The 2012 Montes Claros earthquake sequence in the São Francisco craton: another evidence of inverse faulting and compressional stresses in Eastern Brazil.

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This paper was prepared for presentation during the 13th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 26-29, 2013.

Small earthquakes with magnitudes up to 3.5 had been occurring in Montes Claros, MG, since about 1995. On 19-May-2012 a magnitude 4.0 event frightened the population and caused damage in several poorly built houses (intensities V to VI MM). A network of nine stations, deployed by the universities of Brasília and São Paulo, showed that the events are concentrated in two small areas on the northwestern side of the town. The main activity occurs in a NNW-SSE trending, ESE dipping inverse faulting. The event depths range from about 1 to 2 km, well beneath the thin Bambuy limestone layer. The focal mechanism is similar to those of the 1990 swarm in Manga, MG, and the 2007 Itacarambi, MG. This finding confirms that this area of the São Francisco craton has a regional compressional field roughly E-W oriented.

Introduction

Seismic activity in Montes Claros have been felt and recorded by regional stations since 1995 (Fig. 1), although an unconfirmed report of a small tremor felt in 1978 had been mentioned by Berrocal et al.(1984).

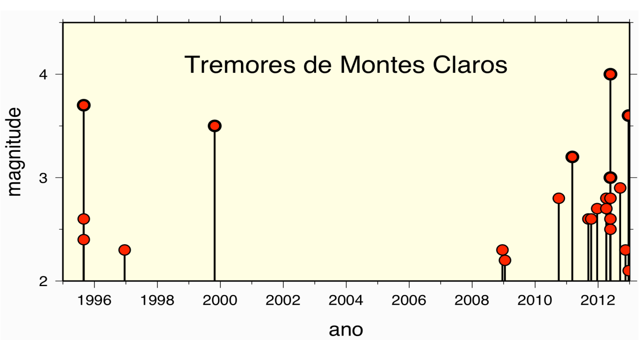

Fig. 1. *Temporal evolution of earthquakes in Montes Claros, MG, since 1995.*

On May 19, 2012, an event with magnitude 4.0 was strongly felt in the town causing damage to some poorly built houses (intensity V to VI MM) and prompted the installation of a 9-station network by the universities of Brasília (five stations) and São Paulo (four stations). This paper presents the main results of this network: identification of two active areas, relative location of the main shock, and a composite focal mechanism showing reverse faulting.

Magnitude and location of the largest events

Fig. 2 shows some of the regional stations that recorded the mainshock of May 2012. No local station was available and the closest station (PMNB) was about 340 km away. The regional magnitude of this event, as measured by eight regional stations, was m_R= 3.9, and the teleseismic P-wave magnitude (NEIC/ISC) was m_b= 4.1. These two magnitude scales are equivalent (Assumpção, 1983) and so the best value for the main event magnitude is 4.0.

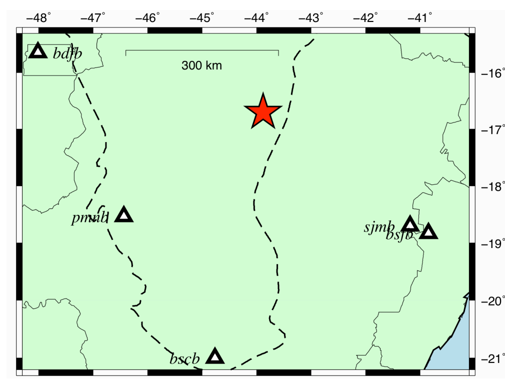

Fig. 2. *Regional stations used in the relative location of the mainshock of 19-May-2012.*

The epicenter of the main event cannot be accurately determined by the regional stations only. For this reason, a relative location was obtained using as master (reference) event a strong aftershock (magnitude 2.9) well recorded by the 9 stations of the local network. Both P- and S-wave arrivals were determined by waveform cross-correlation, as seen in Fig. 3. The station residuals of the master event at the regional stations were used as station corrections to locate the main event more accurately.

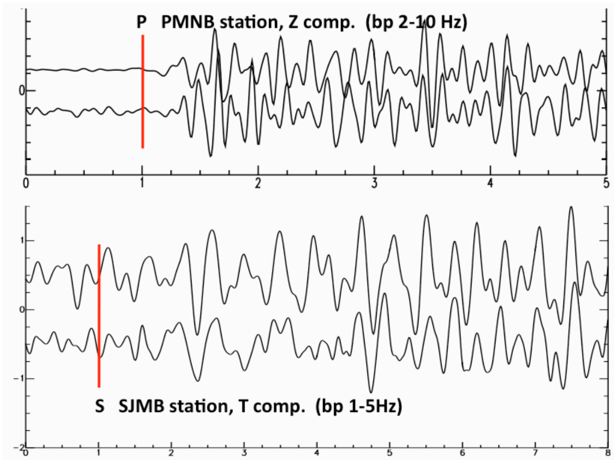

***Fig. 3**. Example of cross-correlation of P and S waveforms at stations PMNB and SJMB. Top trace is the 19-May (mainshock), bottom trace is the 12-September (master event). Vertical lines show the picked arrival times. Horizontal scale is in seconds.*

To locate the events with the local network, a velocity model was derived using two shallow layers similar to the model used in the Itacarambi area, representing the weathered and intact limestone layers, with thicknesses of 10 m and 40 m, and P-wave velocities of 4.4 km/s and 5.5 km/s respectively. A half-space velocity, beneath these two layers, was determined as the one that best located four quarry blasts from local mining areas. The best half-space velocity of 5.75 km/s locates the four quarry blasts with a mean error of ~250 m. This velocity also produces the least rms residuals for all local events. A constant Vp/Vs ratio of 1.68 was determined with a composite Wadati diagram.

Table 1 shows the locations and magnitudes of the four largest events occurred until December 2012. The main shock of 19-May-2012 and the two events of 19-December were located using the Sept.-12 aftershock as reference event. Cross-correlation of P and S arrivals were used. For the 19-May, five regional stations were used; for the 19- December only four local stations were used. The depths of these events show that they occur in the igneous/metamorphic basement of the upper crust, well beneath the limestone layers.

Table 1. Largest events in Montes Claros, 2012.

Date YYYY-MM-DD	Time (UTC	Latit.	Long.	depth (km)	mag
2012-05-19	13:41:22.56	-16.6955	-43.8828	1.1	4.0
2012-09-12	23:56:45.75	-16.7033	-43.8798	1.2	2.9
2012-12-19	04:54:38.57	-16.6972	-43.8783	1.8	3.6
2012-12-19	05:31:16.93	-16.7005	-43.8790	1.5	3.6

Faulting mechanism

Fig. 4 shows the hypocenters of the four largest events listed in Table 1, together with several smaller aftershocks of the September-12 event. These smaller aftershocks were also located by cross-correlating the P- and S-wave arrivals with the same master event of September 12. The hypocenters define a NNW-SSE oriented fault dipping to the ESE, as seen in the bottom part of Fig.4.

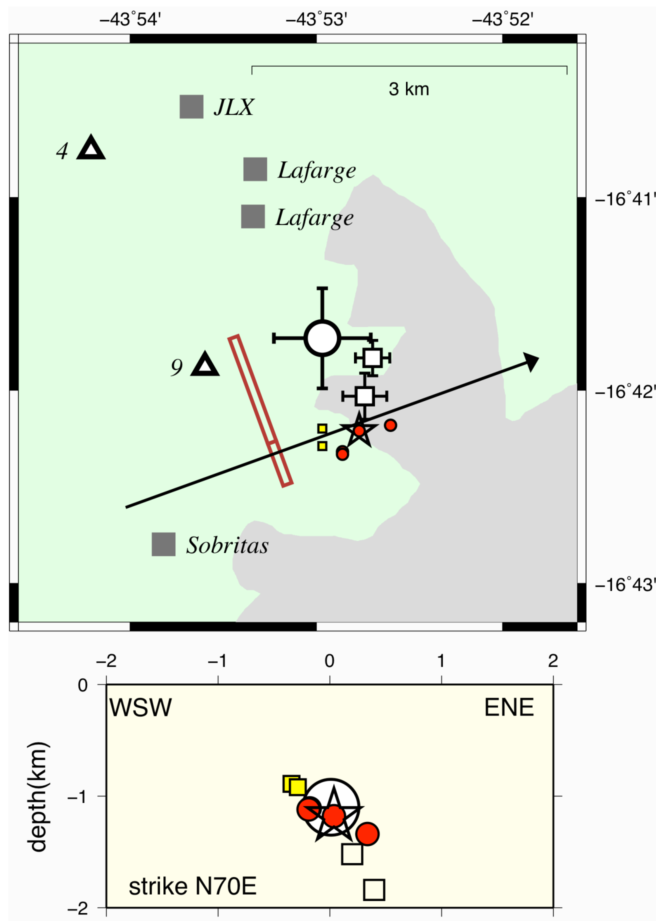

***Fig. 4. <u>top</u>**) Epicenters of the four largest events, Table 1: white circle=19/05 mainshock; white squares=19/12; white star=12/09. Small yellow squares and red circles are smaller aftershocks of the 12/09 event. Triangles show some of the local stations. Dark gray squares are quarry locations, and light gray shade indicates the Montes Claros urban area. The arrow indicates the projection direction (dip direction of 70^o E of N) shown in the bottom figure, The brown double line indicates the approximate location of the fault plane at the surface (uncertainty about +- 0.5 km). **<u>bottom</u>**) projection of the hypocenters on a vertical plane in the direction of the arrow showing a fault dipping about 45^o to the ESE.*

Fig. 5 shows a preliminary composite focal mechanism solution using P-wave polarities mainly from the local stations. The polarity data indicate an E-dipping nodal plane roughly in the WNW-ESE direction, consistent with the hypocentral distribution of Fig. 4.

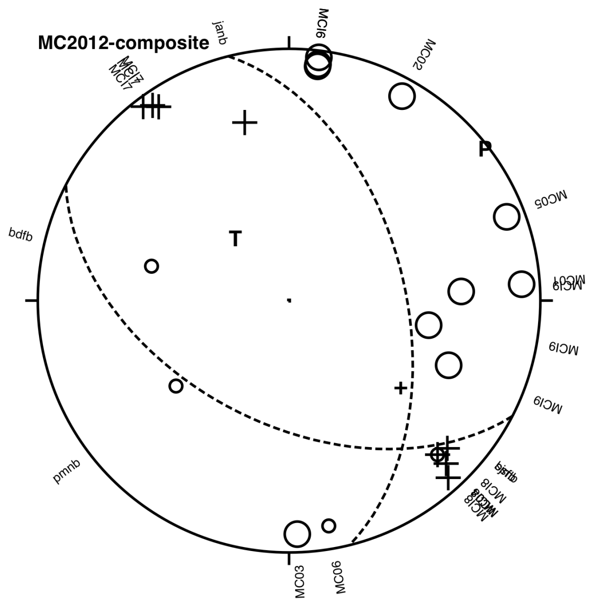

***Fig. 5**. Composite fault plane solution for the main seismic area of the 2012 Montes Claros sequence. Crosses are forward motion of the P waves, circles are backward motion. The strike, dip and rake of the two nodal planes are: a) fault: 346°, 52°, 125°, b) auxiliary plane: 117°, 50°, 54°. The "P" and "T" axes are the diretions of compressional and extensional stresses released by the earthquakes.*

Fig. 6 shows the locations of the houses most affected by the two magnitude 3.6 events of December 19th, according to the telephone calls made to the Fire Department and Civil Defense. Most houses are less than ~ 1 km from the two epicenters, and probably lie near the lobe of maximum radiation of the S-waves. These felt reports are consistent with the hypocentral location of the two events, considering their depths of 1.8 and 1.5 km.

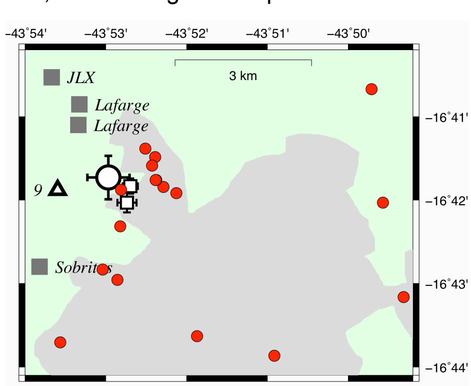

***Fig. 6**. Location of residences (red circles) that called the Fire Department and Civil Defense on the night of December 19th, 2012. Other symbols as in Fig. 4.*

Discussion and Conclusions

The Montes Claros 2012 earthquake series occurred mainly in a small geological fault (or fracture) in the upper crustal basement, at approximately 1-2 km depth. The aftershock sequence seems to indicate that the main event of 19-May-2012 had a rupture length of about 1 km or less, consistent with a P-wave magnitude of 4.0.

The focal mechanism (East dipping reverse fault) is similar to the faulting mechanism of the 4.9 m_b Itacarambi earthquake of December 9, 2007 (Chimpliganond et al. 2010), as well as the 1990 swarm of events in Manga, northern Minas Gerais (Fig. 7). All these events occurred as shallow (less than 2 km), reverse faults under the present ~E-W oriented regional compression. The stress field in this area of the São Francisco craton (northern Minas Gerais) seems to be slightly different from the stresses in the southern part of the craton (Southern Minas Gerais) where stresses are characterized by ~E-W compression and N-S extension (Assumpção et al., 1998).

It seems that in the Eastern part of the São Francisco craton, most earthquakes occur on E-dipping basement faults, probably as reactivation of upper crustal faults originated during the Araçuaí fold belt thrusting.

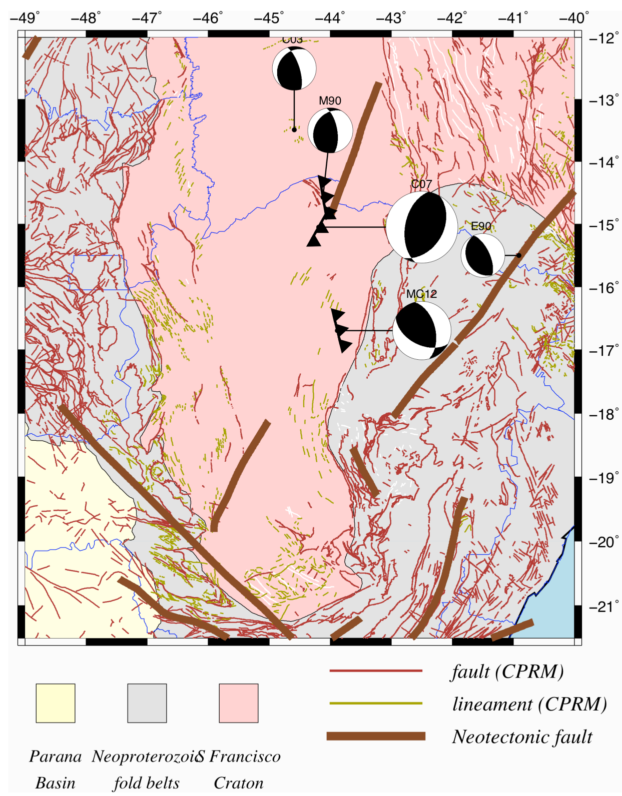

***Fig. 7**. Focal mechanisms in the central part of the São Francisco craton. Faults and lineaments from CPRM database. Neotectonic faults as proposed by Saadi et al. (2002). The barbed lines indicate the orientation and fault movement of the three fault mechanisms with known fault plane (<u>line size not to scale</u>!).*

Acknowledgments

We thank the Montes Claros Civil Defense and Prefecture for field support during the installation of the seismic network. We thank Hans Agurto for improvements in the text.

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