Item #2 - Day1

Reevaluation of the Magnitudes of Three Destructive Aftershocks of the 1886 Charleston Earthquake

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ABSTRACT

A review of newspaper reports of the three largest aftershocks of the August 31, 1886 Charleston earthquake, which occurred on October 22, 1886 (5:20 AM and 2:45 PM local time) and on November 5, 1886 (12:20 PM local time), documents that they were felt over larger areas than those listed in current catalogs. We estimated felt areas and area within various isoseismal levels. Using recursion relationships of Johnston (1996) between intensity areas and their seismic moments, we have calculated their moment magnitudes. Our results give M_w of 5.1, 5.7, and 5.3 for the three events, significantly greater than the m_b 4.4, 4.7, and 4.4, respectively, listed in current catalogs. These new magnitude estimates are probably more reasonable values for the largest aftershocks of the M 7.3 mainshock.

INTRODUCTION

The destructive Charleston, South Carolina earthquake of August 31, 1886 was followed by thousands of aftershocks. These include two large earthquakes on October 22, 1886 at 5:20 AM and 2:45 PM local time (10:20 and 19:45 UTC) and one on November 5, 1886 at 12:20 PM local time (17:20 UTC). These events were felt over a large area and were assigned Rossi-Forel intensities of VII, VIII, and VIII respectively by Taber (1914). However, in the seismic history of the United States (Coffman and von Hake, 1973) and later in a map of the seismicity of South Carolina (Reagor *et al.*, 1980), these events were assigned Modified Mercalli Intensity values of VI, VII, and VI respectively, and a felt area of 30,000 square miles (~77,000 km^2) for each of the three events.

During the Electric Power Research Institute study of seismicity in central and eastern North America various intensity values of earthquakes were converted to magnitude scales (EPRI, 1986). The current EPRI/VPI catalog for the southeastern United States (Chapman, personal communication, 1996) and South Carolina catalog (Talwani, 1996) list the magnitudes of these events as m_b 4.4, 4.7, and 4.4 respectively. These magnitudes were derived from a relationship developed between magnitudes and maximum Modified Mercalli Intensity and between magnitudes and felt area, by Sibol *et al.* (1987), using the intensities and felt areas listed in the United States earthquake catalog (Coffman and von Hake, 1973). In this note we report on the reevaluation of the magnitudes of these events by examining first-hand reports and using recently derived recursion relations by Johnston (1996). We conclude that the magnitudes in the current catalogs are too low.

THIS STUDY

The magnitude of the August 31, 1886 earthquake has been estimated by many authors, most recently by Johnston (1996), who assigned it a moment magnitude of M_w 7.3. (See that study for earlier estimates.)

We evaluated newspaper accounts of these aftershocks at different locations and assigned them intensity values (Tables 1 and 2). These were then plotted on a map of South Carolina (Figures 1 to 3) and an estimate made of the radii of the felt area and of areas of MMI IV and V shaking (assuming circular isoseismals). The epicenters of the shocks were taken to be midway between Summerville and Middleton Place, the location of current seismicity and also near the highest intensities for the three events (32°58′N, 80°10′W). We estimated the moment magnitudes of these events by using Johnston's (1996) recursion relationships between felt areas, various Modified Mercalli Intensity isoseismal areas (*e.g.*, A_{IV}, A_V), and moment magnitudes (M_o) for earthquakes in North America:

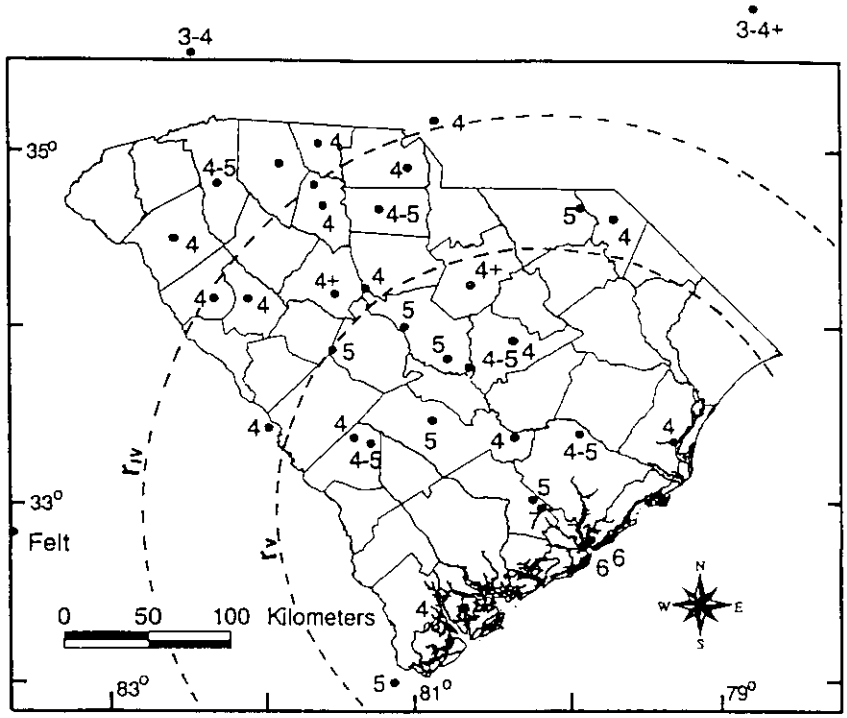
$$\begin{aligned} \log M_o &= 19.67 + 0.440 \log A_{felt} + 0.00168\sqrt{A_{felt}} \\ \log M_o &= 18.53 + 0.823 \log A_{IV} + 0.00188\sqrt{A_{IV}} \\ \log M_o &= 20.29 + 0.574 \log A_V + 0.00282\sqrt{A_V} \end{aligned} \qquad (1)$$

TABLE 1
Intensity Reports for the October 22, 1886 Earthquake at 10:20 UTC and 19:45 UTC

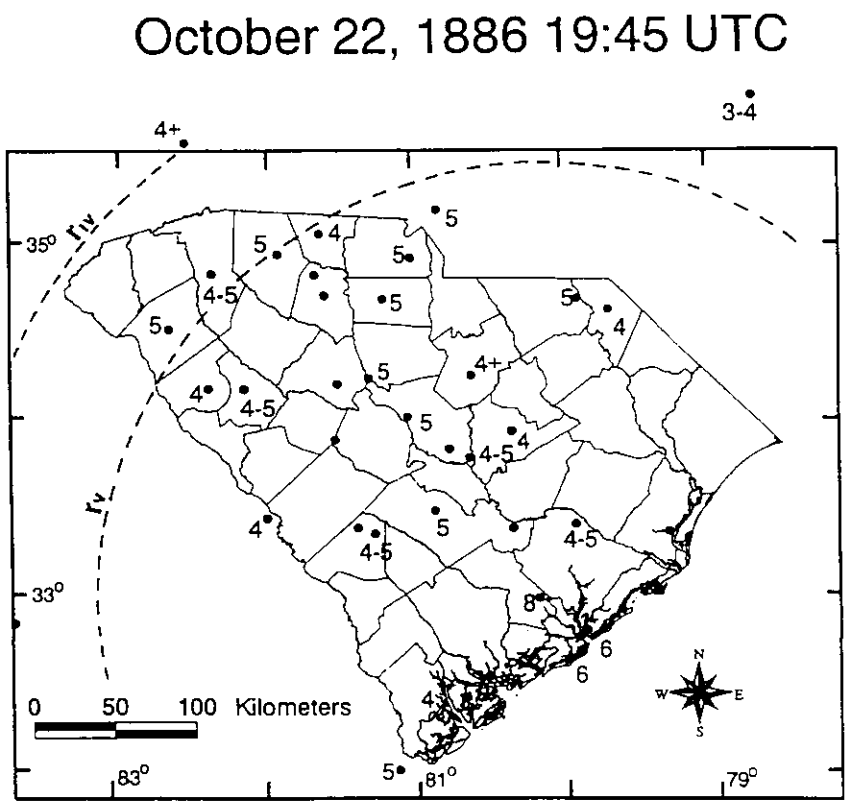
Location	Latitude	Longitude	Epicentral Distance (km)	MM Intensity	
				10:20 UTC	19:45 UTC
Abbeville	34°11′N	82°23′W	245	IV	IV
Alston	34°15′N	81°19′W	175	IV	V
Anderson	34°31′N	82°39′W	285	IV	V
Asheville, NC	35°34′N	82°33′W	380	III–IV	IV+
Atlanta, GA	33°46′N	84°25′W	313	Felt	
Augusta, GA	33°27′N	82°00′W	180	IV	IV
Batesburg	33°54′N	81°33′W	165	V	
Beaufort	32°26′N	80°41′W	75	IV	IV
Bennettsville	34°38′N	79°41′W	185	IV	IV
Blackville	33°22′N	81°17′W	110	IV–V	IV–V
Camden	34°16′N	80°37′W	145	IV+	IV+
Charleston	32°47′N	79°55′W	40	VI	VI
Charlotte	35°12′N	80°50′W	275	IV	V
Chattanooga, TN	35°04′N	85°15′W	535	Felt	
Cheraw	34°42′N	79°54′W	190	V	V
Chester	34°42′N	81°13′W	215	IV–V	V
Columbia	34°02′N	81°03′W	140	V	V
Columbus, OH	39°59′N	82°59′W	835		Felt
Eutawville	33°24′N	80°21′W	50	IV	
Gadsden	33°51′N	80°46′W	110	V	
Gaffney	35°04′N	81°39′W	245	IV	IV
Georgetown	33°22′N	79°18′W	90	IV	
Greenville	34°50′N	82°22′W	290	IV–V	IV–V
Greenwood	34°11′N	82°09′W	230	IV	IV–V
Jedburg	33°03′N	80°14′W	11	V	
Jonesville	34°50′N	81°41′W	250	IV	
Louisville, KY	38°13′N	85°44′W	788		Felt
Macon, GA	32°50′N	83°39′W	335	Felt	
Mount Pleasant	32°49′N	79°52′W	40	VI	VI
Orangeburg	33°30′N	80°52′W	85	V	V
Prosperity	34°13′N	81°32′W	185	IV+	
Raleigh, NC	35°49′N	78°40′W	345	III–IV+	III–IV
Richmond, VA	37°32′N	77°28′W	575		Felt
Rock Hill	34°56′N	81°01′W	330	IV	V
Saint Stephen's	33°25′N	79°56′W	50	IV–V	IV–V
Savannah, GA	32°01′N	81°08′W	130	V	V
Spartanburg	34°57′N	81°56′W	275		V
Summerville	33°00′N	80°11′W	5	VII	VIII
Sumter	33°57′N	80°21′W	105	IV	IV
Union	34°43′N	81°37′W	235	IV	
Washington, DC	38°54′N	77°01′W	725		Felt
Wateree	33°48′N	80°38′W	100	IV–V	IV–V
Williston	33°24′N	81°24′W	125	IV	
Wilmington, NC	34°13′N	77°55′W	245	IV	V

TABLE 2
Intensity Reports for the November 5, 1886 Earthquake at 17:20 UTC

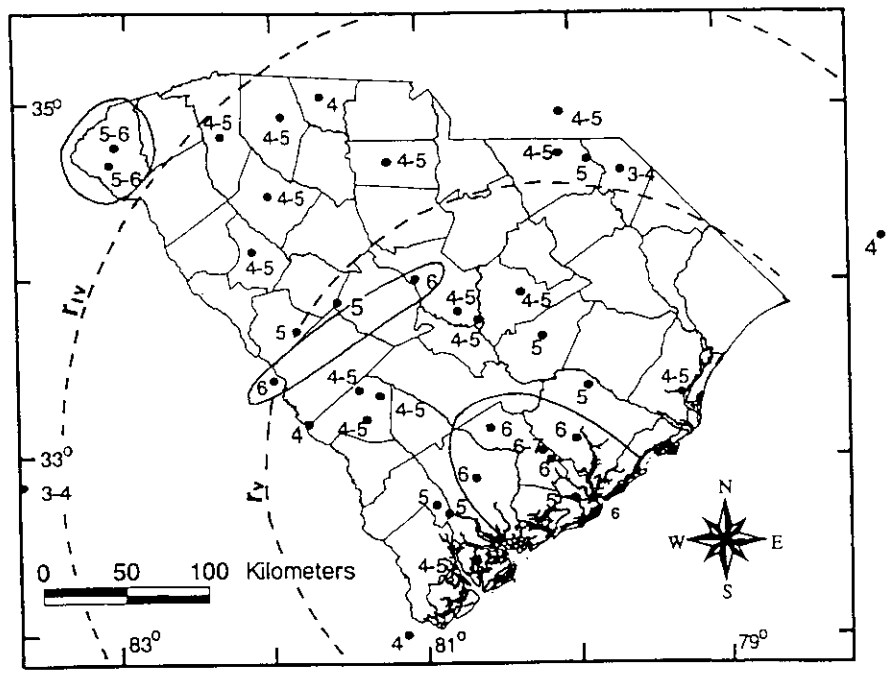
Location	Latitude	Longitude	Epicentral Distance (km)	MM Intensity 17:20 UTC
Augusta, GA	33°27′N	82°00′W	180	VI
Barnwell	33°14′N	81°22′W	115	IV–V
Batesburg	33°54′N	81°33′W	165	IV–V
Beaufort	32°26′N	80°41′W	80	IV–V
Bennettsville	34°38′N	79°41′W	185	III–IV
Blackville	33°22′N	81°17′W	115	IV
Charleston	32°47′N	79°55′W	40	VI
Cheraw	34°42′N	79°54′W	190	V
Chester	34°42′N	81°13′W	215	IV–V
Chesterfield	34°44′N	80°05′W	195	IV–V
Columbia	34°02′N	81°03′W	140	VI
Columbus, GA	32°31′N	84°52′W	470	III
Early Branch	32°45′N	80°56′W	78	V
Ellenton	33°12′N	81°45′W	155	IV
Gadsden	33°51′N	80°46′W	110	IV–V
Gaffney	35°04′N	81°39′W	270	IV
Georgetown	33°22′N	79°18′W	90	IV–V
Greenville, AL	31°50′N	86°38′W	625	Felt
Greenville	34°50′N	82°22′W	295	IV–V
Greenwood	34°11′N	82°09′W	233	IV–V
Jedburg	33°03′N	80°14′W	10	VI–VII
Laurens	34°30′N	82°02′W	240	IV–V
Macon, GA	32°50′N	83°39′W	380	III–IV
Manning	33°42′N	80°13′W	80	V
Oakland	32°47′N	80°02′W	27	V
Oakley	33°07′N	80°01′W	20	VI
Raleigh, NC	35°49′N	78°40′W	350	III–IV
Richmond, VA	37°32′N	77°28′W	575	Felt
Saint George	33°11′N	80°34′W	45	VI
Saint Stephen's	33°25′N	79°56′W	55	V
Savannah, GA	32°01′N	81°08′W	130	IV
Spartanburg	34°57′N	81°56′W	275	IV–V
Summerville	33°00′N	80°11′W	5	VI
Sumter	33°57′N	80°21′W	105	IV–V
Trenton	33°44′N	81°50′W	180	V
Wadesboro, NC	34°58′N	80°04′W	220	IV–V
Walhalla	34°46′N	83°04′W	335	V–VI
Walterboro	32°54′N	80°40′W	50	VI
Washington, DC	38°54′N	77°01′W	725	Felt
Wateree	33°48′N	80°38′W	105	IV–V
Westminster	34°40′N	83°06′W	330	V–VI
Williston	33°24′N	81°25′W	130	IV–V
Wilmington, NC	34°13′N	77°55′W	240	IV
Yemassee	32°42′N	80°51′W	75	V



▲ **Figure 1.** Intensity data for the earthquake on October 22, 1886 at 10:20 UTC. The assigned radii for intensities IV and V are shown by dashed arcs.



▲ **Figure 2.** Intensity data for the earthquake on October 22, 1886 at 19:45 UTC. The assigned radii for intensities IV and V are shown by dashed arcs.



▲ **Figure 3.** Intensity data for the earthquake on November 5, 1886 at 17:20 UTC. The assigned radii for intensities IV and V are shown by dashed arcs. Isoseismals for intensity V and VI are also shown.

The results so obtained were compared with those obtained from the relationships developed by Sibol *et al.* (1987) between body-wave magnitudes (m_b) and felt areas (FA) and epicentral intensities (Io):

$$m_b = 2.48 + 0.0769 \log^2 (FA) \quad (2)$$
$$m_b = 2.16 + 0.0219\ Io^2 + 0.0596 \log^2 (FA)$$

RESULTS

The Earthquakes of October 22, 1886

We first describe the effects of the earthquakes in the meizoseismal area and then at selected locations to estimate the felt area and outer radii for various isoseismals.

Several aftershocks occurred on October 22, 1886, of which two that occurred at 5:20 AM and 2:45 PM (local time) were widely felt. These earthquakes caused severe damage in Summerville. The *Charleston News and Courier* (*CNC*, October 23, 1886) described them as follows.

> SUMMERVILLE HOLDS HER OWN AS AN EARTHQUAKE FOCUS
>
> Summerville, October 22, 1886—The most severe earthquake shock since August 31 visited Summerville today at 2:45 PM. It was preceded at 5:20 AM by a somewhat slighter shock. The afternoon shock caused considerable damage in the way of cracking nearly all of the chimneys which had been rebuilt since August 31.
>
> The relief committee held a meeting tonight and found that at least seventy-five chimneys are so badly damaged that they will have to come down. They estimate the damage to buildings at three thousand dollars.
>
> A number of geysers have been discovered where an oily water spouts up continuously. The water has an odor similar to that of kerosene oil and is accompanied by fine sand of different colors.
>
> The people of the town are thoroughly worked up again, and great uneasiness is felt by all.
>
> The duration of the shock is estimated at from twenty to thirty seconds, and its force was so great that persons found it exceedingly difficult to open doors or get out of their houses to what they considered a safer locality, and some cases were reported where persons were thrown down by the shaking. During the day numerous slighter shocks have been felt.
>
> No damage has been done to the railroad track but the officials are keeping a close watch and are having the fast trains reduce their speed.

Based on this description we assigned a Modified Mercalli Intensity VII for the morning shock and VIII for the afternoon shock.

The morning shock awakened the folks in Charleston and damaged the Customhouse. According to the *CNC* (October 23, 1886), "The Customhouse was damaged by the shocks yesterday. The morning shock opened cracks in the brick and stonework on the east and west faces of the building. It was also found that the cracks in the crosswalls, which tied the side walls together, and which served to bind the whole structure, had opened wide enough to allow a man to thrust his hand into the cracks ...." "The shock of 2:45 ... made some ugly gaps in the external stonework and split the heavy lintel immediately over the capital at the southeast angle of the building." We have assigned intensities of VI to both the shocks at Charleston.

Estimating Felt Areas

The early morning earthquake was felt as far as Chattanooga, Tennessee (535 km). Reports in the *CNC* (October 24, 1886) described the earthquake in the following terms.

> Chattanooga, October 22, 1886—A distinct shock of earthquake was felt here at 4:15 this morning. The earthquake oscillated very perceptibly, and many awakened, but the shock was so slight that it created no alarm.

We have assigned a radius of ~500 km to estimate the felt area.

The afternoon earthquake, as reported in the *CNC* of October 24, 1886, was felt as far away as Columbus, Ohio (835 km); Louisville, Kentucky (788 km); and Washington, D.C. (725 km). At both Columbus and Louisville it was described as "[a] slight shock of earthquake was felt." At Columbus, Ohio, "[i]t was very perceptible in upper stories of building but not on the streets." At Louisville, the paper reported "[i]t lasted five seconds and vibration was nearly north and south." At Washington, D.C., "... the shock was so distinct on the fourth floor of the State, War, and Navy Building that some clerks became alarmed and ran into the corridor. On the lower floors of the building, however, no one seems to have noticed any unusual disturbance."

We have assigned a radius of ~725 km to estimate the felt area.

Estimating Area of Intensity IV Shaking (A_{IV})

For the morning shock we estimated a MMI IV at Abbeville (245 km); Anderson (285 km); Charlotte, North Carolina (275 km); Gaffney (245 km); Greenwood (230 km); Jonesville (250 km); Rockhill (230 km); Union (235 km); and Wilmington, North Carolina (245 km) (Table 1). At these places the earthquake was described variously as a "severe", "considerable", "sharp", or "heavy" shock that shook houses and woke up people.

We have assigned a radius of ~245 km to estimate A_{IV}.

The afternoon shock was more heavily felt and caused panic and people to run outdoors. At Asheville, North Carolina (380 km), the *CNC* reported that "[t]his afternoon ... a severe shock was felt. Many people rushed from their houses into the street ...."

We have assigned a radius of ~380 km to calculate A_{IV} for the afternoon shock.

Estimating Area of Intensity V Shaking (A_V)

For the morning shock we estimated a MMI V at Batesburg (165 km), Cheraw (190 km), Columbia (140 km), and Spartanburg (275 km). At Cheraw, the *CNC* described the event: "... aroused all the sleepers ... lasted seventeen or eighteen seconds ... the shock was preceded by an unusually loud rumbling sound. The earthquake motion made things lively, during its continuance, rattling the furniture and kitchen and pantry stock with much violence." At Spartanburg "[d]oors and windows rattled and people were aroused suddenly from their morning nap." At Batesburg "... the walls of the houses quivered audibly ...."

We have assigned a radius of ~165 km to estimate A_V for the morning shock.

For the afternoon shock we assigned an intensity V to the shaking felt at Anderson (285 km), Charlotte (275 km), Chester (214 km), Rockhill (230 km), Spartanburg (275 km), and Wilmington, North Carolina (245 km). *CNC* described the shaking at Spartanburg as "... walls swayed perceptibly here, and crockery rattled and swinging lamps moved. In some houses furniture began to move as though a spiritual medium was around. Those in stores and upper rooms ran out on the street in a hurry." At Chester, "[t]he violence of the shock ... produced a general stampede of people ...."

We have assigned a radius of ~275 km to estimate A_V for the afternoon shock.

Table 1 lists the distances and intensities for the two shocks. These intensities are plotted on Figures 1 and 2. Using the assigned radii and the recursion relations (1), we calculated the seismic moments and M_w for these events (Table 3). The resulting magnitudes are 5.1 and 5.7 for the morning and afternoon shocks respectively. For comparison, the average of the body-wave magnitudes calculated from the recursion relations (2) were 5.2 and 5.7 respectively (Table 3).

The Earthquake of November 5, 1886

The shock occurred at 12:20 PM local time. The damage was much lighter at Summerville and Charleston but greater at Jedburg than the afternoon shock of October 22, 1886. *CNC* (November 6, 1886) reported that Jedburg (10 km) experienced "... a very hard shock of earthquake, doing damage to houses and chimneys, but affording great relief in water. Our wells were raised from three and a half feet to four feet in water, and the rumbling, as thunder has been going on all night. The bricks around N. B. Field's still were badly damaged and clay chimneys that stood the first shock on the 31st of August were torn to pieces." At Summerville

TABLE 3
Calculated Magnitudes

Date/Time	Estimated Radii (km)		M_o 10^{16} Nm	M_w	Average	m_b
October 22, 1886	felt	500	5.66	5.10		
10:20 UTC	A_{IV}	245	4.88	5.06	5.2	5.2
	A_V	165	8.83	5.23		
October 22, 1886	felt	725	36.7	5.64		
19:45 UTC	A_{IV}	380	28.3	5.57	5.7	5.7
	A_V	275	56.3	5.77		
November 5, 1886	felt	600	13.2	5.35		
17:20 UTC	A_{IV}	300	10.4	5.28	5.3	5.4
	A_V	180	11.6	5.31		

"... nothing unusual occurred—the momentary excitement which it occasioned soon passed off ..." and "... none of the new brickwork in the village was thrown down or injured by the motion ...."

That the shock was of a different origin was noted by the *CNC* report from Charleston. The paper noted "that the tremor of yesterday was more nearly uniform throughout the period of its duration. It developed by slow degrees and died out in the same manner. There was not the sudden jar, which is so terrifying and which it is generally conceded, is productive of the most serious damage to buildings." "The shock of earthquake which was felt in Charleston yesterday, in common with other places over so wide an area of the country, was very decided and could not fail to arrest the attention of even the most unobservant. It was, however, neither 'sharp' nor 'severe' in any proper sense of those terms ...." The paper further noted that "[t]he shock yesterday was preceded by the usual rumbling sound, and was quite perceptible, although a good many people who were out on the streets were unaware of the perturbation. The damage to buildings was very slight, being confined to three or four dilapidated houses, parts of which were shaken down, and to broken plastering which fell a little before its natural time."

These observations suggest that the earthquake was possibly deeper and/or occurred on a fault other than the one that caused damage at Summerville on the afternoon of October 22, 1886. Another possibility is that the fault motion was of a different type or direction. We have assigned intensity values of VI–VII, VI, and VI to Jedburg, Summerville, and Charleston respectively.

Anomalous Reports

At Walhalla (335 km) in the Piedmont of South Carolina, the earthquake made "two large rents [fissures] in Reid's brick store and enlarging some made in the Courthouse during a former quake." At Westminster (330 km) "lamps were thrown from mantelpieces and broken, and other accidents are reported." We assigned intensities V–VI to these two locations (Table 2 and Figure 3), ascribed them to local effects, and did not use these distances in estimating the radius for A_V.

At Augusta, Georgia (180 km) the earthquake "created great alarm, the people all running from their homes into the streets." At Columbia (140 km) "[a] number of cracks in plastering were discovered ..." and "[t]here was ... a rush for the streets by many people. The Court of Common Pleas was in session. ... Bench, Bar, witnesses, officers and spectators stampeded ...." We have assigned an intensity VI to the effects at Augusta, Georgia and at Columbia. However, these effects are likely related to focusing of energy along the fall line (Chapman *et al.*, 1990) and have not been considered in determining A_V or A_{VI}.

Estimating the Felt Area and Areas of Intensity IV and V Shaking (A_{IV} and A_V)

The earthquake was distinctly felt in Greenville, Alabama (625 km); Richmond, Virginia (575 km); and Washington, D.C. (725 km). We have assigned a radius of ~600 km to estimate the felt area.

At most locations in the Piedmont and upper Coastal Plain of South Carolina, the earthquake was described as "severe", "severest", "considerable", "heavy", "heavier than three weeks ago", and "heaviest." We have assigned Modified Mercalli Intensities IV–V to these locations. The farthest report of MMI IV–V came from Spartanburg (275 km) where "[f]urniture and crockery rattled considerably." The earthquake was described as "quite perceptible" at Raleigh, North Carolina (350 km). For estimating A_{IV}, we assigned a radius of ~300 km.

At Cheraw (190 km), *CNC* (November 6, 1886) noted that "[t]he buildings were shaken almost as badly as by the mainshock that did so much damage to Charleston. The shock was ... thirty seconds duration ...." At Trenton (180 km), too, "Many pronounce it the severest yet experienced, excepting the one of the 31st of August." We have assigned MMI V and assigned a radius of 180 km to estimate A_V.

Table 2 lists the distances to various towns and the intensities for the November 5, 1886 shock. The intensities are also plotted on Figure 3. Using the assigned radii for the felt area and isoseismal areas and the recursion relations (1) we calculated the seismic moment and M_w for the event (Table 3). An average value of M_w 5.3 was obtained. The average of corresponding body-wave magnitude calculated from recursion relations (2) is 5.4 (Table 3).

Sources for the Three Aftershocks of the August 31, 1886 Earthquake

Another observation suggests that these earthquakes may have been associated with two or more faults. For example, reports from Columbia described the morning earthquake on October 22, 1886 (*CNC*, October 23, 1886) thus: "It was preceded by loud sound and vibrations seems to be vertical instead of lateral as they usually are. ... The sound and shake together ... lasted fully a minute", whereas "At 2:45 this afternoon without any premonitory sound there was a strong shake of some ten seconds in duration." At both Charleston and Savannah the morning shock was accompanied by a noise and lasted longer than the afternoon shock. At Mount Pleasant, too, the afternoon shock was felt but was not accompanied by a sound, whereas the morning shock aroused the whole village. As we have seen earlier, the November 5 event caused major effects at Jedburg but not at Summerville, unlike the October 22 afternoon shock. These observations suggest the possibility of multiple sources for the three aftershocks of the August 31, 1886 earthquake.

CONCLUSIONS

The results of reevaluation of the first-hand accounts of the three large aftershocks of the August 31, 1886 earthquake that occurred on October 22 and November 5, 1886 suggest that their magnitudes are larger than those listed in current catalogs. The new magnitudes M_w 5.1, 5.7, and 5.3 should perhaps be incorporated in assessing the seismic hazards in the region. There is a conspicuous absence of M 5+ aftershocks for the 1886 event in the current analyses of magnitude relations for the Charleston area (*e.g.*, see Bollinger *et al.*, 1989).

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