Final Technical Report

Award Number: G10AC00088

Project Title: Montana Regional Seismic Network

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Abstract
Cooperative agreement G10AC00088 provided funding to the Montana Regional Seismograph Network for maintenance and repair of seismograph and telemetry field sites, and supported approximately 80 percent of the seismic analyst position. Continuous waveform data from all the network stations along with response files are archived at the IRIS Data Management Center. Earthquake Studies Office personnel used these data to locate and archive over 9,000 earthquakes with magnitudes up to 4.9 during the award term. These earthquakes occur primarily along the northern Intermountain Seismic Belt. A subset of these earthquakes with fault plane solutions indicate that a regional stress field with horizontal extension oriented ENE-WSW is driving normal and strike-slip faulting throughout most of western Montana. A smaller extensional stress field with N15°E-S15°W extension drives a band seismicity located west of Yellowstone National Park and north of the Snake River Plain.

Body
Funding from this cooperative agreement continued to support the operation and maintenance of the Montana Regional Seismograph Network (MRSN), and analysis, reporting, and archival of network data. This cooperative agreement also supported approximately 80 percent of a seismic analyst's position in the Earthquake Studies Office. The MRSN is comprised of 35 seismograph stations (Figure 1), four telemetry repeater sites, two remote Earthworm nodes, and the central Earthworm node at the Earthquake Studies Office in Butte, MT.

From June through October, 2014, MRSN personnel visited nine remote field sites to troubleshoot and repair problems with seismic monitoring and telemetry equipment. On five of these site visits, an expert seismograph technician, paid from this cooperative agreement, provided invaluable expertise with repairs and adjustments. The 2014 field season maintenance was typical of the previous four field seasons. Over the five-year course of this agreement, the MRSN has operated much more reliably and provided less noisy data because of the dedicated work of this seismograph technician.

The MRSN includes two remote Earthworm nodes and a central recording node where multiple channels of analog seismic data are received and digitized for redistribution and analysis using Earthworm software. The digitizers at all three of these nodes relied on first-generation satellite clocks, which reached their useful end of life and failed. We purchased and installed three replacement digitizers with GPS time control for the central recording node using funding from this cooperative agreement. The Confederated Salish and Kootenai Safety of Dams program provided replacement digitizers for the two remote nodes.

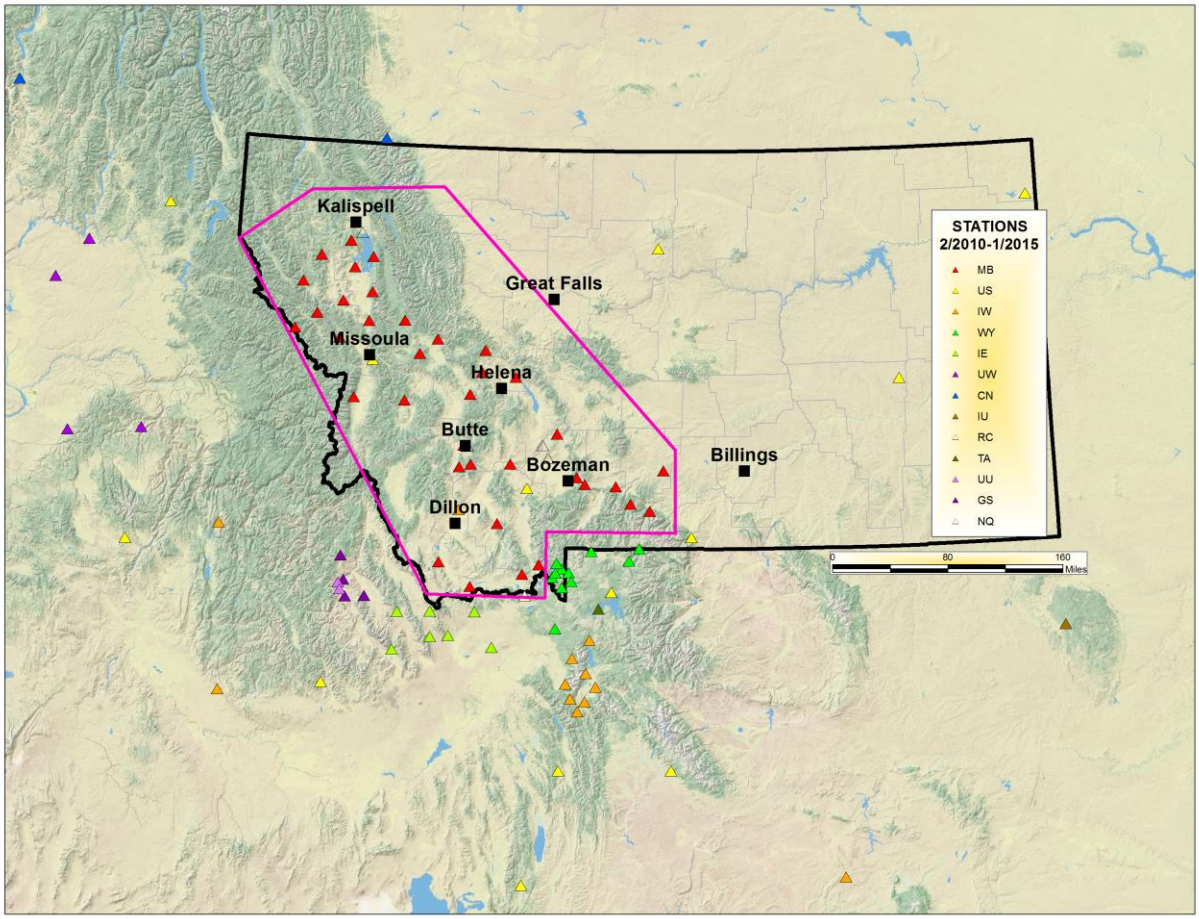

Figure 1. Map showing seismograph stations of the Montana Regional Seismograph Network (network code MB) as red triangles. Magenta polygon shows the MB authoritative region. Other networks that provide (and in most cases also receive) seismic waveform data recorded in real time include: the US Backbone (US) and Intermountain West (IW) networks operated by the US Geological Survey; the Yellowstone network (WY) operated by the University of Utah Seismograph Stations; the Idaho National Lab (IE); the University of Washington (UW); the Canadian National Network (CN) operated by the Canada Geological Survey; the IRIS/USGS Global Seismograph Network operated by the US Geological Survey (IU); BYU Idaho (RC); IRIS Transportable Array (TA); temporary stations deployed in the Challis, Idaho area by the University of Utah Seismograph Stations (UU) and the USGS (GS); and NetQuakes stations (NQ).

On October 27, 2010, we incorporated a free field strong motion seismograph, previously operated by the National Strong Motion Program, located in the seismic vault on the Montana Tech Campus into the MRSN. On January 17, 2014, we added a short period vertical channel to the existing three channels of

strong motion. All four channels are archived at the IRIS Data Management Center, along with the rest of MRSN data, and used for routine hypocenter and magnitude determinations.

The MRSN first began using early versions of Earthworm software to acquire, exchange, and process seismic data in 1999. In 2014, we upgraded to the current Earthworm version, 7.7 at our remote nodes and at the central recording center.

Several years ago, ANSS classified member networks as either Tier 1 or Tier 2, based on network size, seismicity rates, personnel, and resources. The MRSN may have qualified as a Tier 1 network based on network size and seismicity rates but because of limited staff and resources, ANSS classified the MRSN as a Tier 2 network. This distinction became important when ANSS adopted AQMS as the standard software package for regional seismic network data analysis, reporting and archiving. ANSS would support Tier 1 networks with implementing and operating AQMS. Tier 2 networks were encouraged to partner with Tier 1 networks to utilize AQMS. MRSN and University of Utah Seismograph Stations (UUSS) personnel met several times to plan and discuss this implementation.

Using this model, the MRSN partnered with the UUSS and over several years developed a plan and prepared to incorporate MRSN network data into the UUSS instance of AQMS. One major obstacle to this plan was the fact that AQMS was originally designed to support a single seismic network, not multiple networks. The MRSN-UUSS partnership was the first to face this shortcoming. An ANSS committee studied this issue and requested support to have multi-network functionality incorporated into AQMS. The AQMS multi-network modifications were made but apparently never thoroughly tested. When UUSS implemented the multi-network AQMS version and began testing with data from both networks, they discovered significant problems. Following discussions with ANSS personnel, it was decided that the least costly and most expeditious way to get the MRSN operating on AQMS was to implement a second instance of AQMS at the UUSS specifically for the MRSN. ANSS provided funding to UUSS to purchase an appropriate computer, which is now operational.

In early October, 2014, we began using AQMS in a test mode to analyze MRSN data. Testing and evaluation is ongoing and we hope to implement AQMS as our primary analysis package by July. This change in analysis technique is the largest operational change in the MRSN since the change from paper seismograms to continuously recording and exchanging digital data using Earthworm in 1999.

During the five-year duration of this cooperative agreement, we used data from the MRSN along with data from surrounding stations to determine hypocenter locations and magnitudes for 9,301 earthquakes with magnitudes ranging from -0.4 to 4.9 (Figure 2). Within the MRSN authoritative region, we located 7,947 earthquakes with a maximum magnitude of 4.4. Four earthquakes within the MRSN had magnitudes of 4.0 or larger and 60 had magnitudes ranging from 3.0 to 3.9. Residents reported feeling 38 earthquakes.

Earthworm software automatically picks and locates earthquakes in the western Montana and surrounding areas. For automatic solutions within the MRSN region that pass a quality test, hypocenter locations for earthquakes with magnitudes of 1.0 or greater are posted to the MBMG and ANSS website, typically within two to three minutes of an event. At a later time, all earthquakes (including those without automatic solutions) are reviewed and those with magnitudes of 1.0 or larger are contributed to the ANSS Composite Catalog. All reviewed earthquake locations, regardless of magnitude, are contributed to the ANSS Composite Earthquake Catalog (http://quake.geo.berkeley.edu/cnss/) operated at the Northern California Earthquake Data Center.

A significant amount of time and effort was devoted to developing accurate response files for MRSN stations. Accurate response files are critical when using AQMS for network data analysis. All station

response files are stored at the IRIS Data Management Center and at the UUSS. Continuous waveform data for all MRSN stations are archived in near real-time at the IRIS DMC.

Seismicity within the MRSN authoritative region clearly defines the northern Intermountain Seismic Belt (Figure 2). Most well-determined hypocenter depths fall in the 5-15 km depth range, typical of other regions of the Intermountain Seismic Belt. However a 40-km wide band of seismicity located north of a line extending between Helena and Missoula and lying east of the Mission Mountains includes hypocenters that extend to depths of 20 to 24 km below the surface. The proximity of these deeper earthquakes to the southern ends of the Mission, Swan, and South Fork Flathead faults suggests the possibility that these faults may be capable of storing elastic energy to depths as great as 24 km. If so, then future fault-rupturing earthquakes may be larger than those inferred for faults with an assumed seismogenic depth of 15 km.

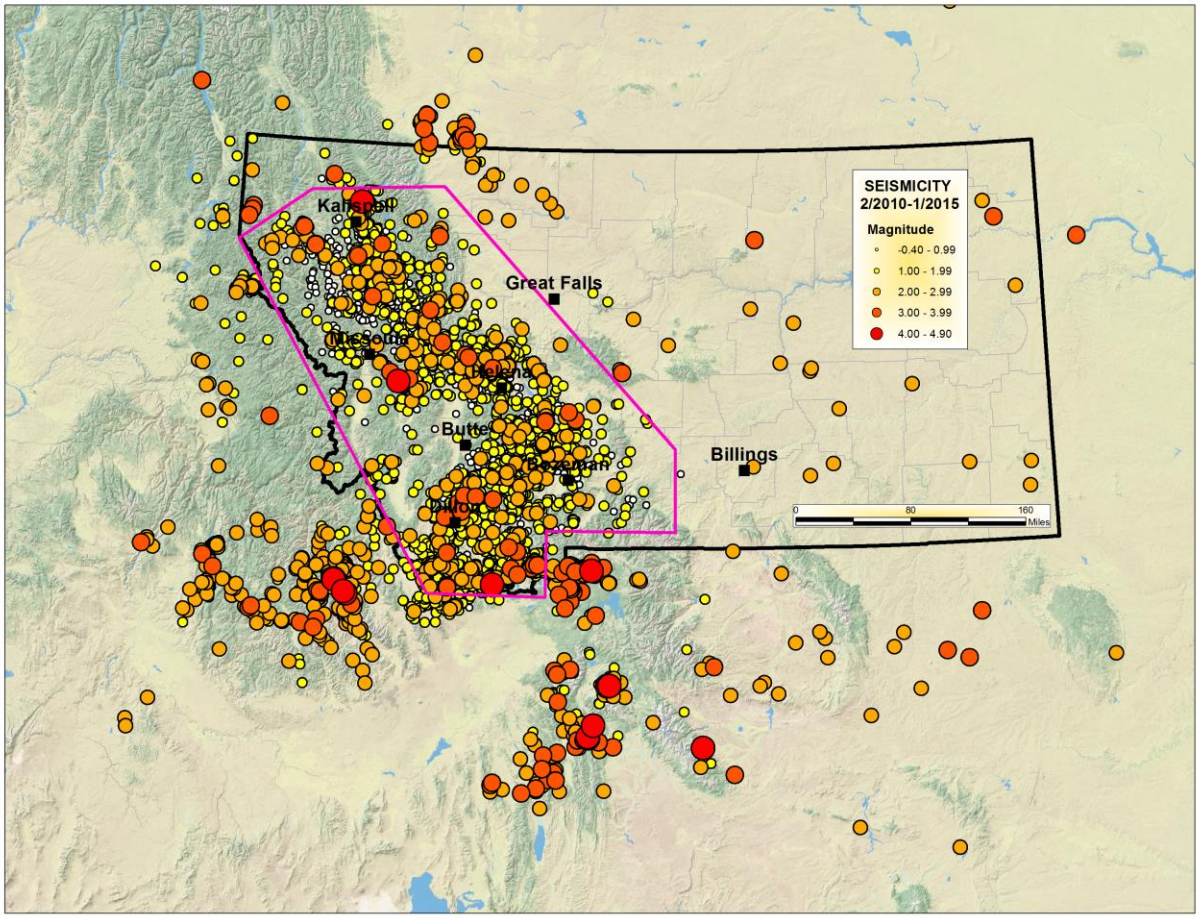

Figure 2. Epicenter locations for 9,301 earthquakes located with data from the MRSN and surrounding stations. The magenta polygon shows the MRSN authoritative region.

Fault plane solutions determined from P-wave first motions indicate that most recent seismicity along the northern Intermountain Seismic Belt results from normal and strike-slip faulting, as well as combinations of both—oblique-normal faulting. The stress field that drives this seismicity is characterized by horizontal extension oriented ENE-WSW. A narrow band of seismicity extending approximately 100 km westward from Hebgen Lake includes both normal and strike-slip faulting but within this smaller area, the extensional stress field is oriented N15°E-S15°W. The proximity of this smaller region, with an

anomalous extension direction, to Yellowstone and the trailing Snake River Plain suggests the influence of the Yellowstone volcano-tectonic province on this area of the Intermountain Seismic Belt.

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