The 2005 Alpha Earthquake Swarm, Valley County, Idaho

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Staff Report 07-3
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The 2005 Alpha Earthquake Swarm, Valley County, Idaho

Kenneth F Sprenke[1]
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Joshua L. Peterson[1]

SUMMARY

Beginning in September 2005, thousands of small earthquakes occurred near the community of Alpha in Valley County, Idaho. These events, five with magnitudes as high as 4, were centered about 16 kilometers south of Cascade, Idaho in the vicinity of Clear Creek. Although little damage has been reported, the events were widely felt, and caused considerable concern in the local population. The events appear to be very shallow, about 0-6 kilometers deep. Moment tensor solutions for four of the larger events in the swarm indicate a northwest-oriented direction of compression and a significant component of strike-slip on a previously unidentified fault possibly associated with the Alpha escarpment which separates Long Valley to the north and Round Valley to the south. The latest of the five larger events may have been triggered by stress relief from the other events. This latter event occurred several kilometers northwest of the others and showed a moment tensor consistent with normal faulting on the Long Valley fault. Microseismicity in the months after the main swarm appears to be clustered near the Alpha escarpment. The seismic energy release of this swarm tapered off by the first week of October, although numerous micro-earthquakes continued into November and several magnitude 3 events occurred in December. Some swarms develop into stronger swarms capable of significant building damage and about 10 % of major earthquakes in the western United States are preceded by foreshock swarms. The Idaho Geological Survey, with support from the Idaho Bureau of Homeland Security, is continuing to study the situation.

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INTRODUCTION

In September 2005, small earthquakes began near Alpha in west central Idaho (Figure 1). The ensuing swarm, the largest known to have occurred in western Idaho, was centered near the escarpment that separates Long Valley and Round Valley (Figure 2). In Alpha, a small community 14 km south of Cascade and some 100 km north of Boise, the shaking as reported by residents was most severe.

The swarm was preceded by three earthquakes several kilometers south of Alpha on September 3. The swarm began in earnest on September 21. By September 26, enough earthquakes were being felt that concern among local residents was rising along with media interest. Regional seismographs showed that both the rate of earthquakes and their maximum magnitude were increasing (Figure 3). The swarm reached its peak intensity between September 27 and October 2, when five earthquakes of about magnitude 4 occurred. Some slight damage occurred during the swarm peak, mainly foundation or slab cracks and objects knocked off shelves. Over ten thousand swarm events were large enough to be registered on regional seismographs. Seventeen had magnitudes larger than 3. Alpha area residents were feeling many shocks each day and experiencing minor damage.

The Idaho Geological Survey with support from the Idaho Bureau of Homeland Security, contracted with Northwest Geosensing to monitor the Alpha swarm. This report is a compilation and analysis of information on the 2005 Alpha swarm as provided by Northwest Geosensing (Zollweg, 2006a,b,c). Also included is a summary of additional information from the National Earthquake Information Center, the Montana Bureau of Mines and Geology Earthquake Studies Office, the Boise Regional Seismic Network, the Pacific Northwest Seismic Network, and the Saint Louis University Earthquake Center.

EARTHQUAKE SWARMS

While earthquake swarms are not uncommon in Idaho compared to other states, it is unusual to have so many events reported as felt in Idaho swarms (Zollweg, 2006a). Several of the 2005 earthquakes had larger magnitudes than any events observed in Long Valley since a M 4.5 event on November 27, 1977 and, before that, a M 4.3 event on October 15, 1950 (Figure 4).

Seismologists classify swarms in several ways (Zollweg, 2006a). Ordinary swarms have quakes up to the magnitude 4 range and cause only incidental damage. Strong swarms feature events with magnitudes up to 5 and have potential for building damage. Foreshock swarms are followed by a much larger earthquake and aftershocks.

Although earthquake swarms are a recognized precursor to larger earthquakes, most swarms are not foreshock swarms, and, in fact, most large earthquakes worldwide are not preceded by foreshock swarms. Foreshocks did not precede the largest events in the

Idaho region's history: the 1983 M6.9 Borah Peak event and the 1959 M7.3 Hebgen Lake earthquake. However, of 20 historic main shocks in the San Andreas system of California, seven were preceded by immediate foreshock sequences and of these seven, two had swarm-like appearances (Jones, 1984). Therefore, the occurrence of a swarm is certainly suggestive of increased seismic hazard.

LOCATION OF LARGER EVENTS

Table 1 shows the best available solutions for the hypocenters of the larger Cascade swarm events. These were determined using data from the Montana regional seismic network and available Idaho stations, particularly those of the Boise Regional Seismic Network. Also used were picks from Lincoln Mountain Oregon (LNO) and, significantly, Blue Mountains, Oregon (BMO). The maximum azimuthal gaps for these solutions were about 90 degrees. The locations of the larger events in the swarm clustered in a several square kilometer area about 11 km south of Cascade, Idaho (Figure 5).

During the swarm, there was much confusion about the location of the larger events. On their website, the National Earthquake Information Center (NEIC) located the earthquakes at Cascade or even farther north (Figure 5). However, Cascade residents reported feeling only the largest of the earthquakes, while Alpha area residents were feeling many shocks each day and experiencing damage (Zollweg, 2006c). The earthquakes actually were occurring in the area where they were the most intensely felt, near Alpha (Figure 6).

The NEIC locations were incorrect as a result of poor seismograph coverage by their national backbone network. The closest US Geological Survey (USGS) seismograph to the epicentral region was near Hailey, Idaho some 100 km to the east was not functional during much of the swarm. Except for BMO, the other USGS stations are much further from the swarm. The existing distribution of USGS backbone stations fails to adequately record events much smaller than magnitude 3 in west-central Idaho. Without the benefit of data from local stations and an appropriate regional velocity model the resulting USGS epicenter locations may be up to 10 km in error.

MAGNITUDE ESTIMATION

Magnitude estimates for the larger events in the swarm are given in Table 1. The first three estimates are a coda duration magnitude, Richter local magnitude determined from the Butte Wood-Anderson equivalent seismograph, and local magnitude determined from US National Seismic Network broadband stations. These three magnitude estimates, determined by the Montana Bureau of Mines and Geology (MBMG) Earthquake Studies Office agree to within 0.2 magnitude units of each other. The fourth estimate shown is the reported NEIC magnitude (MAG); the fifth is the moment magnitude estimated by Saint Louis University Earthquake Center, and the sixth estimate is an empirical coda scale based on the character of the received signal at the closest regional station (WHKI). Discrepancies of about a quarter to half a magnitude between estimates occurs as a result of different scaling used and different seismic velocity and wave attenuation models assumed for the region. In west-central Idaho, the magnitude determinations from MBMG seem to consistently be larger than the values reported by the USGS. The differences range from 0.4 to 0.8 magnitude units. Similar discrepancies between MBMG and USGS magnitudes occur for earthquakes throughout the Northern Rocky Mountain region.

The closest regional station WHKI provided the most complete available records of the swarm during its most intense period. Seismograms for these stations for the period Sept 22 to Oct 4 are reproduced in the appendix. Table 2 lists a catalog of the events with magnitudes of 1.5 or larger as estimated from these records. The magnitudes shown are coda magnitudes based on the character of the signal at WHKI. Figure 3 shows a plot showing the time sequence of magnitude during the intense period of the swarm. . Although several events above magnitude 3 were recorded as late as December 2005 (Table 1), the dominant energy release of the swarm ended by October 3.

Figure 7 depicts the daily number of events ($M>1.5$) and seismic energy release during the intense period of the swarm . It is interesting to note that over the period shown, the residents in the epicentral area were subjected to the energy equivalent to that of eighty one-ton bombs exploding four kilometers from their homes.

A magnitude-frequency plot (Figure 8) of the events during the intense period of the swarm indicates that some 17 events during the swarm exceeded magnitude 3 and over 100 events exceeded magnitude 2. For magnitudes between 4.0 and 2.7, the regression equation was found to be:

$$\text{Log } N = 4.398 - 1.005M$$

where N is the number of events of magnitude greater than M. The correlation coefficient was -0.994. Extrapolation of this logarithmic magnitude-frequency relationship suggests that some 25,000 events near magnitude 0 or larger occurred during the most intense period of the swarm.

Spectral analysis of the event frequency (Figure 9) suggests periodicities of 4.5 days, 32 hrs, and 10 hrs in the shaking during the swarm. The average 4.5 day interval between episodes of increased shaking is also apparent in the plot of daily number of events and magnitudes (Figure 3). No evidence in the spectral analysis was apparent of a tidal effect in the seismicity level during the swarm. Earth tidal forces would show a periodicity of about 12 hours.

FAULTS IN THE EPICENTRAL AREA

The swarm occurred at the southern end of the Long Valley. Long Valley is a structural graben complex which Highway 55 more or less follows south from McCall, through

Donnelly, and Cascade down to Alpha, Idaho. An escarpment immediately south of Alpha separates Long Valley from Round Valley to the south. Round Valley is a curious geomorphic feature some 60 feet in elevation above Long Valley with streams flowing toward its center in a radial drainage pattern. To retain such a drainage pattern, the escarpment between Long Valley and Round Valley is, geologically speaking, a youthful feature. Although this escarpment may be glacial, its linear appearance suggests that it is structural in origin.

The major faults in the area are shown in Figure 10. These faults are fully described, along with appropriate references, on the Map of Miocene and Younger Faults in Idaho (Breckenridge et al., 2003), and the descriptions of the faults discussed below are from that publication. More details on a gravity model and a proposed structural model of Long Valley can be found in Giorgis et. al. (2006).

Figure 11 shows a schematic cross-section across the Long Valley system . Cascade Reservoir occupies an asymmetric graben with its deeper western side lying along the east-dipping Long Valley fault. The eastern portion of Long Valley system is bounded by the east-dipping Cascade fault on the west and the west-dipping Alpha fault on the east (Kinoshita, 1962). The graben is filled with thousands of meters of glacial, alluvial, fluvial, and eolian deposits that are post-Miocene in age and which thin to hundreds of meters in the southern part of the valley. The structural graben is bounded on both sides by granitic basement rocks of the Idaho Batholith. To the east there is granite that has a two-mica-suite with a transition at the Long Valley fault to granite with tonalite and quartz diorite (Lewis, 2002).

The Long Valley fault is nearly 76 km in length and is broken into a north and a south sections with the respective lengths of 44 km and nearly 37 km and is considered to be amongst the most significant active faults in western Idaho. The fault trends nearly due north and dips east with some oblique movement to it as well. There is the possibility of somewhere between 4600 and 7000 meters of displacement along the fault. This estimate is based the distance from the valley floor and the Columbia River Basalts that are present on top of West Mountain. There are no recognized scarps in the Quaternary deposits but Quaternary movement is assumed to have occurred along this fault because of the character of the surface expression along the fault.

The Alpha fault is a single segment that is slightly over 14 km long. It is a normal fault that dips towards the west and has some oblique slip similar to the Long Valley fault. This fault bounds the swarm area on the east side and has a north-south trend as well. The displacement on this fault is much less, about 300 meters, than the displacement that occurs on the Long Valley fault. The ridge to the east of the fault has a much gentler slope then the face of West Mountain. There is not much information available on the Alpha fault since it is an understudied part of the Long Valley fault complex.

The Cascade fault is a high-angle down-to-the-east normal within the Long Valley graben complex. It coincides with steep gravity gradient; the adjoining valley to the east is a symmetrical graben with 900 m of Neogene sediments in contact with bedrock along the fault. The extension of the Cascade fault to the north is referred to as the Little Valley fault.

The West Round Valley fault is a down-to-the-east normal fault that bounds the west side of Round Valley. It features a 200 m escarpment that offsets Cretaceous granite. This border fault is an extension of the Long Valley fault south into the Round Valley structural system.

The North Fork Range fault is a down-to-the-west normal fault. The North Fork Range on east side of fault stands 300 m above floor of Round Valley. The North Fork Range fault forms the eastern border of Round Valley, analogous to the Alpha fault in Long Valley to the north.

MOMENT TENSOR SOLUTIONS

Saint Louis University Earthquake Center calculated moment tensor solutions for the five largest events (Table 3). In Figure 12, which shows the locations and associated fault-plane solutions, the compressional quadrants of the lower hemisphere equal-area stereograms are dark; the dilatational quadrants are light. The earliest four of the five larger events have oblique-reverse slip mechanisms with either left-lateral slip on north-northwest trending planes, or right-lateral slip on northeasterly trending faults. These events may originate along splay segments of the Long Valley fault system. The last of the large events occurs northwest of the earlier events and has a normal mechanism with a northwest-trending, moderately northeast-dipping nodal plane that is consistent with the expected dip-slip movement on Long Valley border faults. For the four oblique-reverse slip events, the P (compressional) axes are consistently oriented nearly horizontal in a WNW-ESE direction. For all events, the T (extensional) axes are oriented NE as is typical for seismicity in the northern Rocky Mountains.

In Figure 13 suggests a possible explanation of the two styles of slip indicated by the moment tensor solutions. Round valley sits on an upthrown block some 60 feet higher in elevation than Long Valley and has a separate drainage system. The escarpment between Long Valley and Round valley is possibly an eroded vertical fault. The first four large (near M4) events located near Alpha are consistent with right-lateral strike slip on northeast-trending faults, very possibly on the Alpha escarpment, which is the only northeast trending feature in the vicinity. Alternatively, the first four events may have occurred as left-lateral slip on north-northwesterly trending splays of the Long Valley fault. Regardless, northeastward extension at the southern end of the Long Valley would create extensional stress on the Long Valley fault, which, in the epicentral area, trends northwest. Thus the strike-slip of the earlier events may have triggered the last of the five large events, which exhibited normal dip-slip motion, down to the northeast, consistent with the geological history of motion along the Long Valley fault..

TEMPORARY LOCAL NETWORK

The intensity of the Alpha swarm, its unusual characteristics, and its possible precursory implications motivated the deployment of a temporary network in the epicentral region of the swarm. Existing regional seismograph networks are inadequate for providing sufficiently accurate epicenter locations or hypocenter depths to relate seismicity to fault structures. Accordingly, the Idaho Geological Survey with support from the Idaho Bureau of Homeland Security, contracted with Northwest Geosensing to install and operate a network of temporary seismograph stations in the epicentral area, and to analyze the resulting data.

The technical details of the temporary deployment are described in Zollweg (2006a). Table 4 lists the locations of temporary stations. Very high rates of microseismicity were observed. Accelerations as high as 0.015g were observed for earthquakes in the magnitude 2.5 range. Such accelerations are somewhat higher than expected for such small events. The unusually shallow depths of many events may help explain the high ground motions.

A preliminary analysis of the temporary network data for the Alpha earthquake swarm shows that the microseismicity is generally shallow (3-5 km) and located near the western side of Long Valley, possibly trending parallel to the valley edge (see Figure 6). The microseismicity seems to be generally south and east of Alpha whereas the main swarm event are located north and west of Alpha. Whether this represents a systematic error in the main swarm locations or an actual shift with time in seismicity is not known at present. However, it is most likely that the larger swarm events are located several kilometers too far northwest.

The epicenters of the microseismicity located by Northwest Geosensing cluster along the Alpha escarpment, the geomorphic feature separating Long Valley from Round Valley (Figure 14). The micro-earthquakes appear to be spatially consistent with the border faults of the valley, and seem to be occurring in the hanging wall of the Long Valley fault. A cross-section (Figure 15) through the northern portion of this cluster appears to suggest two fault planes consistent with or parallel to the orientation of the Long Valley fault. These faults dip at an angle of about 70^o beneath the valley north of Alpha. A fault parallel to the Long Valley fault and lying about one kilometer northeast of it is also visible in the microearthquake hypocenter distribution. Although not mapped at the surface, this fault is perhaps similar in orientation and style to the Cascade fault but extended into the epicentral area. However, much of the microseismicity, particularly in the southern portion of the cluster is very diffuse and not easily associated with any of the border faults. This seismicity might be associated with movement on the Alpha escarpment itself or on other unmapped splays of the Long Valley fault.

SEISMIC HAZARD

The involvement of the Long Valley fault in the Alpha swarm raises serious concern from an earthquake hazard standpoint (Zollweg, 2000c). Because of its length (37 km in its southern segment alone), the fault is capable of producing earthquakes as large as magnitude 7. The average recurrence rate of major earthquakes on the Long Valley fault is unknown, but probably is at least thousands of years. Nevertheless, design and operation of critical facilities in the Long Valley area should take the possibility of destructive earthquakes very seriously. Any Long Valley earthquake having a magnitude greater than about 6 is likely to cause local damage and at least minor building damage as far away as Boise.

With the present instrumental limitations of routine seismic monitoring in Idaho, it is regarded as a virtual certainty that immediate foreshocks to a major Long Valley earthquake would not be recorded or recognized as such. Had it been known in late September 2005 that many swarm events were occurring on the Long Valley fault itself, the level of concern of state emergency and disaster planning personnel would undoubtedly, and justifiably, been high (Zollweg, 2006c).

CONCLUSION

The 2005 Alpha swarm involved five events near magnitude 4 and some 25,000 earthquakes above magnitude zero. Several hundred events were felt, leading to considerable consternation by local residents. The first four of the five large events showed near horizontal compressional axes oriented northwest, suggestive of strike-slip on splays of the Long Valley fault. The last of the large events, on the other hand, showed normal dip-slip motion as might be expected on the Long Valley fault itself. This earthquake may have been triggered by the earlier swarm events. Microseismicity in the months after the main swarm events was clustered on the Alpha escarpment, the boundary between Long Valley and Round Valley, and appeared to be occurring in the hanging wall of the Long Valley fault.

The 2006 earthquake swarm in Valley County of western Idaho focused media attention on earthquake monitoring and response. State agencies responsible for response, mitigation, facilities, and scientific information responded to the Governor's Office request for overviews, briefings, and status reports. The Idaho Bureau of Homeland Security and the Idaho Geological Survey funded short term monitoring and analysis by Northwest Geosensing yet long-term monitoring capabilities remain inadequate.

More specifically, the Cascade events have highlighted the following points:
1) Poor state network coverage emphasizes the need for a readily deployable portable array and support mechanism to monitor earthquake swarms in areas of historical seismicity and poor network coverage.

2) More accurate immediate locations of events for study of geologic sources and impacts on critical facilities are needed. Spacing of the National Seismic Network stations was not sufficient to locate the events for planning and response needs requested by state and local agencies.
3) A state Seismic Safety Commission needs to be established to support earthquake and fault studies and network monitoring and articulate the earthquake hazard in Idaho.

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Table 1. Catalog of the larger events in the 2005 Alpha swarm. See text for description of magnitudes (M1-M6).

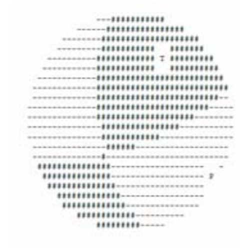
DATE			TIME			Lat	Long	D Km	M1	M2	M3	M4	M5	M6	Distance from Alpha	
05/	9 /	3	13	34	25.2	44.388	116.046	16	2.8						-0.4 km N	2.9 km W
05/	9 /	3	15	30	27.7	44.375	116.016	17	2.5						-1.8 km N	0.6 km W
05/	9 /	3	19	0	51.7	44.378	116.032	18	3	2.8					-1.5 km N	1.8 km W
05/	9 /	7	12	55	33.6	44.379	116.020	16	2.7						-1.4 km N	0.9 km W
05/	9 /	22	5	19	53.8	44.412	116.038	11	3.2	3.1		3.1		3.5	2.3 km N	2.3 km W
05/	9 /	23	2	23	29.5	44.439	116.023	7	3					2.8	5.2 km N	1.1 km W
05/	9 /	23	4	9	37.5	44.439	116.082	4	3	3.3		3.1		3.5	5.2 km N	5.7 km W
05/	9 /	23	18	2	4.2	44.407	116.034	12	3.5	3.5		3.2		3.5	1.7 km N	2.0 km W
05/	9 /	23	22	19	20.2	44.407	116.029	13	2.6					2.8	1.7 km N	1.6 km W
05/	9 /	24	5	11	56.2	44.418	116.045	12	3					3.3	2.9 km N	2.8 km W
05/	9 /	27	19	2	37.3	44.405	116.029	14	3.3	3.4				3.1	1.5 km N	1.6 km W
05/	9 /	27	20	55	19.2	44.407	116.037	13	3	3				3	1.7 km N	2.2 km W
05/	9 /	28	5	27	31.0	44.396	116.020	15	4.3	4.1	4.2	3.8	3.7	3.8	0.5 km N	0.9 km W
05/	9 /	28	8	7	6.5	44.400	116.028	13	3.1	3.2		2.6		2.9	1.0 km N	1.5 km W
05/	9 /	28	10	3	9.0	44.396	116.023	13	3.3	3.2				2.8	0.5 km N	1.1 km W
05/	9 /	28	10	13	28.1	44.410	116.022	13	3.2	3.2				2.8	2.1 km N	1.0 km W
05/	9 /	28	17	25	10.4	44.427	116.048	12	3.2	3				3.1	3.9 km N	3.1 km W
05/	9 /	28	18	28	58.2	44.419	116.031	12	3	2.9				2.9	3.0 km N	1.7 km W
05/	9 /	28	23	17	59.5	44.407	116.031	14		4.1	4.1	3.6	3.5	3.7	1.7 km N	1.7 km W
05/	9 /	28	23	20	44.7	44.402	116.020	13	4.2	4.3	4.4	3.8	3.5	3.9	1.2 km N	0.9 km W
05/	9 /	29	13	50	15.1	44.404	116.026	13	4.3	4.2	4.4	3.9	3.7	4	1.4 km N	1.3 km W
05/	9 /	29	15	8	34.4	44.420	116.038	14	3.3	3.4		2.9		3.1	3.2 km N	2.3 km W
05/	9 /	30	10	54	10.1	44.396	116.015	13	3.4	3.5		3		3.4	0.5 km N	0.5 km W
05/	9 /	30	14	59	35.7	44.426	116.032	14	3.5	3.8		3.5		3.6	3.8 km N	1.8 km W
05/	10 /	1	11	34	10.7	44.427	116.048	11	3.1	3.4				2.9	3.9 km N	3.1 km W
05/	10 /	2	1	10	1.1	44.418	116.049	12	4.2	4.3		3.8	3.8	4	2.9 km N	3.1 km W
05/	10 /	2	1	43	58.2	44.415	116.051	12	3.5	3.7		3		3.3	2.6 km N	3.3 km W
05/	10 /	2	7	18	25.9	44.408	116.031	14	3	3.1				2.9	1.8 km N	1.7 km W
05/	10 /	4	0	52	22.9	44.416	116.050	13	3.3	3.4		2.9		3.1	2.7 km N	3.2 km W
05/	10 /	19	17	55	58.2	44.401	116.012	12	3.1	3.1					1.1 km N	0.2 km W
05/	11 /	17	6	35	55.5	44.400	116.048	12	2.8						1.0 km N	3.1 km W
05/	12 /	11	19	48	29.0	44.407	116.023	15	2.9		3.3				1.7 km N	1.1 km W
05/	12 /	26	2	42	0.4	44.413	116.030	12	3.3	3.2	3.4	2.7			2.4 km N	1.7 km W
05/	12 /	27	22	3	11.5	44.399	116.018	13	3.2	3.2	3.4	3.2			0.8 km N	0.7 km W

Table 2 Moment Tensor Solutions available from the Saint Louis University Earthquake Center http://mnw.eas.slu.edu/Earthquake_Center.

Date	**Time**	**Location**		**D**	**Mw**	**Id**
2005/09/28	05:27:32	44.60N	116.07W	5.	3.7	20050928052732

Plane	**Strike**	**Dip**	**Rake**
NP1	71	72	154
NP2	170	65	20

Axis	**Value**	**Plunge**	**Azimuth**
T	6.46e+21	31	29
N	0.00e+00	58	219
P	-6.46e+21	5	122



Mechanism: Right-lateral and reverse slip on steep N71E fault or left-lateral and reverse slip on steep N10W fault.

Date	**Time**	**Location**		**D**	**Mw**	**Id**
2005/09/28	23:18:00	44.56N	115.99W	5.	3.5	20050928231800

Plane	**Strike**	**Dip**	**Rake**
NP1	250	90	-140
NP2	160	50	0

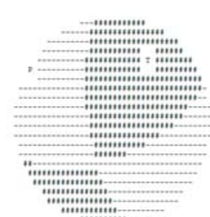
Axis	**Value**	**Plunge**	**Azimuth**
T	3.24e+21	27	17
N	0.00e+00	50	250
P	-3.24e+21	27	123

Mechanism: Right-lateral and vertical slip on vertical N70E fault or pure left-lateral slip on moderately dipping N20W fault.

Date	**Time**	**Location**		**D**	**Mw**	**Id**
2005/09/28	23:20:45	44.61N	116.05W	5.	3.5	20050928232045

Plane	**Strike**	**Dip**	**Rake**
NP1	170	70	30
NP2	69	62	157

Axis	**Value**	**Plunge**	**Azimuth**
T	5.43e+21	35	32
N	0.00e+00	54	201
P	-5.43e+21	5	298



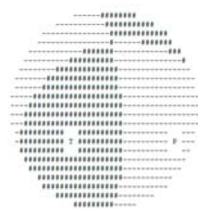
Mechanism: Right-lateral and reverse slip on steep N69E fault or left-lateral and reverse slip on steep N10W fault.

Table 2 (cont.) Moment Tensor Solutions available from the Saint Louis University Earthquake Center http://mnw.eas.slu.edu/Earthquake_Center.

Date	**Time**	**Location**		**D**	**Mw**	**Id**
2005/09/29	13:50:15	44.49N	116.06W	5.	3.7	20050929135015

Plane	**Strike**	**Dip**	**Rake**
NP1	355	75	55
NP2	245	38	155

Axis	**Value**	**Plunge**	**Azimuth**
T	6.68e+21	48	228
N	0.00e+00	34	5
P	-6.68e+21	22	111



Mechanism: Right-lateral and reverse slip on gently dipping N65E fault or left-lateral and reverse slip on steep N5W fault.

Date	**Time**	**Location**		**D**	**Mw**	**Id**
2005/10/02	01:10:01	44.54N	115.99W	5.	3.8	20051002011001

Plane	**Strike**	**Dip**	**Rake**
NP1	302	63	-104
NP2	150	30	-65

Axis	**Value**	**Plunge**	**Azimuth**
T	6.46e+21	17	42
N	0.00e+00	12	308
P	-6.46e+21	69	184

Mechanism: Normal slip on steep N30W fault down to the west or on N58W gently dipping fault down to the east..

Table 3. Approximate arrival times and coda magnitudes of the 2005 Alpha swarm events as recorded at (WHKI) the nearest regional station at an epicentral distance of about 100 km.

DATE	TIME hr m s	M	DATE	TIME hr m s	M	DATE	TIME hr m s	M	DATE	TIME hr m s	M
05 9 22	51950	3.5	05 9 27	203045	1.9	05 9 28	212107	1.7	05 10 2	11008	4.0
05 9 22	231738	1.8	05 9 27	203046	1.9	05 9 28	212358	2.1	05 10 2	11335	1.5
05 9 22	232229	1.9	05 9 27	205526	3.0	05 9 28	212933	2.1	05 10 2	11516	1.8
05 9 23	22336	2.8	05 9 27	205722	2.1	05 9 28	214015	1.5	05 10 2	11557	1.8
05 9 23	22418	2.8	05 9 27	210940	1.8	05 9 28	215225	1.8	05 10 2	11808	1.7
05 9 23	22509	2.7	05 9 27	211300	1.7	05 9 28	220557	1.8	05 10 2	12956	1.8
05 9 23	22554	1.7	05 9 27	211300	1.9	05 9 28	222416	1.7	05 10 2	13108	2.1
05 9 23	33814	1.6	05 9 27	222632	2.1	05 9 28	230930	2.1	05 10 2	14406	3.3
05 9 23	40934	3.5	05 9 27	223712	1.9	05 9 28	231046	1.9	05 10 2	14612	1.5
05 9 23	41355	1.6	05 9 27	224211	2.7	05 9 28	231806	3.7	05 10 2	15747	1.8
05 9 23	44620	1.6	05 9 27	224412	2.1	05 9 28	232027	2.1	05 10 2	15858	2.8
05 9 23	63421	1.9	05 9 28	1605	2.6	05 9 28	232052	3.9	05 10 2	20045	1.5
05 9 23	63453	1.6	05 9 28	1900	2.1	05 9 28	232225	2.6	05 10 2	20512	1.7
05 9 23	84540	1.5	05 9 28	2210	1.5	05 9 28	232620	2.5	05 10 2	20638	1.5
05 9 23	93620	1.5	05 9 28	2452	1.5	05 9 28	233403	1.8	05 10 2	20954	2.0
05 9 23	180212	3.5	05 9 28	4649	1.5	05 9 28	233520	1.7	05 10 2	23803	1.5
05 9 23	180650	1.8	05 9 28	12959	2.1	05 9 28	234631	1.6	05 10 2	24326	2.1
05 9 23	180655	1.8	05 9 28	23057	1.7	05 9 28	235244	1.6	05 10 2	24350	1.5
05 9 23	180818	1.6	05 9 28	24200	1.5	05 9 29	3730	1.9	05 10 2	32830	1.7
05 9 23	200304	1.5	05 9 28	24241	1.6	05 9 29	10518	1.7	05 10 2	33803	1.5
05 9 23	221929	2.8	05 9 28	31305	1.9	05 9 29	13418	1.8	05 10 2	71833	2.9
05 9 23	224349	2.7	05 9 28	31707	1.8	05 9 29	13833	1.5	05 10 2	100902	1.7
05 9 23	230543	2.1	05 9 28	32548	1.7	05 9 29	24113	2.1	05 10 2	130058	1.8
05 9 23	231254	1.5	05 9 28	32827	1.5	05 9 29	25252	1.5	05 10 2	170254	1.9
05 9 24	50916	2.3	05 9 28	50010	1.5	05 9 29	30515	1.9	05 10 2	170324	1.8
05 9 24	51002	2.2	05 9 28	52517	2.1	05 9 29	32118	1.5	05 10 2	170350	1.9
05 9 24	51204	3.3	05 9 28	52738	3.8	05 9 29	40034	1.6	05 10 2	172851	1.8
05 9 24	51238	2.7	05 9 28	52956	1.9	05 9 29	40205	1.8	05 10 2	173113	1.6
05 9 24	55422	1.9	05 9 28	53010	1.9	05 9 29	40210	1.7	05 10 2	173247	1.6
05 9 24	55916	1.5	05 9 28	53445	2.7	05 9 29	42442	1.9	05 10 2	201727	1.8
05 9 24	121605	1.5	05 9 28	53552	1.9	05 9 29	55052	1.6	05 10 3	550	2.9
05 9 24	122057	1.5	05 9 28	53618	2.1	05 9 29	55057	1.6	05 10 3	5313	2.3
05 9 24	180920	2.1	05 9 28	54339	2.7	05 9 29	62200	1.5	05 10 3	23754	1.5
05 9 24	225301	1.7	05 9 28	60228	2.1	05 9 29	71332	2.0	05 10 3	35118	2.1
05 9 25	30358	1.6	05 9 28	62452	1.6	05 9 29	82321	2.0	05 10 3	163741	1.5
05 9 25	41220	1.5	05 9 28	62745	2.7	05 9 29	95508	2.9	05 10 3	164603	1.8
05 9 25	53753	1.7	05 9 28	63432	1.7	05 9 29	95750	1.7	05 10 3	164619	1.7
05 9 25	53810	1.9	05 9 28	64630	1.5	05 9 29	101036	2.5	05 10 3	183534	2.0
05 9 25	54313	1.6	05 9 28	71106	1.5	05 9 29	113234	1.5	05 10 3	200134	1.8
05 9 25	180323	1.8	05 9 28	73143	1.6	05 9 29	113421	2.5	05 10 3	215628	2.0
05 9 25	181139	1.5	05 9 28	73218	1.7	05 9 29	131648	1.9	05 10 4	2454	1.6
05 9 25	182610	2.8	05 9 28	75718	2.1	05 9 29	135022	4.0	05 10 4	5230	3.1
05 9 25	183153	1.5	05 9 28	80713	2.9	05 9 29	140108	2.7	05 10 4	20034	2.0
05 9 25	191219	2.1	05 9 28	80855	1.8	05 9 29	140229	1.5	05 10 4	73142	1.6

DATE			TIME hr m s	M
05	9	26	23313	3.3
05	9	26	23435	1.7
05	9	26	23540	1.5
05	9	26	23828	2.9
05	9	26	23928	2.7
05	9	26	24517	1.5
05	9	26	33302	1.9
05	9	26	34908	1.6
05	9	26	44326	1.9
05	9	26	50952	1.9
05	9	26	92550	1.7
05	9	26	93146	1.5
05	9	26	110951	2.1
05	9	26	115248	2.0
05	9	26	121006	1.8
05	9	26	134153	1.6
05	9	26	140115	1.5
05	9	26	205725	1.5
05	9	26	215513	2.5
05	9	26	223052	2.1
05	9	27	12654	2.6
05	9	27	12734	2.4
05	9	27	13403	1.7
05	9	27	64124	1.9
05	9	27	64157	1.6
05	9	27	65039	1.6
05	9	27	82437	1.5
05	9	27	102707	1.9
05	9	27	111855	1.7
05	9	27	125638	1.8
05	9	27	174826	2.8
05	9	27	175105	1.8
05	9	27	190133	1.8
05	9	27	190244	3.1
05	9	27	190402	1.9
05	9	27	191306	1.5
05	9	28	100316	2.8
05	9	28	101307	2.1
05	9	28	101334	2.8
05	9	28	101509	2.1
05	9	28	101640	1.6
05	9	28	102224	1.5
05	9	28	124030	1.6
05	9	28	124446	1.8
05	9	28	134145	2.1
05	9	28	134350	1.5
05	9	28	135417	1.7
05	9	28	141131	1.5
05	9	28	151257	1.5
05	9	28	151517	1.5
05	9	28	152133	2.4
05	9	28	153022	1.7
05	9	28	160750	2.1
05	9	28	161245	1.5
05	9	28	163708	2.1
05	9	28	164400	1.7
05	9	28	165132	1.7
05	9	28	165640	1.8
05	9	28	165826	1.6
05	9	28	172510	3.1
05	9	28	173317	2.6
05	9	28	173320	2.1
05	9	28	173324	2.0
05	9	28	173701	2.1
05	9	28	173824	2.1
05	9	28	173828	2.1
05	9	28	174435	1.8
05	9	28	182905	2.9
05	9	28	190748	2.1
05	9	28	195657	1.8
05	9	28	200910	1.7
05	9	28	203508	2.1
05	9	28	204737	1.7
05	9	28	211602	2.6
05	9	29	140547	1.8
05	9	29	141716	2.9
05	9	29	142054	1.8
05	9	29	145403	1.9
05	9	29	150842	3.1
05	9	29	150931	2.3
05	9	29	155350	2.3
05	9	29	194245	1.5
05	9	29	222219	1.9
05	9	29	231240	1.5
05	9	30	2506	3.1
05	9	30	33943	1.8
05	9	30	63213	1.8
05	9	30	63256	1.9
05	9	30	63334	1.9
05	9	30	73217	1.9
05	9	30	80240	1.9
05	9	30	81411	1.5
05	9	30	91441	2.3
05	9	30	105417	3.4
05	9	30	145910	2.8
05	9	30	145943	3.6
05	9	30	152825	2.1
05	9	30	185540	1.8
05	9	30	233255	1.8
05	9	30	233315	1.8
05	10	1	458	2.0
05	10	1	104053	1.9
05	10	1	105240	1.5
05	10	1	110555	1.5
05	10	1	113246	2.9
05	10	1	113418	2.9
05	10	1	113720	2.7
05	10	1	131336	2.7
05	10	1	131441	2.8
05	10	1	135038	2.5
05	10	1	141302	1.8
05	10	2	458	1.9
05	10	4	162819	1.9
05	10	5	14850	1.6
05	10	5	22703	2.0
05	10	5	23213	2.7
05	10	5	50804	1.8
05	10	5	235526	1.5
05	10	6	105251	1.5
05	10	6	105252	1.5
05	10	6	184809	1.7
05	10	6	184809	1.5
05	10	6	184825	1.8
05	10	6	184825	1.5
05	10	6	201129	1.5
05	10	6	201923	2.1
05	10	6	201952	2.1
05	10	6	201958	2.1
05	10	6	202032	1.6
05	10	6	202032	2.1
05	10	6	202100	1.9
05	10	6	202100	1.5
05	10	6	202138	1.9
05	10	6	202138	2.1
05	10	6	203748	1.6
05	10	6	203756	1.5
05	10	6	203757	1.5
05	10	7	63630	1.5
05	10	7	162815	1.6
05	10	8	88036	1.8
05	10	8	144512	1.6
05	10	8	153250	1.6
05	10	8	153624	2.8
05	10	8	154735	2.9
05	10	8	211250	1.5
05	10	8	211255	1.5
05	10	9	181944	2.1
05	10	9	210405	1.5
05	10	9	211443	1.8

Table 4. Temporary Stations operated by Northwest Geosensing, 2005 Alpha Swarm.

STATION	LAT N	LON W	START END	INSTRUMENT
JAR	44 23.29	116 00.58	10/03/05-	3-C accelerometer
LVCS	44 30.93	116 02.76	10/07/05-11/04/05	3-C accelerometer
EMR	44 23.43	115 58.85	10/09/05-10/28/05	1-C smoked drum
			10/28/05-	3-C geophone
SUM	44 21.49	115 59.45	10/09/05-10/28/05	1-C smoked drum
			10/28/05-	3-C geophone
CRL	44 26.10	115 58.33	10/21/05-12/01/05	3-C broadband
SQP	44 17.89	116 01.01	10/20/05-03/02/06	3-C broadband
MFP	44 11.68	115 56.25	11/14/05-12/02/05	3-C broadband
PCR	44 27.97	116 02.73	02/11/06-03/02/06	3-C broadband

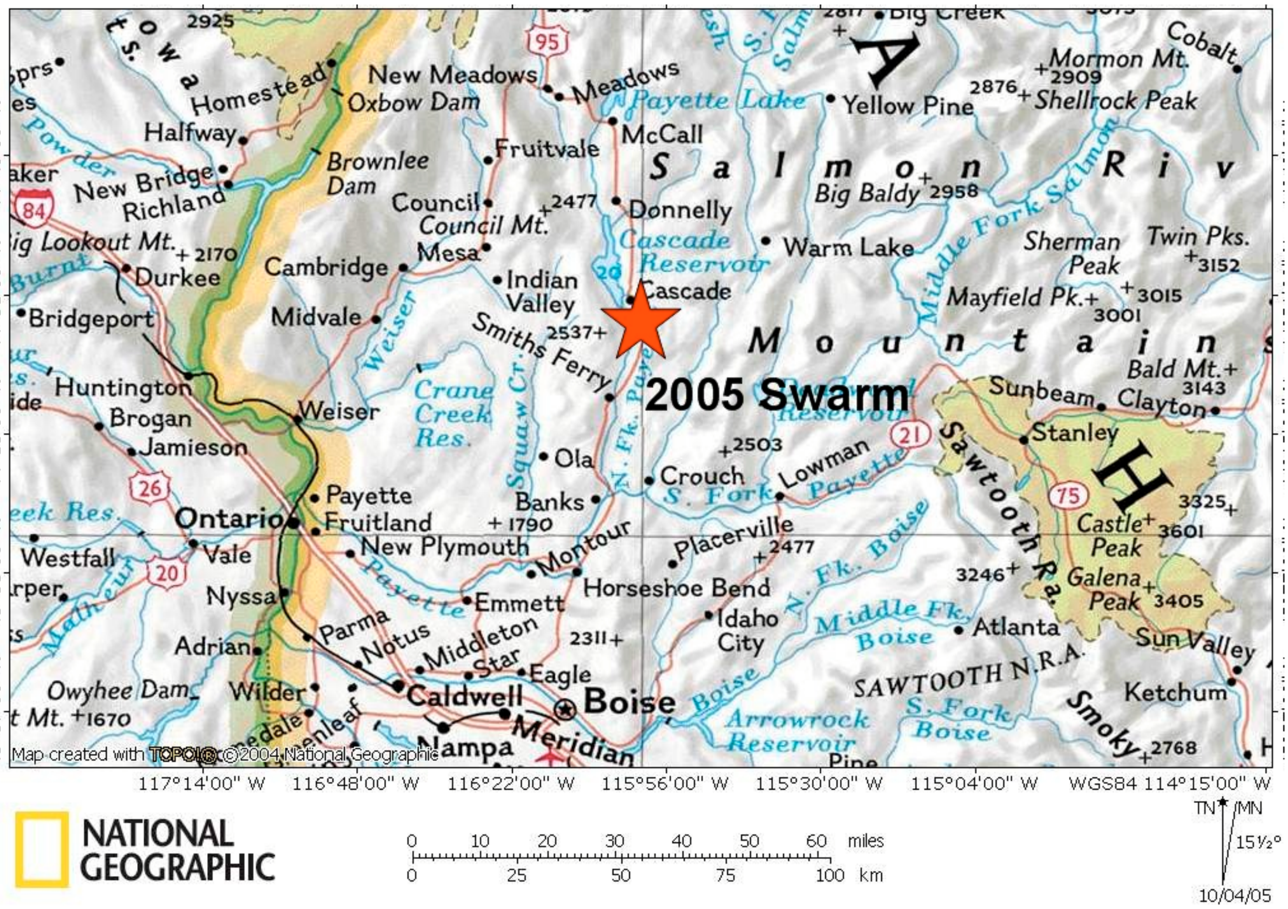


Figure 1. Location map for the 2005 Alpha swarm.

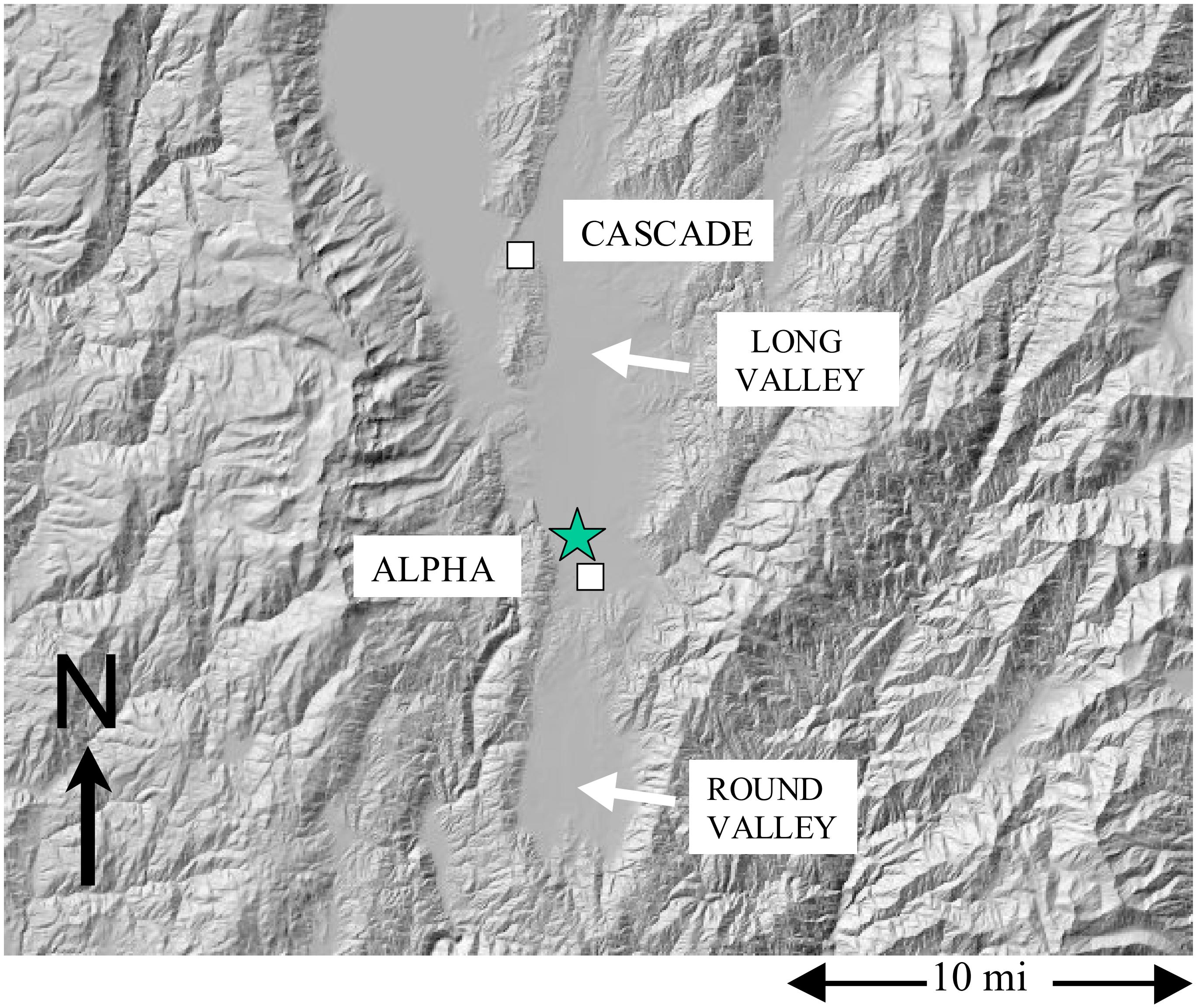


Figure 2. Shaded relief map of the Alpha Idaho area. The star shows the general epicentral area.

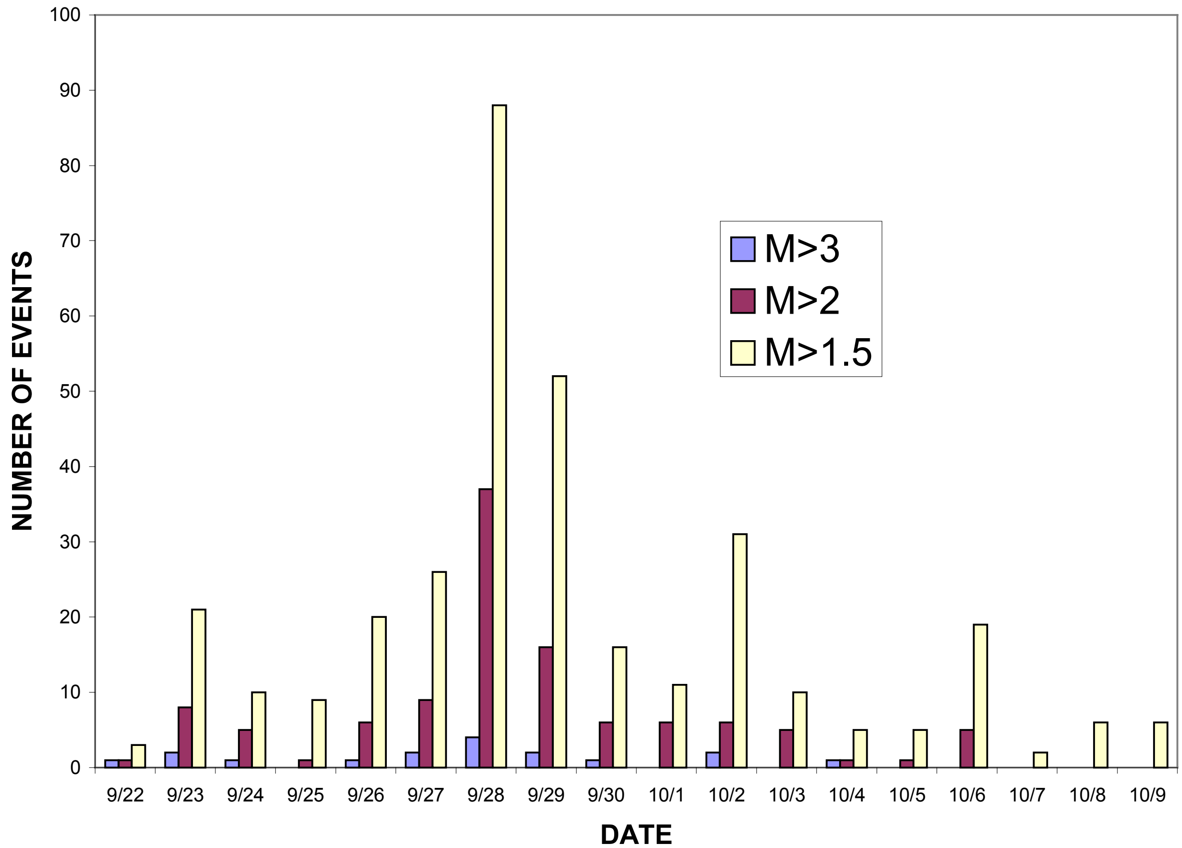


Figure 3. The daily number of events and their magnitude during the most intense period of the swarm.

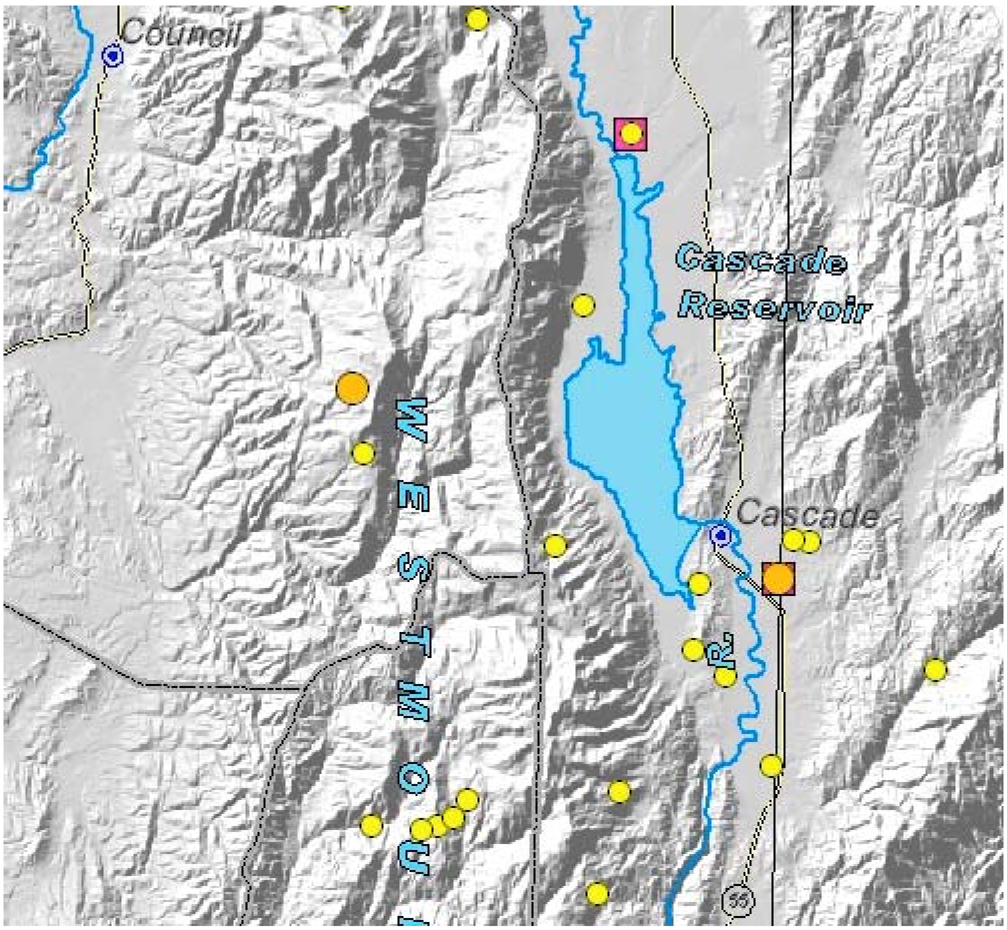


Figure 4. Historical seismicity in the Cascade area prior to the 2005 swarm. The two orange dots are in the M4-M5 range. The epicentral locations are probably no better than 10-20 km. Modified from Idaho Geological Survey (2006).

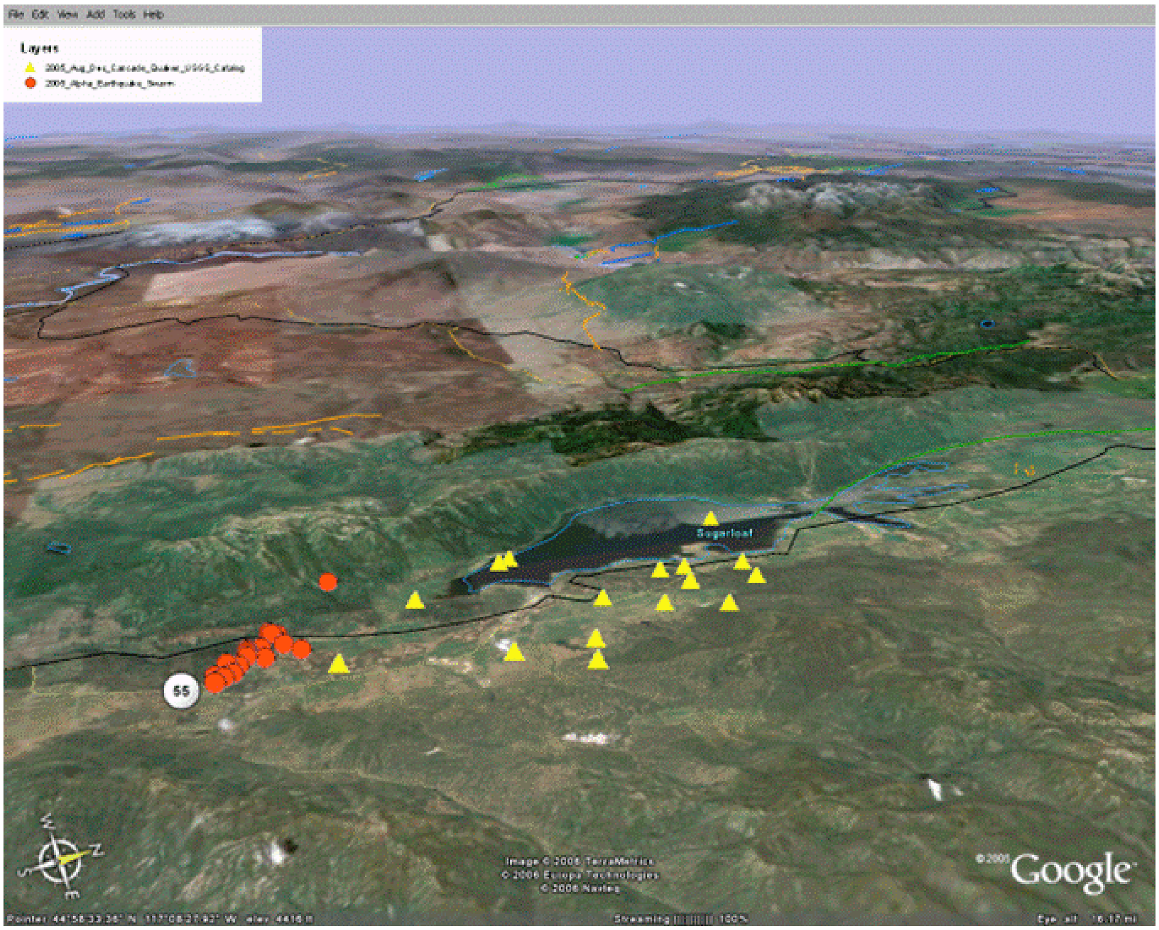


Figure 5. The red dots show the best available locations of the larger events in the 2005 swarm. Cascade reservoir is in the center of the photo. Alpha Idaho is close to the large white circle (HW 55). The yellow triangles show the misleading preliminary locations of the same events as issued by the National Earthquake Information Center.

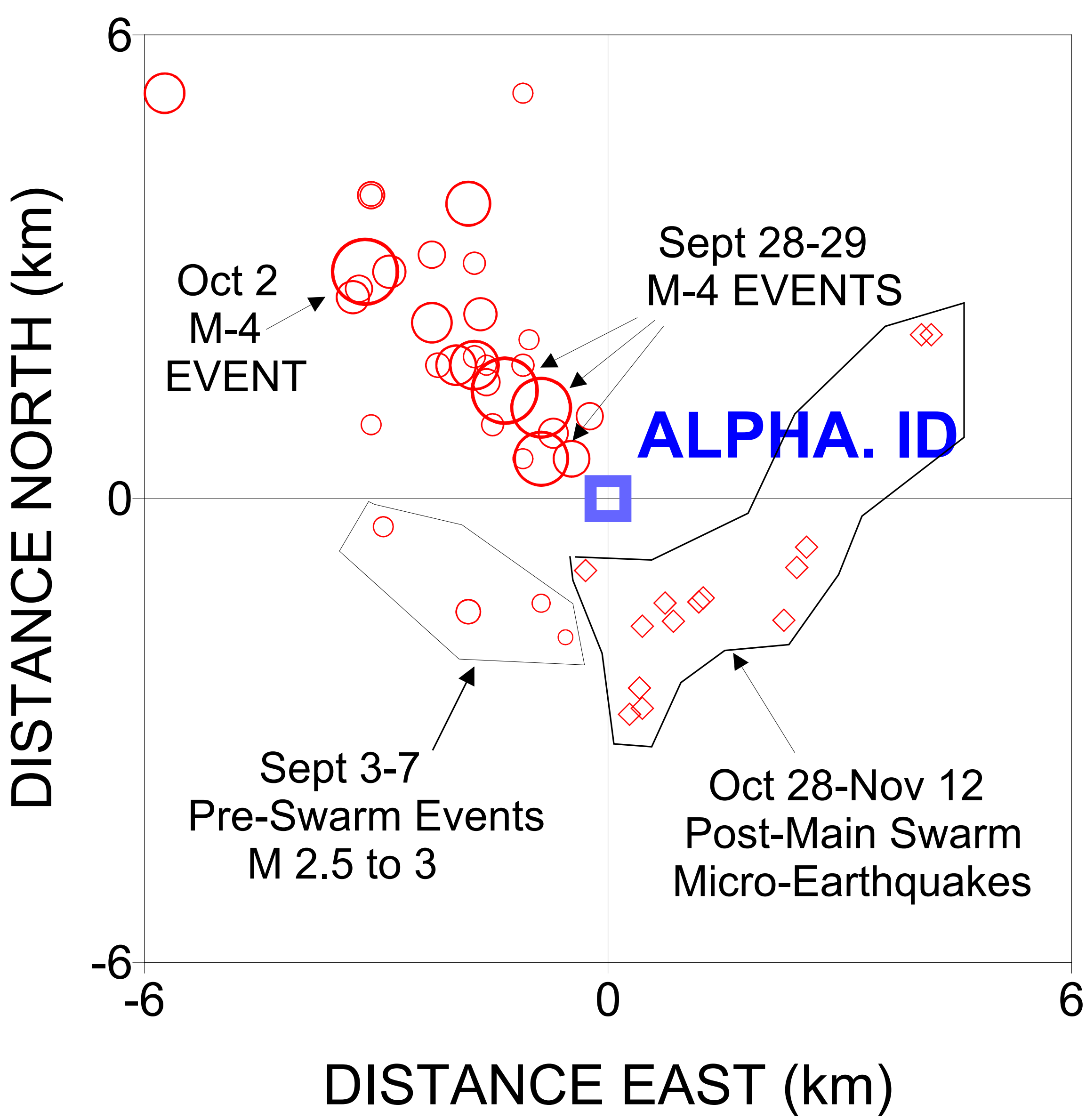


Figure 6. Location of epicenters relative to Alpha, Idaho. Alpha is located at latitude 49.3913 degrees N and longitude 116.0090 degrees W. Microseismicity epicenters from Zollweg (2006b). All other epicenters from the Montana Bureau of Mines and Geology catalog.

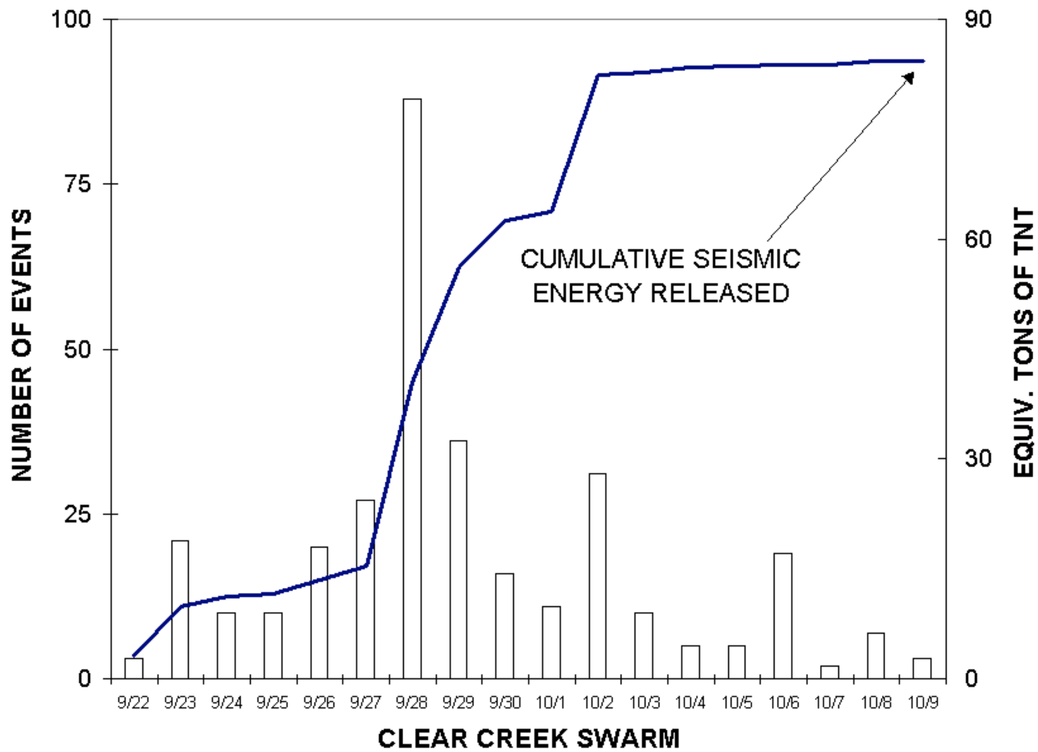


Figure 7. The daily number of events M>1.5 and the cumulative seismic energy release during the most intense period of the 2005 Alpha swarm.

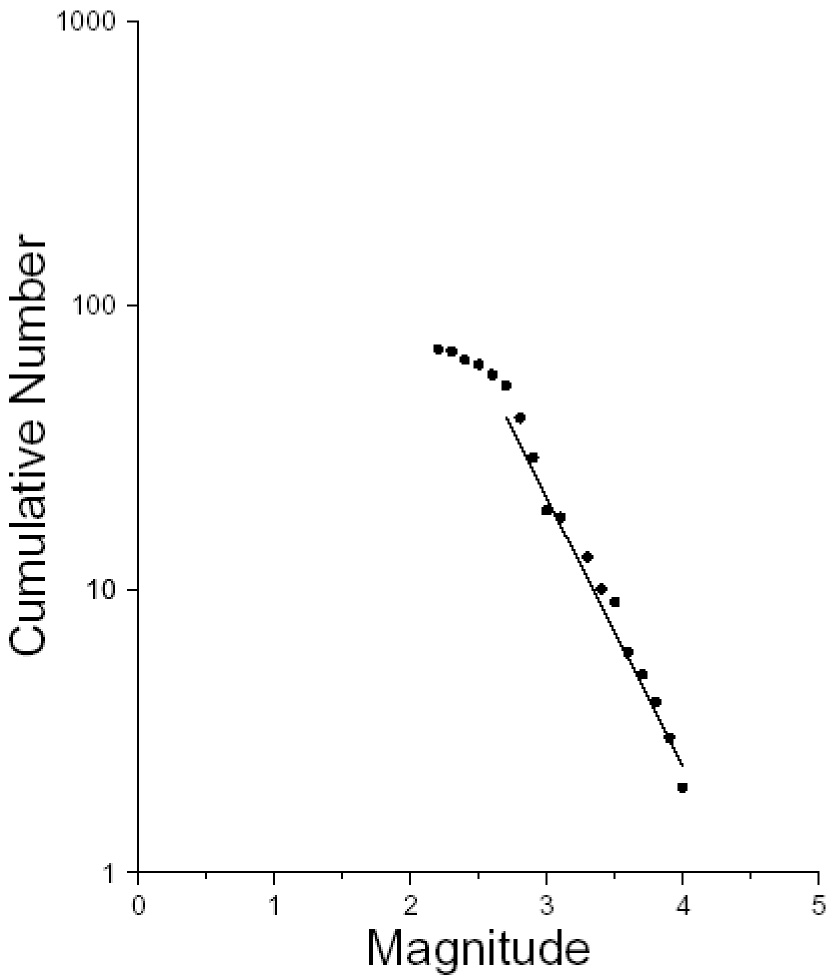


Figure 8. Magnitude-frequency plot for the events greater than magnitude two as recorded at the nearest regional seismograph WHKI during the intense period of the swarm (Sept 22 – Oct 4). The trend line on the graph suggests that some 25,000 events of about magnitude zero or greater occurred during this period.

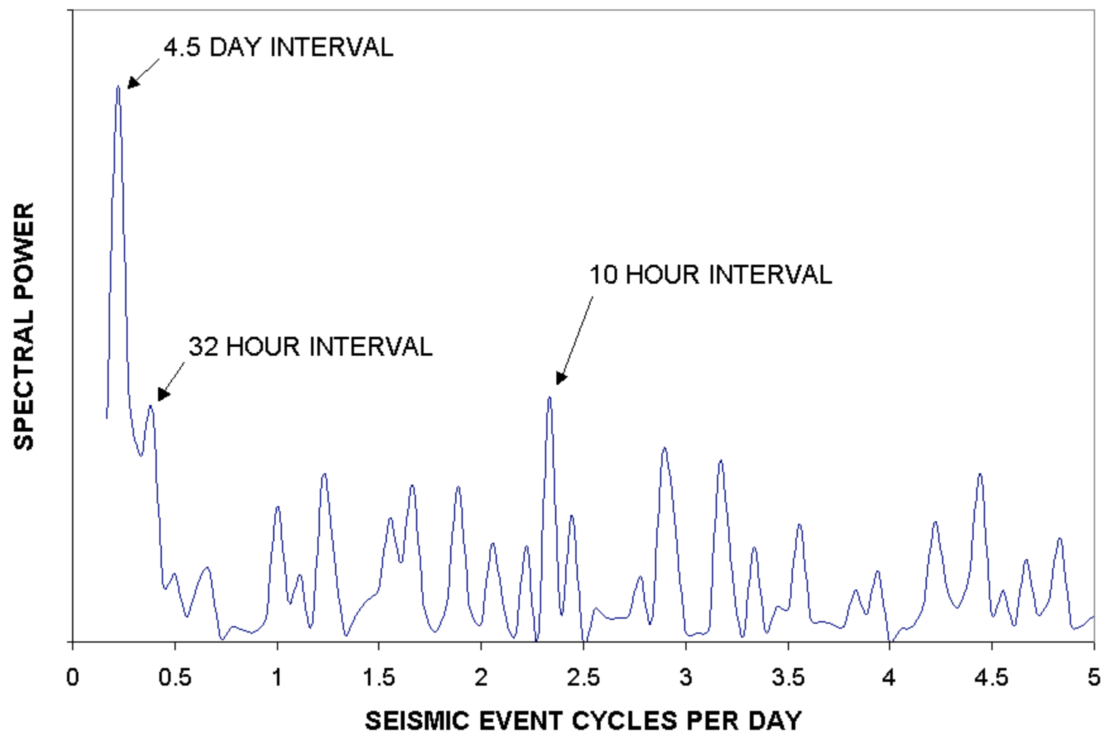


Figure 9. Spectrum of seismic event occurrence during the most intense period of the 2005 Alpha swarm. Peaks on the spectrum indicate the average time intervals between events.

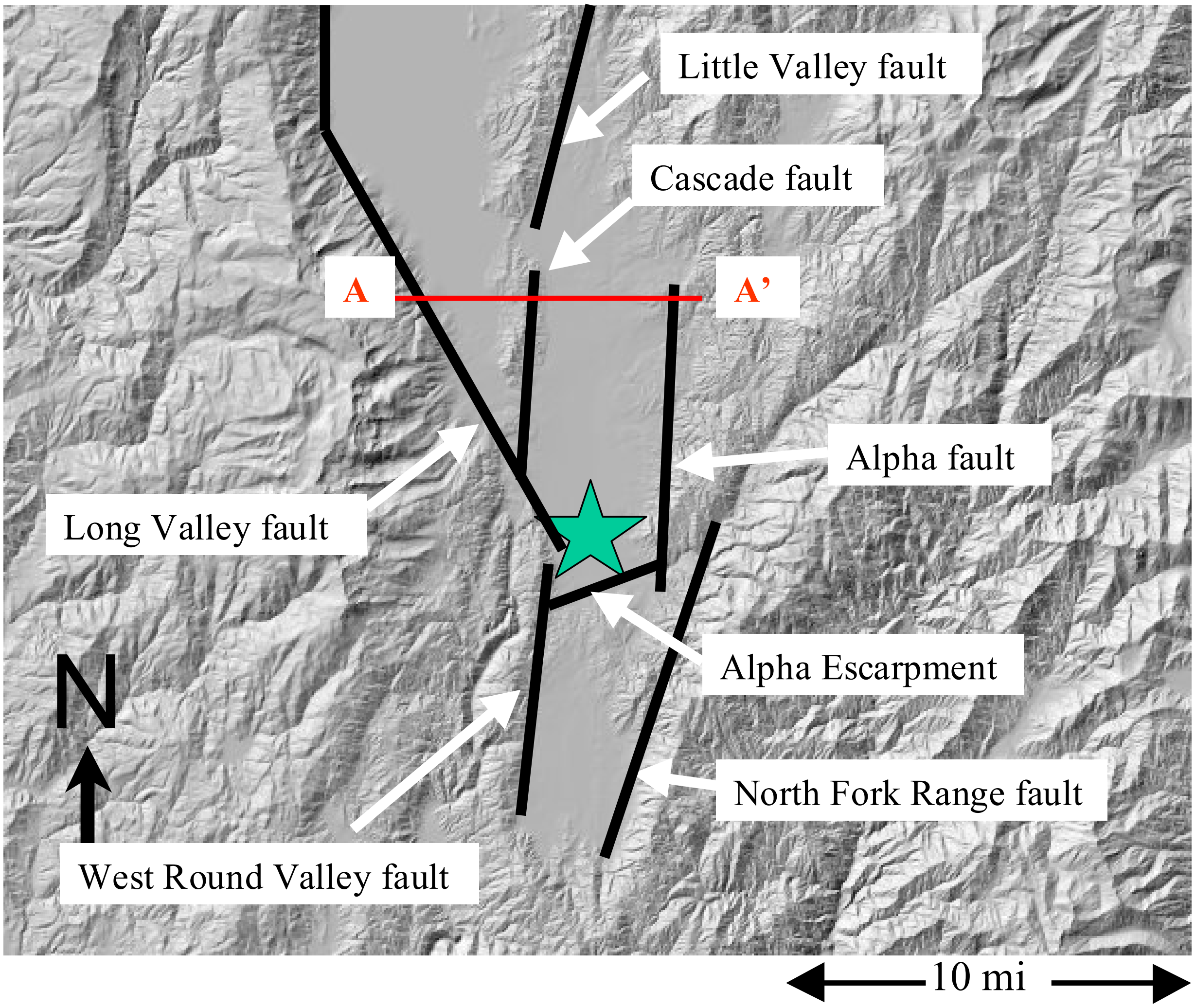


Figure 10. Faults (black lines) in the vicinity of the epicentral area (green star) of the Alpha swarm. The major Long Valley fault borders the west side of Long Valley, transitioning into the West Round Valley fault.; the Alpha fault borders the east side of Long Valley and transitions into the North Fork Range fault which borders the east side of Round Valley. The Cascade Fault is an intra-graben normal fault dipping east. The Alpha escarpment separates Long Valley from Round Valley.

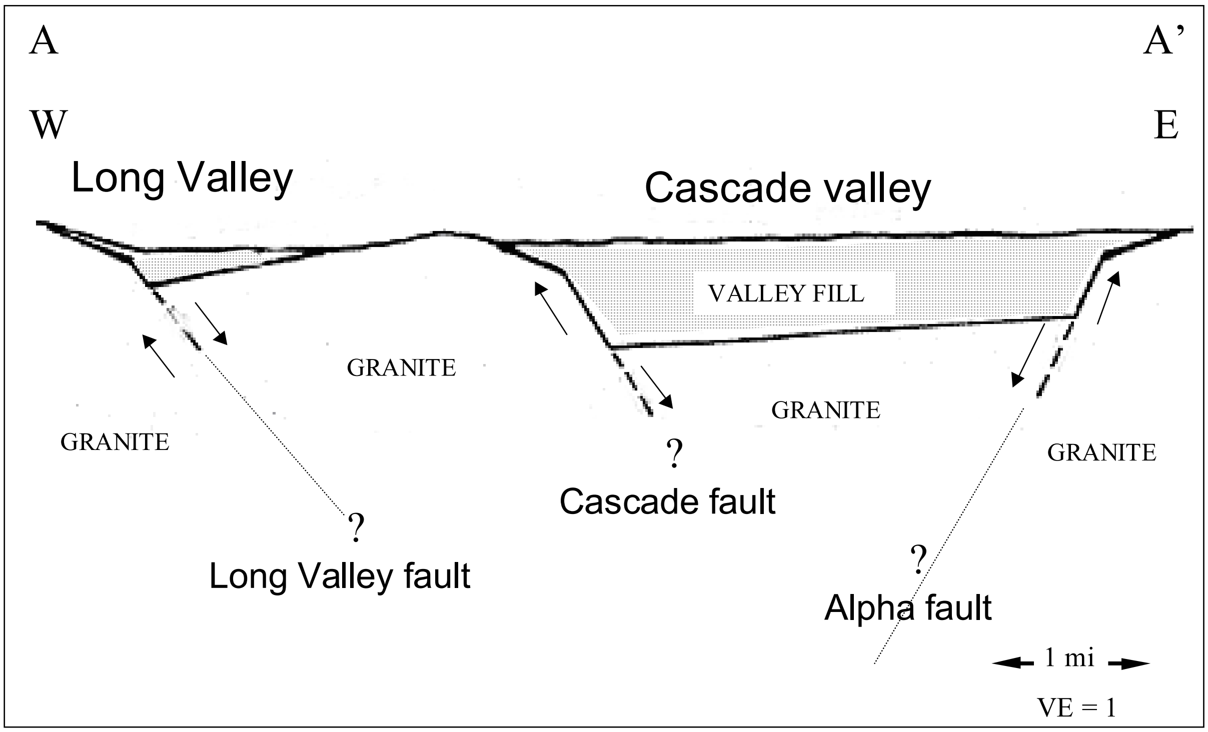


Figure 11. Schematic E-W cross-section across the Long Valley structural graben near Cascade, Idaho. See Figure 10 for location of section.

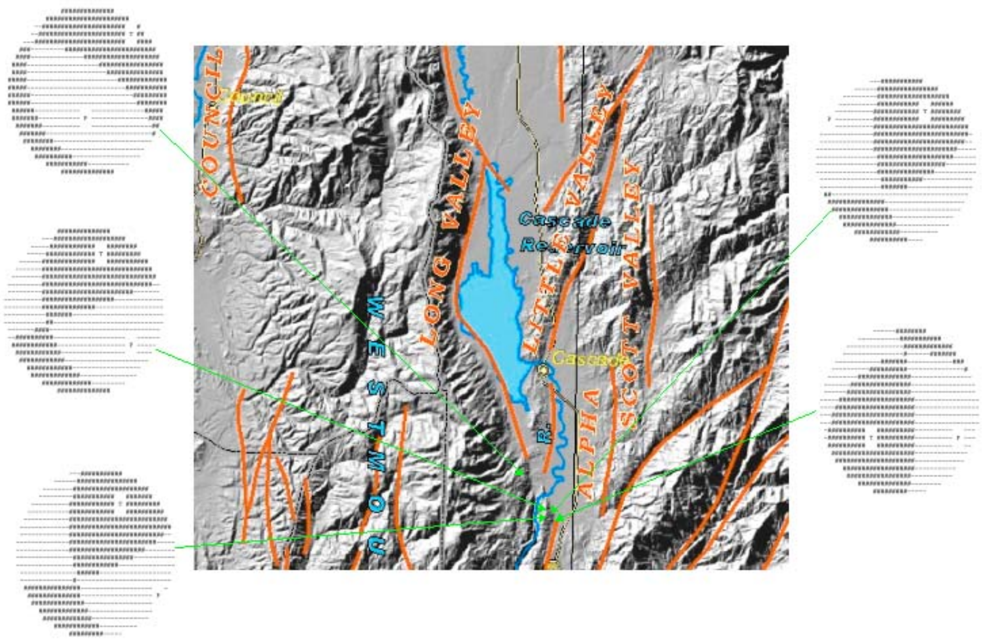


Figure 12. Fault plane solutions computed for the five largest events of the 2005 swarm. The event in the upper left is a simple normal fault. The other four events are oblique reverse faults representing either left-lateral movement on northerly striking faults or right-lateral movement on northeasterly striking faults. Moment tensor solutions are by the Saint Louis University Earthquake Center.

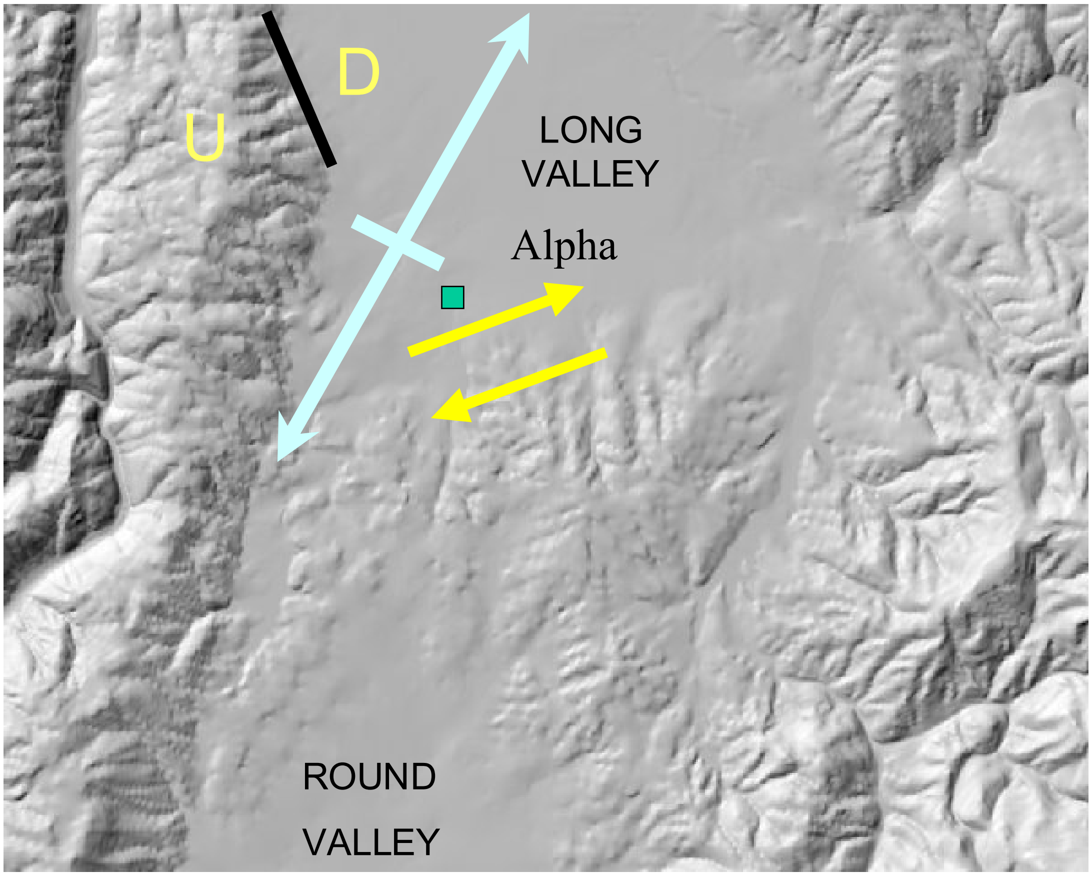


Figure 13. Shaded relief map, five miles across, of the Alpha, Idaho vicinity. North is toward the top. The moment tensor solutions of the first four large earthquakes in the swarm were located near Alpha and all showed right-lateral strike slip motion on a northeasterly trending fault. This transverse slip was probably on the fault causing the escarpment and is indicated by the yellow arrows. The last large earthquake in the swarm was located several kilometers northwest of Alpha. The moment tensor of this event indicated normal dip-slip down to the east on a north-northwesterly trending fault. This movement is indicated on the map by the U (up) and D (down) on the southernmost extent of the Long Valley Fault. The double-ended arrow shows the direction of extension indicated by all five large earthquakes in the swarm.

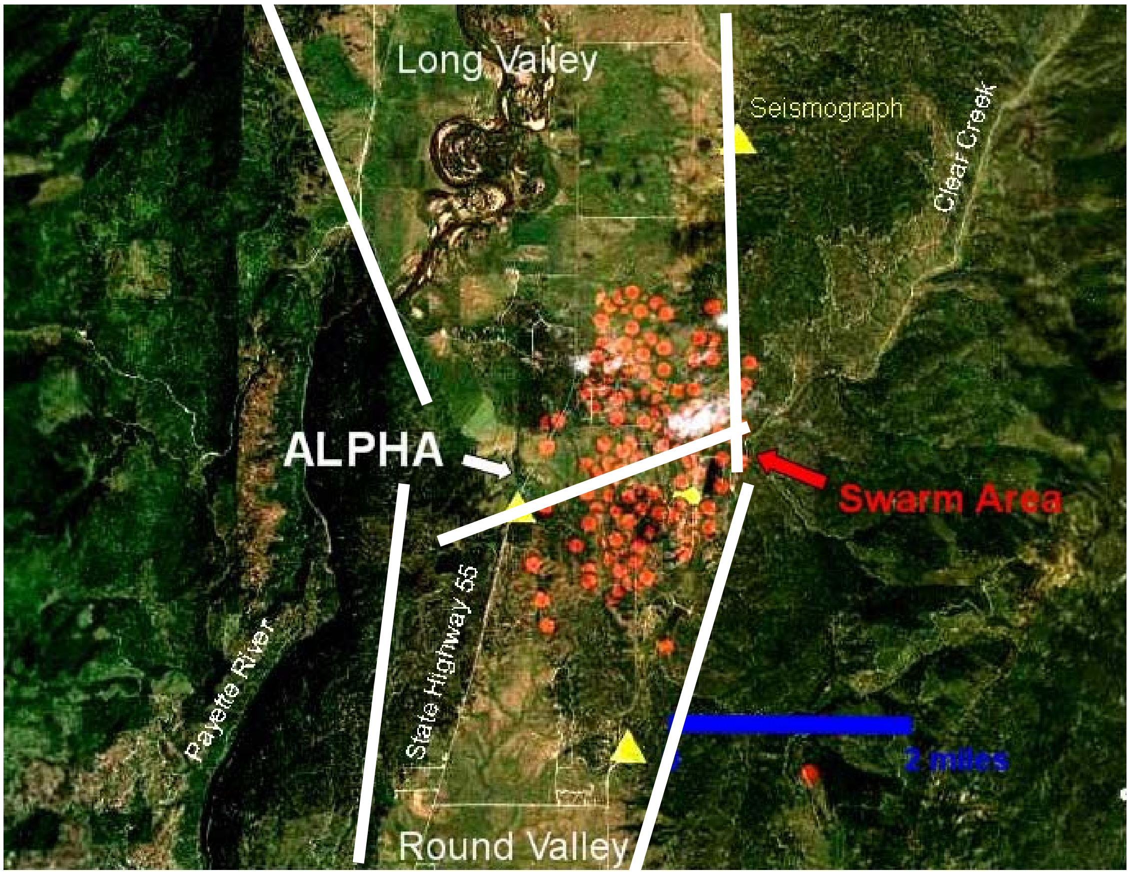


Figure 14. Microearthquake epicenters (orange circles) located by Zollweg (2006 c) using data collected by the temporary network. Yellow triangles are seismograph stations. The white lines show the approximate traces of the northerly trending border faults of Long valley and Round Valley and the northeasterly trending Alpha escarpment, which separates Long Valley from Round Valley.

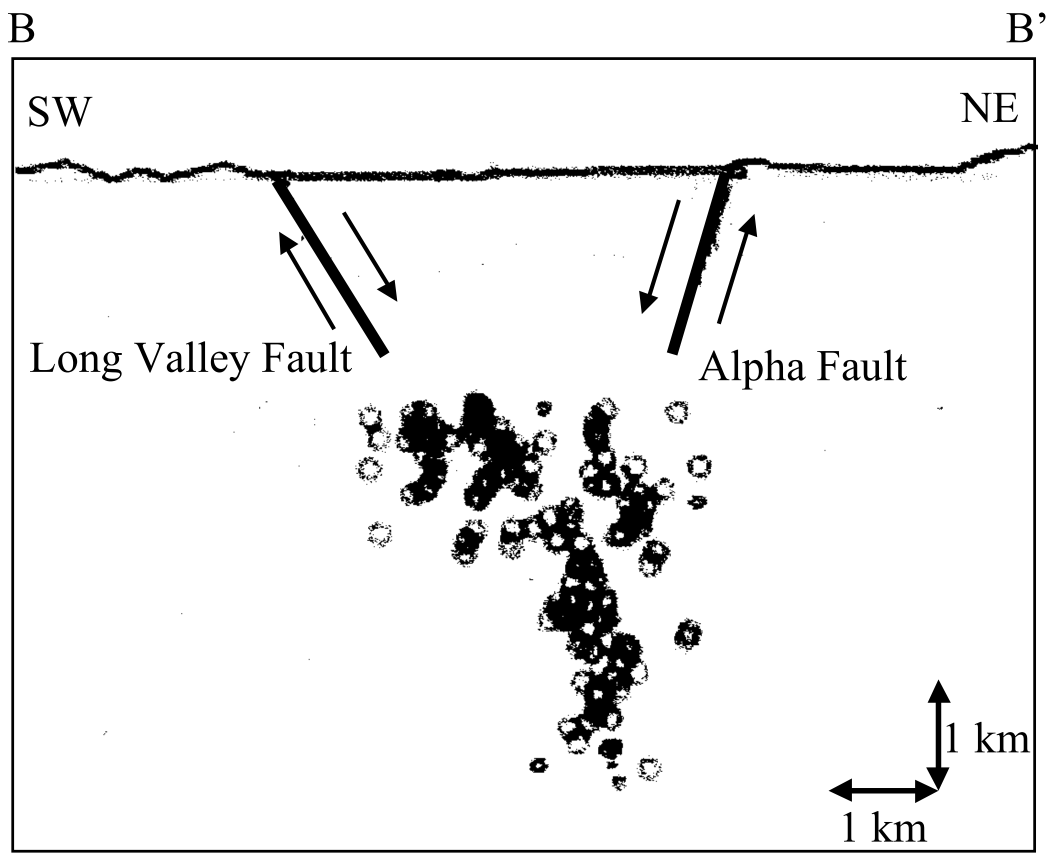
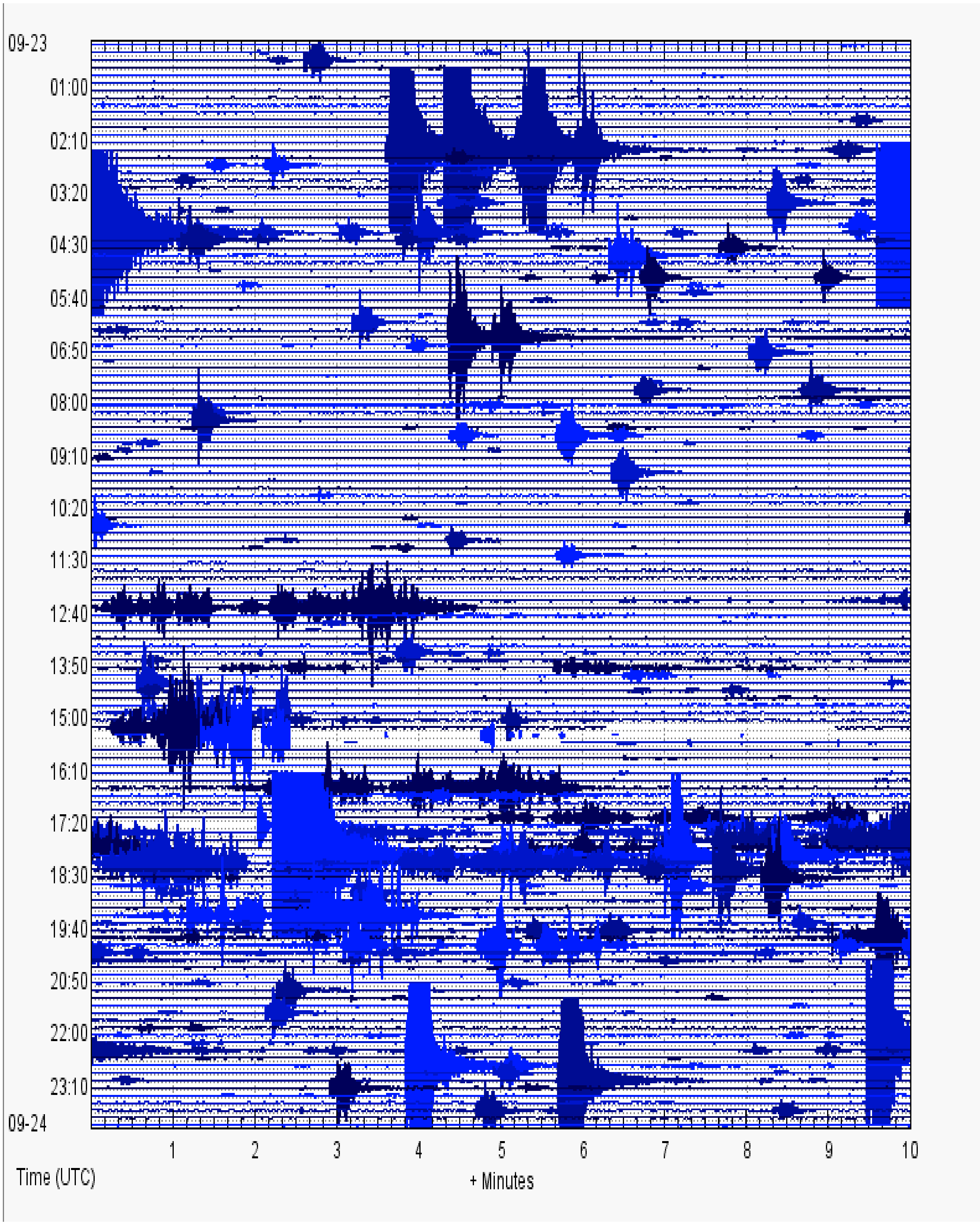


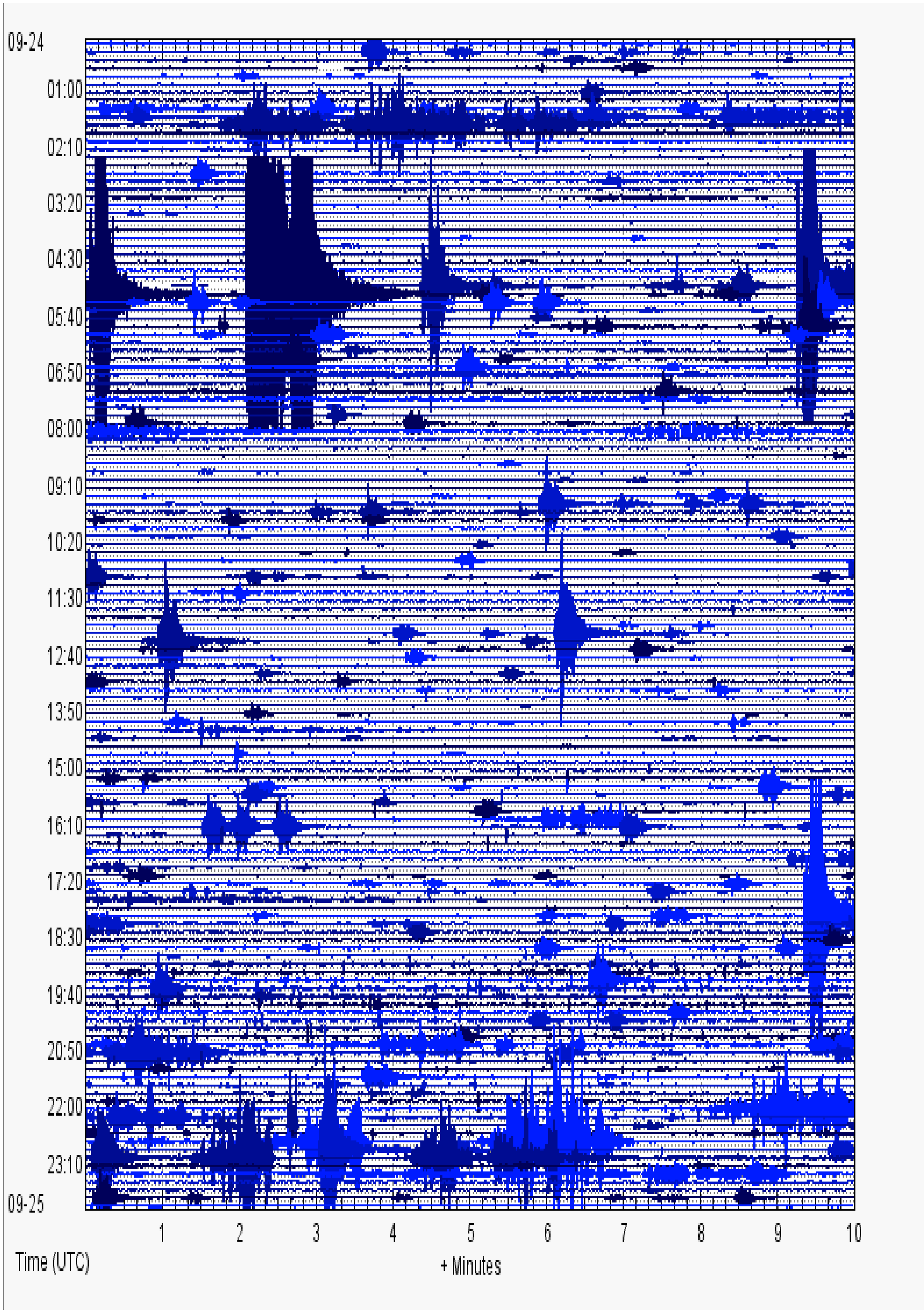
Figure 15. Cross-section (7 km wide, no vertical exaggeration) showing the hypocenters of the microseismicity in the northern portion of the cluster shown in Figure 14. These are all post main swarm events that occurred October 28-November 12 as reported by Northwest Geosensing (Zollweg, 2006c). Modified from Peterson (2006).

APPENDIX

ARCHIVE OF SEISMOGRAMS
Station WHKI
Boise regional Network
100 km from Alpha

Table 3 lists the earthquake arrival times and estimated magnitudes of the swarm events recorded on WHKI. All times are UTC. M = magnitude based on coda durations calibrated to NEIC magnitudes.


09-23
01:00
02:10
03:20
04:30
05:40
06:50
08:00
09:10
10:20
11:30
12:40
13:50
15:00
16:10
17:20
18:30
19:40
20:50
22:00
23:10
09-24
1
2
3
4
5
6
7
8
9
10
Time (UTC)
+ Minutes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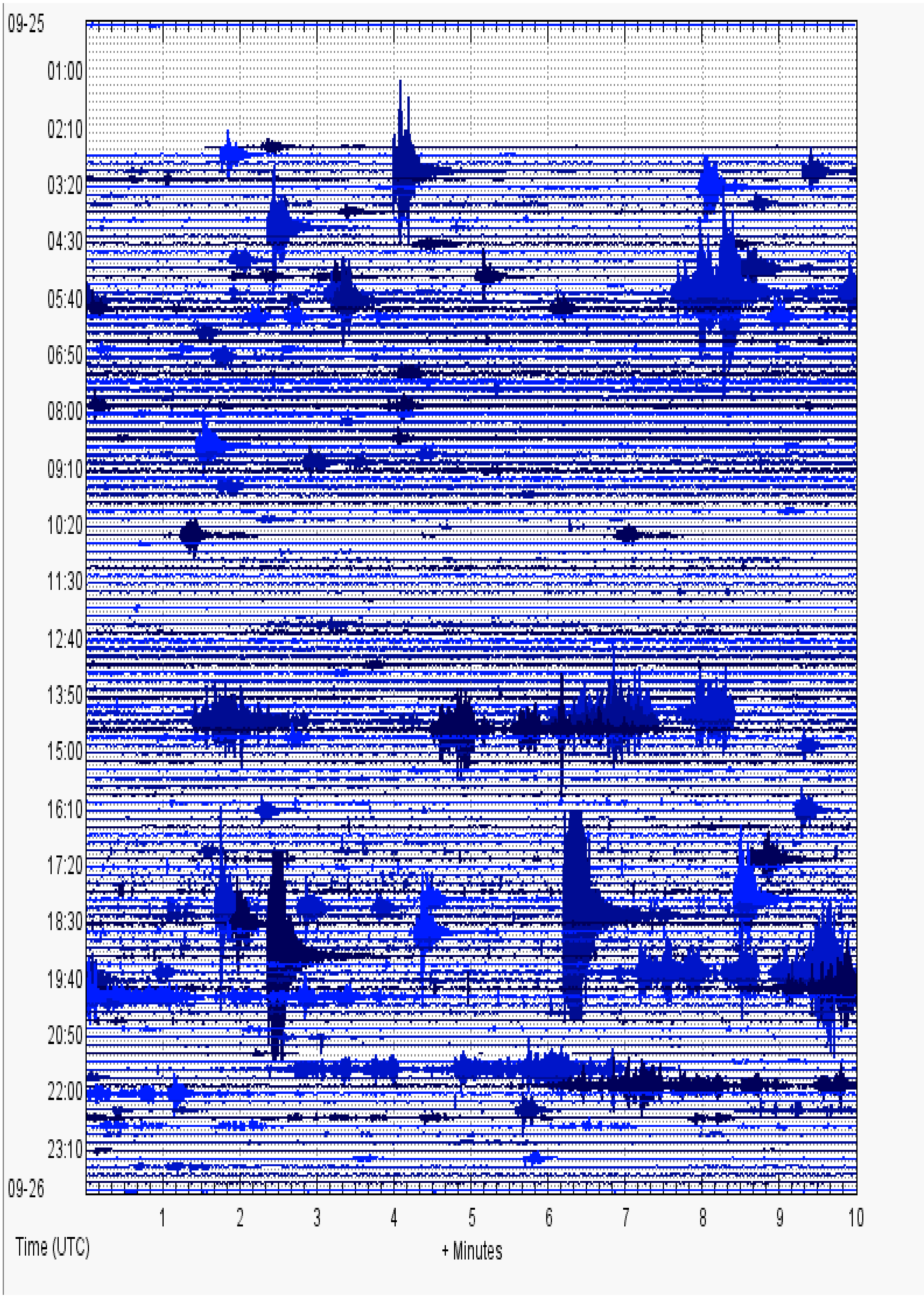
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Time (UTC)
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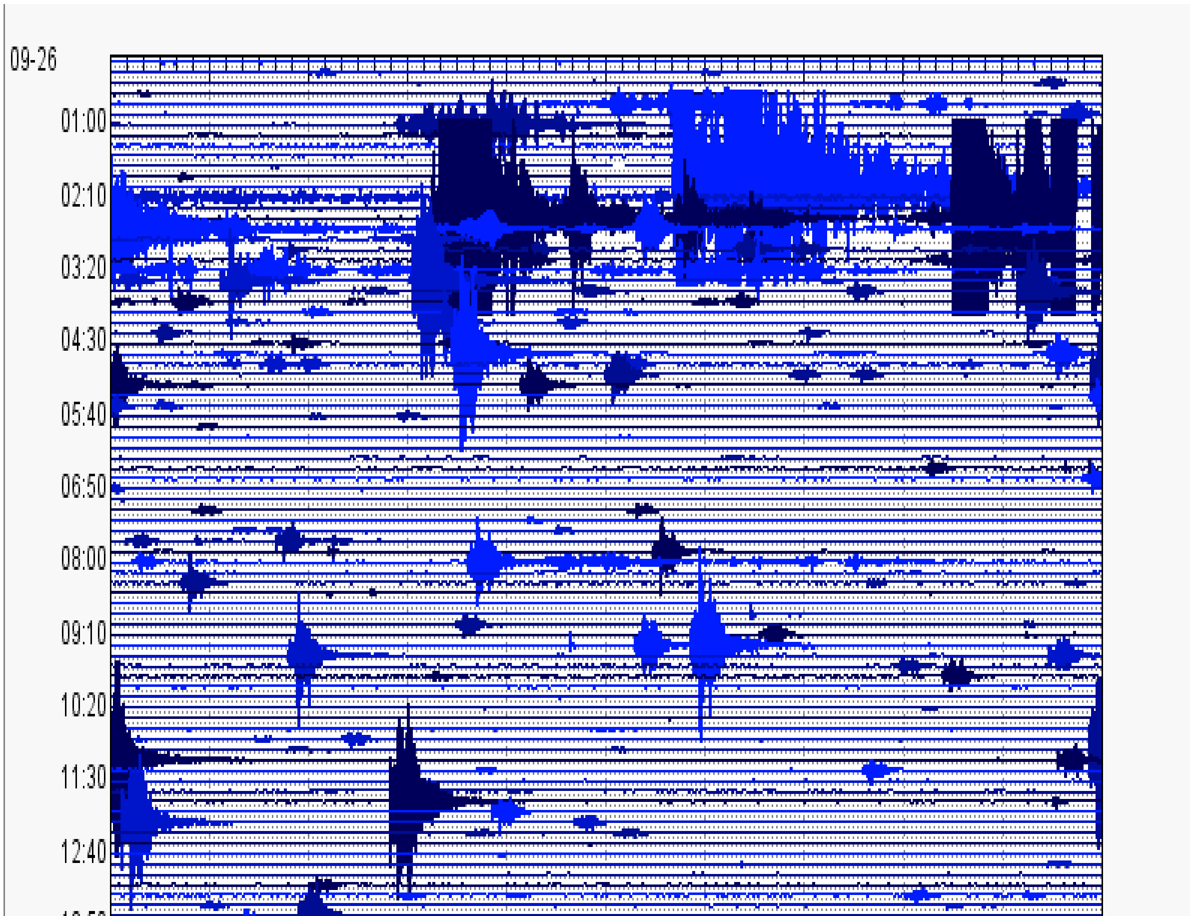
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Time (UTC)
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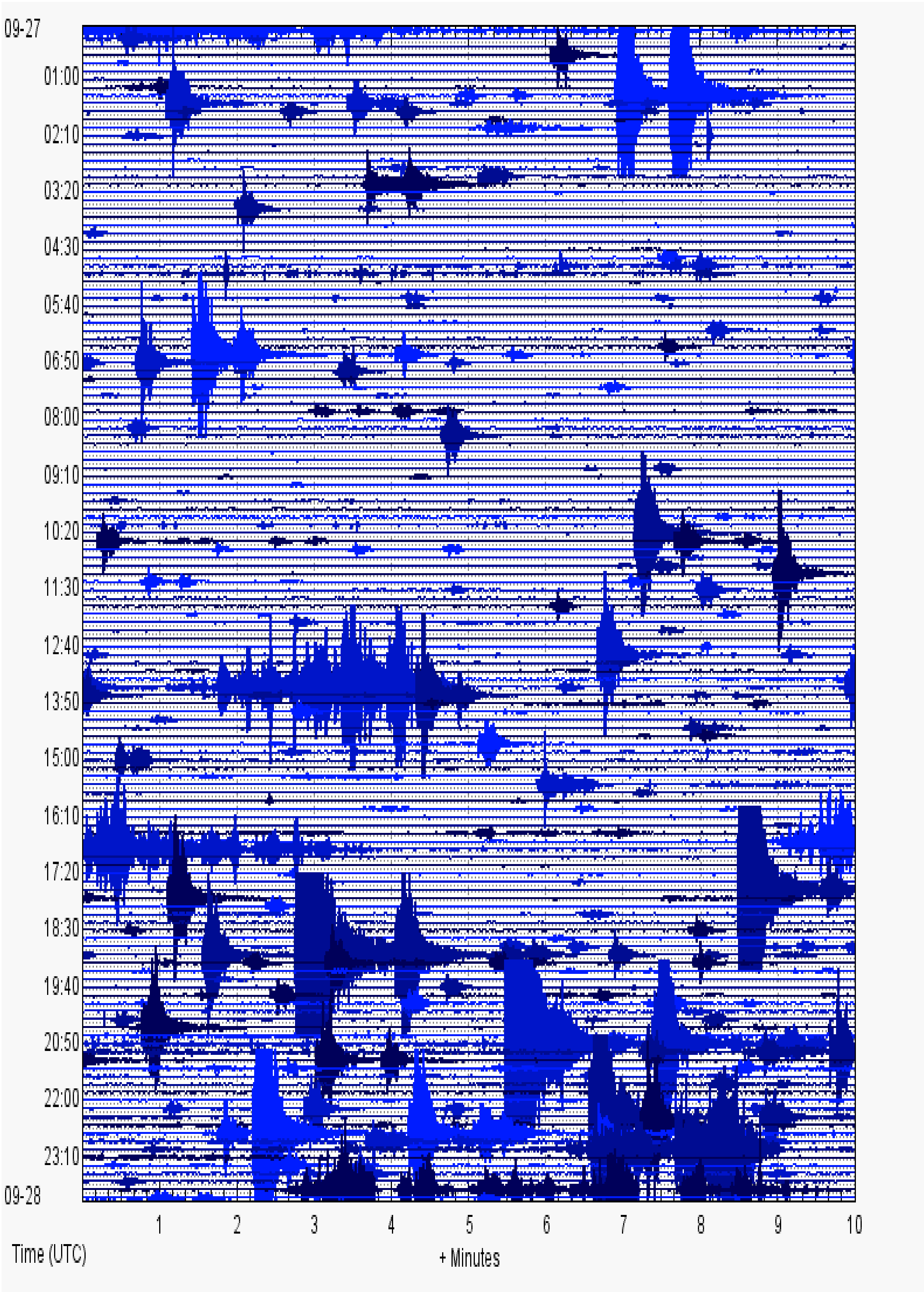
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Time (UTC)
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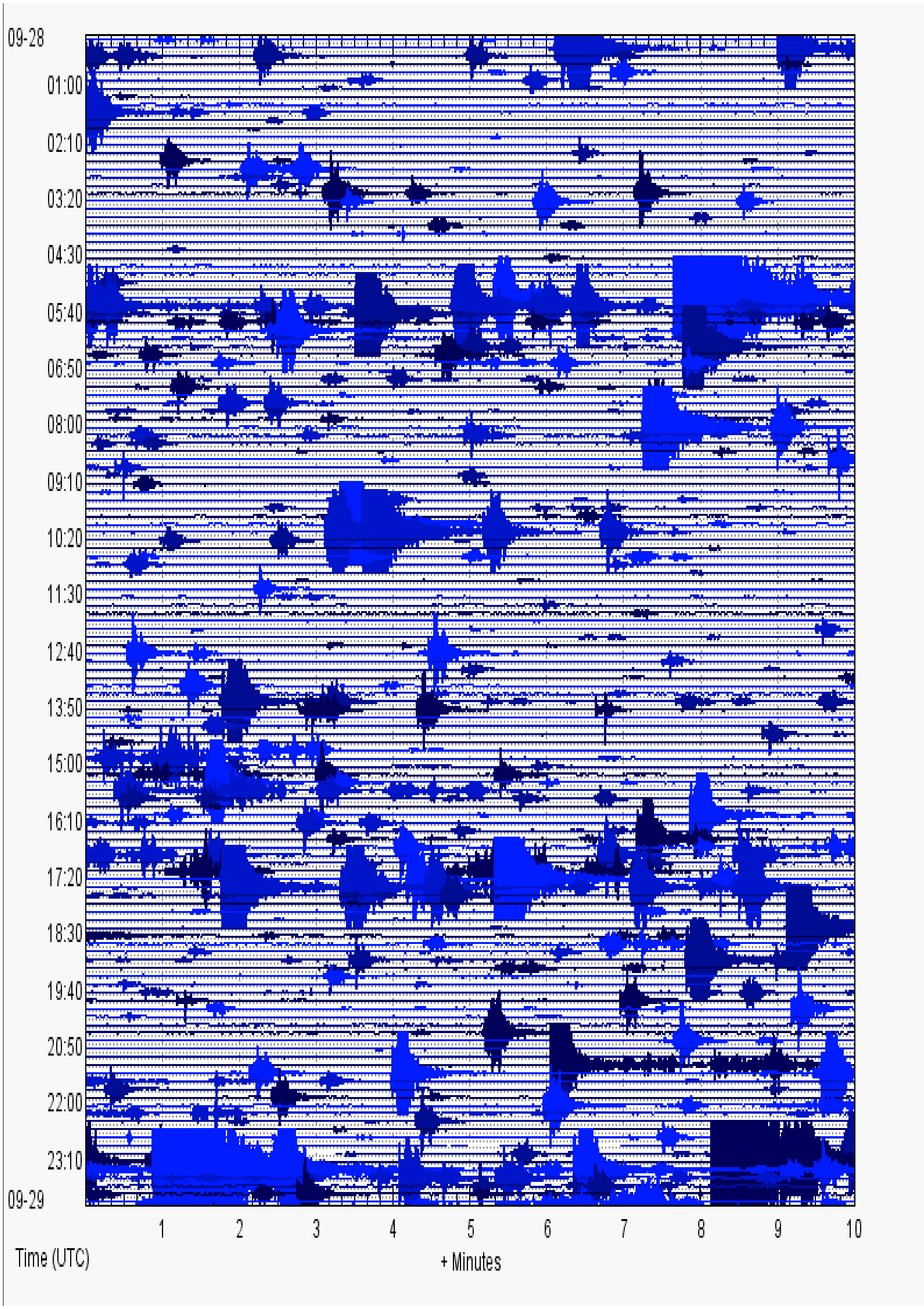
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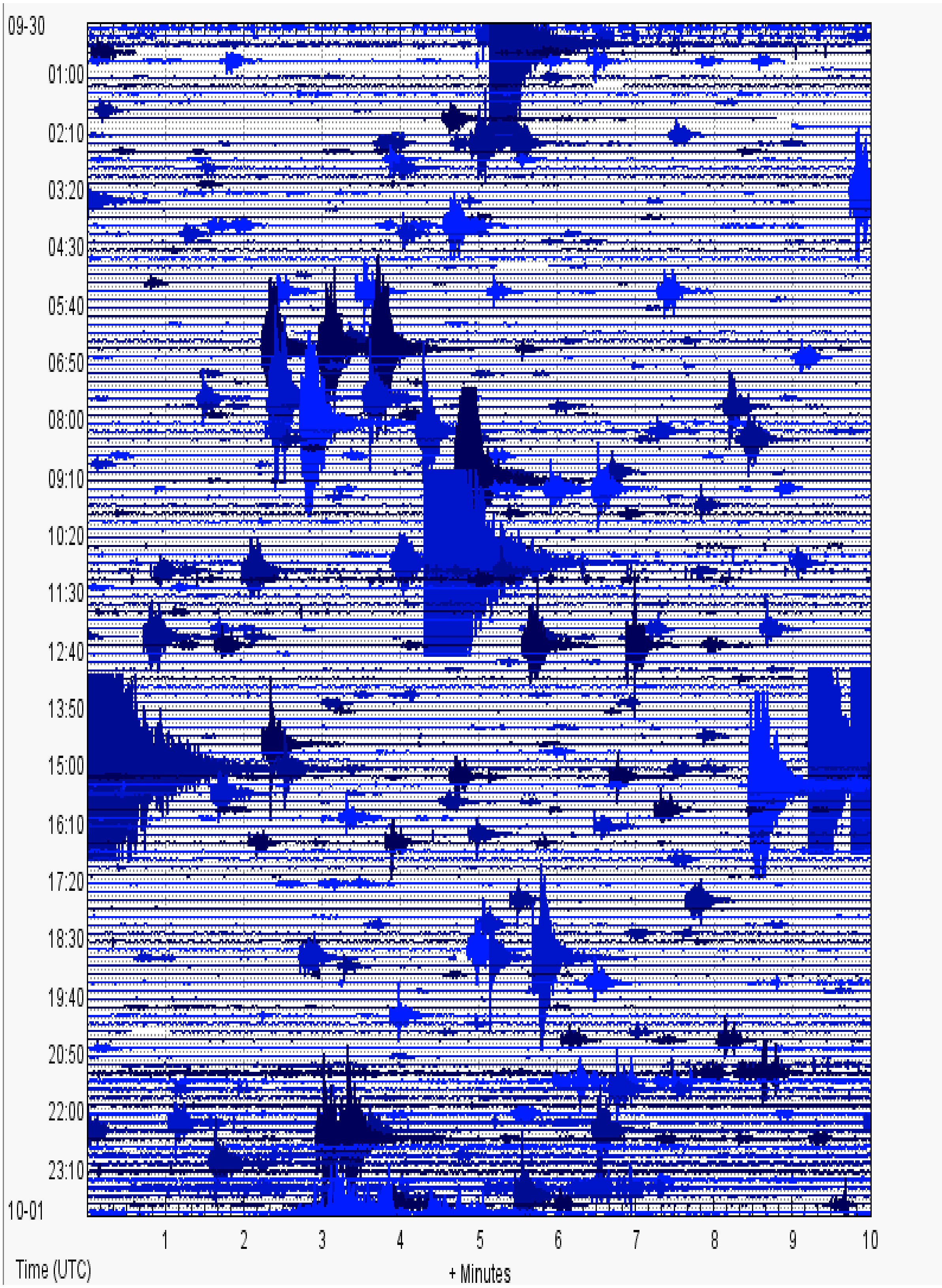
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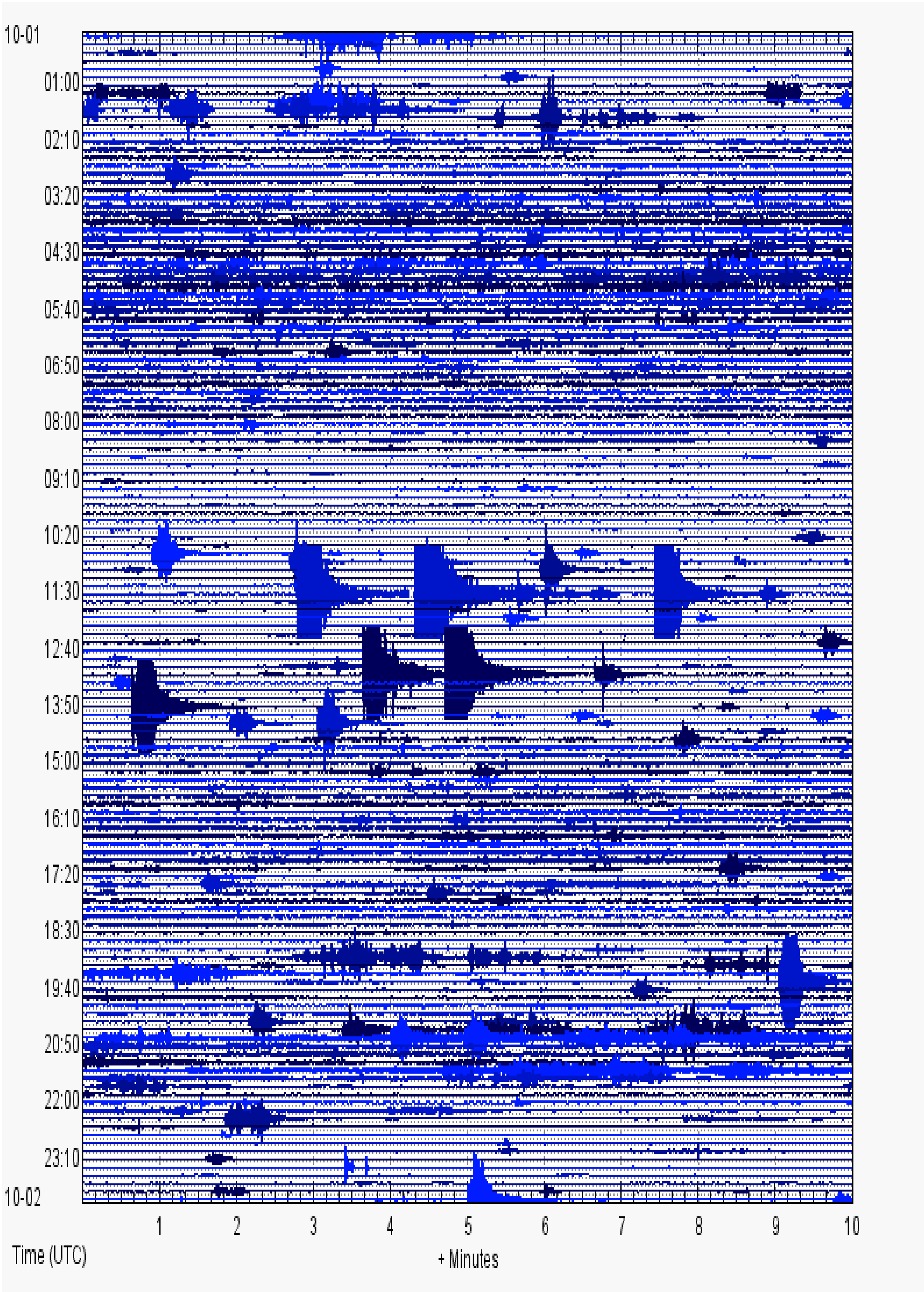
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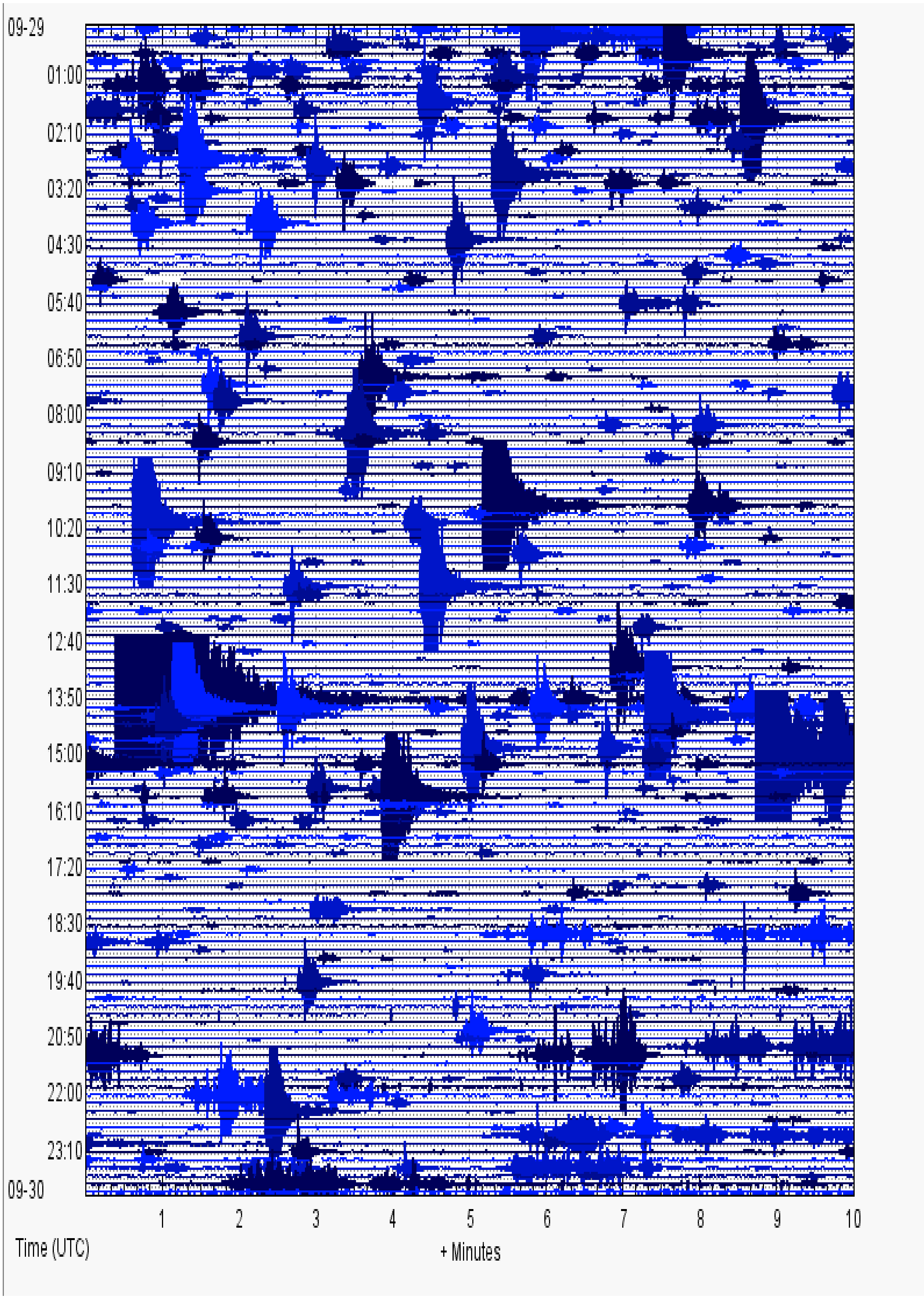
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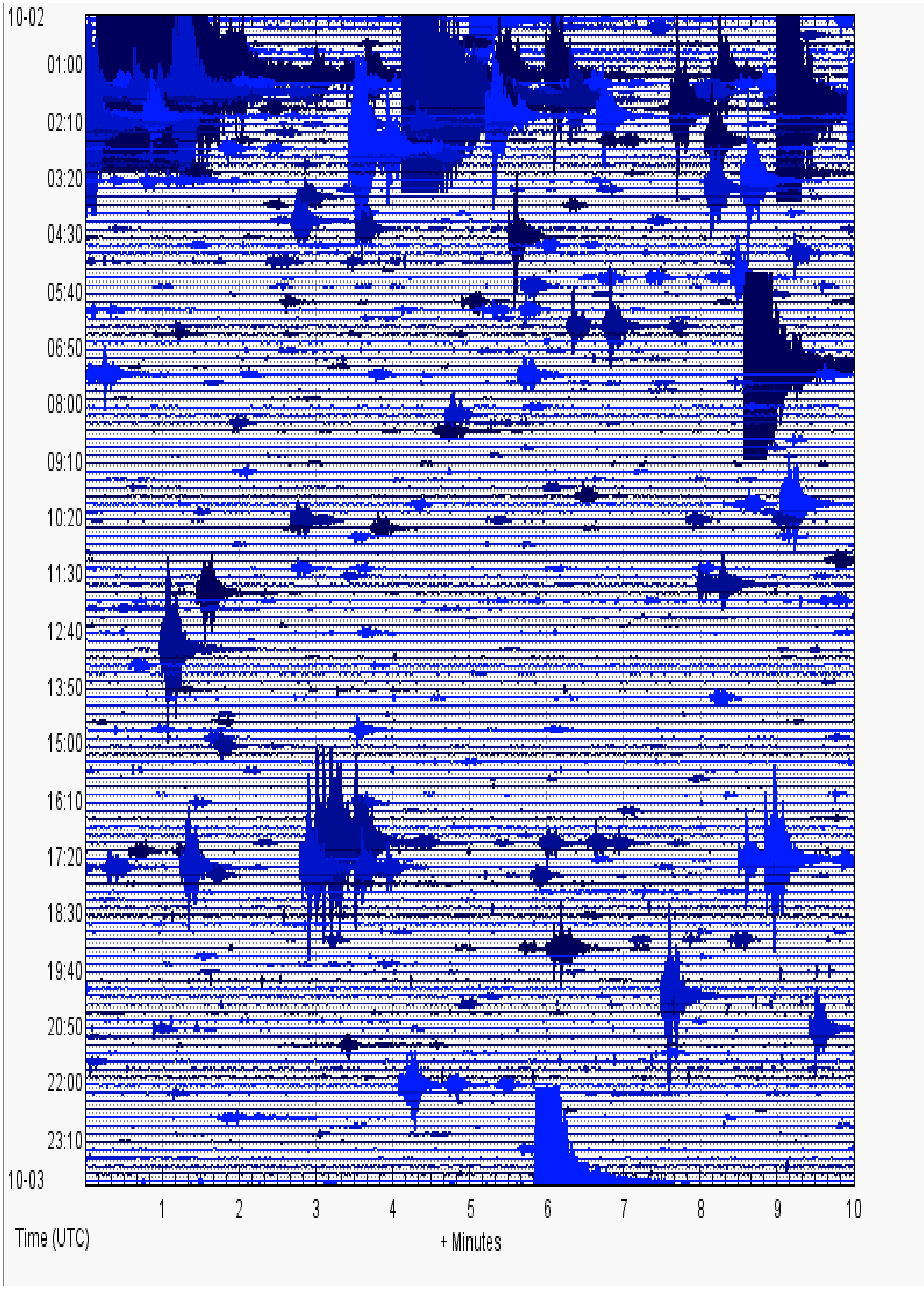

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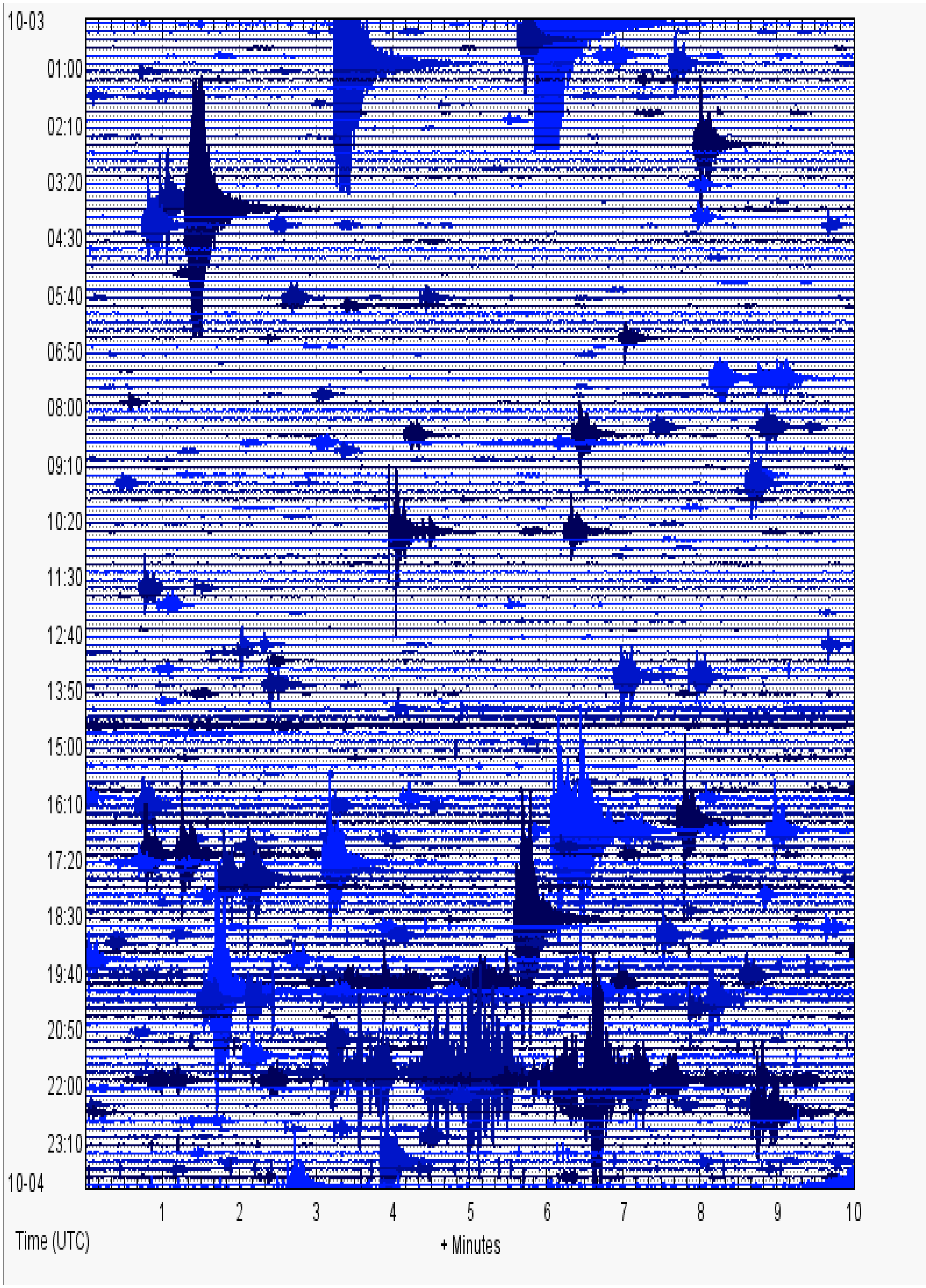
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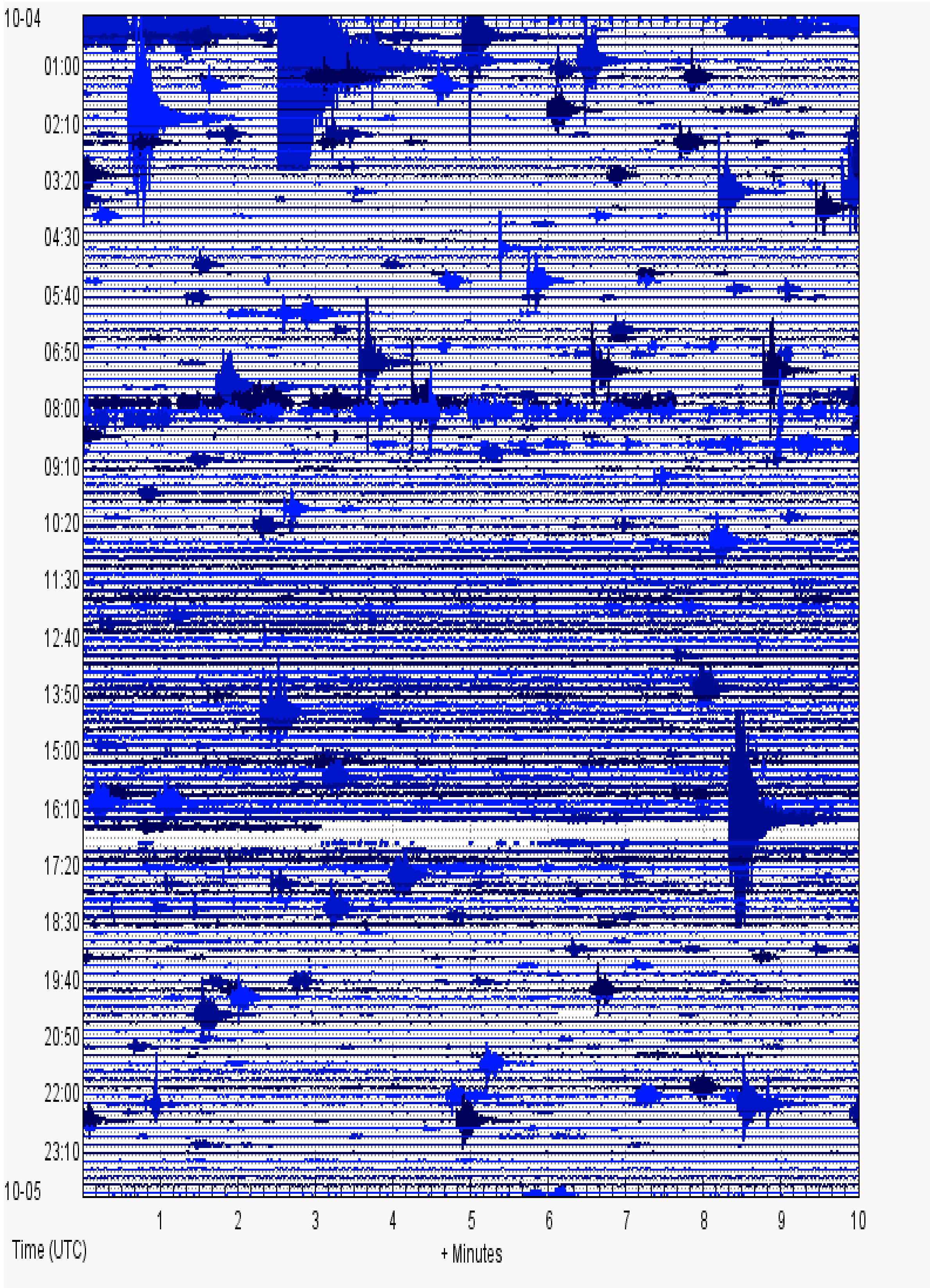
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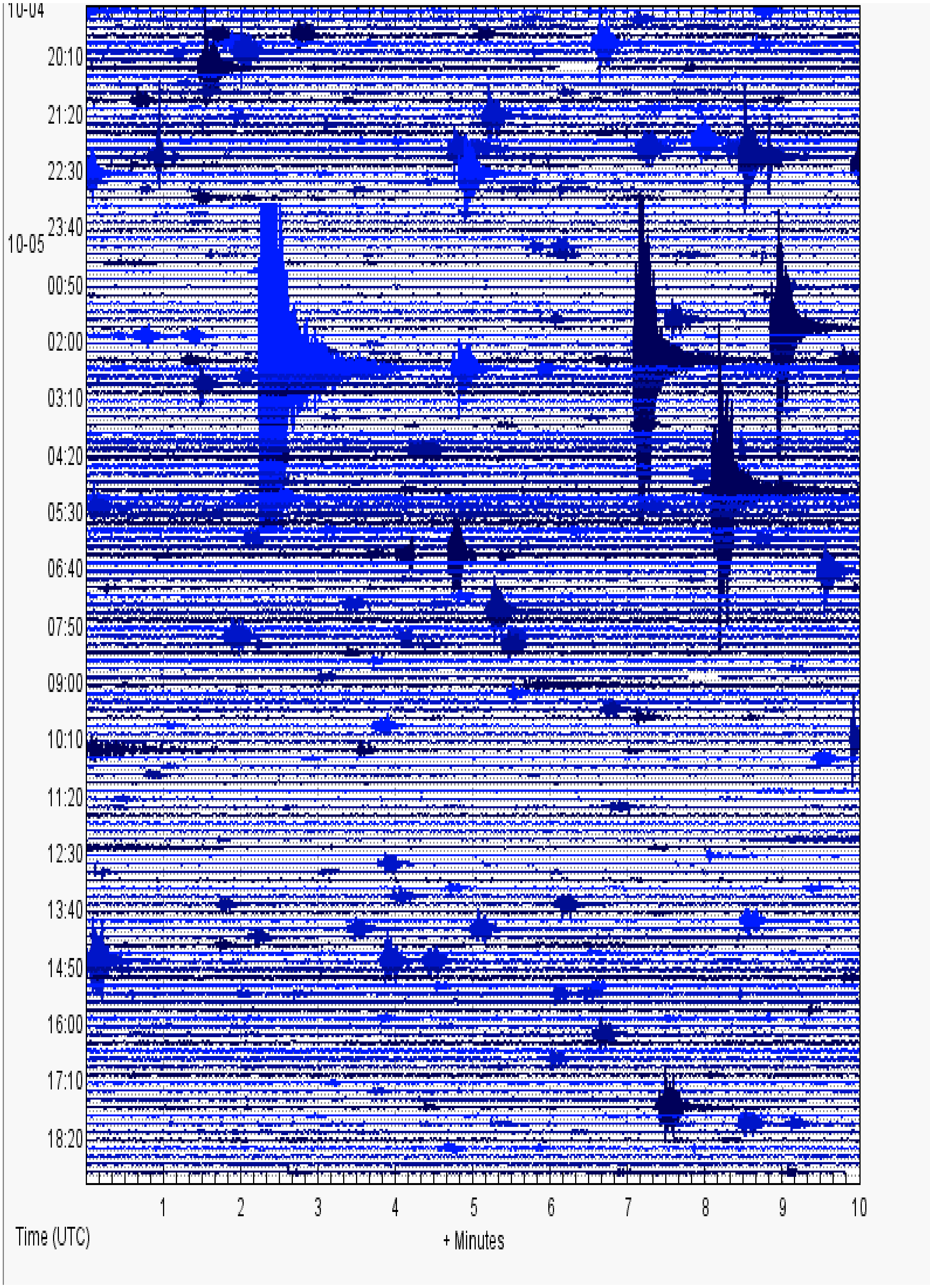
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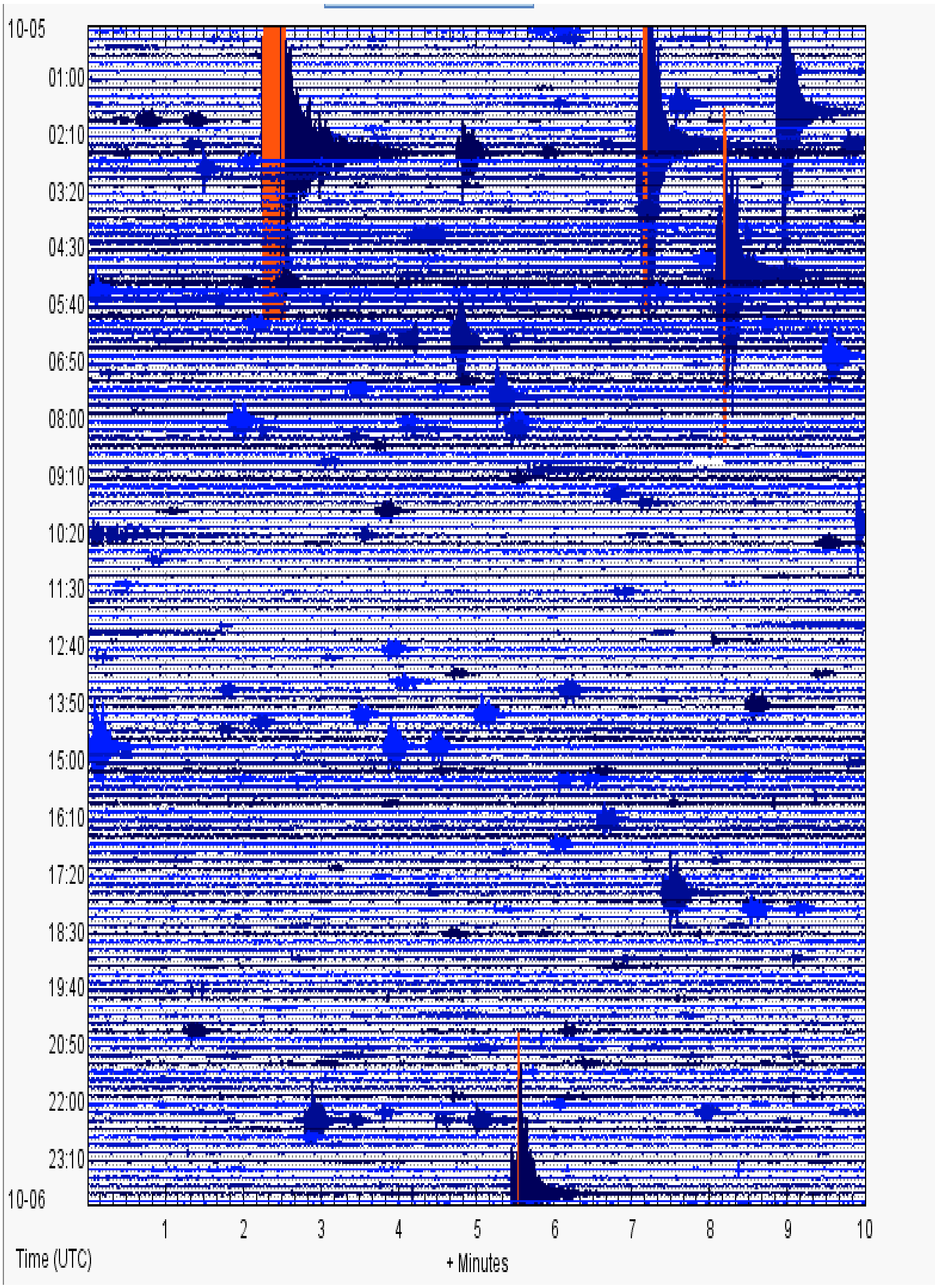
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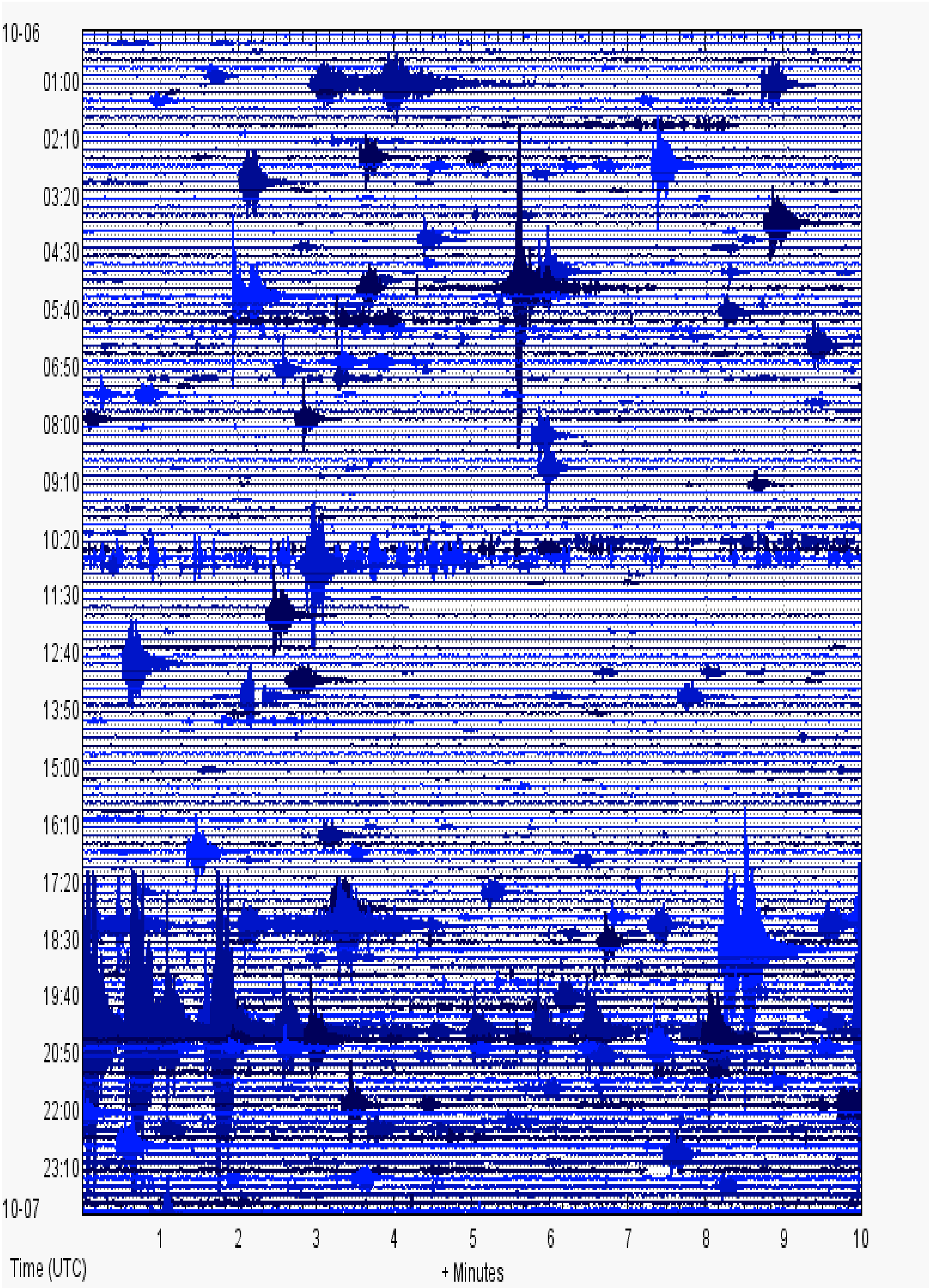

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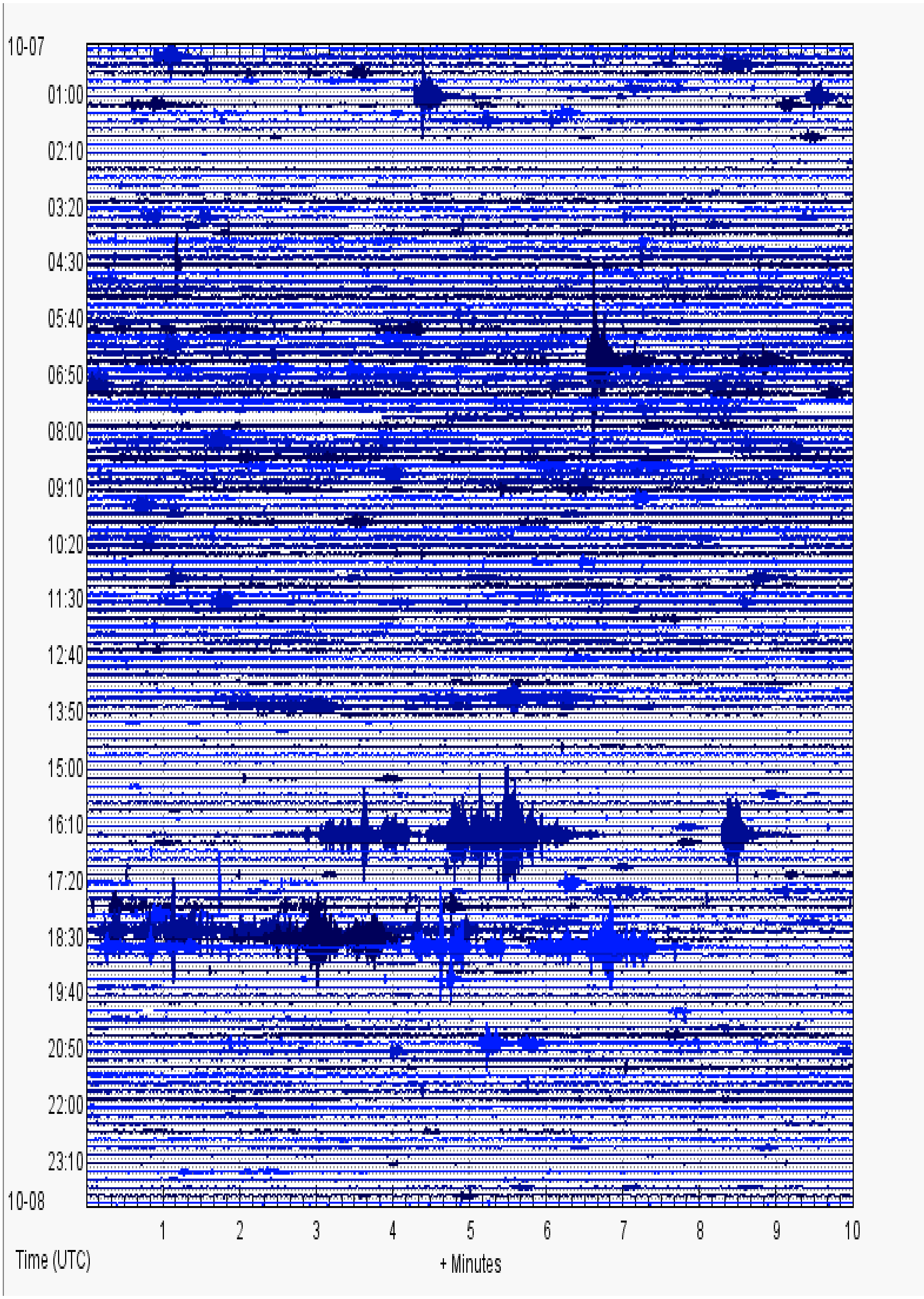

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