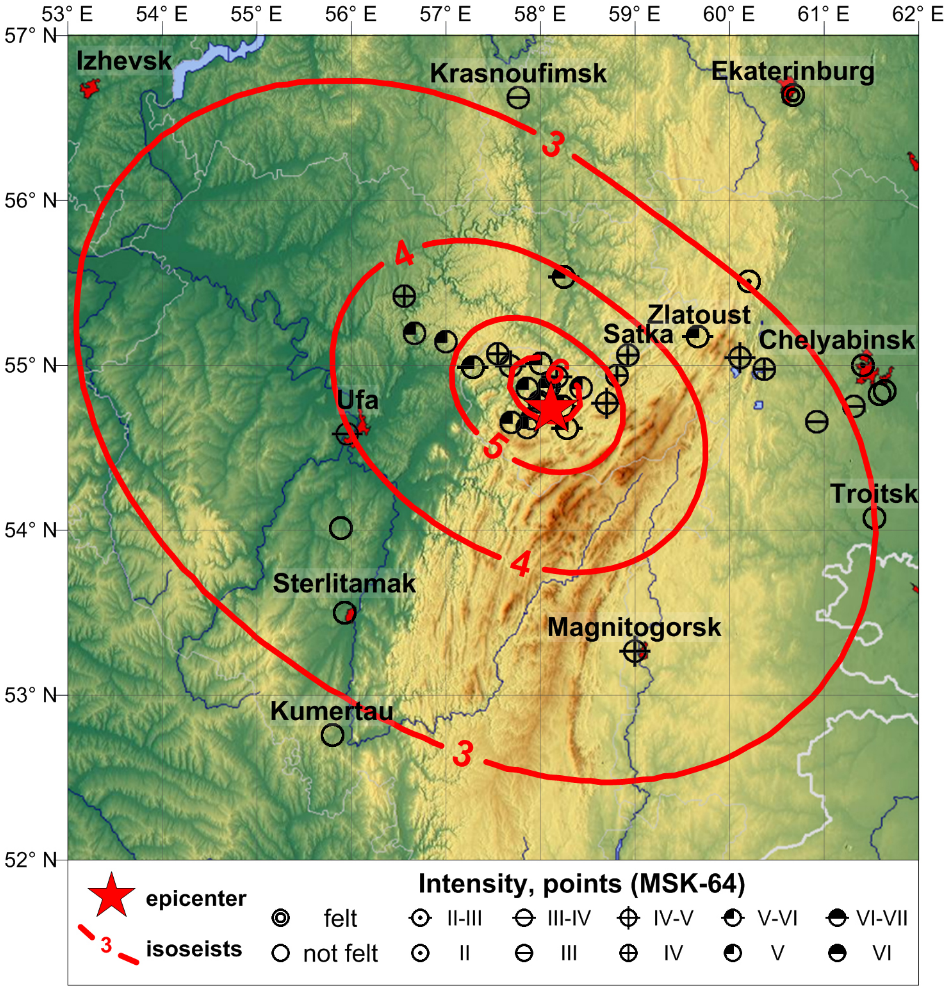

Figure 7.6: *Map of the macroseismic field of the Katav-Ivanovsk earthquake.*

7.1.4 Conclusion

The Katav-Ivanovsk earthquake became the strongest instrumentally recorded earthquake in the Urals (mb=5.4) and at the same time the most perceptible on the territory of Russia in 2018 (I_0=6 according to SIS-2017). The uniqueness of this event was given by the fact that after it, for the first time in the Urals, a powerful aftershock process was recorded, the active stage of which lasted for more than one year. Analysis of the historical seismicity showed that this area has been seismically active for a long time. The available data indicate the predisposition of many tectonic events of the Southern Urals to be accompanied by aftershocks and the Katav-Ivanovsk earthquake itself became the most productive of them.

The application of traditional approaches to the processing of primary data yielded approximate parameters of the main shock and two strong aftershocks, which spatially poorly matched the seismicity recorded after the installation of the network of temporary stations around the epicenter. The relative location procedure made it possible to clarify the location of problem hypocenters and to considerably reduce the location error. Calculations of the parameters of the focal mechanism together with the orientation of the aftershock field indicate slip along a left-hand reverse fault with a sub meridional strike.

The macroseismic effect of the main shock is analysed in terms of the SIS-2017 scale. As a result of this analysis, a map of the macroseismic field was built taking into account the azimuthal heterogeneity of the distribution of the macroseismic effect. The resulting field indicates predominant propagation of ground shaking in the Northwest direction.

7.1.5 Acknowledgements

The work was supported by the Ministry of Science and Higher Education of the Russian Federation. The data used in the work were obtained with large-scale research facilities "Seismic infrasound array for monitoring Arctic cryolitozone and continuous seismic monitoring of the Russian Federation, neighbouring territories and the world".

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