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Macroseismic survey of Salsk (Russian platform) earthquake of 22 May 2001

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Abstract. The Salsk, 22 May 2001, earthquake occurred within the Russian platform in almost aseismic area. Its magnitude (M_S = 4.6) is the largest instrumentally recorded one in the region. This makes the event of a crucial importance in hazard evaluation. Because of poor instrumental data, the earthquake was studied by macroseismic survey. This also gives possibility to evaluate directly impact of the earthquake on the hazard in terms of intensity. Area covered by the survey includes 36 datapoints in the frames of 110 over 170 km. The interpretation of data obtained results in location of macroseismic epicenter and depth, evaluation of its maximum observed and epicentral intensities, and assessment of intensity attenuation.

Introduction

The Salsk earthquake (M_S = 4.6) occurred within the Russian platform, more than 200 km to the North from the Great Caucasus mountain range, where the largest instrumentally recorded earthquake magnitude is 7.0 (Racha, April 29, 1991). Events with smaller magnitudes (less, than 5.5) occur within the Stavropol Highland, which borders with Great Caucasus on the south. This area of medium size seismic activity is located ca. 100 km to the south of Salsk earthquake epicentral area (Figure 1; events with $M \geq 3.5$ are plotted). So, within about 100-km area the Salsk earthquake is the largest instrumentally recorded seismic event. Naturally, being the largest earthquake of the nearly aseismic region, it attracts a great attention. Only two instrumentally recorded earthquakes are known within the Salsk earthquake epicentral area with magnitudes 2.7 and 3.2 in 1984 and 1996 correspondingly. The impact of this event on seismic hazard evaluation of the region could not be overestimated.

Tectonically, the Great Caucasus is considered a collision zone between the Eurasian and Arabian plates (for example, [*Rebai et al.,* 1993]) (Figure 2). The Stavropol Highland is a transition zone lying between this collision zone and the platform itself. In frames of this scheme, the epicentral area of Salsk earthquake is situated within the Russian platform, being an intraplate earthquake.

Because the epicentral area has been considered nearly aseismic, it never had been covered with regional seismometric network to monitor its seismic activity. From the other hand, the magnitude of the event is very small to make possible the earthquake study in details based on records of worldwide network. The instrumentally determined earthquake parameters are summarized in Table 1. Both quick and refined solutions are taken from the official site of the Geophysical Service of Russian Academy of Science (http://www.ceme.gsras.ru/1251/mainnn.htm).

Epicentral intensity I_o is theoretically calculated from magnitude. The nearest station data used in location is more than 150 km far from the epicenter. This fact together with the poor azimuth coverage makes possible location accuracy within 10–15 km.

The situation with instrumental data makes the macroseismic survey the most optimal way of its study. For certain technical reasons the survey could be started only 8 months after the earthquake occurrence and has to be done in very limited time interval. This superimposed some restrictions on the survey. Two main goals of the survey were formulated. First one is to locate the epicenter based on macroseismic data and to evaluate the maximum observed and epicentral intensities, then to assess the focal depth. Second, to trace the intensity attenuation in the northern direction from the epicenter. This direction was considered of special

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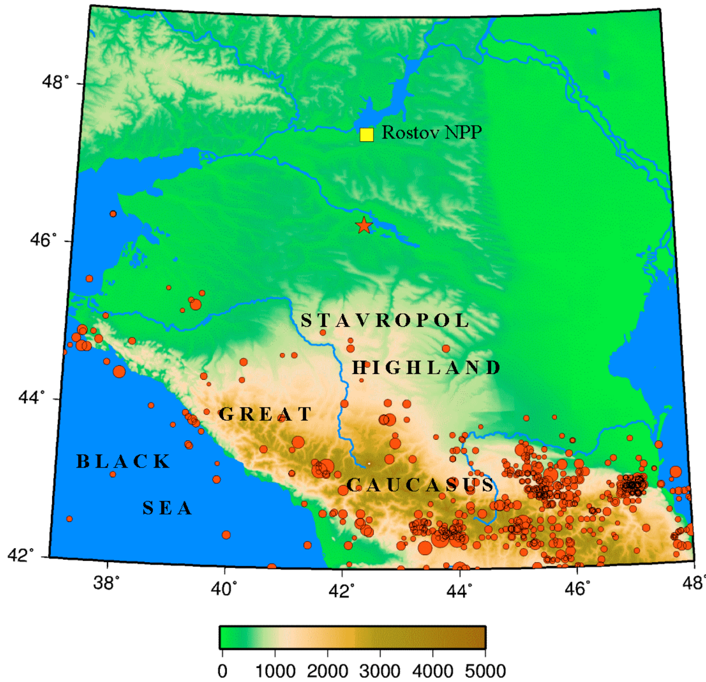

Figure 1. Seismological setting of the region. Earthquake epicenters (M≥3.5) since 1900 are plotted according to the Earthquake Catalogue of Northern Eurasia [*Ulomov,* 1993]. Star indicates the Salsk earthquake epicenter.

interest because at about 130 km to the North from the epicenter there is the site of Rostov NPP. The Salsk earthquake is the largest event in the vicinities of the site.

A special approach to the macroseismic survey of the earthquake has to be developed because some of its peculiarities. We have already mentioned, that 8 months passed from the earthquake occurrence and only very limited time could be spent on survey. The situation is complicated by the fact that according to preliminary information of the Emergency committee (Emercom) of Russia the earthquake was not destructive. So, there are no material witnesses of the intensity of shaking. The other negative feature for full-scale macroseismic survey is the rare population of the epicentral area, which limits the accuracy of epicenter location. The problem of attenuation assessment makes very important the homogeneity of intensity assessments at different distances.

Method

Homogeneity of intensity assessment is very important in any kind of macroseismic survey, especially when taking into account specific goals of our study. Usually, when studying macroseismic effects of strong earthquakes (so, earthquake prone area is very large), different groups collect initial data. This arises heavily the problem of data attachment. In our case, when the prone area is limited, one group of two specialists did the whole survey to get homogeneous evaluations.

To get well-balanced intensity assessments, we tried to reach as soon as possible the zone of maximum macroseismic effects. Then weaker effects will be distributed relatively accurately within the whole range from maximum effects up to the “not felt” limit.

Because Geophysical Service did not report any damages

Table 1. Instrumentally determined parameters of the Salsk earthquake

N	E	H, km	mb/N	MS/N	I_o, degree	N stations	Remarks on solution
46.43	42.30	15	5.0/5	4.8/4	6	8	Quick
46.402	42.436	11	5.0/5	4.8/4	6	15	Refined
46.36	42.22	10		4.6			NEIC

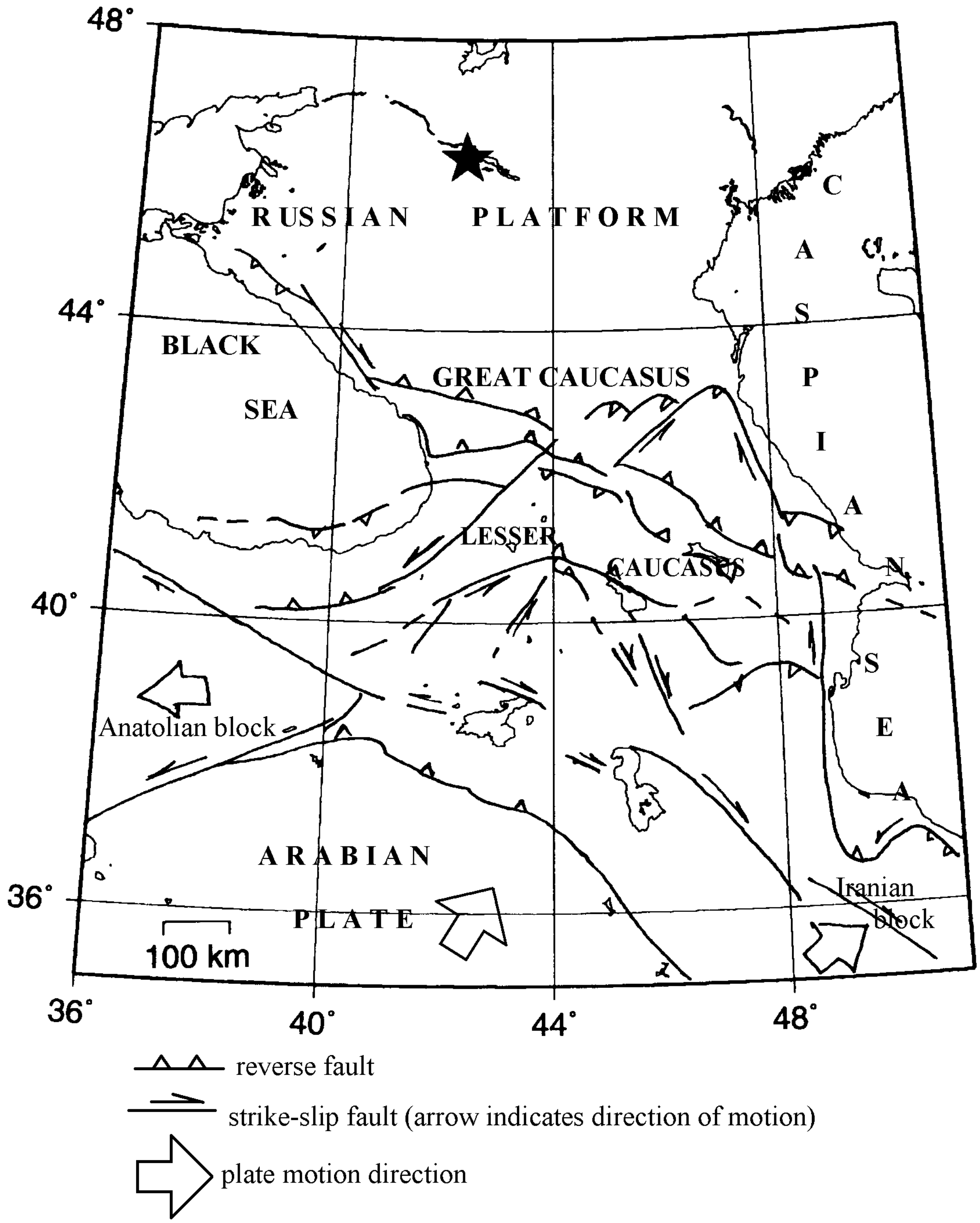

Figure 2. Tectonic setting of the region (simplfied from [*Rebai et al.,* 1993]).

caused by the earthquake, we supposed that the intensity assessment mostly would be based on effects on people. In principal this make possible to distinguish intensity degrees up to 5. Intensity 6 requires at least damage degree 1 even for low vulnerable constructions (according to the [*European Macroseismic Scale,* 1998]).

Before starting macroseismic survey it was decided that methodologically we would follow recommendations on the macroseismic scale application suggested in the EMS98. For example, when the data does not allow us to make unique assessment of intensity being 5 or 6, we give interval 5–6, which reflects the uncertainty of evaluation. It does not mean the half value intensity degree, which would be in contradiction with the scale.

According to EMS98 recommendations, no any kind of considerations on site effect can be included in intensity assessment. Just opposite, the site effect is something, which is supposed, could be found objectively afterward from intensity distribution map, when some local areas of intensity amplification would be outlined.

Table 2. Generalized different situations and corresponding intensity degrees

Generalized situation	Intensity
many reports on degree 1 damage (hair cracks in plaster) and panic	6
few reports on degree 1 damage (hair cracks in plaster) and light panic	5
no damage, felt by most people in rest, some frightened, some woke up	4
felt by many people in rest, nobody frightened, nobody woke up	3
felt by few in rest	2

Results and Discussion

Area covered by the survey includes 36 datapoints in the frames of 110 over 170 km. The intensity assessments were done based on filled questionnaires and visual inspection of experts. Before referring to the intensity datapoint Table some remarks on general situation have to be presented.

Topography and ground water. Generally, the topography is flat. Practically everywhere the view of horizon is unlimited. Within the epicentral region there are two rivers – one, Manych, is very large. It reaches ca. 3 km width; there are some lakes and reservoirs associated with it. Its banks are flat. The nearest locality is Manichskiy situated on slightly elevated hill at few hundred meters from the Manych bank. The other locality close to the Manych riverbank is Manychstroy (about 70 km from the epicenter). The other river is N. Egorlyk – it is the tributary of Manych. There are 3 localities on its banks: Baraniki, N. Egorlyk and Sandata. The banks of N. Egorlyk River are hilly; differences on elevation within those localities could reach 15–30 m. The ground water table is high (ca. 1 m) and varies very little within the whole epicentral area.

At about 130 km from the epicentral area there is a very large water reservoir – Tsimlyansk Sea. It is artificial reservoir created by the dam across Don River. On the southern bank of the Tsimlyansk Sea is the Rostov NPP site.

Urban planning and Construction type. Typical view of the village street is shown in Figure 3. Houses are well separated from each other. Predominant type (more than 80%) of construction is red brick with cement mortar (Figure 4). Houses are one-store, square in plan. Buildings are generally in good conditions. They could be considered as having vulnerability class B or C depending on mortar quality (EMS98). Buildings up to 9 stores could be found only in one locality – Salsk. To eliminate the effect, which related to high stores and different type of construction, also in Salsk we evaluate intensity based only on one-store brick houses with cement mortar.

Locality size effect. In general, the locality sizes (both in territory and population) are more or less the same with some exceptions. To eliminate the size effect, we distributed the same number of questionnaires in all localities. Questionnaires were distributed in different parts of localities.

As far, as we can judge, the situation is favorable to get homogeneous evaluation of intensity. There are no grounds to expect some serious distortions in intensity distribution caused by local conditions or artificial effects.

Summarizing the information received from questionnaires and visual inspection of localities all the reports were classified as following (Table 2). To each of the situation we put in correspondence the intensity degree.

The illustration of what is called here “as hair crack in plaster” is given in Figure 5.

The intensity assessments done following the Table 2 for

Figure 3. Typical view of countryside planning. Photo is taken in Romanovka vilage of Salsk region. The topography is flat, ground is clay and sandy clay.

Figure 4. Typical country house (Village Volochaevskaya). It is a predominant type of buildings: one store good quality brick with cement mortar. Basis is square or slightly elongated.

Table 3. Intensity datapoints. Data is sorted by intensity and distance from macroseismic epicenter

N	locality	intensity degree	Δ, km
1	Yashalta	6	4
2	Manychskiy	6	5
3	MTF Manychskiy	6	5
4	Erketen	5–6	9
5	Ulyanovskoe	5–6	9
6	Berezovskoe	5–6	14
7	Baga Tugtun	5	16
8	Krasnopole	5	17
9	Esto Altay	5	19
10	Baraniki	5	35
11	Romanovka	4-5	12
12	Sladkoe	4–5	21
13	N. Egorlyk	4-5	33
14	Solenoe	4	24
15	Vinogradnoe	4	30
16	Tsopos	4	33
17	Krupskiy	4	36
18	Sandata	4	43
19	Gorodovikovsk	3–4	40
20	Manychstroy	3-4	55
21	Proletarsk	3-4	57
22	Salsk	3–4	60
23	Volochaevskiy	3	34
24	Oktyabrskiy	3	44
25	Orlovskiy	3	59
26	Lvov	2–3	35
27	Zimovniki	2	87
28	V. Serebryanka	2	112
29	Grushevka	not felt	80
30	Verkholomov	not felt	114
31	Krasnoyarskiy	not felt	124
32	Volgodonsk	not felt	127
33	Verboviy Log	not felt	131
34	Podgorenskaya	not felt	134
35	Tsimlyansk	not felt	143
36	Aldabulsk	not felt	146

36 localities are presented in Table 3. Corresponding isoseismal map is shown in Figure 6.

Accuracy of intensity evaluation. As it has been mentioned, very limited time was available for macroseismic survey. Except visual inspection we distribute 7–10 questionnaires in each locality. Even though the localities generally are not large, assessments done on such small number of questionnaires has to be verified to have some accuracy evaluation. For this reason we chose by chance one locality (Ulyanovskoe) in which, after intensity assessment based on "standard" sample of 7 questionnaires, another 38 questionnaires were distributed additionally. Data processing of the larger sample did not change preliminary given intensity degree for this locality. Taking into account, that interval degrees were used to reflect uncertainty of interpretation, our intensity assessments are reasonably accurate.

Figure 5. Crack in plaster in separating brick wall on ground floor of two store brick building. Foto is taken in village Manichskiy. The intensity in this village is assessed to be 6.

Isoseismal map. Mean radius of 6-degree isoline is relatively large (about 20 km) compared with the one for 5 (40 km). Several reasons have to be considered. First of all, there might be some area with intensity 7 ground shaking within the 6 degree isoline, which could not be detected because the epicentral area is located in rarely populated place in salt marshes (Figure 7).

The other possible reason is that some local effects could be responsible for macroseismic effects in Manychskiy (it is located very close to the Manych riverbank). The local amplification in Manychskiy would result in artificial enlargement of intensity 6-isoline. Anyway macroseismic epicenter could be located rather accurately, we suppose within ±5-km accuracy. By the way, its position is near the one given by NEIC (difference in locations is about 5 km). Epicentral intensity (not observed one) is possibly within the range 6–7 degrees.

Elongation of 5-degree isoline toward Baraniki and N. Egorlyk could be explained by source geometry and rupturing directivity, or by local amplification effects due to the fact that these localities are situated on the riverbanks. Elongation of 4-degree isoline toward Salsk is in good agreement with the 5-degree isoline configuration. Indirectly, this talks about non-local character of the reasons, which conditioned the isoline configuration. Anyway, without going too deep in reasons, it could be stressed that the propagation of ground shaking in western and southern directions is more intensive. This also proved by the Emercom report, that the earthquake was felt in Stavropol with intensity 3–4 degree, which is in southern direction at ca. 150 km. Possibly both source and local effects contribute into forming of the specific features of the macroseismic field. It has to be noted that from the very general physical reasons the

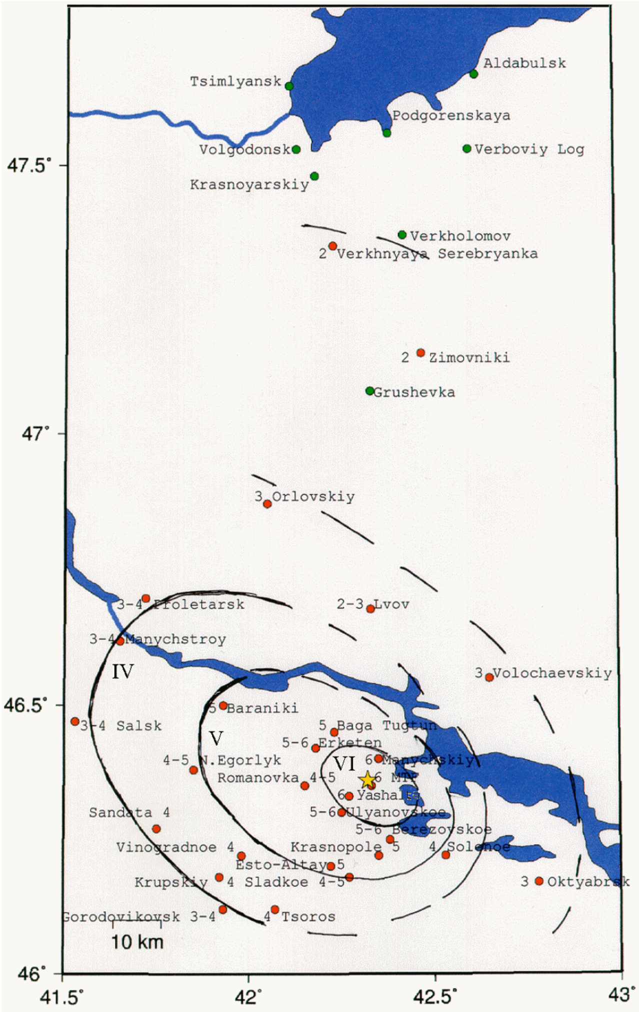

Figure 6. Isoseismal map of Salsk earthquake. Uncertain parts are shown in dashed line. Star indicates macroseismic epicenter. Green circles – not felt.

quality factor for the platform could not be less than for the Stavropol highland. But the distribution of macroseismic field is just opposite: the shaking is more intensive toward Stavropol highland. It means that there has to be some specific mechanisms, which controls wave propagation at least in "macroseismic" frequency band, different from, expected one. Accuracy of intensity evaluation also has to be kept in mind as possible "contributor" in forming distribution of macroseismic field, though the general features, which we are discussing here, are well enough established.

Because for the Stavropol highland the earthquake with magnitude 4.6 is not something especially important and because the Rostov NPP is to the North from epicenter we did not trace 4-degree isoline to the south with same accuracy as to the north. In the northern direction we also evaluate the distance at which intensity 3 and 2 were observed, and starting from where the shaking had not been felt.

Due to the fact that earthquake occurred late evening and most of the people were at home in rest (but yet not

Table 4. Intensity distribution from macroseismic epicenter toward Rostov NPP site

intensity, EMS98	mean distance, km
6	7.5
5	15
4	25
3	40
2	up to 110
not felt	from 120

sleeping), the shaking from it was felt at possibly maximum large distance for an event of that size. In certain sense it gives very conservative evaluation of hazard for the NPP site from the $M_S = 4.6$.

Finally, we got macroseismic epicenter of the Salsk earthquake of May 22, 2001, being 46.36°N, 42.32°E. Epicentral intensity is 6–7. Macroseismic hypocenter depth derived from epicentral intensity and magnitude is 9 km. Distribution of intensity from macroseismic epicenter toward the NPP site is given in Table 4.

Hypothetical historical earthquake. We would like to discuss some historical aspects of hazard assessment of the region related with the Salsk earthquake. First of all, let us remember that the Salsk earthquake is the largest in the region not only from all instrumentally recorded ones, but also for the whole known seismic history. But the problem is that reliable seismic history is rather short (not more than 150 years). This happens because of absence of permanent settlements in the region earlier. For example, Yashalta, closest to the epicenter locality, is going to celebrate its 125 anniversary in 2002. Salsk (former Torgovaya) was found in late 1800 when the railroad from Russia to Caucasus was built. Zimovniki, which is now a large town, was found in 1898. Occurrence of the Salsk earthquake with $M_S = 4.6$ in an area where such events were unknown in seismic his-

Figure 7. Epicentral area of the Salsk earthquake. This is an area of salt marshes lying to the South from Manych River. Because of the river, the water table is shallow.

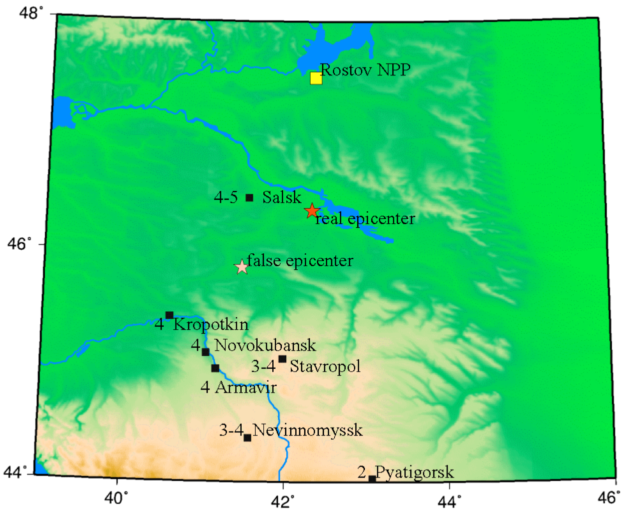

Figure 8. The hypothetical "historical" false earthquake which may appear in catalogue if only preliminary data on the Salsk earthquake will survive in future.

tory, let us suggest that the recurrence time of moderate size events is at least 150 years.

But the shortness of the history is obvious but not the only one problem related with historical aspect of hazard assessment. Initial data quality and interpretation contain background for even more severe errors. Let us make a mental experiment. Imagine, that the only information which will survive in historical time concerning Salsk earthquake, will be the information collected quickly after the event by Geophysical Service of RAS. This data is plotted in Figure 8. Its interpretation will lead to a falsequake with magnitude 5.4 located about 100 aside from its actual place. This illustrates that much care and critisizm have to be taken when dealing with historical data.

Conclusions

1. Known seismic history of southern parts of Russian platform is too short for reliable hazard evaluation. The recurrence time of moderate size ($M_S \approx 4.5$) is not less than 150 years.

2. Macroseismic survey is a powerful tool for moderate size earthquake parameter evaluation in low active regions with poor instrumental coverage.

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