BULLETIN 46

COLORADO EARTHQUAKE DATA AND INTERPRETATIONS 1867 TO 1985

Robert M. Kirkham
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Colorado Geological Survey
Department of Natural Resources
Denver, Colorado 1985

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ABSTRACT

Over 400 earthquakes have been felt or instrumentally recorded in Colorado since 1867. Information on the date, location, time, magnitude, depth, intensity, felt effects, pertinent references and, where available, an isoseismal or intensity map for each earthquake is included in this report. The strongest earthquakes centered in Colorado have been in the magnitude 5 1/2 to 6 1/2 range. Other strong tremors have occurred in surrounding states and their effects have sometimes been felt within Colorado.

Although no complete collapse of structures or deaths have yet resulted from a Colorado earthquake, numerous instances of minor and moderate damage have occurred. Cracked plaster, cracked walls or foundations, cracked and fallen chimneys, broken windows, dishes, and other household goods, damaged roof tiles, and other similar effects have been reported for many of Colorado's earthquakes.

Isoseismal or intensity maps for most of the larger earthquakes are presented in this report. Interesting observations and interpretations, based on these maps and the historic seismicity, are made regarding seismicity patterns, apparent favored wave paths, and earthquake sensitive areas. A map illustrating the maximum experienced intensity in Colorado since 1867 was prepared by combining the known effects of all historical earthquakes. A series of graphs relating magnitude (both ML and mb) to felt area size and maximum intensity for all Rocky Mountain region earthquakes are presented. Also included are equations that relate size of felt area to magnitude for all Rocky Mountain earthquakes.

1.0 INTRODUCTION

This report summarizes the findings of a Colorado Geological Survey (CGS) investigation of historical seismicity in Colorado. Research work was supported in part by the U.S. Geological Survey (USGS) through Grant No. 14-08-0001-G975 to develop a better understanding of seismic hazards in Colorado.

Primary goals of the first-year phase of this project include 1) compilation of a complete, up-to-date listing of Colorado earthquakes, 2) evaluation of all felt reports for historical Colorado earthquakes, 3) preparation and evaluation of isoseismal and intensity maps for selected earthquakes, 4) publication of extended abstracts or short articles summarizing recent research relevant to Colorado seismicity and seismic hazards conducted by governmental agencies and private industry, and 5) preliminary determination of seismic source zones for the state.

Items 1 through 3 are described in this report. CGS Information Series 23 provides verbatim newspaper accounts, interviews, and government records for many historic Colorado earthquakes. Item 4 is the subject of a companion report, CGS Special Publication 28, which contains numerous contributions by professional scientists that greatly expand our knowledge of Colorado's seismicity. Preliminary determination of Colorado's seismic source zones, Item 5, has been accomplished, with the results available as in-house file information at CGS. During the upcoming year of research these seismic source zones will be further evaluated to enable development of seismic risk zones in the state. Results of our future studies will be published as the investigations are completed.

This study has drawn heavily upon previously published and unpublished reports. The numerous U.S. Coast and Geodetic Survey (USCGS) quarterly and annual earthquake summaries, along with various quarterly, annual, and open-file publications by the USGS contain the bulk of the basic earthquake data. Hadsell (1968) provided additional earthquake information, part of which was based on previously undiscovered newspaper articles. Major and Simon (1968) studied the earthquakes associated with the Rocky Mountain Arsenal. Earthquakes occurring east of the mountain front are described by Docekal (1970). An estimate of seismic hazards in Colorado based on instrumental data from the Colorado School of Mines seismograph (GOL) was developed by Presgrave (1977). Kirkham and Rogers (1981) published one of the initial, comprehensive earthquake listings for Colorado. Dames and Moore (1981) and McGuire and others (1982) discovered additional newspaper accounts of the November 8, 1882 (UTC) earthquake and describe their conclusions regarding the location, size, and possible causative fault for the event.

Stover, Reagor, and Algermissen (1984) throughly searched the existing earthquake literature and developed an extensive earthquake listing. Their publication forms the basis for our earthquake list presented in Table 1. An in-depth survey of newspapers and Federal Archive records for felt reports of selected Colorado earthquakes by Oaks and Kirkham (1986) discovered several previously unreported events and numerous additional descriptions of the effects of several known earthquakes. A re-evaluation of the November 8, 1882 (UTC) earthquake by Kirkham and Rogers (1986) provides further insight into this difficult to understand event. Nicholl and Butler (1985) reported on extended microseismic monitoring in the central Front Range. Butler and Nicholl (1985a, b) described the Divide earthquake and Conifer earthquake.

All earthquake dates and times cited in this report utilize Universal Coordinated Time (UTC) unless indicated otherwise. The Modified Mercalli Intensity (MMI) scale of 1931, described in Appendix A, is used to rate all felt reports. A common practice in many USCGS and USGS publications was to include felt reports of MMI I and III in a single list usually described as "intensity III and under". Because of this, part of the intensity III reports described in the text of this report and shown on the isoseismal and intensity maps may actually be less than intensity III. This aspect does not alter the conclusions presented herein. The small squares shown on the isoseismal and intensity maps indicate the location of a described town. When a zero or other number is within the square, this signifies that either the earthqauake was not felt in that town (0) or was felt at the indicated intensity (3,4,5, etc.).

We would like to acknowledge the numerous individuals who have contributed to our study. In particular we wish to thank C.W. Stover, USGS, and J.L. Coffman and C.A. von Hake, National Oceanic and Atmospheric Administration (NOAA), for their assistance in compiling the data needed for this report. Our investigation would not have been conducted without the cooperation and financial support of the USGS. Regression equations were developed for us by Thomas Rogers, Southern Methodist University and were reviewed by Susan Cannon, Colorado Geological Survey. The felt reports for the January 1, 1894 Telluride earthquake were first brought to our attention by P. Carrarra, USGS. Chris Avila, Brenda Richardson, and Betty Jones typed the manuscript. Lois Kirkham assisted with report editing and drafting of the figures, while Cheryl Brchan drafted the plate and prepared the report for publication.

2.0 EARTHQUAKE LISTING

Table 1 lists all seismic events known to have occurred historically within Colorado along with a few man-made explosions. The explosions are included in the list to prevent possible confusion by researchers using original seismographic records. A complete description of the various aspects of the table is included in the following paragraphs. Earthquakes in this list are plotted on Plate 1, a map illustrating epicentral locations and relative sizes of each earthquake.

Data presented in Table 1 are for earthquakes that have been described in numerous references. Each utilized reference is cited and numbered in the reference list (Sections 5.0 and 6.0). Generally, only original references or those which provide additional or revised data, are cited. The earthquakes are listed chronologically based on the date and origin time in Coordinated Universal Time (UTC). In order to provide ready access to certain earthquakes the approximate geographic location of the earthquake epicenter is described. Latitude and longitude are recorded to a hundredth of a degree, if located to that degree of accuracy. Earthquake depth is given in kilometers. "Expl." in the depth column indicates the data is for a man-made explosion or rock burst. Man-made events are not plotted on the seismicity map (Plate 1). A depth assignment of 33 kilometers signifies that the hypocentral depth is equal to or less than 33 kilometers.

Magnitudes listed under the "USGS" heading in Table 1 are mb values that were published in the Preliminary Determination of Epicenters prepared by the National Earthquake Information Center and its predecessor organizations.

Contained in the "Other" column are magnitude values from other sources and other types of magnitudes. Source codes are as follows:

BRK Seismograph Station, University of California, Berkley, California.

GOL Geophysical Observatory, Colorado School of Mines, Golden, Colorado.

GS National Earthquake Information Service (and fore-runner organizations), USGS, Golden, Colorado.

HDP Hermann, R.B., Dewey, J.W., and Park, Sam-Kuen, 1980, The Dulce, New Mexico earthquake of 23 January 1966: Seismological Society of America Bulletin, v. 70, no. 6, p. 2171-2183.

HER Hermann, R.B., Park, S. and Wang, C., 1981, The Denver earthquakes of 1967-1968: Seismological Society of America Bulletin, v. 71, no. 3, p. 731-745.

NUT Nuttli, O.W., Bollinger, G.A., and Griffith, D.W., 1979, on the relation between Modified Mercalli intensity and body-wave magnitude: Seismological Society of America Bulletin, v. 69, no. 3, p. 893-909.

UU University of Utah, Salt Lake City, Utah

Type codes follow the source code and are identified as follows: 1=ML, 2=mbLg, 3=mb, and 4=duration of coda length. Listed intensities are the maximum Modified Mercalli Intensity reported for the earthquake. Reference codes are keyed to the list of references in Sections 5.0 and 6.0.

"ML" is a local magnitude defined by Richter, C.F., 1958, Elementary Seismology: San Francisco, W.H. Freeman and Co., Inc., 768 p. "mbLg" is a type of local magnitude developed for east of the Rocky Mountains by Nuttli, O.W., 1973, Seismic wave attenuation and magnitude relations for eastern North America: Journal of Geophysical Research, v. 78, no. 5, p. 876-885. "mb" is a body wave magnitude defined by Gutenburg, B., and Richter, C.F., 1956, Magnitude and energy of earthquakes: Annali di Geofisica, v. 9, no. 1, p. 1-15.

Table 1. Colorado earthquakes from 1870 to 1985.

YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1870	DEC.	4	12:00	PUEBLO-FT. REYNOLDS	38.5	104.0				VI	20,26,60
1871	OCT.			LILY PARK-MOFFAT CO.	40.5	108.5				VI	24,55
1871	NOV.	9	17:15	GEORGETOWN	39.7	105.7				IV	26,55,60
1880	SEP.	17	07:00	ASPEN	39.2	106.7				VI	26,55,60
1881				GEORGETOWN						V	55
1882	FEB.	12	08:30	PAGOSA SPRINGS	37.3	107.0				F	61,78
1882	MAY	12	03:00	PAGOSA SPRINGS	37.3	107.0				III	61,78
1882	NOV.	8	01:30	NORTH CENTRAL COLO.	40.5	105.5				VII	18,19,26,34,55
1882	NOV.	8	11:45	NORTH CENTRAL COLO.	40.5	105.5				F	19,34,55
1882	NOV.	23	07:30	SILVERTON	37.7	107.7				IV	26
1886	JUL.			CIMARRON	38.2	107.3				F	26,60
1888	OCT.	23	18:40	WET MOUNTAINS	38.1	105.2				IV	26,60
1889	JAN.	15		GLENWOOD SPRINGS	39.5	107.3				V	26,55,60
1891	DEC.			AXIAL BASIN	40.5	108.0				VI	26,55,60
1894	JAN.	1	10:00	TELLURIDE	37.9	107.8				IV	34,55
1894	AUG.	5	12:00	GEORGETOWN	39.7	105.7				V	26,55,60
1895	MAR.	22	20:00?	STEAMBOAT SPRINGS	40.5	107.1				V	18,26,55
1897	AUG.	3	7:00	RIDGWAY	38.2	107.8				F	55
1899			02:30	LAY	40.5	107.9				IV	24,55,60
1901	NOV.	15	10:00	BUENA VISTA	38.8	106.2				VI	26,55
1902	DEC.	29	07:00	DENVER	39.7	105.0				IV	55
1903	SEP.	9		NORTH OF LYONS	40.3	105.3				IV	20,78,93
1906	APR.			MAYBELL	40.5	108.3				V	55
1906	DEC.	21	16:10	NEW CASTLE	39.6	107.6				III	59,78,93
1913	NOV.	11	21:55	RIDGWAY AREA	38.1	107.7				V	18,55,59,78
1913	NOV.	11	22:18	RIDGWAY AREA	38.1	107.7				F	18,59,78
1913	NOV.	11	23:45	RIDGWAY AREA	38.1	107.7				F	18,59,78
1915	FEB.	28	07:51	GRAND JUNCTION	39.1	108.6				III	32,78,93
1916	OCT.	12	05:41	BOULDER	40.0	105.0				IV	20,26,32,78
1920	DEC.	29	02:50	NEW CASTLE	39.5	107.5				V	32,55

Table 1. (continued)

YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1920	DEC.	29	03:00	NEW CASTLE	39.5	107.5				IV	32,55,78
1920	DEC.	29	09:50	NEW CASTLE	39.5	107.5				V	32
1920	DEC.	30	17:50	NEW CASTLE	39.5	107.5				V	32
1921	FEB.	6	06:15	ST. ELMO	38.6	106.3				IV	32,78
1921	FEB.	6	06:25	GARFIELD	38.6	106.3				IV	32,78
1921	FEB.	6		ST. ELMO	38.6	106.3				IV	32,78
1921	FEB.	17	01:45	GARFIELD	38.6	106.3				III	32
1921	FEB.	17	13:05	GARFIELD	38.6	106.3				III	32
1921	FEB.	26	15:55	GARFIELD	38.6	106.3				III	32
1921	FEB.	27	17:00	GARFIELD	38.6	106.3				III	32
1921	MAR.	4	06:00	GARFIELD	38.6	106.3				II	32
1921	MAR.	8	19:15	GARFIELD	38.6	106.3				IV	32
1921	MAR.	9	01:25	GARFIELD	38.6	106.3				III	32
1921	MAR.	12	07:00	GARFIELD	38.6	106.3				II	32
1921	MAR.	22	21:45	GARFIELD	38.6	106.3				III	32
1921	JUL.	27	21:30	GARFIELD	38.6	106.3				III	32,78
1921	JUL.	29	02:55	GARFIELD	38.6	106.3				III	32,78
1921	OCT.	15	02:55	EADS	38.5	102.8				III	20,32
1923	JAN.	27	08:04	DENVER	39.7	105.0				F	33,78
1924	JAN.	4	21:56:30	DENVER	39.7	105.0				F	33,78
1924	SUMMER			CRAIG	40.5	107.6				III	24,55
1925	FEB.	18	20:00	WETMORE	38.2	105.1				IV	20,78,85
1928	APR.	20	09:40	CREEDE	37.8	107.0				IV	27,78
1928	APR.	24	10:00	CREEDE	37.8	107.0				IV	27,78
1928	APR.	29	10:00	CREEDE	37.8	107.0				IV	27,78
1928	APR.	29	10:20	CREEDE	37.8	107.0				IV	27,78
1928	APR.	29	10:45	CREEDE	37.8	107.0				IV	27,78
1928	APR.	29	16:00	CREEDE	37.8	107.0				IV	27,78
1928	APR.	30	15:50	CREEDE	37.8	107.0				V	27,78
1928	MAY	1	09:22	CREEDE	37.8	107.0				IV	27,78
1928	MAY	1	09:25	CREEDE	37.8	107.0				IV	27,78
1928	MAY	1	09:35	CREEDE	37.8	107.0				IV	27,78
1928	MAY	1	12:20	CREEDE	37.8	107.0				IV	27,78
1928	MAY	3	19:40	CREEDE	37.8	107.0				IV	27,78
1928	MAY	4	10:00	CREEDE	37.8	107.0				IV	27,78

Table 1. (continued)

YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1928	MAY	10	10:10	CREEDE	37.8	107.0				V	27,78
1928	SEP.	29	07:17	HOLLY	38.1	102.1				V	27,78
1940	APR.	8	17:00	ASPEN	39.3	106.8				III	50,55,78
1941	FEB.	13	11:32:30	ASPEN	39.3	106.8				IV	26,51,55,78
1941	FEB.	21	21:22	ASPEN	39.3	106.8				IV	26,51,55,78
1941	FEB.	28	06:19	ASPEN	39.3	106.8				IV	26,51,55,78
1941	AUG.	29	11:34	DURANGO/BAYFIELD	37.3	107.7				V	26
1942	JUL.	23	07:46	WESTERN MOFFAT CO.	40.3	108.6				V	55
1942	AUG.			WESTERN MOFFAT CO.	40.3	108.6	(MAY BE SAME EVENT AS ABOVE)			IV	55,78
1944	SEP.	9	04:12:20	MONTROSE/BASALT	39.0	107.5				VI	18,55,78,86
1944	OCT.	5	14:05	ASPEN	39.2	106.8				IV	2,78,84
1945	APR.	29	17:08	SILVERTON	37.7	107.7				IV	3,78,84
1945	APR.	29	17:32	SILVERTON	37.7	107.7				III	3,78,84
1946	JAN.	31	22:45	GLENWOOD SPRINGS	39.6	107.3				IV	4,78,84
1946	APR.	3	02:05	RILAND	39.8	107.1				IV	4,78,84
1948	OCT.	3	04:30	WALDEN	40.9	106.1				IV	42,78,84
1952	OCT.	7	09:20	ANTONITO	37.0	106.0				V	18,42
1954	FEB.	21	20:20:51	RANGELY/GRAND JCT.	40.0	108.75				IV	43
1955	FEB.	10	17:30	STEAMBOAT SPRINGS	40.4	106.9				VI	18,26,55
1955	AUG.	3	06:35	LAKE CITY	37.9	107.3				IV	44,78
1955	AUG.	3	06:37	LAKE CITY	37.9	107.3				F	44,78
1955	AUG.	3	06:39:42	LAKE CITY	38.0	107.3				VI	44,26
1955	NOV.	28	05:25:13	FOWLER-SUGAR CITY	38.2	103.7				IV	20,26,44
1956	JAN.	14	18:40	LAMAR	37.9	102.6				III	5,20,26
1956	JAN.	14	18:49	LAMAR	37.9	102.6				IV	5,20,26
1957	MAY	3	08:30	CREEDE AREA	37.8	106.9				III	6,78
1960	OCT.	11	08:05:30.5	MONTROSE/RIDGWAY	38.3	107.6	49		5.5 BRK-3	VI	18,78,83
1960	OCT.	12	00:30	MONTROSE/RIDGEWAY	38.3	107.6				IV	78,83
1960	OCT.	17	16:00	ASPEN	39.2	106.9				V	18,83
1961	NOV.	27	00:55:45.7	SOUTH PARK	39.0	106.1	≤33			IV	37,86
1961	NOV.	27	01:05	SOUTH PARK	39.0	106.1				III	37,78
1962	JAN.	13	13:33	MONTROSE	38.4	107.8			4.4 GOL-1	IV	26,38
1962	JAN.	18	01:28	N.E. OF DENVER	39.9	104.9				IV	20
1962	JAN.	18	01:36	N.E. OF DENVER	39.9	104.9				IV	20
1962	FEB.	5	14:45:51.1	RIDGWAY/MONTROSE	38.2	107.6	25		4.7 GOL-1	V	38,86

Table 1. (continued)

YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
											38
1962	MAR.	5	04:23:06.7	ASPEN	39.2	106.8	25				38,78,86
1962	MAR.	17	09:14:04.4	RIDGWAY AREA	38.3	108.1	≤33				26,78
1962	JUN.	18	00:46:05.0	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	V	39,78
1962	JUN.	18	01:36:06.7	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	38,78
1962	JUN.	19	04:48:54.3	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	V	
											38
1962	JUN.	24	17:11:04.0	UNCOMPAHGRE PLATEAU	38.5	108.5	≤33				38,78
1962	JUN.	24		N.E. OF DENVER	39.9	104.9				IV	38,78
1962	AUG.	7	00:51:00.2	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	V	38,78
1962	AUG.	7	01:22:09.7	N.E. OF DENVER	39.9	104.9			1.8 GOL-1	III	38,78
1962	AUG.	7	01:40:30.4	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	
1962	AUG.	7	04:00	N.E. OF DENVER	39.9	104.9				IV	38,78
1962	AUG.	16	02:03:17.7	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1962	AUG.	16	06:55	N.E. OF DENVER	39.9	104.9				III	38,78
1962	OCT.	8	16:26:12.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1962	OCT.	8	20:45:12.9	N.E. OF DENVER	39.9	104.9			4.0 GOL-1	F	39,78
1962	DEC.	4	17:49:59.4	N.E. OF DENVER	39.8	104.7	≤33		3.2 GOL-1	VI	38,86
1962	DEC.	5	06:26:49.9	N.E. OF DENVER	39.8	104.9			1.9 GOL-1	IV	38,78
1962	DEC.	5	13:48:07.1	N.E. OF DENVER	39.9	104.6	≤33		3.8 GOL-1	VI	38,78,86
1962	DEC.	6	00:20	N.E. OF DENVER	39.9	104.9				F	38,78
1962	DEC.	6	00:25	N.E. OF DENVER	39.9	104.9				F	38,78
1962	DEC.	16		N.E. OF DENVER	39.9	104.9				IV	20,78
1963	JAN.	3	22:00	N.E. OF DENVER	39.9	104.9				II	20,78
1963	JAN.	25	22:22	N.E. OF DENVER	39.9	104.9				II	20,78
1963	JAN.	26	00:22:46.0	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	39,78
1963	JAN.	30	23:05:09.6	N.E. OF DENVER	39.8	104.6	≤33		3.2 GOL-1	IV	26,86
1963	JAN.	30	23:10	N.E. OF DENVER	39.9	104.9				III	20,78
1963	JAN.	30	23:11	N.E. OF DENVER	39.9	104.9				III	20,78
1963	FEB.	25		N.E. OF DENVER	39.9	104.9				III	20,78
1963	FEB.	25	15:24:01.0	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	39,78
1963	FEB.	26		N.E. OF DENVER	39.9	104.9				III	20,78
1963	MAR.	15	16:59:44.0	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	39,78
1963	MAR.	26	23:51:14.3	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1963	APR.	4	02:04:59.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1963	APR.	4	02:19:59.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	39,78
1963	APR.	4	07:48:08.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	39,78

Table 1. (continued)

DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1963	APR.	7	08:12	N.E. OF DENVER	39.9	104.9				F	20,78
1963	APR.	8	00:03:57.1	N.E. OF DENVER	39.9	104.8	20		3.4 GOL-1	V	26,87
1963	APR.	24	22:29:34.4	N.E. OF DENVER	39.8	104.7	20	4.1	3.4 GOL-1	IV	26,86
1963	MAY	25	10:44:36.7	N.E. OF DENVER	39.8	104.7	10		3.5 GOL-1	V	9,86
1963	JUN.	5	00:13:56.6	N.E. OF DENVER	39.77	104.75		4.4	3.0 GOL-1	III	9,68,78
1963	JUL.	2	08:02:56.3	N.E. OF DENVER	39.8	104.6	≤33	4.6	4.0 GOL-1	V	9,86
1963	JUL.	28	13:18:45.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	II	26,39,78
1963	SEP.	29	09:54:08.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1963	NOV.	13	21:34	PUEBLO	38.3	104.6			2.8 GOL-1	IV	26
1964	FEB.	9	09:19:59.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1964	MAR.	27	07:08:08.8	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1964	APR.	10	17:39:36.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1964	MAY	23	21:44:59.1	CLIMAX	39.37	106.17	EXPL.				86
1964	AUG.	4	11:13:25.2	DILLON	39.7	106.0	≤33	4.0			87
1964	OCT.	17	14:35:39.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1964	OCT.	17	22:02:48.0	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1964	DEC.	4	21:27:06.3	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	39,78
1965	JAN.	5	23:26	ROCKY FLATS	39.9	105.3			2.0 GOL-1	III	26
1965	FEB.	16	19:52:21.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	IV	78,89
1965	FEB.	16	20:17:53.5	N. OF DENVER	39.9	105.1	5	4.6	3.1 GOL-1	IV	86,89
1965	FEB.	16	22:21:43.7	N. OF DENVER	39.9	105.0	5	4.9	3.0 GOL-1	VI	87,89
1965	FEB.	18	11:38:52.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1965	MAR.	25	20:23:55.5	N.E. OF DENVER	39.8	104.9			2.6 GOL-1	II	26,39,78
1965	APR.	16	17:25	N.E. OF DENVER	39.8	104.9			2.7 GOL-1	V	26,39,78
1965	MAY	18	23:47:55.8	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1965	MAY	30	17:31:04.1	TENNESSEE PASS	39.4	106.3	≤33	4.3			87
1965	JUN.	14	09:24:43.9	N.E. OF DENVER	39.8	104.9			3.0 GOL-1	IV	26,39,78
1965	JUN.	29	13:14:49.3	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1965	JUL.	18	21:07:28.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1965	JUL.	18	21:13:27.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	78,89
1965	JUL.	18	21:19:49.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	II	78,89
1965	JUL.	18	21:40:44.7	N.E. OF DENVER	39.8	104.8	5	4.6	2.5 GOL-1	V	86,89
1965	JUL.	18	21:48:05.2	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1965	JUL.	31	13:41:42.8	N.E. OF DENVER	39.7	104.9	5	4.6	2.7 GOL-1	V	87,89
1965	JUL.	31	17:40:41.3	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	39,78

Table 1. (continued)

DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1965	AUG.	9	15:38:39.2	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	IV	78,89
1965	AUG.	9	17:18	N.E. OF DENVER	39.9	104.9				III	78,89
1965	AUG.	9	23:18:20.2	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	39,78
1965	AUG.	10	04:02:22.9	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1965	AUG.	14	20:52	N.E. OF DENVER	39.9	104.9				IV	78,89
1965	AUG.	14	22:52:18.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	39,78
1965	AUG.	18	04:30	N.E. OF DENVER	39.9	104.9				III	78,84
1965	AUG.	18	15:21:27.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	78,89
1965	AUG.	22	18:16:17.2	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	39,78
1965	AUG.	27	20:32:10.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	78,89
1965	AUG.	27	20:33:21.0	N.E. OF DENVER	39.9	104.9			1.8 GOL-1	II	78,89
1965	SEP.	2	19:11:15.3	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	78,89
1965	SEP.	13	09:58:17.9	N.E. OF DENVER	39.8	104.8	5	4.5	3.5 GOL-1	V	86,89
1965	SEP.	13	11:03:24.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	39,78,89
1965	SEP.	14	16:36:46.8	N.E. OF DENVER	39.8	104.8	5	4.7	2.8 GOL-1		86
1965	SEP.	14	21:15:05.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	III	78,89
1965	SEP.	14	22:46:24.1	N.E. OF DENVER	39.9	104.6	5	4.7	3.6 GOL-1	VI	86,89
1965	SEP.	14	22:53:53.5	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	III	78,89
1965	SEP.	14	23:16:10.4	N.E. OF DENVER	39.5	104.9	5	4.8	3.0 GOL-1	F	87,89
1965	SEP.	15	07:16	N.E. OF DENVER	39.9	104.9				III	78,89
1965	SEP.	27	10:34:16.0	N.E. OF DENVER	39.9	104.9		3.3	2.9 GOL-1	IV	78,89
1965	SEP.	29	18:59:56.1	NORTH OF DENVER	39.8	105.1	5	4.7	3.5 GOL-1	VI	86,89
1965	SEP.	29	19:05:29.5	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	IV	39,78,89
1965	SEP.	29	19:20:40.8	N.E. OF DENVER	39.8	104.8	5	4.6	2.6 GOL-1	VI	18,86
1965	SEP.	29	19:32:55.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	78,89
1965	SEP.	29	20:07:36.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	IV	39,78,89
1965	SEP.	29	23:22:58.0	N.E. OF DENVER	39.8	104.8	5	4.6	2.8 GOL-1	IV	86,89
1965	NOV.	7	09:25:14.2	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	IV	78,89
1965	NOV.	14	17:16:39.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	78,89
1965	NOV.	14	18:45:23.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	78,89
1965	NOV.	21	03:59:58.9	N.E. OF DENVER	39.8	104.8	5	4.6	3.2 GOL-1	IV	26,86
1965	NOV.	21	04:02:28.7	N.E. OF DENVER	39.8	104.8	5	4.5	3.8 GOL-1	VI	86,89
1965	NOV.	21	04:09:28.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	39,78,89
1965	NOV.	21	04:24:48.5	N.E. OF DENVER	39.9	104.7	5	4.4	2.8 GOL-1		86
1965	NOV.	21	05:00:27.3	N.E. OF DENVER	39.8	104.9	5	4.7	3.2 GOL-1	V	26,86

Table 1. (continued)

YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1965	NOV.	21	14:48:35.5	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	III	78,89
1966	JAN.	2	00:13:41.8	N.E. OF DENVER	39.9	104.8	5		2.3 GOL-1	III	87,90
1966	JAN.	5	00:37:17.8	N.E. OF DENVER	39.8	104.7	5	5.0	3.4 GOL-1	V	87,90
1966	JAN.	8	00:17	N.E. OF DENVER	39.9	104.9				III	78,90
1966	JAN.	23	01:56:38.8	DULCE, N.M.	37.0	107.0	3	5.5	5.1 HDP-2	VII	28,31,47,88,90
1966	JAN.	23	04:00	CREEDE	37.9	106.9				III	78,90
1966	JAN.	31	15:43:52	DULCE, N.M.	37.0	106.9				IV	90
1966	MAR.	18	14:18:22.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	78,90
1966	APR.	3	16:21:34.0	SOUTH PARK	39.36	106.46	EXPL.	4.7			33
1966	MAY	8	17:24	DULCE, N.M.	37.0	106.9			4.2 GOL-1	F	26,78
1966	MAY	8	17:50:37	DULCE, N.M.	37.0	107.0	5	3.9			34,47
1966	MAY	9	01:26:45.0	DULCE, N.M.	37.0	106.8	5				34,47
1966	MAY	9	02:57:23.6	DULCE, N.M.	37.0	106.9	5	4.4			34,47
1966	MAY	26	02:21:45.5	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	II	39,78,90
1966	JUN.	6	19:56:53.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	78,90
1966	JUL.	5	18:26:13.3	RANGELY	40.09	109.00	7	3.7	3.2 UU-1		1
1966	JUL.	5	20:02:41.7	RANGELY	40.06	109.00	7	3.5	3.3 UU-1		1
1966	JUL.	6	05:47:08.4	RANGELY	40.09	108.95	7	4.1	3.7 UU-1		1
1966	AUG.	19	05:29:05.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	78,90
1966	SEP.	4	09:52:34.5	CIMARRON RIDGE	38.3	107.6	≤33	4.2			86
1966	OCT.	3	02:26:02.3	N.E. OF TRINIDAD	37.4	104.1	10	4.5	4.6 GOL-1	VI	86,90
1966	OCT.	13	00:33	CASTLE ROCK	39.3	104.6			3.0 GOL-1	F	26
1966	OCT.	25	17:14:02.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	II	39,78,90
1966	NOV.	1	07:40:28.0	YAMPA	40.2	106.9	≤33	4.0	3.9 GOL-1		86
1966	NOV.	13	15:17:00.8	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	III	78,90
1966	NOV.	14	20:02:35.9	N.E. OF DENVER	39.9	104.7	5	4.4	3.5 GOL-1	VI	86,90
1966	NOV.	15	02:51:16.3	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	39,78
1966	DEC.	19	20:52:33.3	ASPEN	39.0	106.5	5	4.6	3.3 GOL-1	III	26,86
1967	JAN.	12	03:52:06.2	SOMERSET	38.98	107.51	≤33	4.4			86
1967	JAN.	16	09:22:45.9	SILVERTON	37.67	107.86	≤33	4.1			86

FROM JANUARY 23, 1966 TO JANUARY 6, 1967 NUMEROUS EARTHQUAKES OCCURRED IN THE DULCE, N.M. AREA. ONLY THOSE EVENTS WITH EPICENTERS IN COLORADO ARE INCLUDED IN THIS LIST.

Table 1. (continued)

YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
											86
1967	JAN.	18	06:12:00.6	FLAT TOPS	40.05	107.05	≤33	3.8			29,78,91
1967	FEB.	3	05:27:58.9	N.E. OF DENVER	39.88	104.95	7	4.3	3.3 GOL-1	V	29,78,91
1967	FEB.	3	05:34:13.3	N.E. OF DENVER	39.89	104.90	8		2.3 GOL-1	IV	86
1967	FEB.	12	10:11:52.4	RICO	37.67	108.00	5				1
1967	FEB.	15	04:33:22.3	RANGELY	40.22	108.97	7		2.7 UU-4		
1967	FEB.	21	21:55:27.0	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	IV	78,91
1967	APR.	4	22:53:39.5	MONTROSE	38.32	107.75	≤33	4.5	3.0 GOL-1		86
1967	APR.	10	19:00:25.5	N.E. OF DENVER	39.94	104.75	5	4.9	4.3 HER-2	VI	39,86,91
1967	APR.	10	19:02	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	19:08	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	19:23	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	19:26	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	19:28	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	19:35:53.0	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	39,78
1967	APR.	10	19:36:38.0	N.E. OF DENVER	39.89	104.77	5	4.4	3.5 GOL-1	IV	84,86
1967	APR.	10	20:08	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	10	20:11:14.6	N.E. OF DENVER	39.86	104.91	5	4.8	3.0 GOL-1	V	84,86
1967	APR.	10	20:37:45.3	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	78,91
1967	APR.	10	22:09:16.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	III	39,78,91
1967	APR.	10	22:12:01.3	N.E. OF DENVER	39.87	104.88	4				29
1967	APR.	10	23:58:40.8	N.E. OF DENVER	39.92	104.79	5	4.3	3.0 GOL-1	IV	84,86
1967	APR.	11	00:37	N.E. OF DENVER	39.9	104.9				III	78,91
1967	APR.	12	02:22:58.0	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	78,91
1967	APR.	12	05:40:23.7	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	78,91
1967	APR.	12	09:47:42.3	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	IV	78,91
1967	APR.	23	02:34:55.1	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	IV	78,91
1967	APR.	27	17:24:42.3	N.E. OF DENVER	39.91	104.77	5	4.5	3.8 GOL-1	VI	86,91
1967	APR.	27	17:25:37.0	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	F	39,78
1967	APR.	28	06:53:48.6	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	39,78,91
1967	APR.	28	12:21:21.0	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	39,78,91
1967	MAY	12	01:58:19.6	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	IV	78,91
1967	MAY	19	17:46:45.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	78,84
1967	JUN.	8	07:50:48.2	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1967	JUN.	19	15:39:22.0	N.E. OF DENVER	39.9	104.8	5		2.9 GOL-1	IV	87,91
1967	JUN.	19	17:47:19.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	II	78,91

Table 1. (continued)

YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1967	JUL.	12	01:45:43.9	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	78,91
1967	JUL.	27	17:54:13.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	39,78
1967	AUG.	9	13:25:06.2	N.E. OF DENVER	39.9	104.7	5	5.3	4.9 NUT-2	VII	87,91
1967	AUG.	9	14:10	N.E. OF DENVER	39.9	104.9				III	78,91
1967	AUG.	9	14:56:19.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	II	39,78
1967	AUG.	9	17:48:29.3	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	39,78
1967	AUG.	9	20:45	N.E. OF DENVER	39.9	104.9				II	39,78
1967	AUG.	13	05:02:31.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	39,78
1967	AUG.	13	05:46:10.2	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	39,78
1967	AUG.	13	17:05:55.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	III	39,78
1967	OCT.	25	06:32	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	IV	78,91
1967	OCT.	26	04:18	N.E. OF DENVER	39.9	104.9			1.6 GOL-1	III	57,78
1967	OCT.	28	08:00	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	57,78,91
1967	NOV.	14	10:07	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	IV	78,91
1967	NOV.	14	10:41	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	78,91
1967	NOV.	15	07:10:12.1	N.E. OF DENVER	39.9	104.6	5	3.7	3.6 GOL-1	V	87,91
1967	NOV.	25	07:02	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	78,91
1967	NOV.	27	05:09:22.7	N.E. OF DENVER	39.87	104.88	5	5.2	4.6 NUT-2	VI	29,91
1967	NOV.	27	05:35:00.7	N.E. OF DENVER	39.9	104.7	5	4.4	4.3 GOL-1	V	78,87,91
1967	NOV.	27	05:42:53.3	N.E. OF DENVER	39.9	104.9	5		3.5 GOL-1	V	78,87,91
1967	DEC.	9	03:35	N.E. OF DENVER	39.9	104.9			1.9 GOL-1	III	57,78,91
1968	JAN.	13	18:46	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	III	10,57,78
1968	JAN.	18	14:30	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	10,57,78
1968	JAN.	18	21:16:38.2	DINOSAUR NAT. MON.	40.44	108.84	7		2.9 UU-1		1
1968	FEB.	24	14:06:50.6	N.E. OF DENVER	39.88	104.89	4		2.2 UU-1	III	10,29
1968	APR.	13	22:47:36.6	N.E. OF DENVER	39.88	104.89	11		2.7 GOL-1	III	10,29,78
1968	APR.	21	07:08:07.0	S. OF HOLLY	37.8	102.1	≤33	3.8			87
1968	JUN.	4	18:58:14.0	N.E. OF DENVER	39.88	104.90	9		2.6 GOL-1		29
1968	JUN.	10	05:23:20.6	N.E. OF DENVER	39.87	104.90	9		2.7 GOL-1		29
1968	JUN.	23	20:16:13.0	S.W. OF CARBONDALE	39.31	107.41	≤33	3.8			87
1968	JUL.	15	18:33:13.6	N.E. OF DENVER	39.87	104.88	6		3.4 GOL-1	V	10,29
1968	JUL.	15	18:46	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	57,78
1968	JUL.	27	19:04:54.3	N.E. OF DENVER	39.89	104.89	7		2.9 GOL-1	III	10,29,78
1968	AUG.	14	02:03:26.4	N.E. OF DENVER	39.89	104.92	8		2.6 GOL-1	III	10,29,78
1968	SEP.	24	14:51:27.4	N.E. OF DENVER	39.90	104.94	8		2.4 GOL-1	IV	10,29

DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1968	NOV.	2	14:29:02.5	N.E. OF DENVER	39.86	104.90	6		3.2 GOL-1	IV	10,29
1968	NOV.	29	04:28	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	III	10,29,78
1969	FEB.	22	18:43	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	57,78
1969	FEB.	23	22:50	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	57,78
1969	MAR.	20	06:36	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	57,78
1969	MAR.	23	01:21	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	78,92
1969	APR.	17	16:49	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	IV	57,78
1969	APR.	28	07:16	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	57,78
1969	APR.	30	14:28	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	V	78,92
1969	MAY	23	09:00:53.5	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	III	18,78,92
1969	MAY	23	10:43	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	V	57,78
1969	MAY	23	10:47	N.E. OF DENVER	39.9	104.9			3.5 GOL-1	IV	87,92
1969	MAY	26	01:30:08.6	FELT IN N.E. DENVER	40.4?	104.4?	≤33	4.2			87
1969	SEP.	10	21:00:00.1	PROJECT RULISON	39.41	107.95	EXPL.	5.3			
1969	SEP.	13	11:25	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	78,92
1969	SEP.	13	12:14	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	57,78,92
1969	SEP.	30	09:04	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	57,78
1969	NOV.	5	13:50	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	57,78
1969	NOV.	5	14:24	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	57,78
1970	FEB.	3	05:59:35.6	S. OF NORWOOD	37.92	108.31	≤33	4.0			87
1970	MAR.	31	12:36	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	57,78
1970	APR.	21	08:53:52.4	RANGELY	40.1	108.9	4	4.3	3.9 GS-1	V	14,87
1970	APR.	21	15:05:47.5	RANGELY	40.09	108.90	4	4.6	3.7 GS-1	IV	14,78,87
1970	MAY	23	08:55:09.4	N. OF DENVER	39.90	105.10	5	4.1	3.2 GOL-1	V	14,87
1970	JUL.	12	18:18	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	57,78
1971	JAN.	7	20:39:52.1	GLENWOOD SPRINGS	39.49	107.31	≤33	4.3	3.8 GS-1	V	15,87
1971	MAR.	11	14:08	N.E. OF DENVER	39.9	104.9			3.0 GOL-1	III	15,78
1971	MAR.	18	09:08:59.9	CLARK	40.70	106.97	10	4.4		V	15,87
1971	AUG.	8	05:22:44.0	N.E. OF DENVER	39.89	104.76	5	4.4	3.8 GOL-1	IV	15,87
1971	AUG.	8	07:50	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	57,78
1971	AUG.	14	08:36	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	57,78
1971	NOV.	12	09:30:44.6	GRAND JUNCTION	38.91	108.68	5		4.0 GS-1	III	14,78,87
1971	DEC.	9	05:28	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	IV	15,57,78
1972	NOV.	12	18:33	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	15,57,78
1972	NOV.	29	22:15	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	15,57,78

Table 1. (continued)

DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1973	MAY	17	16:00:00	PROJECT RIO BLANCO	39.79	108.37	EXPL.	5.4	5.7 BRK-3		87
1973	SEP.	19	13:28:20.5	VALDEZ	37.16	104.59	5			III	17,77,87
1973	SEP.	22	21:47:38.1	BONCARBO	37.2	104.6				III	17,78
1973	SEP.	23	03:58:54.9	VALDEZ	37.15	104.57	5	4.2		III	17,77,87
1973	SEP.	23	04:41:14.8	BONCARBO	37.2	104.6				III	17,78
1973	SEP.	23	09:51:27.2	BONCARBO	37.2	104.6				III	17,78
1974	MAR.	31	11:58:47.1	CLARK	40.70	107.05	5		3.5 GS-1	II	11
1975	JAN.	30	14:48:40.3	N. OF GRAND JCT.	39.27	108.65	5	4.4	3.7 GS-1	V	12
1976	MAY	30	01:43:37.3	PINON CANYON AREA	37.41	104.02	5		3.0 GS-1		56
1977	SEP.	24	11:16:48.4	S.W. OF CARBONDALE	39.31	107.31	5	4.0	3.0 GS-1		79
1977	NOV.	3	05:34	POUDRE R. CANYON	40.7	105.4			2.0 GS-1	II	13,78
1978	MAY	29	16:45:18.0	S.W. OF CARBONDALE	39.28	107.32	5		3.0 GS-1		80
1978	JUN.	10	20:57:53.5	N.E. OF DENVER	39.79	104.87	20		2.9 GS-1	IV	80
1978	NOV.	30	18:50:15.8	CRAIG	40.47	107.61	5		2.8 GS-1		80
1979	JAN.	6	01:58:55.3	DIVIDE	38.96	105.16	5		2.9 GS-1	VI	81,A*
1979	JAN.	20	06:59:08.4	N.W. OF CRAIG	40.82	107.86	5		3.3 GS-1		81
1979	MAR.	19	14:59:29.7	RANGELY	40.18	108.90	2		3.1 GS-1	IV	81
1979	MAR.	29	22:07:13.3	RANGELY	40.27	108.81	2		2.6 GS-1	IV	81
1981	MAR.	24	13:03:40.0	N.E. OF DENVER	39.75	104.94	5		2.8 GS-1	F	69,88
1981	APR.	2	16:10:06.4	N.E. OF DENVER	39.91	104.95	9	4.3	3.8 GS-1	VI	69,88
1981	SEP.	16	19:58:38.9	N.E. OF DENVER	39.88	104.91	5		2.1 GS-1	IV	69,88
1981	NOV.	2	03:03:00.2	CONIFER	39.52	105.30	1		2.8 GS-1	V	69,88,B
1981	DEC.	9	02:45:36.2	CONIFER	39.5	105.3				F	69,78
1982	MAR.	11	23:55:28.2	N.E. OF DENVER	39.86	104.85	5		2.8 GS-1	III	75,87,88
1982	SEP.	18	16:11:44.9	N.E. OF DENVER	39.90	104.91	5		2.8 GS-1	III	41,87,88
1982	NOV.	22	10:09:01.4	RIFLE	39.74	107.58	5		2.9 GS-1	F	72,87,88
1983	AUG.	14	19:08:30.7	CIMARRON	38.36	107.40	5		3.4 GS-1	II	87,88,94
1983	AUG.	17	15:03:27.6	N.E. OF TRINIDAD	37.47	104.31	5		3.4 GS-1		87,88
1983	SEP.	24	16:57:45.7	BROWNS PARK	40.79	108.84	5		4.1 GS-1	III	87,88
1984	FEB.	25	09:18:19.0	N.E. OF DENVER	39.92	105.02	5		2.5 GS-1	F	87,88

*References denoted by a letter signal symbol are contained in the Supplemental References - Section 6.0

Table 1. (continued)

YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REF
1984	APR.	12	20:16:57.8	CARBONDALE	39.30	107.23	5		2.2 GS-1	F	87,88
1984	APR.	22	17:30:56.7	CARBONDALE	39.28	107.19	5		3.1 GS-1	IV	87,88
1984	APR.	3	18:25:35.4	CARBONDALE	39.29	107.23	5		2.5 GS-1		87,88
1984	APR.	3	18:28:54.1	CARBONDALE	39.30	107.25	5		3.0 GS-1	F	87,88
1984	APR.	3	19:18:23.0	CARBONDALE	39.33	107.25	5		2.3 GS-1		87,88
1984	APR.	4	01:17:10.4	CARBONDALE	39.33	107.27	5		2.4 GS-1		87,88
1984	APR.	4	02:13:33.1	CARBONDALE	39.34	107.25	5		2.2 GS-1	F	87,88
1984	APR.	4	18:44:37.4	CARBONDALE	39.28	107.20	5		2.2 GS-1		87,88
1984	APR.	6	02:00:56.6	CARBONDALE	39.33	107.25	5		2.1 GS-1	F	87,88
1984	APR.	6	02:12:49.7	CARBONDALE	39.34	107.28	5		2.3 GS-1	F	87,88
1984	APR.	6	02:13:34.4	CARBONDALE	39.35	107.26	5		2.6 GS-1	F	87,88
1984	APR.	6	02:51:36.9	CARBONDALE	39.33	107.23	5		2.2 GS-1	F	87,88
1984	APR.	6	04:17:35.5	CARBONDALE	39.35	107.26	5		2.5 GS-1		87,88
1984	APR.	6	04:21:37.7	CARBONDALE	39.33	107.24	5		2.7 GS-1		87,88
1984	APR.	10	01:20:14.9	CARBONDALE	39.35	107.25	5		1.9 GS-1		87,88
1984	MAY	10	01:53:51.8	CARBONDALE	39.36	107.30	5		2.4 GS-1		87
1984	MAY	11	13:34:57.9	CARBONDALE	39.34	107.26	5		2.3 GS-1		87
1984	MAY	14	10:14:17.2	CARBONDALE	39.32	107.23	5		3.2 GS-1	IV	87
1984	MAY	17	09:11:20.2	CARBONDALE	39.34	107.25	5		2.4 GS-1	F	87
1984	MAY	27	23:30:19.3	BURLINGTON	39.22	102.16	5		3.6 GOL-1		87
1984	JUN.	12	04:48:54.1	REDSTONE AREA	39.14	107.39	1		3.0 GOL-1	(COAL BUMP ?)	87
1985	MAR.	16	21:55:02.5	SALIDA	38.56	105.85	5		3.2 GS-1	V	87,88

3.0 DESCRIPTIONS OF SELECTED EARTHQUAKES

Included in this section are felt reports, references, isoseismal maps, and intensity maps for selected earthquakes that have been felt in Colorado. All events for which isoseismal or intensity maps have been prepared are discussed. Additionally, early events that were not instrumentally recorded are briefly described and the sources of information for these events are listed. All dates and times for earthquakes are in Universal Coordinated Time, unless otherwise indicated. "Not felt" reports are listed if the only record for these are in the NOAA microfilm files.

3.1 April 24, 1867

On April 24, 1867 a large earthquake occurred in Kansas along the Nemaha Ridge. The Rocky Mountain News on November 24, 1875 (p.2,c.4) reported that the tremor was felt in eastern Colorado. Rizzari (1959) suggested it was not felt in Denver or the mining camps to the west. An isoseismal map for this earthquake by DuBois and Wilson (1978) is open-ended to the west. Maximum intensity in Colorado was probably about IV.

3.2 December 4, 1870

The first earthquake of record to center in Colorado occurred on December 4, 1870. The most complete description of this event is contained in the Pueblo Chieftain on December 8, 1870. Included in this issue are the reactions of various community members to the earthquake and reference is made to a letter from Fort Reynolds that states "Bottles on my washstand standing about one inch apart were violently knocked together. The shock was accompanied by a rumbling noise and appeared to move from east to west. It was also felt on the opposite side of the [Arkansas] river." Maximum intensity for this event was VI (Hadsell, 1968).

According to the Colorado Transcript on December 7, 1870 the earthquake was felt by a least two citizens in Golden. Other references to this earthquake are found in the Rocky Mountain News (12/10/1870) and the Central City Register (12/11/1870). Hadsell (1968) suggested the earthquake was felt over about 160,000 km^2.

3.3 October, 1871

Fitzpatrick (1974, p.26-27) recounted a description of an earthquake in Lily Park, Moffat County in October of 1871 as follows:

> The "hunters' moon" of early October [1871] had come and waned. ...Suddenly, this deep silence was shattered by the most deafening roar, and rumble, and hiss and bellow that mortal ears ever heard. At the same moment the earth beneath shuttered, heaved, rose, fell as if in mortal agony. The towering cliffs of the canyon walls sent loosened boulders in torrents. The spot where the terrified man crouched, a tiny atom of life in the midst of the awful powers of the upheaval of nature, was in the path of the devastating avalanche of rock, yet the man was unharmed and presently the final rolling stone came to a stop and the silence following the earthquake closed in like some physical thing pressing from all sides.

> Not knowing what moment another shock might come, Wallihan endured the night that seemed as long as eternity.

A maximum intensity of VI is assigned to this felt report. The date of this October event is poorly constrained, and it is possible that this earthquake, and the following event on November 9, 1871 were actually the same event. If the felt reports from Moffat County and the Georgetown-Central City area are from the same earthquake, the felt area for this earthquake would be fairly large.

3.4 November 9, 1871

The earthquake on November 9, 1871 was first described briefly in the Rocky Mountain News on November 10, 1871 (p.1,c.5) as follows: "An earthquake is reported from the mountains. It is said to have made things 'get up and stand around' for a few minutes."

On November 17, 1871 (p.1,c.4) the Rocky Mountain News reported that the Georgetown Courier described the effects of the earthquake. An original of the Georgetown Courier article has not yet been located, but according to the Rocky Mountain News the buildings in Georgetown quivered in an unusual manner, many residents rushed into the streets, and crockery, hardware, and the printing press rattled and shook. The earthquake was also felt in Central City and Silver Plume, but there was no report of property damage in either town. A description of the effects in Central City was in The Colorado Miner on November 16, 1871 and the Colorado Herald on November 9, 1871.

This event is assigned an intensity IV. As described in the preceding section, this earthquake may possibly be the same event which caused the shaking in Moffat County.

3.5 November 15, 1877

Docekal (1970, p.88) indicated that the eastern Nebraska earthquake of November 15, 1877 was felt in the northeastern corner of Colorado. Maximum intensity in Colorado was III or less.

3.6 September 17, 1880

The only available reference to the September 17, 1880 earthquake that shook Aspen was an article in the Leadville Chronicle which was reprinted in The Denver Tribune on September 21, 1880 (p.2,c.1). Unfortunately, no copies of the Aspen newspapers or the Leadville Chronicle for this time period have been located.

The earthquake occurred at midnight on the 16th (local time) and brought many of the residents out of their homes. As they left their homes a second tremor "loosened their teeth and dislocated their locomotion" and "threw the camp into the wildest confusion".

There were a total of four shocks, separated by intervals of about thirty seconds. During each shock "the earth seemed moved three or four feet out of place, and a low rumbling noise to be compared to nothing save the rolling of distant thunder, was heard". At about 8 o'clock the following morning a large landslide or rockslide on Aspen Mountain was reported.

Rizzarri (1959) discredited this account based on conversations with Don and Jean Griswald, Colorado historians. The Griswalds indicate that the author of the article, Mr. Orth Stein, was prone to exaggeration or even fabrication. Hadsell (1968) rated the event at intensity VI. For complete discussions of this earthquake, please refer to Rizzari (1959) and Oaks and Kirkham (1986).

It is interesting to note that an earthquake was also reported in Salt Lake City at 10:27 p.m. on the 16th (Coffman, von Hake, and Stover, 1982; Oaks and Kirkham, 1986). The report from Aspen might possibly be associated with the Salt Lake City event, but since the times of the reports are somewhat different it is more likely that the report from Aspen represents a distinct local earthquake.

3.7 1881

In the Georgetown Courier on August 11, 1894 brief mention was made of an earthquake that occurred "just after dark thirteen years ago". The quake "rocked the buildings like a boat on rolling water" and made for difficult walking. The quake is rated intensity V. The author of this article may have been off by one year, and may actually be referring to the November 8, 1882 earthquake.

3.8 February 12 and May 12, 1882

On February 12, 1882, an earthquake was reported felt in Pagosa Springs, Lake City, and Capitol City (now abandoned, formerly about 9 miles west of Lake City) by Rockwood (1883). No intensity information is available for this event.
Rockwood (1883) indicated that a slight shock was again felt at Pagosa Springs on May 11, 1882 at 8:00 p.m. local time. A maximum intensity of III has been assigned to this event (Stover, Reagor, and Algermissen, 1984).

3.9 November 8, 1882

On November 7, 1882 at about 6:30 p.m. local Denver time, a moderately strong earthquake shook much of Colorado and parts of southern Wyoming and northeastern Utah. The earthquake was apparently felt as far east as Salina, Kansas and perhaps even in Plattsmouth, Nebraska (Rockwood, 1883; Oaks and Kirkham, 1986). An aftershock followed on the morning of November 8 (local time) and was felt in Denver, Boulder, Greeley, and Laramie, and near Meeker.

The main event was probably the largest earthquake to occur in the Colorado region during the period of historical record, and because of this, has received considerable study by numerous researchers. Heck (1938) reported the felt area as 28,000 km^2. Hadsell (1968), as part of the investigation of the earthquakes at the Rocky Mountain Arsenal, conducted the first extensive evaluation of this event. He concluded the earthquake may have centered in the north Denver area, had maximum intensity of VII, and had a Richter magnitude of 5.0 $\pm$ 0.6 based on the maximum observed intensity or 6.7 $\pm$ 0.6 based on a circular felt area of just under 1,200,000 km^2.

Dames and Moore (1981) studied this event as part of their seismic hazards evaluation for the Rocky Flats Plant. A summary of their investigation was described by McGuire and others (1982). They collected additional felt

reports and reassessed others, particularly the account of landsliding and severe ground shaking in the Douglas Pass area that was discounted by Hadsell (1968). Dames and Moore (1981) discredited the felt report from Salina, Kansas because the event was not reported in Salina's newspaper. They placed the earthquake epicenter in northwestern Colorado and suggested that the Dudley Gulch graben in the Piceance Creek Basin was a possible causative structure. A radiocarbon date on unfaulted material collected by the authors, and detailed studies of the Dudley Gulch graben by Eckert (1982) have since demonstrated that no surface rupture has occurred on the Dudley Gulch graben for over one thousand years. Dames and Moore (1981) estimated the felt area size at 500,000 km^2, assigned a maximum intensity of VIII to the event, and suggested the earthquake had a local magnitude of around 6.5.

A re-evaluation of existing felt reports, combined with newly discovered felt reports and a confirmation of the felt report in Salina, Kansas by Oaks and Kirkham (1986), led Kirkham and Rogers (1986) to somewhat different conclusions. Their isoseismal map is reproduced as Figure 1. Kirkham and Rogers (1986) reported a 470,000 km^2 felt area and suggested the earthquake had a magnitude of 6.2 $\pm$ 0.3 ML based on the regression equations that compare magnitude and felt area for all Rocky Mountain earthquakes. The relatively large felt area, combined with only moderate reported intensities, suggest the earthquake occurred at a moderate hypocentral depth, perhaps about 20 km or more, similar to the more recent Laramie Mountains earthquake.

The felt reports for the event do not define a consistent epicentral location. The felt area for the aftershock on November 8th at 4:45 a.m. local time (see Figure 2), along with 1) the large number of higher intensity reports in the Denver-Fort Collins-Laramie area, 2) the Salina, Kansas felt report, 3) the apparent favored wave paths and focusing effects of more recent earthquakes (as demonstrated by the isoseismal maps contained in this report), and 4) the intensity patterns associated with the October 15, 1984 Laramie Mountains earthquake (Oaks and others, 1985) suggest an epicentral area somewhere in north-central Colorado, perhaps in the northern Front Range or southern Laramie Mountains.

An intensity map for the aftershock during the morning of November 8 (local time) is presented in Figure 2. The aftershock was felt in Denver, Boulder, Greeley, and Laramie, and near Meeker. No intensity ratings can be assigned to the known aftershock felt reports. In Laramie and Denver, however, the aftershock was reported to be nearly as strong as the main quake. If all known aftershock felt reports are included in a single felt area, then the felt area size is approximately 61,000 km^2. This suggests the aftershock may have been around magnitude 4.5 to 5.0. An equally plausible interpretation could include the Denver, Boulder, Greeley, and Laramie felt reports in a smaller felt area and show the report from near Meeker as an isolated felt account.

An epicentral location of 40 1/2° N and 105 1/2° W has been assigned to both the main quake and the aftershock by Kirkham and Rogers (1986), but this location is probably accurate to only 1/2° latitude or longitude.

3.10 November 10, 1882

Several previous earthquake listings have indicated an earthquake in Gunnison on November 10, 1882. Oaks and Kirkham (1986) examined newspapers for this

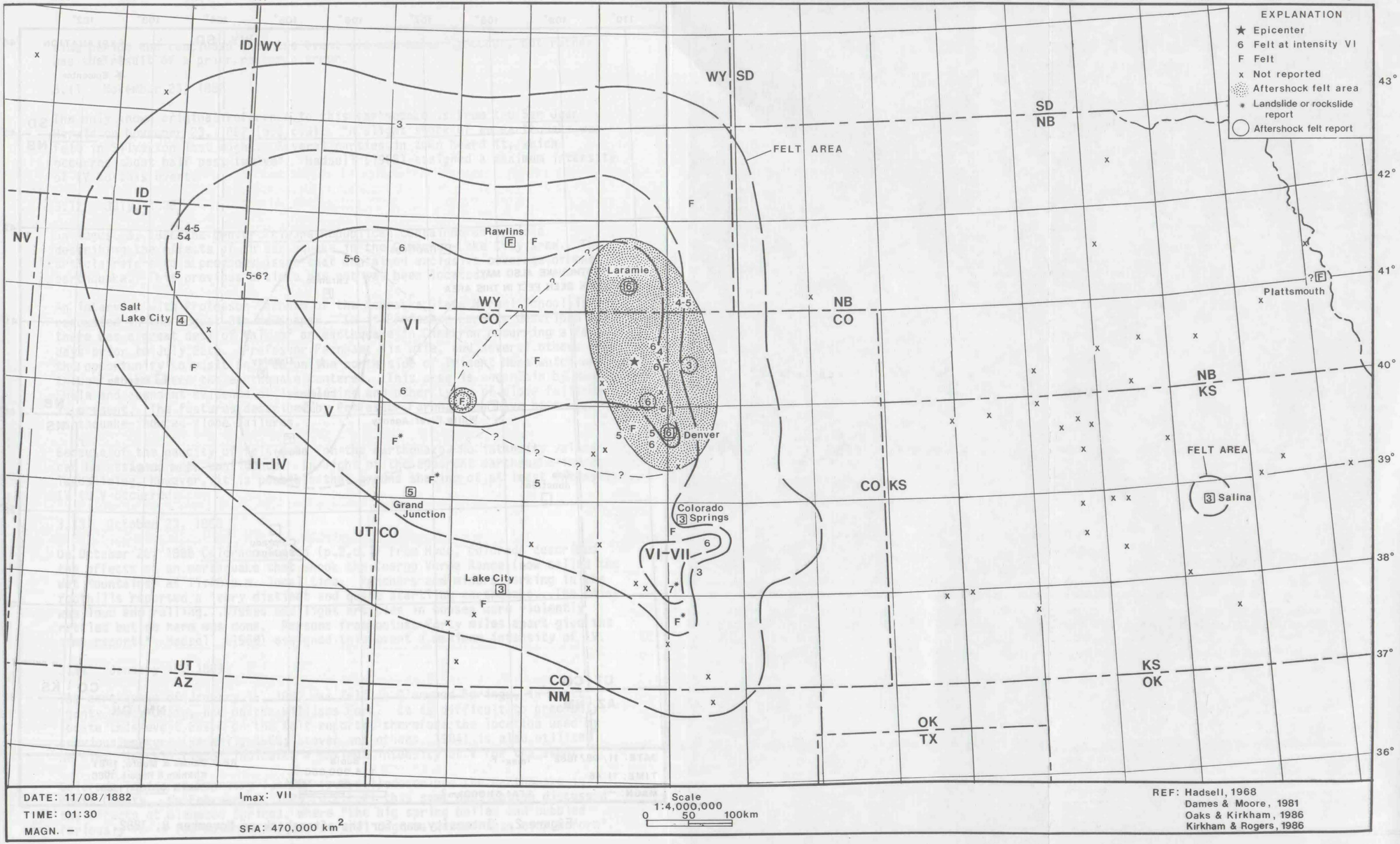

Figure 1. Isoseismal map for the November 8, 1882 earthquake.

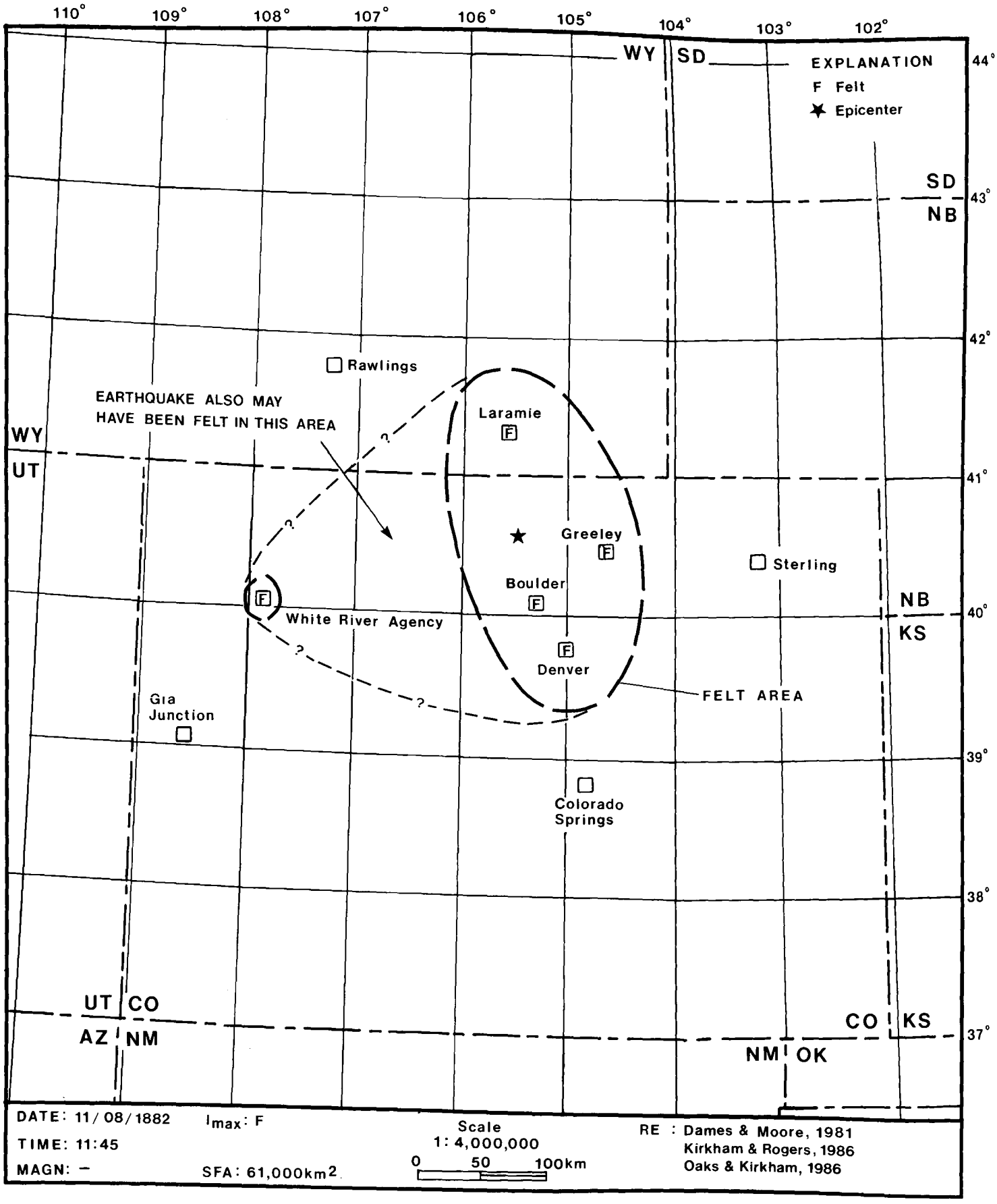

Figure 2. Intensity map for the aftershock on November 8, 1882.

time period and concluded that the event did not actually occur, but rather was the result of a prior research error.

3.11 November 23, 1882

The only known original reference to this earthquake is from the San Juan Herald on November 23, 1882 (p.3,c.3): "A slight shock of an earthquake was felt in Silverton last night. Several parties in town heard it, which occurred about half past twelve". Hadsell (1968) assigned a maximum intensity of IV to this event.

3.12 July, 1886

On August 8, 1886 the Denver Tribune-Republican contained an article describing the effects of an earthquake in the Cimarron-Lake City area. The article refers to a previous issue that contained exclusive coverage of the earthquake. This previous article has not yet been located.

An interview with Professor Farnham of the Nebraska State Normal School is recounted in the August 8th newspaper. In it Professor Farnham described that there was a great deal of talk of an earthquake in Cimarron occurring a few days prior to July 28th. Professor Farnham, his wife, and several others took the opportunity to visit an area on the north side of Trident Mesa which was thought to be where the earthquake centered. This area is underlain by Mancos Shale and abundant evidence of landsliding and other types of slope failures is present. The features described by Professor Farnham may have been earthquake-induced slope failures.

Because of the paucity of felt data for the earthquake, no intensity values can be assigned with confidence. In light of the apparent earthquake-induced landsliding, however, it is possible that ground shaking of at least intensity IV to V occurred.

3.13 October 23, 1888

On October 26, 1888 Colorado Topics (p.2,c.1) from Hyde, Colorado described the effects of an earthquake that shook the Cuerno Verde Range (now called the Wet Mountains) at 11:40 a.m. local time. Ranchers and miners working in the foothills reported a "very distinct and quite startling earthquake...The noise was loud and rolling...Dishes and light articles in houses were violently rattled but no harm was done. Persons from points forty miles apart give the same report." Hadsell (1968) assigned this event a maximum intensity of IV.

3.14 January 15, 1889

The earthquake of January 15, 1889 was felt in Glenwood Springs, in Routt County, near Craig, and on the Williams Fork. It is difficult to precisely locate this event based on the felt reports, therefore the location used by previous workers (Hadsell, 1968; Stover and others, 1984) is also utilized herein. Hadsell (1968) indicated a maximum intensity of V for the event.

Colorado Topics on February 1, 1889 (p.2,c.1) described the earthquake in Routt County. On February 8, 1889 (p.2,c.2) this same publication discussed the effects at Glenwood Springs, where "the big spring boiled and bubbled furiously for a few moments and was several degrees warmer than ever before".

The Craig Empire Courier recalled the earthquake in a February 27, 1952 article. Ms. Ossa Cooper remembered the earthquake, which rattled the dishes in her home about one kilometer east of Craig. Her brothers, the Haughey boys, felt the shock in the barn. Mrs. Robert Ratcliff says her family was living at a ranch on the Williams Fork at the time and that they distinctly felt the earthquake.

3.15 December, 1891

Hadsell (1968) listed an intensity VI earthquake occurring during December of 1891 in Axial Basin. Rizzari (1959) cited an article in the August 18, 1942 issue of The Steamboat Pilot that describes this earthquake. Oaks and Kirkham (1986) searched numerous sources for additional reports, but discovered only two, an eyewitness account in Fitzpatrick (1974) and a brief mention of the earthquake in The Daily Sentinel (Grand Junction) on November 14, 1901. Oaks and Kirkham (1986) also contains an article from the August 13, 1942 issue of The Steamboat Pilot which is nearly identical to the article cited by Rizzari (1959).

The Steamboat Pilot said "The earth was convulsed by 'waves' that rolled at intervals of a few seconds, lasting for a minute or more" and summarized the effects recalled by Hortense Fitzpatrick in Fitzpatrick (1974). The earthquake was reported in Lily Park and by settlers scattered across the area.

Fitzpatrick (1974) described the earthquake as a sound that "was as if a hundred-mile wind had struck with a roar and a seething hiss, while some stupendous power had hurled tons of loose earth against the side of the house". Their house moved, calendars and pictures on the wall oscillated, dishes in the cupboard clattered, the lids on the cookstove made noise, and the earth rolled and vibrated. Their cow fell against the house. Thousands of tons of boulders rolled down Fitzpatrick's cliff.

The Grand Junction Daily Sentinel on November 14, 1901, mentioned that an earthquake was felt in town in 1891 and that it was "not nearly so distinct" in their town as the November 13, 1901 earthquake.

3.16 January 1, 1894

The only known account of the January 1, 1894 earthquake is a fairly detailed article in the Telluride Journal on February 20, 1902. One to three shocks were felt in Telluride. Beds shook and hanging lamps and pictures swung during the quake. Descriptions of the effects in underground mine workings are also included in this article. The effects in Telluride are rated at intensity IV.

3.17 August 5, 1894

The only known original reference to the August 5, 1894 earthquake is from the Georgetown Courier on August 11, 1984. Rizzari (1959) quoted from this article as follows: "The mining towns of Georgetown and Silver Plume were visited again in August 1894. It hit about 5 a.m. on a Sunday morning, coming from the north and was accompanied by a low rumbling sound."

Hadsell (1968) indicated this earthquake occurred on August 5 and assigns an intensity of V to it.

3.18 March 22, 1895

The March 24, 1895 issue of the Rocky Mountain News (p.1,c.5) discussed the March 22, 1895 Yampa Valley earthquake. It was felt from Pleasant Valley, about 19 km south of Steamboat Springs to Hayden. The earthquake jarred windows and made dishes and spoons dance. Hadsell (1968) rated this event at intensity V.

3.19 August 3, 1897

The Telluride Journal on February 20, 1902 mentioned an earthquake that was felt in Ridgway and Telluride on August 3, 1897 (Oaks and Kirkham, 1986). The quake was felt violently in Ridgway, while only one observer noticed it in Telluride. Two other earthquakes were felt in Telluride during 1897 and 1898, but no date is given for either. We assign an intensity V rating to Ridgway and intensity III to Telluride for the August 3rd shock.

3.20 1899

Fitzpatrick (1974) reported an earthquake felt near Lay during 1899. The tremor occurred about 7:30 p.m. local time, but no month or day is given. At this time the Fitzpatricks were living near where U.S. Highway 40 crosses Lay Creek. As they describe it, "The earthquake shook the house, made dishes rattle, and lasted for about fifteen seconds". We rate this account at intensity IV.

3.21 November 13 and 14, 1901

On November 13 and 14, 1901 earthquakes occurred in Utah that were felt over much of western Colorado. Oaks and Kirkham (1986) provide numerous descriptions from Durango, Delta, Fruita, Grand Junction, and Montrose that were reported in many Colorado newspapers. Our intensity assignments for various locations in Colorado for this event are as follows: Durango-V, Delta-IV to V, Fruita-IV to V, Grand Junction-V, Montrose-V to VI (if foundation damage can be substantiated).

3.22 November 15, 1901

Numerous newspapers published accounts of an earthquake felt in and near Buena Vista on November 15, 1901 (Oaks and Kirkham, 1986). It is somewhat difficult to discriminate the felt reports of the November 13 and 14 events from those for the November 15 earthquake. It is our interpretation that the felt reports from Buena Vista and Cottonwood Lake are for a distinct earthquake on November 15 that was felt only in that immediate area. It is possible, but we believe unlikely, that the date of the Buena Vista report is incorrect and that these felt reports resulted from the Utah earthquakes on November 13 and 14.

An interesting aspect of this earthquake is that moderate intensities (VI) are reported for this event in the immediate vicinity of Buena Vista, but that surrounding towns did not report the event. Many residents of Buena Vista ran excitedly into the streets wearing only night clothes, and a large plate glass window was broken. The water in Cottonwood Lake was agitated, and numerous boulders rolled down Mount Princeton and Mount Harvard. Newspapers in Salida described the effects in Buena Vista, but did not report any local effects

(Salida Mail, November 19, 1901). Likewise, newspapers in both Leadville and Aspen failed to mention any local manifestations to the earthquake. Such evidence suggests the Buena Vista earthquake may have occurred at a fairly shallow depth, and may have been only magnitude 4.0 to 5.0.

3.23 November, 1901

Reference is made to an event in Aspen in The Daily Sentinel of Grand Junction on November 15, 1901 (p.1,c.2 & 3) as follows:

> Aspen Democrat: Grand Junction had an earthquake shock last evening and the sugar beets were shaken to their roots. We had one up here a week or more ago caused by the dull thud of the Republican party.

Because this report can be interpreted in several ways, we have elected not to include this event in our list of Colorado earthquakes until further supportive information is brought forth.

3.24 December 29, 1901

The December 30, 1901 issue of The Denver Times (p.2,c.4) questioned "Did Denver Have A Real Earthquake Saturday Night". Just before midnight on December 28 a disturbance rattled windows and dishes and was accompanied by a loud noise followed by a low rumbling for a few seconds. The event was also felt in Montclair, on Sand Creek, and in south Denver. We believe this event may well have been an earthquake and it is therefore included on our earthquake list and assigned a MMI of IV.

3.25 September 9, 1903

Wollard (1968) described the September 9, 1903 earthquake based on unpublished data from H.F. Reid. Houses in Boulder shook noticeably, causing doors and windows to rattle during the tremor. It was also felt in Fort Collins, Longmont, and Loveland. Docekal (1970) indicated the quake was felt over 5,200 to 7,800 km^2. Stover, Reagor, and Algermissen (1984) suggested an epicentral location of 40.3° N and 105.3° W. A location slightly to the east may, however, be more appropriate.

Figure 3, an intensity map for this event, indicates the possible extent of the felt area. We estimate the earthquake felt area at approximately 3,900 km^2, but recognize that the felt area may be slightly larger.

3.26 April, 1906

An article in The Craig Empire Courier on February 27, 1952 refered to an earthquake felt in Moffat County during 1906 at the time of the great San Francisco earthquake (April 18). A report from the Templetons along the Yampa River just below Maybell stated that dirt was shook loose from the riverbank and that the water in the river was agitated. Pans in the pantry of a nearby log house rattled and clattered and one was shaken from the shelf. A woman living at a ranch on the Little Snake River was so startled by the quake that she tipped over backward in her chair. The shock apparently was felt over much of northwestern Colorado. Please refer to Oaks and Kirkham (1986) for a complete account of this article.

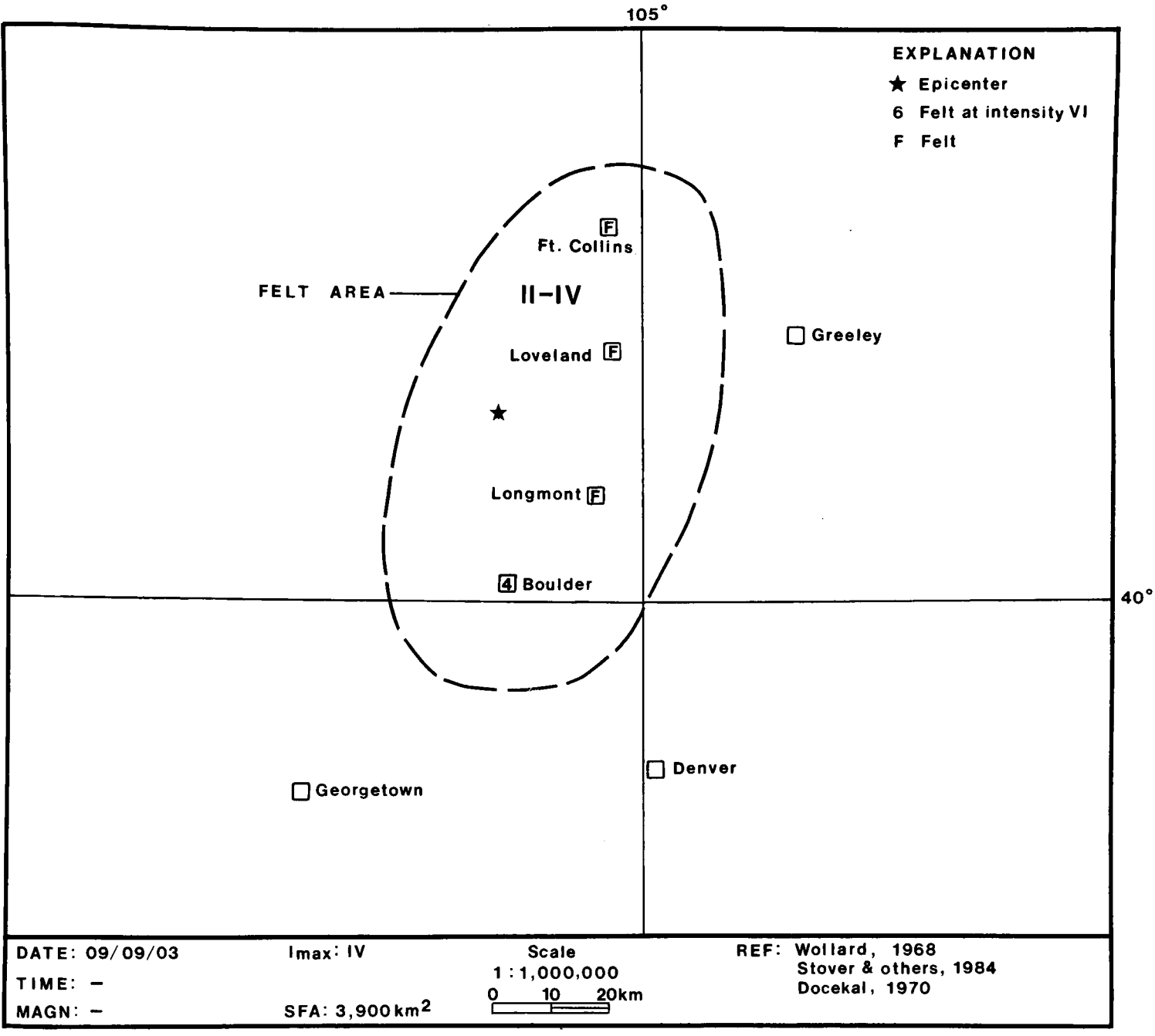

Figure 3. Intensity map for the September 9, 1903 earthquake.

3.27 December 21, 1906

The December 21, 1906 earthquake was described by Wollard (1968) based on unpublished data from H.F. Reid. According to Wollard, the earthquake was felt in Newcastle at 9:10 local time. The duration was reported as being 10 seconds, and the maximum intensity was given as III.

3.28 November 11, 1913

Coffman, von Hake, and Stover (1982) described the three earthquakes on November 11, 1913 based on unpublished data from H.F. Reid. They indicate the quake was strong at Montrose, Ouray, and Telluride, and that objects were thrown from shelves and rocks rolled down cliffs at Ouray. According to Coffman, von Hake, and Stover (1982) the earthquake was felt over nearly 20,000 km^2 and the maximum intensity was V.

Oaks and Kirkham (1986) discovered a recollection of these events in a newspaper article describing the September 9, 1944 earthquake in the Montrose Daily Press on September 9, 1944. This article suggests that Ridgway was hardest hit in the area and that the quake centered near Portland, about 10 kilometers south of Ridgway. Pictures fell from walls, dishes were broken, and the Ridgway school ceiling was damaged during the earthquake. Similar types of damage were reported over a wide area. Original newspaper accounts of this earthquake have not yet been located.

We assign the damage reported in Ridgway an intensity VI and the reports from Montrose, Ouray, and Telluride an intensity V. An isoseismal map for this event is shown in Figure 4. The felt area for this earthquake is estimated to be 13,600 km^2, based on our isoseismal map. The epicentral location is slightly revised from previous studies to 38.1° N and 107.7° W, as a result of the above described newspaper account.

3.29 February 28, 1915

The earthquake on February 28, 1915 is described by Humphreys (1915) and by Wollard (1968) based on unpublished data by H.F. Reid. Stover, Reagor, and Algermissen (1984) rated the maximum intensity for this event at III. An indirect reference to this event is described under the "Palisade News" section of The Daily Sentinel (Grand Junction) on March 1, 1915. This article mentions that the earthquake was felt in Grand Junction, but not in Palisade.

3.30 October 12, 1916

Hadsell (1968) and Humphreys (1916) reported an earthquake on October 12, 1916 in Boulder. The quake occurred about one hour before midnight on October 11 (local time). Docekal (1970) indicated it was a "light" earthquake felt at Boulder. An intensity III rating was given by Hadsell (1968) for the earthquake.

3.31 December 29 and 30, 1920

Four earthquakes occurred on December 29 and 30, 1920, according to Stover, Reagor, and Algermissen (1984) and Humphreys (1921). Newspaper reports for two of the earthquakes appeared in The Rifle Telegram on December 30, 1920 (p.1 and p.7) and in The Glenwood Post on January 1, 1921 (p.1). There is some confusion in correlating the earthquakes between the scientific reports and the newspaper accounts. In our opinion the two earthquakes described in the newspapers occurred on November 29 at 02:50 and 09:50 (UTC).

The newspapers indicate the event at 02:50 was felt strongest at New Castle, where several windows were broken. Along Canon Creek the quake caused some ranch families to rush from their homes. The Glenwood Post suggests that only

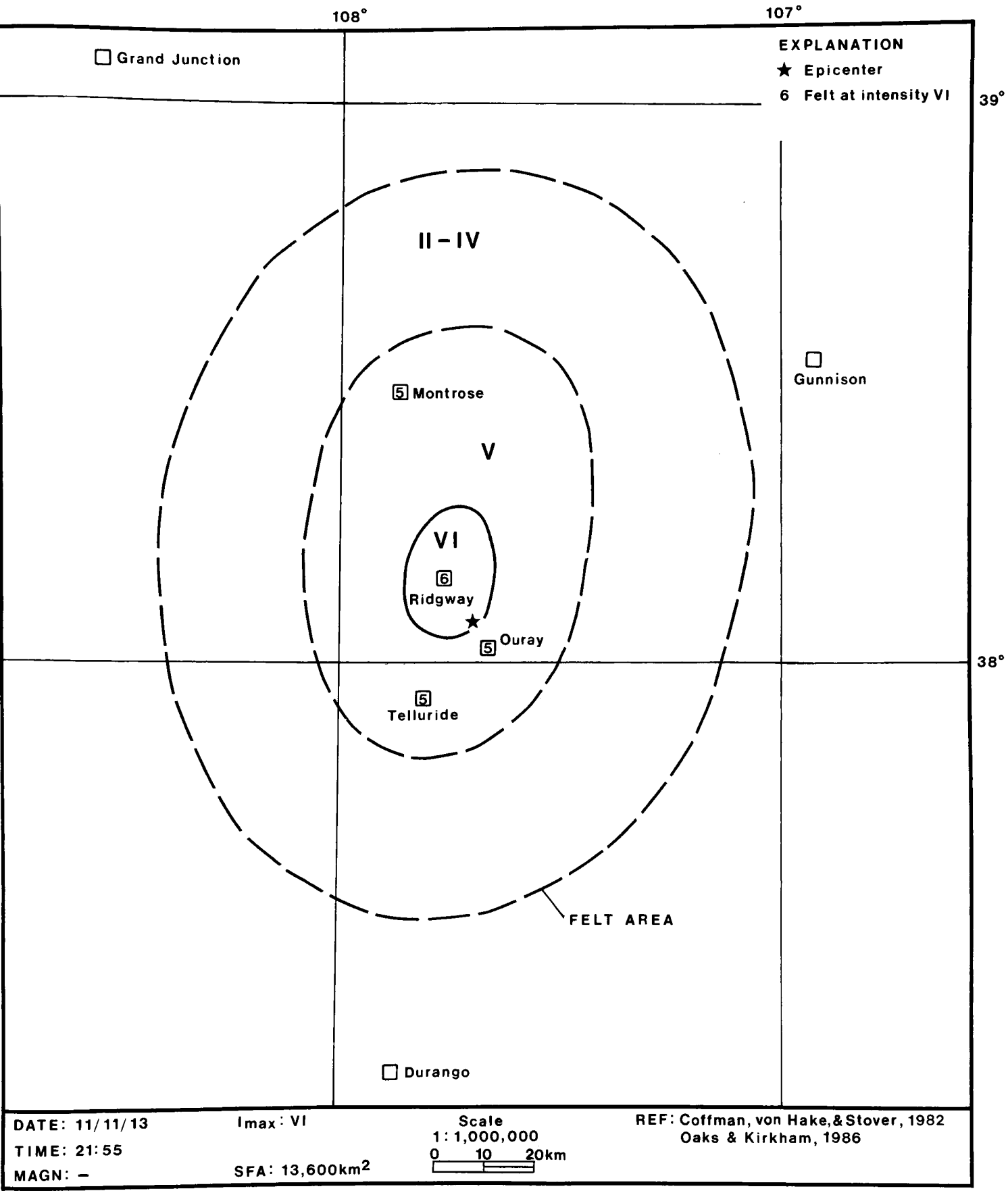

Figure 4. Isoseismal map for the November 11, 1913 earthquake.

a few citizens of their city felt the tremor, but that it may have been felt as far down river as Palisade (although this has not been substantiated).

Our intensity assignments for this event are as follows: New Castle-V, Canon Creek-IV to V, Cardiff-III, Glenwood Springs, Rifle, Silt, Antlers, West Elk Creek Ranch, South Canon, and south side of river in Mamm Creek area-felt. An isoseismal map for this event is shown in Figure 5. The earthquake was felt over an estimated 1,400 km^2.

3.32 February through July, 1921

A swarm of earthquakes involving 14 small events ranging from intensity II to IV centered near Garfield between February and July of 1921 (Humphreys, 1921). This sequence of events is of great interest because they represent the only historic earthquakes known to have occurred in the southern end of the Upper Arkansas Valley. Unfortunately, very little is known about this earthquake swarm.

3.33 October 15, 1921

Humphreys (1921) and Wollard (1968) reported that an earthquake lasting for 2 to 3 seconds was felt by several in Eads. It was rated at MMI III.

3.34 January 27, 1923 and January 4, 1924

The International Seismological Summary (1918-1963) reported earthquakes in the Denver area on January 27, 1923 and January 4, 1924. All that is currently known about the events is that they were felt in Denver.

3.35 Summer, 1924

A mild earthquake occurred in Craig during the summer of 1924 (Fitzpatrick, 1974). Numerous cars were observed to roll back and forth a few inches. The quake was neither heard nor felt by the observers, but the movement of the cars continued for about 30 seconds.

3.36 February 18, 1925

On February 18, 1925 residents of Wetmore reported an earthquake that cracked the ground (USCGS Seismological Reports, January-March, 1925; Docekal, 1970). The quake was also felt at Judkins (or Junkins) Park and at Rosita. Figure 6 is an intensity map for this event. Based on this map we estimate the felt area of this earthquake to be 1,300 km^2. Docekal (1970) suggested the event was felt over about 2,100 km^2, but recognized that his figure was a rough approximation.

3.37 July 30, 1925

A large area in Texas, Oklahoma, eastern New Mexico, Kansas, southeastern Colorado, and western Missouri was shaken by this widely felt Texas Panhandle earthquake on July 30, 1925. Maximum intensity for this event was VI and it was felt over 518,000 km^2 (Docekal, 1970; Coffman, von Hake, and Stover, 1982). An isoseismal map for this earthquake was shown in Docekal (1970). Docekal indicated the quake was felt at intensity III or less in the southeast corner of Colorado.

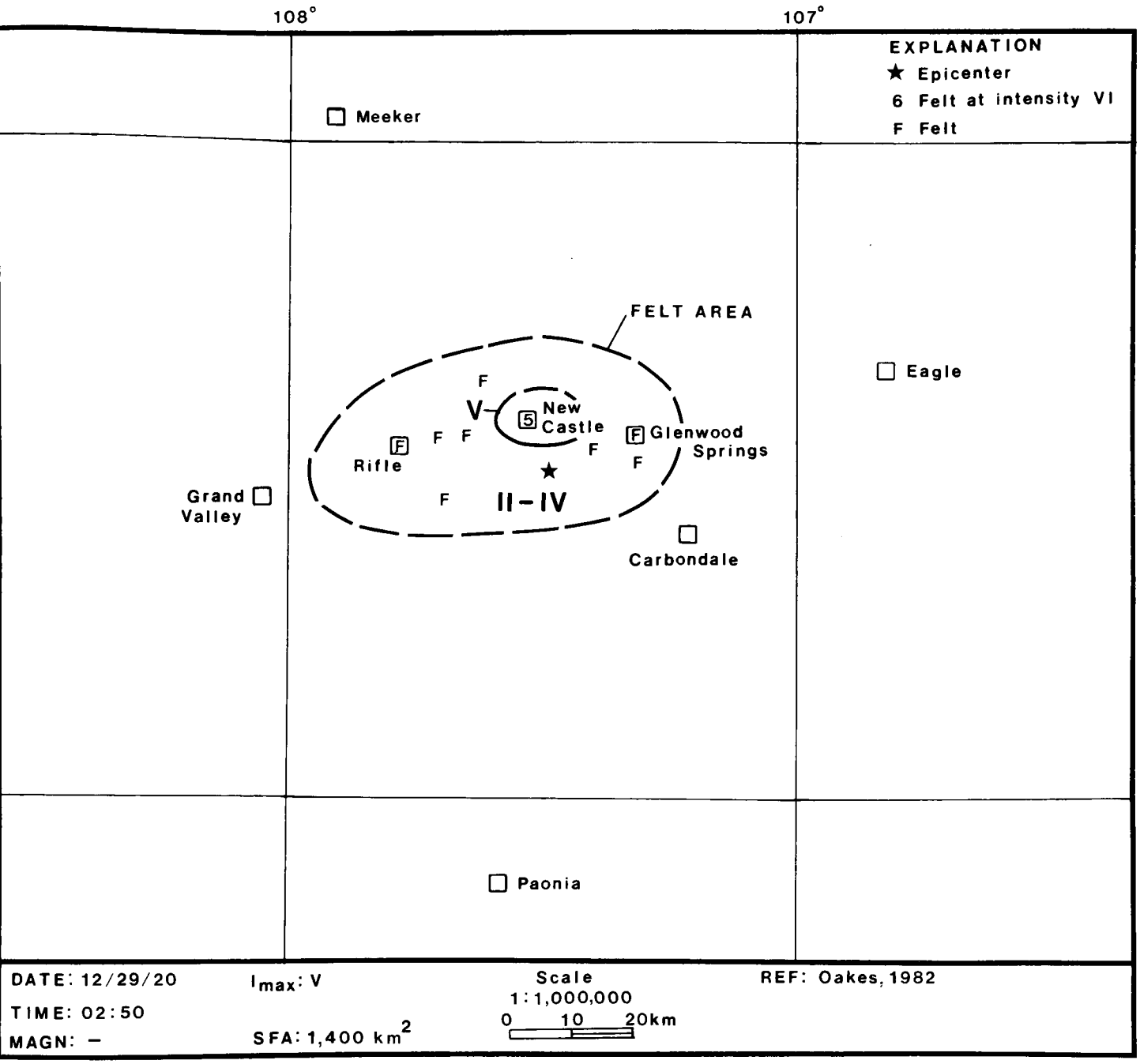

Figure 5. Intensity map for the December 29, 1920 earthquake.

3.38 April 20 to May 10, 1928

A swarm of earthquakes consisting of over fourteen reported events shook the Creede vicinity from April 20 through May 10, 1928. Heck and Bodle (1930) provided the most complete description of these events, and Stover, Reagor, and Algermissen (1984) contributed additional data. Most tremors rated intensity IV, causing the earth to tremble and dishes to rattle.

Heck and Bodle (1930) stated that the "shocks on May 1st were quite strong and more widely felt, at least 15 or 20 miles from Creede. The shock on May 10

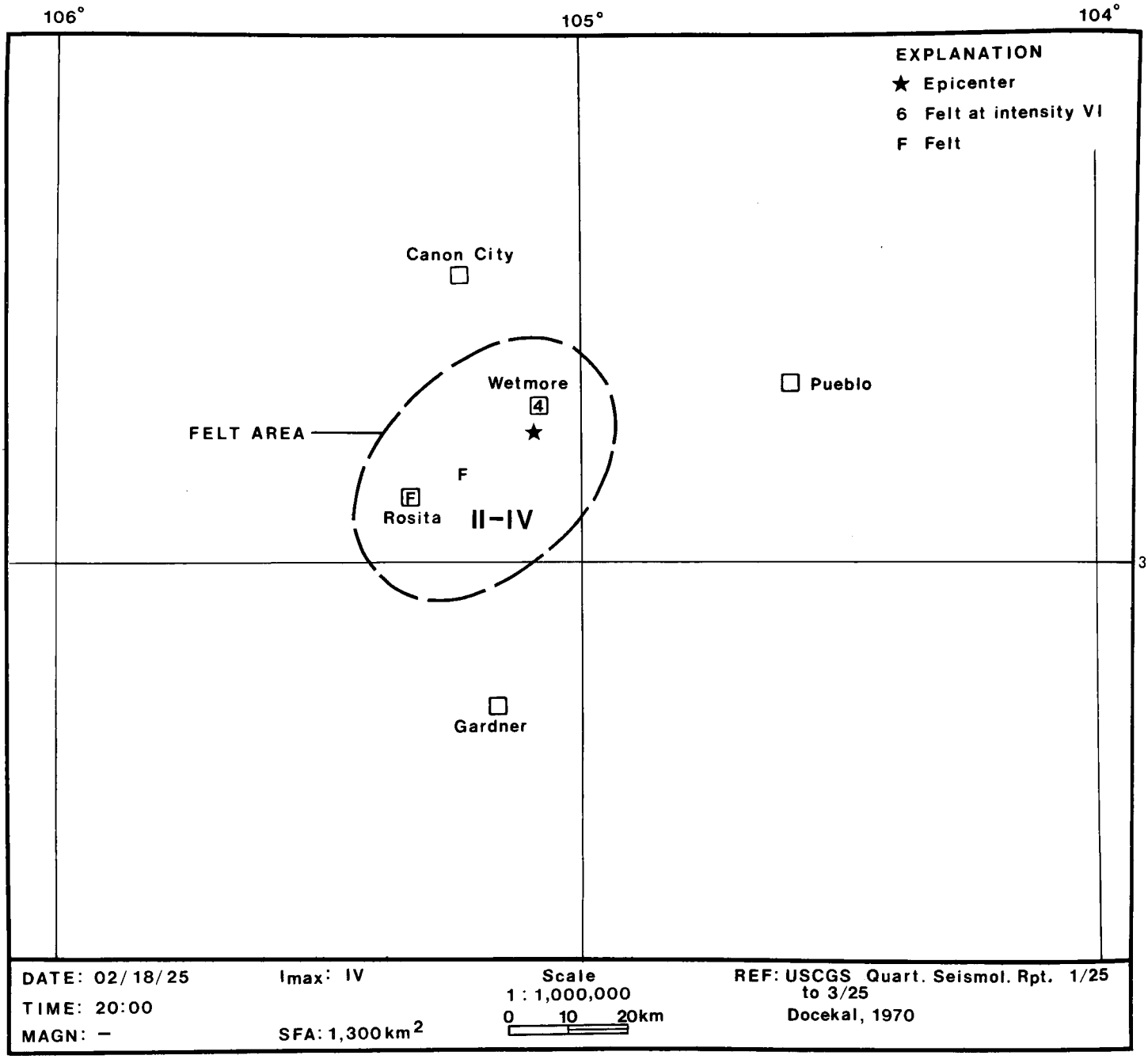

Figure 6. Intensity map for the February 18, 1925 earthquake.

was also more widely felt. In no case was the area over which the shocks were felt very large". Stover, Reagor, and Algermissen (1984) assigned intensities to these events and their determinations are used in our earthquake list (Table 1). The earthquakes on April 30th and May 10th were rated at intensity V, an apparently slight deviation from the description of Heck and Bodle (1930). This discrepancy might be reconciled if the records of the Creede weather observer could be located.

3.39 September 29, 1928

On September 29, 1928 an earthquake shook Holly and other parts of Prowers County. Heck and Bodle (1930) described the earthquake as a rocking motion generally felt in Holly and indicated that many people were awakened and alarmed throughout the county. Stover, Reagor, and Algermissen (1984) rated this event at intensity IV.

3.40 March 12, 1934

A large earthquake originated near Kosmo, Utah on March 12, 1934. The earthquake was widely felt over a large area (440,000 km^2) in Utah, Idaho, Nevada, Wyoming, Montana, and northwest Colorado (Neuman, 1936). Surface faulting occurred in the epicentral area, along with "The emission of large quantities of water from fissures and craterlets".

Gutenburg and Richter (1954) assigned this earthquake a modified magnitude of 6.6, while the maximum intensity was reported at VIII (Neuman, 1936; Coffman, von Hake, and Stover, 1982). The earthquake was reported felt at Craig, Colorado with an intensity of III or less (Neuman, 1936).

3.41 July 30, 1934

Parts of Nebraska, South Dakota, Wyoming, and Colorado were shaken by the July 30, 1934 Chadron, Nebraska earthquake (Neuman, 1936). MMI VI damage was reported at Crawford and Chadron, Nebraska, where a few chimneys were damaged and some plaster fell. Sterling, Colorado reported intensity III or less for this event. Neuman (1936) suggested the earthquake was felt over 60,000 km^2. Isoseismal maps for this event are contained in Neuman (1936) and Docekal (1970).

3.42 June 20, 1936

An earthquake was felt in the Texas Panhandle, western Oklahoma, southeastern Colorado, and southwestern Kansas on the evening of June 19, 1936 (local time). An intensity map for this event prepared from the reports in Neuman (1938) is shown in Figure 7. Slight damage occurred over scattered areas in Texas, Oklahoma, and Kansas (Neuman, 1938).

Richards, Colorado reported an intensity III or less, and the earthquake was apparently heard at this location. According to a map in Neuman (1938) the tremor was also felt in the Colorado towns of Vilas and Blaine, and at an unnamed location southeast of Springfield.

The earthquake was felt over 87,000 km^2, an unusually large felt area for an earthquake with a maximum intensity of only V.

3.43 April 8, 1940 to February 28, 1941

Neuman (1942,1943) described earthquakes felt in Aspen on April 8, 1940 and on February 13, 21, and 28, 1941. Newspaper accounts in the Aspen Times provide additional supportive data (see Oaks and Kirkham, 1986). MMI values were assigned to each quake by Stover, Reagor, and Algermissen (1984).

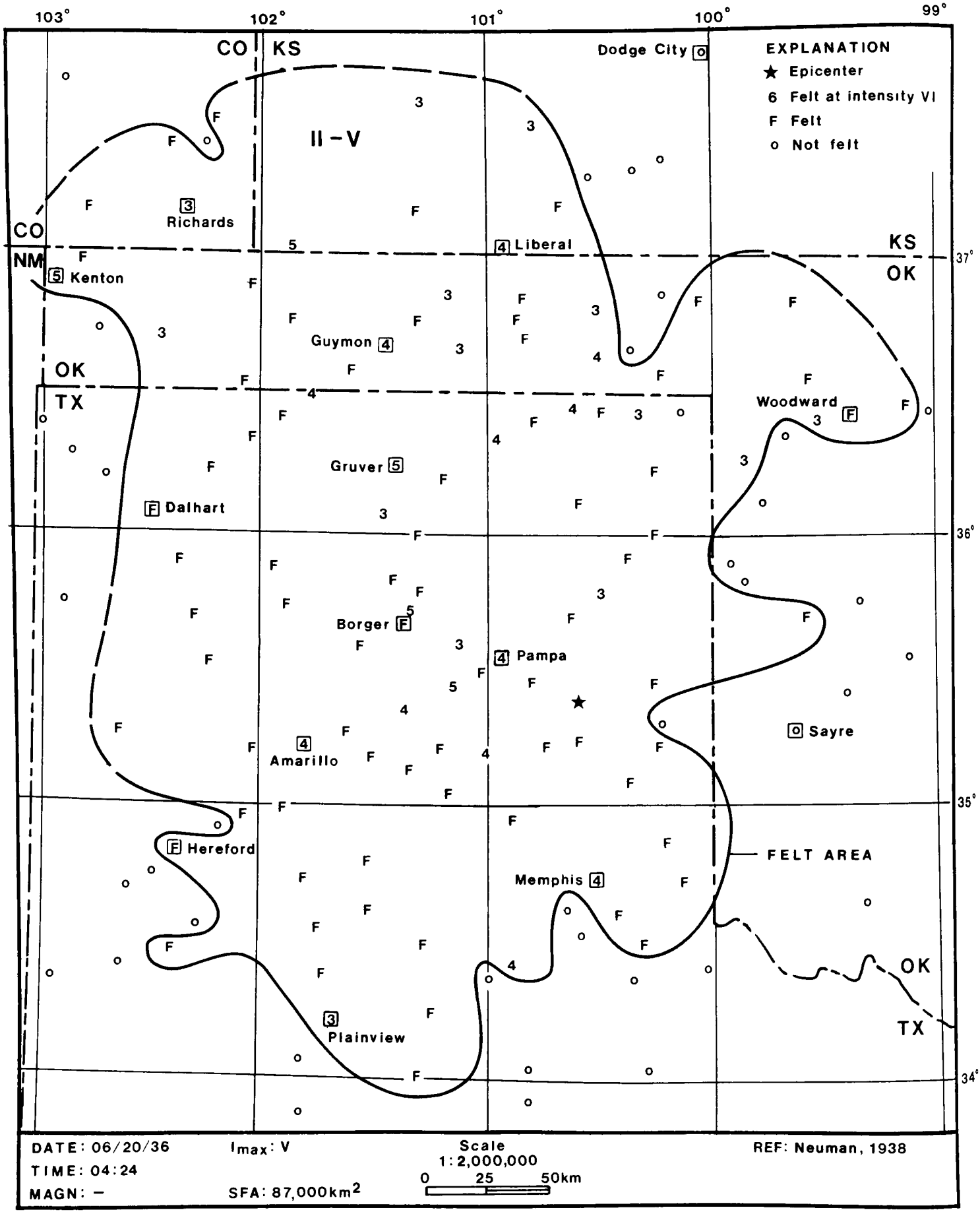

Figure 7. Intensity map for the June 20, 1936 earthquake.

The April 8, 1940 event was a light shock generally felt only by people in or near buildings, and was rated intensity III. The February 13th earthquake was slightly stronger, causing windows to rattle and houses to shake. It was felt as far down valley as the Snowmass Store and Woody Creek and was assigned a MMI of IV. According to the Aspen Times, the February 21st event was similar in size to the preceding quake and was also rated at IV. During the February 28th quake a man in Aspen was awakened and alarmed. This earthquake, along with other previous shocks, was reported felt in the Frying Pan Creek area in the March 6th issue of the Aspen Times, suggestive that the February 28th event also may have been intensity IV. Hadsell (1968) described a circular felt area of about 800 km^2 for these events.

3.44 July 23, 1942

Oaks and Kirkham (1986) located a newspaper clipping in Craig that described an earthquake in western Moffat County and northeastern Utah on July 23, 1942. The clipping is thought to be from The Craig Empire Courier on July 27 or 29, 1942. The article says a number of people in the area from Elk Springs, Colorado to Vernal, Utah reported "that the quake rattled dishes, shook houses and was so pronounced as to be unmistakably a small quake". Mr. Steele, of the Massadona tourist camp 110 km west of Craig, thought the earthquake might shake loose his porch supports. Only a few people in Craig felt the disturbance.

We rate the Massadona tourist camp report at intensity V, the Elk Springs and Vernal reports at intensity IV, and the Craig report at intensity III. The earthquake was felt over an estimated 16,000 km^2.

3.45 August, 1942

An excerpt from an article in The Steamboat Pilot on August 13, 1942 said "Distinct earthquake shocks felt by residents of the west end of Moffat County reminded old timers of similar occurrences in 1891. While the shock last week shook dishes in cupboards and alarmed ranches, the one in pioneer times assumed the proportions of a real earthquake, says the Moffat County Mirror".

A strict interpretation of this article would indicate the earthquake happened sometime during the first week of August and, hence, is a different event that the July 23rd earthquake. It is possible, however, that this article does refer to the July 23rd event and that the writer of the article was slightly mistaken in the timing of the earthquake.

We have chosen to list these two events separately in our earthquake list (Table 1), but assign the same location to both. It is acknowledged that the two reports may describe a single event.

3.46 September 9, 1944

A moderate earthquake was felt over part of western Colorado during the evening of September 8, 1944 (local time). Bodle (1946) described felt reports ranging up to intensity VI at Basalt, Montrose, and Riland. The earthquake cracked walls and chimneys, rattled windows, and overturned small objects in Basalt. Buildings creaked, loose objects rattled, and some plaster was cracked in Montrose. Reports from Riland indicate a strongly built log house was moved slightly out of line. Aspen, Eagle, Edwards, Gilman, and

Grand Junction experienced intensity V shaking. Additional felt reports were contained in Bodle (1946), while "not felt" reports were in USCGS "Abstracts of Earthquake Reports".

Oaks and Kirkham (1986) described numerous newspaper articles concerning this earthquake. Additional felt reports were obtained from these articles and, along with those of Bodle (1946), were utilized to construct the isoseismal map in Figure 8. This map suggests the felt area for the earthquake was approximately 19,000 km^2. Other estimates of the felt area size were 7,800 km^2 (Bodle, 1946) and 41,000 km^2 (Hadsell, 1968).

3.47 March 12, 1948

Figure 9 is an isoseismal map for an earthquake that occurred during the late evening of March 11, 1948 (local time) and centered near Dalhart, Texas. The quake was felt in parts of Texas, New Mexico, Colorado, Kansas, and Oklahoma.

Felt reports and MMI assignments were in Murphy and Ulrich (1951) and the USCGS quarterly series "Abstracts of Earthquake Reports" for 1948. Intensity VI was reported in Texas at Amarillo, Channing, Dalhart, Electric City, Panhandle, Perico, and Perryton, in New Mexico at Bell Ranch, Bueyeros, Gladstone, Ione, Logan, Mount Dora, and Seneca, in Colorado at Kim and Trinchera, and in Oklahoma at Boise City, Felt, Kenton, and Regnier. Earthquake damage was slight, involving minor cracked plaster, cracked masonary and adobe building walls, and slight damage to wooden structures. In Trinchera, Colorado windows, doors, and dishes rattled, hanging objects swung, and plaster cracked.

Murphy and Ulrich (1951) indicated the earthquake was felt over 130,000 km^2, while Docekal (1970) suggested it was felt over 298,000 km^2. Our isoseismal map reveals the felt area size for this event to be 123,000 km^2, in close agreement with Murphy and Ulrich (1951).

3.48 January 18, 1950

This interesting earthquake occurred on January 17, 1950 at about 7 p.m. local time. Murphy and Ulrich (1952) placed the epicenter at 40.5° N and 110.5° W near Soldier Summit, Utah, outside of the felt area for the quake. It is possible that the published epicentral location is mislocated.

Felt reports, intensity assignments, and "not felt" reports were recorded in Murphy and Ulrich (1952) and in the USCGS quarterly series "Abstracts of Earthquake Reports". "Not felt" reports were also located in the NOAA microfilm files. An intensity map was prepared based on these reports (Figure 10). Maximum intensity for this event is V, and the felt area is approximately 11,100 km^2.

An interesting aspect of this tremor is that the most severe ground shaking for this event developed in Grand Junction, where a few plaster cracks formed. The event was felt in all parts of Grand Junction and from about 5 km east of town to about 19 km west, forming an isolated felt area in Grand Valley that was about 200 km from the published epicentral location and about 75 km from the next closest felt report.

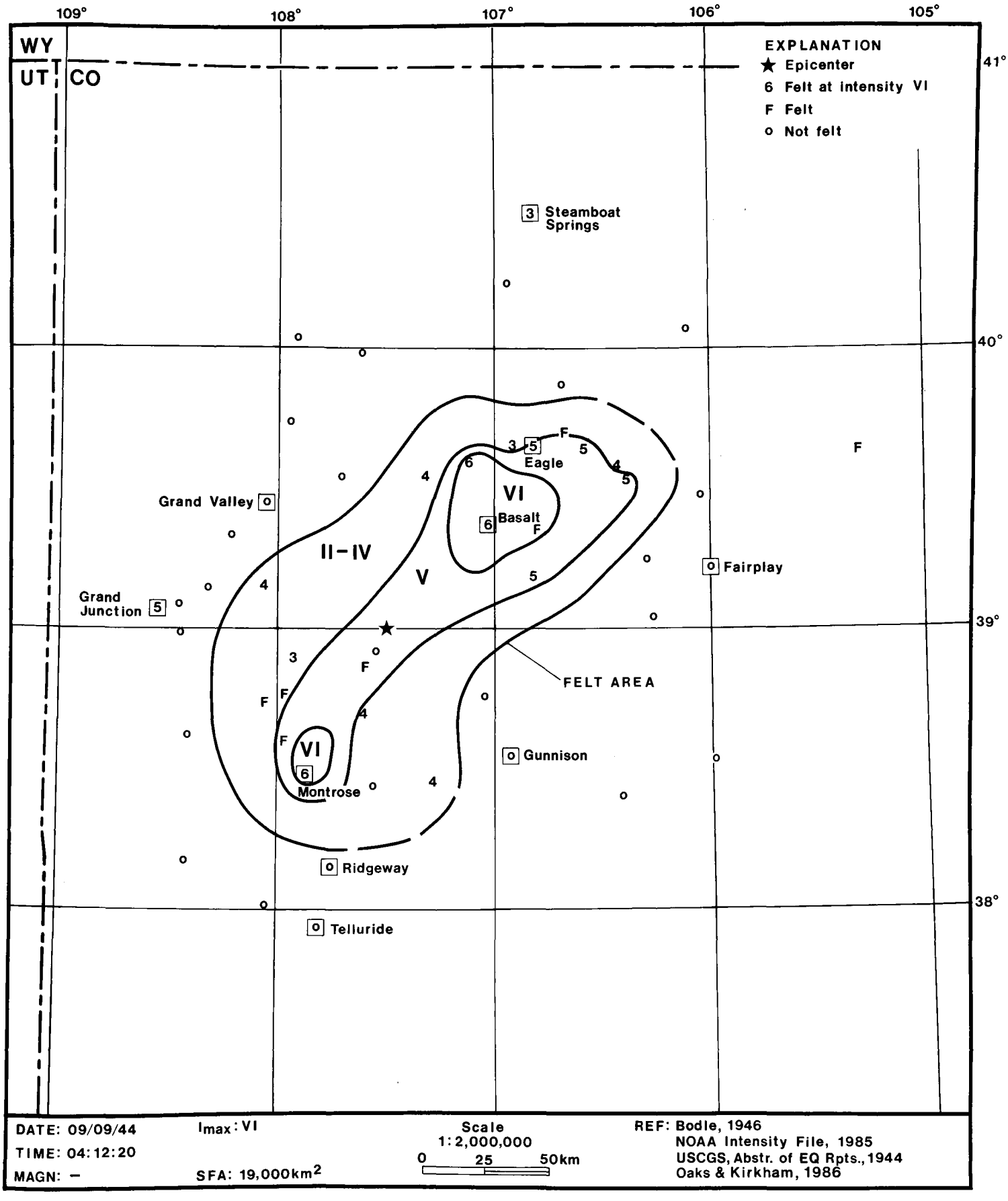

Figure 8. Isoseismal map for the September 9, 1944 earthquake.

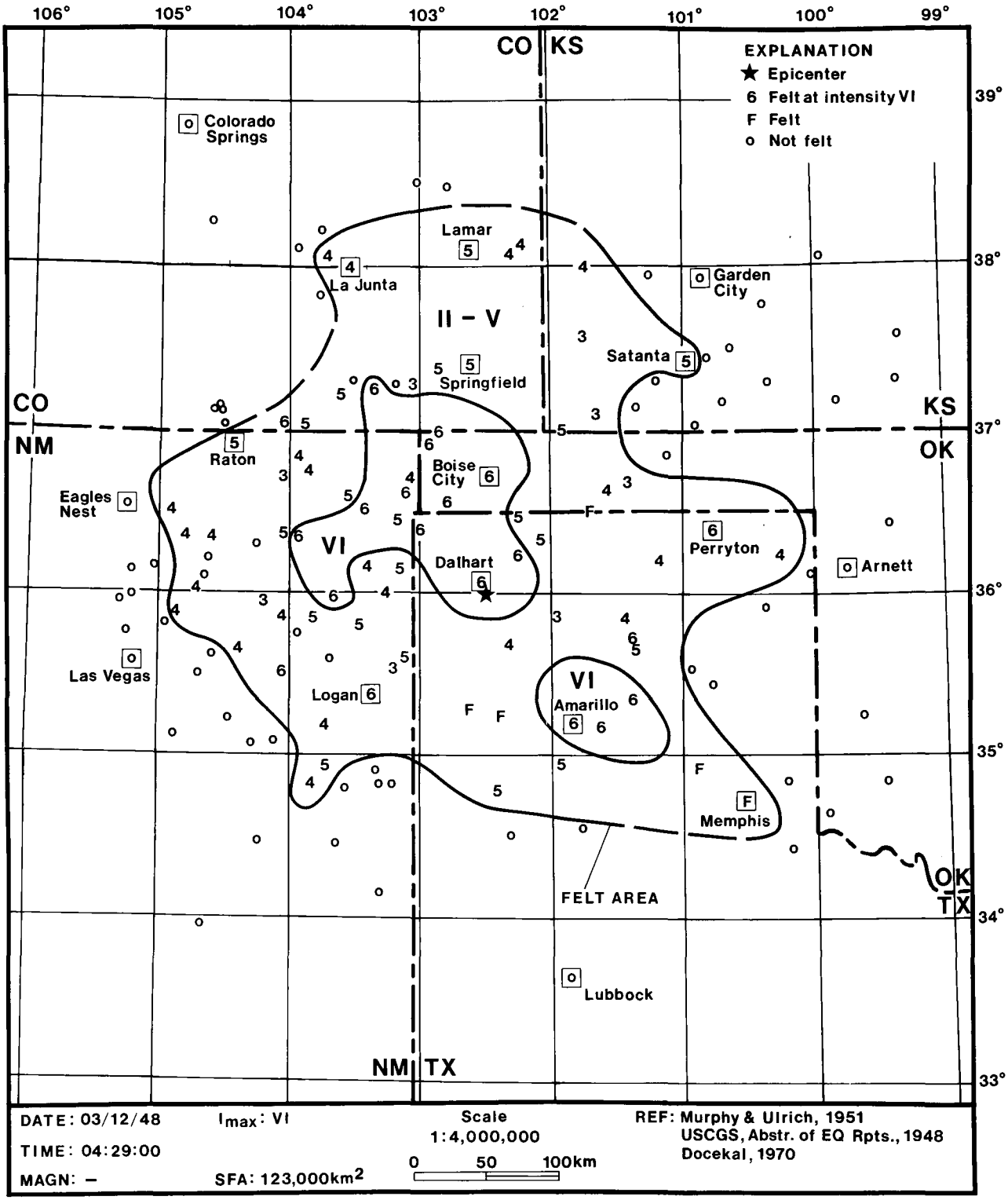

Figure 9. Isoseismal map for the March 12, 1948 earthquake.

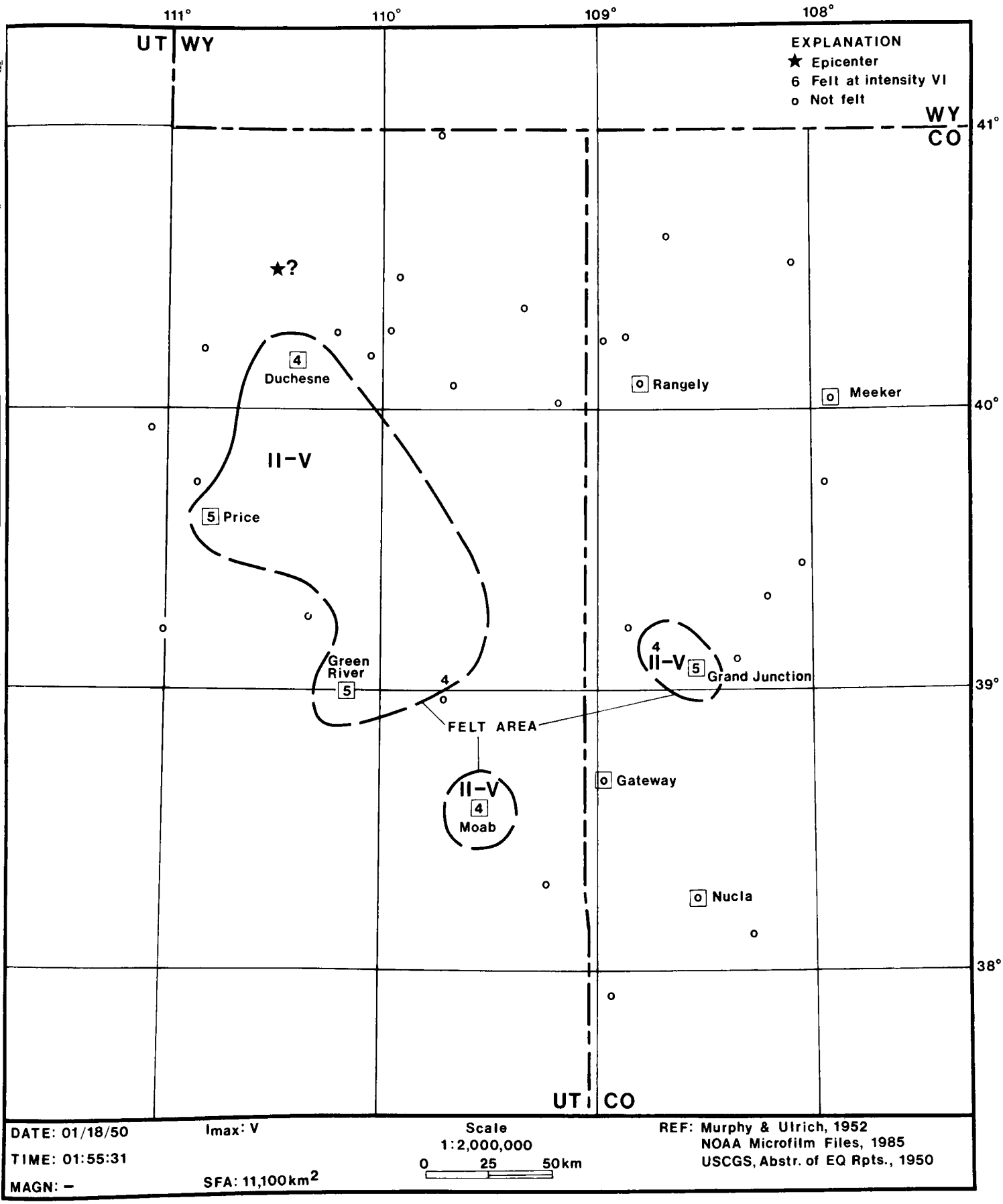

Figure 10. Intensity map for the January 18, 1950 earthquake.

3.49 October 7, 1952

A small area along the southern Colorado-northern New Mexico border was shaken by an earthquake on October 7, 1952. Murphy and Cloud (1954) described the felt reports and assigned MMI values to each report. "Not felt" reports were obtained from the NOAA microfilm files. They are as follows: Blanca, Jarosa, Monte Vista, Mosca, San Acacio, Sanford, San Luis, and Summitville, Colorado, and Canjilon, Cebolla, Cerro, Costilla, Los Tablas, Monero, Pataca, Questa, Tierra Amarilla, and Vallecito, New Mexico. Figure 11 is an intensity map for this event.

Maximum intensity for this event was rated at V. It was felt strongest in Antonito, where dishes, windows, and doors rattled, and rocks and boulders were dislodged. Other locations where the earthquake was felt at intensity V include Osier, Colorado and Chama and Tres Piedras, New Mexico. As shown on Figure 11, the earthquake was felt over approximately 4,500 km^2. Hadsell (1968), however, suggested the circular felt area for this event was 15,600 km^2. This quake is the only known felt earthquake centered in the San Luis Valley portion of the Rio Grande Rift during the historic period. The epicenter was along the west side of the valley, possibly in the foothills of the San Juan Mountains.

3.50 January 20, 1954

Murphy and Cloud (1956) described an earthquake felt in southeastern Wyoming and northern Colorado on January 20, 1954. Several locations in Wyoming, including Albany, Centennial, Foxpark, Laramie, and Lake Hattie, reported intensity V shaking. Four miles north of Cowdrey, Colorado the windows, doors, and dishes rattled, and a house creaked. We assign intensity IV to the report near Cowdrey. Two light aftershocks were felt in Fox Park and Jelm.

An intensity map for this event is presented in Figure 12. Murphy and Cloud (1956) suggested the earthquake was felt over 5,200 km^2, while Figure 12 shows the earthquake felt over about 6,700 km^2.

3.51 February 21, 1954

Northwestern Colorado experienced an earthquake on February 21, 1954. Murphy and Cloud (1956) indicated the tremor caused a maximum intensity of IV. Dishes, venetian blinds, and a door rattled in Grand Junction. The ground shook noticeably between Fruita and Loma, and hanging plants swung. It was also felt two miles north of Mack and at Redlands and Cameo. In the Castle Park area of Dinosaur National Park windows and dishes rattled, a house shook, and chairs danced. Oaks and Kirkham (1986) describe a newspaper account of this event in Rangely, where dishes rattled and neighbors ran outside. An intensity IV rating is given to this report.

Figure 13 is an intensity map for the February 21st earthquake. We have chosen to outline two distinct felt areas for this event in a manner similar to the better documented September 30, 1977 earthquake. The felt area for this quake is estimated at 8,100 km^2, but would be somewhat higher if all felt reports were enclosed in a single felt area.

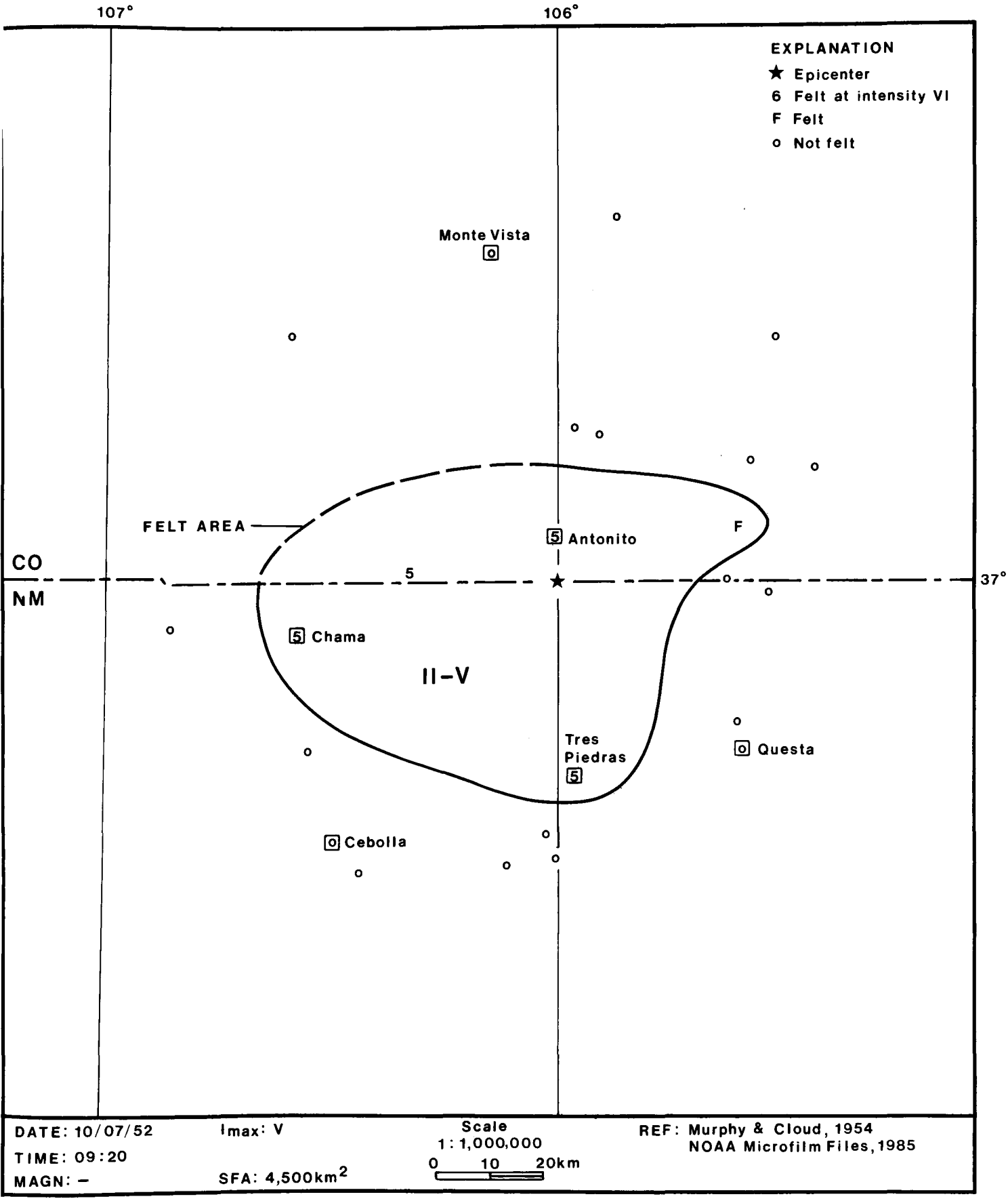

Figure 11. Intensity map for the October 7, 1952 earthquake.

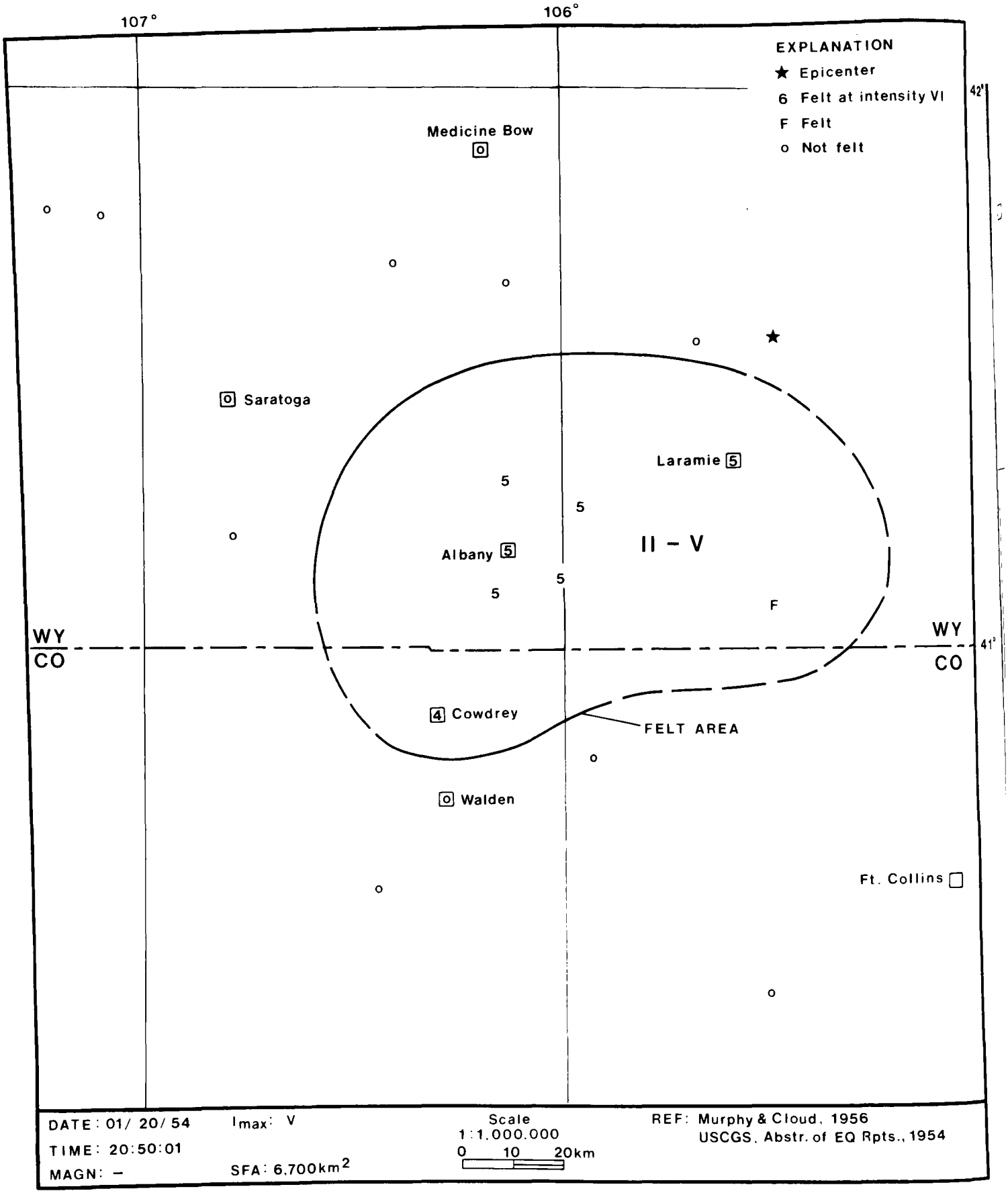

Figure 12. Intensity map for the January 20, 1954 earthquake.

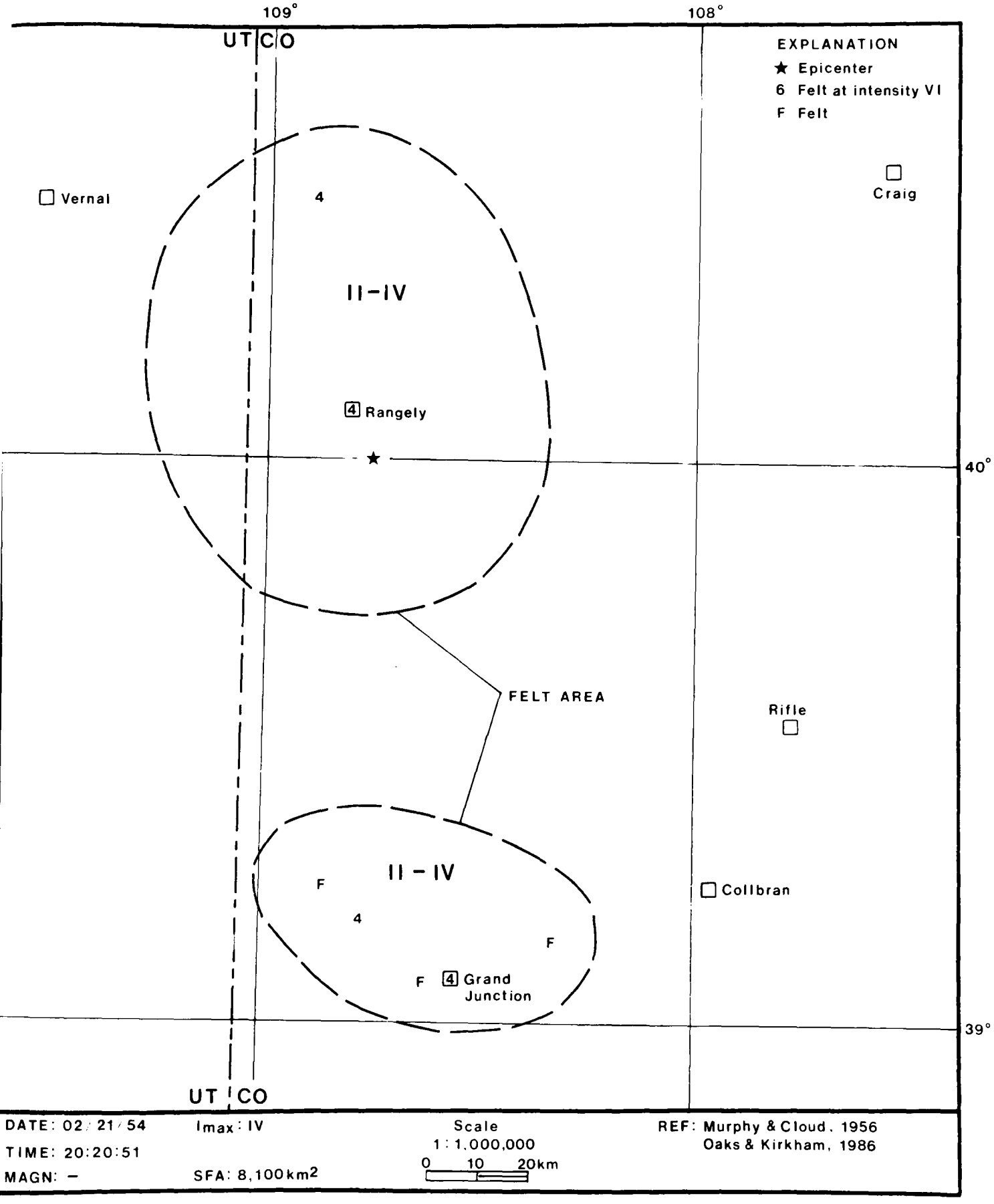

Figure 13. Intensity map for the February 21, 1954 earthquake.

3.52 February 10, 1955

On February 10, 1955 the Steamboat Springs area was hit by a moderate earthquake. An isoseismal map for this event is presented in Figure 14. Murphy and Cloud (1957) recounted the felt reports. There was general alarm in Steamboat Springs, where plaster cracked, a few old cracks re-opened, a cement garage floor cracked, and a few dishes were shaken from tables. We upgrade the intensity rating for Steamboat Springs to VI, based on these damages.

Additional felt reports for this earthquake are found in newspaper articles in The Steamboat Pilot and interviews (Oaks and Kirkham, 1986). A description from Sidney warrants an intensity rating of V. Several persons interviewed recalled that U.S. Highway 40 had been cracked during the earthquake, but this has not be substantiated.

The felt area for this earthquake, based on our isoseismal map, is approximately 6,000 km^2. Slight modification of the northwest end of the felt area could somewhat enlarge the felt area. Using a circular felt area, Hadsell (1968) reported the felt area at 15,600 km^2.

3.53 August 3, 1955

Southwestern Colorado experienced a moderate earthquake just before midnight on August 2, 1955 (local time). Murphy and Cloud (1957) and the USCGS quarterly series "Abstracts of Earthquake Reports" described the effects of the shock and assigned MMI values. Intensity VI was reported at Lake City, where one chimney was cracked and another fell (Figure 15). The U.S. Fisheries Station 19 km southwest of Creede, an area 32 km southwest of Creede, and Silverton reported MMI V. Two foreshocks were also recorded.

Murphy and Cloud (1957) suggested the earthquake was felt over 5,200 km^2, whereas the isoseismal map in Figure 15, indicates the felt area to be approximately 4,600 km^2. Hadsell (1968) reported the size at 15,600 km^2.

3.54 November 28, 1955

During the late evening on November 27, 1955 (local time) a light earthquake shook a limited area in southeastern Colorado. Murphy and Cloud (1957) stated that intensity IV was reported at Fowler and Sugar City. We rate the report for the Colorado Experiment Station at III. The earthquake was also felt at Nepesta, Ordway, and Rocky Ford. Figure 16 is an intensity map for this event.

According to the USCGS quarterly series "Abstracts of Earthquake Reports", Pueblo experienced MMI IV effects. Murphy and Cloud (1957) apparently discounted the Pueblo report, and we concur with them. Based on our intensity map, the felt area for this event is around 1,500 km^2. Hadsell (1968) reported it at 1,000 km^2.

3.55 January 14, 1956

A small earthquake on January 14, 1956 was felt in the Lamar area. Brazee and Cloud (1958) indicated it was felt by many at Lamar, causing considerable excitement and some alarm. A number of residents of Springfield also felt the quake, and a few reported creaking of buildings and rattling of loose objects.

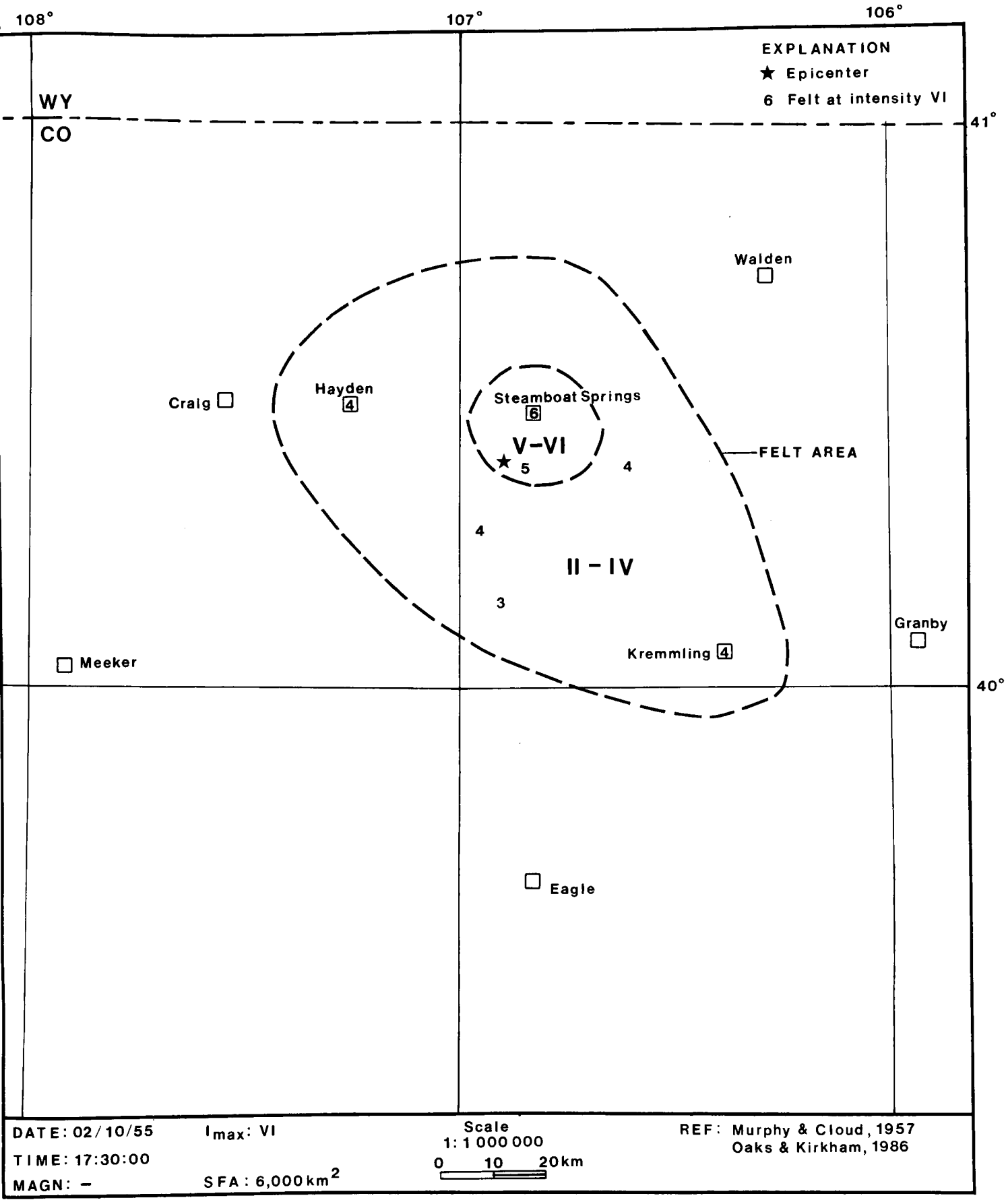

Figure 14. Isoseismal map for the February 10, 1955 earthquake.

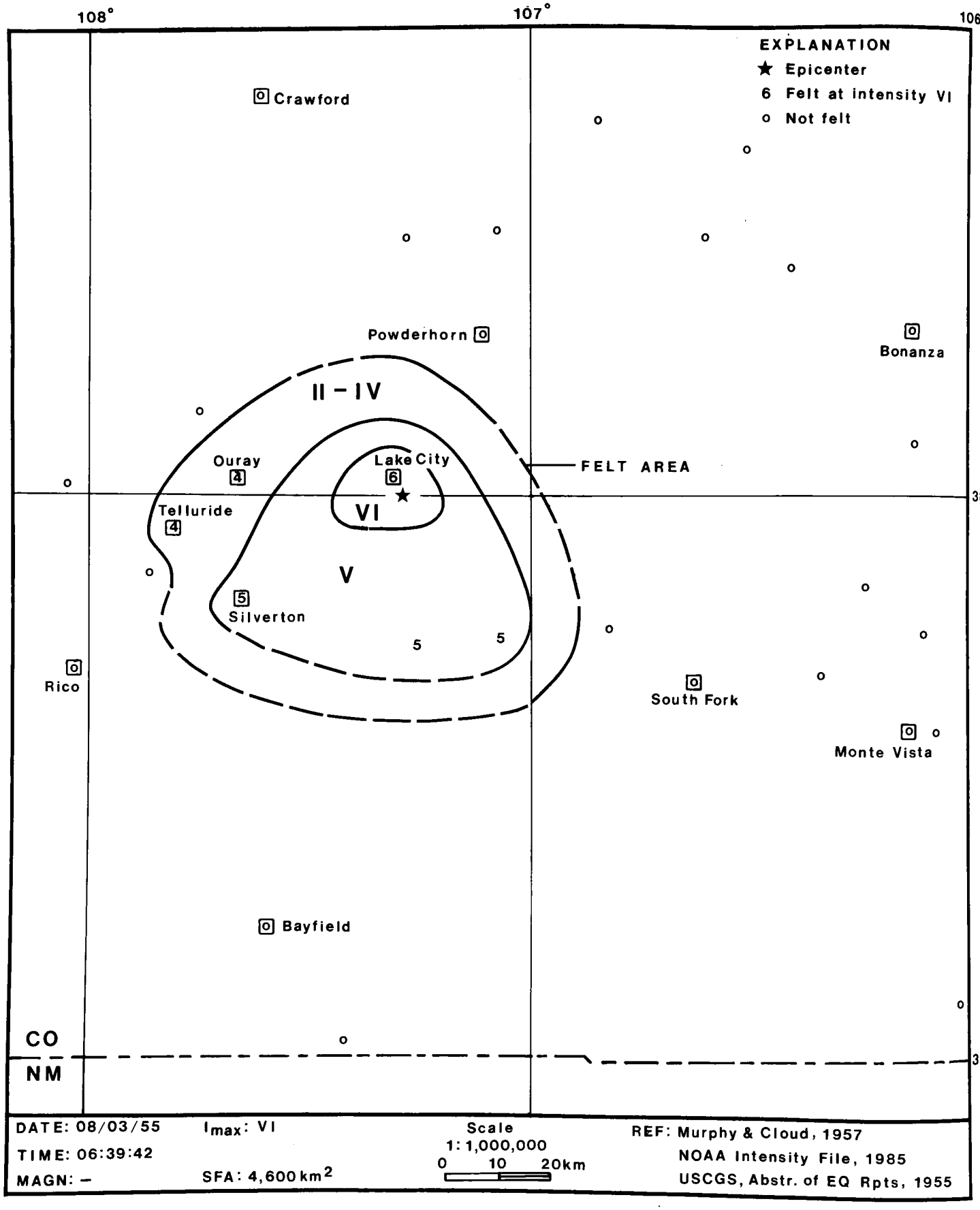

Figure 15. Isoseismal map for the August 3, 1955 earthquake.

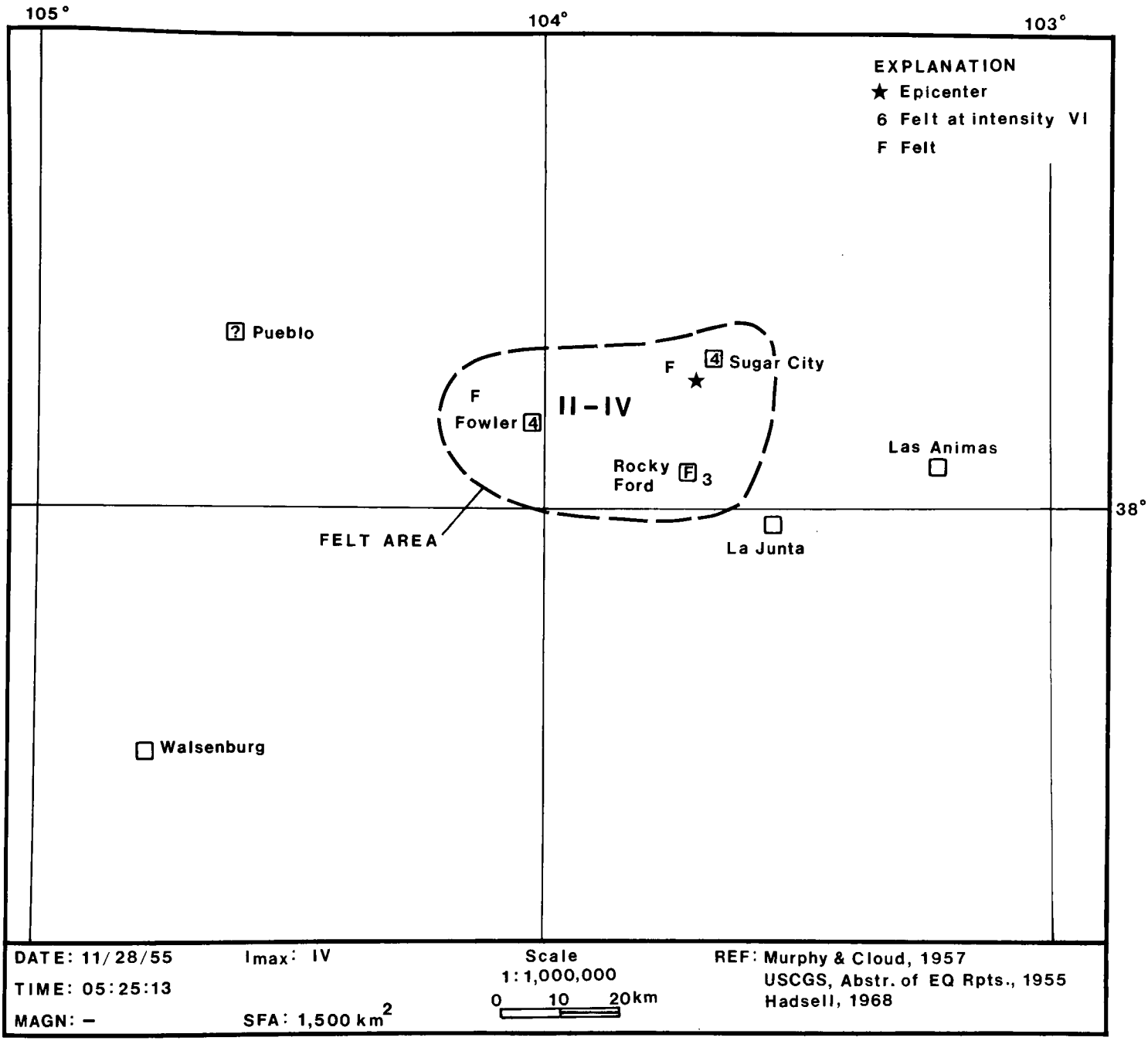

Figure 16. Intensity map for the November 28, 1955 earthquake.

Figure 17 illustrates an intensity map for this earthquake based on the two felt reports. The felt area could be outlined in several ways, but based on our map the felt area is 9,900 km^2. Hadsell (1968) suggested the felt area was about 41,000 km^2, while Docekal (1970) reported it at 21,000 km^2.

3.56 October 11, 1960

In the early morning hours on October 11, 1960 (local time) a large part of southwestern Colorado was shaken by one of the larger earthquakes to occur historically in the state. Talley and Cloud (1962) described the effects of

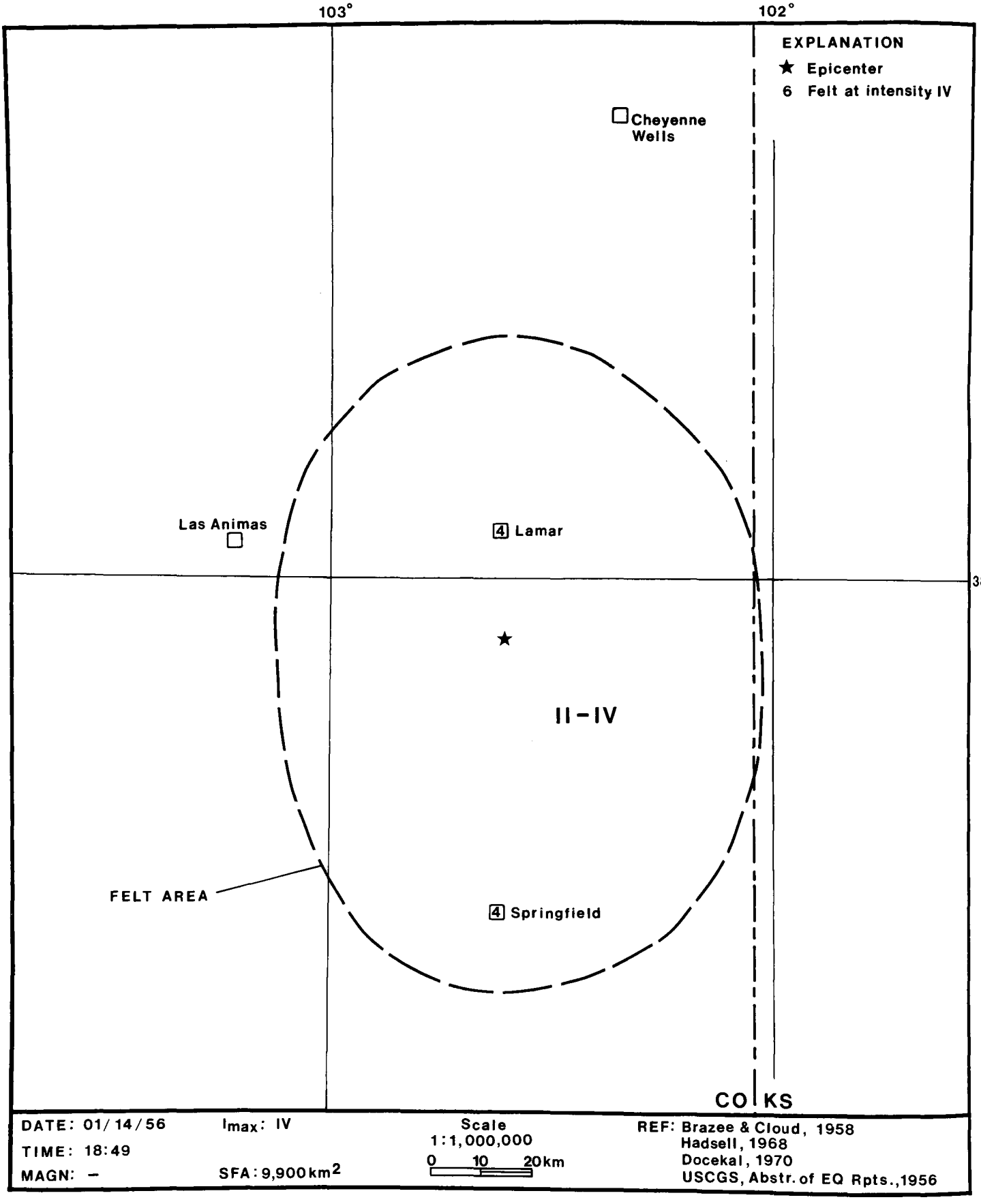

Figure 17. Intensity map for the January 14, 1956 earthquake.

the tremor. Intensity VI damage was reported in Cimarron, Lake City, Montrose, Ophir, Ouray, Placerville, Powderhorn, Ridgway, and Telluride. Plaster, chimneys, and windows were cracked in many of these locations. Perhaps the hardest hit was Montrose, where a foundation was cracked in three places. Numerous other locations reported the earthquake effects at lesser intensity. Grand Junction experienced somewhat high intensities for its distance to the epicenter.

Talley and Cloud (1962) presented an isoseismal map for the event and indicated the quake was felt over an area of about 26,000 km^2. The isoseismal map shown in Figure 18 was prepared from information in Talley and Cloud (1959), the USCGS quarterly series "Abstracts of Earthquake Reports", and the NOAA intensity file computer printout. The felt area is somewhat larger on Figure 18, being approximately 39,000 km^2.

3.57 November 27, 1961

Central Colorado was shaken by an earthquake on November 27, 1961. Figure 19 illustrates an intensity map for this event. Intensity IV shaking was reported at Buena Vista, Leadville, Fairplay, Jefferson, Hartsel, Alma, Garo, and at other rural locations (Lander and Cloud, 1963). Aftershocks were felt in Jefferson and Hartsel. The epicenter was reportedly located about 10 km northeast of Buena Vista, near the east side of the Upper Arkansas Valley. The earthquake was felt over at least 4,800 km^2.

3.58 August 7, 1962

During 1962 the series of earthquakes apparently related to the fluid disposal at the Rocky Mountain Arsenal initiated. The first of these earthquakes for which an isoseismal map is available (Figure 20) occurred on August 7, 1962. Intensity V was reported at several locations (Lander and Cloud, 1964). "Not felt" reports are described in the USCGS quarterly series "Abstracts of Earthquake Reports". A magnitude of 2.5 ML was calculated for the event (Major and Simon, 1968) and the felt area size was only an unusually small 500 km^2. Docekal (1970) reported a 780 km^2 felt area.

3.59 August 30, 1962

On August 30, 1962 a damaging earthquake occurred on the northern Utah-southern Idaho border in the Cache Valley area. Lander and Cloud (1964) described the effects of this magnitude 5.7 mb quake. The isoseismal map shown in Figure 21 is redrafted from the one presented by Lander and Cloud (1964).

Nearly $1 million in damage was estimated to result from this earthquake. Intensity VII damage was reported in a number of locations, while the effects associated with lesser intensities occurred over a five-state area. The earthquake was felt over about 170,000 km^2, including parts of northwestern Colorado. The outline of the felt area has an unusual "dog leg" on its southeast edge which includes the intensity III and IV reports from the Grand Valley area.

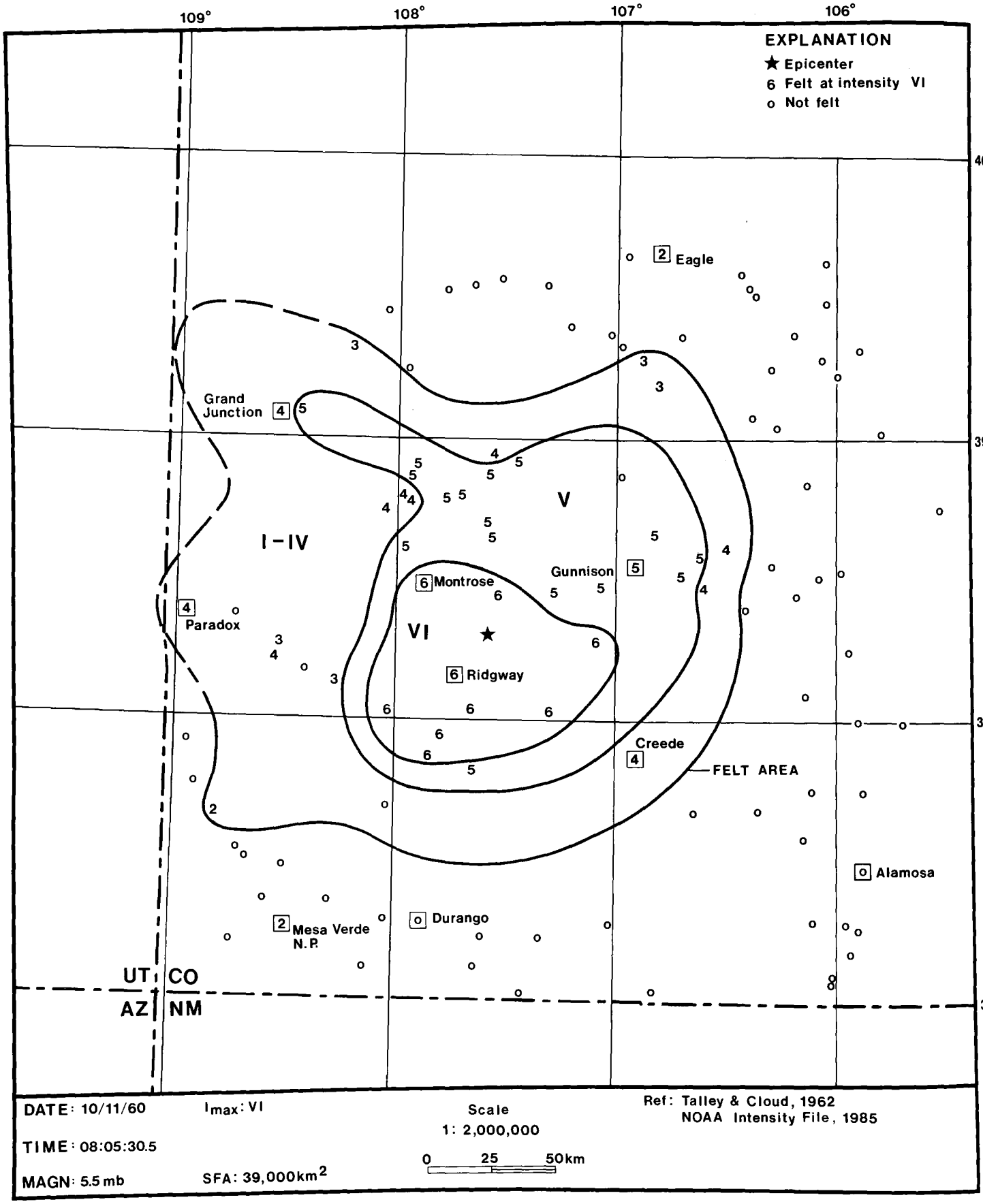

Figure 18. Isoseismal map for the October 11, 1960 earthquake.

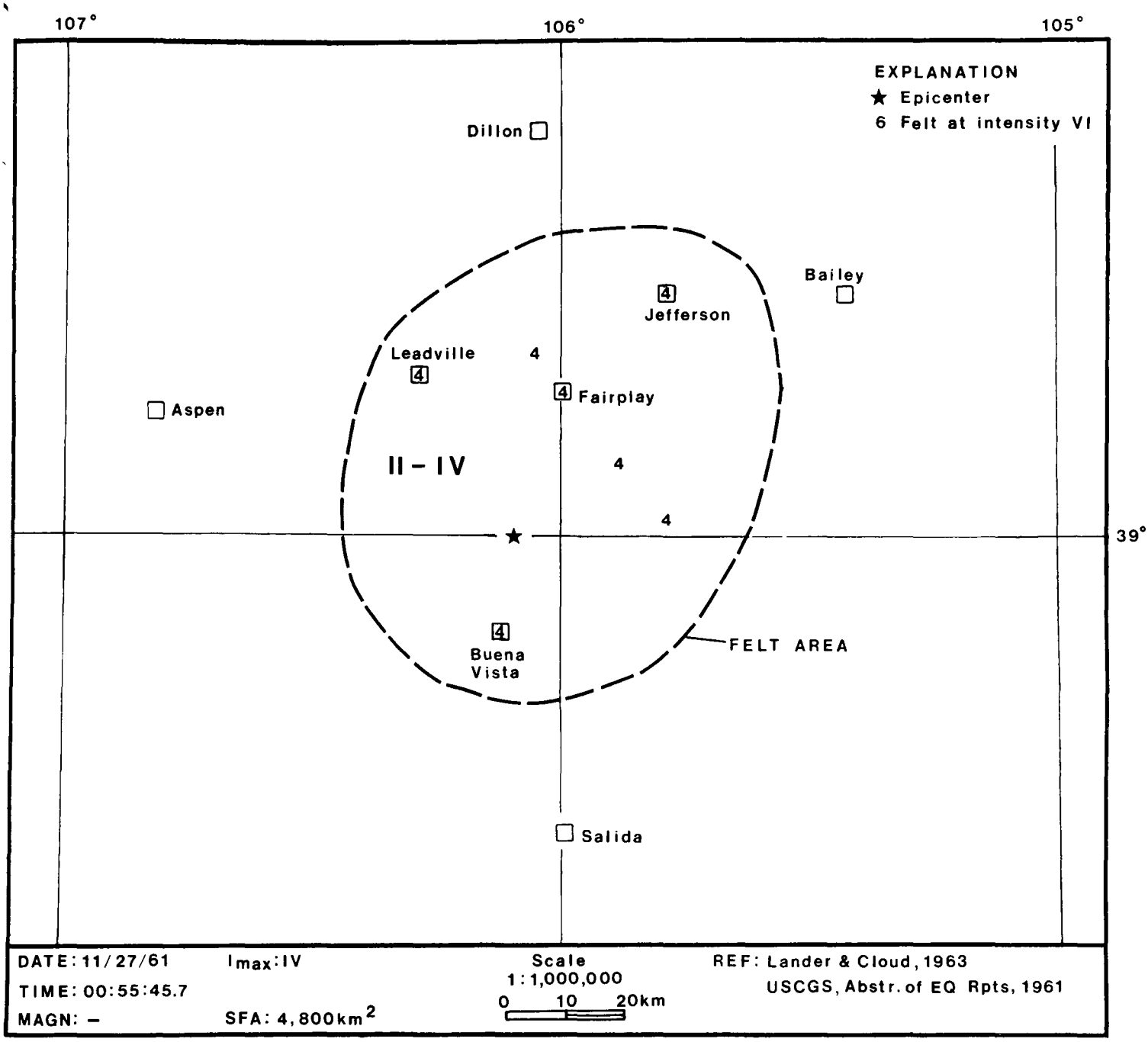

Figure 19. Intensity map for the November 27, 1961 earthquake.

3.60 December 4, 1962

The Denver area experienced an earthquake on December 4, 1962 that was felt over approximately 12,000 km^2 (Figure 22). Major and Simon (1968) calculated the magnitude of this event at 3.5 ML. Earthquake effects were described by Lander and Cloud (1964) and the USCGS quarterly series. Intensity VI was reported in Dupont, where a picture window was broken, and in Irondale, where windows were broken, electrical wiring damaged, and brick tiles loosened at a school. The higher intensities were concentrated along the mountain front, with one anomalous report from Silver Plume. Hadsell

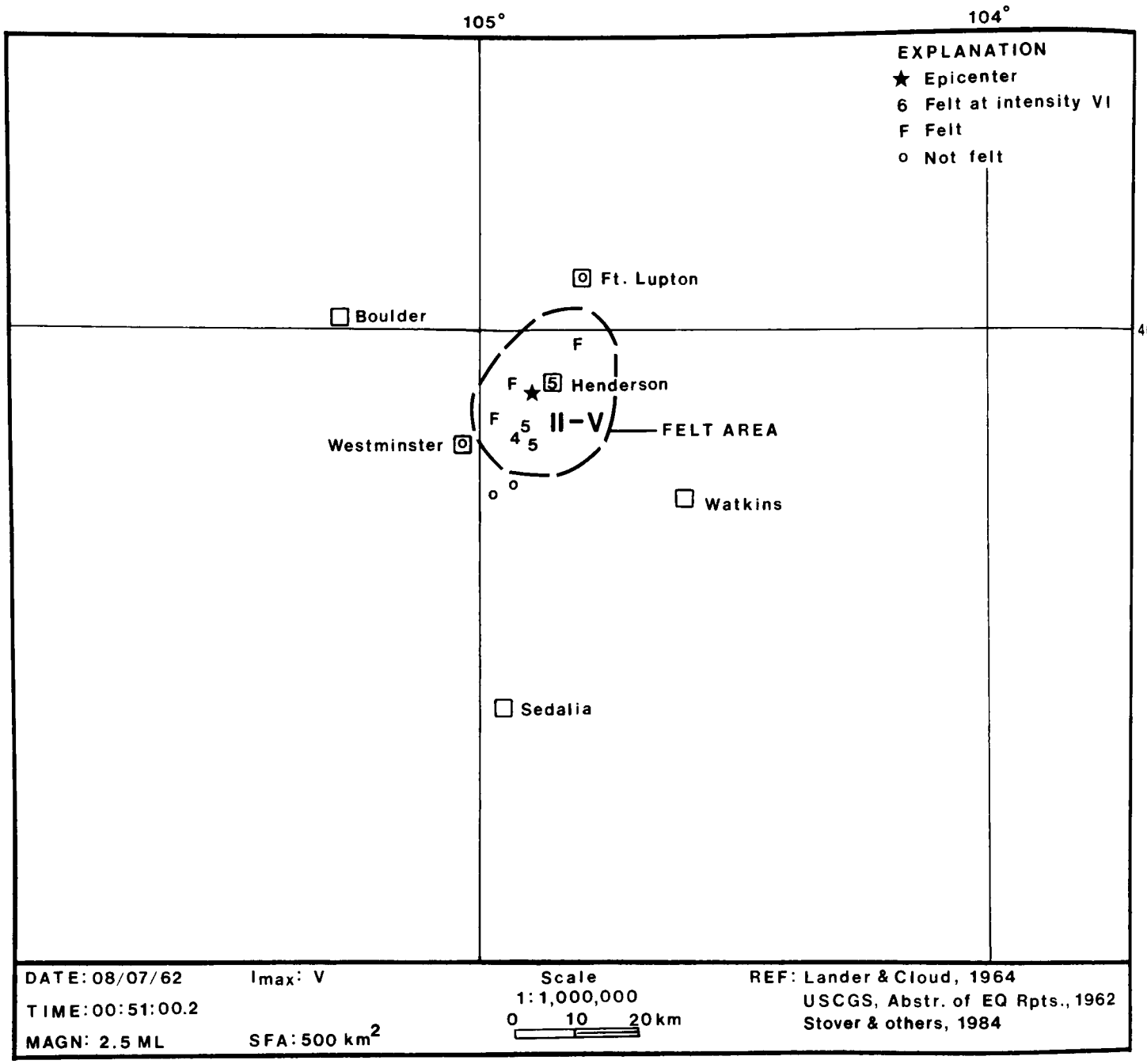

Figure 20. Intensity map for the August 7, 1962 earthquake.

(1968) indicated the felt area size to be 19,000 km^2, while Docekal (1970) reported it at 65,000 km^2.

3.61 December 5, 1962

On December 5, 1962, the Denver area was again struck by a moderate earthquake. This event caused intensity VI effects in Dupont (a crack formed in a wall) and in the Derby area (cracked plaster). Other effects described by Lander and Cloud (1964) and the USCGS quarterly series were felt over 16,400 km^2 (Figure 23). The higher intensities were reported in areas

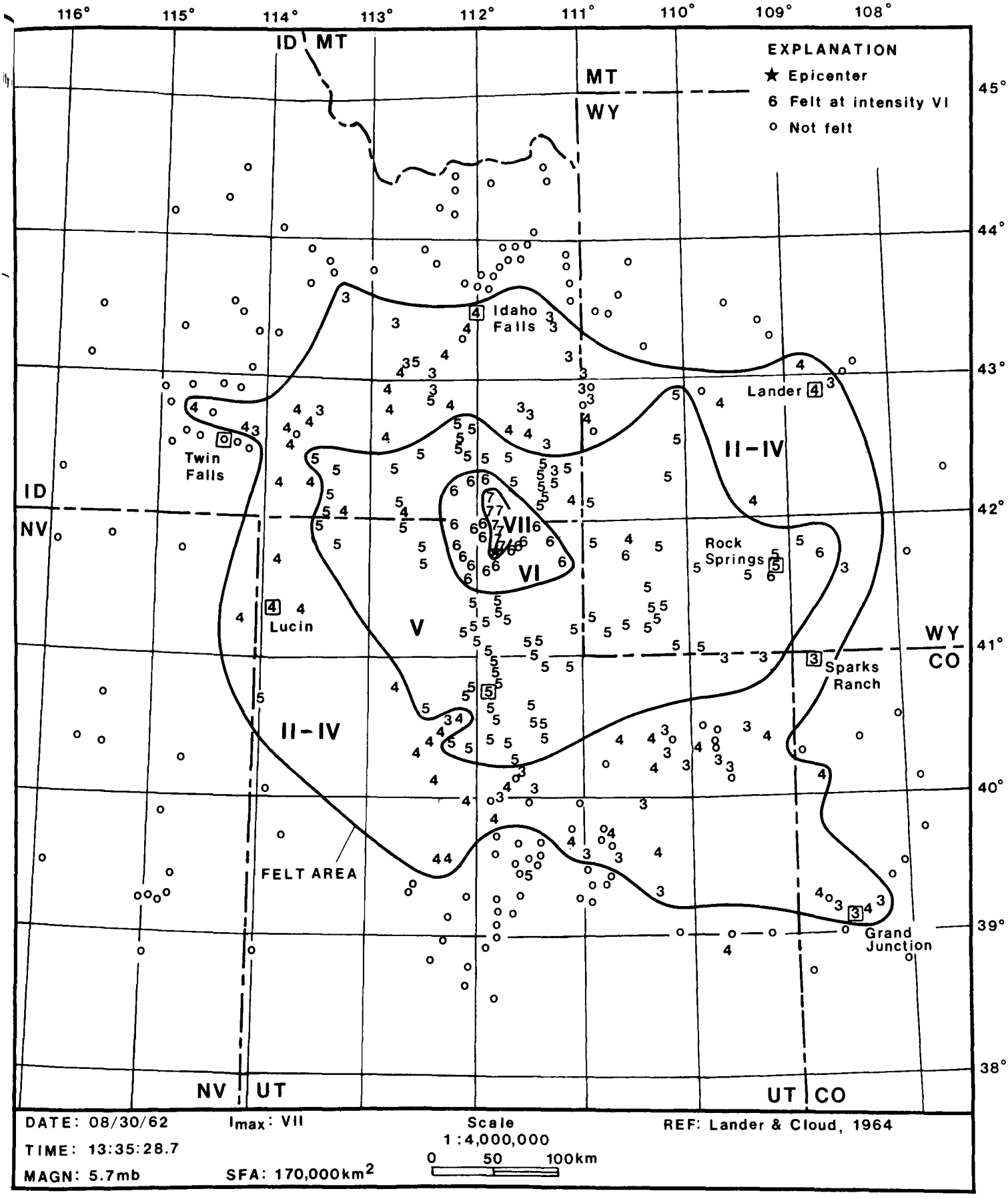

Figure 21. Isoseismal map for the August 30, 1962 earthquake.

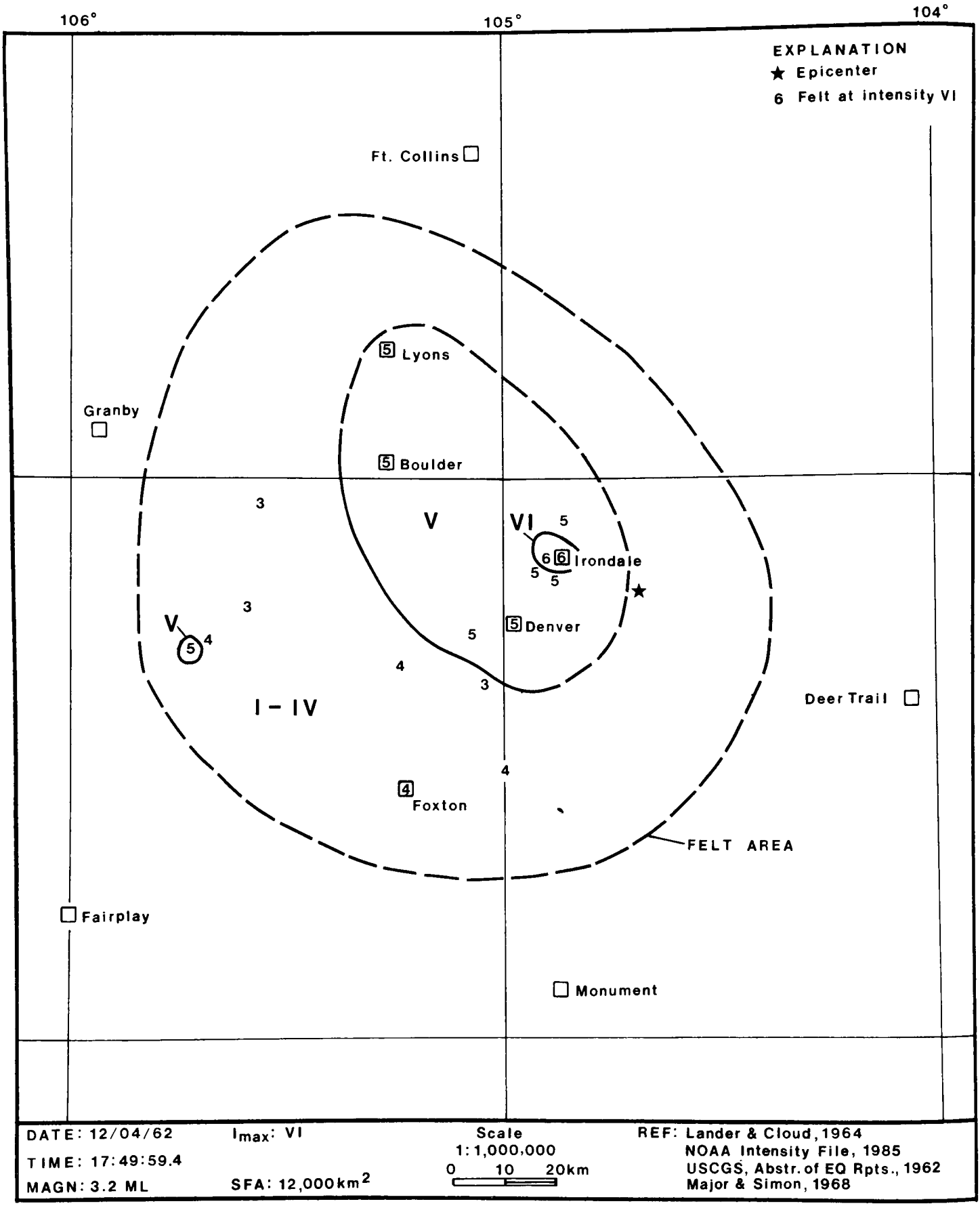

Figure 22. Isoseismal map for the December 4, 1962 earthquake.

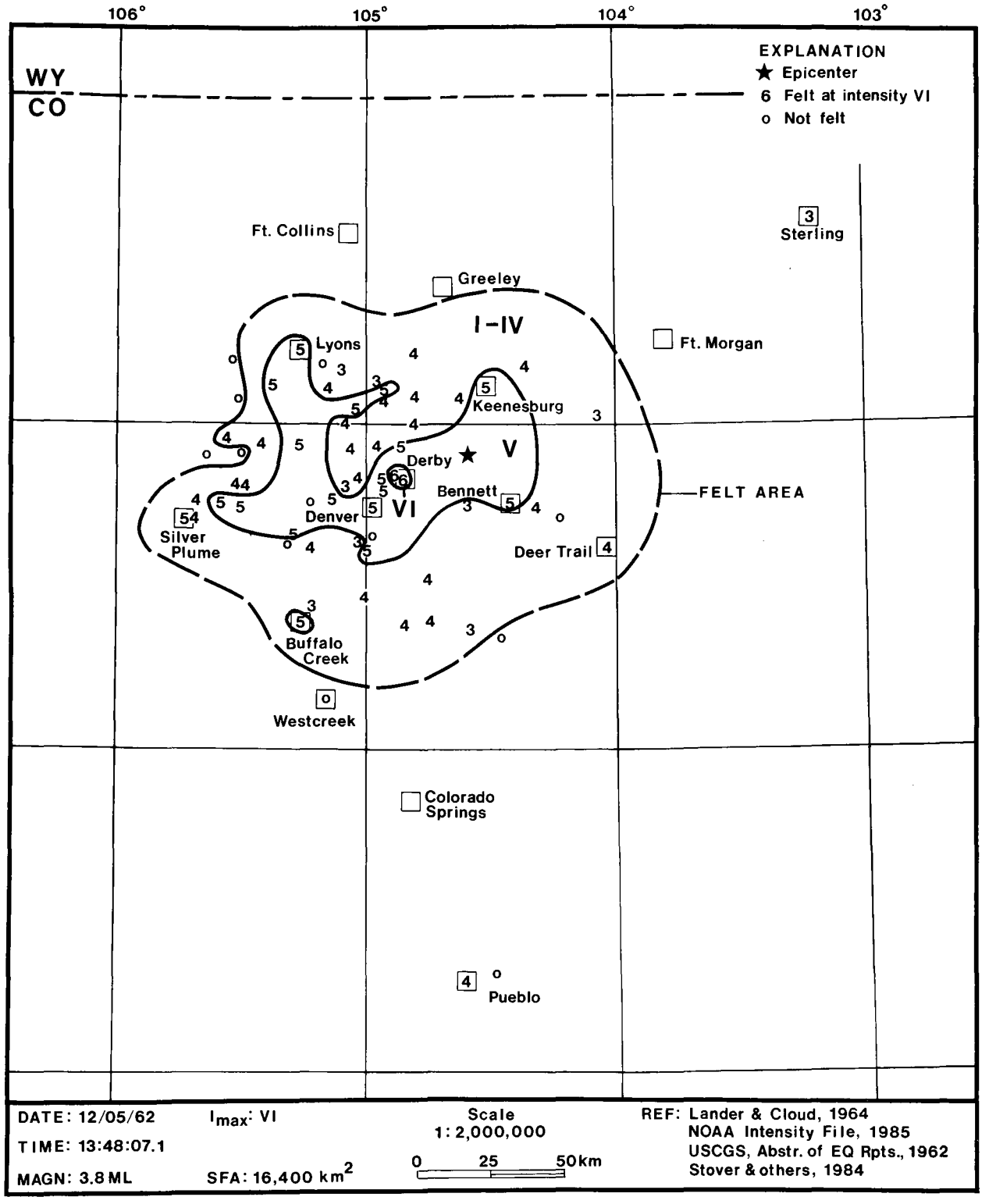

Figure 23. Isoseismal map for the December 5, 1962 earthquake.

elongated parallel and perpendicular to the mountain front. It was felt as far away as Sterling, Pueblo, and Silver Plume. Earthquake magnitude was 3.8 ML (Major and Simon, 1968). Hadsell (1968) suggested a felt area size of 26,000 km^2, and Docekal (1970) indicated it was felt over 70,000 km^2.

3.62 May 25, 1963

Felt reports for the May 25, 1963 earthquake and intensity assignments were described by von Hake and Cloud (1965) and the USCGS quarterly series "Abstracts of Earthquake Reports". Docekal (1970) suggested the quake was felt over 7,000 km^2, while von Hake and Cloud (1965) and our isoseismal map indicate it is 2,300 km^2. The overall felt area and the area of highest intensities were elongated perpendicular to the mountain front (Figure 24). Major and Simon (1968) indicate a magnitude of 3.5 ML for this event.

The epicenter for this quake and for two others located in the northeast Denver area plot outside of the felt area (see Figures 24, 25, and 30). We interpret this seemingly anomalous phenomenon as probably being a result of inaccurate epicentral locations due to the lack of sufficient seismographs in the immediate epicentral vicinity, not on unusual focusing or wave path effect.

3.63 July 2, 1963

The July 2, 1963 earthquake in the northeast Denver area was felt over an unusually shaped area (Figure 25). The earthquake was felt over about 8,300 km^2, and the overall felt area and area of reported higher intensities (V) were strongly oriented in elongate patterns that were parallel and perpendicular to the mountain front. A 39,000 km^2 felt area is indicated by Hadsell (1968), while von Hake and Cloud (1968) reported it at 7,800 km^2 and Docekal (1970) at 39,000 km^2. von Hake and Cloud (1965) and the USCGS quarterly series described and rated the felt reports. The only reported damage for this event was slight cracking of plaster in Pinecliff, a small town located in the mountains northwest of the epicentral area. Magnitude determinations for this earthquake were 4.0 ML (Major and Simon, 1968) and 4.6 mb (von Hake and Cloud, 1965).

3.64 February 16, 1965

The Denver area experienced yet another earthquake on February 16, 1965. Figure 26 presents an isoseismal map for this event. Felt reports and intensity assignments for this quake were described in von Hake and Cloud (1967) and the USCGS quarterly series. Intensity VI damage was reported at Northglenn, where a large crack appeared in a house and other older wall cracks were possibly enlarged. The earthquake was felt only over 700 km^2, an unusually small area considering the effects of the quake. Hadsell (1968) stated the felt area size was 1,600 km^2, while von Hake and Cloud (1968) reported it at 780 km^2. Von Hake and Cloud (1967) indicated the magnitude was 4.9 mb, and Major and Simon (1968) reported 4.0 ML.

3.65 September 14, 1965

The September 14, 1965 Denver area earthquake was felt over an area of unusual shape (Figure 27). The effects were felt in elongated regions reaching into the mountains west of Denver in directions perpendicular to the mountain front. Felt reports were described and rated by von Hake and Cloud (1967) and the USCGS quarterly series "Abstracts of Earthquake Reports". Reports of cracked plaster and chimneys, and broken windows and dishes indicating MMI VI came in from Commerce City, Derby, Broomfield, and Denver. Felt area size for this event, based on Figure 27, is about 2,700 km^2, whereas Hadsell (1968) suggested it was 4,700 km^2. Earthquake magnitude was determined at 3.6 ML by Major and Simon (1968) and 4.7 mb by von Hake and Cloud (1967).

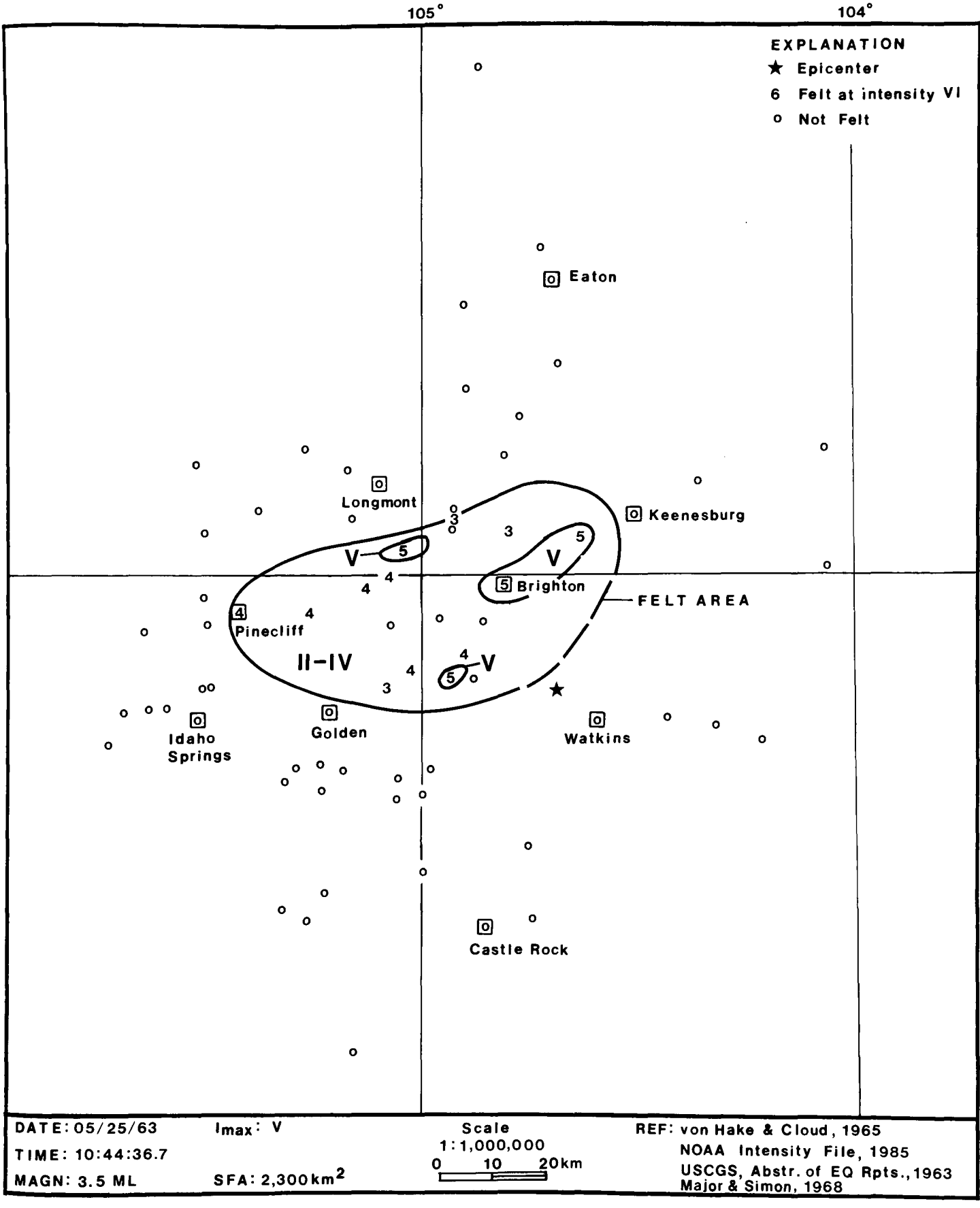

Figure 24. Isoseismal map for the May 25, 1963 earthquake.

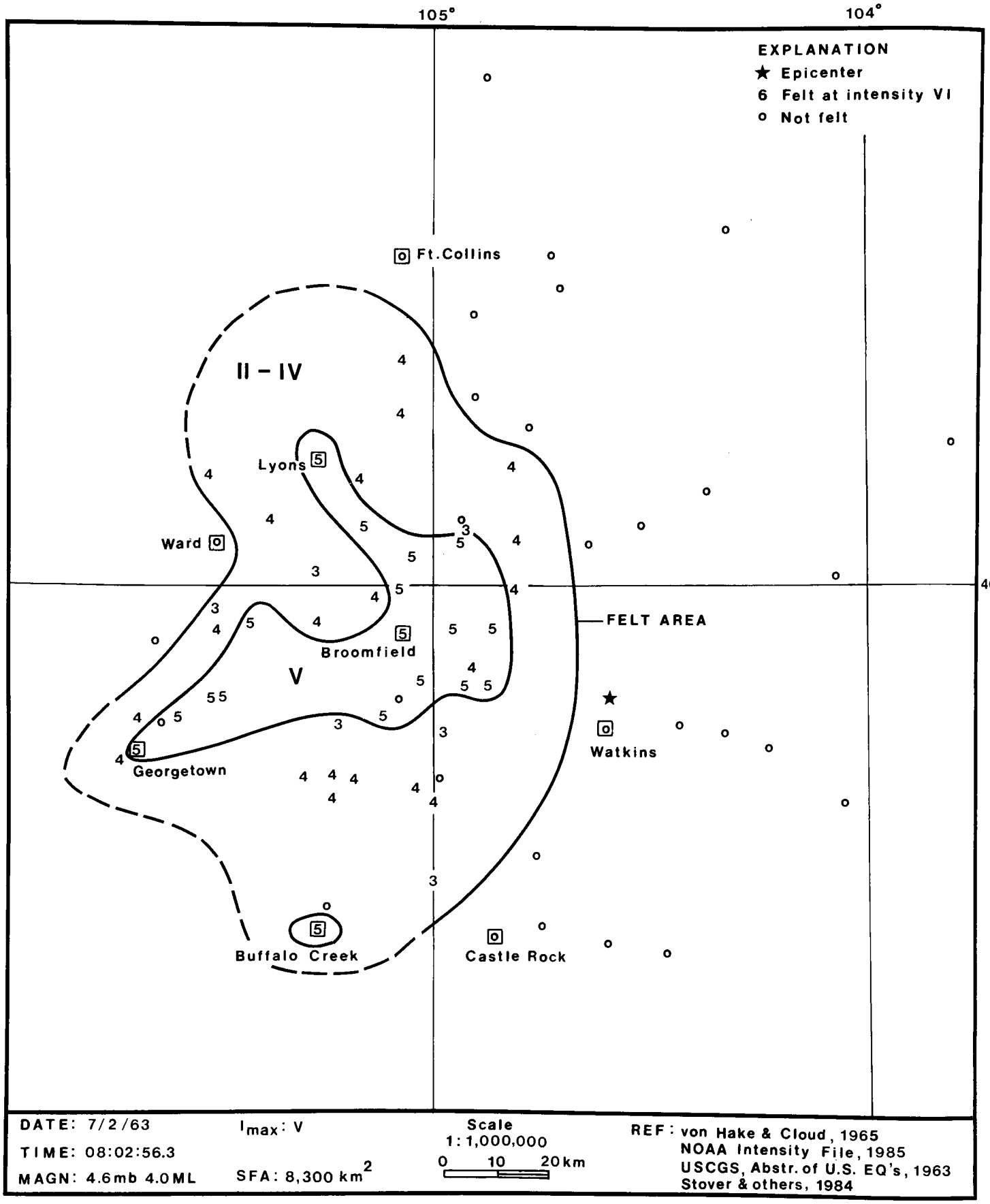

Figure 25. Isoseismal map for the July 2, 1963 earthquake.

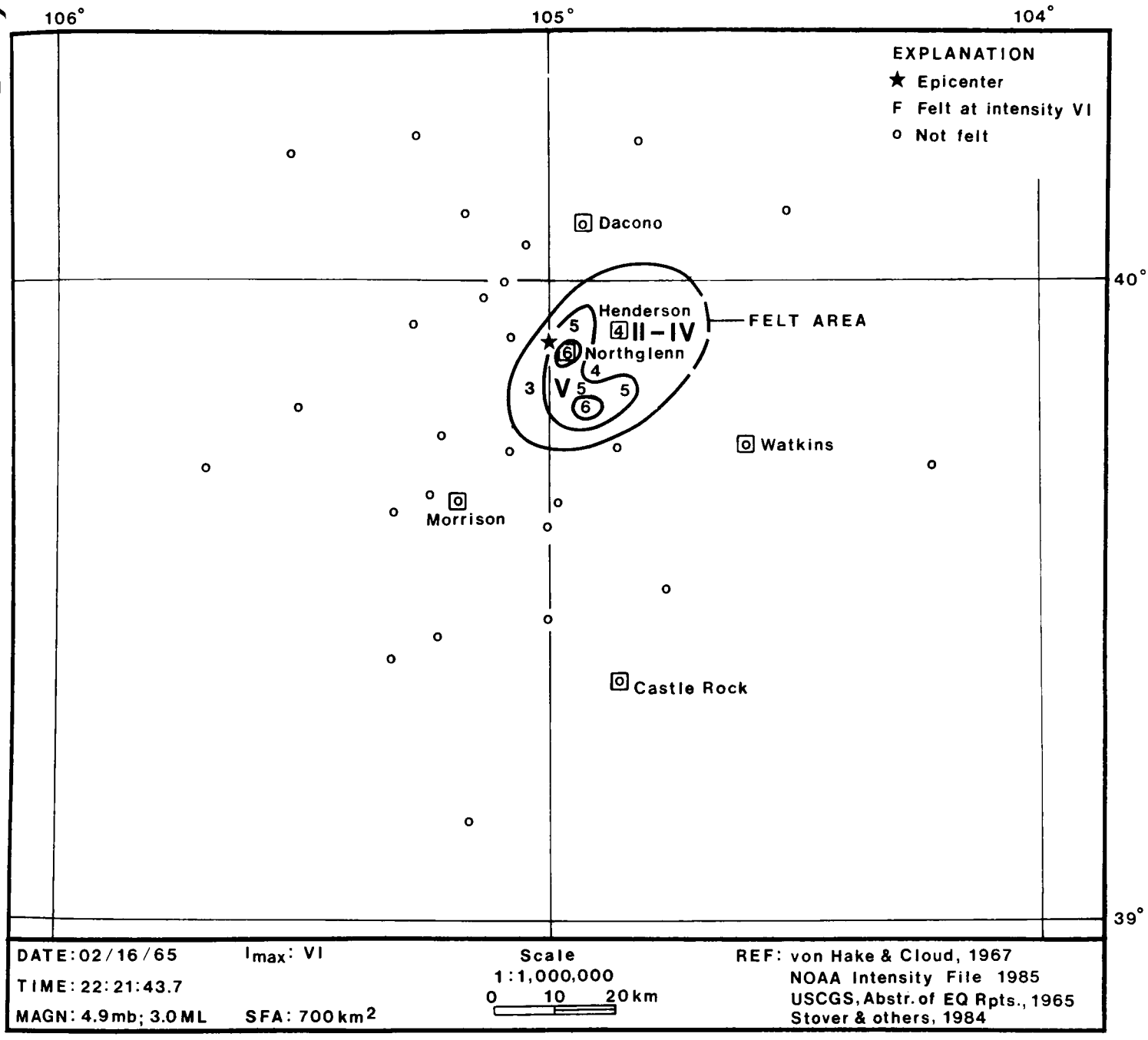

Figure 26. Isoseismal map for the February 16, 1965 earthquake.

3.66 September 29, 1965

On September 29, 1965 another earthquake shook the Denver area (Figure 28). Von Hake and Cloud (1967) described intensity VI damage in Commerce City, Denver, and Northglenn, including the cracking of plaster and windows. The earthquake was felt over about 3,700 km ^{2} and was rated 3.5 ML (Major and Simon, 1968) and 4.7 mb (von Hake and Cloud, 1967). Hadsell (1968) suggested the felt area was larger, being about 10,400 km^2.

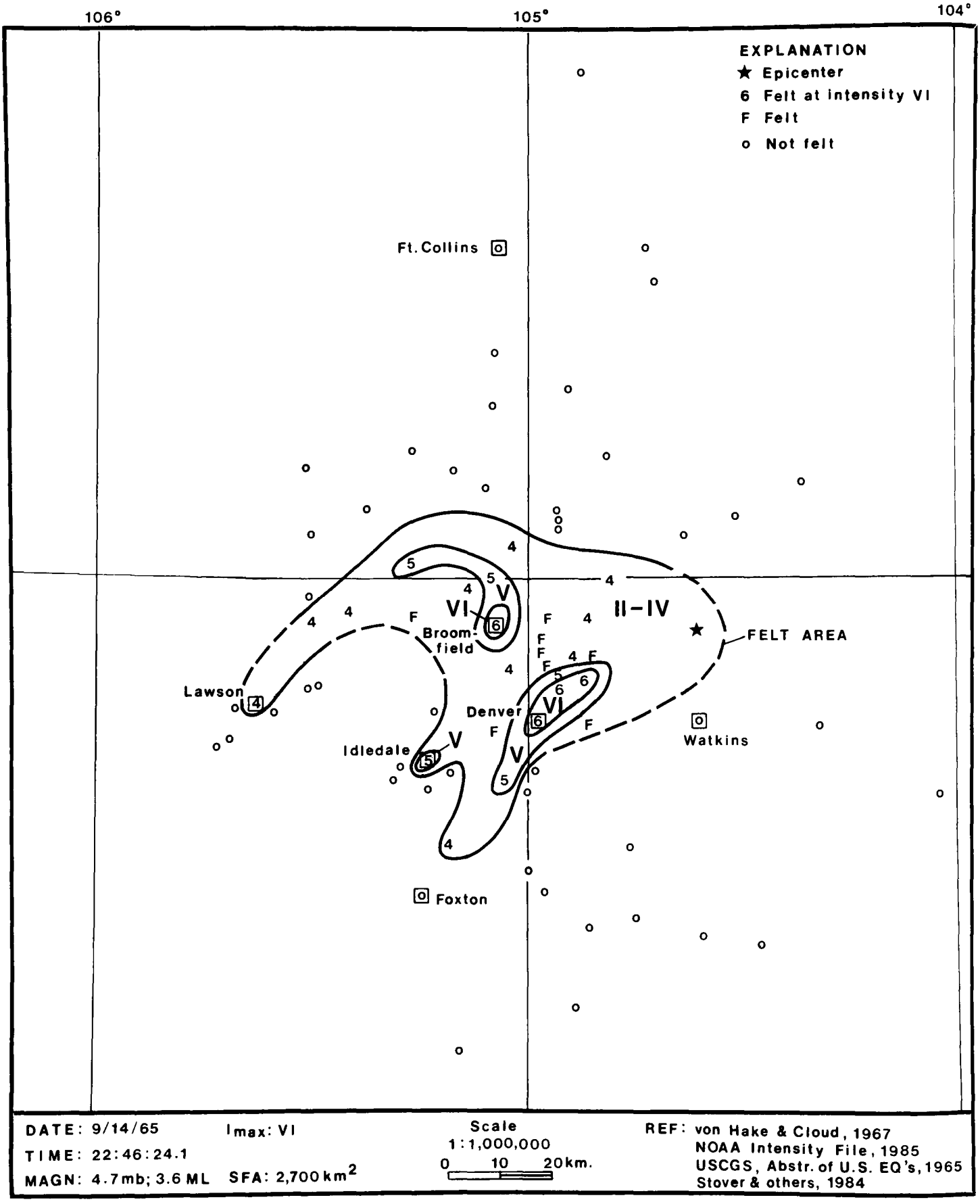

Figure 27. Isoseismal map for the September 14, 1965 earthquake.

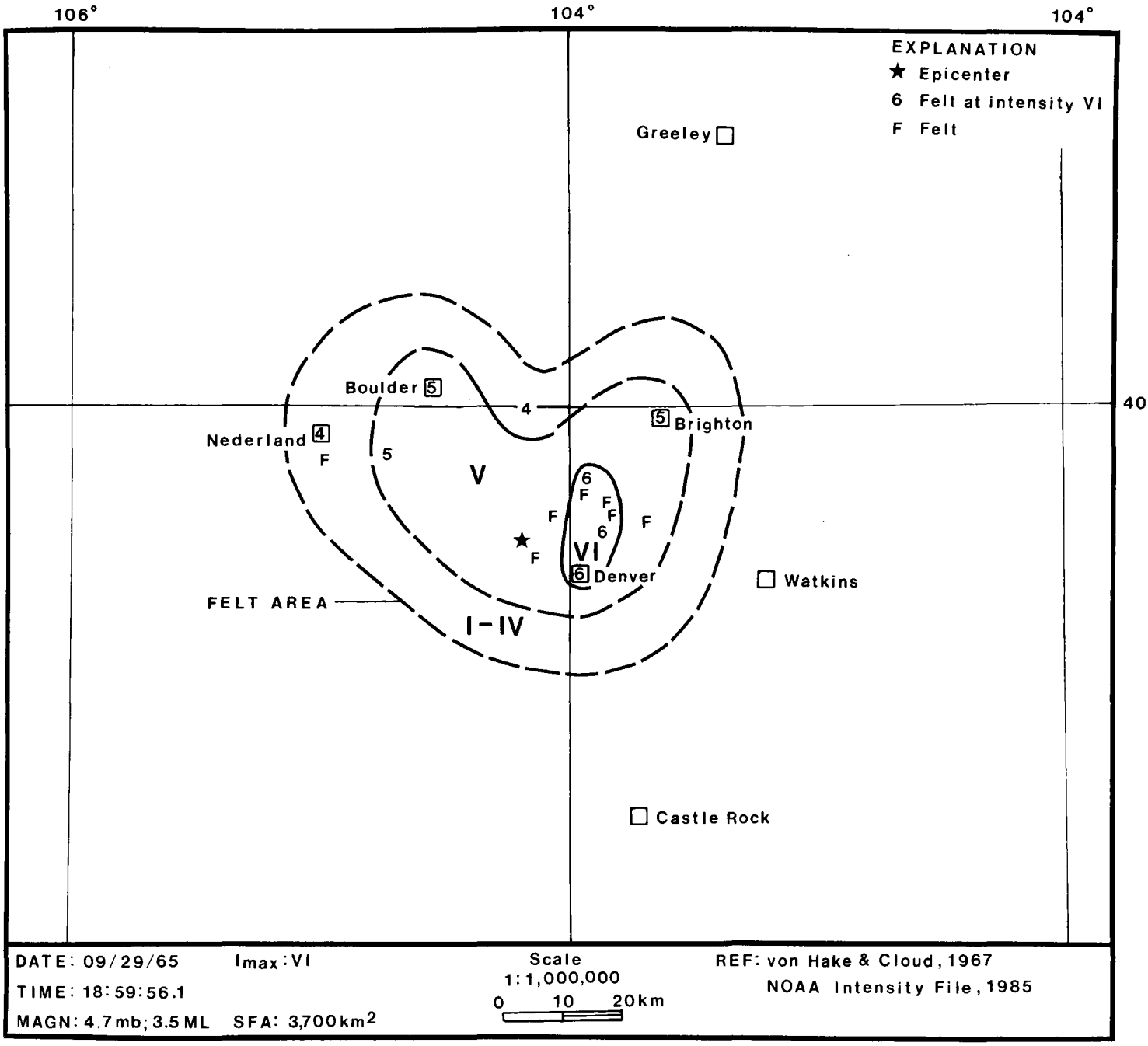

Figure 28. Isoseismal map for the September 29, 1965 earthquake.

3.67 November 21, 1965

The felt area for the November 21, 1965 earthquake is also somewhat usual (Figure 29). Felt reports and MMI ratings were included in von Hake and Cloud (1967) and the USCGS quarterly series. Intensity VI effects occurred in Commerce City (plaster cracked and one window broke), Hudson (plaster cracked and fell), Louisville (plaster cracked), Northglenn and Thornton (numerous broken windows), and Westminster. One injury was also reported during the event. Felt area size for this quake is around 6,900 km^2 based on Figure 29. Other estimates of the felt area size included 41,400 km^2 (Hadsell,

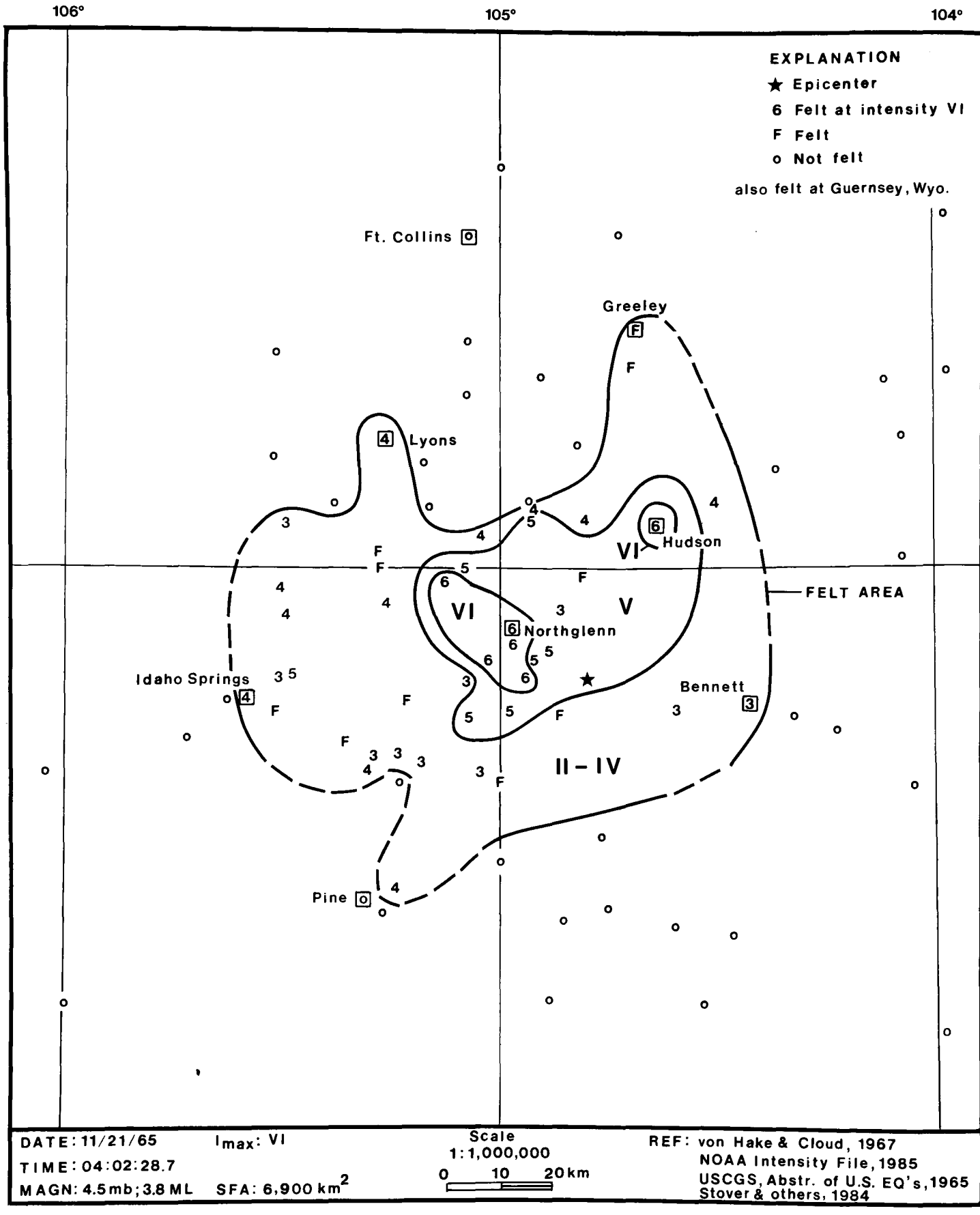

Figure 29. Isoseismal map for the November 21, 1965 earthquake.

1968), 15,500 km^2 (Docekal, 1970), and 7,800 km^2 (von Hake and Cloud, 1967). A 3.8 ML was assigned by Major and Simon (1968) and 4.5 mb by von Hake and Cloud (1967).

3.68 January 5, 1966

The January 5, 1966 earthquake was felt over a small area in the Denver-Brighton vicinity. An isoseismal map for this event is shown in Figure 30. Von Hake and Cloud (1968) and the USCGS quarterly series provided the felt reports and intensity ratings for the earthquake. Intensity V was reported in Denver, Commerce City, and Northglenn. Major and Simon (1968) indicated a magnitude of 3.4 ML for the tremor, while von Hake and Cloud (1968) described it as 5.0 mb. Figure 30 suggests the earthquake was felt over an estimated 1,100 km^2, while Hadsell (1968) reported a felt area of 2,100 km^2.

3.69 January 23, 1966

The Colorado-New Mexico border region was rocked by a moderate earthquake on January 23, 1966 that centered near Dulce, New Mexico. Felt effects and intensities for the earthquake were described by von Hake and Cloud (1968) and the USCGS quarterly series "Abstracts of Earthquake Reports". Figure 31 is an isoseismal map of the event prepared from the available felt reports. It indicates the quake was felt over a rectangular-shaped region covering about 27,000 km^2. Von Hake and Cloud (1968) reported a felt area of 39,000 km^2 for this event.

Between January 22 and January 28 (local time) the USCGS seismological center in Albuquerque recorded 119 events in the Dulce area. Three temporary seismographs were installed in the Dulce area on January 28th. During the first week of operation 218 earthquakes were recorded, all located in a small area near Dulce. 532 aftershocks were recorded during 30 days of monitoring, with hypocentral depths of about 5 to 10 km (Hoffman and Northrop, 1977). Earthquake activity continued at a high rate for about a year following the main shock. Minor activity continues to be instrumentally detected in the Dulce area.

Nearly every house in Dulce was damaged to some degree by the earthquake, but the principal damage was to structures at the Bureau of Indian Affairs (BIA) complex and local schools. Damage was estimated at $200,000, but no deaths or injuries were reported. The BIA dormitories suffered extensive damage to interior and exterior walls. The steam-heating plant for the BIA school was severely damaged. Older homes in the Dulce area experienced considerable structural damage, but new homes suffered mostly only cosmetic damage. A number of chimneys were damaged, especially those 0.3 to 0.7 meters high. Considerable rockfall occurred on buttes in the area. Photographs of some of the damage were contained in von Hake and Cloud (1968). A maximum intensity of VII was originally reported for this quake in Dulce, but Hoffman and Northrup (1977) suggest a VII to VIII or VII+ rating may be more appropriate. Intensity VI damage was reported in several locations along the Colorado-New Mexico border.

Earthquake magnitude was originally determined at 5.5 mb. Later studies by Hermann and others (1980) reported a 5.1 mbLg magnitude for the main shock.

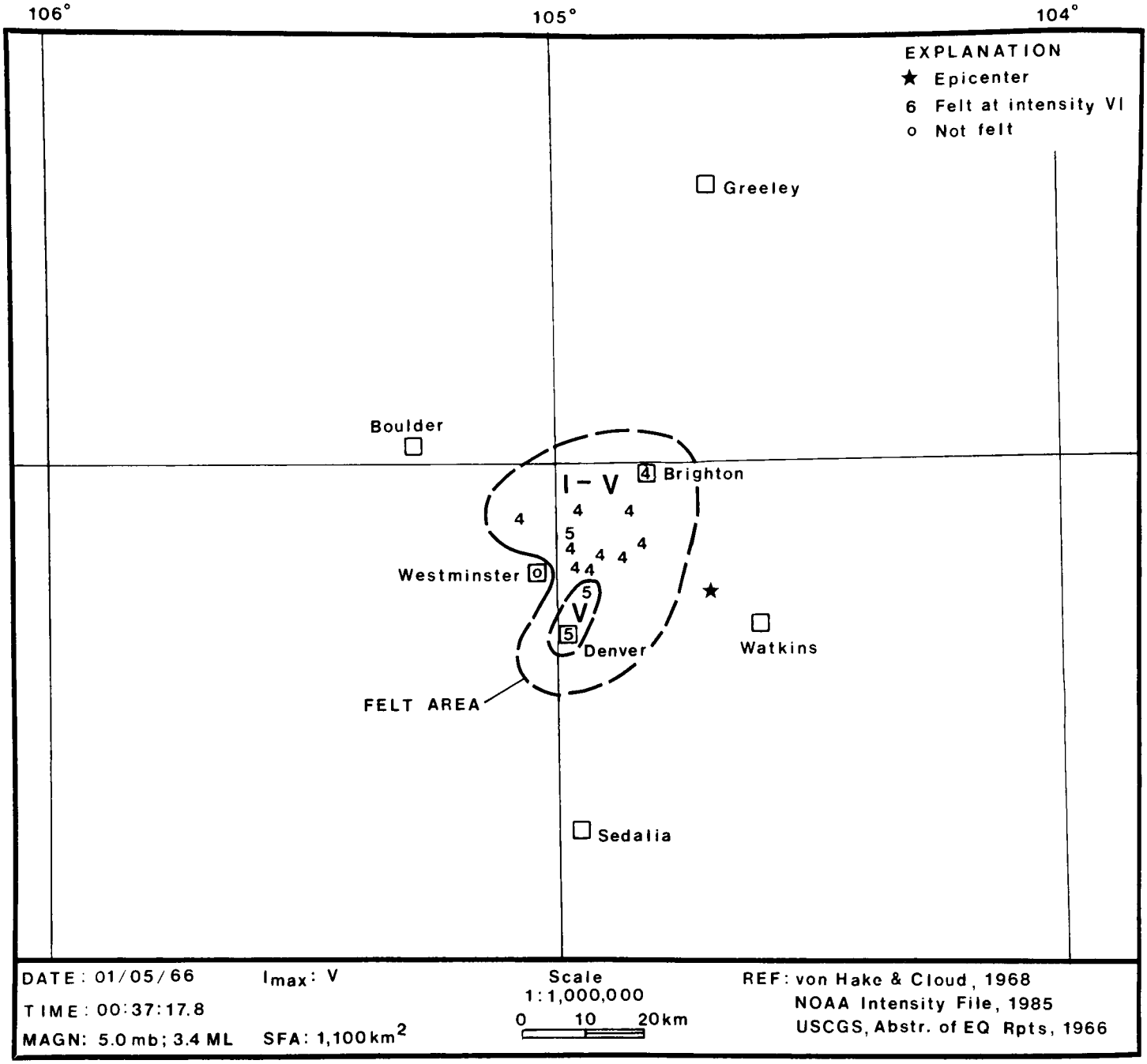

Figure 30. Isoseismal map for the January 5, 1966 earthquake.

3.70 September 24, 1966

Another earthquake occurred along the Colorado-New Mexico border on September 24, 1966. An intensity map for this event is illustrated in Figure 32. Von Hake and Cloud (1968) and the USCGS quarterly series described the felt reports and assigned intensities. A total of three shocks occurred, all of which were felt in Cimarron, New Mexico at up to intensity IV. The main shock was felt in Weston, Colorado, where dishes, windows, and doors rattled. A press report for the October 3rd earthquake mentioned that some residents of

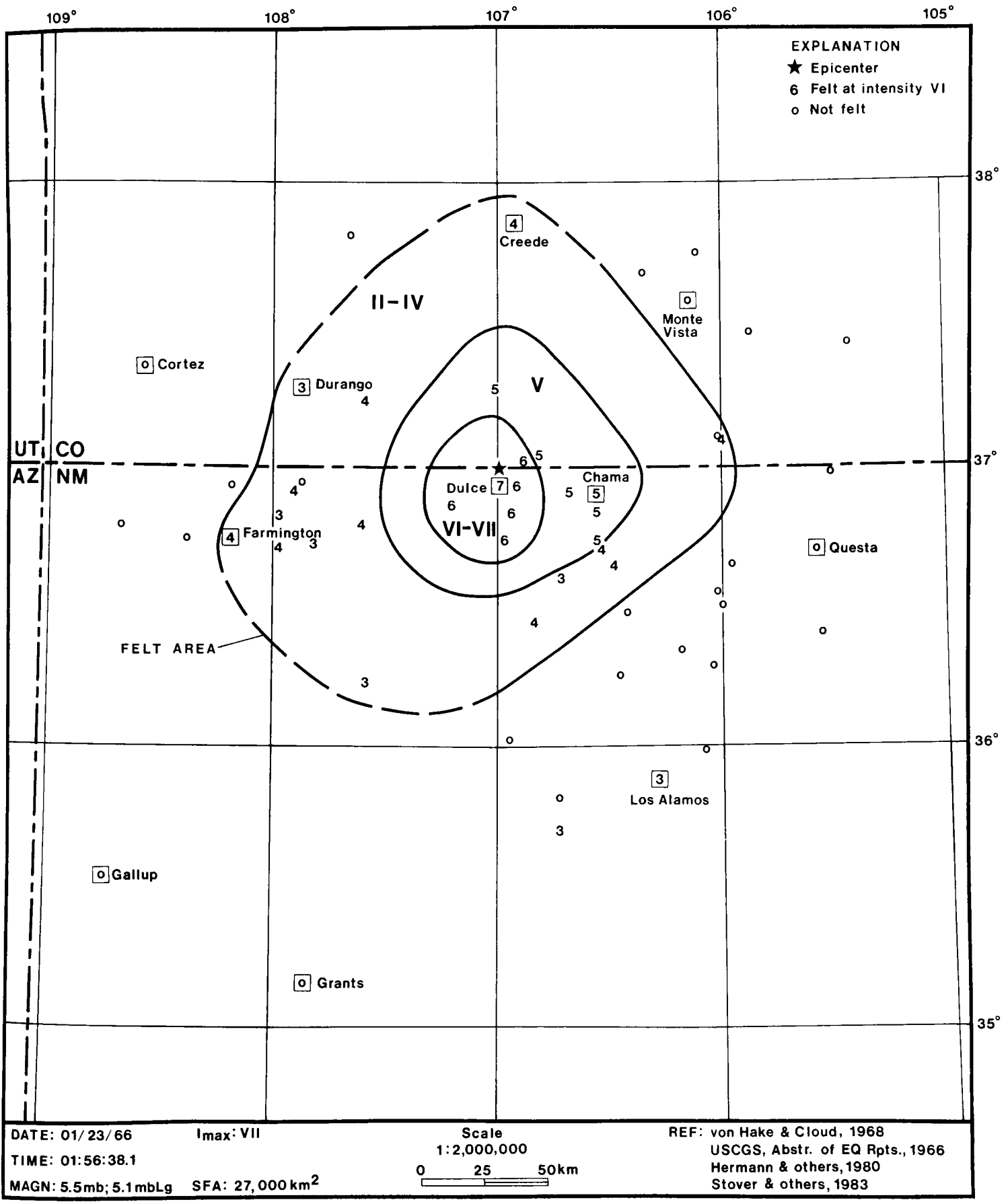

Figure 31. Isoseismal map for the January 23, 1966 earthquake.

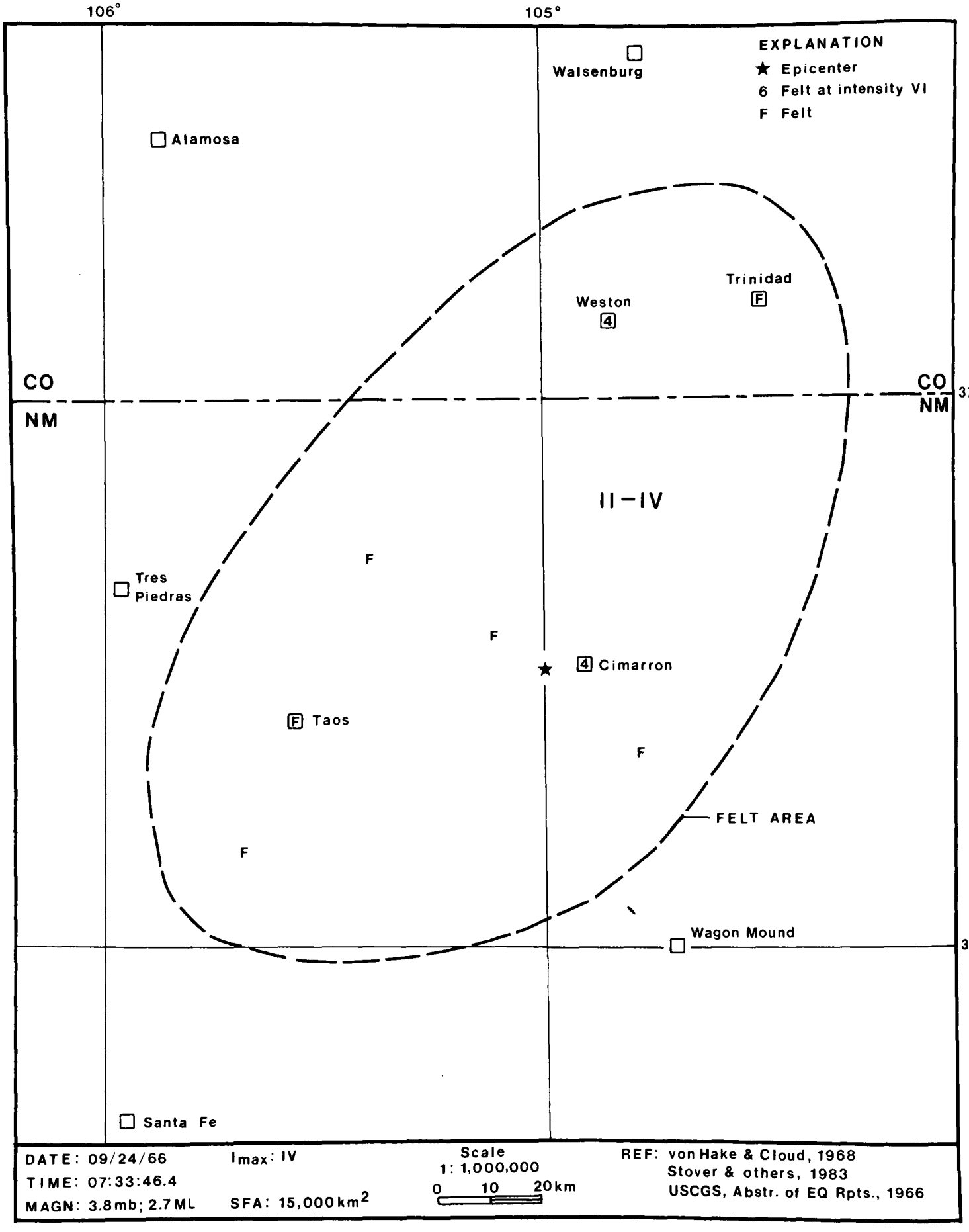

Figure 32. Intensity map for the September 24, 1966 earthquake.

Trinidad felt a tremor "a week or so ago", probably referring to the September 24th quake. The earthquake was felt over an estimated 15,000 km^2.

Von Hake and Cloud (1968) originally reported the magnitude at 4.1 mb. Stover, Reagor, and Algermissen (1983) later published magnitudes of 3.8 mb and 2.7 ML for the quake.

3.71 October 3, 1966

The Colorado-New Mexico border region experienced another earthquake on October 3, 1966. This event apparently centered in the Plains east of Aguilar. Von Hake and Cloud (1968) and the USCGS quarterly series documented the felt effects and assigned intensity ratings. MMI VI was reported at Aguilar (a house was cracked in several places), Segundo (one house cracked on the west side), Trinchera (plaster and windows cracked), and Trinidad (cracked plaster and broken dishes and windows).

Figure 33 is an isoseismal map for this event. Based on Figure 33, the quake was felt over approximately 45,000 km^2. Hadsell (1968) reported a felt area of 155,000 km^2 while Docekal (1970) and von Hake and Cloud (1968) indicated it was 39,000 km^2. A magnitude of 4.5 mb was described for this quake by von Hake and Cloud (1968), and Stover, Reagor, and Algermissen (1984) listed the magnitude at 4.6 ML.

3.72 November 14, 1966

A slightly damaging earthquake occurred in the Denver area on November 14, 1966. Von Hake and Cloud (1968) and the USCGS quarterly series described the felt effects and assigned intensity ratings. Plaster was cracked and old cracks lengthened at Commerce City, evidence of MMI VI. Eastlake also was rated at intensity VI.

Figure 34 is an isoseismal map of this event. The outline of the felt area is highly unusual, being elongate along two paths perpendicular to the mountain front and along one path parallel to the mountain front. We estimate the felt area size at 3,900 km^2, whereas Hadsell (1968) indicated a felt area of 26,000 km^2 and Docekal (1970) suggested 15,500 km^2. Both estimates are, in our opinion, far too high. Von Hake and Cloud (1968) determined the magnitude of this event to be 4.1 mb, while Stover, Reagor, and Algermissen (1984) report magnitudes of 4.4 mb and 3.5 ML.

3.73 April 10, 1967

The April 10, 1967 earthquake caused damage over part of the Denver Metro area. Felt reports and MMI assignments were described by von Hake and Cloud (1969) and the USCGS quarterly series "Abstracts of U.S. Earthquakes". Intensity VI damage was reported in 20 locations. Plaster cracked, foundations cracked, chimneys cracked, concrete and asphalt parking lot surfaces cracked, water pipes broke, and many windows, including 118 at the Rocky Mountain Arsenal, were broken.

An isoseismal map for this earthquake is shown in Figure 35. Note the unusual two-pronged elongate area of higher intensities that extends westward perpendicular to the mountain front. Figure 35 indicates the felt area is

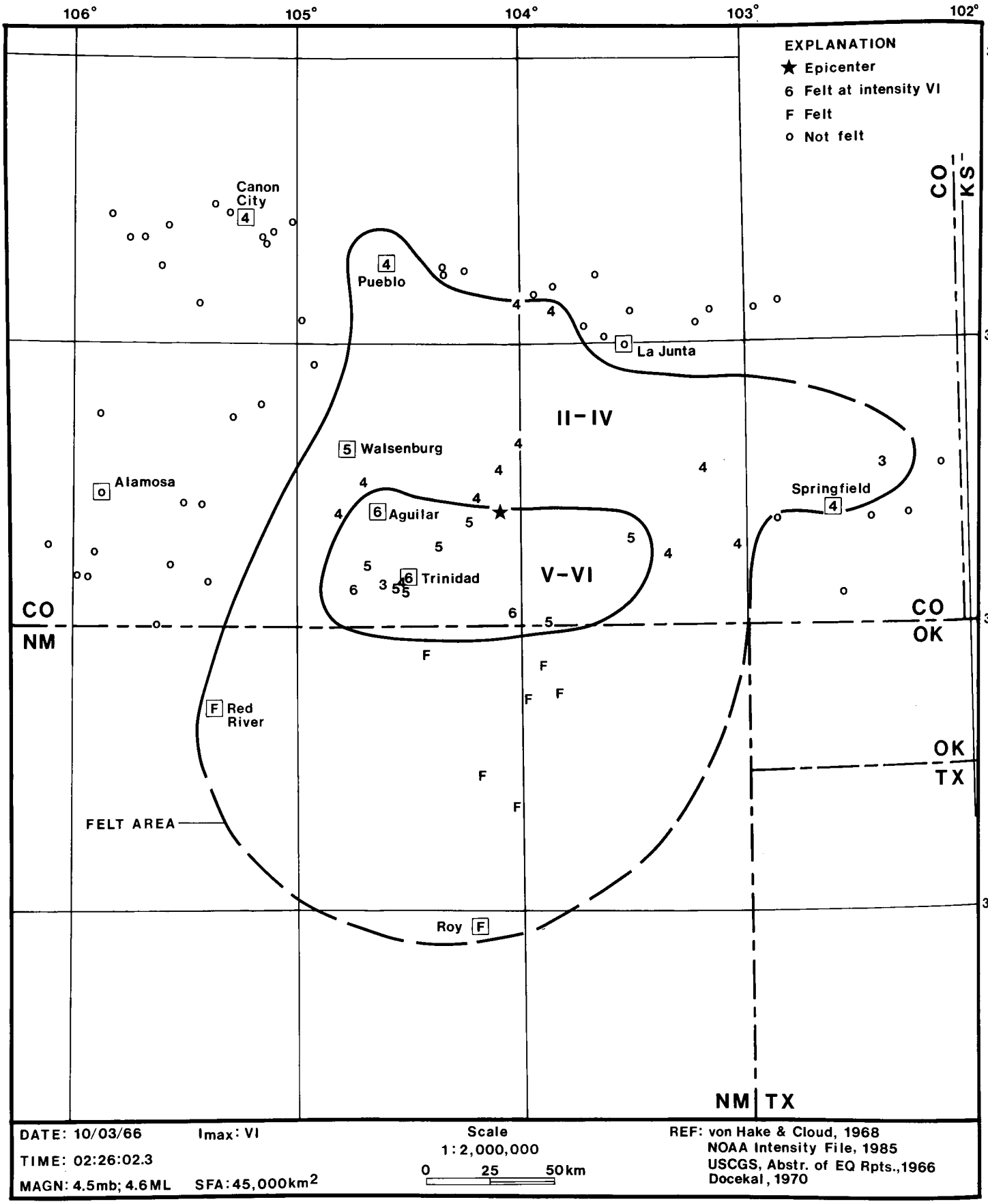

Figure 33. Isoseismal map for the October 3, 1966 earthquake.

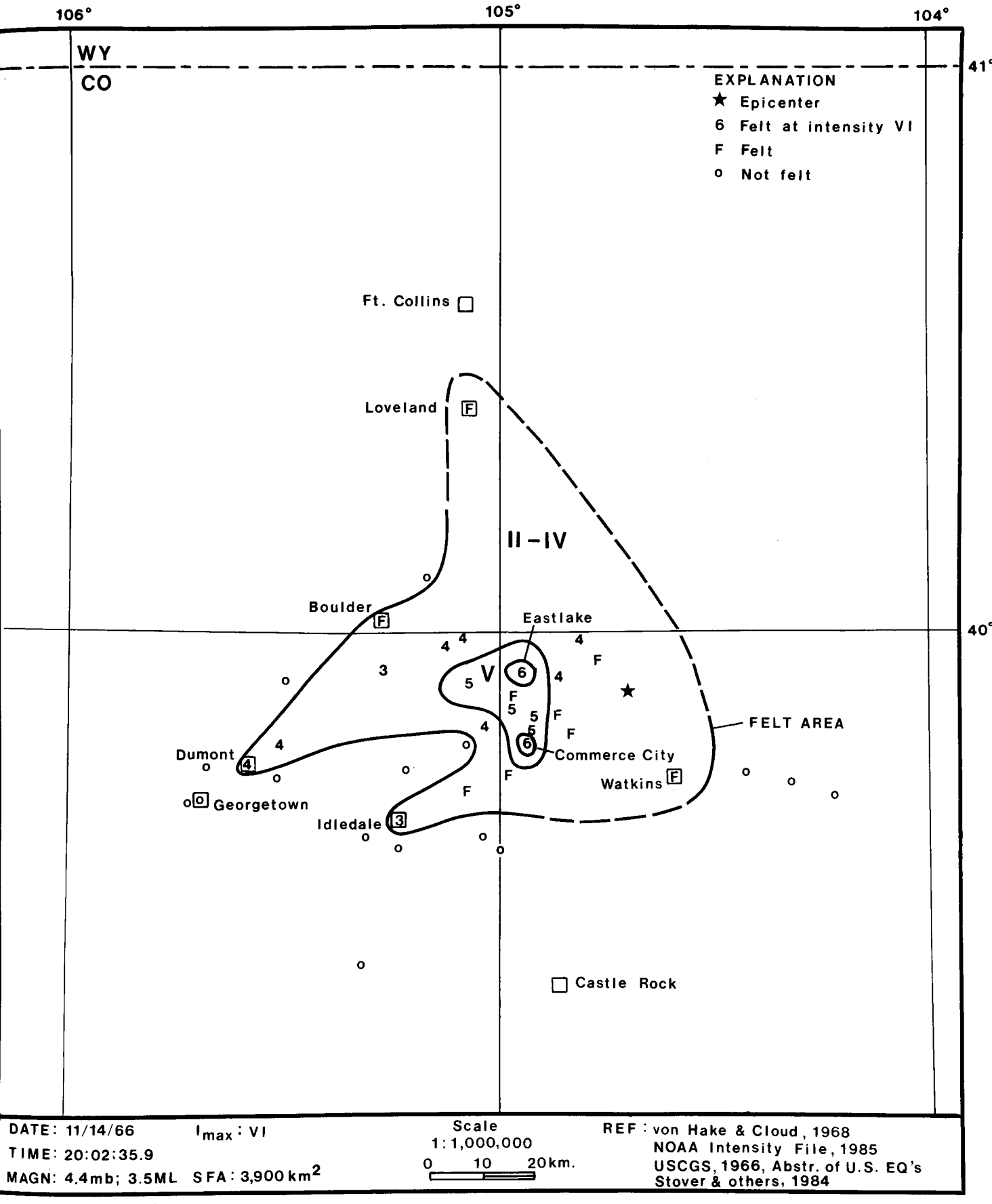

Figure 34. Isoseismal map for the November 14, 1966 earthquake.

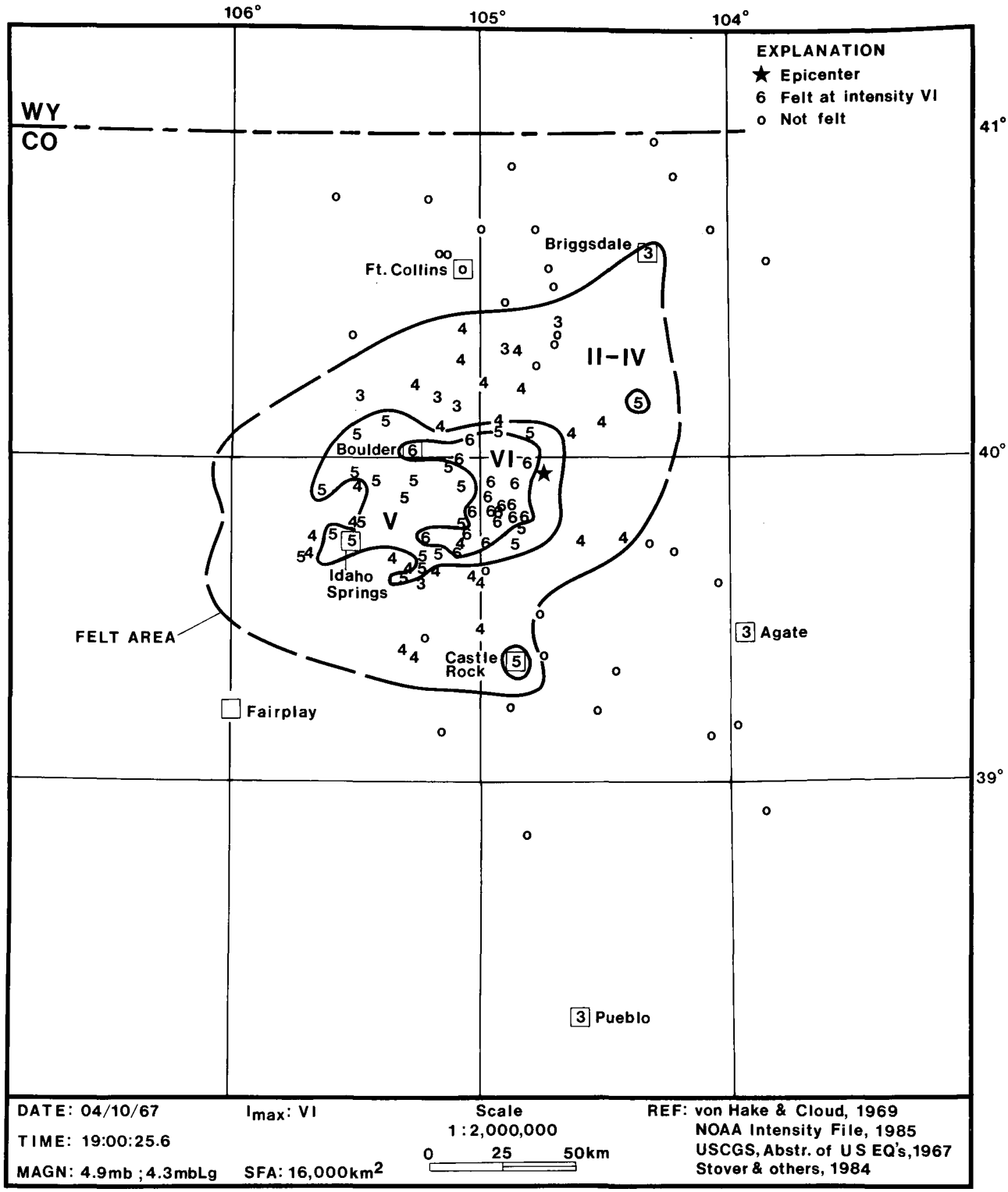

Figure 35. Isoseismal map for the April 10, 1967 earthquake.

16,000 km^2. A 16,800 km^2 felt area was suggested by von Hake and Cloud (1969), while Hadsell (1968) proposed the felt area covered 31,000 km^2. A magnitude of 4.8 mb was intitally published by von Hake and Cloud (1969), but

Stover, Reagor, and Algermissen (1984) reported a 4.9 mb. Hermann and others (1981) estimated the magnitude of this earthquake at 4.3 $\pm$ 0.2 mbLg and 4.2 $\pm$ 0.2 MS.

3.74 April 27, 1967

A small earthquake on April 27, 1967 caused slight damage in Boulder and Commerce City. Walls and a tile ceiling at a school in Boulder were cracked, and plaster was cracked in Commerce City (von Hake and Cloud, 1969). Both towns were rated intensity VI. Few other felt reports are available.

Figure 36 represents an isoseismal map for this event. We estimate the felt area to be about 3,800 km^2, whereas Hadsell (1968) reported it at 10,000 km^2. Our approximation may be slightly low. Earthquake magnitude was listed at 4.4 mb by von Hake and Cloud (1969), and 4.5 mb and 3.8 ML by Stover, Reagor, and Algermissen (1984).

3.75 August 9, 1967

One of the strongest shocks to effect the Denver area in the 1960's occurred on August 9, 1967. An isoseismal map for this event is shown in Figure 37. Felt reports and intensity ratings were described by von Hake and Cloud (1969). Intensity VII damage was reported in Northglenn, where plate glass windows broke, many walls, ceilings, foundations, and concrete floors cracked, and several businesses sustained damage due to fallen merchandise. A liquor store estimated damage at $10,000 to $20,000. Intensity VI damage was reported in 28 locations, many of which suffered considerable cracked plaster and mortar, broken windows, damaged foundations and chimneys, and damage to household goods. The earthquake was felt as far as Sterling, Pueblo, and Laramie.

Based on Figure 37, we estimate the felt area size to be about 50,000 km^2. Von Hake and Cloud (1969) proposed a size of 39,000 km^2, while Hadsell (1968) indicated it was felt over 117,000 km^2. Docekal (1970) reported a felt area size of 52,000 km^2. A magnitude 5.3 mb was calculated for this earthquake by von Hake and Cloud (1969), whereas Nuttli and others (1974) calculated an mbLg of 4.9 and MS of 4.4.

The overall felt area is prominently elongated in directions parallel and perpendicular to the mountain front. The intensity V and VI contours also are oriented in an elongate pattern perpendicular to the mountain front.

3.76 November 27, 1967

The Denver area was hit by another damaging earthquake on November 27, 1967. Figure 38 illustrates an isoseismal map for this event. Descriptions of felt effects and intensity ratings were recorded in von Hake and Cloud (1967) and the USCGS quarterly series. Intensity VI damage occurred at 20 locations. Damage was described as "chiefly cracked plaster, enlargement of existing cracks, and loss due to fallen merchandise in stores".

The earthquake was felt over an estimated 56,000 km^2, based on Figure 38. Von Hake and Cloud (1969) reported a felt area of 44,000 km^2, whereas

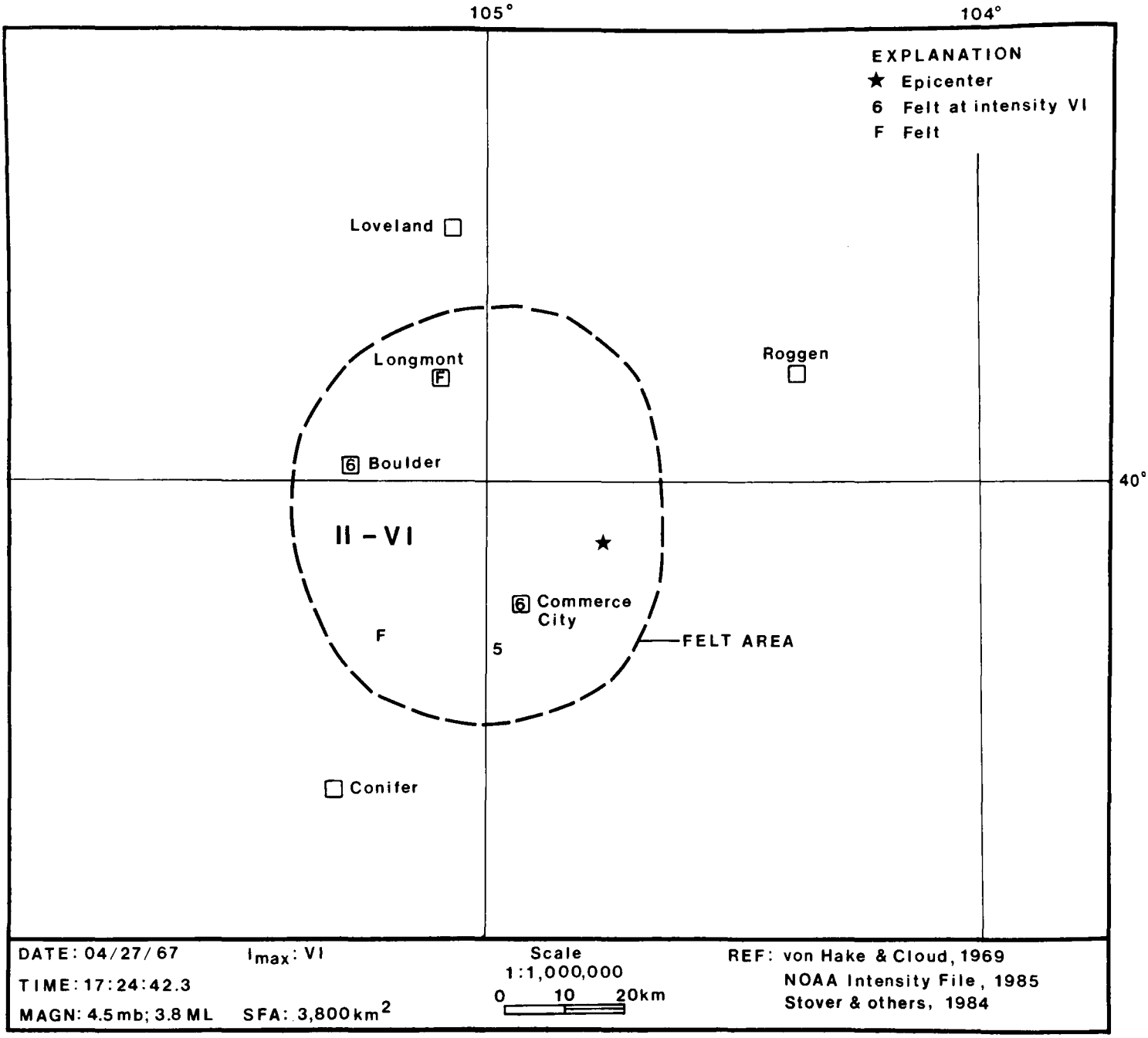

Figure 36. Intensity map for the April 27, 1967 earthquake.

Docekal (1970) suggested it was felt over 62,000 km^2. The outline of the felt area is strongly skewed in directions parallel and perpendicular to the mountain front. The distribution of higher intensities is elongated perpendicular to the mountain front. Von Hake and Cloud (1969) place the earthquake magnitude at 5.2 mb, while Stover, Reagor, and Algermissen (1984) report an mbLg of 4.6.

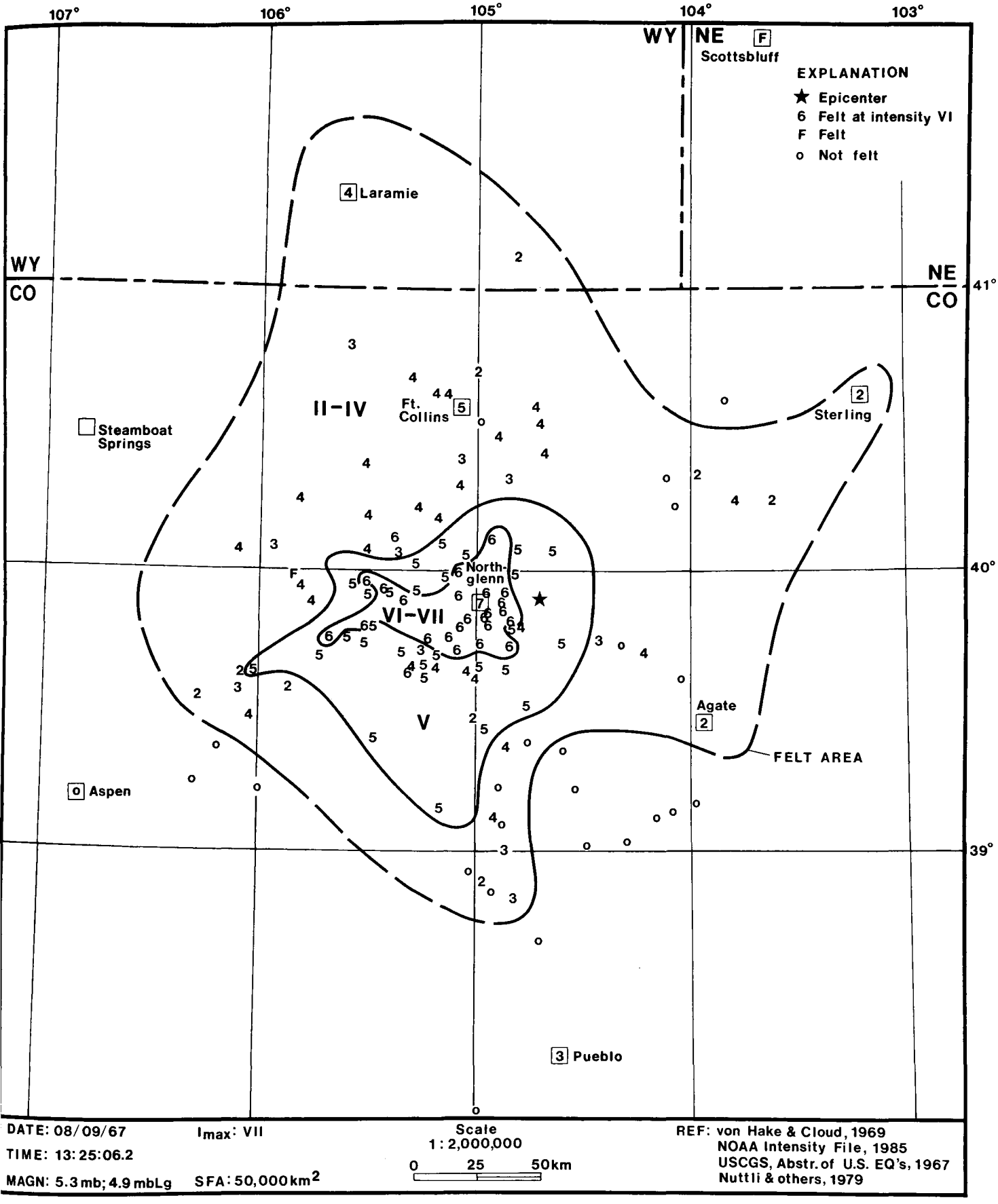

Figure 37. Isoseismal map for the August 9, 1967 earthquake.

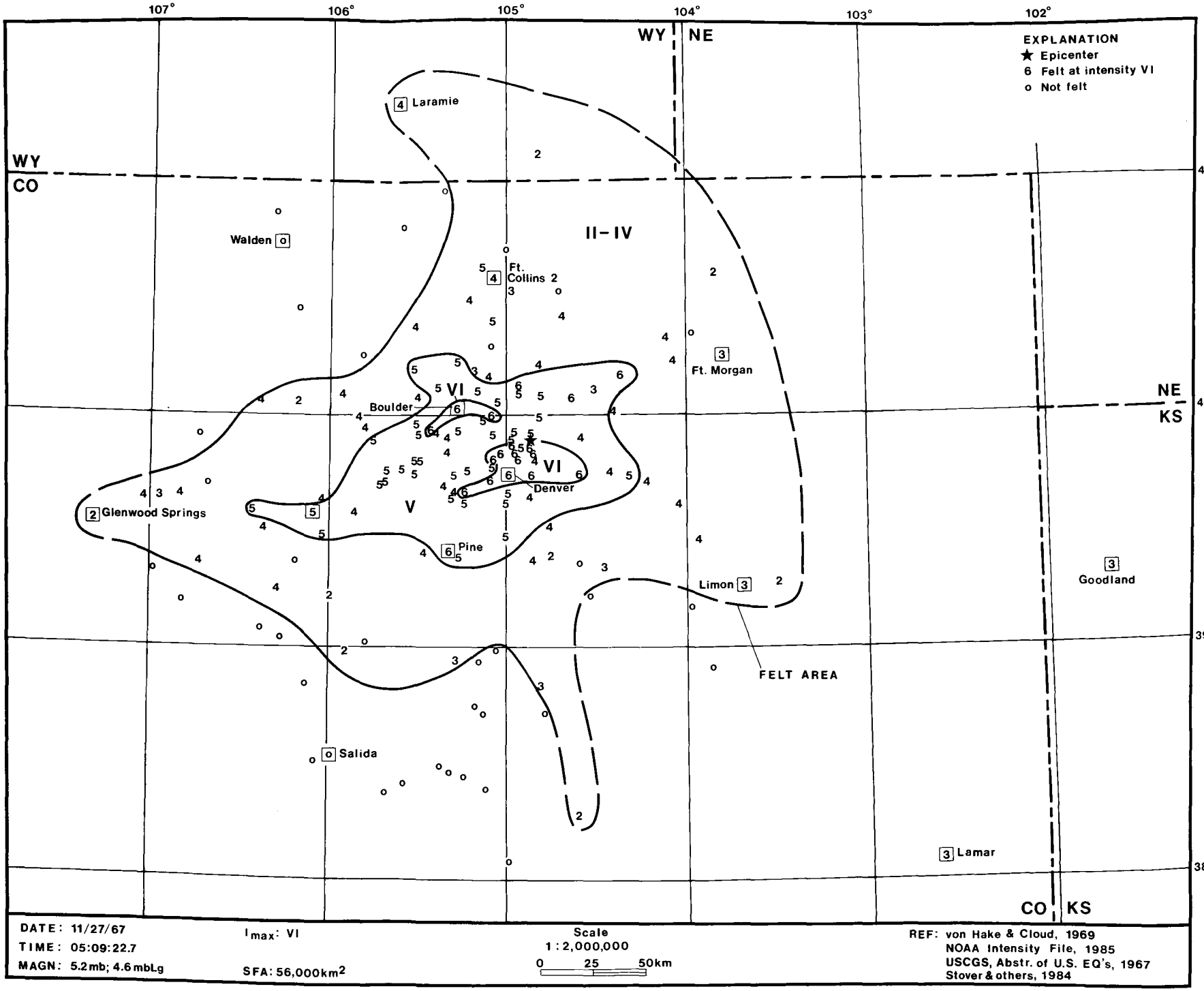

Figure 38. Isoseismal map for the November 27, 1967 earthquake.

3.77 March 18, 1971

A small region in northern Colorado felt the March 18, 1971 earthquake. Felt effects and intensity assignments were described in Coffman and von Hake (1973) and the USCGS quarterly series. An additional "not felt" report was located in the NOAA microfilm files for Craig. Intensity V effects were reported for the rural Clark area and Milner. The report from the rural Clark area is not shown on Figure 39 because the location of this report is not accurately known.

Based on our intensity map, the earthquake was felt over 1,700 km^2. Coffman and von Hake (1973) assign a magnitude of 4.4 mb to the quake.

3.78 August 8, 1971

A slight earthquake shook the Denver metro area on August 8, 1971. Intensity IV was reported at Commerce City, and several other areas reported that the quake was felt (von Hake and Cloud, 1973). An intensity map for the event is shown in Figure 40. The earthquake was felt over an estimated 3,000 km^2 and was assigned a magnitude of 4.4 mb by von Hake and Cloud (1973) and 3.8 ML by GOL (Stover, Reagor, and Algermissen, 1984).

3.79 November 29, 1972

The November 29, 1972 earthquake shook a small area north of Denver. Intensity IV effects were reported for eleven towns (Coffman and von Hake, 1974). As shown on Figure 41, the earthquake was felt over an estimated 700 km^2. Stover, Reagor, and Algermissen (1984) report a magnitude of 2.7 ML for this event.

3.80 January 30, 1975

The Grand Junction area was shaken by a local earthquake on January 30, 1975. An isoseismal map for this event is illustrated in Figure 42. The earthquake was felt from Mack to DeBeque and Austin, with intensity V effects reported at Whitewater and the Colorado National Monument (Coffman and Stover, 1977). Earthquake magnitude was 4.4 mb and 3.7 ML (Stover, Reagor, and Algermissen, 1984).

3.81 January 5, 1976

The Four Corners area experienced a moderate earthquake on January 5, 1976. The quake centered in northwestern New Mexico and was felt in the adjacent states of Colorado, Arizona, and Utah (Figure 43). Felt reports and intensity ratings were described by Simon and others (1978). Intensity VI damage occurred in New Mexico, Arizona, and Colorado. Plaster and a chimney were cracked in Cahone, Colorado and cracks formed in a new concrete platform in Hesperus.

Felt area size for the tremor was estimated at 115,000 km^2 by Simon and others (1978). Earthquake magnitude was 5.0 mb and 4.6 ML, while its depth was estimated at 25 km.

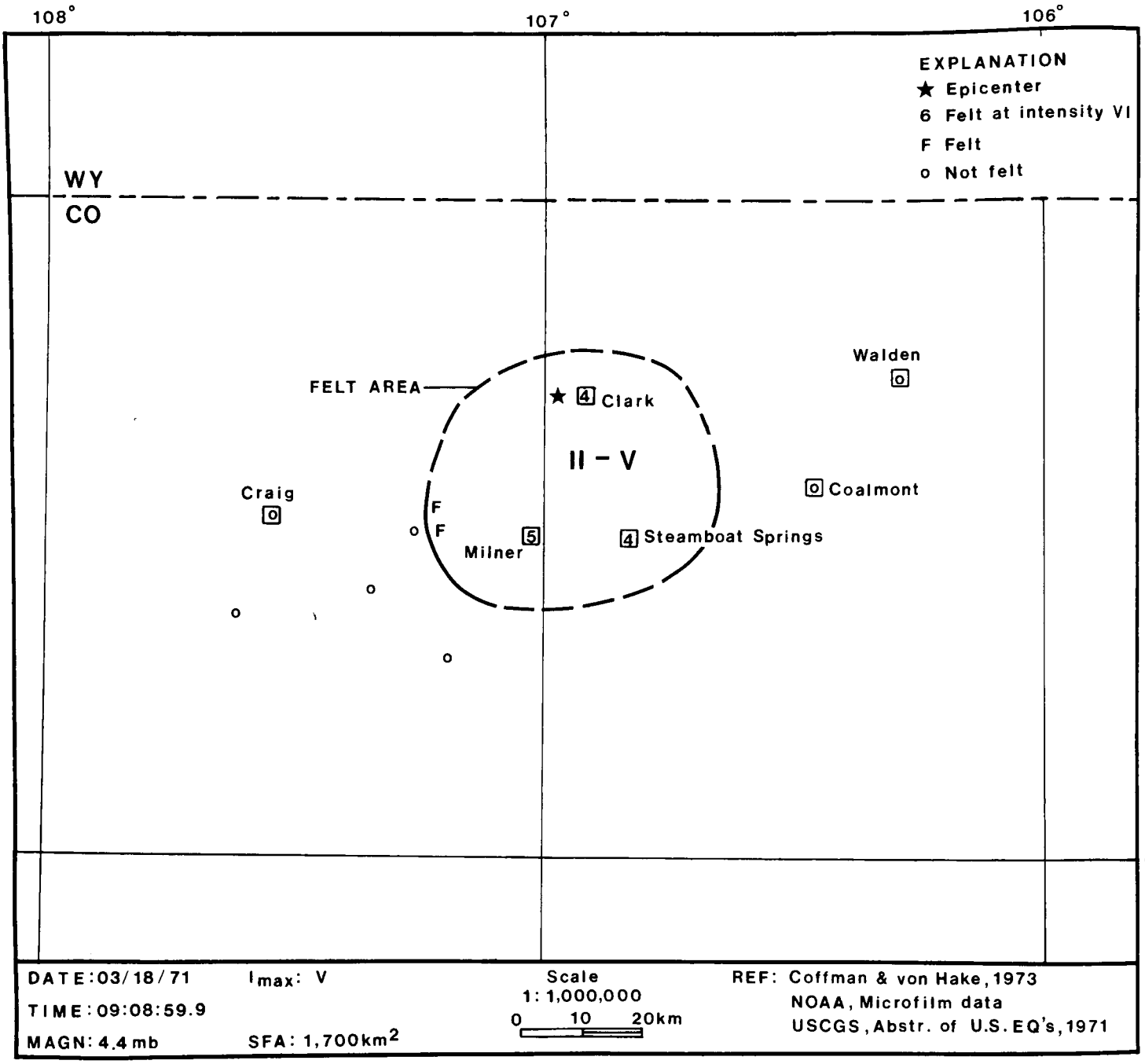

Figure 39. Intensity map for the March 18, 1971 earthquake.

3.82 March 5, 1977

Another earthquake shook the Four Corners area on March 5, 1977. Parts of Colorado, Arizona, and possibly Utah were effected by this quake (Figure 44). According to Simon and others (1979), intensity VI damage was reported in two New Mexico towns. Intensity V was reported in Colorado at Cortez and Durango. The quake was felt over 51,400 km^2 (Simon and others, 1979) and was estimated to be 4.6 mb and 4.2 ML at a depth of 22 km.

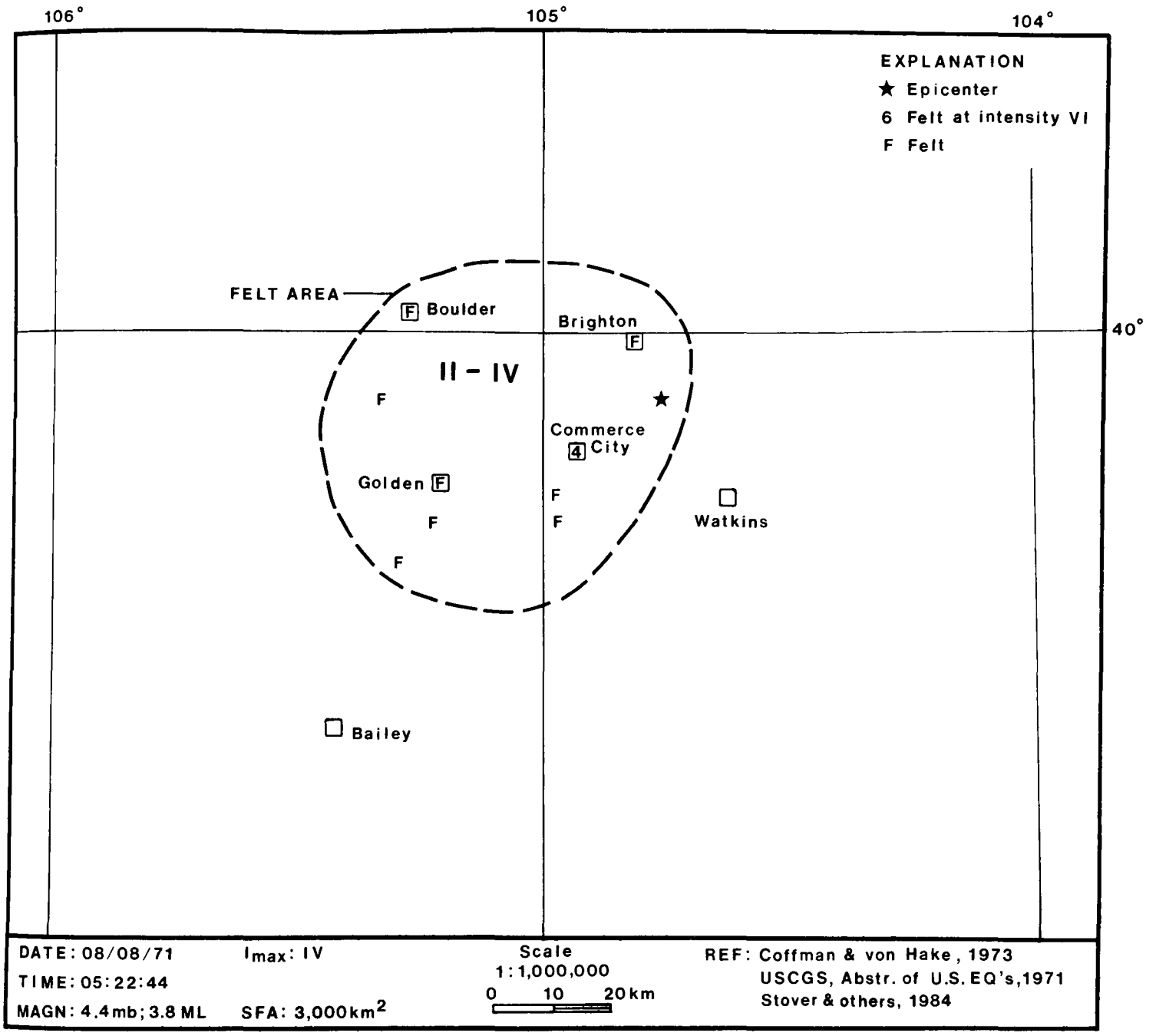

Figure 40. Intensity map for the August 8, 1971 earthquake.

3.83 September 30, 1977

The Colorado-Utah border region experienced an earthquake on September 30, 1977. Figure 45 is a redrafted version of the isoseismal map prepared by Stover and others (1979). The earthquake was felt in four distinct and separate areas, totaling 20,000 km^2. Intensity VI damage occurred in Colorado at Fruita (plaster cracked) and at Grand Junction (stone fence and plaster cracked). An unusual aspect of this event was that the Grand Junction area, which is about 200 km^2 from the epicentral area, reported shaking as

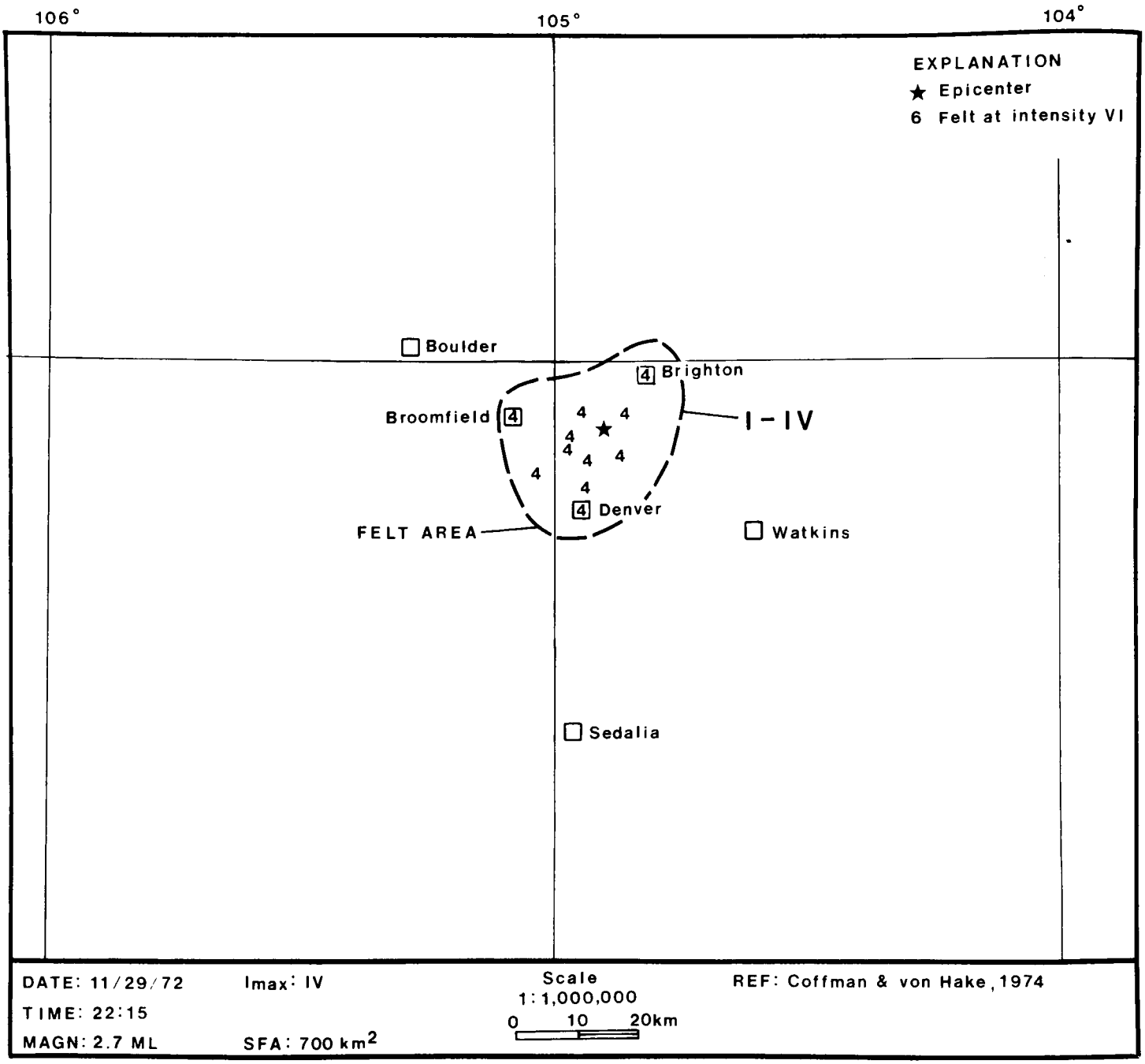

Figure 41. Intensity map for the November 29, 1972 earthquake.

strong or stronger than the epicentral area. Stover and others (1979) estimate the magnitude at 5.0 mb and 5.1 ML and the depth at 5 km.

3.84 January 6, 1979

A small earthquake on January 6, 1979 rumbled through central Colorado. Stover and von Hake (1981) described the felt reports and assigned intensities. The isoseismal map shown in Figure 46 is based on these reports.

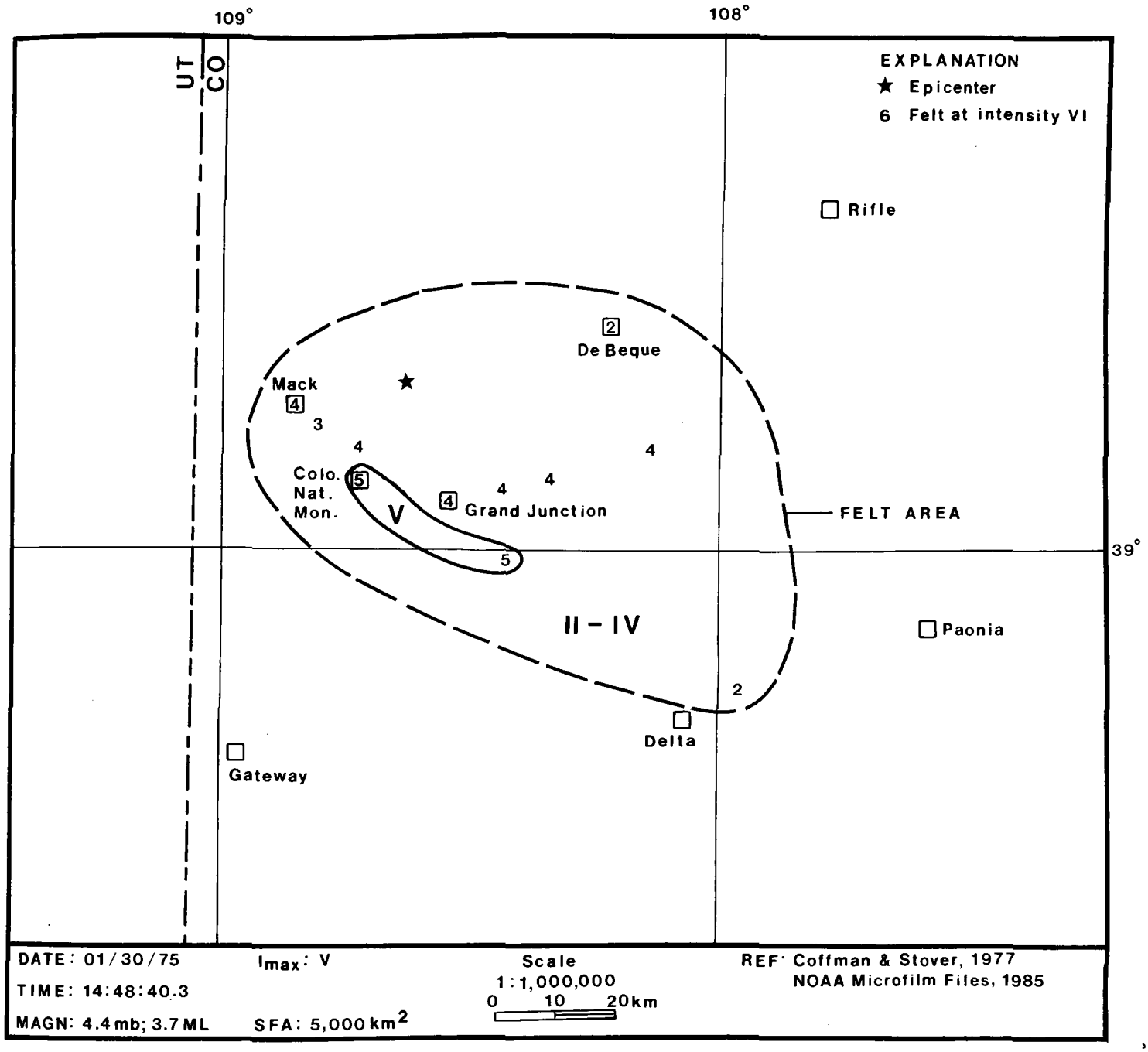

Figure 42. Isoseismal map for the January 30, 1975 earthquake.

Cripple Creek experienced intensity VI shaking, during which plaster cracked. Numerous reports from Florissant and the surrounding rural area indicate intensity V. Our isoseismal map, which is based on the felt reports in Stover and von Hake (1981), suggests the earthquake was felt over 11,200 km^2. Butler and Nicholl (1985a) report a much smaller felt area of only 1,800 km^2. Earthquake magnitude was estimated at 2.9 ML and 3.3 mbLg by Stover and von Hake (1981), and hypocentral depth was calculated at 5 km. Audible effects associated with the earthquake led Butler and Nicholl (1985a) to conclude the hypocentral depth was less than 5 km.

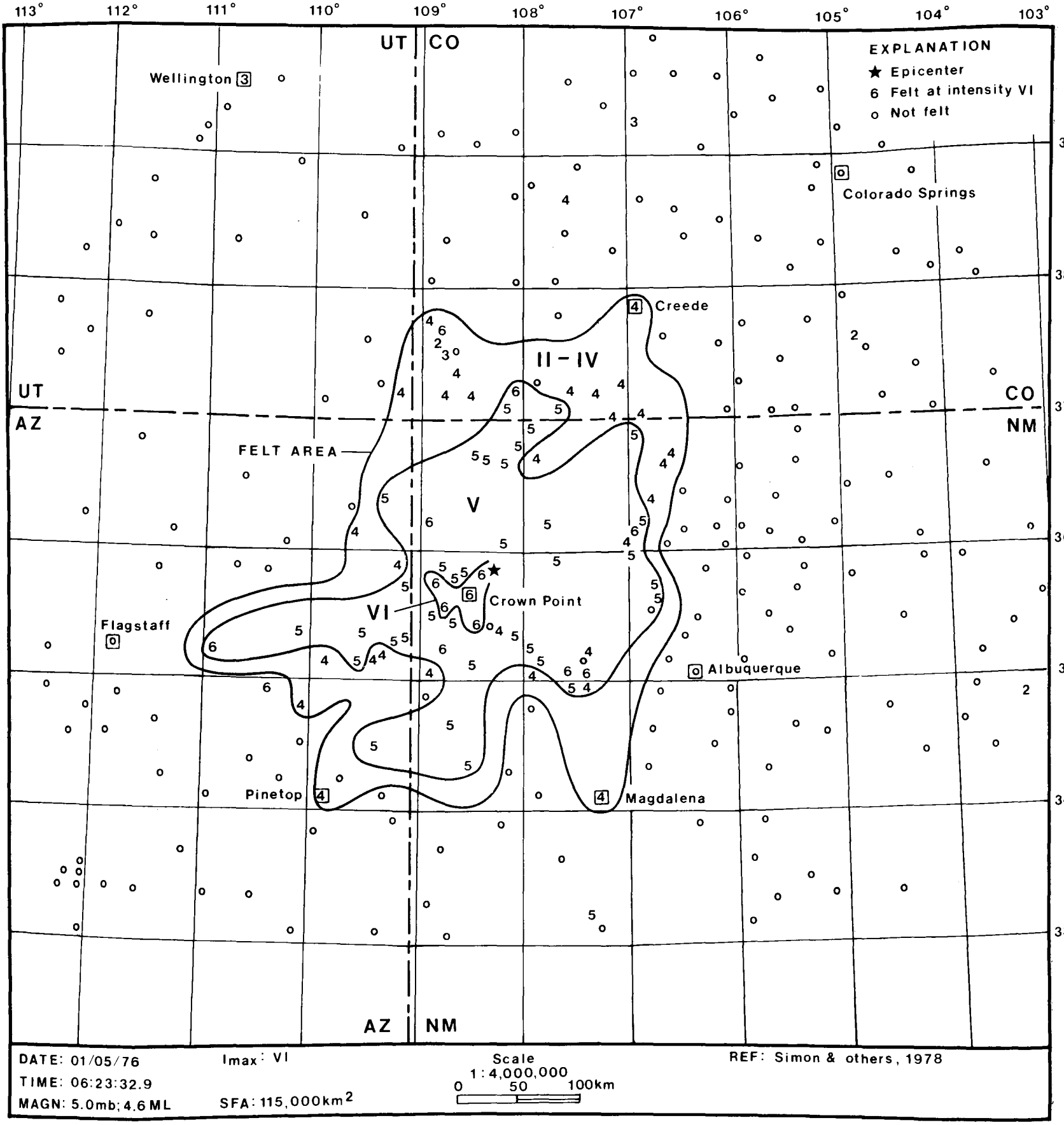

Figure 43. Isoseismal map for the January 5, 1976 earthquake.

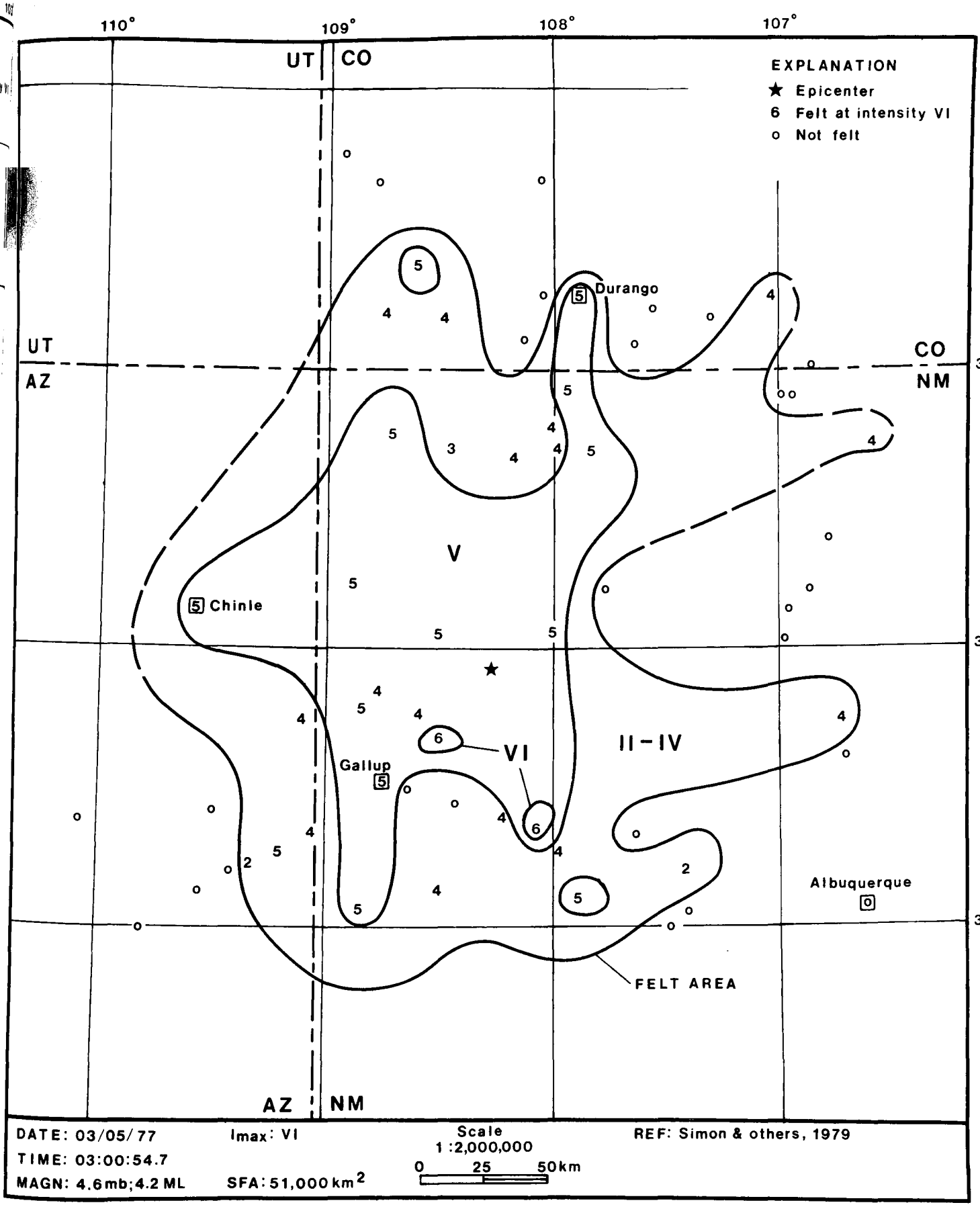

Figure 44. Isoseismal map for the March 5, 1977 earthquake.

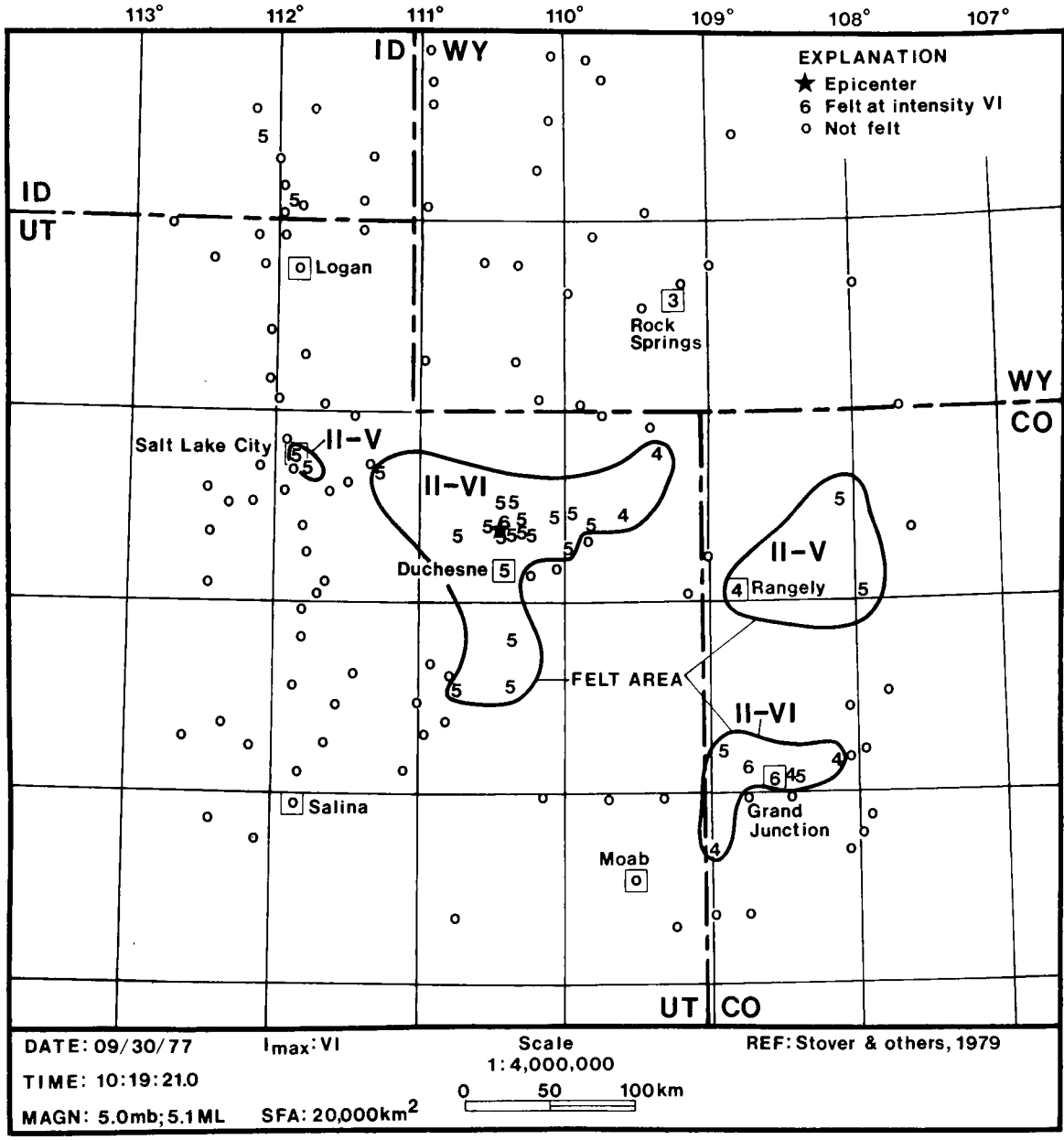

Figure 45. Intensity map for the September 30, 1977 earthquake.

3.85 April 2, 1981

The April 2, 1981 earthquake centered in the north Denver area. Felt effects and intensity ratings were presented in Stover and others (1982a), along with an intensity and detailed isoseismal map that are replicated in Figure 47 in a slightly revised version.

The earthquake was felt over about 7,000 km^2 and its maximum reported intensity was VI. At Commerce City many large cracks formed in plaster walls at a school. Numerous small cracks developed in plaster, drywall, and cinder block walls, and one window was cracked in Thornton.

Magnitude assignments for this event include 4.3 mb, 3.8 ML, and 4.5 Mn, while the hypocentral depth is reported at 9 km (Stover and others, 1982a).

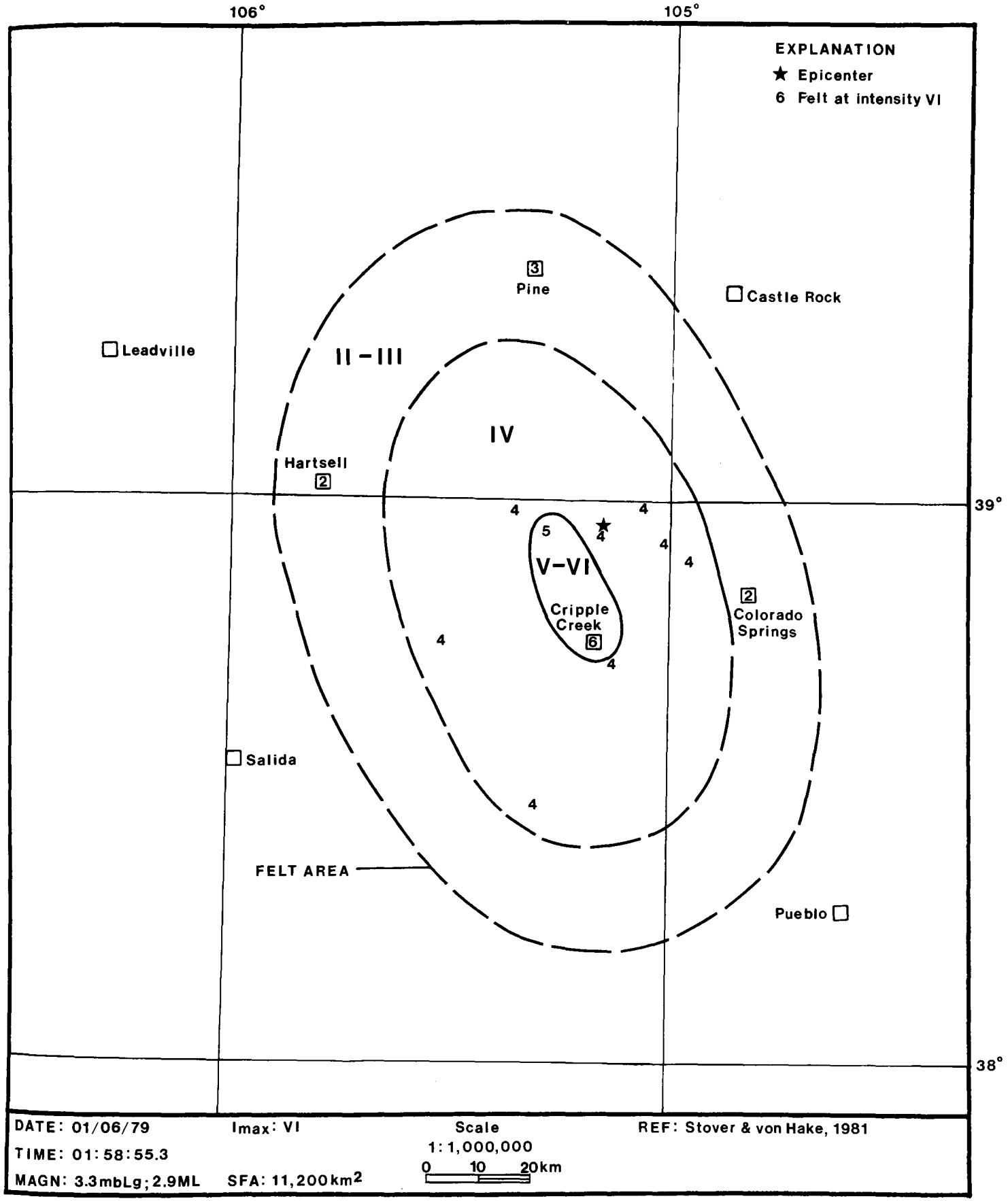

Figure 46. Isoseismal map for the January 6, 1979 earthquake.

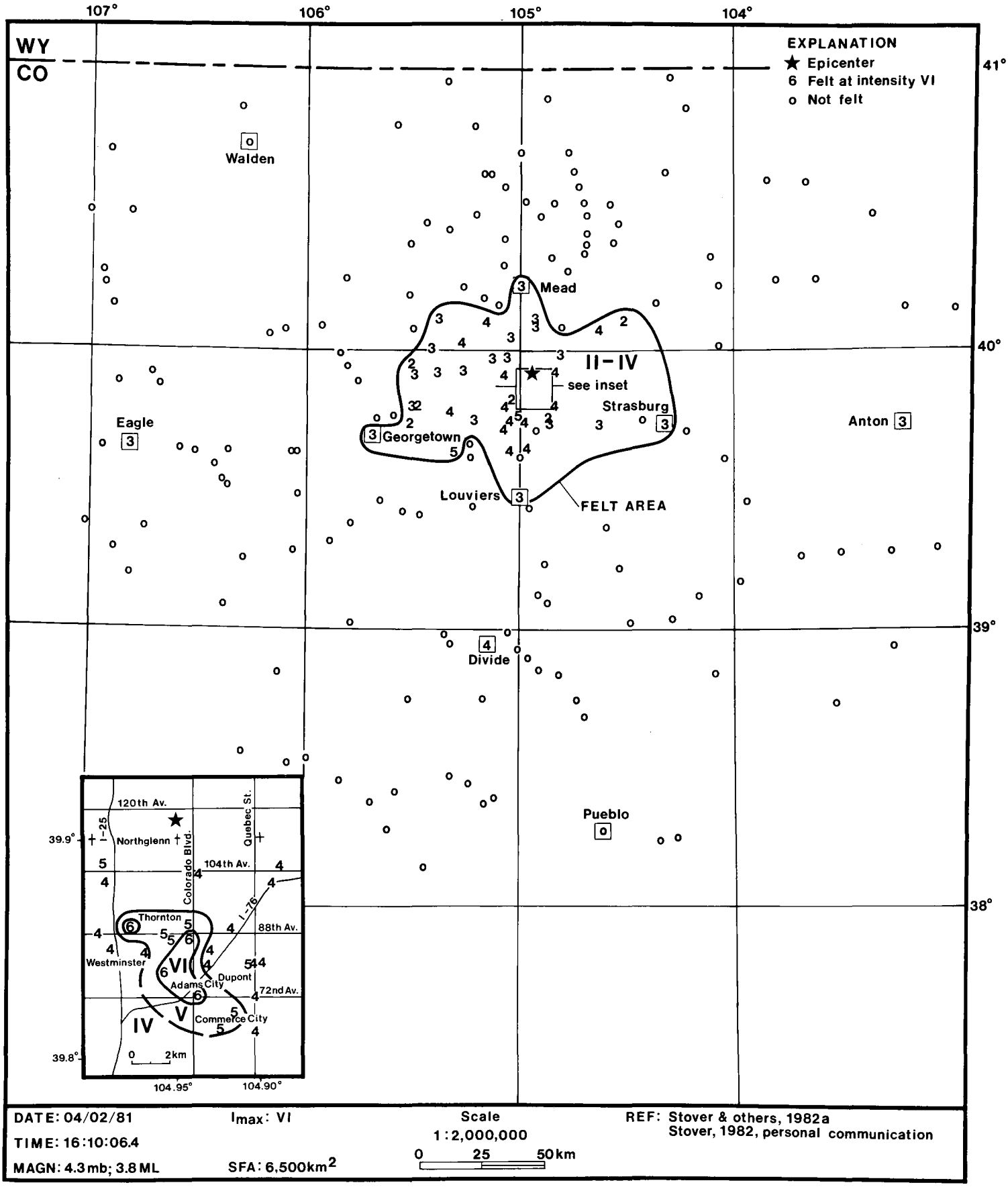

Figure 47. Intensity and isoseismal maps for the April 2, 1981 earthquake.

3.86 November 2, 1981

A small area that includes Conifer, Bailey, and Evergreen experienced an earthquake on November 2, 1981. Intensity V damage occurred east of Aspen Park in South Turkey Creek Canyon (cracked windows and broken glassware) and in Pine Junction (Stover and others, 1982b). Our isoseismal map for this event, which is based on USGS data, is shown in Figure 48. It suggests the quake was felt over 2,300 km^2. Butler and Nicholl (1985b) report a felt area of only 1,000 km^2. Stover and others (1982b) reported magnitudes of 2.8 ML and 3.1 Mn for this earthquake, and their hypocentral location is near or on the Kennedy Gulch Fault. Butler and Nicholl (1985b) suggest a slightly different location that places the epicenter between the Kennedy Gulch Fault and Floyd Hill Fault.

3.87 August 14, 1983

On August 14, 1983, a small earthquake of magnitude 3.4 ML occurred near Cimarron (USGS, 1985). Wong and Humphrey (1986) analyzed data from numerous seismograph stations, concluded the earthquake had a focal depth of 6.3 km, and suggested a fault plane solution exhibiting predominantly normal faulting. They believe that the location and fault plane solution "strongly suggest that the Cimarron Fault was the source of this event."

3.88 April 12 to May 17, 1984

A swarm of earthquakes shook the Carbondale area between April 12 and May 17, 1984 (USGS, PDE for April and May, 1984). Nineteen events were recorded during this period, ranging up to magnitude 3.2 ML and intensity IV. Several of the quakes were recorded by a microseismic network established by the USGS (B.W. Presgrave, 1985, pers. comm.), but the results of that study are not yet available.

3.89 October 18, 1984

A large area in Wyoming, Colorado, South Dakota, Nebraska, Kansas, Utah, and Montana was shaken by an earthquake on October 18, 1984. Stover (1985) described the effects of this event and presented an isoseismal map. A redrafted version of his map is included in this report as Figure 49.

The earthquake was felt over 287,000 km^2, an unusually large area for an event rated at 5.3 mb, 5.1 MS, and 5.5 ML. Stover (1985) suggested this may be a result of the focal depth of the earthquake. The focal depth of the main shock is not accurately known, but Langer and others (1985) determined accurate focal depths for some of the aftershocks of the October 18th event. The aftershocks range from about 20 to 25.5 km in depth. The focal depth of the main event probably falls within or is near this range.

Even though the earthquake was felt over a wide area, no major damage resulted from it. Intensity VI damage was reported at several locations in Wyoming. Cracks developed in exterior brick or cinder block walls at Douglas, Medicine Bow, Casper, Guernsey, Hanna, Lusk, McFadden, Rock River, and Shirley Basin. Chimneys were cracked in Casper, Douglas, Guernsey, Lusk, and Rock River, while underground pipes at Casper and Shirley Basin were broken.

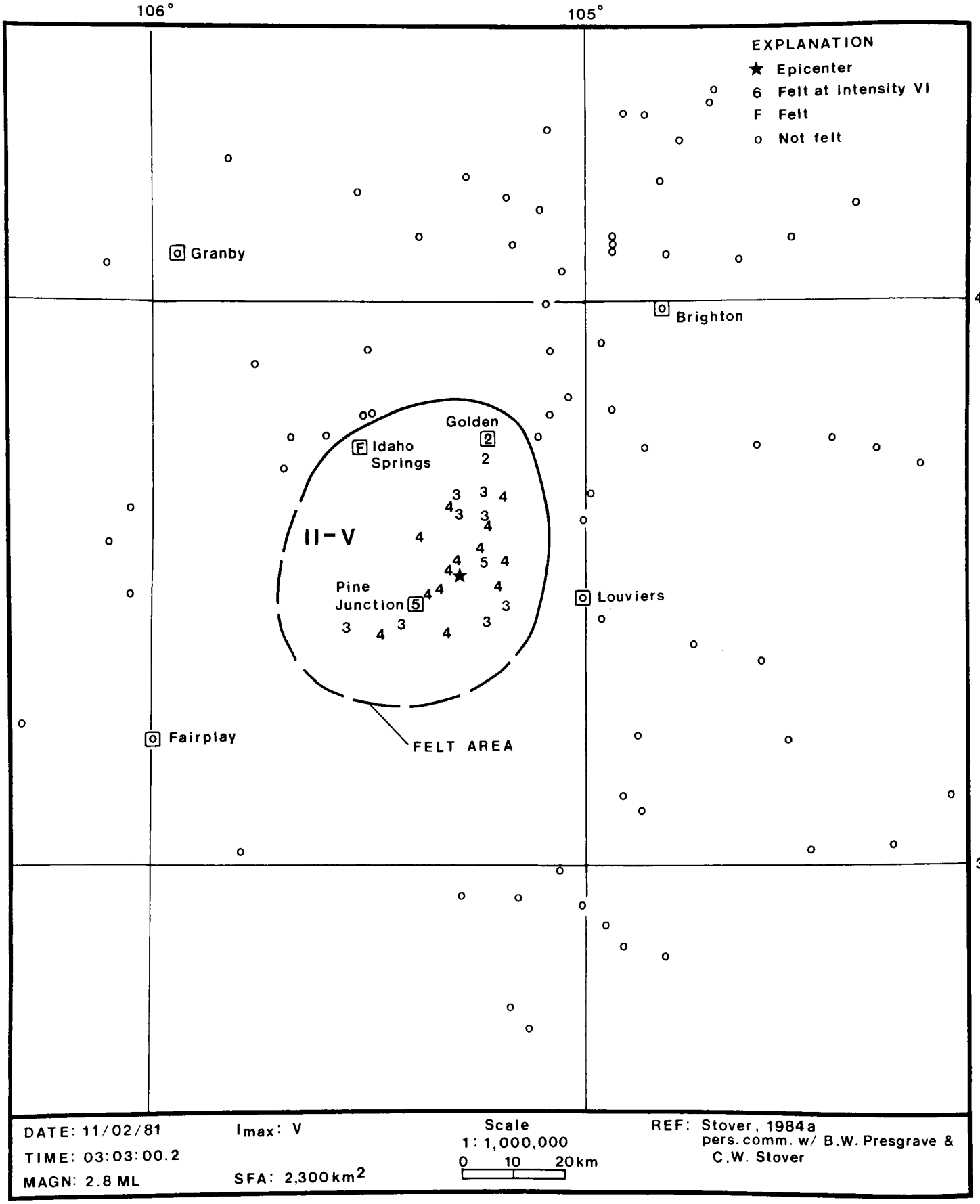

Figure 48. Intensity map for the November 2, 1981 earthquake.

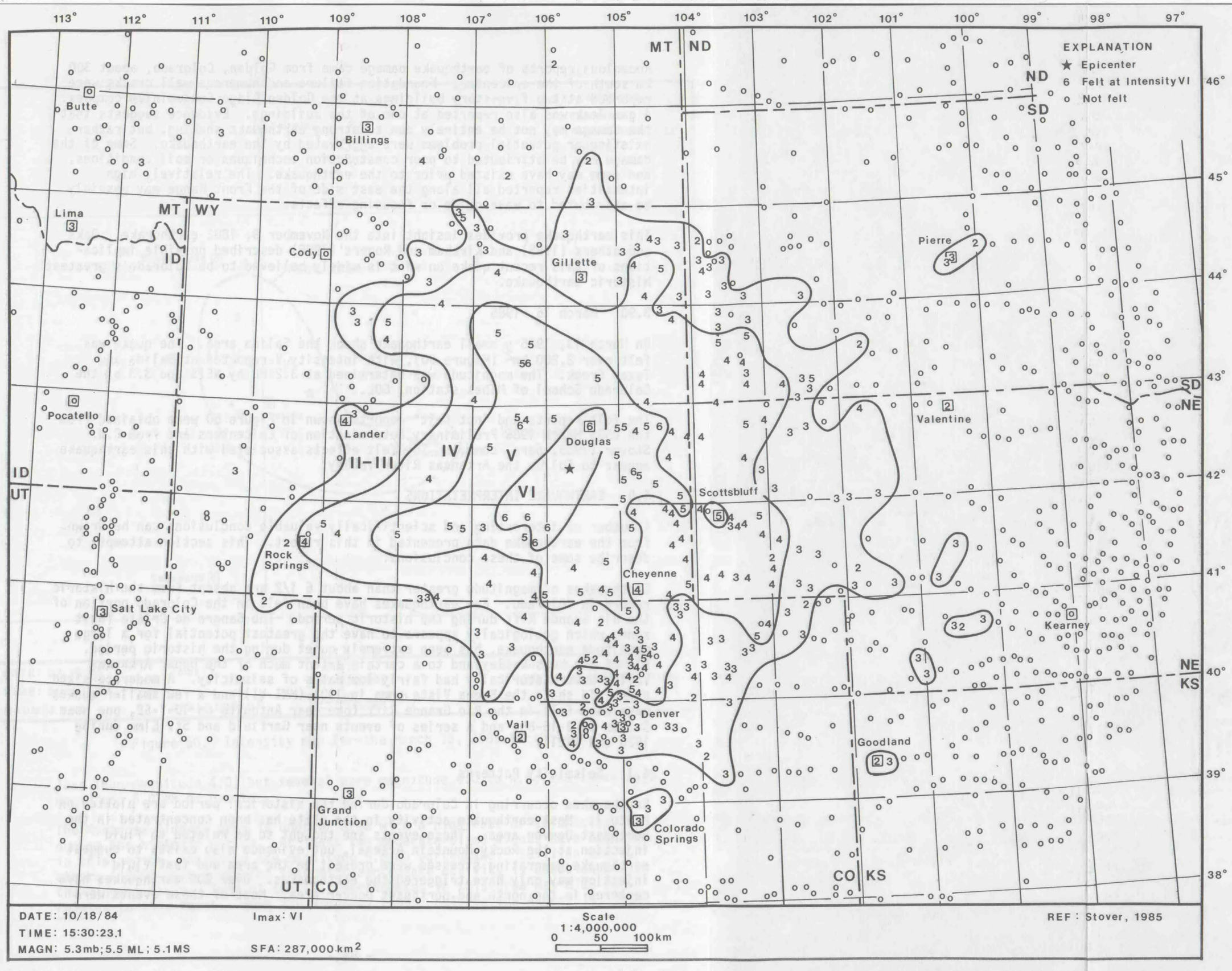

Figure 49.
Isoseismal map for the October 18, 1984 earthquake.

Anomalous reports of earthquake damage came from Golden, Colorado, about 300 km south of the epicenter. Foundation failure and numerous wall cracks were reported at two five-story buildings at the Golden Ridge Condominium complex. A gas leak was also reported at one of the buildings. Evidence suggests that the damage may not be entirely due to strong earthquake shaking, but rather existing or potential problems were aggravated by the earthquake. Some of the damage may be attributed to poor construction techniques or soil conditions, and some may have existed prior to the earthquake. The relatively high intensities reported all along the east side of the Front Range may possibly be attributed to wave guide or focusing effects.

This earthquake provides insight into the November 8, 1882 earthquake. Oaks and others (1985) and Kirkham and Rogers (1986) described possible implications of this recent quake on what is widely believed to be Colorado's greatest historic earthquake.

3.90 March 16, 1985

On March 13, 1985 a small earthquake shook the Salida area. The quake was felt over 2,200 km^2 (Figure 50), with intensity V reported at Salida and Texas Creek. The magnitude was determined at 3.2 ML by NEIS and 3.3 by the Colorado School of Mines station, GOL.

The felt reports and "not felt" reports shown in Figure 50 were obtained from the USGS March 1985 Preliminary Determination of Epicenters and from C.W. Stover (1985, pers. comm.). The felt effects associated with this earthquake appear to follow the Arkansas River Valley.

4.0 EARTHQUAKE INTERPRETATIONS

A number of interesting and scientifically valuable conclusions can be drawn from the earthquake data presented in this report. This section attempts to describe some of these conclusions.

Earthquakes of magnitude greater than about 6 1/2 are absent from the historic record in Colorado. Few earthquakes have been felt in the Colorado portion of the Rio Grande Rift during the historic period. The Sangre de Cristo fault zone, which geologically appears to have the greatest potential for a large magnitude earthquake, has been extremely quiet during the historic period. All of San Luis Valley and to a certain extent much of the Upper Arkansas Valley have historically had fairly low rates of seismicity. A moderate-sized event did shake the Buena Vista area in 1901 (MMI VI) and a few smaller quakes have been felt in the Rio Grande Rift (one near Antonito on 10-7-52, one near Salida on 3-16-85, and a series of events near Garfield and St. Elmo during 1920 and 1921).

4.1 Seismicity Patterns

Earthquakes occurring in Colorado during the historical period are plotted on Plate 1. Most earthquake activity in the state has been concentrated in the northeast Denver area. These events are thought to be related to fluid injection at the Rocky Mountain Arsenal, but evidence also exists to suggest earthquake-generating stresses were present in the area and that fluid injection may only have triggered the earthquakes. Over 200 earthquakes have centered in the north and northeast Denver area. Most of these events were

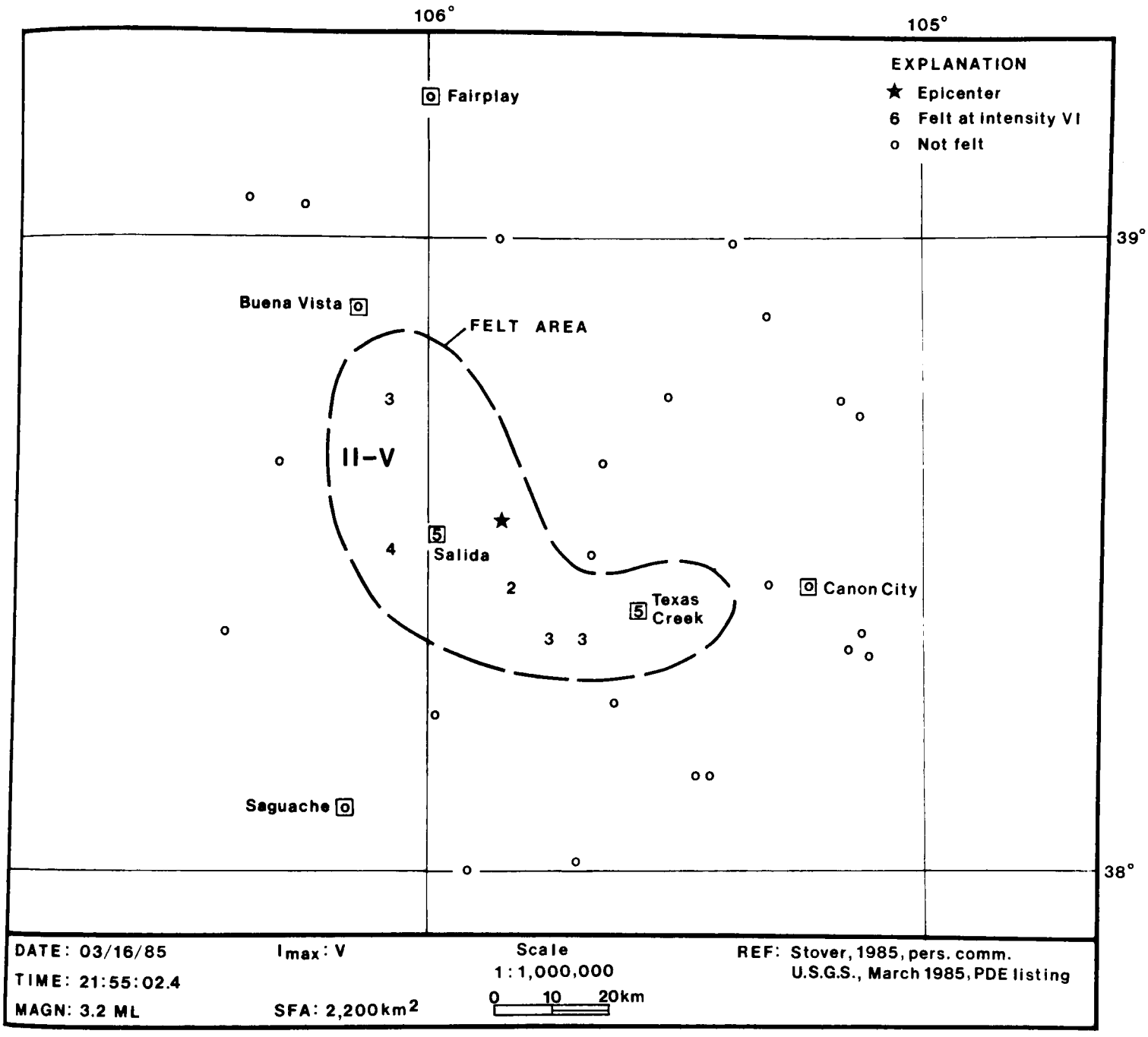

Figure 50. Intensity map for the March 16, 1985 earthquake.

less than magnitude 4.0, but several were magnitude 4.0 to 4.9, and three were magnitude 5.0 mb or greater.

The Montrose-Ridgway area is another area with a high rate of seismicity during the historic period. At least two moderate-sized events have occurred in this region, including one magnitude 5.5 mb earthquake. Sullivan and others (1980) have suggested that microearthquake activity is associated with the Ridgway fault. Some of the felt earthquakes in this area may also be related to this fault. Wong and Humphrey (1986) believe the August 14, 1983

earthquake occurred on the Cimarron fault and that the magnitude 5.5 earthquake in 1960 may also be related to this fault.

The Glenwood Springs-Carbondale-Aspen area also has had a relatively high rate of historic seismicity. Earthquake activity has been reported in this region throughout the historical period. In view of the recent findings of B.K. Stover (1986), part of this seismicity may be associated with the Grand Hogback.

The Rangely area has experienced several historic earthquakes. Part of these are known to have been related to water-flooding at the Rangely oil field, but some of the quakes pre-date water-flooding. A number of earthquakes have been felt or instrumentally recorded in other areas of the northwestern part of the state. These events are scattered across the area and do not appear restricted to any single location.

The series of earthquakes on the Colorado-New Mexico border south of Pagosa Springs were related to a main shock and a sequence of aftershocks. This area continues to experience minor earthquake activity. The seismic activity may possibly be related to the Archuleta Anticlinorium.

Numerous other earthquakes have occurred at scattered locations in the San Juan Mountain region and across southeastern Colorado. Only two areas in the state have not experienced any significant earthquake activity during the historic period. They are 1) northeastern Colorado from about 39.25°N to 41°N and 102°W to 104.5°W and 2) the northern San Luis Valley. The geologic characteristics of northeastern Colorado support the apparent lack of seismicity in that region, but the northern San Luis Valley area contains abundant evidence of late Quaternary fault activity. Perhaps this latter region is presently within the midst of an aseismic period that separates periods of major earthquake activity.

4.2 Maximum Historical Earthquake Intensities

Figure 51 illustrates the maximum earthquake intensities experienced in Colorado during the historical period. It was developed by combining the numerous isoseismal and intensity maps published in this report. In a few instances, data was utilized from earthquakes for which we do not have a map.

Maximum felt intensity during the historic period in Colorado is VII. This intensity has been reported in the Northglenn area and in the Greenhorn or Wet Mountains. Intensity VII or greater shaking may have occurred at other locations during the 1882 event. The 1966 Dulce earthquake possibly caused intensity VII damage along the Colorado-New Mexico border, but no documented reports have been received.

Intensity VI damage has occurred over several areas of the state. Much of northwestern and north-central Colorado have experienced a minimum of intensity VI shaking. Other areas that have reported historic intensity VI effects include the Montrose-Ridgway-Ouray vicinity, Snowmass-Carbondale region, Grand Valley, the Buena Vista area, the Canon City-Wet Mountain-Chico Creek region, an area south of Pagosa Springs, and the Trinidad-Mesa de Maya area.

Much of the Plains region of northeastern and east-central Colorado has experienced only intensity IV or less during the period of historic record.

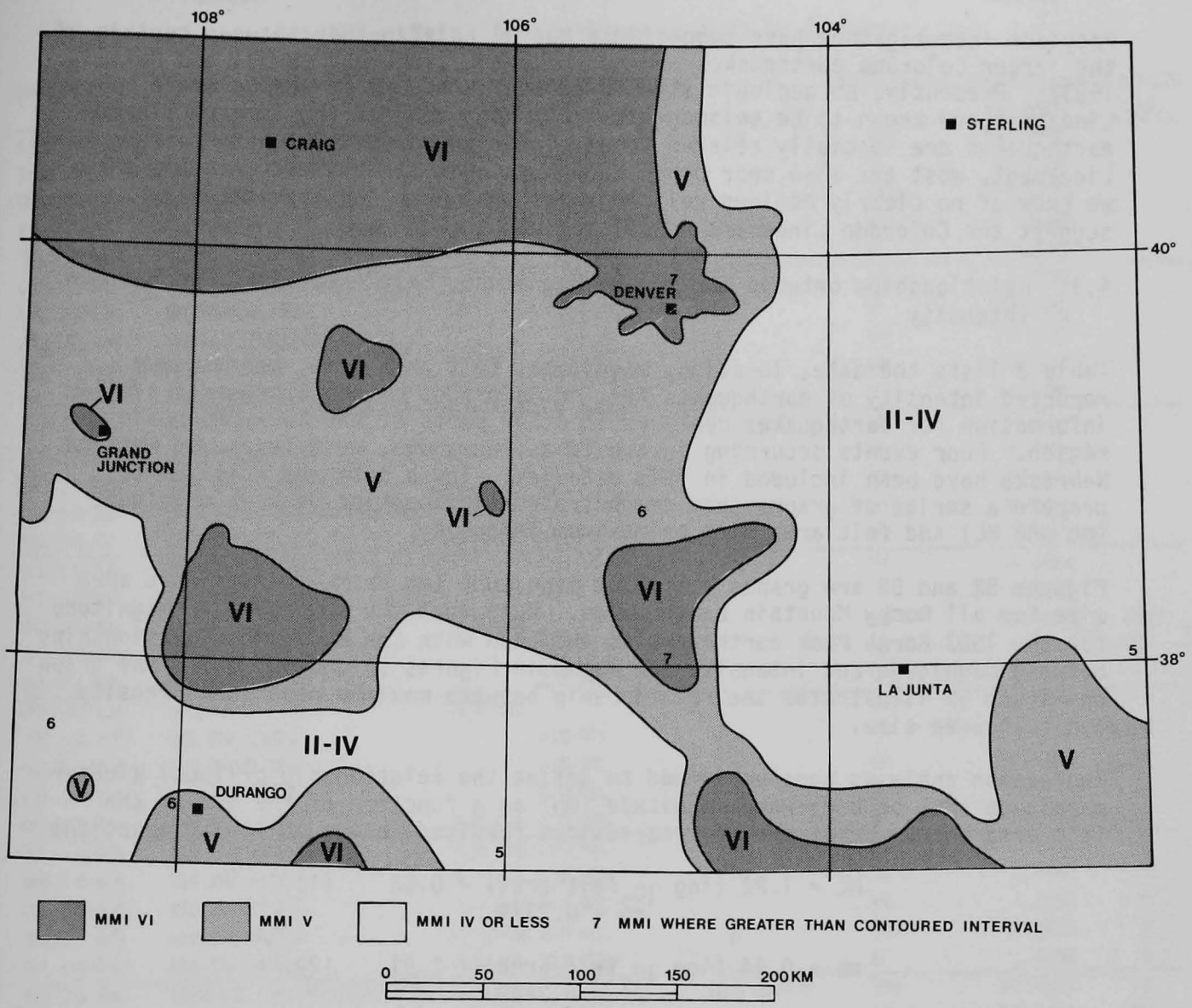

Figure 51. Maximum historical earthquake intensities in Colorado.

Another area to experience only intensity IV effects or less extends from the Culebra Range and San Luis Valley on the east, across the southern San Juan Mountains, and into the Colorado Plateau on the west.

The November 8, 1882 earthquake is the controlling event for much of northwestern, north-central, and central Colorado. The June 20, 1936 and March 12, 1948 Texas earthquakes, along with the October 3, 1966 Trinidad quake influence the patterns shown in southeastern Colorado. The series of earthquakes during the 1960's affect contouring in the Denver area, while the November 11, 1913, September 9, 1944, August 3, 1955, and October 11, 1960 earthquakes generated the maximum historic intensities in the Ridgway-Montrose-Basalt-Lake City areas. Maximum historic intensities in southwestern Colorado reflect the January 23, 1966 Dulce earthquake and the January 5, 1976 and March 5, 1977 northwest New Mexico tremors. Other historic events provide the maximum experienced intensity in selected isolated areas.

Previous investigators have suggested a causal relationship between certain of the larger Colorado earthquakes and the Colorado lineament (Brill and Nuttli, 1983). Presently, no geologic structures that are part of the Colorado Lineament are known to be seismogenic. Although some of the larger Colorado earthquakes are spacially related to the inferred position of the Colorado Lineament, most are also near other known geologic structures. At this time, we know of no clearly defined relationships that prove or even strongly suggest the Colorado Lineament is seismogenic in Colorado.

4.3 Relationships between Earthquake Magnitude, Felt Area Size, and Maximum Intensity

Table 2 lists the date, location, magnitude, felt area size, and maximum reported intensity of earthquakes felt in Colorado. Table 3 presents similar information for earthquakes centered in other parts of the Rocky Mountain region. Four events occurring in the Texas Panhandle, west Texas, or western Nebraska have been included in this data set. These data are utilized to prepare a series of graphs that demonstrate relationships between magnitude (mb and ML) and felt area size or maximum intensity.

Figures 52 and 53 are graphs that plot magnitude (mb or ML) versus felt area size for all Rocky Mountain earthquakes. Note that the surface wave magnitude for the 1983 Borah Peak earthquake is included with the ML data. Relationships between magnitude and intensity are shown in Figures 54 and 55, while the graph on Figure 56 illustrates the relationship between maximum reported intensity and felt area size.

Regression analyses were performed to define the relationship of local Richter magnitude (ML) or body-wave magnitude (mb) as a function of the log of the felt area size. Least squares regressions resulted in the following equations:

$$ML = 1.22 (\log_{10} \text{felt area}) - 0.68 \quad (1)$$
$$r^2 = 0.7379$$

$$mb = 0.44 (\log_{10} \text{felt area}) + 2.91 \quad (2)$$
$$r^2 = 0.2449$$

F-tests of the significance of the correlation coefficients were used to determine if these relations are significant and can thus be used to estimate earthquake magnitudes if the felt area size is known. Testing indicates that at a 95% confidence level a strong linear relationship exists between the log of the felt area size and Richter magnitude (ML), and a barely significant linear relationship exists between the log of felt area size and body-wave magnitude (mb). Thus equation 1 can be used with confidence to estimate the Richter magnitude of an earthquake if the size of the felt area is known, while equation 2 should be used with considerable caution.

4.4 Observations Related to Intensity Patterns and Reported Felt Effects

The most striking feature of the isoseismal and intensity maps included in this report is the unusual intensity pattern exhibited by many of the earthquakes centered in the northeast Denver area. Figures 23, 24, 27, 29, 34, 35, 37 and 38 illustrate these seemingly anomalous intensity patterns. The overall felt area and many of the isoseismal countour lines are elongated in narrow zones, both parallel and perpendicular to the mountain front. At first glance, one might infer that these patterns are biased by the population

Table 2. Data for earthquakes felt in Colorado.

DATE (UTC)	LOCATION	MAGNITUDE			INTENSITY	FELT AREA (sq. km)	DEPTH (km)
11/08/82	N CENT. COLORADO				VII	470,000	
11/08/82	N CENT. COLORADO				F	61,000	
09/09/03	BOULDER				IV	3,900	
11/11/13	RIDGWAY				VI	13,600	
12/29/20	NEW CASTLE				V	1,400	
02/18/25	WETMORE				IV	1,300	
06/20/36	BORGER, TX				V	87,000	
09/09/44	MONTROSE/BASALT				VI	19,000	
03/12/48	NW TEXAS				VI	123,000	
01/18/50	SOLDIER SUMMIT, UT				V	11,100	
10/07/52	ANTONITO				V	4,500	
01/20/54	SE WYOMING				V	6,700	
02/21/54	NW COLORADO				IV	8,100	
02/10/55	STEAMBOAT SPRINGS				VI	6,000	
08/03/55	LAKE CITY				VI	4,600	
11/28/55	ROCKY FORD				IV	1,500	
01/14/56	LAMAR				IV	9,900	
10/11/60	MONTROSE	5.5 mb			VI	39,000	49?
11/27/61	SOUTH PARK				IV	4,800	≤33
08/07/62	NE DENVER		2.5 ML		V	500	
08/30/62	N UTAH	5.7 mb			VII	170,000	
12/04/62	NE DENVER		3.2 ML		VI	12,000	≤33
12/05/62	NE DENVER		3.8 ML		VI	16,400	≤33
05/25/63	NE DENVER		3.5 ML		V	2,300	10
07/02/63	NE DENVER	4.6 mb	4.0 ML		V	8,300	≤33
02/16/65	NE DENVER	4.9 mb	3.0 ML		VI	700	5
09/14/65	NE DENVER	4.7 mb	3.6 ML		VI	2,700	5
09/29/65	NE DENVER	4.7 mb	3.5 ML		VI	3,700	5
11/21/65	NE DENVER	4.5 mb	3.8 ML		VI	6,900	5
01/05/66	NE DENVER	5.0 mb	3.4 ML		V	1,100	5
01/23/66	DULCE, NEW MEXICO	5.5 mb		5.1 mbLg	VII	27,000	3
09/24/66	N NEW MEXICO	3.8 mb	2.7 ML		IV	15,000	18
10/03/66	TRINIDAD	4.5 mb	4.6 ML		VI	45,000	10
11/14/66	NE DENVER	4.4 mb	3.5 ML		VI	3,900	5
04/10/67	NE DENVER	4.9 mb		4.3 mbLg	VI	16,000	5
04/27/67	NE DENVER	4.5 mb	3.8 ML		VI	3,800	5
08/09/67	NE DENVER	5.3 mb		4.9 mbLg	VII	50,000	5
11/27/67	NE DENVER	5.2 mb		4.6 mbLg	VI	56,000	5
03/18/71	CLARK	4.4 mb			V	1,700	10
08/08/71	NE DENVER	4.4 mb	3.8 ML		IV	3,000	5
11/29/72	NE DENVER		2.7 ML		IV	700	-
01/30/75	GRAND JUNCTION	4.4 mb	3.7 ML		V	5,000	5
01/05/76	NW NEW MEXICO	5.0 mb	4.6 ML		VI	115,000	25
03/05/77	NW NEW MEXICO	4.6 mb	4.2 ML		VI	51,000	22
09/30/77	NE UTAH	5.0 mb	5.1 ML		VI	20,000	5
01/06/79	DIVIDE		2.9 ML	3.3 mbLg	VI	11,200	5
04/02/81	NE DENVER	4.3 mb	3.8 ML		VI	6,500	9
11/02/81	CONIFER		2.8 ML		V	2,300	1
10/18/84	LARAMIE MTNS, WY	5.3 mb	5.5 ML	5.1 MS	VI	287,000	20-25
03/16/85	SALIDA		3.2 ML		V	2,200	

Table 3. Data for Rocky Mountain region earthquakes excluding those reported in Table 2.

DATE (UTC)	LOCATION	MAGNITUDE	INTENSITY	FELT AREA (sq. km)	DEPTH (km)
06/27/25	HELENA, MT	6 3/4 MOD. MAG*	VIII	803,000	
07/30/25	TX PANHANDLE	?	VI	518,000	
08/16/31	MT. LIVERMORE, TX	6.4 ML?	VIII	1,166,000	
03/12/34	KOSMO, UT	6.6 MOD. MAG	VIII	440,000	
07/30/34	CHADRON, NE	?	VI	60,000	
10/18/35	HELENA, MT	6 1/4 MOD. MAG	VIII	596,000	
10/31/35	HELENA, MT	6.0 MOD. MAG.	VIII	363,000	
08/17/59	HEBGEN LAKE, MT	7.7 ML 7.5 MS	X	1,550,000	
08/30/62	CACHE VALLEY, UT	5.7 ML	VII	168,000	
09/05/62	SALT LAKE CITY, UT	5.1 mb 5.2 ML	VI	23,000	
02/15/63	SW MT	4.5 mb	V	16,000	
07/07/63	CENTRAL UT	4.9 mb 4.4 ML	VI	41,000	
09/10/63	CENTRAL ID	4.9 mb 5.0 ML	VI	9,100	
09/11/63	SE AZ	4.1 mb	V	6,500	
12/20/63	HEBGEN LAKE, MT	4.3 mb	V	7,700	
08/22/64	EASTERN WY	4.5 mb	V	3,800	
10/21/64	HEBGEN LAKE, MT	5.8 mb 5.2 ML ?	V	65,000	
01/06/65	SW MT	5.1 mb	VI	31,000	
03/07/66	W CENTRAL MT	4.8 mb	V	32,000	
03/17/66	NE UT	4.4 mb 4.6 ML	V	15,500	
10/04/67	MARYSVILLE, UT	5.2 mb 5.2 ML	VII	39,000	5
04/01/69	NW MT	4.7 mb 4.3 ML	VII	26,000	
04/26/69	WESTERN ID	4.9 mb 4.8 ML	VI	23,000	
04/30/69	NW MT	3.9 mb 3.8 ML	V	7,800	
06/09/69	NW MT	4.2 mb 4.2 ML	V	9,100	
09/14/69	NW MT	4.3 mb 4.1 ML	VI	5,200	
01/12/70	AMISTAD, NM	3.5 mb 3.3 ML	VI	9,600	
10/18/70	WESTERN MT	4.3 mb	V	9,100	
11/28/70	ALBUQUERQUE, NM	4.5 mb 3.8 ML	VI	3,100	
01/04/71	ALBUQUERQUE, NM	4.7 mb 3.5 ML	VI	1,600	
01/11/71	SW MT	3.6 mb	V	6,500	
07/28/71	NW MT	4.9 mb 4.4 ML	V	12,400	
03/06/72	NORTHERN UT	4.6 mb 3.2 ML	V	2,600	
06/02/72	CENTRAL UT	4.6 mb 4.0 ML	V	1,800	
10/01/72	SALT LAKE CITY, UT	4.7 mb 4.3 ML	VI	6,500	
11/02/72	CENTRAL MT	4.2 mb 4.5 ML	V	3,100	
02/15/74	TX PANHANDLE	4.5 mb 4.6 mbLg	V	37,000	
02/04/75	NW MT	4.6 mb 5.0 ML	VI	50,000	8
03/28/75	ID-UT BORDER	6.1 mb 6.1 ML 6.0 MS	VIII	160,000	5
06/30/75	YELLOWSTONE NP, WY	5.6 mb 6.4 ML	VII	50,000	7
02/04/76	CENTRAL AZ	4.9 mb 5.1 ML	VI	25,000	12
10/19/76	YELLOWSTONE NP, WY	5.3 mb 4.0 ML	IV	3,000	4
11/27/77	WESTERN ID	4.2 mb 4.5 ML	VI	24,000	5
04/23/78	WESTERN MT	4.5 mb 4.9 ML	V	94,000	5
06/16/78	WESTERN TX	4.4 mb 5.3 ML 4.6 mbLg	V	52,000	10
10/29/78	CENTRAL ID	4.2 mb 5.0 ML	V	25,000	5
11/30/78	SE ID	4.6 mb 4.7 ML	V	18,000	4
10/14/82	SE ID	4.6 mb 4.7 ML	VI	13,500	7
10/28/83	BORAH PEAK, ID	6.2 mb 7.3 MS	VII	855,000	10
05/29/84	GILLETTE, WY	5.0 mb	V	56,000	18
09/08/84	GILLETTE, WY	5.1 mb	V	68,000	20

*Modified Magnitude from Gutenberg and Richter (1954)

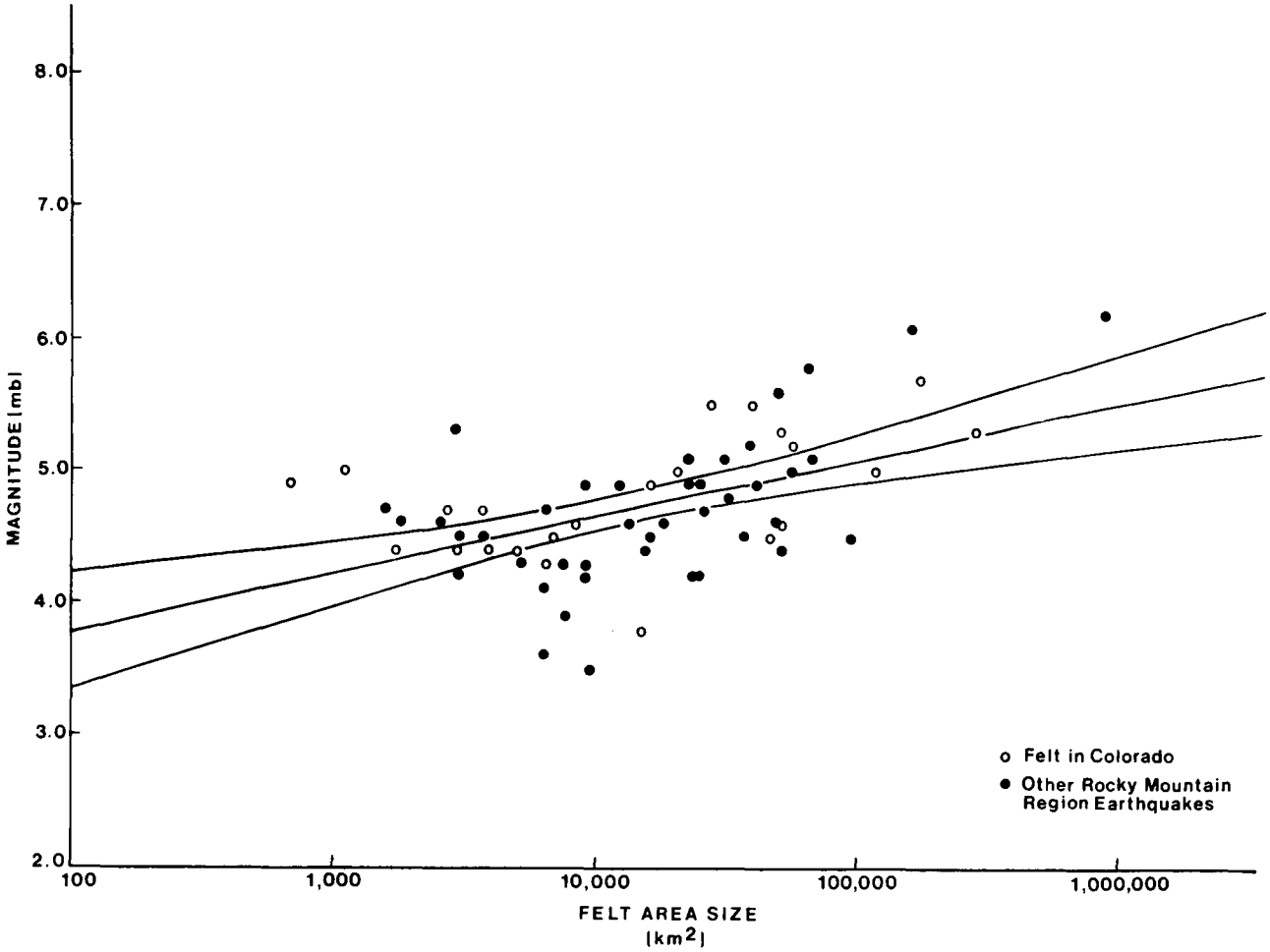

Figure 52. Magnitude (mb) versus felt area size for all Rocky Mountain region earthquakes.

distribution or localities that reported the earthquake. This, however, does not appear to be the case. The unusual patterns are clearly delineated by the scattered felt reports, and "not felt" reports often separate the narrow zones of felt reports.

Some of the anomalous felt reports for these earthquakes may be explained by soil-bedrock interaction effects. A series of valleys filled with unconsolidated alluvial and glacial deposits drain the uplifted Front Range. These valleys extend eastward from the Continental Divide, and many small towns are situated within the valleys. Many of the mountain towns lie on relatively thin layers of surficial deposits that rest on competent igneous and metamorphic bedrock. Seismic energy is efficiently transmitted through the bedrock and may be amplified by the often water-saturated unconsolidated deposits. Similar effects may explain the distant felt reports along the Colorado River during the larger northeast Denver earthquakes.

Another possible explanation for part of the observed effects may relate to focusing and wave guide factors associated with major structural trends in the region. The east flank of the Front Range forms a major inhomogeniety in the

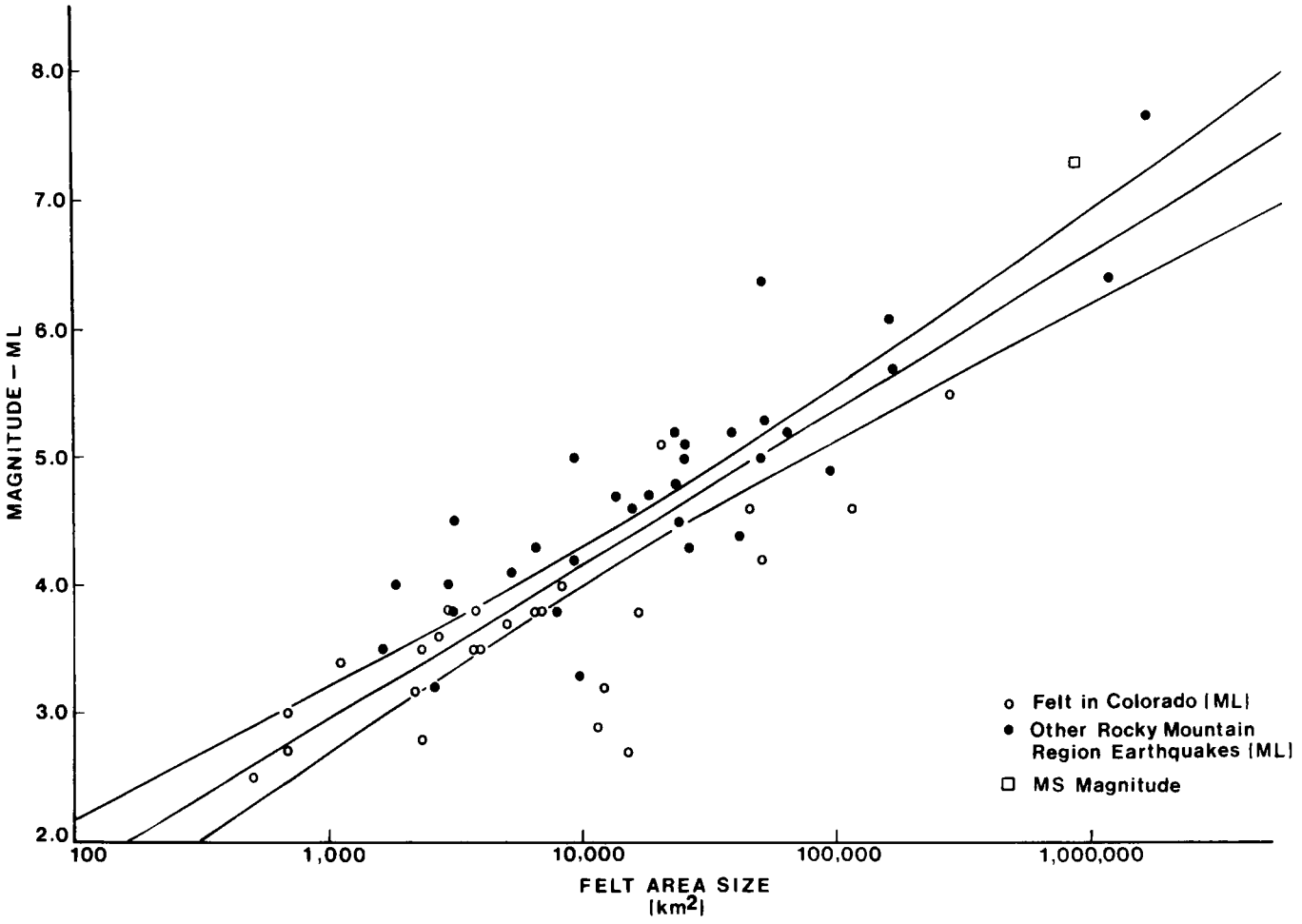

Figure 53. Magnitude (ML) versus felt area size for all Rocky Mountain region earthquakes. Note that the surface wave magnitude for the 1983 Borah Peak earthquake is included in this graph.

shallow crust. Within the Front Range faulting, shearing, mineralized zones and igneous dikes trend generally northeast and northwest. The orientation of the anomalous intensity patterns is coincident with both of these structural trends.

Many of the northeast Denver tremors have felt areas that are strikingly asymmetrical. The felt effects are reported for greater distances westward than eastward. These earthquakes occurred at relatively shallow depths within a major sedimentary basin filled with thousand's of meters of relatively soft sedimentary rocks. These soft rocks, especially the over 1,000 m thick Pierre Shale, tend to absorb seismic energy and affect attenuation rates. The northeast Denver earthquakes centered near the western margin of this sedimentary basin. Seismic energy had to travel only a short distance westward before entering competent igneous and metamorphic rocks that transmit vibrational energy more efficiently. To the east, however, lies a continuous sedimentary cover for hundreds of kilometers. This phenomena may also help to explain the limited number of felt reports east of the Front Range Urban corridor for the November 8, 1882 earthquake.

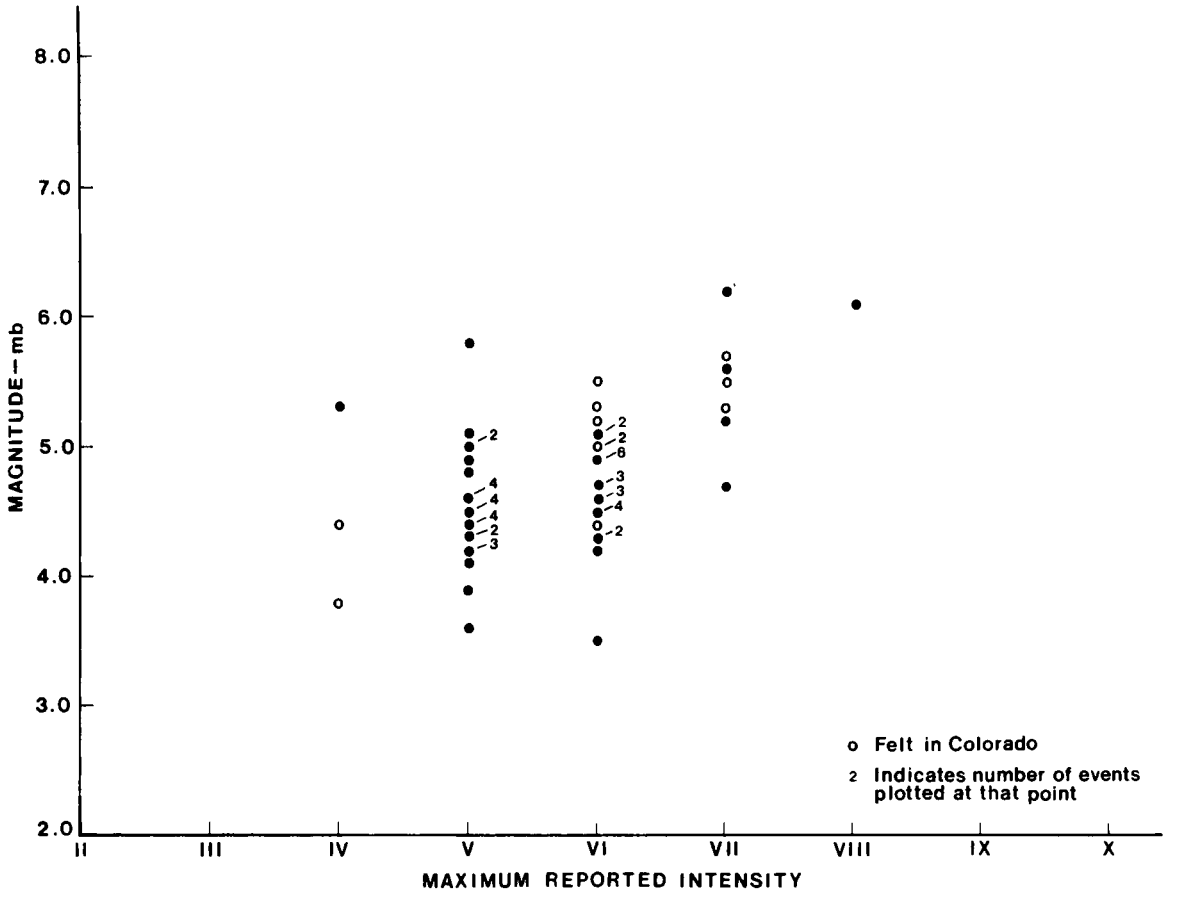

Figure 54. Magnitude (mb) versus maximum reported intensity for all Rocky Mountain region earthquakes.

The Grand Junction area appears to be unusually sensitive to earthquakes. This relationship is perhaps best illustrated by the September 30, 1977 earthquake that occurred north of Duchesne, Utah. The strongest intensities for this magnitude 5.1 ML earthquake were reported in the Grand Junction area over 100 km from the epicenter (Figure 45). A similar situation developed for the January 18, 1950 tremor (Figure 10). The felt areas of many of the larger regional earthquakes have extensions that reach out to include the Grand Junction area (Figures 18 and 21). In other cases the reports from the Grand Junction region form an isolated felt area that lies outside the main felt area (Figures 8 and 49). Another example of this phenomenon is provided by the Rio Blanco nuclear explosion on May 17, 1973. The blast was felt more strongly in Grand Junction than in other towns nearer to the blast site.

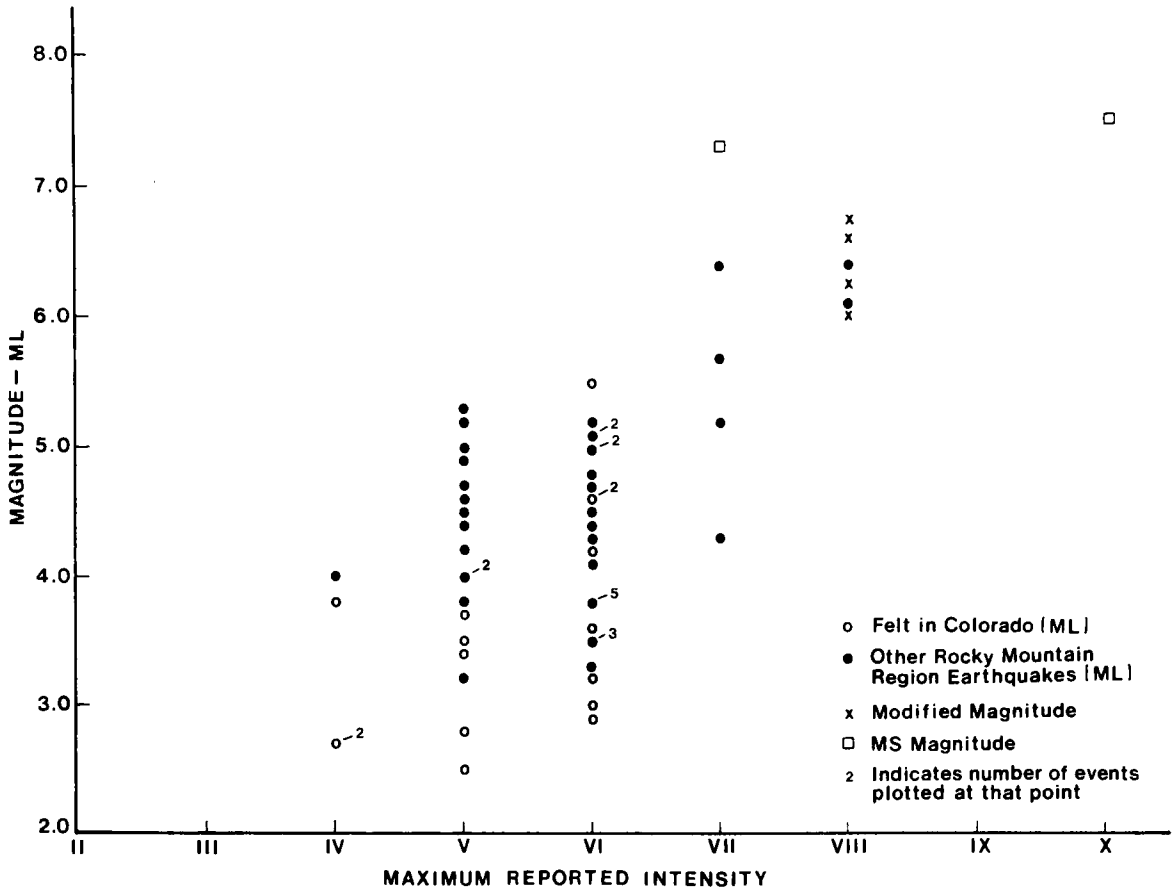

Figure 55. Magnitude (ML) versus maximum reported intensity for all Rocky Mountain region earthquakes.

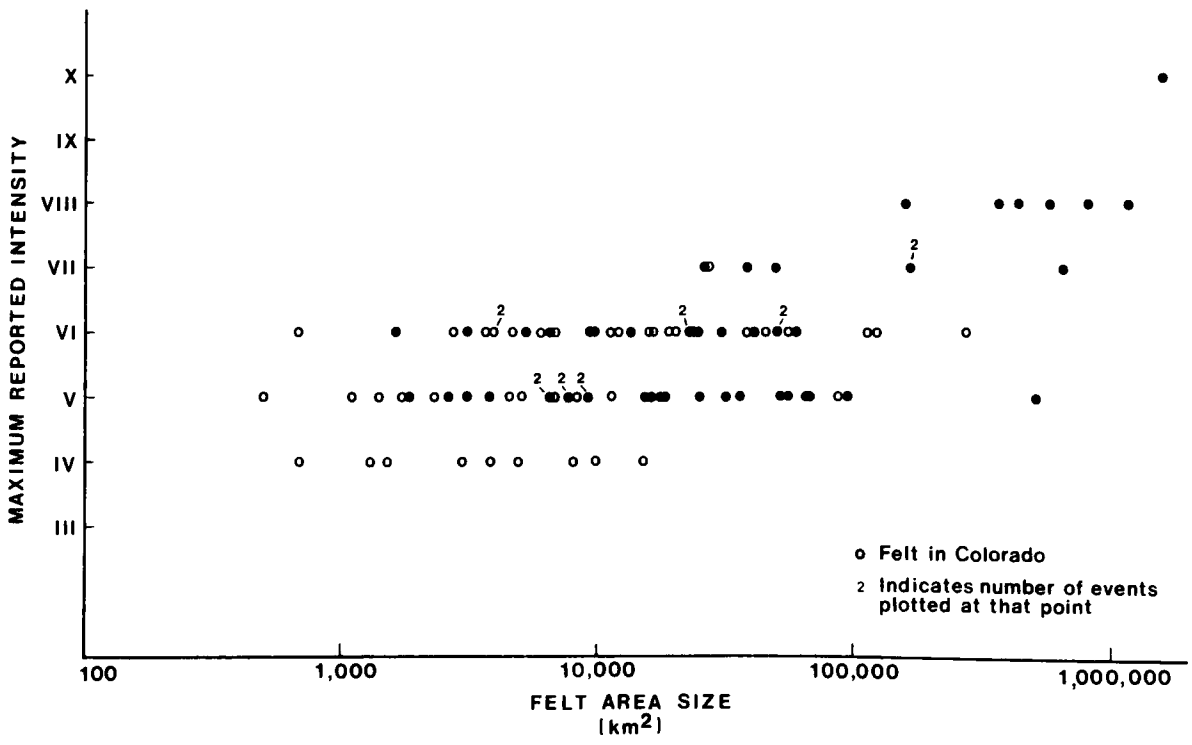

Figure 56. Maximum reported intensity versus felt area size for all Rocky Mountain region earthquakes.

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6.0 SUPPLEMENTAL REFERENCES

These supplemental references became available while the report was being edited and have been added to this report because of their relevance.

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B. Butler, D., and Nicholl, J.J., 1985b, Seismicity of the Conifer, Colorado earthquake, in Geologic and seismotectonic investigations-central Front Range, Colorado: Denver Water Department, Third Interim Report, Report O, 15 p.

C. Nicholl, J.J., and Butler, D., 1985, Front Range seismicity study, progress report, February, 1983-May, 1985, in Geologic and seismotectonic investigations-central Front Range, Colorado: Denver Water Department, Third Interim Report, Report L, 112 p.

APPENDIX A

MODIFIED MERCALLI INTENSITY SCALE OF 1931

I. Not felt-or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway -- doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few -- slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows -- in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang -- church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks in chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some

windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all -- general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general -- alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly -- branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipelines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipelines buried in earth completely out of service.

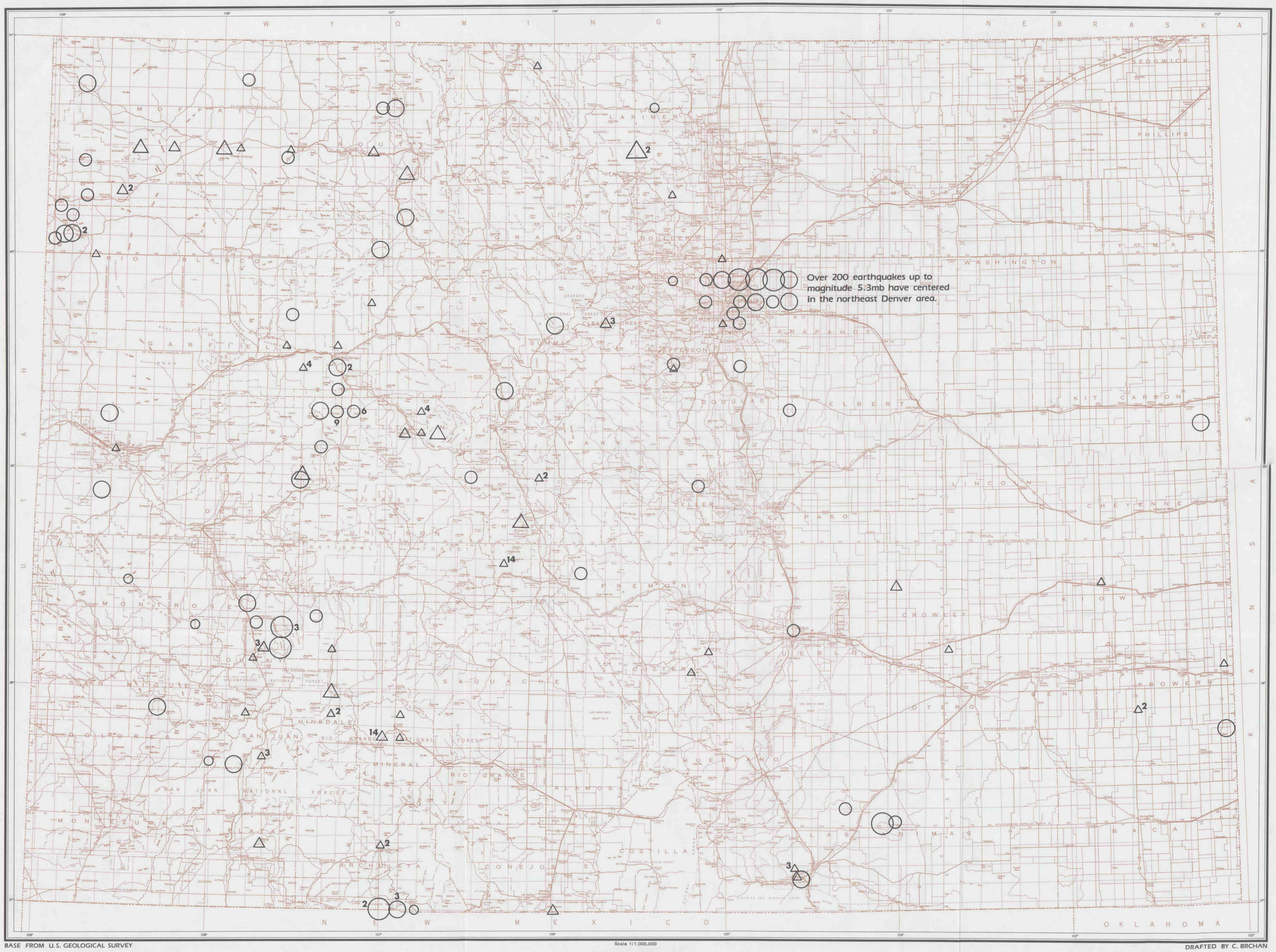
XII. Damage total -- practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
JOHN W. ROLD, DIRECTOR

COLORADO SEISMICITY MAP

by Robert M. Kirkham and William P. Rogers

BULLETIN 46
PLATE 1
1985



Explanation

The earthquakes plotted on this map are listed in Table 1. Instrumentally located events are indicated by the open circles. When available, ML magnitudes are used as the preferred magnitude value. Felt earthquakes with no magnitude determinations are indicated by the open triangles which are plotted at the coordinates assigned for the epicenter by the original or primary reference. The size of the circle or triangle reflects the size of the earthquake and is defined by the following:

INSTRUMENTALLY LOCATED EARTHQUAKES

- magnitude 4.6 to 5.5
- magnitude 3.6 to 4.5
- magnitude 2.6 to 3.5
- magnitude 2.5 or less

FELT EARTHQUAKES

- intensity VII
- intensity VI
- intensity V
- intensity IV or less

The number next to some circles or triangles indicates the number of events that plot at that location. Refer to the text for complete descriptions of these earthquakes.

BASE FROM U.S. GEOLOGICAL SURVEY

Scale 1:1,000,000

Lambert conformal conic projection based on standard parallels 33° and 45°

DRAFTED BY C. BRCHAN

APPENDIX B

LIST OF EARTHQUAKES WITH RICHTER LOCAL MAGNITUDE 2.5 OR GREATER RECORDED BY THE DENVER WATER DEPARTMENT'S FRONT RANGE SEISMIC NETWORK FROM FEBRUARY, 1983 TO MAY, 1985. (NICHOLL AND BUTLER, 1985)

Date (UTC)	Hour & Minute	Latitude	Longitude	Depth (km)	Magnitude (ML)
Sept. 15, 1983	15:44	39°46'25.8"	105°41'33.6"	11.0	2.5
June 1, 1984	16:34	38°55'18.6"	104°56'51.6"	11.1	2.6
June 30, 1984	07:40	39°00'15.0"	105°16'30.6"	8.4	2.6
July 30, 1984	22:18	39°49'04.2"	105°04'18.6"	11.1	3.1

Numerous other microearthquakes were recorded during this investigation. Please refer to the original report for data on the date, time, location, depth, and magnitude of these other events.