Analysis of the Jones, Oklahoma, Earthquake Swarm

Austin A. HOLLAND (austin.holland@ou.edu), Amie R. GIBSON

MEWBOURNE COLLEGE OF EARTH & ENERGY
THE UNIVERSITY OF OKLAHOMA

OKLAHOMA GEOLOGICAL SURVEY 1908

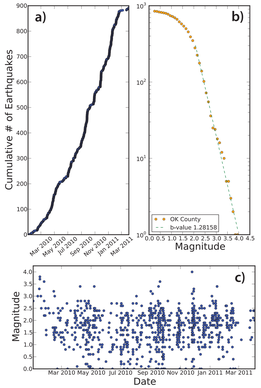
Abstract

The Jones, Oklahoma, earthquake swarm began with two felt earthquakes late in 2008 and included another 35 felt earthquakes in 2009. Prior to 2008, the Oklahoma Geological Survey (OGS) had reported only 7 earthquakes in Oklahoma County. In early 2010 a local network of tri-axial accelerometers was installed in order to gain a better understanding of the seismicity that was occurring in eastern Oklahoma County just miles from Oklahoma City. In 2010 the OGS located more than 660 earthquakes in Oklahoma County ranging in magnitude from 0.1 to 4.0. Local residents felt more than 64 of these earthquakes. The local network of accelerometers regional seismic stations and Earthscope USArray Transportable Array seismic stations all contributed data used to develop a velocity model and locate the earthquakes. The focal depths range from 0.0 to 14.0 km with the majority of earthquakes occurring in the basement at depths ranging from 3 to 6 km. Focal mechanisms for these earthquakes are consistently strike-slip with the compressional axis for the stress field oriented in a NE-SW direction. Double difference hypocenter relocations for the earthquake swarm provide very well located hypocenters that appear to delineate a set of nearly east-west oriented faults. We determined a b-value of 1.2 for the earthquake swarm and the catalog of seismicity appears complete down to a magnitude of about 2.0.

Introduction

In late 2008 there were two felt earthquakes in Oklahoma County, Oklahoma, and in 2009 there were another 35 felt earthquakes. Starting in early 2010 the USGS and Oklahoma Geological Survey deployed 10 accelerometers to the area in eastern Oklahoma County, which was experiencing the earthquakes. The accelerometers are still operating in Oklahoma County. These seismic instruments combined with the Earthscope USArray Transportable Array and regional seismic stations offer a unique dataset for an intracontinental earthquake swarm. The centroid of earthquakes occurring in eastern Oklahoma County is very near, about 2 km ENE, the town of Jones Oklahoma, leading to the Jones Earthquake Swarm designation. Local residents felt more than 65 earthquakes in 2010 as part of this swarm activity.

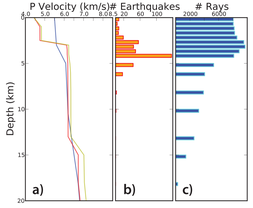
The most notable and well-documented mid-continent earthquake swarm is the Enola, Arkansas earthquake swarm, which had a reported 30,000 earthquakes (Chiu et al., 1984). There are currently ongoing swarms in Guy, Arkansas nearby where the Enola swarm occurred, and in Coal County in Oklahoma.



Cumulative number of earthquakes (a) and magnitude frequencies (b) for earthquakes within Oklahoma County from 2010 to 2011-3-31. The b-value calculated for this seismicity is well above 1.0 at 1.28 and the magnitude of completeness appears to be about 1.8. On average there were two earthquakes a day large enough to be located. The time magnitude plot (c) shows the temporal distribution of earthquakes in Oklahoma County. The earthquakes are clustered in time, but not in a simple mainshock/aftershock pattern.

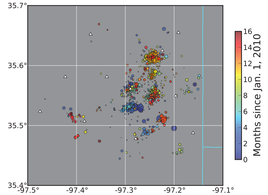
1-D Velocity Model

A velocity model was established using earthquakes recorded through September of 2010. This includes 395 earthquakes recorded on 4 or more stations with more than 8000 rays. The 1-D velocity model was determined using VELEST version 3.1 (Kissling et al., 1994). The inversion was done using catalog P and S arrival times in multiple steps with an assumed Vp/Vs ratio of 1.73 and only using stations within 200 km of the epicenter.

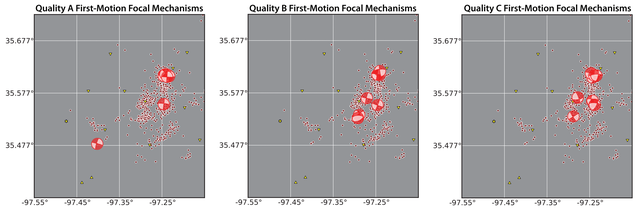


a) Blue line is the regional velocity model currently used by the OGS, gold line is the velocity model determined from the velocity inversion not allowing station delays, and the red line is the model results from the velocity inversion allowing station delays, b) earthquakes by depth for velocity model shown in gold and c) number of ray hits for each layer in the velocity model.

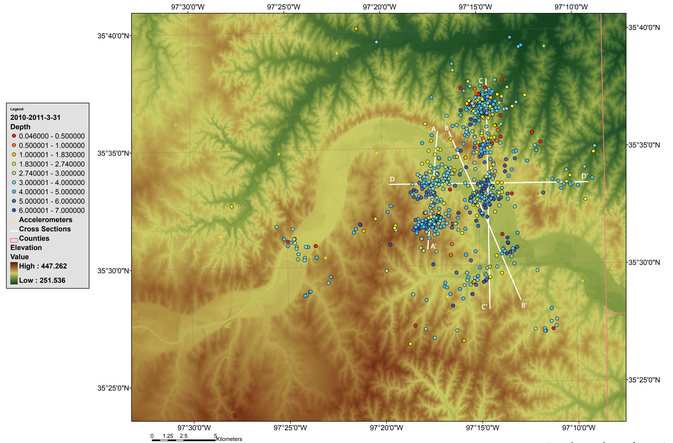
Depth to basement contour map, contours are in feet with a contour interval of 500 feet modified from Luza and Lawson (1982). The basement has been mapped at a depth of 6000 to 9000 feet or (1,828-2,743 m) dipping to the southwest in eastern Oklahoma County. The area experiencing the earthquake swarm in eastern Oklahoma County is located within a crustal block between two complex and large uplift structures the Nemaha and Seminole Uplifts. Rock units within this block dip to the SW at about 1.5 degrees. The Nemaha Uplift transects western Oklahoma County about 20 km west of the centroid of the Jones Earthquake Swarm.



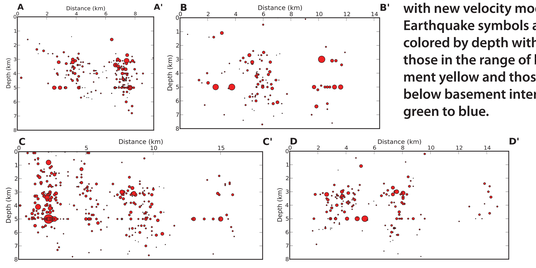
Oklahoma County earthquake locations using the updated 1-D velocity model earthquake symbols (circles) are scaled by magnitude and colored by time to show the time progression of the earthquake swarm, and cyan lines show the county boundaries. White triangles show the location of the local accelerometer network. The swarm has a clear temporal evolution from the south to slightly more north and the west and north again over about 9 months.

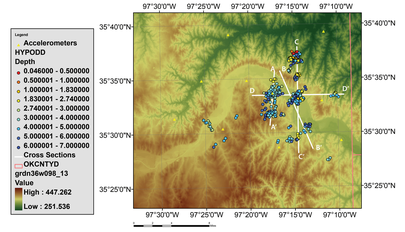


First-motion focal mechanisms were determined using the locations provided by the new velocity model. The focal mechanisms were calculated using HASH and qualities were as assigned as described by Hardebeck & Shearer (2002). Earthquake locations for the entire sequence are shown as maroon circles with a white border. Accelerometer locations are shown as upside down yellow triangles and OGS seismic stations are shown as yellow triangles.



Earthquake relocations with new velocity model. Earthquake symbols are colored by depth with those in the range of basement yellow and those below basement interface green to blue.

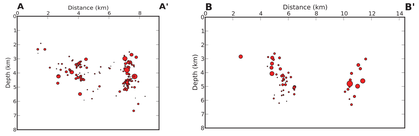


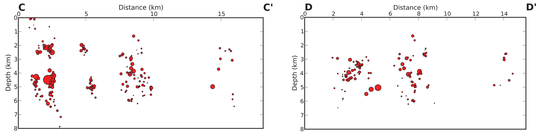


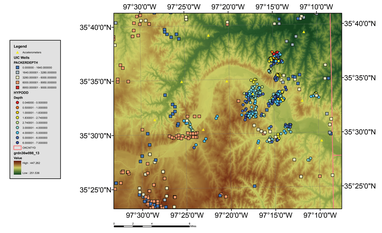
Relocations using HYPODD

The earthquakes were relocated using HYPODD (Waldhauser & Ellsworth, 2010).

- P and S-Phase arrivals from catalog
- Maximum event separation of 1 km
- Distance cutoff of 200 km
- Resulting number of earthquakes 488
- 24 individual clusters largest cluster 236 earthquakes
- Mean weighted RMS ~ 0.05 seconds absolute < 0.1 seconds
- Mean 2-sigma errors less than < 250 m using least squares







Earthquakes relocated using HYPODD and injection wells from the Oklahoma Corporation Commission database colored by depth with the same depth interval breaks as the earthquakes. Red boxes show wells that are at or near basement. The majority os seismicity is well away from injection wells. Some have suggested these earthquakes are anthropogenically induced from fluid injection. We continue to evalutate this possibility.

Observations from Earthquake Relocations

- East-west fault south of Jones, Oklahoma, southern end of A-A'
- Perhaps a set of east-west faults on the northern end of C-C'
- Seismicity close to the Canadian River is more diffuse

Conclusions

- 850 earthquakes and 65 felt in one county in Oklahoma in just over year is unusual
- HYPODD relocations improved earthquake locations
- Majority of seismicity appears diffuse
- No through-going faults are readily identified from seismicity and there are no major mapped faults where the earthquakes are occurring
- Suggestions of several small roughly east-west faults
- The majority of seismicity does not spatially correlate with active injection wells in the area
- Focal mechanisms are mostly consistent with the regional stress field

Future & Ongoing Work

- Conduct a 1-D seismic reflection survey in the area
- Conduct a detailed gravity survey of the area
- Add cross-correlation data to the HYPODD relocations
- Recalculate focal mechanisms using improved HYPODD locations

References

Chiu, J.M., A.C. Johnston, A.G. Metzger, L. Haar, and J. Fletcher (2002), Analysis of Analog and Digital Records of the 1982 Arkansas Earthquake Swarm, Bull. Seismol. Soc. Amer. 74(5), p. 1721-1742.

Hardebeck J.L. and P.M. Shearer (2002), A New Method for Determining First-Motion Focal Mechanisms, Bull. Seismol. Soc. Amer. 92(6), p. 2264-2276.

Luza, K. V., and Lawson, J. E., Jr., 1982, Seismicity and tectonic relationships of the Nemaha uplift in Oklaho- ma—part IV: Oklahoma Geological Survey Special Publication SP82-1, 52 p.

Waldhauser, F. and W.L. Ellsworth, 2000, A double-difference earthquake location algorithm: Method and application to the northern Hayward fault, Bull. Seismol. Soc. Am., 90, 1353-1368.