

# HISTORY OF EARTHQUAKE ACTIVITY IN COLORADO

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## ABSTRACT

A qualitative evaluation in terms of intensity based on felt reports recorded in the press is presented for the period 1870 to 1967. After 1962 short period instruments of high magnification were available for quantitative evaluation. This report concludes that:

1. The majority of earthquake activity in Colorado occurs west of the mountain front.

2. No earthquake with intensity greater than VII on the Modified Mercalli Scale has occurred in Colorado in the past 100 years.

3. The VII intensity earthquake of November 7, 1882, *could* have been similar in magnitude and location to the August 9, 1967, quake discussed in the preceding report. This would be consistent with the idea that significant strain energy is stored near Denver and while its release can conceivably be triggered by fluid injection in the Arsenal well, it can also occur spontaneously.



The first known reference to an earthquake in Colorado is in the Colorado Transcript of December 7, 1870. A careful observer at Fort Reynolds, 20 miles east of Pueblo, noted that bottles standing 1 inch apart were knocked together violently. The first seismograph in Colorado was installed at Regis College in 1909 by Father Armand W. Forstall; however, it was not until the early 1960's, when the Federal nuclear detection program (Vela Uniform) and Federal and State programs directed toward the study of the Commerce City earthquakes provided funds, that seismographs of sufficient quality and in sufficient quantities were available to properly locate and evaluate Colorado earthquakes. Thus for earthquakes from 1870 to about 1962, we must rely almost entirely on felt reports as they were published by our newspapers.

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The newspaper reporter has a very difficult job when dealing with earthquakes for he must deal with subject matter from a field in which he has no training, and he must write a paper which the public will buy. Under these conditions even conscientious reporters may contaminate the noninstrumental data while unscrupulous reporters may invent or exaggerate felt reports. The people also give reporters grossly exaggerated reports merely in hopes of seeing their names in print. The above mentioned factors tend to make earthquakes appear to have been more violent than they actually were.

The low population density of most parts of Colorado, on the other hand, tends to produce a paucity of felt reports, none of which may be from the direction of maximum acceleration. Of course, this is especially true for the larger earthquakes. This often makes the earthquake appear to have been smaller than it was.

The following table is a summary of the history of earthquake activity in Colorado. Columns 1 through 6 are self-explanatory. Columns 7 and 8 are noninstrumental data which were, for the most part, derived from newspapers. Each component of column 7 is the area of the smallest circle that could be drawn to enclose all locations where an earthquake was felt. Each component of column 8 is the maximum intensity (Modified Mercalli Scale, 1956 version) that could be given to a felt report. Column 9 of table 1 gives Richter magnitudes as obtained primarily from seismograms of the Cecil H. Green Geophysical Observatory at Bergen Park.

The table indicates that for the period January 1962 through August 1967 the relationships between the noninstrumental data (maximum observed intensity,  $I_M$ , and circular felt area in thousands of square miles,  $F$ ) and the instrumental data (magnitude,  $M$ ) are given by

$$M = \frac{I_M + 3}{2} \pm 0.6,$$

for  $5 > M > 3$ .

$$M = \log_{10} F + 4 \pm 0.6$$

These relationships permit one to make crude estimates of the magnitudes of earlier earthquakes of Colorado. As an example of the use of these relationships, one might observe that the maximum observed intensity, VI, of the Pueblo earthquake of 1870 implies a magnitude of  $4.5 \pm 0.6$  while the larger felt area, 62,000 square miles implies a magnitude of  $5.3 \pm 0.6$ . This result could be interpreted either that no one was in the epicentral region at the time of the felt reports from Golden were fictitious. Of course, there is a

LIST OF COLORADO EARTHQUAKES

Year	Date	Local time	Locality	N. lat.	W. long.	Circular felt area Thousands of sq. mi.	Max. observed	
							M.M. intensity	Richter magnitude
1870	4 Dec.	05:00	Pueblo	38.5	104	62	VI	
1871	9 Nov.	10:15	Georgetown	39.7	105.7	—	IV	
1880	16 Sept.	24:00	Aspen	39.3	106.7	—	VI	
1882	7 Nov.	18:30	Denver?	40?	105?	460?	VII	
1882	10 Nov.	a.m.	Gunnison	38.6	107.0	—	IV	
1882	23 Nov.	—	Silverton	37.7	107.7	—	IV	
1886	July	—	Lake City	38.2	107.3	—	?	
1888	23 Oct.	11:40	San Isabel Nat. Forest	38.1	105.2	2.5	IV	
1889	15 Jan.	—	Glenwood Spgs.	39.5	107.3	—	V	
1891	Dec.	—	Axial Basin	40.5	108	1	VI	
1894	5 Aug.	05:00	Georgetown	39.7	105.7	—	V	
1895	22 Mar.	—	Steamboat Spgs.	40.5	107.1	2	V	
1901	15 Nov.	03:00	Buena Vista	38.8	106.2	—	VI	
1913	11 Nov.	14:55 } 15:18 } 16:45 }	Ouray	38.2	107.2	7.5	V	
1916	11 Oct.	22:41	Boulder	40.0	105.0	—	III	
1928	20 Apr. to 11 May	Many shocks }	Creede	37.8	107.0	3	V	

Year	Date	Local time	Locality	N. lat.	W. long.	Circular felt area Thousands of sq. mi.	Max. observed M.M. intensity	Richter magnitude
1941	13-21-27 Feb.	—	Aspen	39.3	106.8	0.3	IV	
1941	29 Aug.	—	Durango	37.3	107.7	1	V	
1944	8 Sept.	22:30	Mt. Gumnison	38.8	107.5	16	VI	
1952	7 Oct.	02:20	Conejos Co.	37.0	106.0	6	V	
1954	21 Feb.	13:20	Grand Junction	39.1	108.7	—	IV	
1955	10 Feb.	10:30	Steamboat Spgs.	40.4	106.9	6	V	
1955	2 Aug.	23:40	Lake City	38.0	107.3	6	VI	
1955	27 Nov.	22:25	Rocky Ford	38.2	103.7	0.4	IV	
1956	14 Jan.	11:49	Lamar	37.9	102.6	16	V	
		11:43						
1960	11 Oct.	01:05	Montrose	38.5	107.9	13	VI	
1960	17 Oct.	09:00	Aspen	39.2	106.9	—	V	
1961	27 Nov.	00:56	South Park	39.1	106.0	2.5	IV	
1962	13 Jan.	06:33	Montrose	38.4	107.8	0.2	IV	4.4
1962	5 Feb.	07:46	Cimarron	38.4	107.6	2.5	V	4.7
1962	17 June	17:46	Commerce City	38.3	104.9	0.6	V	3.1
1962	4 Dec.	10:50	"	39.3	104.9	7.5	V	3.6
1962	5 Dec.	06:48	"	39.3	104.9	10	V	3.8
1963	30 Jan.	16:05	"	39.3	104.9	6	IV	3.2
1963	7 Apr.	17:04	"	39.8	104.9	6	V	3.2
1963	24 Apr.	15:30	"	39.8	104.9	3	IV	3.2

Year	Date	Local time	Locality	N. lat.	W. long.	Circular felt area Thousands of sq. mi.	Max. observed M.M. intensity	Richter magnitude
1963	25 May	03:45	Commerce City	39.8	104.9	—	IV	3.5
1963	2 July	01:03	"	39.8	104.9	15	V	3.7
1963	28 July	06:19	"	39.8	104.9	—	II	3.1
1963	13 Nov.	14:34	Pueblo	38.3	104.6	—	IV	2.8
1965	5 Jan.	16:26	Rocky Flats	39.9	105.3	—	III	2
1965	16 Feb.	15:22	Commerce City	39.8	104.9	0.6	V	3.2
1965	25 Mar.	13:24	"	39.8	104.9	—	II	3.1
1965	16 Apr.	10:25	"	39.8	104.9	0.2	V	3.4
1965	14 June	03:25	"	39.8	104.9	0.05	IV	3.1
1965	18 July	15:41	"	39.8	104.9	0.3	III	3.1
1965	13 Sept.	03:58	"	39.8	104.9	0.7	V	3.8
1965	14 Sept.	16:47	"	39.8	104.9	1.8	V	4.1
1965	27 Sept.	04:34	"	39.8	104.9	0.05	IV	3.1
1965	29 Sept.	13:00	"	39.8	104.9	4.0	V	4.1
1965	20 Nov.	21:00	"	39.8	104.9	0.4	IV	3.5
1965	20 Nov.	21:03	"	39.8	104.9	16	V	4.3
1965	20 Nov.	22:01	"	39.8	104.9	0.9	V	3.8
1966	4 Jan.	17:37	"	39.8	104.9	0.8	V	3.5
1966	3 Apr.	09:21	South Park	39.2	106.0	—	—	3+
1966	8 May	10:24	Archuleta County	37.0	106.9	—	—	4.2

Year	Date	Local time	Locality	N. lat.	W. long.	Circular felt area Thousands of sq. mi.	Max. observed M.M. intensity	Richter magnitude
1966	5 July	11:27	Rangely	40.2	109.0	—	—	3.7
1966	2 Oct.	19:26	Trinidad	37.4	104.1	60	VI	4.6
1966	12 Oct.	17:33	Castle Rock	39.3	104.6	—	—	3.0
1966	1 Nov.	00:40	Glenwood Springs	39.6	107.3	—	—	3.9
1966	13 Nov.	08:17	Commerce City	39.8	104.9	0.1	III	3.1
1966	14 Nov.	13:02	Commerce City	39.8	104.9	10	VI	4.2
1966	19 Dec.	14:52	Aspen	39.3	106.7	—	III	3.3
1967	16 Jan.	02:23	Silverton	37.7	107.7	—	—	4.1
1967	2 Feb.	22:28	Commerce City	39.8	104.9	—	III	3.3
1967	15 Feb.	20:28	Rangely	40.1	109.1	—	—	4.4
1967	4 Apr.	15:54	Montrose	38.2	107.5	—	—	3.0
1967	10 Apr.	12:00	Commerce City	39.8	104.9	12	VI	4.7
1967	10 Apr.	12:36	Commerce City	39.8	104.9	—	—	3.5
1967	27 Apr.	10:24	Commerce City	39.8	104.9	4	V	3.8
1967	27 Apr.	10:25	Commerce City	39.8	104.9	—	—	3.3
1967	9 Aug.	6:25	Commerce City	39.8	104.9	—	—	4.3
1967	9 Aug.	6:25+	Commerce City	39.8	104.9	45	VII	5.3

distinct possibility that no one was in the epicentral region *and* the reports from Golden were fictitious.

The known significant earthquakes of Colorado from 1870 to 1967 are shown on plate 1 in the pocket. Roman numerals and the radii of the open circles denote maximum observed intensity. Two digit Arabic numbers denote the year of the earthquake. Large, irregular, solid black regions represent post-Oligocene (less than  $26 \times 10^6$  years) extrusive volcanic rocks. This map indicates that the majority of Colorado earthquakes in this period have been west of the Rocky Mountain Front Range (roughly  $105^\circ$  W) and within 50 miles of post-Oligocene extrusives. This is not surprising because most of the earthquakes of the world exhibit the same relationship to extrusives. In addition to the above mentioned epicenters there appears to be an active zone near the Arkansas River.

The earthquake of November 7, 1882, deserves special mention. This event was reported to have been felt throughout Colorado and in southern Wyoming, supposedly causing a near panic in the jail in Golden and causing some damage immediately north of Denver. If the previous equations are applied to this earthquake, then the maximum observed intensity of VII yields a Richter magnitude of  $5.0 \pm 0.6$  while the circular felt area of 460,000 square miles yields of magnitude of  $6.7 \pm 0.6$ . This discrepancy is probably indicative of the unreliability of felt reports.

Felt reports from 25 newspapers, which were published in 1882, were used to estimate the intensities shown on plate 2. From this map one can see that the felt reports for the 1882 earthquake are inconsistent with any one epicenter; however, it is difficult to imagine 3 or 4 earthquakes occurring almost simultaneously at widely separated points or to think of some other phenomena which might explain these reports. If one assumes that there was but one earthquake then many of the felt reports must be discounted. These newspaper stories are reproduced in the Appendix.

The intensity IX in the western part of the State is probably not valid. It is inconsistent with almost all of the other reports.

The reports along the Union Pacific Railroad in southern Wyoming are not so easily discounted; however, it is conceivable that these are but a hoax perpetrated by one telegraph operator or reporter in Laramie or Cheyenne. If Colorado can conclude a very exciting election day with an earthquake, Wyoming should certainly do as well and perhaps have pyrotechnics above the capital city of Cheyenne. This hoax theory is partially substantiated by an investigation of the Carbon County Journal of Rawlins, Wyoming, which revealed no local report of the earthquake. The hoax theory is weakened by the fact that the Laramie Sentinel of November 11 and the Cheyenne Daily Leader of November 8 do give reports; however, no names of

observers are given and the articles seem to be more of the nature of editorials. The Laramie and Cheyenne articles are reproduced in the Appendix.

The report from the Gunnison Daily Review-Press of November 11, 1882, upon which an intensity of V at Gunnison was based, does not specifically state that the earthquake was felt at Gunnison. The article can be interpreted as: "some people (of Colorado) were very much frightened" and not "some people (of Gunnison) were very much frightened."

If one adopts the point of view expressed in the previous three paragraphs for the 1882 event, then a fairly consistent picture of an earthquake similar to that of August 9, 1967, emerges; i.e., magnitude 5+ somewhat north of Denver. This would be consistent with the idea that significant stress energy is stored in the earth's crust near Denver and while it can conceivably be triggered by the Arsenal well, it can also be released spontaneously.

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#### APPENDIX A

##### MODIFIED MERCALLI INTENSITY SCALE OF 1931 (Abridged and Rewritten, 1956, Richter, C.F., 1958)

- I. Not felt, marginal and long-period effects of large earthquakes.
- II. Felt by persons at rest, on upper floors, or favorably placed.
- III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
- IV. Hanging objects swing. Vibration like passing of heavy trucks—or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.
- V. Felt outdoors; direction estimated; sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
- VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle—CFR).
- VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys (also unbraced parapets and architectural ornaments—CFR). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
- VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

APPENDIX B  
NEWSPAPER ARTICLES

The following newspaper articles constitute all of the data from which the intensities of plate 2 were determined.

*Rocky Mountain News, Denver, November 8, 1882:*

About 6:25 o'clock last evening residents of that part of Denver north of Larimer street were startled by a sudden trembling of the earth. There were three distinct shocks. The first one was decidedly the strongest, oscillating from west to east and backward and forward. The second and third shocks were comparatively light, but clearly perceptible to a person standing on the ground. The shocks were more perceptible in the upper stories of buildings and caused great consternation among many of the occupants of rooms there.

A general stampede was caused among the employees of The News office, especially in the editorial rooms. The editors and reporters were seated engaged at work when the floors of the editorial rooms began to tremble violently. The first shock was followed by two lighter shocks, and for a short time it appeared as if the building was about to tumble in. The trembling ceased as suddenly as it began, lasting only a few seconds. On the streets the strange phenomenon was generally talked of by persons who had felt the shocks, and they were generally accredited to a passing earthquake. The most noticeable effect of the shock was felt at the Windsor, especially in the rooms on the upper stories. A lady named Mrs. Furst, wife of the chief clerk of the hotel, was lying ill in her room on the fifth floor. When the shocks visited the city Mr. Furst was absent from the room to his supper. He was startled by a hasty call from his wife and when he reached her room she related how the walls and floor had trembled in a violent and alarming way, as if the building were about to tumble in. It was at first supposed that Mrs. Furst was delirious, and that the trembling was only a fancy. But other women corroborated her story. Some gentlemen, who were descending the stairs in the hotel when the shocks were felt, also corroborated her story and explained how the stair case had shaken violently, making passage on them exceeding hazardous. Afterward it was discovered that all pendulum (sic) clocks, including the large railway time piece on the office floor, had stopped at 6:25 o'clock. This is one of the strangest coincidences of the phenomenon.

The shocks were also felt by a perceptible trembling on the upper floor of the Tabor block, especially in the Western Union telegraph operating room. There the operators were rocked to and fro in their chairs in a manner that alarmed them to no inconsiderable extent. The rocking ceased as suddenly as it begun, and they hardly had time to realize what was the matter. All along Larimer street the shocks were distinctly felt by occupants of business blocks, but there were no alarming consequences reported.

It seems to have affected the residence of Mr. Birks Conforth, corner of Holladay and Twenty-third streets, more than any place reported last night. His house trembled so violently that his family fled to the street, fearing that it would cave in over their heads. News reporters interviewed numerous persons last night about the strange phenomenon and in every case the story of the existence was corroborated.

The oscillations of the earthquake appeared to come from the direction of the mountains, traveling almost directly from west to east. The oscillation seemed to pass backward and forward. Interviews with old-timers last night revealed the fact that it is the first time in the history of Denver that earthquake shocks have ever been felt here.

The most peculiar feature of the earthquake is the fact that it was not felt only in the northern half of Denver, that is the portion of the city lying north of Larimer

street. (Note that this sentence is inconsistent with the first sentence of this article and with the Tribune of 9 November.) On the latter thoroughfare it was barely perceptible. Interviews with the clerks at the St. James revealed the fact that it did not visit that section of the city at all.

That it was not entirely local will be seen from the following dispatches: The Shock in Georgetown: Special to the News, Georgetown, Nov. 7.—A slight earthquake shock was felt in various parts of the city at half-past six this evening. In one store the shock was such as to cause the inmates to run out of the building. By Western Associated Press.

Georgetown, Nov. 7.—At 6:30 this evening quite a perceptible earthquake shock was noticed here.

Laramie City, Wy., Nov. 7.—An earthquake shock was experienced here at 6:30 this evening. It was felt plainly all along the line of the Union Pacific, west as far as Evanston. Plastering fell in buildings at Rawlins, Point of Rocks and other points. Trains will be sent with great care as bridges may have been thrown out of place.

Louisville, Colo., Nov. 7.—Three distinct earthquake shocks were felt here at 6:30 this evening.

*The Denver Republican, Nov. 8, 1882:*

At 6:20 o'clock last evening the shock of an earthquake was plainly felt in Denver, the buildings shaking violently. Reports from different portions of the city indicate that it was noticed and felt by hundreds of people. There was no rumbling sound or unusual atmospheric disturbance. The shock was exceedingly well defined in the business portion of the city, it being very severe where the Republican building stands. Those within the building, on the upper floors, felt the shock so sharply that they scampered for down stairs to reach terra firma. The clock at the Windsor Hotel was stopped, and at several points in the city, buildings rocked to and fro. No serious damage resulted however, so far as heard from. The shock lasted for more than a minute. Old '59ers say this is the first shock of an earthquake ever felt in Colorado.

Telegraphic reports from points outside of Denver indicate that the earthquake extended over quite a large section of the country and was quite severe.

The Shock in Georgetown, Georgetown, November 7. A slight earthquake shock was felt in various parts of the city at half-past six this evening. In one store the shock was such as to cause the inmates to run out of the building.

Laramie City's Experience. An earthquake shock was experienced here at 6:30 this evening. It was felt plainly all along the line of the Union Pacific, west as far as Evanston. Plastering fell in buildings at Rawlins, Point of Rocks and other points. Trains will be sent with great care as bridges may have been thrown out of place.

Louisville Shaken Up. Three distinct earthquake shocks were felt there at 6:30 this evening.

State at Large. The earthquake visited nearly every Colorado town.

Boulder. About 6:30 this evening an earthquake shook many houses at Boulder. At Louisville the shocks was so great that the wall of the depot was badly cracked. The ceilings of the University were stripped of plastering. Considerable damage reported elsewhere.

At Cheyenne. The earthquake here was accompanied by an electric flash that lighted up the northern sky. The shock was so violent that chandeliers and queensware in the houses rattled violently.

*The Colorado Transcript, Golden, Nov. 8, 1882:*

Last Tuesday evening every business house, office and hotel lobby was crowded with excited politicians and interested citizens, who were discussing the probable outcome of the days fight (election). Suddenly in the midst of all this confusion, came a violent shock. Strong men reeled and tottered an instant, reaching out as if to

grasp some support. Those who had experienced the sensation before, pronounced it an earthquake, but many thought it the probable explosion of the powder works at Moorsville, about four miles from Denver, on Platte river. This fear was soon dispelled by dispatches from Denver, northern Colorado and points in Wyoming relating an experience similar to that felt in Golden. In Denver three distinct shocks were felt, while in Golden there was but one at 6:30. In the larger buildings the effect was the most apparent. In the court house which is situated on higher grounds the shock was felt with alarming distinctness. Walls of the building trembled and tottered as though they would crash to the earth. Deputy Sheriff Todd, who was at his desk, felt the floor tremble, sprang to his feet and rushed into jail corridor where a scene of wildest confusion ensued. Prisoners had felt the shock and were hammering on their cell doors and calling to be released. Terror had taken complete possession of them and it was sometime before the Deputy and his Assistant could quiet their fears and restore order. In lower part of City the effect was not so violent, yet the agitation of the larger business blocks was sufficient to cause the occupants to rush out into the street as if to escape the disaster that seemed imminent. This is the second shock that has been experienced in this locality. The first one occurred about seven years ago and is vividly remembered by occupants of the Golden House. (November 25, 1875. epicenter thought to have been in Kansas.)

*Gunnison Daily Review-Press, Nov. 11, 1882:*

The usually staid and sober character of Mother Earth in this section of the country was disturbed on Tuesday night and again yesterday morning by an earthquake shock. No very great damage was done here, but some people were very much frightened.

*Rocky Mountain News, Denver, Nov. 28, 1882:*

The earthquake on the night of the 7th opened a crater in the Book Plateau Mountains about 50 miles from Grand Junction.

So say prospectors who were on the ground at the time, smelled the sulphur, saw the chasm and the smoke issuing from it.

The report of the Rocky Mountain News of November 28, 1882, was largely discounted in the location of the epicenter. This report refers to the opening of a "crater" about 50 miles from Grand Junction in the "Book Plateau Mountains." This probably means that the site was roughly 50 miles northwest of Grand Junction. If this report is assumed to be valid, then the epicenter is immediately placed at this site; however, such an epicenter is inconsistent with most of the other felt reports.

*The Tribune, Denver, November 8, 1882:*

Georgetown, Nov. 7 At half-past six this evening quite a perceptible earthquake shock was noticed here.

Laramie City, Wyoming, November 7. An earthquake shock was experienced here at 6:30 this evening and felt plainly all along the line of the Union Pacific west as far as Evanston. Plastering fell from buildings at Rawlins, Point of Rocks and other points. Trains will be sent with great care, as bridges may have been thrown out of place.

(Special Dispatch to The Tribune). Green River, Wyoming, November 7. A heavy shock of earthquake was felt here at 7 o'clock p.m. Heavy rocks came down from Castle Rock, above the town. Hon. P. J. Hines' wife was thrown from her bed. No damage to person or property has been reported as yet.

Nov. 9—The earthquake Tuesday evening not only created a sensation but did some damage. It was observed by a few pedestrians who were not particularly interested in the election returns that the electric lights were suddenly extinguished at half past 8. Among the observers was Superintendent Runkle. He went immediately to the electric light building at the foot of Twenty-first street and found that an accident had occurred to the machinery. From the driving pulley of the engine there is a connection of shafting five inches in diameter and divided into sections of 12 feet. These sections are connected by large iron belt screws an inch in diameter. After the instant of the earthquake shock one of these bolts was snapped in twain and the other bent out of shape. The whole machinery was thrown out of gear, and it became necessary to stop the machinery at once. Mr. Runkle is of the opinion that the upheaval which caused the earthquake ran east and west and centered about his establishment and the residence of Mr. Birks Cornforth. It was ascertained yesterday that the shock was so severe in the northern portion of the city that many families ran from their houses.

*Rocky Mountain Sun, Aspen, November 11, 1882:* The fact that this weekly does not mention the event discredits the intensity of V for Gunnison.

*Georgetown Courier, November 9, 1882:*

A distinct shock of earthquake was felt in Georgetown on Tuesday evening at 6:30 o'clock. It was heavy enough to make buildings rock perceptibly but not sufficient to cause much alarm although a few persons got out on the street in just a little hurry, while others felt a little sea-sick for a few moments. A shock was felt here on Thursday, Nov. 9th, 1871, at 10:15 a.m. a little heavier than the one on Tuesday, which was accompanied by a rumbling sound. The only satisfactory solution of the shock is that the mountains were trembling with indignation at the way Republicans were scratching their tickets.

At Denver the shock was frightfully perceptible in the upper stories of the Windsor hotel, the occupants thinking that the building was tumbling in. The pendulum clocks, in the building, including the large railway time-piece, stopped at 6:25.

Plastering fell in buildings at Rawlins, Point of Rocks and other places in Wyoming. Three distinct shocks were felt at Leadville.

*Castle Rock Journal, November 9, 1882:* This weekly does not mention the event.

*The Post, Central City, November 11, 1882*

Denver, November 7—At 6:20 to-night the shock of an earthquake was distinctly felt throughout the city. Some of the employees of the Western Union Telegraph company, located on the fifth floor, corner of Sixteenth and Larimer streets, fled from their apartments. There were three distinct vibrations, lasting fully twenty seconds.

Georgetown, Colo. November 7. About half-past six this evening quite a perceptible earthquake shock was noticed here.

Laramie City, Wyoming, Nov. 7. An earthquake shock was experienced here at 6:30 this evening. It was felt plainly all along the line of the Union Pacific road, and west as far as Evanston. The plastering fell from buildings at Rawlins, Point of Rocks and other points. Trains will be sent with great care over the road, as bridges may have been thrown out of place.

Cheyenne, Nov. 7. The earthquake here was accompanied by an electric flash that lighted up the northern sky. The shock was violent. Chandeliers and queensware in the houses rattled violently.

Note that this paper includes no local felt reports.

*Fairplay Flume, November 9, 1882:*

Just about the time that the polls closed on Tuesday evening a very perceptible quaking of the earth was noticed throughout the state and in Wyoming. In Boulder county the walls of the depot were cracked and plastering dropped off the State University walls in Boulder city. Denver buildings rocked and jarred, and in Rawlins, Cheyenne and Laramie the buildings and bridges were, many of them, shaken out of place. An electric flash was one of the accompanying phenomena. No other earthquake has ever been reported in Colorado.

The fact this paper devotes considerable space to the event but does not mention any local felt reports discredits the intensity V for Gunnison.

*Leadville Daily Herald, November 8, 1882:* The fact that this paper does not mention the event discredits the intensity V for Gunnison; however, it should be noted that the Georgetown Courier reported that three distinct shocks were felt in Leadville.

*Pueblo Daily Chieftain, November 9, 1882:*

A light shock of earthquake was perceptible at Georgetown and Denver last Tuesday. It also extended south of the divide, but from what we can learn at the present writing the principal sufferers were confined to the ranks of the democracy.

*Dolores News, Rico, November 11, 1882:*

An earthquake startled the people of Eastern Colorado last Wednesday. We don't know what time of day the earth will open up at our feet and swallow Rico. Whenever it does, it will have a hard dose to digest. Regarding the shock in the North the dispatches tell us that at 6:20 o'clock Wednesday evening the shock of an earthquake was plainly felt in Denver, the buildings shaking violently. Reports from different portions of the city indicate that it was noticed and felt by hundreds of people. There was no rumbling sound or unusual atmospheric disturbance. The shock was exceedingly well defined in the business portion of the city, it being very severe where the Republican building stands. Those within the building, on the upper floors, felt the shock so sharply that they scampered for down stairs to reach terra firma. The clock at the Windsor hotel was stopped, and several points in the city, buildings rocked to and fro. No serious damage resulted, however, so far as heard from. The shock lasted for more than a minute. Old '59ers say this is the first shock of an earthquake ever felt in Colorado.

Telegraphic reports from points outside of Denver indicate that the earthquake extended over quite a large section of the country and was quite severe.

Boulder, Colorado. November 7. About 6:30 this evening an earthquake shook many houses in Boulder. At Louisville the shock was so great that the wall of the depot was badly cracked. The ceilings at the University were stripped of the plastering. Considerable damage reported elsewhere.

*Lake City Mining Register, 10 November 1882:* This weekly does not mention the event.

*Silver World, Lake City, 11 November 1882:*

Only a few of our citizens felt the shock of the earthquake, Tuesday evening, about 6:20 o'clock. Yet it was a genuine earthquake—a thorough "blow-out," perhaps indicative that Bossism must die—and was forcibly felt in Northern Colorado and Wyoming.

*Huerfano Herald, La Veta, 9 November 1882:* This weekly does not mention the event.

*Saguache Advance, 9 November 1882:* This weekly does not mention the event.

*Saguache Chronicle, 10 November 1882:* This weekly does not mention the event.

*Longmont Ledger, 10 November 1882:*

It must have been quite a surprise to some of our readers, as indeed it was to the editor himself, to learn last Wednesday morning that the political cyclone which passed over our state election day, culminated in a genuine earthquake of moderate dimensions. But it seems that such was the fact. In Denver, Georgetown, Louisville, Laramie City, and probably other localities, the shock was unmistakable, and even alarming to persons of weak nerves. In the office of the Denver News, the editorial force rushed down stairs without much regard to the order of their going, under the impression that the building was about tumbling into a heap of ruins. Mr. Cornforth's house shook and trembled so violently, that the members of his family rushed pell-mell into the street.

In Laramie City, the shock was even more severe than in Denver. In Rawlins, Point of Rocks, and other points on the line of the Union Pacific railroad, some buildings received such a severe shaking up, as to dislodge large pieces of plaster from the walls, and break window glass.

It is claimed by the oldest settlers in Denver, that this is the first known instance of an earthquake having visited Colorado. And it might be added, that this is the first and only instance in the political history of Colorado, when a fall election has ever been carried by the democratic party. It was probably nature's protest, against democratic rule in the Centennial state, uttered at the time of closing the polls Tuesday evening. Nature had kept remarkably quiet during the day. But when the polls were closed, and it became evident that the democratic party was finally to take control of our state government, she could no longer control her feelings, but uttered a groan of anguish which caused the very mountains to tremble. Curious but true.

Note that no felt reports from Longmont are given.

*The Queen Bee, Denver, November 8, 1882 (published by and for the ladies):*

The papers this morning report an earthquake in Denver, Nov. 7, at six in the evening. Most of the newspapers felt the shock plainly in their offices. It was certainly a good time for a commotion. It is almost a wonder that it was not a swallowing earthquake. Likely the electrical currents were being equalized from the one-sided results of an (end of article).

*Colorado Chieftain, Pueblo, November 9, 1882:*

A slight shock of earthquake was perceptible at Georgetown and Denver last Tuesday. It also extended south of the divide, but from what we can learn at the present writing, the principal sufferers were confined to the ranks of the democracy.



*Colorado Springs Weekly Gazette, November 11, 1882:*

We learned yesterday that the shock of an earthquake so noticeable at Denver, Georgetown and other places in the northern part of the state was also perceptible here, although it was felt by comparatively few people. Mr. Fred Hart, who is a clerk at Durkee and Lee's hardware store, noticed the shock very plainly and spoke of it at the time. It occurred shortly after six o'clock. Mr. Hart at the time was sitting on the counter and felt the jar, and also noticed that the gas lights were swinging slightly. He thought that the shock was caused by the blowing open of the door of the furnace in the basement. One or two others besides Mr. Hart spoke of noticing the shock.

*Cheyenne Daily Leader, November 8, 1882:*

Last evening at half-past 6 many of our citizens were startled and somewhat alarmed by a very plainly felt earthquake shock, which rattled dishes, shook lamps and shook up people of very delicate nerves to a very unpleasant extent. The direction of the vibrations seemed to be from east to west, and its duration for nearly a minute. This was accompanied by an electrical disturbance of the air, a peculiar report and a peculiar glow in the air.

The following dispatch from Laramie City records the observance at that and other places west of the same phenomenon:

Laramie City, November 7—An earthquake shock was experienced here at 6:30. It was plainly and severely felt all along the line of the Union Pacific railway west as far as Evanston. Plastering fell off in buildings at Rawlins, Point of Rocks and other places. Trains will be sent west with great care, as bridges may have been thrown out of place.

Denver, November 7—A slight earthquake was felt in Denver and vicinity at 6:30 p.m. The occupants of high buildings ran into the streets.

*Laramie Weekly Sentinel, 11 November 1882:*

Tuesday evening at about 6:30 a very distinct shock of an earthquake was felt throughout the city. Another shock occurred at 5 o'clock Wednesday morning. The first one was noticed by nearly everybody in town, and was violent enough to cause considerable apprehension.

In several cases people ran out into the streets. Clocks were stopped, plastering cracked, crockery rattled and in a few instances glass was broken in windows. The second shock was not noticed so greatly, on account of the hour at which it occurred, but those who were awake at that hour claim that it was quite as distinct as the first.

The earthquake seems to have extended over quite an area of country. It was quite strong at Denver, where the electric lights were suddenly extinguished, and people were seriously frightened. We have reports of it all along the line of the U.P. as far west as Ogden. It is the first time we have ever been treated to such a phenomenon in this country, and the sensation produced is exceedingly novel and not particularly pleasant.

## PROPERTIES OF THE ROCKY MOUNTAIN ARSENAL DISPOSAL RESERVOIR AND THEIR RELATION TO DERBY EARTHQUAKES

G. R. PICKETT

### ABSTRACT

One purpose of this study was to establish from injection pressure and volume data and other available information the physical characteristics of the reservoir into which waste fluids were injected. These characteristics coupled with the history of earthquake activity in the immediate area lead to the following statements.

1. Analyses of fluid injection volume data and transient pressures indicate that the Rocky Mountain disposal reservoir contains a total fluid volume between 0.6 and  $1.9 \times 10^9$  barrels. The fluid pressure data indicate that the total reservoir consists of several parts which have significantly different fluid permeabilities.

The initial reservoir pressure before start of injection in 1962 is indicated to be between 300 and 1400 psi subhydrostatic. After cessation of injection in 1966, the different parts of the reservoir were at different pressures, the most permeable part having the highest pressure (about 100 psi subhydrostatic). The different parts of the reservoir are now gradually coming to a common equilibrium fluid pressure.

2. An empirical correlation exists for the injection history of the Arsenal well between cumulative number of earthquakes ( $\Sigma N$ ) and calculated static reservoir pressure ( $P_s$ ). This correlation appears to be of sufficient quality to allow prediction of the total number of earthquakes to be expected for injection of an arbitrary volume of fluid.

3. If it is assumed that each part of the reservoir follows the same pressure vs. number of earthquakes curve exhibited for the most permeable part, then the final equilibrium pressure of the entire reservoir can be estimated. A means for predicting the total number of earthquakes to be anticipated before the reservoir comes to pressure equilibrium is also implied. This possible predictive technique needs further study.

4. Empirical comparison of injection energy with earthquake magnitude shows that if injection energy is returned as earthquake energy, it is stored

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