Bulletin 52

COLORADO EARTHQUAKE INFORMATION, 1867-1996

By Robert M. Kirkham and William P. Rogers

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Greg E. Walcher, Director, Department of Natural Resources
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Colorado Geological Survey
Denver, Colorado

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado 2000

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Colorado seismicity map
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ABSTRACT

Colorado Geological Survey Bulletin 52 is an updated and revised version of our original Bulletin 46, which was published in 1985. Colorado is an area of moderate to low seismicity. This report contains data on about 500 earthquakes that have been felt or instrumentally located in Colorado since 1867. Information on the date, location, time, magnitude, depth, intensity, felt effects, and pertinent references for these earthquakes is included in this report. An isoseismal or intensity map is available for most of the larger events. The strongest historical earthquake centered in Colorado occurred in 1882. It probably had a Richter local magnitude (ML) of around 6 1/2. Most recently published studies, but not all, place the 1882 earthquake in the northern Front Range or southern Laramie Mountains.

Although no major structural damage 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 a number of Colorado's earthquakes.

Isoseismal or intensity maps for most of the larger earthquakes are presented in this report. Observations and interpretations based on these maps and the historic seismicity are presented regarding seismicity patterns. 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 to felt area size and maximum intensity for the larger Rocky Mountain region earthquakes through 1996 are presented. Also included are equations that relate the size of the felt area to the magnitude of these earthquakes.

Detection thresholds have lowered and seismicity has been more accurately located in parts of Colorado subsequent to release of our original Bulletin 46. This has resulted from better seismographic coverage of the area, improved location techniques, and cooperative work by governmental agencies and private consultants. Three regional networks have operated in Colorado by the Denver Water Department, U.S. Bureau of

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Reclamation, and U.S. Geological Survey during the past eleven years; they are largely responsible for the improved seismographic data.

Regional monitoring of the central and southern Front Range by the Denver Water Department indicates seismicity is distributed in clusters and diffuse patterns across much of that region. Fewer earthquakes were recorded north of Clear Creek than in other parts of the Denver Water Department's network. Seismicity rates along the boundary between the Rocky Mountains and Great Plains may be somewhat higher than in other areas monitored by the Front Range network. Clusters of earthquakes may be associated with some Neogene faults within and adjacent to the central and southern Front Range.

In western Colorado seismicity continues to occur along the boundary between the Colorado Plateau and Rocky Mountains and persistent seismic activity continues in the vicinity of Cimarron Ridge. Swarms of earthquakes near Carbondale and Crested Butte were in part monitored by portable seismic arrays, providing some of the most precise data available for Colorado earthquakes.

INTRODUCTION

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This report is an updated and revised version of Colorado Geological Survey (CGS) Bulletin 46, which recently went out-of-print. Earthquake data for the time period 1986 to 1996, along with additional references and two short sections, have been added to the original bulletin. Other sections within this updated report are mostly verbatim accounts of what was originally contained in Bulletin 46, with only minor changes. We hope that the release of this document in CD-ROM format will be valuable to many users.

Research work for the original CGS Bulletin 46 was supported in part by the U.S. Geological Survey (USGS) through Grant No. 14-08-0001-G975. Primary goals of that project included 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 were described in CGS Bulletin 46 and are updated herein. CGS Information Series 23 contained newspaper accounts, interviews, and government records for many historic Colorado earthquakes, which addressed Item 2. Item 4 was the subject of CGS Special Publication 28, which included a number of contributions by scientists with governmental agencies, industry, and academia. Preliminary determination of Colorado's seismic source zones, Item 5, has been accomplished, with the results available as in-house file information at CGS.

Research and compilation work for this updated report was funded in part by the Colorado Office of Emergency Management. A wealth of information further characterizing seismicity and Neogene tectonism in Colorado has been released since the CGS Bulletin 46 was published.

Both the original bulletin and this update have 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 publications by the USGS, work which now is under the auspice of the National Earthquake Information Center (NEIC), contain the bulk of the basic earthquake data. **Hadsell (1968)** conducted one of the earliest efforts to collect information on historical Colorado earthquakes. **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. **Bollinger and others (1983)** evaluated the 1981 earthquake sequence in northeast Denver.

Stover, Reagor, and Algermissen (1984) thoroughly searched the existing earthquake literature and developed an extensive earthquake listing. Their publication formed the basis for our earthquake list presented in Table 1 of the original Bulletin 46. 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. The controversial 1882 earthquake has been re-evaluated by **Kirkham and Rogers (1986)**, **Risk Engineering, Inc. (1994)**, and **Spence and others (1996)**. **Nicholl and Butler (1985)** reported on the initial microseismic monitoring of the central Front Range for the Denver Water Department. MicroGeophysics Corporation expanded seismographic coverage of the central Front Range for the Denver Water Department; this project, known as the Front Range Network, operated until 1993. Annual reports to the Denver Water Department describe the seismic records of the Front Range Network; summaries of this work are contained in **MicroGeophysics Corporation (1993; 1995)**.

The 1983 Cimarron earthquake was described by **Wong and Humphry (1986)**. **Butler and Nicholl (1985a, b)** described the Divide and Conifer earthquakes. **Goter and others (1986; 1988)** investigated the 1984 Carbondale earthquake swarm. Reports on the 1986 Crested Butte earthquake swarm have been published by **Wong (1991)**, **Bott and others (1993)**, and **Bott and Wong (1995)**. The U.S. Bureau of Reclamation has conducted seismotectonic investigations of a number of dams in Colorado. It also has operated regional seismic networks at Ridgway Dam and in Paradox Valley cooperatively with the USGS. Reports on the U.S. Bureau of Reclamation's studies include **Martin and Spence (1986)**, **Unruh and others (1992; 1993; 1994; 1996)**, **Ake and others (1994)**, **Vetter and others (1995)**, and **Lettis and others (1996)**. **Stover and Coffman (1993)** describe the larger historic Colorado earthquakes through 1989, while **Stover and Brewer (1994)** provide data on earthquakes occurring in 1986.

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, the section following **Table 1**, is used to rate all felt reports. A common practice in many USCGS and USGS publications was to include felt reports of MMI I to III in a single list usually described as "intensity III and under". Because of this, some 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 earthquake was not felt in that town (0) or was felt at the indicated intensity. The letter "F" indicates a felt report with no intensity assigned.

We would like to acknowledge the numerous individuals who contributed to our original study and this updated version. C.W. Stover, USGS, and J.L. Coffman and C.A. von Hake, National Oceanic and Atmospheric Administration (NOAA), provided data and answered many questions during our original study. J.W. Dewey, B.G. Reagor, M.G. Hopper, and W.K. Smith, USGS, contributed computer printouts of the NEIC database and an unpublished isoseismal map for the 1988 Utah earthquake and guided us through their files during the update project. Susan Steele Weir, Denver Water Department, kindly provided copies of several of their reports. Seismotectonic reports for several U.S. Bureau of Reclamation dams were furnished by J.P. Ake or I.G. Wong. Discussions with Mr. Wong and J.D.J. Bott, with Woodward-Clyde Federal Services, and J.J. Nicholl, Woodward-Clyde Consultants, Mr. Ake and U.R. Vetter, U.S. Bureau of Reclamation, and D. Butler, MicroGeophysics Corporation, were enlightening. W.A. Charlie, Colorado State University, contributed copies of several interesting original reports related to the 1882 and 1903 earthquakes. Mr. Wong, Mr. Charlie, D. Doehring with Colorado State University, and R. Battalora with Foster Wheeler Environmental Corporation gratiously reviewed all or parts of this manuscript.

Regression equations prepared for the original report were developed for us by Thomas Rogers and were reviewed by Susan Cannon. Felt reports for the January 1, 1894 Telluride earthquake were first brought to our attention by P. Carrara, USGS. Chris Avila, Brenda Richardson, and Betty Jones typed the original manuscript, while Annissa Olguin was responsible for most of the word processing for the updated version. Lois Kirkham assisted with report editing, drafting of the figures, and word processing. Cheryl Brchan drafted the plate and prepared both original and updated reports for publication. Randy Phillips led efforts to release this report as a CD-ROM, which was designed by Melissa Stajcar, Manzanita Graphics. We sincerely thank all of them.

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Table 1 lists all seismic events known to have occurred historically within Colorado along with several man-made explosions and coal bumps. 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 all known Colorado earthquakes through 1996. The earthquakes are listed chronologically based on the date and origin time in Universal Coordinated Time (UTC). The approximate geographic location of each earthquake epicenter or location of strongest felt effects is described. Latitude and longitude are reported as described in the references, but are rounded to two decimal places, unless the original reference reported the epicentral location with less precision. Earthquake depth is given in kilometers. Explosions and coal bumps are denoted in the reference column. Man-made events are not plotted on the seismicity map (**Plate 1**).

Magnitudes listed under the "USGS" heading in Table 1 are body-wave magnitudes (mb) 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, Berkeley, California.

EPB Catalog of Canadian earthquakes, 1568–1992, complied by the Earth Physics Branch of Canada, now known as the Geological Survey of Canada.

EWC Ely, R.W., Wong, I.G., and Chang, P., 1986, Neotectonics of the Uncompahgre Uplift, eastern Utah and western Colorado, *in* Rogers, W.P., and Kirkham, R.M., eds., Contributions to Colorado seismicity and tectonics-A 1986 update: Colorado Geological Survey Special Publication 28, p. 75–92.

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

GS National Earthquake Information Center (and fore-runner organizations), U.S. Geological Survey, Golden, Colorado.

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

HER Herrmann, 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.

KR Kirkham, R.M., and Rogers, W.P., 1986, An interpretation of the November 7, 1882 earthquake, in Rogers, W.P., and Kirkham, R.M., eds., Contributions to Colorado seismicity and tectonics-A 1986 update: Colorado Geological Survey Special Publication 28, p. 122-144.

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.

SLC University of Utah, Department of Geology and Geophysics, Seismograph Station, 705 W.C. Browning Building, Salt Lake City, Utah.

SP Spence W., Langer, C.J., and Choy, G.L., 1996, Rare, large earthquakes at the Laramide deformation front-Colorado (1882) and Wyoming (1984): Seismological Society of America Bulletin, v. 86, no. 6, p. 1804-1819.

TGG Unpublished data by James Taggart, U.S. Geological Survey, referenced in USGS-NEIC earthquake database.

TUL Oklahoma Geological Survey Observatory, P.O. Box 8, Leonard, Oklahoma.

UU University of Utah, Salt Lake City, Utah.

WCC Bott, J.D.J., and Wong, I.G., 1995, The 1986 Crested Butte earthquake swarm and its implications for seismogenesis in Colorado: Seismological Society of America Bulletin, v. 85, no. 6, p. 1495-1500.

Type codes follow the source code in Table 1 and are identified as follows: 1=ML, 2=mbLg or Mn, 3=mb, 4=duration of coda length, and 5=Mw. Listed intensities are the maximum Modified Mercalli Intensity reported for the earthquake.

"ML" is local magnitude defined by Richter, C.F., 1958, Elementary Seismology: San Francisco, W.H. Freeman and Co., Inc., 768 p. "mbLg" or "Mn" 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 Gutenberg, B., and Richter, C.F., 1956, Magnitude and energy of earthquakes: Annali di Geofisica, v. 9, no. 1, p. 1-15. "Mw" is a moment magnitude defined in Kanamori, H., 1977, The energy release in great earthquakes: Journal of Geophysical Research, v. 82, p. 2981-2987.

Table 1. Colorado earthquakes from 1870 to 1996.

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		1	1870	DEC.	4	12:00:00	PUEBLO-FT. REYNOLDS	38.5	104.0				VI	35,45,90
M		2	1871	OCT.			LILY PARK-MOFFAT CO.	40.5	108.5				VI	41,83,105
M		3	1871	NOV.	9	17:15:00	GEORGETOWN	39.7	105.7				V	45,83,90
M		4	1880	SEP.	17	07:00	ASPEN	39.2	106.7				VI	45,83,90
M		5	1881				GEORGETOWN	39.7	105.7				V	83
M		6	1882	FEB.	12	08:30	PAGOSA SPRINGS	37.3	107.0				F	91,112
M		7	1882	MAY	12	03:00	PAGOSA SPRINGS	37.3	107.0				III	91,112
M		8	1882	NOV.	8	01:30	NORTH-CENTRAL COLO.	40.5	105.5			6.6 SP-5	VII	31,34,45,54,56, 83,89,98,105
M	T	9	1882	NOV.	8	11:45	NORTH-CENTRAL COLO.	40.5	105.5				F	34,54,56,83,89,98
M		10	1882	NOV.	23	07:30	SILVERTON	37.7	107.7				IV	45
M		11	1886	JUL.			CIMARRON	38.2	107.3				F	45,90
M		12	1888	OCT.	23	18:40	WET MOUNTAINS	38.1	105.2				IV	45,90
M		13	1889	JAN.	15		GLENWOOD SPRINGS	39.5	107.3				V	45,83,90,105
M		14	1891	DEC.			AXIAL BASIN	40.5	108.0				VI	45,83,90,105
M		15	1894	JAN.	1	10:00	TELLURIDE	37.9	107.8				IV	54,83
M		16	1894	AUG.	5	12:00	GEORGETOWN	39.7	105.7				V	45,83,90
M		17	1895	MAR.	22	20:00	STEAMBOAT SPRINGS	40.5	107.1				V	31,45,56
M		18	1897	AUG.	3	07:00	RIDGWAY	38.2	107.8				V	83
M		19	1899			02:30	LAY	40.5	107.9				IV	41,83,90
M		20	1901	NOV.	15	10:00	BUENA VISTA	38.8	106.2				VI	45,83
M		21	1901	DEC.	29	07:00	DENVER	39.7	105.0				IV	83
M		22	1903	SEP.	9	07:55	ESTES PARK	40.3	105.4				V	35,112,134
M		23	1906	APR.			MAYBELL	40.5	108.3				V	83
M		24	1906	DEC.	21	16:10	NEW CASTLE	39.6	107.6				III	88,112,134
M	T	25	1913	NOV.	11	21:55	RIDGWAY AREA	38.1	107.7				VI	31,83,88,112
M	T	26	1913	NOV.	11	22:18	RIDGWAY AREA	38.1	107.7				F	31,88,112
M	T	27	1913	NOV.	11	23:45	RIDGWAY AREA	38.1	107.7				F	31,88,112
M		28	1915	FEB.	28	07:51	GRAND JUNCTION	39.1	108.6				III	45,52,112
M		29	1916	OCT.	12	05:41	BOULDER	40.1	105.6				IV	35,45,52,112
M	T	30	1920	DEC.	29	02:50	NEW CASTLE	39.5	107.5				V	52,83
M	T	31	1920	DEC.	29	03:00	NEW CASTLE	39.5	107.5				IV	52,83,112
M		32	1920	DEC.	30	09:50	NEW CASTLE	39.5	107.5				V	52

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		33	1920	DEC.	30	17:50	NEW CASTLE	39.5	107.5				V	52
M		34	1921	FEB.	6	06:15	ST. ELMO	38.6	106.3				IV	52,112
M		35	1921	FEB.	6	06:25	GARFIELD	38.6	106.3				IV	52,112
M		36	1921	FEB.	6	06:30	ST. ELMO	38.6	106.3				IV	52,112
M		37	1921	FEB.	17	01:45	GARFIELD	38.6	106.3				III	52
M		38	1921	FEB.	17	13:05	GARFIELD	38.6	106.3				III	52
M		39	1921	FEB.	26	15:55	GARFIELD	38.6	106.3				III	52
M		40	1921	FEB.	27	17:00	GARFIELD	38.6	106.3				III	52
M		41	1921	MAR.	4	06:00	GARFIELD	38.6	106.3				II	52
M		42	1921	MAR.	8	19:15	GARFIELD	38.6	106.3				IV	52
M		43	1921	MAR.	9	01:25	GARFIELD	38.6	106.3				III	52
M		44	1921	MAR.	12	07:00	GARFIELD	38.6	106.3				II	52
M		45	1921	MAR.	22	21:45	GARFIELD	38.6	106.3				III	52
M		46	1921	JUL.	27	21:30	GARFIELD	38.6	106.3				III	52,112
M		47	1921	JUL.	29	02:55	GARFIELD	38.6	106.3				III	52,112
M		48	1921	OCT.	15	02:55	EADS	38.5	102.8				III	35,52
M		49	1923	JAN.	27	08:04	DENVER	39.7	105.0				F	53,112
M		50	1924	JAN.	4	21:56:30	DENVER	39.7	105.0				F	53,112
M		51	1924	SUMMER			CRAIG	40.5	107.6				III	41,83
M	T	52	1925	FEB.	18	20:00	WETMORE	38.2	105.1				IV	35,112,120
M		53	1928	APR.	20	09:40	CREEDE	37.8	107.0				IV	46,112
M		54	1928	APR.	24	10:00	CREEDE	37.8	107.0				IV	46,112
M		55	1928	APR.	29	10:00	CREEDE	37.8	107.0				IV	46,112
M		56	1928	APR.	29	10:20	CREEDE	37.8	107.0				IV	46,112
M		57	1928	APR.	29	10:45	CREEDE	37.8	107.0				IV	46,112
M		58	1928	APR.	29	16:00	CREEDE	37.8	107.0				IV	46,112
M		59	1928	APR.	30	15:50	CREEDE	37.8	107.0				V	46,112
M		60	1928	MAY	1	09:22	CREEDE	37.8	107.0				IV	46,112
M		61	1928	MAY	1	09:25	CREEDE	37.8	107.0				IV	46,112
M		62	1928	MAY	1	09:35	CREEDE	37.8	107.0				IV	46,112
M		63	1928	MAY	1	12:20	CREEDE	37.8	107.0				IV	46,112
M		64	1928	MAY	3	19:40	CREEDE	37.8	107.0				IV	46,112
M		65	1928	MAY	4	10:00	CREEDE	37.8	107.0				IV	46,112

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		66	1928	MAY	10	10:10	CREEDE	37.8	107.0				V	46,112
M		67	1928	SEP.	29	07:17	HOLLY	38.1	102.1				IV	46,112
M		68	1940	APR.	8	17:00	ASPEN	39.3	106.8				III	77,83,112
M		69	1941	FEB.	13	11:32:30	ASPEN	39.3	106.8				IV	45,78,83,112
M		70	1941	FEB.	21	21:22	ASPEN	39.3	106.8				IV	45,78,83,112
M		71	1941	FEB.	28	06:19	ASPEN	39.3	106.8				IV	45,78,83,112
M		72	1941	AUG.	29	11:34	DURANGO/BAYFIELD	37.3	107.7				V	45
M		73	1942	JUL.	23	07:40	WESTERN MOFFAT CO.	40.3	108.6				V	83
M		74	1942	AUG.			WESTERN MOFFAT CO.	40.3	108.6	May be same event as above			IV	83,112
M	T	75	1944	SEP.	9	04:12:20	MONTROSE/BASALT	39.0	107.5				VI	31,83,105,112,121
M		76	1944	OCT.	5	14:05	ASPEN	39.2	106.8				IV	4,112,119
M		77	1945	APR.	29	17:08	SILVERTON	37.7	107.7				IV	5,112,119
M		78	1945	APR.	29	17:32	SILVERTON	37.7	107.7				III	5,112,119
M		79	1946	JAN.	13	22:45	GLENWOOD SPRINGS	39.6	107.3				IV	6,112,119
M		80	1946	APR.	3	02:05	RILAND	39.8	107.1				IV	6,112,119
M		81	1948	OCT.	3	04:30	WALDEN	40.9	106.1				IV	72,112,119
M	T	82	1952	OCT.	7	09:20	ANTONITO	37.0	106.0				V	31,69
M	T	83	1954	FEB.	21	20:20:51	RANGELY/GRAND JCT.	40.0	108.8			4.7 EPB-1	IV	70,113,123
M	T	84	1955	FEB.	10	17:30	STEAMBOAT SPRINGS	40.4	106.9			4.3 EPB-1	VI	31,45,83,113,123
M	T	85	1955	AUG.	3	06:35	LAKE CITY	37.9	107.3				IV	71,112
M	T	86	1955	AUG.	3	06:37	LAKE CITY	37.9	107.3				F	71,112
M	T	87	1955	AUG.	3	06:39:42	LAKE CITY	38.0	107.3				VI	45,71
M	T	88	1955	NOV.	28	05:25:13	FOWLER/SUGAR CITY	38.2	103.7				IV	35,45,71
M	T	89	1956	JAN.	14	18:40	LAMAR	37.9	102.6				III	11,35,45
M	T	90	1956	JAN.	14	18:49	LAMAR	37.9	102.6				IV	11,35,45
M		91	1957	MAY	3	08:30	CREEDE AREA	37.8	106.9				III	12,112
M	T	92	1960	OCT.	11	08:05:30.5	MONTROSE/RIDGWAY	38.29	107.70	12		5.5 BRK-3	VI	31,112,118,125,137
M		93	1960	OCT.	12	00:30	MONTROSE/RIDGWAY	38.3	107.6				IV	112,118
M		94	1960	OCT.	17	16:00	ASPEN	39.2	106.9				V	31,118
M	T	95	1961	NOV.	27	00:55:45.7	SOUTH PARK	39.0	106.1	≤33			IV	59,121
M	T	96	1961	NOV.	27	01:05	SOUTH PARK	39.0	106.1				III	59,112
M		97	1962	JAN.	13	13:33	MONTROSE	38.4	107.8			4.4 GOL-1	IV	45,60
M		98	1962	JAN.	18	01:28	N.E. OF DENVER	39.9	104.9				IV	35

Table 1. (continued)

	ID	YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M	99	1962	JAN.	18	01:36	N.E. OF DENVER	39.9	104.9				IV	35
M	100	1962	FEB.	5	14:45:51.1	RIDGWAY/MONTROSE	38.2	107.6	25		4.7 GOL-1	V	60,105,121
M	101	1962	MAR.	5	04:23:06.7	ASPEN	39.2	106.8	25		3.0 UU-?		60
M	102	1962	MAR.	17	09:14:04.4	RIDGWAY AREA	38.3	108.1	≤33				60,112,121
M	103	1962	JUN.	18	00:46:05.0	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	V	45,112
M	104	1962	JUN.	18	01:36:06.7	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M	105	1962	JUN.	19	04:48:54.3	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	V	60,112
M	106	1962	JUN.	24	17:11:04.0	UNCOMPAHGRE PLATEAU	38.5	108.5	≤33				60
M	107	1962	JUN.	24		N.E. OF DENVER	39.9	104.9				IV	60,112
M T	108	**1962**	**AUG.**	**7**	00:51:00.2	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	V	60,112
M T	109	**1962**	**AUG.**	**7**	01:22:09.7	N.E. OF DENVER	39.9	104.9			1.8 GOL-1	III	60,112
M T	110	**1962**	**AUG.**	**7**	01:40:30.4	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	60,112
M T	111	**1962**	**AUG.**	**7**	04:00	N.E. OF DENVER	39.9	104.9				IV	60,112
M	112	1962	AUG.	16	02:03:17.7	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M	113	1962	AUG.	16	06:55	N.E. OF DENVER	39.9	104.9				III	60,112
M	114	1962	OCT.	8	16:26:12.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M	115	1962	OCT.	8	20:45:12.9	N.E. OF DENVER	39.9	104.9			4.0 GOL-1	F	62,112
M T	116	**1962**	**DEC.**	**4**	17:49:59.4	N.E. OF DENVER	39.8	104.7	≤33		3.2 GOL-1	VI	60,105,121
M T	117	**1962**	**DEC.**	**5**	06:26:49.9	N.E. OF DENVER	39.8	104.9			1.9 GOL-1	IV	60,112
M T	118	**1962**	**DEC.**	**5**	13:48:07.1	N.E. OF DENVER	39.9	104.6	≤33		3.8 GOL-1	VI	60,112,105,121
M	119	1962	DEC.	6	00:20	N.E. OF DENVER	39.9	104.9				F	60,112
M	120	1962	DEC.	6	00:25	N.E. OF DENVER	39.9	104.9				F	60,112
M	121	1962	DEC.	16		N.E. OF DENVER	39.9	104.9				IV	35,112
M	122	1963	JAN.	3	22:00	N.E. OF DENVER	39.9	104.9				II	35,112
M	123	1963	JAN.	25	22:22	N.E. OF DENVER	39.9	104.9				II	35,112
M	124	1963	JAN.	26	00:22:46.0	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	62,112
M	125	1963	JAN.	30	23:05:09.6	N.E. OF DENVER	39.8	104.6	≤33		3.2 GOL-1	IV	45,121
M	126	1963	JAN.	30	23:10	N.E. OF DENVER	39.9	104.9				III	35,112
M	127	1963	JAN.	30	23:11	N.E. OF DENVER	39.9	104.9				III	35,112
M	128	1963	FEB.	25		N.E. OF DENVER	39.9	104.9				III	35,112
M	129	1963	FEB.	25	15:24:01.0	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	62,112
M	130	1963	FEB.	26		N.E. OF DENVER	39.9	104.9				III	35,112
M	131	1963	MAR.	15	16:59:44.0	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	62,112

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		132	1963	MAR.	26	23:51:14.3	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M		133	1963	APR.	4	02:04:59.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		134	1963	APR.	4	02:19:59.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	62,112
M		135	1963	APR.	4	07:48:08.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	62,112
M		136	1963	APR.	7	08:12	N.E. OF DENVER	39.9	104.9				F	30,112
M		137	1963	APR.	8	00:03:57.1	N.E. OF DENVER	39.9	104.8	20		3.4 GOL-1	V	45,122
M		138	1963	APR.	24	22:29:34.4	N.E. OF DENVER	39.8	104.7	20	4.1	3.4 GOL-1	IV	45,121
M	T	139	**1963**	**MAY**	**25**	10:44:36.7	N.E. OF DENVER	39.8	104.7	10		3.5 GOL-1	V	22,121
M		140	1963	JUN.	5	00:13:56.6	N.E. OF DENVER	39.77	104.75	4.4		3.0 GOL-1	III	22,100,112
M	T	141	**1963**	**JUL.**	**2**	08:02:56.3	N.E. OF DENVER	39.8	104.6	≤ 33	4.6	4.0 GOL-1	V	22,121
M		142	1963	JUL.	28	13:18:45.9	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	II	45,62,112
M		143	1963	SEP.	29	09:54:08.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		144	1963	NOV.	13	21:34	PUEBLO	38.3	104.6			2.8 GOL-1	IV	45
M		145	1964	FEB.	9	09:19:59.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		146	1964	MAR.	27	07:08:08.8	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M		147	1964	APR.	10	17:39:36.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		148	1964	MAY	23	21:44:59.1	BLAST AT CLIMAX	39.37	106.17					121
M		149	1964	AUG.	4	11:13:25.2	DILLON	39.7	106.0	≤33	4.0			122
M		150	1964	OCT.	17	14:35:39.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		151	1964	OCT.	17	22:02:48.0	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M		152	1964	DEC.	4	21:27:06.3	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	62,112
M		153	1965	JAN.	5	23:26	ROCKY FLATS	39.9	105.3			2.0 GOL-1	III	45
M	T	154	**1965**	**FEB.**	**16**	19:52:21.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	IV	112,129
M	T	155	**1965**	**FEB.**	**16**	20:17:53.5	N. OF DENVER	39.9	105.1	5	4.6	3.1 GOL-1	IV	121,129
M	T	156	**1965**	**FEB.**	**16**	22:21:43.7	N. OF DENVER	39.9	105.0	5	4.9	3.0 GOL-1	VI	105,122,129
M		157	1965	FEB.	18	11:38:52.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		158	1965	MAR.	25	20:23:55.5	N.E. OF DENVER	39.8	104.9			2.6 GOL-1	II	45,62,112
M		159	1965	APR.	16	17:25	N.E. OF DENVER	39.8	104.9			2.7 GOL-1	V	45,62,112
M		160	1965	MAY	18	23:47:55.8	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		161	1965	MAY	30	17:31:04.1	TENNESSEE PASS	39.4	106.3	≤33	4.3			122
M		162	1965	JUN.	14	09:24:43.9	N.E. OF DENVER	39.8	104.9			3.0 GOL-1	IV	45,62,112
M		163	1965	JUN.	29	13:14:49.3	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M		164	1965	JUL.	18	21:07:28.0	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		165	1965	JUL.	18	21:13:27.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	112,129
M		166	1965	JUL.	18	21:19:49.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	II	112,129
M		167	1965	JUL.	18	21:40:44.7	N.E. OF DENVER	39.8	104.8	5	4.6	2.5 GOL-1	V	121,129
M		168	1965	JUL.	18	21:48:05.2	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		169	1965	JUL.	31	13:41:42.8	N.E. OF DENVER	39.7	104.9	5	4.6	2.7 GOL-1	V	122,129
M		170	1965	JUL.	31	17:40:41.3	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	62,112
M		171	1965	AUG.	9	15:38:39.2	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	IV	112,129
M		172	1965	AUG.	9	17:18	N.E. OF DENVER	39.9	104.9				III	112,129
M		173	1965	AUG.	9	23:18:20.2	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	62,112
M		174	1965	AUG.	10	04:02:22.9	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		175	1965	AUG.	14	20:52	N.E. OF DENVER	39.9	104.9				IV	112,129
M		176	1965	AUG.	14	22:52:18.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	62,112
M		177	1965	AUG.	18	04:30	N.E. OF DENVER	39.9	104.9				III	112,119
M		178	1965	AUG.	18	15:21:27.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	112,129
M		179	1965	AUG.	22	18:16:17.2	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	62,112
M		180	1965	AUG.	27	20:32:10.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	112,129
M		181	1965	AUG.	27	20:33:21.0	N.E. OF DENVER	39.9	104.9			1.8 GOL-1	II	112,129
M		182	1965	SEP.	2	19:11:15.3	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	112,129
M		183	1965	SEP.	13	09:58:17.9	N.E. OF DENVER	39.8	104.8	5	4.5	3.5 GOL-1	V	121,129
M		184	1965	SEP.	13	11:03:24.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	62,112,129
M	T	185	1965	SEP.	14	16:36:46.8	N.E. OF DENVER	39.8	104.8	5	4.7	2.8 GOL-1		112,121
M	T	186	1965	SEP.	14	21:15:05.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	III	112,129
M	T	187	1965	SEP.	14	22:46:24.1	N.E. OF DENVER	39.9	104.6	5	4.7	3.6 GOL-1	VI	105,121,129
M	T	188	1965	SEP.	14	22:53:53.5	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	III	112,129
M	T	189	1965	SEP.	14	23:16:10.4	S. OF DENVER	39.5	104.9	5	4.8	3.0 GOL-1	F	122,129
M		190	1965	SEP.	15	07:16	N.E. OF DENVER	39.9	104.9				III	112,129
M		191	1965	SEP.	27	10:34:16.0	N.E. OF DENVER	39.9	104.9		3.3	2.9 GOL-1	IV	112,129
M	T	192	1965	SEP.	29	18:59:56.1	N. OF DENVER	39.8	105.1	5	4.7	3.5 GOL-1	VI	105,121,129
M	T	193	1965	SEP.	29	19:05:29.5	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	IV	62,112,129
M	T	194	1965	SEP.	29	19:20:40.8	N.E. OF DENVER	39.8	104.8	5	4.6	2.6 GOL-1	VI	31,112,121
M	T	195	1965	SEP.	29	19:32:55.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	IV	112,129
M	T	196	1965	SEP.	29	20:07:36.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	IV	62,112,129
M	T	197	1965	SEP.	29	23:22:58.0	N.E. OF DENVER	39.8	104.8	5	4.6	2.8 GOL-1	IV	121,129

Table 1. (continued)

ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
198	1965	NOV.	7	09:25:14.2	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	IV	112,129
199	1965	NOV.	14	17:16:39.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	112,129
200	1965	NOV.	14	18:45:23.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	112,129
201	**1965**	**NOV.**	**21**	03:59:58.9	N.E. OF DENVER	39.8	104.8	5	4.6	3.2 GOL-1	IV	45,121
202	**1965**	**NOV.**	**21**	04:02:28.7	N.E. OF DENVER	39.8	104.8	5	4.5	3.8 GOL-1	VI	105,121,129
203	**1965**	**NOV.**	**21**	04:09:28.5	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	62,112,129
204	**1965**	**NOV.**	**21**	04:24:48.5	N.E. OF DENVER	39.9	104.7	5	4.4	2.8 GOL-1		121
205	**1965**	**NOV.**	**21**	05:00:27.3	N.E. OF DENVER	39.8	104.9	5	4.7	3.2 GOL-1	V	12,45
206	**1965**	**NOV.**	**21**	14:48:35.5	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	III	112,129
207	1966	JAN.	2	00:13:41.8	N.E. OF DENVER	39.9	104.8	5		2.1 GOL-1	III	122,130
208	**1966**	**JAN.**	**5**	00:37:17.8	N.E. OF DENVER	39.8	104.7	5	5.0	3.4 GOL-1	V	122,130
209	1966	JAN.	8	00:17	N.E. OF DENVER	39.9	104.9				III	112,130
210	**1966**	**JAN.**	**23**	01:56:38.8	DULCE, N.M.	37.0	107.0	3	5.5	5.1 HDP-2	VII	47,50,74,123,130
211	**1966**	**JAN.**	**23**	04:00	CREEDE	37.9	106.9				III	112,130
212	1966	JAN.	24	09:00:31	DULCE, N.M.	37.00	107.06	13		2.3 TGG-2	III	123
213	1966	JAN.	25	10:38:05.1	DULCE, N.M.	37.00	106.99	13	3.3	3.2 TGG-2	IV	123
214	1966	JAN	25	15:45	DULCE, N.M.	37.0	107.0				III	123
215	1966	JAN.	27	03:59:00.8	DULCE, N.M.	37.03	106.97	3		2.4 TGG-2	III	123
216	1966	JAN.	27	09:28:58.9	DULCE,N.M.	37.02	107.03	3		2.0 TGG-2	IV	123
217	1966	JAN.	28	05:32:20	DULCE,N.M.	37.01	107.03	14		1.8 TGG-2	III	123
218	1966	JAN.	31	15:43:52	DULCE, N.M.	37.0	106.9				IV	130
219	1966	MAR.	18	14:18:22.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	112,130
220	1966	MAR.	24	08:24:04.5	DULCE, N.M.	37.0	107.1	5		2.3 TGG-2		123
221	1966	APR.	3	16:21:34.0	BLAST IN SOUTH PARK	39.36	106.46	4.7				53
222	1966	APR.	14	15:07:29.5	DULCE, N.M.	37.0	107.0	5	3.3	3.2 TGG-2		123
223	1966	APR.	28	11:07:28.9	DULCE, N.M.	37.0	107.1	≤ 33		2.3 TGG-2		123
224	1966	MAY	8	17:24	DULCE, N.M.	37.0	106.9			4.2 GOL-1	F	45,112
225	1966	MAY	8	17:50:37	DULCE, N.M.	37.0	107.0	5	3.9			54,74
226	1966	MAY	9	01:26:45.0	DULCE, N.M.	37.0	106.8	5	2.5			54,74,123
227	1966	MAY	9	02:57:23.6	DULCE, N.M.	37.0	106.9	5	4.4		V	54,74,123
228	1966	MAY	26	02:21:45.5	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	II	62,112,130
229	1966	JUN.	6	19:56:53.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	112,130
230	1966	JUL.	5	18:26:13.3	RANGELY	40.09	109.00	7	3.7	3.2 UU-1		2

Table 1. (continued)

		ID	YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		231	1966	JUL.	5	20:02:41.7	RANGELY	40.06	109.00	7	3.5	3.3 UU-1		2
M		232	1966	JUL.	6	05:47:08.4	RANGELY	40.09	108.95	7	4.1	3.7 UU-1		2
M		233	1966	AUG.	19	05:29:05.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	112,130
M		234	1966	SEP.	4	09:52:34.5	CIMARRON RIDGE	38.3	107.6	≤33	4.2			121
M	T	235	**1966**	**OCT**	**3**	02:26:02.3	N.E. OF TRINIDAD	37.4	104.1	10	4.5	4.6 GOL-1	VI	105,121,130
M		236	1966	OCT.	13	00:33	CASTLE ROCK	39.3	104.6			3.0 GOL-1	F	45
M		237	1966	OCT.	25	17:14:02.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	II	62,112,130
M		238	1966	NOV.	1	07:40:28.0	YAMPA	40.2	106.9	≤33	4.0	3.9 GOL-1		121
M		239	1966	NOV.	13	15:17:00.8	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	III	112,130
M	T	240	**1966**	**NOV.**	**14**	20:02:35.9	N.E. OF DENVER	39.9	104.7	5	4.4	3.5 GOL-1	VI	121,130
M		241	1966	NOV.	15	02:51:16.3	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	62,112
M		242	1966	DEC.	19	20:52:33.3	ASPEN	39.0	106.5	5	4.6	3.3 GOL-1	III	45,121
M		243	1967	JAN.	12	03:52:06.2	SOMERSET	38.98	107.51	≤33	4.4			121
M		244	1967	JAN.	16	09:22:45.9	SILVERTON	37.67	107.86	≤33	4.1			121
M		245	1967	JAN.	18	06:12:00.6	FLAT TOPS	40.05	107.05	≤33	3.8			121
M		246	1967	FEB.	3	05:27:58.9	N.E. OF DENVER	39.88	104.95	7	4.3	3.3 GOL-1	V	48,112,131
M		247	1967	FEB.	3	05:34:13.3	N.E. OF DENVER	39.89	104.90	8		2.3 GOL-1	IV	48,112,131
M		248	1967	FEB.	12	10:11:52.4	RICO	37.67	108.00	5				121
M		249	1967	FEB.	15	03:28:03.5	RANGLEY	40.11	109.05	7	4.5	4.0 UU-1	V	31,105,123
M		250	1967	FEB.	15	04:33:22.3	RANGELY	40.22	108.97	7		2.7 UU-4		2
M		251	1967	FEB.	21	21:55:27.0	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	IV	112,131
M		252	1967	APR.	4	22:53:39.5	MONTROSE	38.32	107.75	≤33	4.5	3.0 GOL-1		121
M	T	253	**1967**	**APR.**	**10**	19:00:25.5	N.E. OF DENVER	39.94	104.75	5	4.9	4.3 HER-2	VI	62,121,131
M	T	254	**1967**	**APR.**	**10**	19:02	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	255	**1967**	**APR.**	**10**	19:08	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	256	**1967**	**APR.**	**10**	19:23	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	257	**1967**	**APR.**	**10**	19:26	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	258	**1967**	**APR.**	**10**	19:28	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	259	**1967**	**APR.**	**10**	19:35:53.0	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	62,112
M	T	260	**1967**	**APR.**	**10**	19:36:38.0	N.E. OF DENVER	39.89	104.77	5	4.4	3.5 GOL-1	IV	119,121
M	T	261	**1967**	**APR.**	**10**	20:08	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	262	**1967**	**APR.**	**10**	20:11:14.6	N.E. OF DENVER	39.86	104.91	5	4.8	3.0 GOL-1	V	119,121
M	T	263	**1967**	**APR.**	**10**	20:37:45.3	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	112,131

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M	T	264	1967	APR.	10	22:09:16.5	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	III	62,112,131
M	T	265	1967	APR.	10	22:12:01.3	N.E. OF DENVER	39.87	104.88	4				48
M	T	266	1967	APR.	10	23:58:40.8	N.E. OF DENVER	39.92	104.79	5	4.3	3.0 GOL-1	IV	119,121
M		267	1967	APR.	11	00:37	N.E. OF DENVER	39.9	104.9				III	112,131
M		268	1967	APR.	12	02:22:58.0	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	112,131
M		269	1967	APR.	12	05:40:23.7	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	112,131
M		270	1967	APR.	12	09:47:42.3	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	IV	112,131
M		271	1967	APR.	23	02:34:55.1	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	IV	112,131
M	T	272	1967	APR.	27	17:24:42.3	N.E. OF DENVER	39.91	104.77	5	4.5	3.8 GOL-1	VI	105,121,131
M	T	273	1967	APR.	27	17:25:37.0	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	F	62,112
M		274	1967	APR.	28	06:53:48.6	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	62,112,131
M		275	1967	APR.	28	12:21:21.0	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	62,112,131
M		276	1967	MAY	12	01:58:19.6	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	IV	112,131
M		277	1967	MAY	19	17:46:45.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	112,119
M		278	1967	JUN.	8	07:50:48.2	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M		279	1967	JUN.	19	15:39:22.0	N.E. OF DENVER	39.9	104.8	5		2.9 GOL-1	IV	122,131
M		280	1967	JUN.	19	17:47:19.5	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	II	112,131
M		281	1967	JUL.	12	01:45:43.9	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	112,131
M		282	1967	JUL.	27	17:54:13.7	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	62,112
M	T	283	1967	AUG.	9	13:25:06.2	N.E. OF DENVER	39.9	104.7	5	5.3	4.9 NUT-2	VII	105,122,131
M	T	284	1967	AUG.	9	14:10	N.E. OF DENVER	39.9	104.9				III	112,131
M	T	285	1967	AUG.	9	14:56:19.5	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	II	62,112
M	T	286	1967	AUG.	9	17:48:29.3	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	II	62,112
M	T	287	1967	AUG.	9	20:45	N.E. OF DENVER	39.9	104.9				II	62,112
M		288	1967	AUG.	13	05:02:31.5	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	62,112
M		289	1967	AUG.	13	05:46:10.2	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	62,112
M		290	1967	AUG.	13	17:05:55.0	N.E. OF DENVER	39.9	104.9			2.3 GOL-1	III	62,112
M		291	1967	OCT.	25	06:32	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	IV	112,131
M		292	1967	OCT.	26	04:18	N.E. OF DENVER	39.9	104.9			1.6 GOL-1	III	85,112
M		293	1967	OCT.	28	08:00	N.E. OF DENVER	39.9	104.9			2.0 GOL-1	III	85,112,131
M		294	1967	NOV.	14	10:07	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	IV	112,131
M		295	1967	NOV.	14	10:41	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	112,131
M		296	1967	NOV.	15	07:10:12.1	N.E. OF DENVER	39.9	104.6	5	3.7	3.6 GOL-1	V	122,131

Table 1. (continued)

ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
297	1967	NOV.	25	07:02	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	IV	112,131
298	1967	NOV.	27	05:09:22.7	N.E. OF DENVER	39.87	104.88	5	5.2	4.6 NUT-2	VI	48,105,131
299	1967	NOV.	27	05:35:00.7	N.E. OF DENVER	39.9	104.7	5	4.4	4.3 GOL-1	V	112,122,131
300	1967	NOV.	27	05:42:53.3	N.E. OF DENVER	39.9	104.9	5		3.5 GOL-1	V	112,122,131
301	1967	DEC.	9	03:34	N.E. OF DENVER	39.9	104.9			1.9 GOL-1	III	85,112,131
302	1968	JAN.	13	18:47	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	III	23,85,112
303	1968	JAN.	18	14:31	N.E. OF DENVER	39.9	104.9			2.4 GOL-1	III	23,85,112
304	1968	JAN.	18	21:16:38.2	DINOSAUR NAT. MON.	40.44	108.84	7		2.9 UU-1		2
305	1968	FEB.	24	14:06:50.6	N.E. OF DENVER	39.88	104.89	4		2.0 GOL-1	III	23,48
306	1968	APR.	13	22:47:36.6	N.E. OF DENVER	39.88	104.89	11		2.7 GOL-1	III	23,48
307	1968	APR.	21	07:08:07.0	S. OF HOLLY	37.8	102.1	≤33	3.8			122
308	1968	JUN.	4	18:58:14.0	N.E. OF DENVER	39.88	104.90	9		2.6 GOL-1		48
309	1968	JUN.	10	05:23:20.6	N.E. OF DENVER	39.87	104.90	9		2.7 GOL-1		48
310	1968	JUN.	23	20:16:13.0	S.W. OF CARBONDALE	39.31	107.41	≤33	3.8			122
311	1968	JUL.	15	18:33:13.6	N.E. OF DENVER	39.87	104.88	6		3.4 GOL-1	V	23,48
312	1968	JUL.	15	18:46	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	F	85,112
313	1968	JUL.	27	19:04:54.3	N.E. OF DENVER	39.89	104.89	7		2.9 GOL-1	III	23,48,112
314	1968	AUG.	14	02:03:26.4	N.E. OF DENVER	39.89	104.92	8		2.6 GOL-1	III	23,48,112
315	1968	SEP.	24	14:51:27.4	N.E. OF DENVER	39.90	104.94			2.4 GOL-1	IV	23,48
316	1968	NOV.	2	14:29:02.5	N.E. OF DENVER	39.86	104.90	6		3.2 GOL-1	IV	23,48
317	1968	NOV.	29	04:28	N.E. OF DENVER	39.9	104.9			2.2 GOL-1	III	23,48,112
318	1969	FEB.	22	18:43	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	85,112
319	1969	FEB.	23	22:50	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	85,112
320	1969	MAR.	20	06:36	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	85,112
321	1969	MAR.	23	01:21	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	85,112
322	1969	APR.	17	16:49	N.E. OF DENVER	39.9	104.9			2.1 GOL-1	IV	112,132
323	1969	APR.	28	07:16	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	85,112
324	1969	APR.	30	14:28	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	85,112
325	1969	MAY	23	09:00:53.5	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	V	112,132
326	1969	MAY	23	10:43	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	III	31,112,132
327	1969	MAY	23	10:47	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	V	85,112
328	1969	MAY	26	01:30:08.6	E. OF GREELEY	40.4	104.4	≤33	4.2	3.5 GOL-1	IV	122,132
329	1969	SEP.	10	21:00:00.1	RULISON AEC TEST	39.41	107.95		5.3			122

Table 1. (continued)

	ID	YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M	330	1969	SEP.	13	11:25	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	III	112,132
M	331	1969	SEP.	13	12:15	N.E. OF DENVER	39.9	104.9			2.6 GOL-1	III	85,112,132
M	332	1969	SEP.	30	09:04	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	85,112
M	333	1969	NOV.	5	13:50	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	F	85,112
M	334	1969	NOV.	5	14:24	N.E. OF DENVER	39.9	104.9			2.9 GOL-1	F	85,112
M	335	1970	FEB.	3	05:59:35.6	S. OF NORWOOD	37.92	108.31	≤ 33	4.0			122
M	336	1970	MAR.	31	12:36	N.E. OF DENVER	39.9	104.9			2.8 GOL-1	F	85,112
M	337	1970	APR.	21	08:53:52.4	RANGELY	40.1	108.9	4	4.3	3.9 GS-1	V	27,122
M	338	1970	APR.	21	15:05:47.5	RANGELY	40.09	108.90	4	4.6	3.7 GS-1	IV	27,112,122
M	339	1970	MAY.	23	08:55:09.4	N. OF DENVER	39.90	105.10	5	4.1	3.2 GOL-1	V	27,122
M	340	1970	JUL.	12	18:18	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	85,112
M	341	1971	JAN.	7	20:39:52.1	GLENWOOD SPRINGS	39.49	107.31	≤ 33	4.3	3.8 GS-1	V	28,122
M	342	1971	MAR.	11	14:08	N.E. OF DENVER	39.9	104.9			3.0 GOL-1	III	28,112
M T	343	**1971**	**MAR.**	**18**	09:08:59.9	CLARK	40.70	106.97	10	4.4		V	28,122
M T	344	**1971**	**AUG.**	**8**	05:22:44.0	N.E. OF DENVER	39.89	104.76	5	4.4	3.8 GOL-1	IV	28,112
M T	345	**1971**	**AUG.**	**8**	07:50	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	F	85,112
M	346	1971	AUG.	14	08:36	N.E. OF DENVER	39.9	104.9			3.1 GOL-1	F	85,112
M	347	1971	NOV.	12	09:30:44.6	GRAND JUNCTION	38.91	108.68	5		4.0 GS-1	III	27,112,122
M	348	1971	DEC.	9	05:20	N.E. OF DENVER	39.9	104.9			3.3 GOL-1	IV	28,85,112
M	349	1972	NOV.	12	18:33	N.E. OF DENVER	39.9	104.9			2.5 GOL-1	III	28,85,112
M T	350	**1972**	**NOV.**	**29**	22:15	N.E. OF DENVER	39.9	104.9			2.7 GOL-1	IV	28,85,112
M	351	1973	MAY	17	16:00:00	RIO BLANCO AEC TEST	39.79	108.37		5.4	5.7 BRK-3		122
M	352	1973	SEP.	19	13:28:20.5	VALDEZ	37.16	104.59	5			III	30,111,122
M	353	1973	SEP.	22	21:47:38.1	BONCARBO	37.2	104.6				III	30,112
M	354	1973	SEP.	23	03:58:54.9	VALDEZ	37.15	104.57	5	4.2		III	30,111,122
M	355	1973	SEP.	23	04:41:14.8	BONCARBO	37.2	104.6				III	30,112
M	356	1973	SEP.	23	09:51:27.2	BONCARBO	37.2	104.6				III	30,112
M	357	1974	MAR.	31	11:58:47.1	CLARK	40.70	107.05	5		3.5 GS-1	II	24
M T	358	**1975**	**JAN.**	**30**	14:48:40.3	N. OF GRAND JCT.	39.27	108.65	5	4.4	3.7 GS-1	V	25
M	359	1976	MAY	30	01:43:37.3	PINON CANYON AREA	37.41	104.02	5		3.0 GS-1		84
M	360	1977	SEP.	24	11:16:48.4	S.W. OF CARBONDALE	39.31	107.31	5	4.0	3.0 GS-1		114
M	361	1977	NOV.	3	05:34	POUDRE CANYON	40.7	105.4			2.0 GS-1	II	26,112
M	362	1978	MAY	29	16:45:18.0	S.W. OF CARBONDALE	39.28	107.32	5		3.0 GS-1		115

Table 1. (continued)

	ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M	363	1978	JUN.	10	20:57:53.5	N.E. OF DENVER	39.79	104.87	20		2.9 GS-1	IV	115
M	364	1978	NOV.	30	18:50:15.8	CRAIG	40.47	107.61	5		2.8 GS-1		115
M T	365	**1979**	**JAN.**	**6**	01:58:55.3	DIVIDE	38.96	105.16	5		2.9 GS-1	VI	14,105,112
M	366	1979	JAN.	20	06:59:08.4	N.W. OF CRAIG	40.82	107.86	5		3.3 GS-1		116
M	367	1979	MAR.	19	14:59:29.7	RANGELY	40.18	108.90	2		3.1 GS-1	IV	116
M	368	1979	MAR.	29	22:07:13.3	RANGELY	40.27	108.81	2		2.6 GS-1	IV	116
M	369	1981	MAR.	24	13:03:40.0	N.E. OF DENVER	39.75	104.94	5		2.8 GS-1	F	101,123
M T	370	**1981**	**APR.**	**2**	16:10:06.4	N.E. OF DENVER	39.91	104.95	9	4.3	3.8 GS-1	VI	101,105,123
M	371	1981	SEP.	16	19:58:38.9	N.E. OF DENVER	39.88	104.91	5		2.1 GS-1	IV	101,123
M T	372	**1981**	**NOV.**	**2**	03:03:00.2	CONIFER	39.55	105.28	4		2.8 GS-1	V	15,16,123
M	373	1981	DEC.	9	02:45:36.2	CONIFER	39.5	105.3				F	101,112
M	374	1982	MAR.	11	23:55:28.2	N.E. OF DENVER	39.86	104.85	5		2.8 GS-1	III	109,122,123
M	375	1982	SEP.	18	16:11:44.9	N.E. OF DENVER	39.90	104.91	5		2.8 GS-1	III	68,122,123
M	376	1982	NOV.	22	10:09:01.4	RIFLE	39.74	107.58	5		2.9 GS-1	F	106,122,123
M	377	**1983**	**AUG.**	**14**	19:08:30.7	CIMARRON	38.29	107.23	6.3		3.4 GS-1	II	122,123,140
M	378	1983	AUG.	17	15:03:27.6	N.E. OF TRINIDAD	37.47	104.31	5		3.4 GS-1		122,123
M	379	1983	SEP.	24	16:57:45.7	BROWNS PARK	40.79	108.84	5		4.1 GS-1	IV	122,123
M	380	1984	FEB.	25	09:18:19.0	N.E. OF DENVER	39.92	105.02	5		2.5 GS-1	III	122,123
M	381	**1984**	**APR.**	**12**	20:16:57.8	CARBONDALE	39.35	107.22	5		2.2 GS-1	F	43,122,123
M	382	**1984**	**APR.**	**22**	17:30:56.7	CARBONDALE	39.31	107.20	5		3.1 GS-1	IV	43,122,123
M	383	**1984**	**MAY**	**3**	18:25:35.4	CARBONDALE	39.29	107.23	5		2.5 GS-1		122,123
M	384	**1984**	**MAY**	**3**	18:28:54.1	CARBONDALE	39.28	107.19	5		3.0 GS-1	F	43,122,123
M	385	**1984**	**MAY**	**3**	19:18:23.0	CARBONDALE	39.35	107.25	5		2.3 GS-1		43,122,123
M	386	**1984**	**MAY**	**4**	01:17:10.4	CARBONDALE	39.40	107.30	5		2.4 GS-1	F	43,122,123
M	387	**1984**	**MAY**	**4**	02:13:33.1	CARBONDALE	39.32	107.21	5		2.2 GS-1	F	43,122,123
M	388	**1984**	**MAY**	**4**	18:44:37.4	CARBONDALE	39.30	107.21	5		2.2 GS-1		43,122,123
M	389	**1984**	**MAY**	**6**	02:00:56.6	CARBONDALE	39.32	107.20	5		2.1 GS-1	F	43,122,123
M	390	**1984**	**MAY**	**6**	02:12:49.7	CARBONDALE	39.36	107.25	5		2.3 GS-1	F	43,122,123
M	391	**1984**	**MAY**	**6**	02:13:34.4	CARBONDALE	39.37	107.25	5		2.6 GS-1	F	43,122,123
M	392	**1984**	**MAY**	**6**	02:51:36.9	CARBONDALE	39.34	107.22	5		2.2 GS-1	F	43,122,123
M	393	**1984**	**MAY**	**6**	04:17:35.5	CARBONDALE	39.36	107.24	5		2.5 GS-1		43,122,123
M	394	**1984**	**MAY**	**6**	04:21:37.7	CARBONDALE	39.34	107.21	5		2.7 GS-1		43,122,123
M	395	**1984**	**MAY**	**10**	01:20:14.9	CARBONDALE	39.34	107.22	5		1.9 GS-1		43,122,123

Table 1. (continued)

ID	YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
396	1984	MAY	10	01:53:51.8	CARBONDALE	39.38	107.27	5		2.4 GS-1		43,122,123
397	1984	MAY	11	13:34:57.9	CARBONDALE	39.34	107.26	5		2.3 GS-1		122,123
398	1984	MAY	14	10:14:17.2	CARBONDALE	39.36	107.23	5		3.2 GS-1	IV	43,122,123
399	1984	MAY	17	09:11:20.2	CARBONDALE	39.36	107.25	4.7		2.4 GS-1	F	43,122,123
400	1984	MAY	27	23:30:19.3	BURLINGTON	39.22	102.16	5		3.6 GOL-1		122,123
401	1984	JUN.	12	04:48:54.1	REDSTONE, COAL BUMP?	39.14	107.39	1		3.0 GS-1		122,123
402	1985	MAR.	16	21:55:02.5	SALIDA	38.56	105.85	5		3.2 GS-1	V	122,123
403	1985	DEC.	6	15:57:26.3	GATEWAY	38.79	108.90	8		2.9 EWC-4		39,122,123
404	1986	APR.	11	06:17:14.7	CRESTED BUTTE	38.98	106.94	5		2.9 GS-1	III	104,122,123
405	1986	MAY	9	21:55:26.7	CRESTED BUTTE	38.89	106.88	5		2.7 GS-1	II	104,122,123
406	1986	AUG.	13	02:42:55.6	CRESTED BUTTE	38.81	107.00	5		2.6 GS-1	F	104,122,123
407	1986	AUG.	13	12:08:31.4	CRESTED BUTTE	38.86	107.04	5		2.1 GS-1	F	122,123
408	1986	AUG.	13	12:13:43.9	CRESTED BUTTE	38.88	107.04	5		2.4 GS-1	F	104,122,123
409	1986	AUG.	14	17:39:25.9	CRESTED BUTTE	38.91	107.08	5		2.6 GS-1	F	104,122,123
410	1986	AUG.	17	12:45:57.7	CRESTED BUTTE	38.94	107.13	5		1.8 GS-1		122,123
411	1986	AUG.	17	22:10:28.3	CRESTED BUTTE	38.90	107.08	5		2.4 GS-1	F	104,122,123
412	1986	AUG.	18	01:15:15.0	CRESTED BUTTE	38.91	107.09	5		3.0 GS-1	III	104,122,123
413	1986	AUG.	18	16:16:13.5	CRESTED BUTTE	38.90	107.07	5		2.3 GS-1		122,123
414	1986	AUG.	19	08:13:08.5	CRESTED BUTTE	38.88	107.05	5		2.1 GS-1		122,123
415	1986	AUG.	19	17:29:37.5	CRESTED BUTTE	38.93	107.07	5		1.6 GS-1		122,123
416	1986	AUG.	19	23:31:27.1	CRESTED BUTTE	38.90	107.05	5		1.9 GS-1		122,123
417	1986	AUG.	20	04:43:40.1	CRESTED BUTTE	38.89	107.08	5		2.3 GS-1	F	104,122,123
418	1986	AUG.	20	20:21:32.9	CRESTED BUTTE	39.00	107.10	8.1		3.1 WCC-1	F	8,104,122,123
419	1986	AUG.	21	14:11:31.6	CRESTED BUTTE	39.00	107.10	7.9		2.6 WCC-1	F	8,104,122,123
420	1986	AUG.	22	11:10:28.6	CRESTED BUTTE	38.99	107.10	8.3		2.7 WCC-1		8,122,123
421	1986	AUG.	23	05:13:03.0	CRESTED BUTTE	38.99	107.10	8.1		2.8 WCC-1	F	8,104,122,123
422	1986	AUG.	24	03:59:17.5	CRESTED BUTTE	39.00	107.10	8.2		2.7 WCC-1	F	8,104,122,123
423	1986	AUG.	24	16:15:38.5	CRESTED BUTTE	39.00	107.10	7.5		2.8 WCC-1		8,122,123
424	1986	AUG.	26	02:06:02.6	CRESTED BUTTE	38.90	107.04	5		3.1 GS-1	IV	104,122,123
425	1986	AUG.	27	21:35:53.0	CRESTED BUTTE	38.88	107.10	5		2.3 GS-1		122,123
426	1986	AUG.	30	11:42:28.6	CRESTED BUTTE	38.88	107.05	5		2.5 GS-1		122,123
427	1986	SEP.	3	06:20:50.9	CRESTED BUTTE	38.98	107.10	11		3.5 GS-1	V	8,104,122,123,137
428	1986	SEP.	6	21:13:19.2	CRESTED BUTTE	38.90	107.08	5		2.2 GS-1		122,123

Table 1. (continued)

ID	YEAR	DATE MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M 429	1986	SEP.	18	04:53:21.7	CRESTED BUTTE	38.94	107.12	5		3.2 GS-1	F	104,122,123
M 430	1986	SEP.	18	09:26:38.1	CRESTED BUTTE	38.93	107.09	5		3.4 GS-1	III	104,122,123
M 431	1986	SEP.	21	09:20:46.6	CONIFER	39.60	105.29	5		2.5 GS-1	F	104,122,123
M 432	1986	SEP.	22	06:20:16.9	CRESTED BUTTE	38.93	107.10	5		2.5 GS-1		122,123
M 433	1986	OCT.	7	12:35:03.2	CRESTED BUTTE	38.95	107.09	5		1.8 GS-1	F	104,122,123
M 434	1987	APR.	16	10:55:09.5	HOWARD	38.54	105.85	5		2.7 GS-1		122,123
M 435	1987	JUL.	20	16:19:16.1	TAYLOR PARK	38.96	106.51	5		2.8 GS-1		122,123
M 436	1987	SEP.	9	09:44:09.6	RICO	37.65	108.11	5		2.5 GS-1		122,123
M 437	1987	SEP.	14	20:31:46.2	WINFIELD	39.04	106.55	5		2.5 GS-1	F	122,123
M 438	1988	JAN.	15	07:33:29.2	SUMMITVILLE	37.52	106.68	5		3.1 GS-1	F	122,123
M 439	1988	FEB.	14	18:32:40.5	MAYBELL	40.63	108.53	5		3.3 GS-1	IV	122,123
M 440	1988	AUG.	31	10:43:18.1	COLD SPRING MTN.	40.84	108.81	10		2.4 GS-1		122,123
M 441	1988	NOV.	19	12:47:53.2	McCLURE PASS	39.04	107.33	5		2.7 GS-1		122,123
M 442	1989	MAR.	24	11:26:46.1	MESA DE MAYA	37.08	103.26	5		2.7 TUL-2		122,123
M 443	1989	MAY	13	21:01:48.8	URAVAN	38.47	108.92	7		3.1 SLC-4		122,123
M 444	1989	JUN.	30	12:52:50.8	MEEKER	40.10	107.87	5		2.2 GS-1	F	122,123
M 445	1989	JUL.	6	10:38:25.6	KIT CARSON	38.77	102.64	5		2.8 GS-1		122,123
M 446	1989	NOV.	8	06:14:24.0	N.E. DENVER	39.83	105.02	5		2.5 GS-1	IV	122,123
M 447	1989	NOV.	19	03:21:13.6	RIDGWAY	38.06	107.77	5		3.0 GS-1	F	122,123
M 448	1989	NOV.	22	22:47:12.6	OURAY	37.98	107.73	5		2.7 GS-1	F	122,123
M 449	**1990**	**SEP.**	**12**	21:38:57.6	VAIL	39.70	106.21	5		3.0 GS-1	V	122,123
M 450	1990	OCT.	19	00:32:06.9	NEW CASTLE	39.57	107.56	5		2.3 GS-1	III	122,123
M 451	1990	OCT.	19	00:43:06.8	NEW CASTLE	39.57	107.58	5		2.1 GS-1	F	122,123
M 452	**1990**	**OCT**	**21**	04:31:19.9	PALISADE	38.91	108.34	10		2.5 GS-1	V	122,123
M 453	1990	DEC.	12	07:24:28.9	NEW CASTLE	39.62	107.57	10		2.7 GS-1	F	122,123
M 454	1991	APR.	21	12:46:08.1	ASPEN	39.12	106.75	5		2.0 GS-1	F	122,123
M 455	1991	MAY	10	12:15:54.3	SUMMITVILLE	37.46	106.58	5		3.4 GS-1	F	122,123
M 456	1991	MAY	10	12:21:59.0	SUMMITVILLE	37.45	106.60	5		2.4 GS-1	F	122,123
M 457	1991	MAY	10	13:23:45.0	SUMMITVILLE	37.45	106.60	5		2.0 GS-1	F	122,123
M 458	1991	MAY	10	14:21:15.0	SUMMITVILLE	37.45	106.60	5		2.4 GS-1	F	122,123
M 459	1991	NOV.	15	08:25:57.5	HAMILTON	40.41	107.54	5		2.6 GS-1		122,123
M 460	1991	DEC.	26	06:39:32.9	POWDERHORN	38.25	107.12	5		2.3 GS-1	III	122,123
M 461	1991	DEC.	26	07:22:44.2	POWDERHORN	38.28	107.16	5		2.3 GS-1	F	122,123

Table 1. (continued)

		ID	DATE YEAR	MONTH	DAY	ORIGIN TIME (UTC)	EPICENTRAL LOCATION	LAT. (N)	LONG. (W)	DEPTH (km)	MAGNITUDE USGS	MAGNITUDE OTHER	INTENSITY (MM)	REFERENCES
M		462	**1992**	**APR.**	**15**	22:46:05.1	AGUILAR	37.34	104.77	5	3.1	3.2 GS-2	V	122,123
M		463	1992	MAY	2	10:19:29.8	GULNARE	37.38	104.78	5	2.9	3.1 GS-2	IV	122,123
M		464	1992	MAY	15	21:36:24.3	OLATHE	38.56	107.91	5		2.8 GS-1	IV	122,123
M		465	1993	APR.	29	07:37:04.6	CLARK	40.69	107.05	5		2.5 GS-1		122,123
M		466	1993	JUL.	7	08:03:51	ASPEN	39.20	106.70	5		2.2 GS-1	F	122,123
M		467	1993	JUL.	7	10:00:46	ASPEN	39.20	106.70	5		2.5 GS-1	F	122,123
M		468	1993	JUL.	8	04:03:52.3	ASPEN	39.23	106.72	5		3.1 GS-1	F	122,123
M		469	1993	JUL.	8	04:26:19.5	ASPEN	39.21	106.72	5		2.6 GS-1	F	122,123
M		470	1994	JAN.	17	01:59:58.4	RIDGWAY	38.22	107.71	5		2.8 GS-1		122,123
M		471	1994	FEB.	14	21:16:20.0	CRAIG	40.61	107.49	5		2.7 GS-1	III	122,123
M		472	1994	MAR.	8	11:40:18.8	DOUGLAS PASS	39.50	108.64	5		2.9 GS-1		122,123
M		473	1994	AUG.	4	16:49:41.1	PONCHA SPRINGS	38.61	106.00	5		2.5 GS-1	IV	122,123
M		474	1994	AUG.	23	05:03:09.6	GOTHIC	38.82	106.95	5		2.2 GS-1	III	122,123
M	T	475	**1994**	**SEP.**	**13**	06:01:23.0	NORWOOD	38.15	107.98	10	4.4	4.6 GS-1	VI	61,122,123
M		476	1994	SEP.	14	03:06:33.1	NORWOOD	38.21	108.08	10		2.8 GS-1	III	122,123
M		477	1994	SEP.	14	04:07:25.6	NORWOOD	38.21	108.31	10		2.0 GS-4		122,123
M		478	1994	SEP.	15	07:07:14.1	NORWOOD	38.19	108.03	10		2.4 GS-1		122,123
M		479	1994	SEP.	26	01:21:45.6	SOMERSET, COAL BUMP	38.93	107.48			3.1 GS-1		122,123
M		480	1994	NOV.	2	02:05:44.4	SOMERSET, COAL BUMP	38.90	107.49			2.8 GS-1		122,123
M		481	1994	NOV.	3	11:40:10.1	MEEKER	40.04	108.27	5		3.4 GS-1		122,123
M	T	482	**1994**	**DEC.**	**25**	19:06:07.5	PALMER LAKE	39.30	104.99	23.5		4.0 GS-2	V	67,122,123
M		483	1995	JAN.	1	12:43:19.3	SOMERSET, COAL BUMP	38.87	107.45			3.0 GS-1		122,123
M		484	1995	JAN.	11	14:01:47.3	ASPEN	39.19	106.62	5		2.5 GS-1	F	122,123
M		485	1995	MAR.	14	22:13:47.7	SOMERSET, COAL BUMP	38.88	107.48			2.9 GS-1		122,123
M		486	**1995**	**MAR.**	**20**	12:46:16.4	DINOSAUR	40.18	108.93	5	4.2	4.1 GS-1	V	122,123
M		487	**1995**	**MAR.**	**20**	13:16:12.5	DINOSAUR	40.18	108.92	5		2.7 GS-1		122,123
M		488	**1995**	**MAR.**	**20**	14:33:59.5	DINOSAUR	40.15	109.03	5		2.5 GS-1	IV	122,123
M		489	1995	MAR.	23	03:31:05.5	DINOSAUR	40.19	108.95	5		3.0 GS-1	IV	122,123
M		490	1995	APR.	1	05:22:37.9	DINOSAUR	40.20	108.98	5	2.9	3.3 GS-1	F	122,123
M		491	1995	APR.	23	16:31:18	GRAND MESA	38.91	108.32	5		2.7 GS-1	F	122,123
M		492	**1995**	**DEC.**	**23**	06:51:48.8	MANITOU SPRINGS	38.73	104.92	5	3.5	3.6 GS-2	IV	122,123
M		493	1995	DEC.	31	00:37:38.1	MANITOU SPRINGS	38.72	104.91	5		2.8 GS-2	III	122,123
M		494	1996	AUG.	1	05:44:22.7	TYRONE	37.40	104.25	5		3.8 GS-2	III	123
M		495	1996	AUG.	1	05:55:54.2	TYRONE	37.38	104.20	5		3.2 GS-2		123
M		496	1996	NOV.	1	03:09:28.4	TYRONE	37.35	104.23	5		3.2 GS-2	F	123

MODIFIED MERCALLI INTENSITY SCALE OF 1931

EARTHQUAKE EARTHQUAKE

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 swing – 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. Frighten 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. Building 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, monu ments, 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. 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 pavement 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.

DESCRIPTIONS OF SELECTED EARTHQUAKES

EARTHQUAKE EARTHQUAKE

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.

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.

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.

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, then the felt area for this earthquake would be fairly large.

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.

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.

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.

Rizzari (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 local earthquake.

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.

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 14 km (9 mi) 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)**.

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, Laramie, and near Meeker.

The main event was the largest earthquake to occur in the Colorado region during the historical period and 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. Hadsell concluded the earthquake may have been centered north of Denver and east of Boulder, had maximum intensity of VII, and was ML 5.0 ± 0.6 based on the maximum observed intensity or ML 6.7 ± 0.6 based on its circular felt area of just under 1,200,000 km^2.

Dames and Moore (1981) studied this event as part of their seismic hazard evaluation for the Rocky Flats Plant. A summary of their investigation into the 1882 earthquake 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 charcoal collected by the authors and W.R. Junge from unfaulted deposits that cover the fault and detailed studies of the Dudley Gulch graben by **Eckert (1982)** and **Clift and Billington (1986)** 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 at 500,000 km^2, assigned a maximum intensity of VIII to the event, and suggested the earthquake had a magnitude of around ML 6.5.

A re-evaluation of existing felt reports, combined with newly discovered felt reports and 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 ML 6.2 ± 0.3 based on regression equations that compare magnitude and felt area for Rocky Mountain earthquakes. The relatively large felt area, combined with only moderate reported intensities, suggested the earthquake occurred at a moderate hypocentral depth, perhaps about 20 km or more, similar to the 1984 Laramie Mountains, Wyoming earthquake.

An aftershock occurred during the morning of November 8 (local time). An intensity map for the aftershock is presented in **Figure 2**. The aftershock was felt in Denver, Boulder, Greeley, Laramie, and near Meeker. No intensity ratings have been 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 felt reports for the aftershock are included in a single felt area, it would encompass an area of about 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 location.

The felt reports for the main shock 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 unusually shaped isoseismal maps of recent Denver area 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**; **Spence and others, 1996**) suggest an epicentral area somewhere in north-central Colorado, perhaps in the northern Front Range or southern Laramie Mountains.

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.

As part of a recent seismotectonic evaluation of the Rocky Flats facility conducted subsequent to the original release of Bulletin 46, G.A. Bollinger re-evaluated the 1882 earthquake (**Risk Engineering, Inc., 1994,** Appendix C). In general, he agreed with the epicentral location of **Kirkham and Rogers (1986)**, but rather than selecting a specific location for the event, he assigned confidence levels of the earthquake having occurred in various areas defined by isoseismal or felt areas. Bollinger also estimated the magnitude of the earthquake using several methods. He suggested it had a moment magnitude of 6.44 and assigned a confidence of 80 percent that this value was correct.

Risk Engineering, Inc. (1994; p. 16) concluded that "Given currently-available data, the epicenter may have been anywhere in north-central or northwestern Colorado, southern Wyoming, or northeastern Utah, and the moment magnitude is estimated to have been in the range 5.0 ± 0.4 to 6.9 ± 0.2, with a best estimate of 6.4 ± 0.3".

The 1882 earthquake has also been investigated by **Spence and others (1996)**, who compared it with the 1984 Laramie Mountains, Wyoming earthquake. They concluded the epicenter for the 1882 event was probably in the northern Front Range in the general vicinity of the location proposed by **Kirkham and Rogers (1986)**, estimated the earthquake would have had a felt area of 870,000 km^2 based on the current population distribution, and suggested it had a magnitude of ML 6.6 ± 0.6. They stated that earthquakes of this size may occur at shallow to mid-crustal depths throughout the Laramie Mountains and Front Range. We have elected to use the magnitude determined by Spence and others (1996) in Table 1.

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

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 (1986)** assigned a maximum intensity of IV to this event.

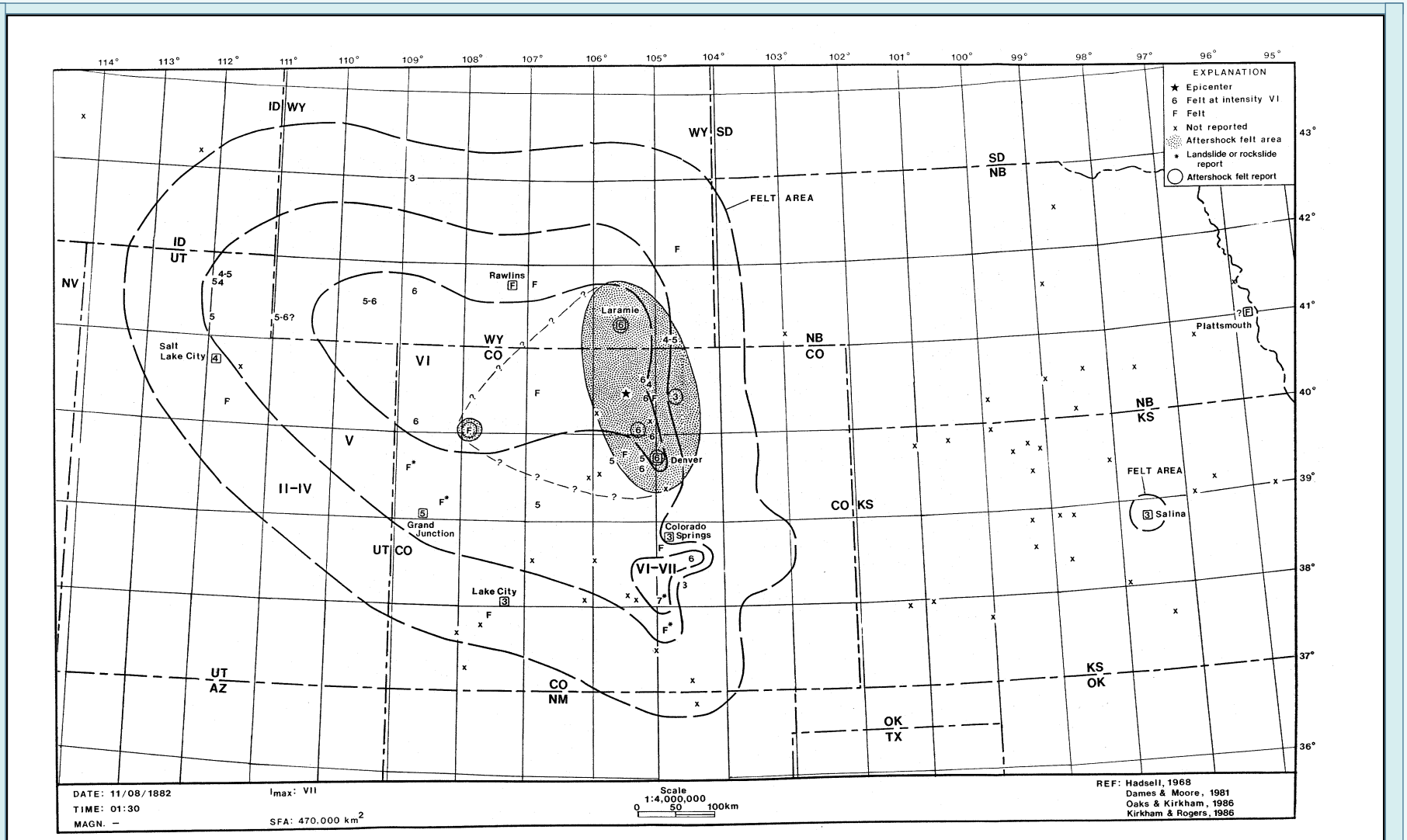


Figure 1. Isoseismal map for the November 8, 1882 earthquake.

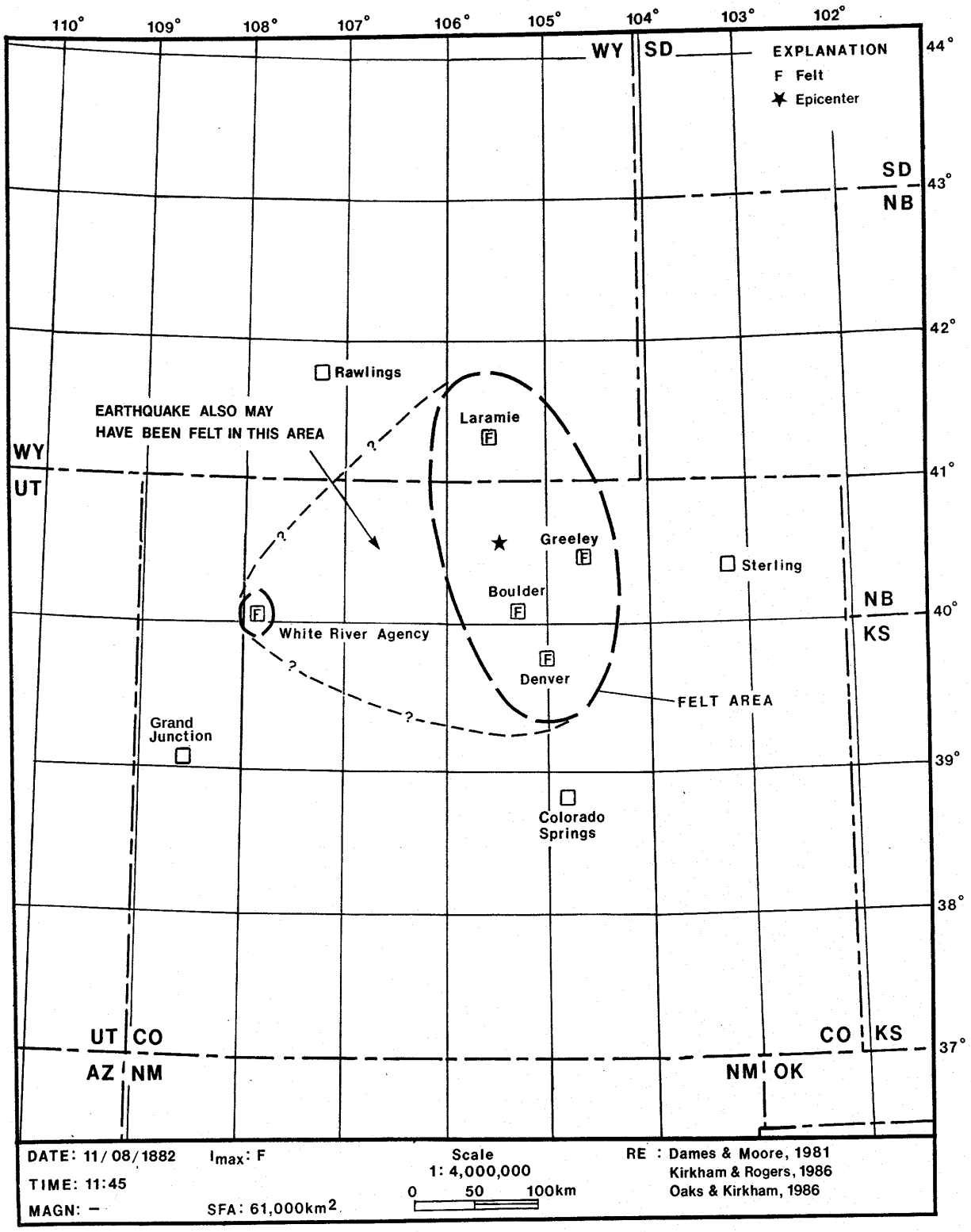


Figure 2. Intensity map for aftershock on November 8, 1882.

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 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.

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.

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.

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 (**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.

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.

August 5, 1894

The only known original reference to the August 5, 1894 earthquake is from the *Georgetown Courier* on August 11, 1894. **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.

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.

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.

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 U.S. Highway 40 where it crosses Lay Creek. As they described it, "The earthquake shook the house, made dishes rattle, and lasted for about fifteen seconds". We rate this account at intensity IV.

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 these events are as follows: Montrose-V to VI (if foundation damage can be substantiated), Durango-V, Grand Junction-V, Delta-IV to V, and Fruita-IV to V.

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 or perhaps even smaller.

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.

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 an intensity of IV.

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. Newspaper reports recently provided to us by W.A. Charlie (1997, written commun.) from *The Weekly Courier* (Fort Collins) and *Fort Collins Express* on September 16, 1903 describe felt effects for the September 9, 1903 earthquake in Estes Park, Loveland, and Buckhorn. We assign a MMI of V to the reports from Estes Park and IV to those from Loveland. The account in *The Weekly Courier* states Estes Park was "near the center of the disturbed area".

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. Based on our intensity map for this event (**Figure 3**), we estimate the earthquake was felt over approximately 6,000 km^2, however the lack of "not felt" reports precludes accurate determination of the limits of the felt area. Also, we assign this earthquake a slightly different epicentral location than **Stover, Reagor, and Algermissen (1984)** based on the report from Estes Park and the intensity map in Figure 3. This earthquake may have occured in the same general vicinity as the November 8, 1882 earthquakes.

April, 1906

An article in *The Craig Empire Courier* on February 27, 1952 referred 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 river bank and that the water in the river was agitated. Pans in the pantry of a nearby log house rattled and clattered; 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. Refer to **Oaks and Kirkham (1986)** for a complete account of this article.

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.

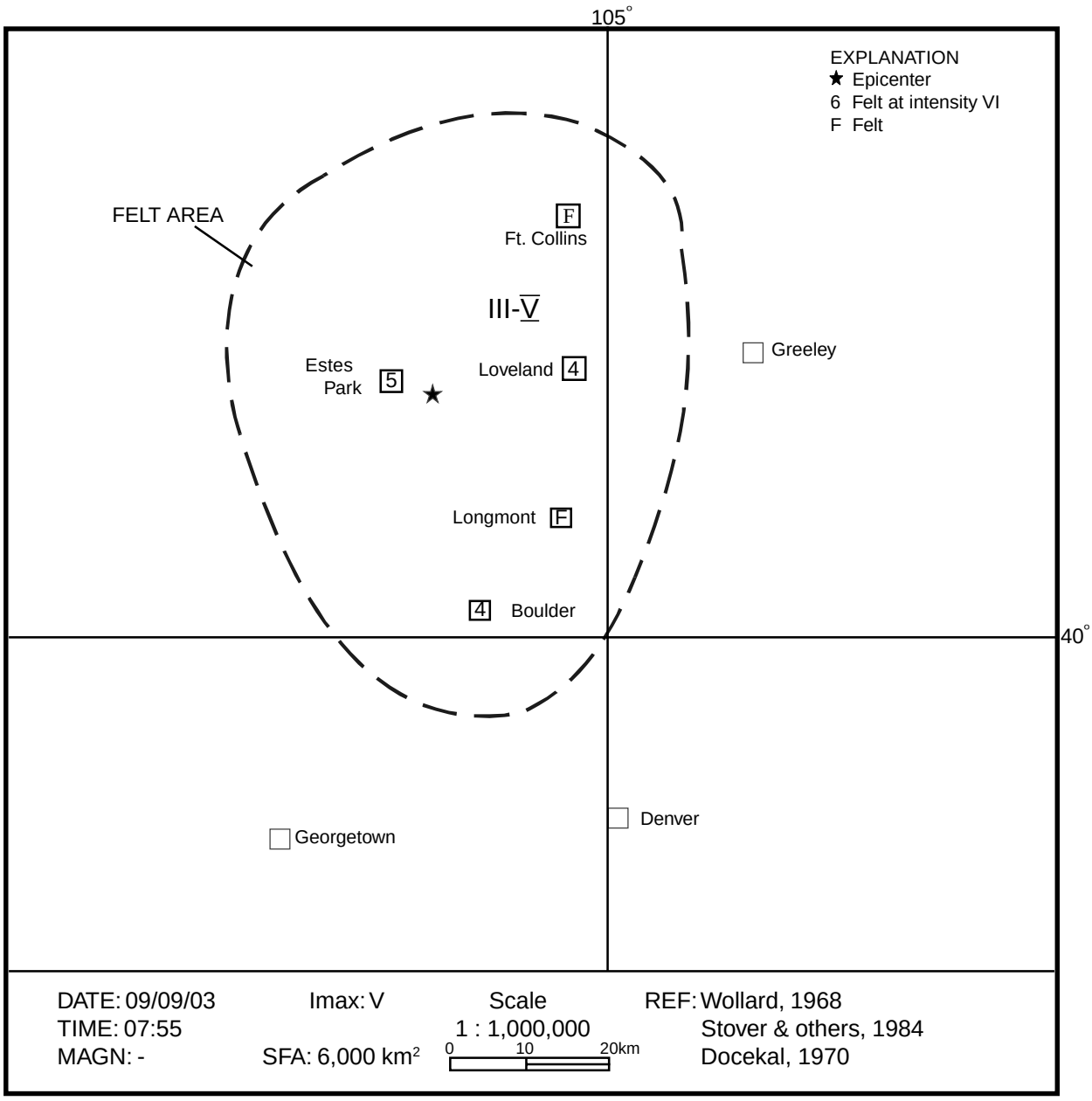


Figure 3. Intensity map for the September 9, 1903 earthquake.

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 km 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 been located.

We assign the damage reported in Ridgway an intensity VI and the reports from Montrose, Ouray, and Telluride an intensity V. A very poorly constrained 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.

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.

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.

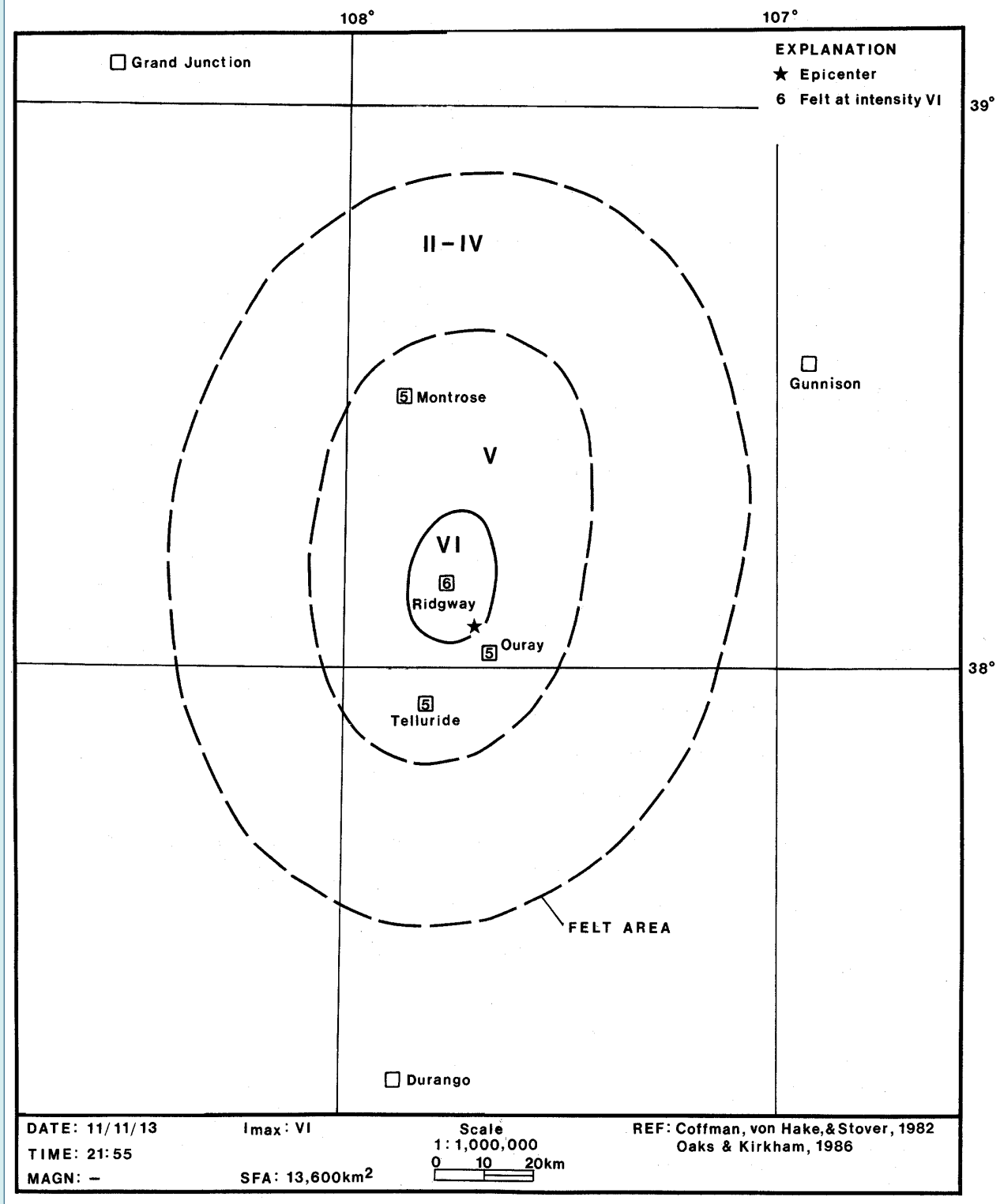


Figure 4. Isoseimal map for the November 11, 1913 earthquake.

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 December 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 Canyon Creek the quake caused some ranch families to rush from their homes. *The Glenwood Post* suggests that only 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, Canyon Creek-IV to V, Cardiff-III, Glenwood Springs, Rifle, Silt, Antlers, West Elk Creek Ranch, South Canyon, 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.

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 near the southern end of the Sawatch Range. Unfortunately, very little is known about this earthquake swarm.

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 intensity III.

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.

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.

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 estimate was a rough approximation.

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.

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) reported that the "shocks on May 1st were quite strong and more widely felt at least 15 or 20 miles [24 or 32 km] from Creede. The shock on May 10 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.

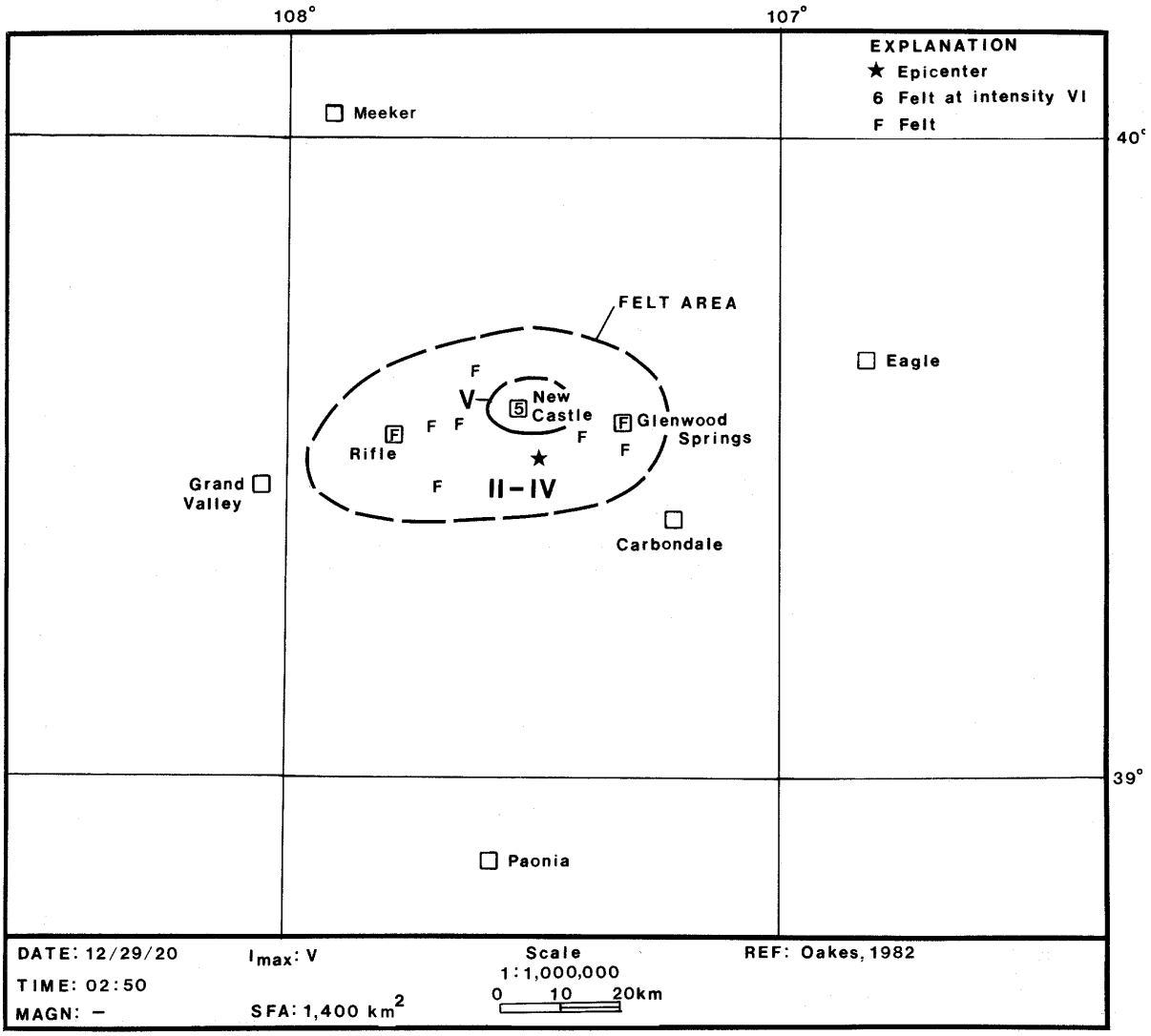


Figure 5. Intensity map for the December 29, 1920 earthquake.

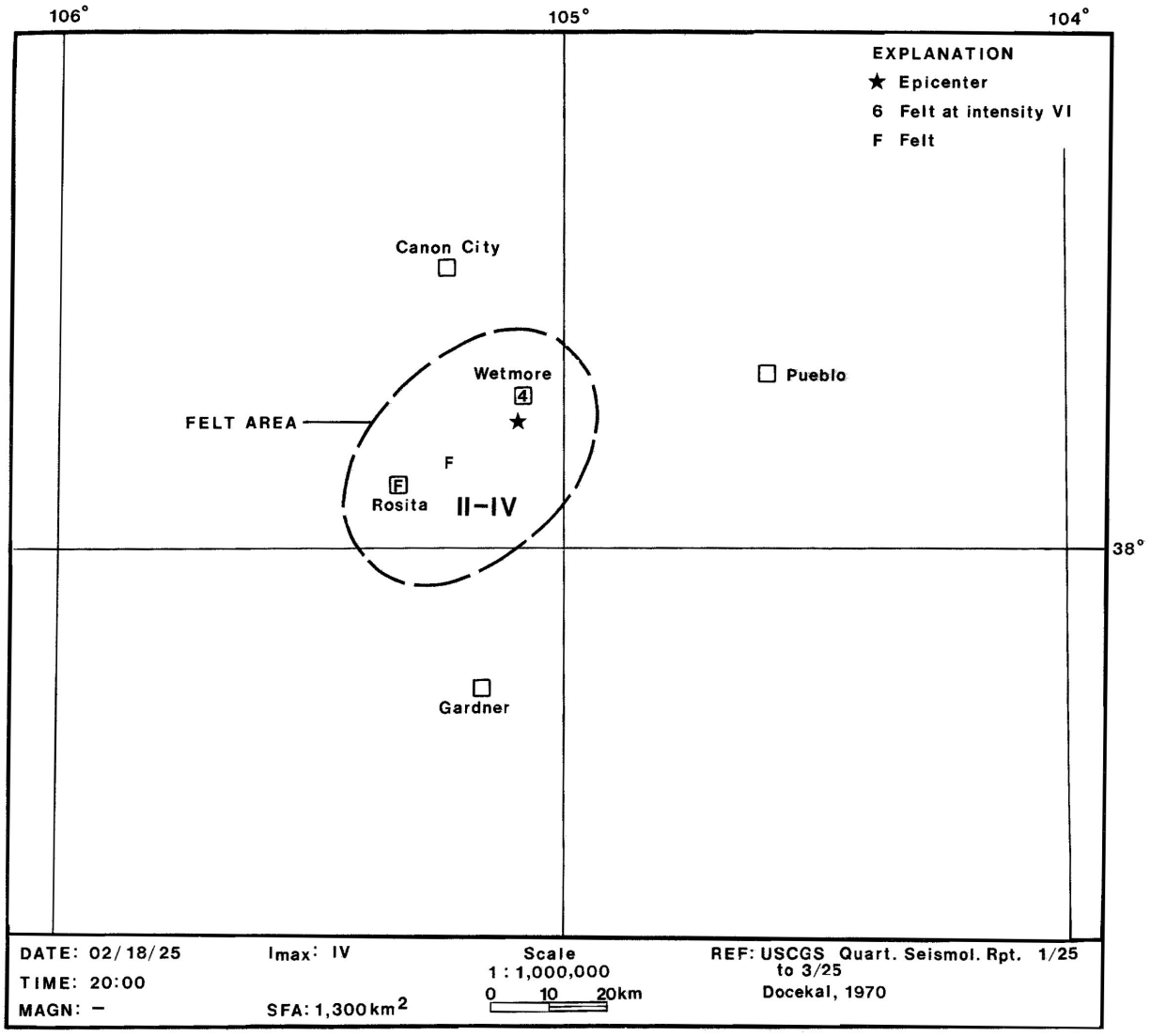


Figure 6. Intensity map for the February 18, 1925 earthquake.

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.

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 **(Neumann, 1936)**. Surface faulting occurred in the epicentral area, along with "The emission of large quantities of water from fissures and craterlets".

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

July 30, 1934

Parts of Nebraska, South Dakota, Wyoming, and Colorado were shaken by the July 30, 1934 Chadron, Nebraska earthquake **(Neumann, 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. Neumann (1936) suggested the earthquake was felt over 60,000 km^2. Isoseismal maps for this event are contained in **Neumann (1936)** and **Docekal (1970)**.

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 **Neumann (1938)** is shown in **Figure 7**. Slight damage occurred over scattered areas in Texas, Oklahoma, and Kansas (Neumann, 1938).

Richards, Colorado reported an intensity III or less, and the earthquake was apparently heard at this location. According to a map in Neumann (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.

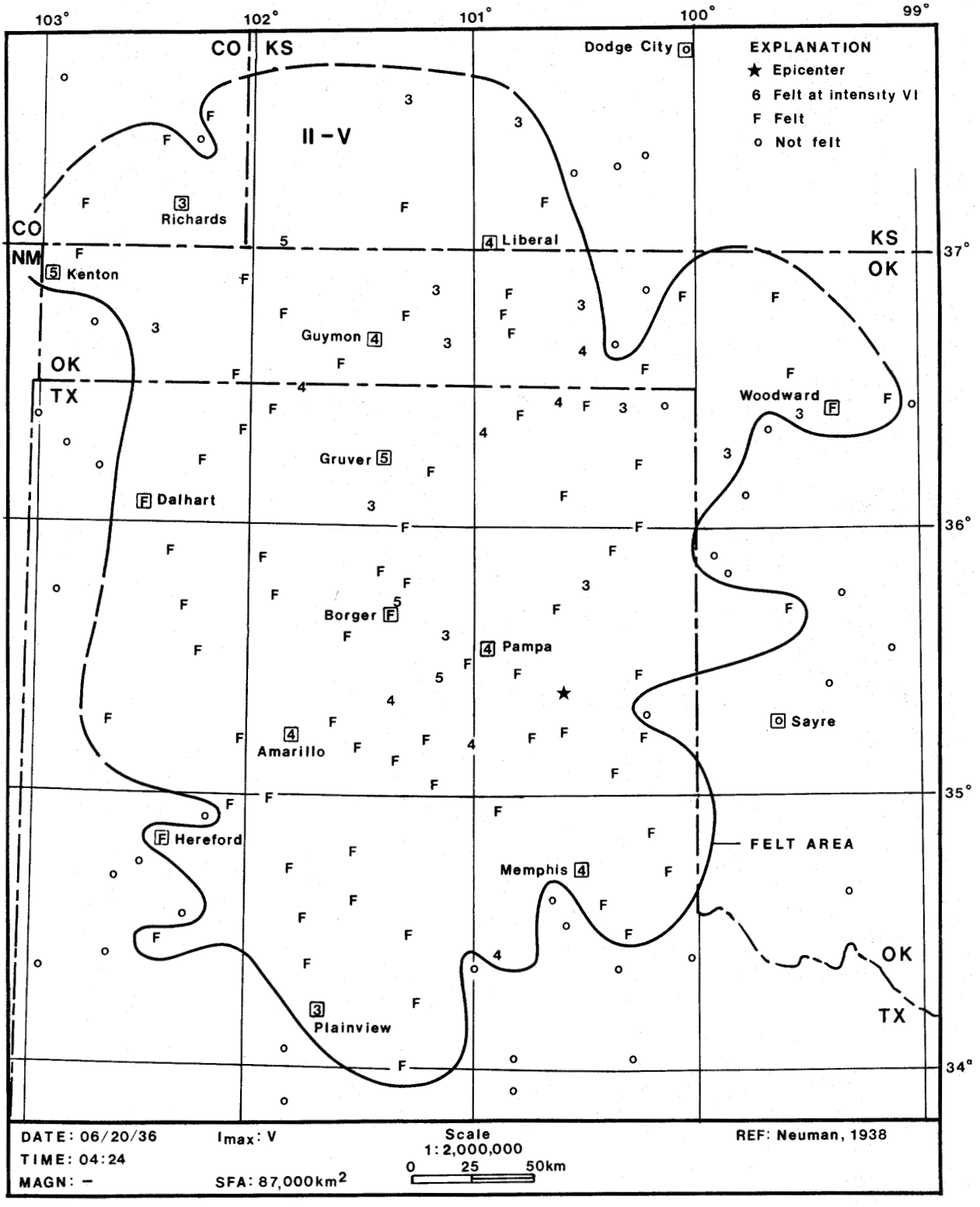


Figure 7. Intensity map for the June 20, 1936 earthquake.

April 8, 1940 to February 28, 1941

Neumann (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)**.

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.

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.

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 than 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.

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)**.

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 masonry 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. On our isoseismal map the felt area for this event is 123,000 km^2, in close agreement with **Murphy and Ulrich (1951)**.

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.

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 (1952)** described the felt reports and assigned MMI values to each report. "Not felt" reports were obtained from the NOAA microfilm files for the following locations: 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 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. The epicenter was along the west side of the valley, possibly in the foothills of the San Juan Mountains.

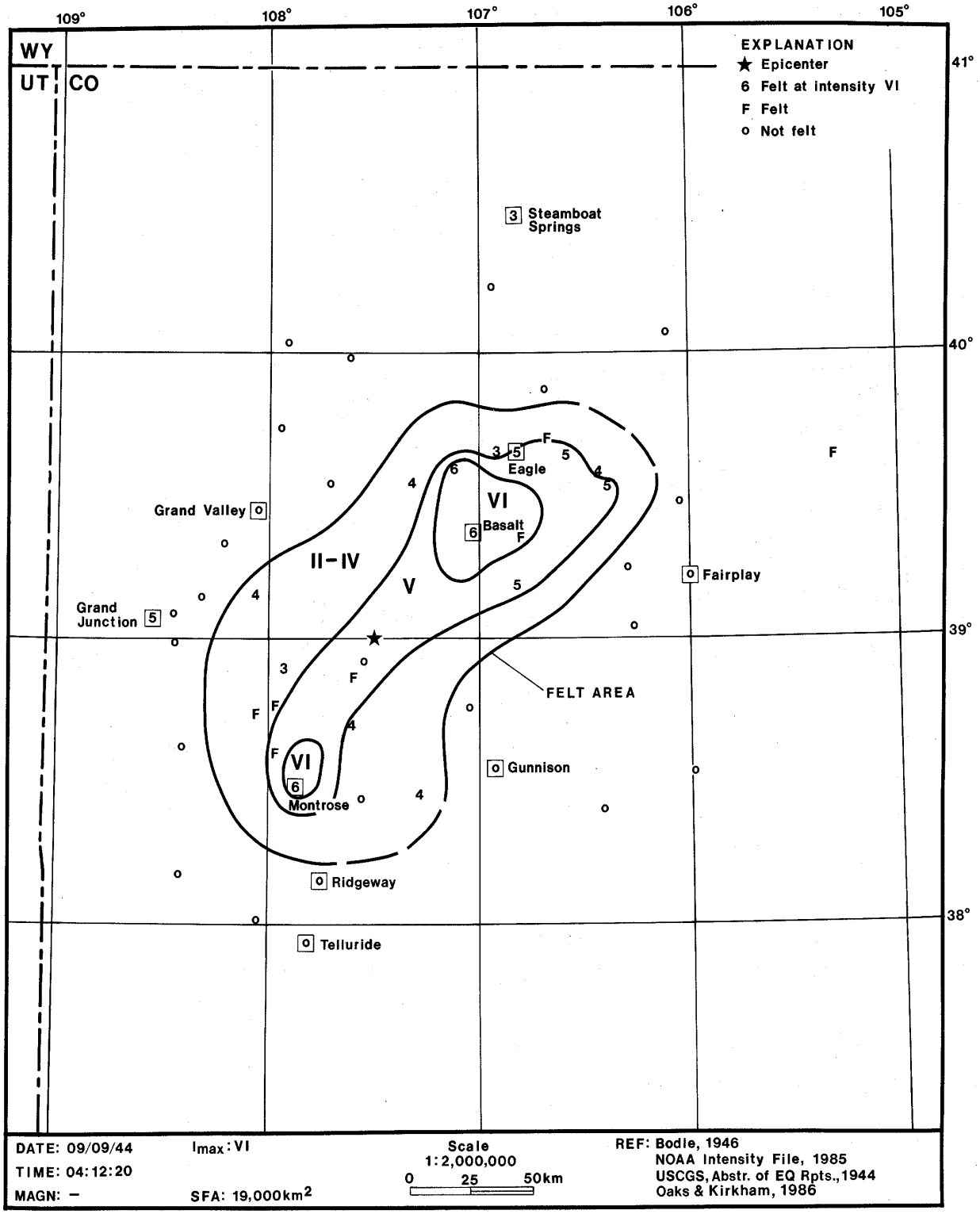


Figure 8. Isoseismal map for the September 9, 1944 earthquake.

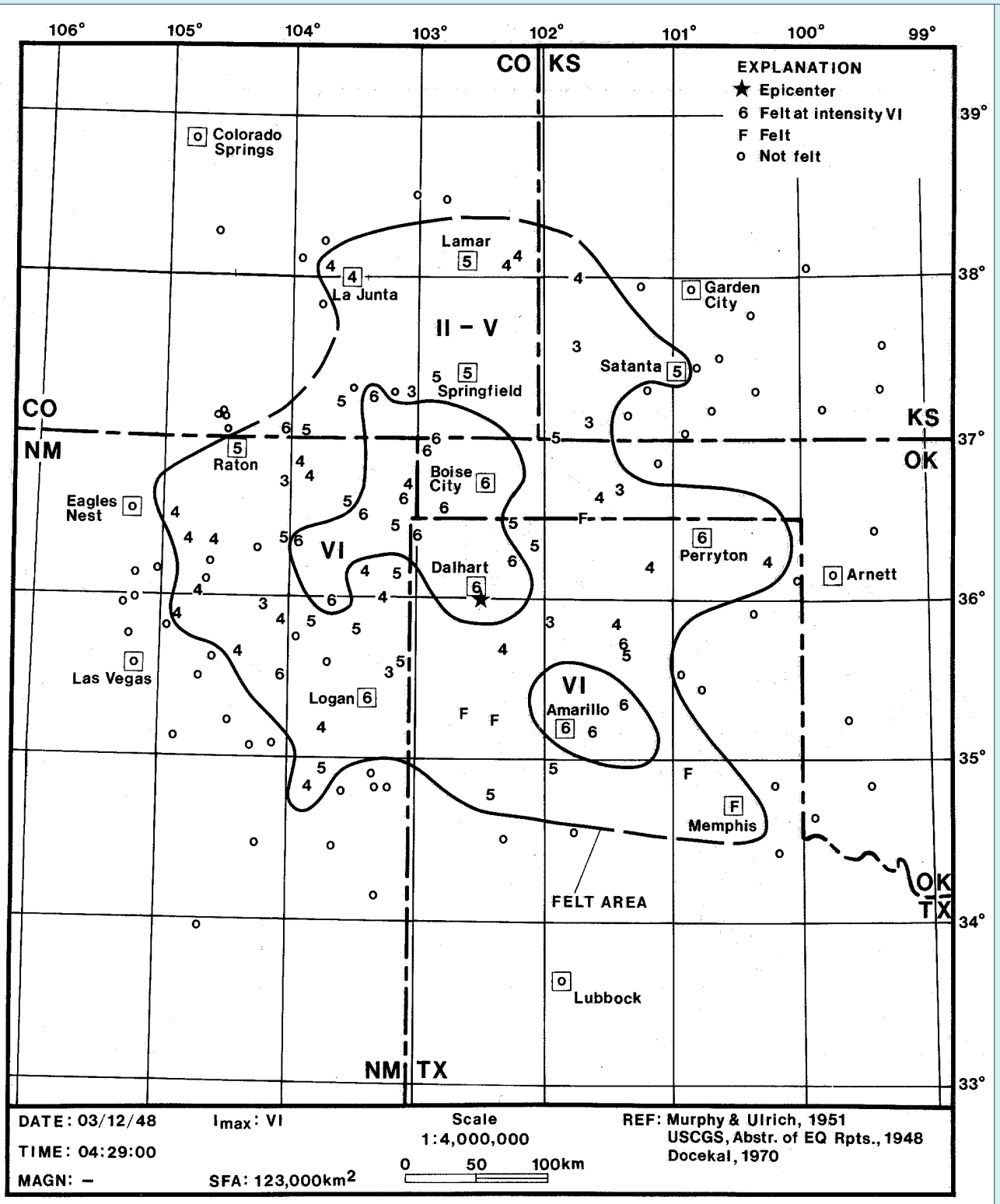


Figure 9. Isoseismal map for the March 12, 1948 earthquake.

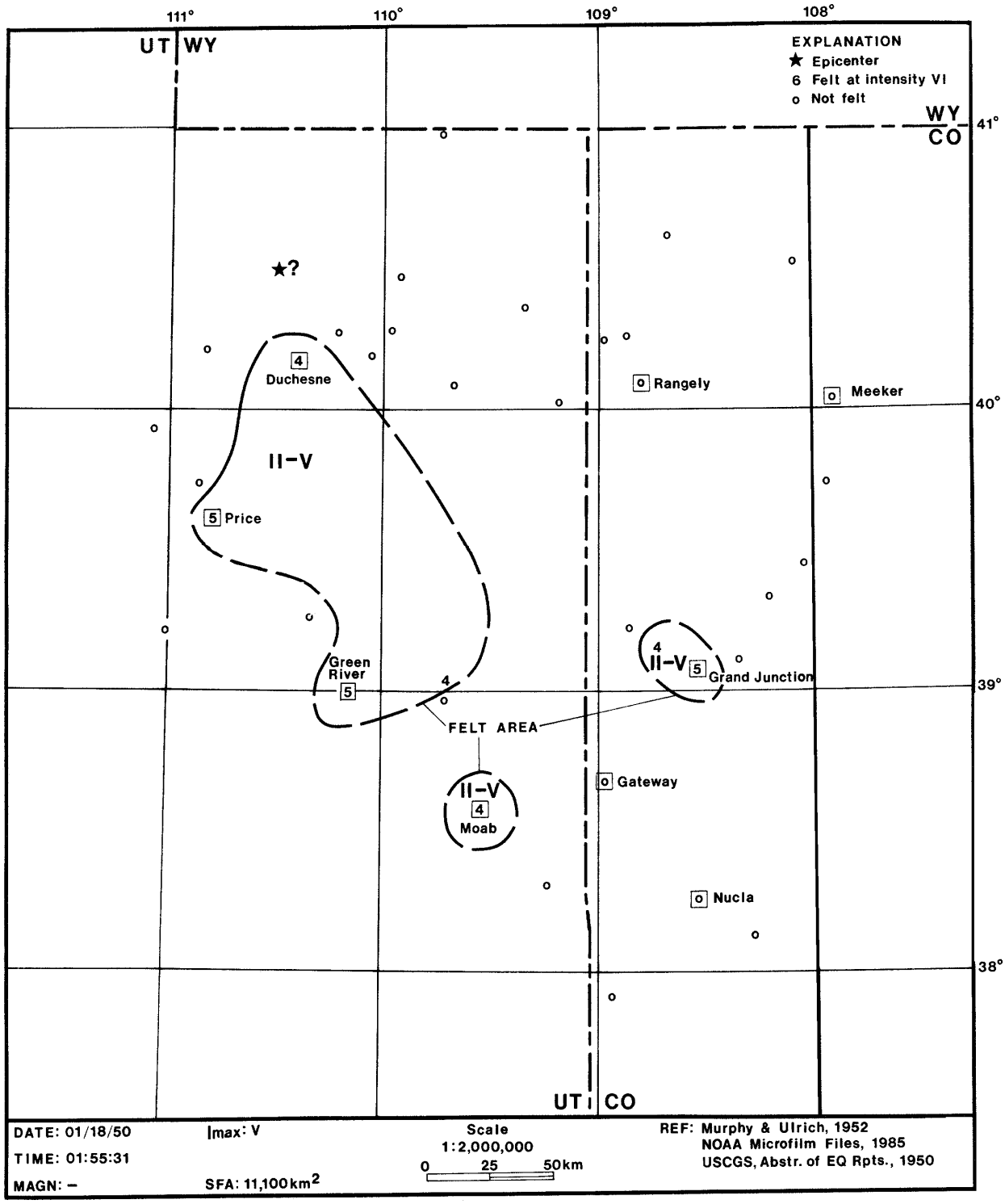


Figure 10. Intensity map for the January 18, 1950 earthquake.

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. About 6 km (four mi.) 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 6,700 km^2.

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 about 3 km 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)** described a newspaper account of this event in Rangley, where dished 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.

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 been substantiated.

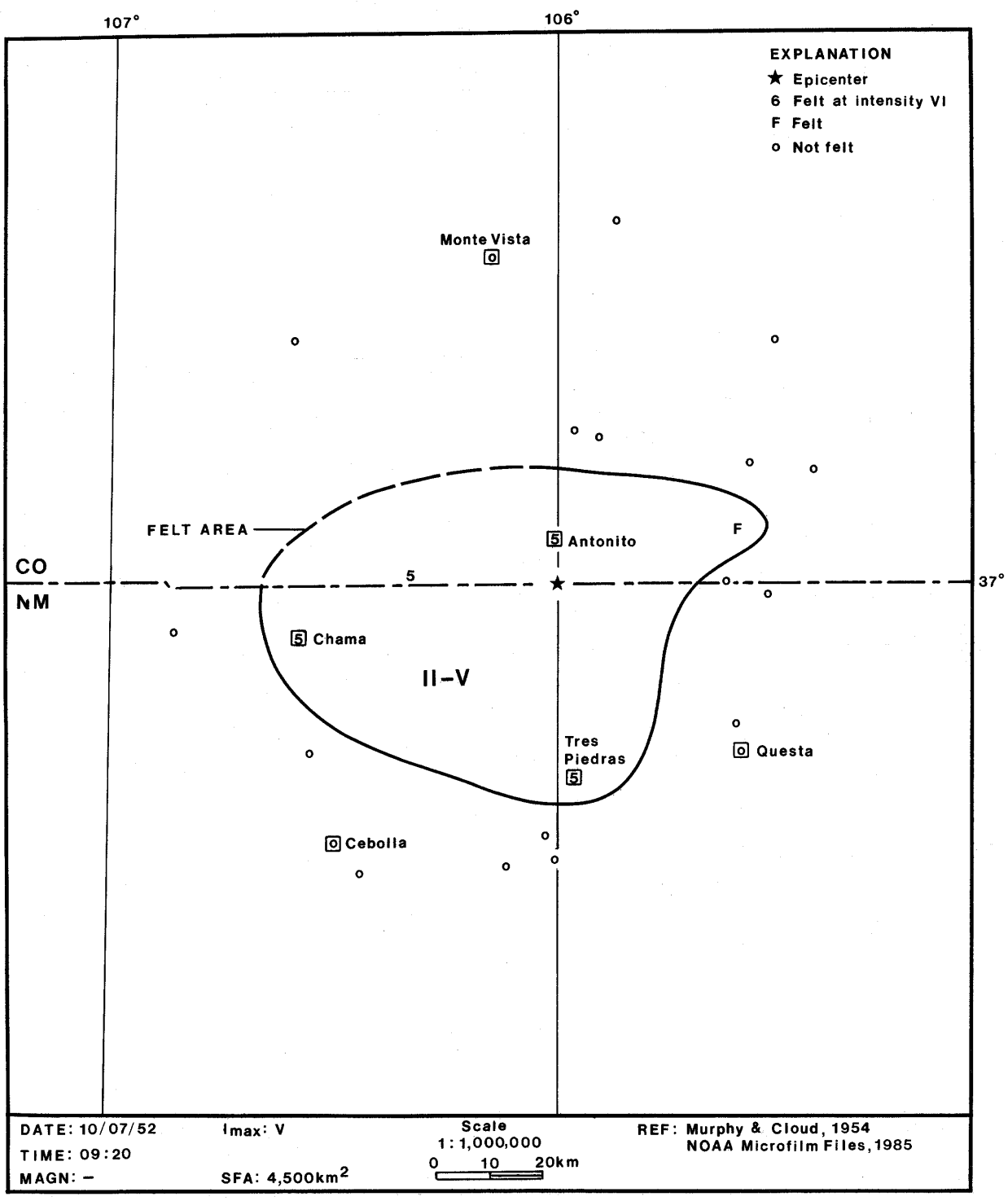


Figure 11. Intensity map for the October 7, 1952 earthquake.

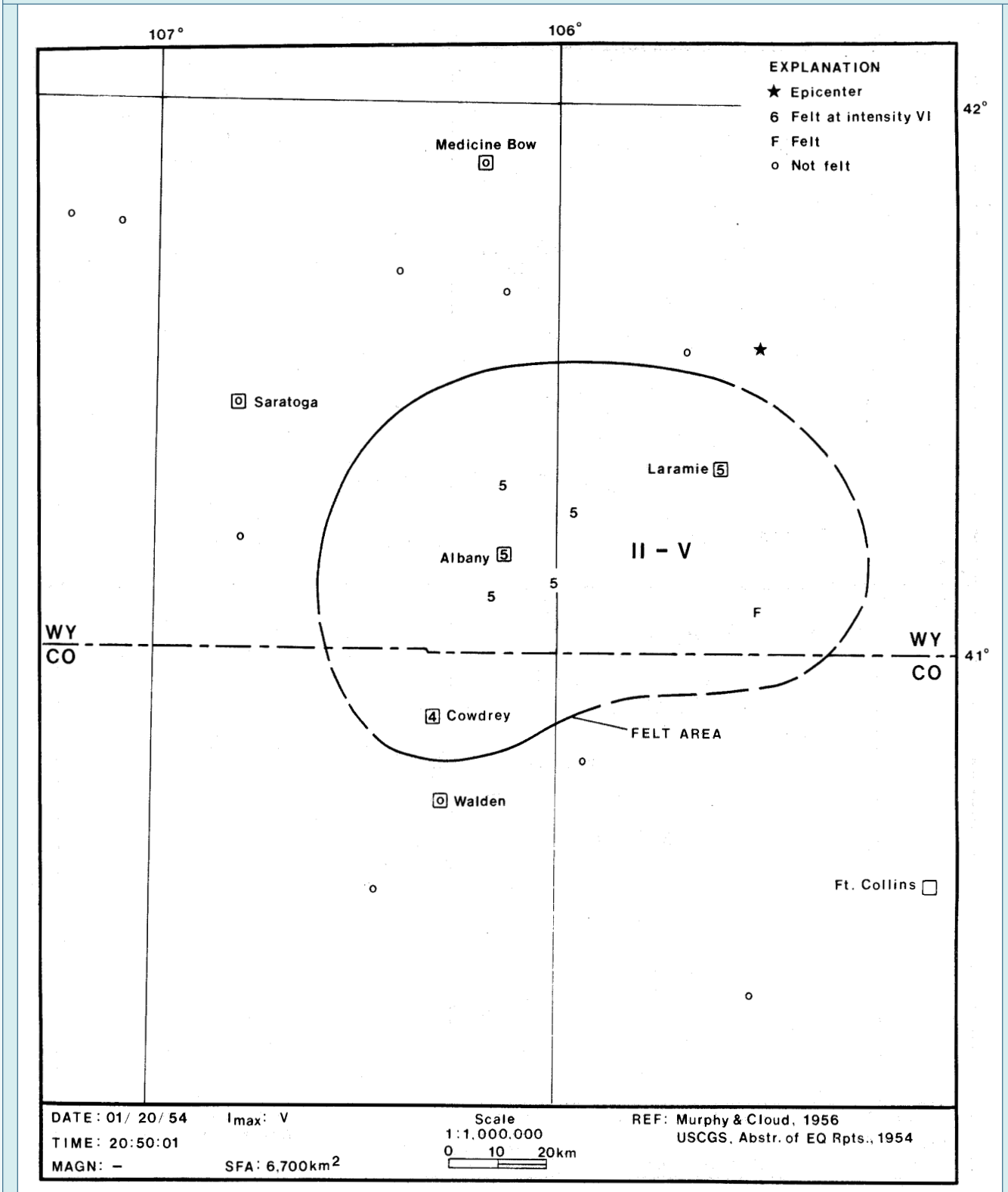


Figure 12. Intensity map for the January 20, 1954 earthquake.

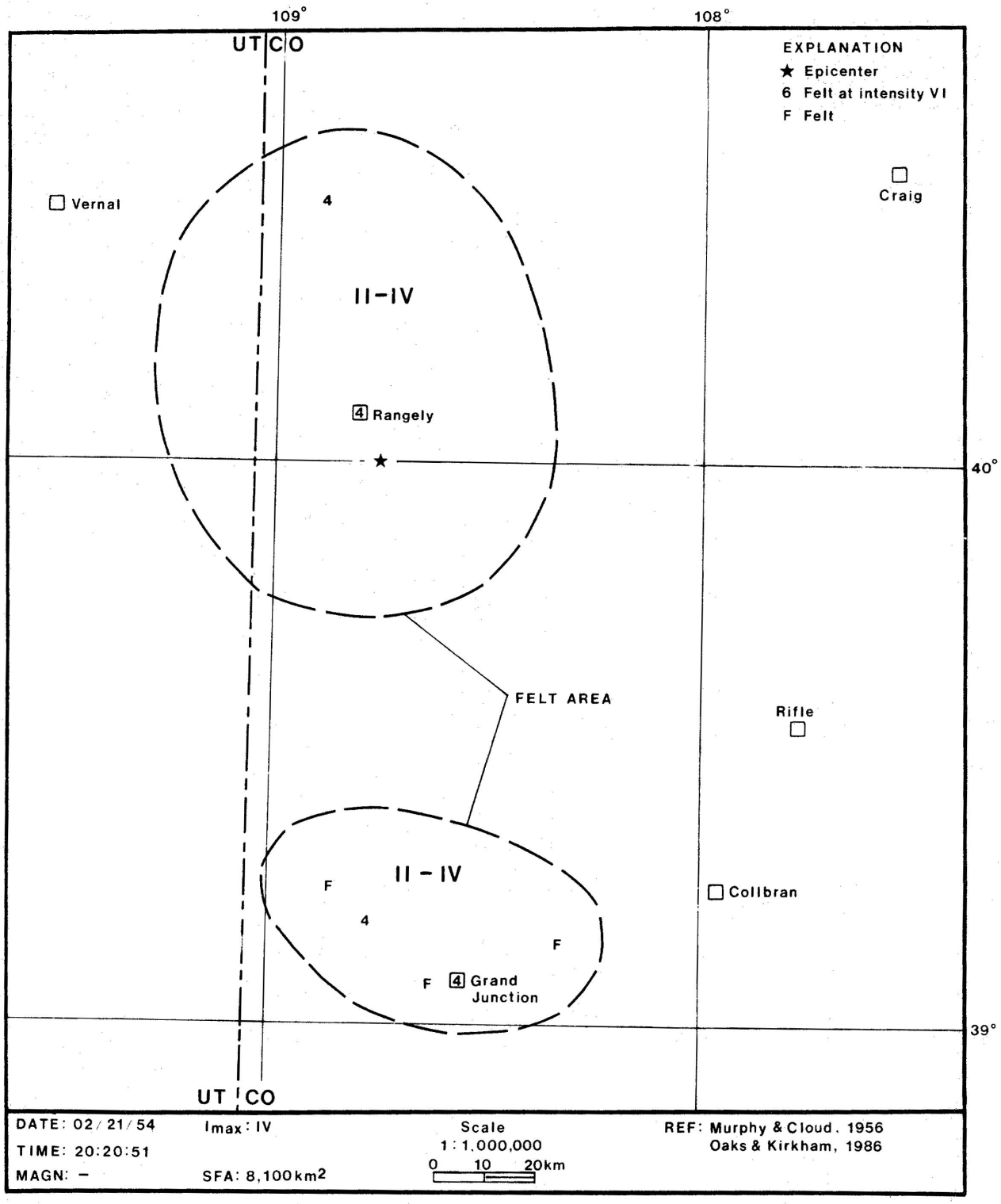


Figure 13. Intensity map for the February 21, 1954 earthquake.

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.

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, a location 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.

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 intensity 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.

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 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.

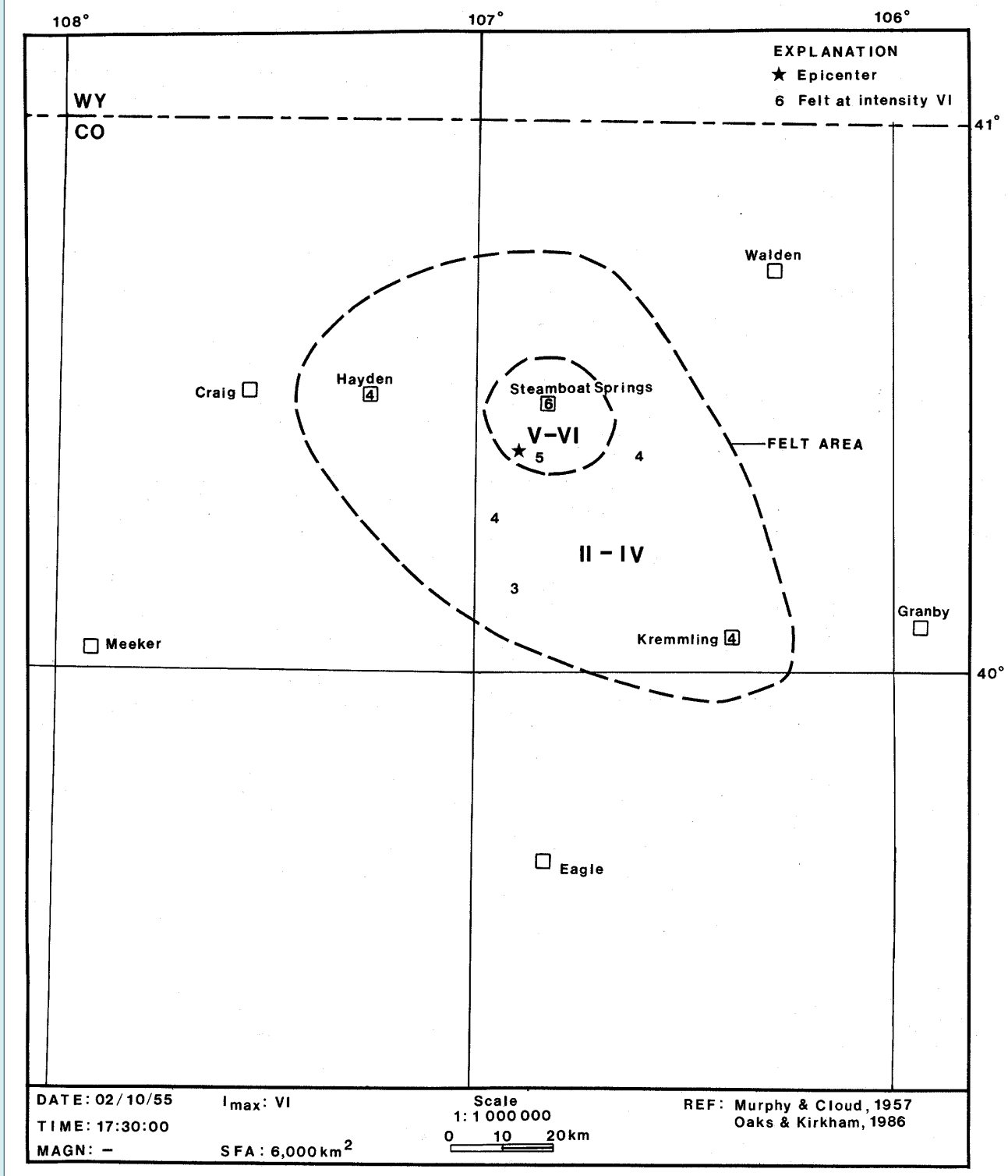


Figure 14. Isoseismal map for the February 10, 1955 earthquake.

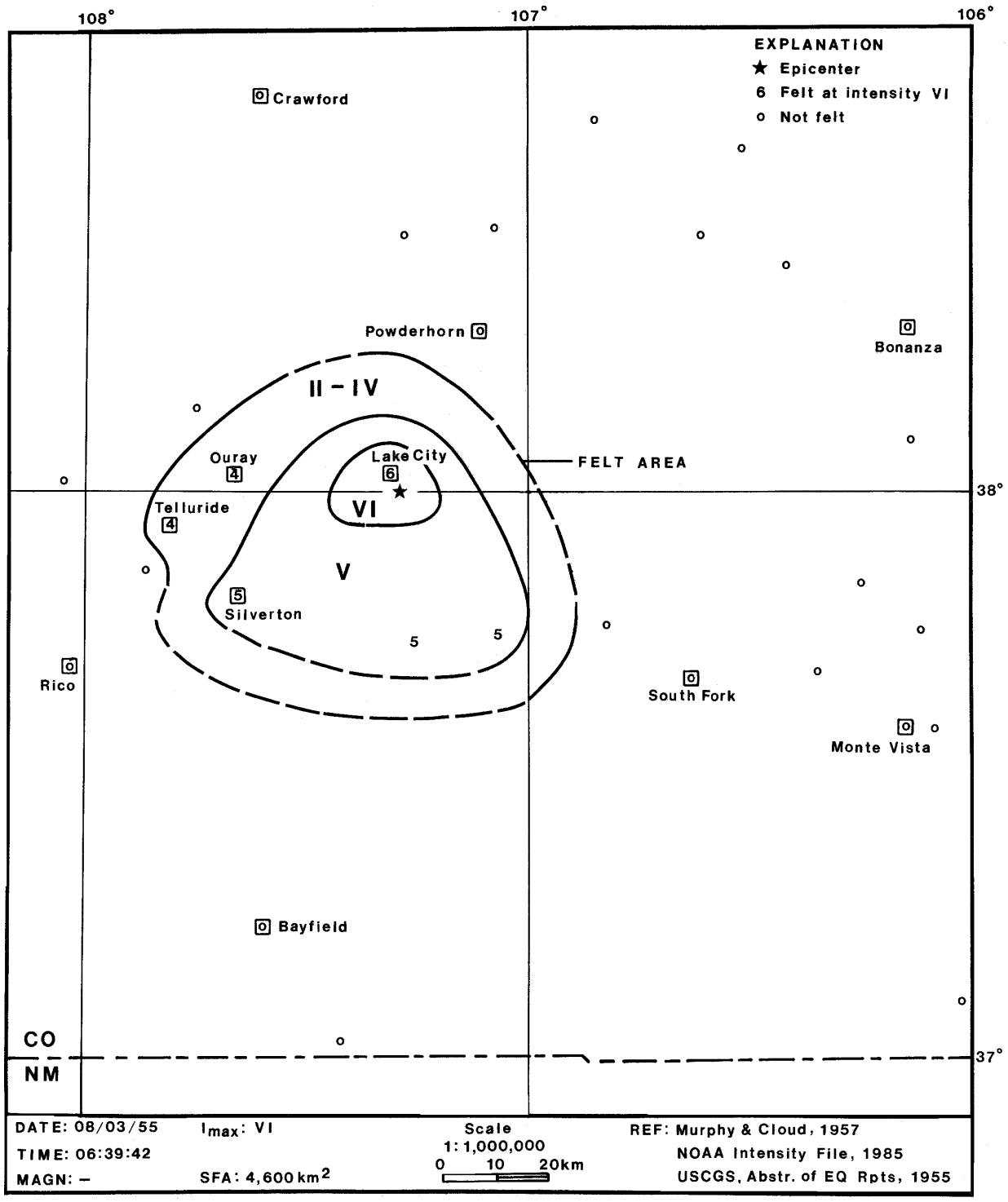


Figure 15. Isoseismal map for the August 3, 1955 earthquake.

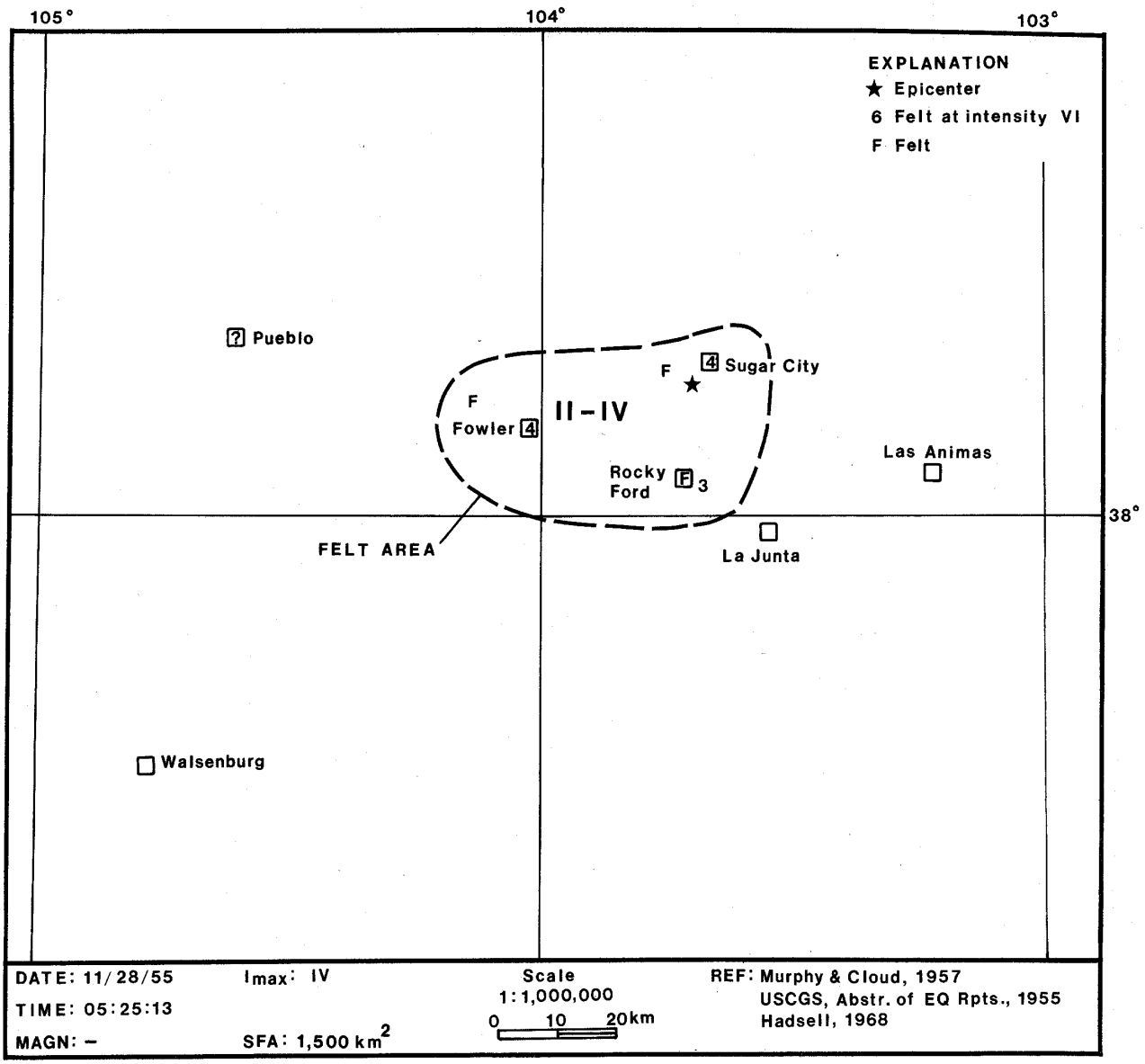


Figure 16. Intensity map for the November 28, 1955 earthquake.

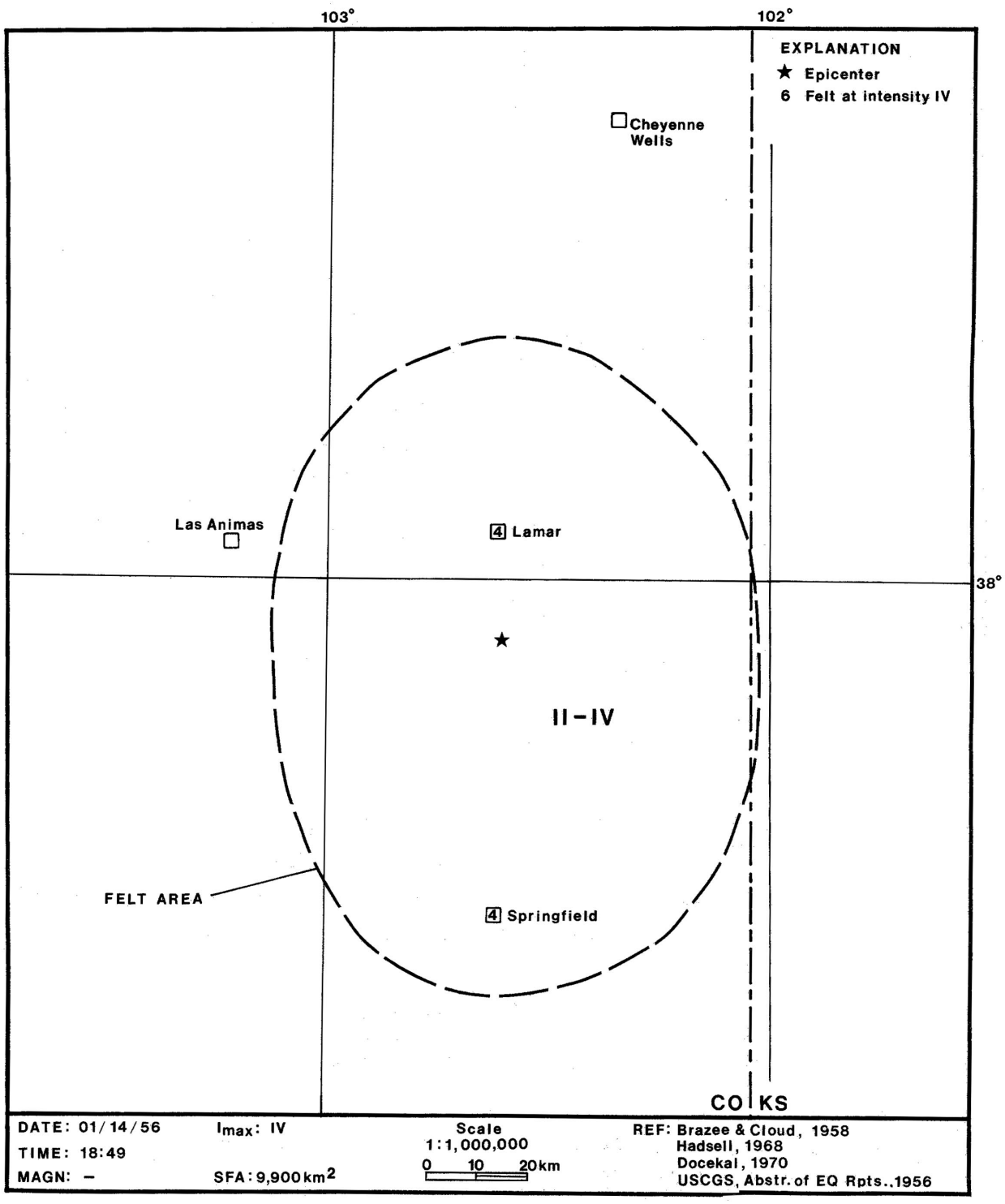


Figure 17. Intensity map for the January 14, 1956 earthquake.

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 largest earthquakes to occur historically in the state. **Tally and Cloud (1962)** described the effects of 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) reported a magnitude of mb 5.5 for this earthquake. Their isoseismal map for the event indicates 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. **Unruh and others (1993)** relocated this event and report a slightly different epicentral location; we use their location in Table 1.

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.

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 ML 2.5 was calculated for the event **(Major and Simon, 1968)** and the felt area was only 500 km^2. **Docekal (1970)** reported a 780 km^2 felt area.

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 mb 5.7 quake. The isoseismal map shown in **Figure 21** is redrafted from one presented by **Lander and Cloud (1964).**

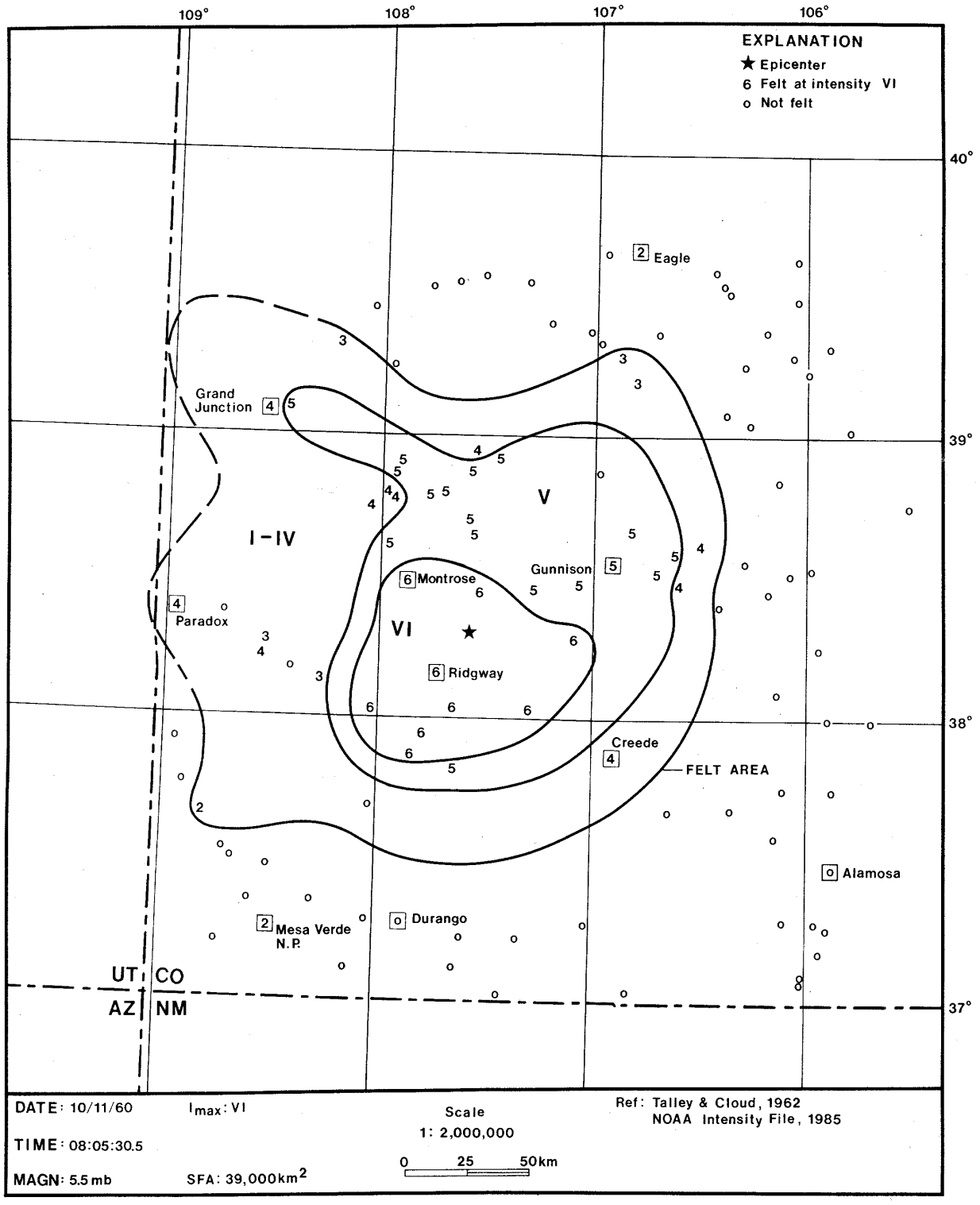


Figure 18. Isoseismal map for the October 11, 1960 earthquake.

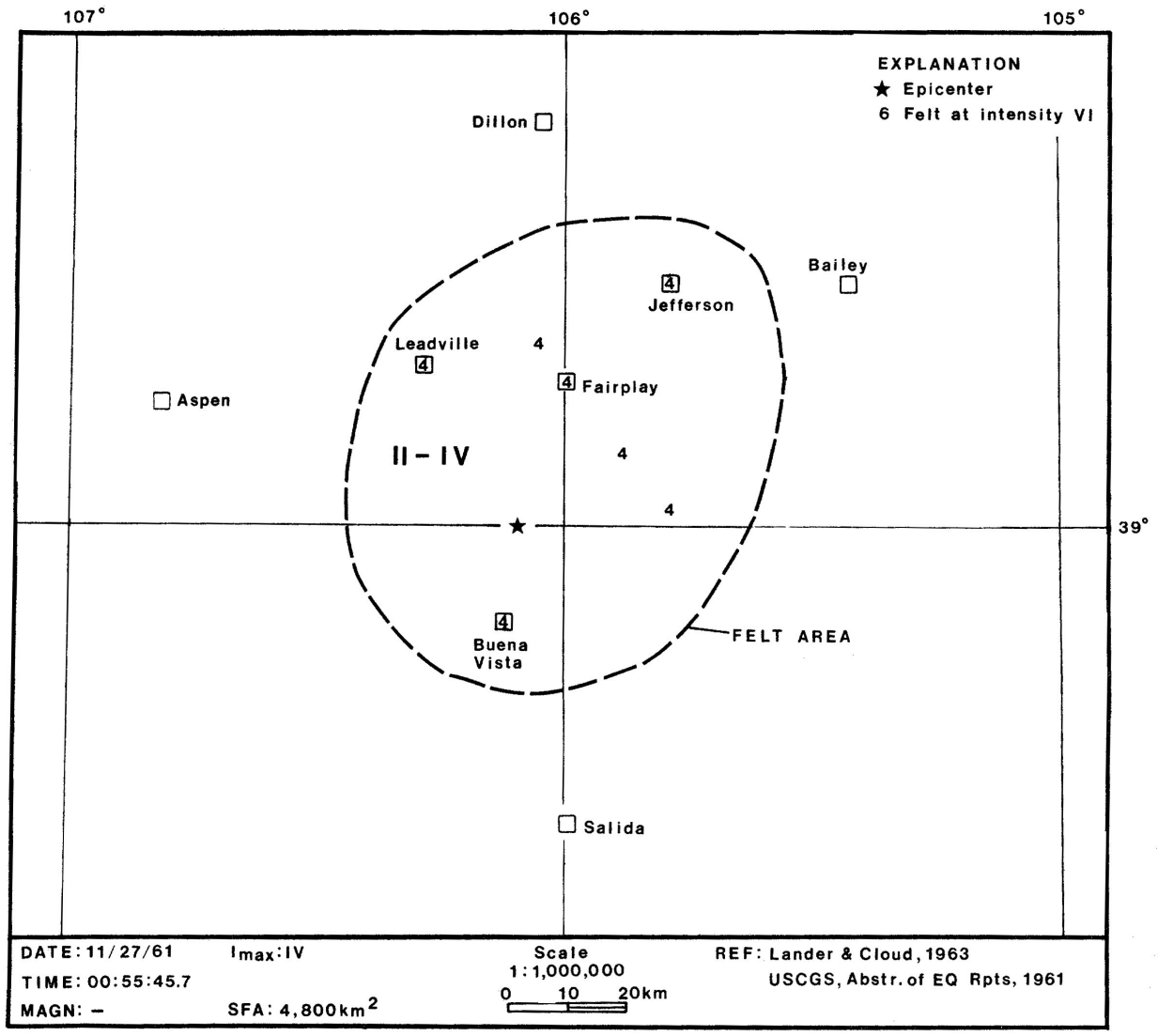


Figure 19. Intensity map for the November 27, 1961 earthquake.

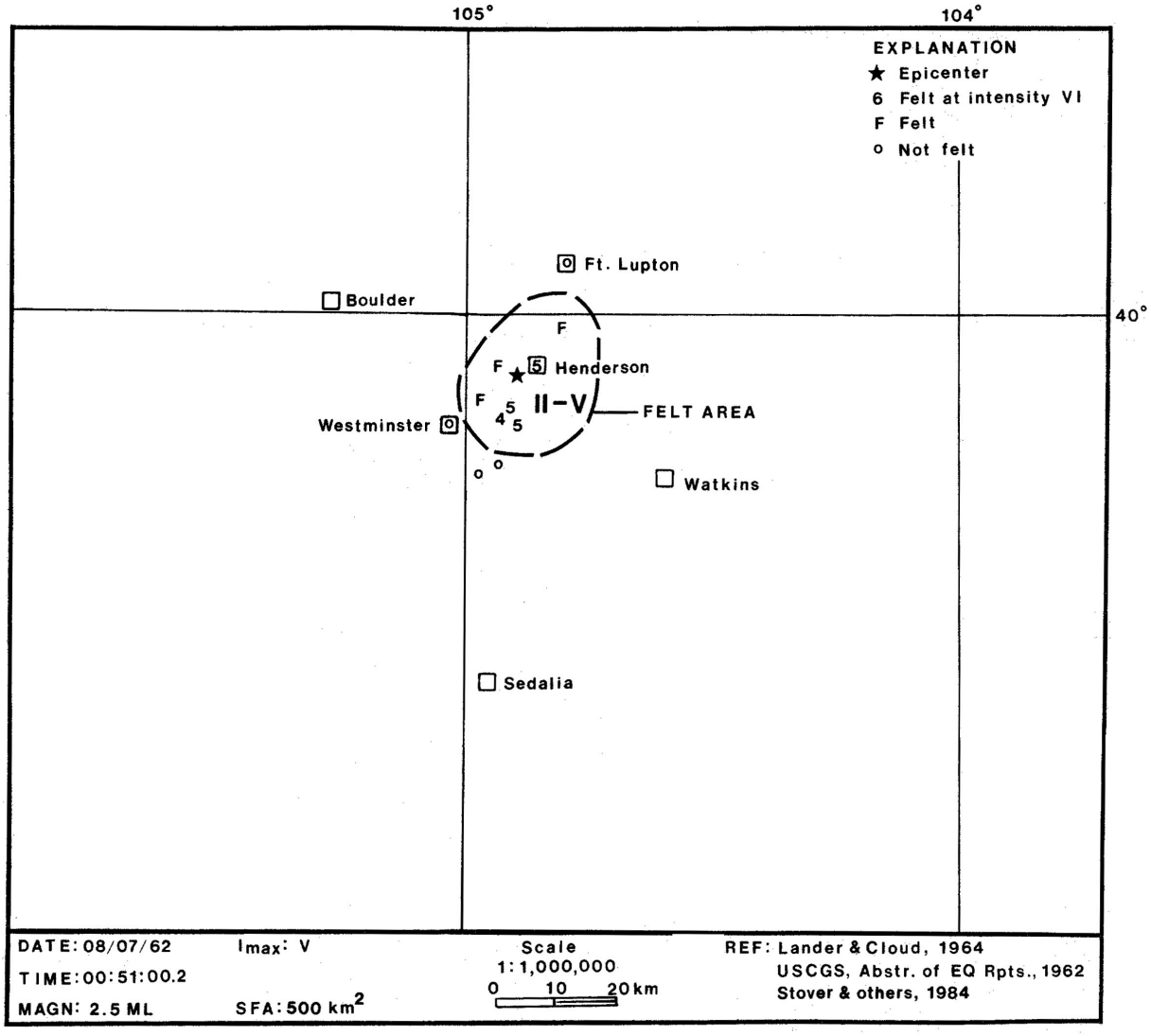


Figure 20. Intensity map for the August 7, 1962 earthquake.

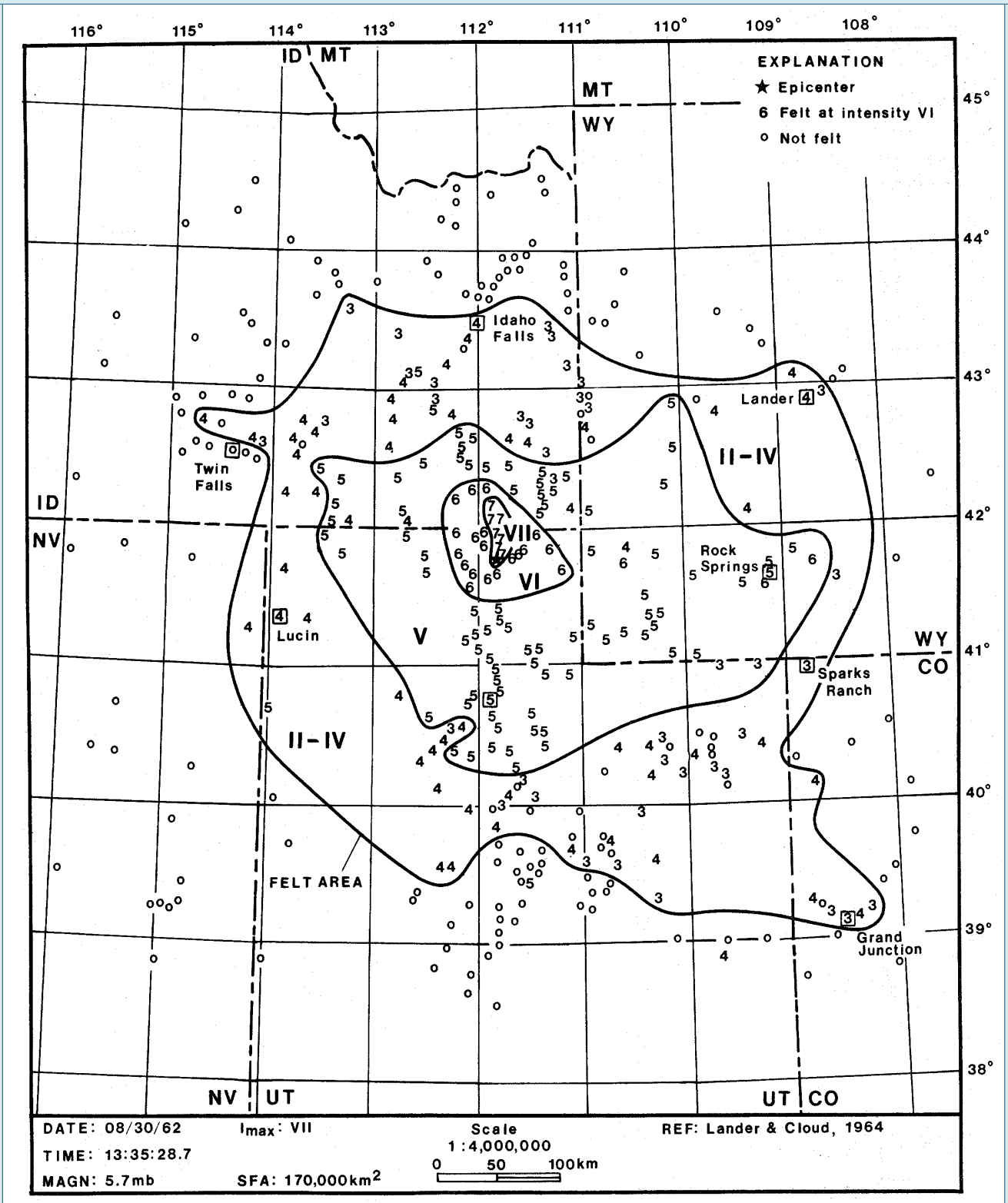


Figure 21. Isoseismal map for the August 30, 1962 earthquake.

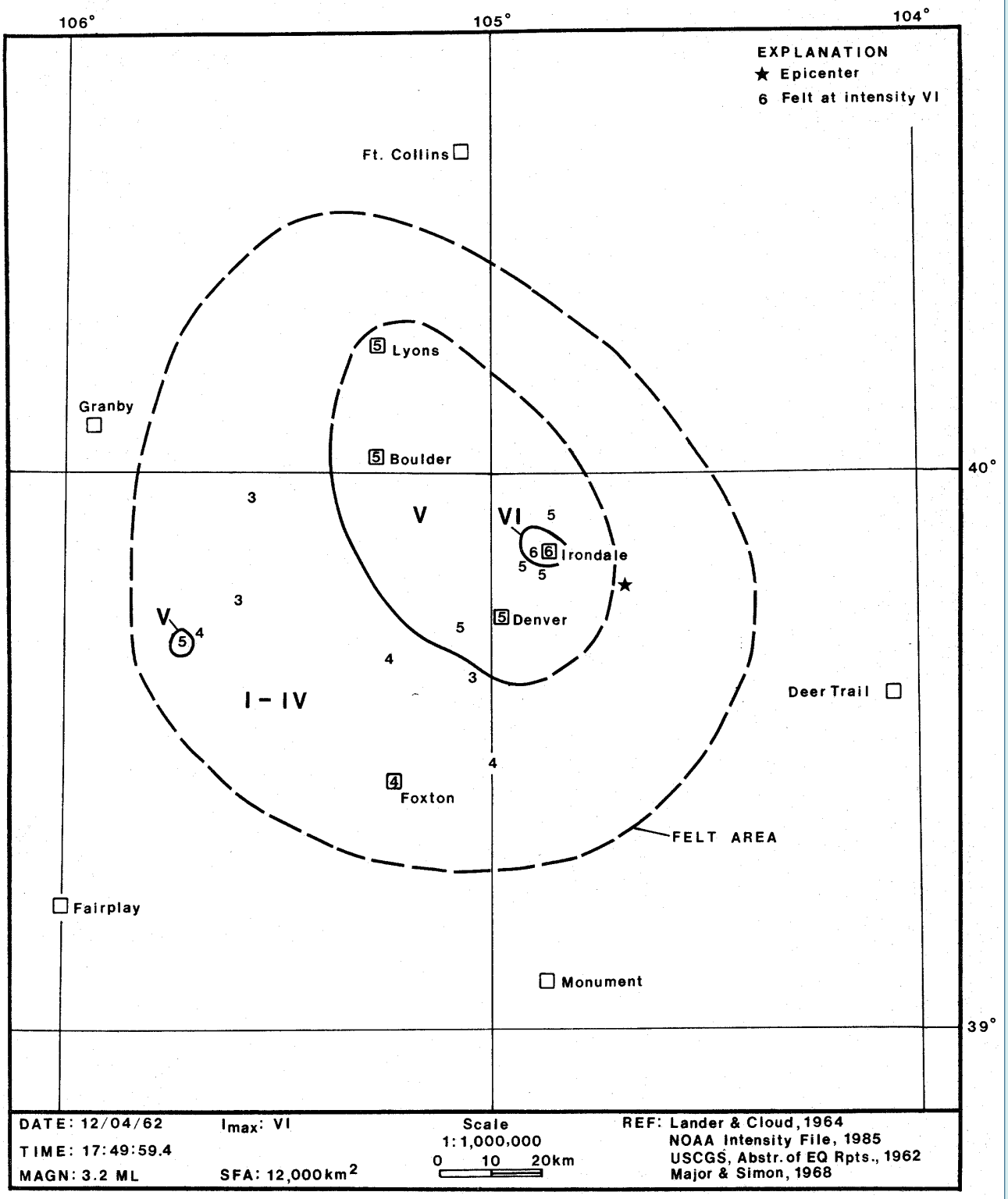


Figure 22. Isoseismal map for the December 4, 1962 earthquake.

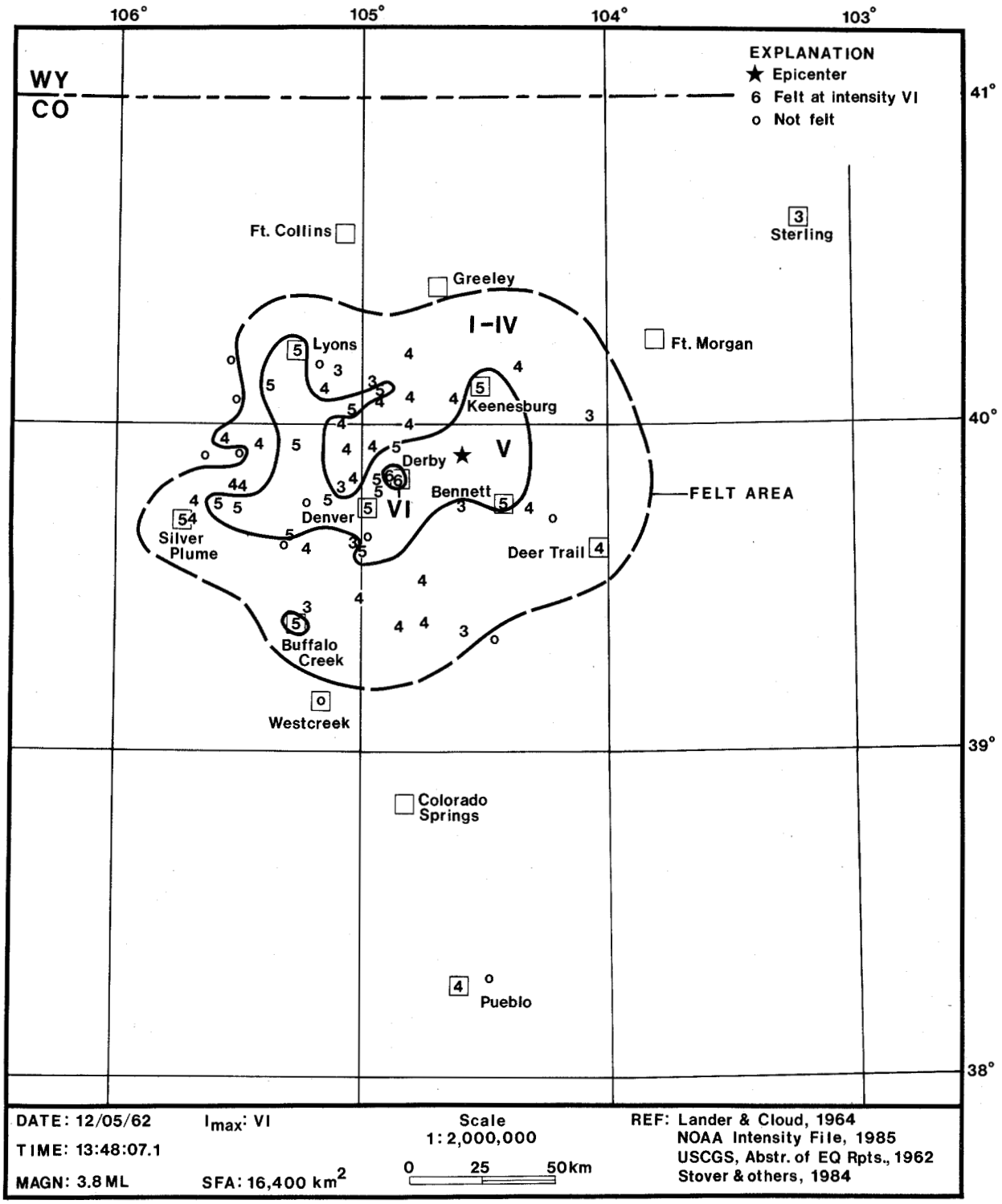


Figure 23. Isoseismal map for the December 5, 1962 earthquake.

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.

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 ML 3.5. 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 (1968)** indicated the felt area was 19,000 km^2, while **Docekal (1970)** reported it at 65,000 km^2.

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

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 region of highest intensities were elongated perpendicular to the mountain front (**Figure 24**). **Major and Simon (1968)** indicate a magnitude of ML 3.5 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.

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 ML 4.0 **(Major and Simon, 1968)** and mb 4.6 (von Hake and Cloud, 1965).

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 was 1,600 km^2, whereas **von Hake and Cloud (1968)** reported it at 780 km^2. **Von Hake and Cloud (1967)** indicated the magnitude was mb 4.9, and **Major and Simon (1968)** reported ML 4.0.

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 for this event, based on Figure 27, is about 27,000 km^2, whereas **Hadsell (1968)** suggested it was 4,700 km^2. Earthquake magnitude was determined at ML 3.6 by **Major and Simon (1968)** and mb 4.7 by **von Hake and Cloud (1967)**.

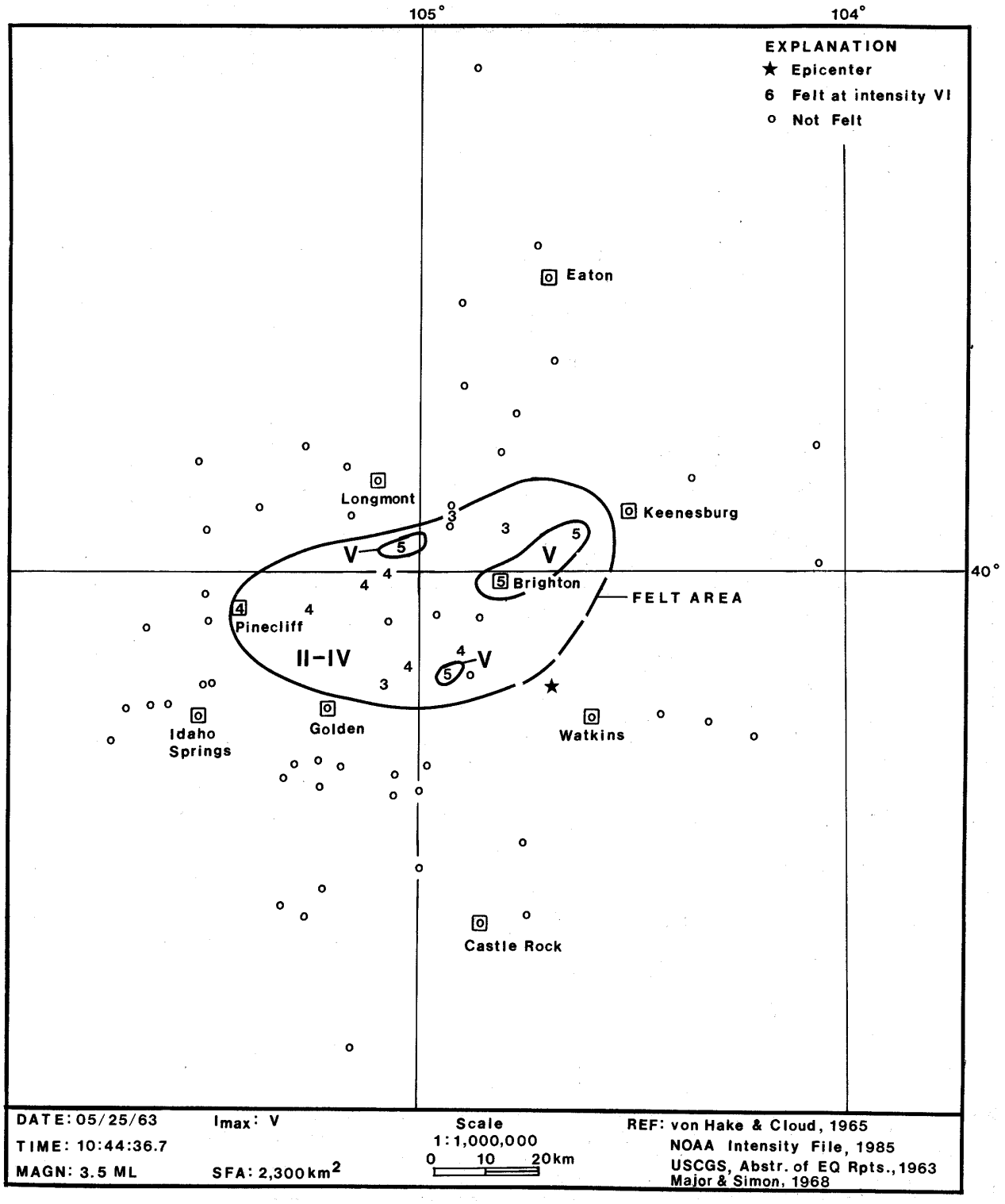


Figure 24. Isoseismal map for the May 25, 1963 earthquake.

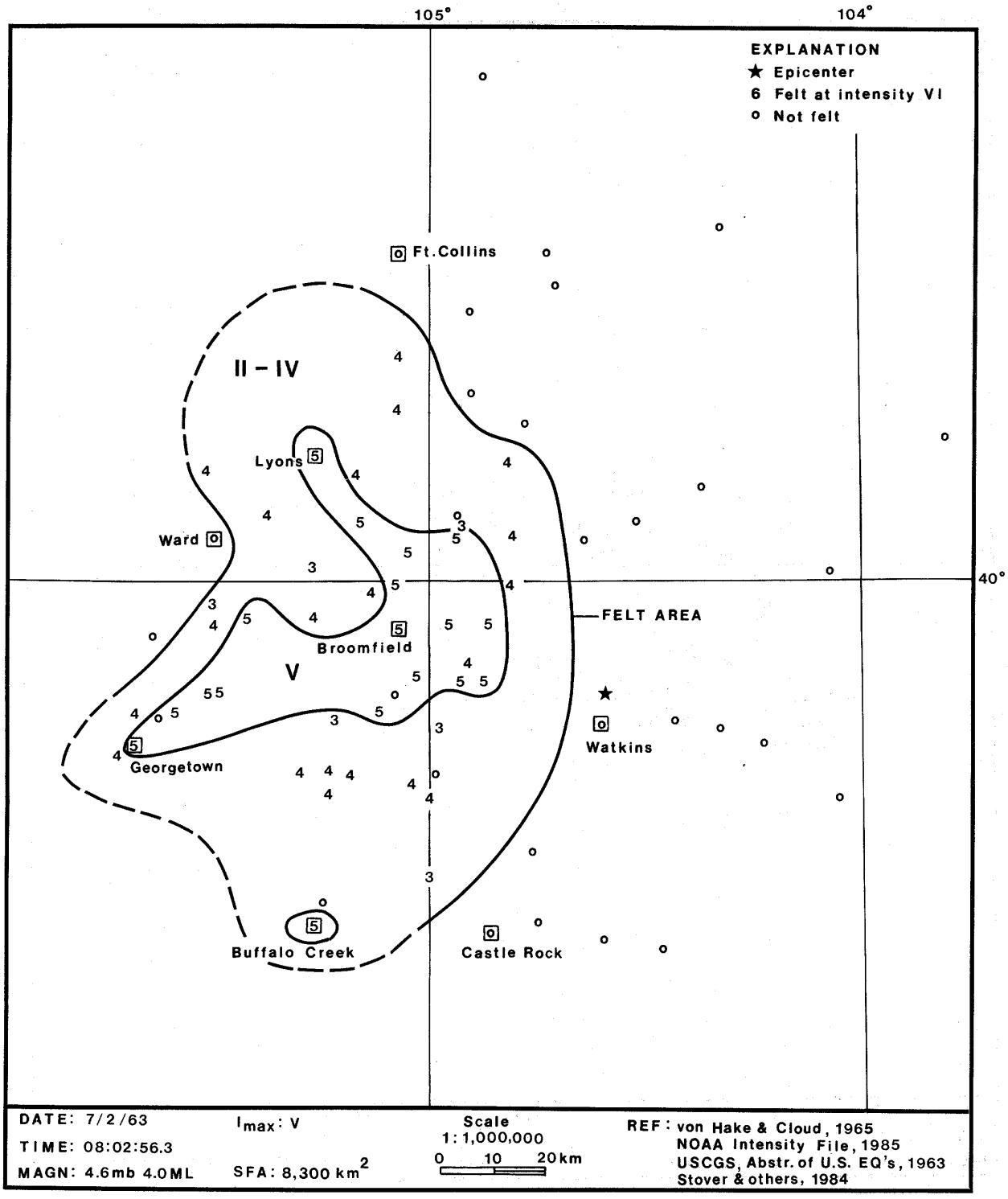


Figure 25. Isoseismal map for the July 2, 1963 earthquake.

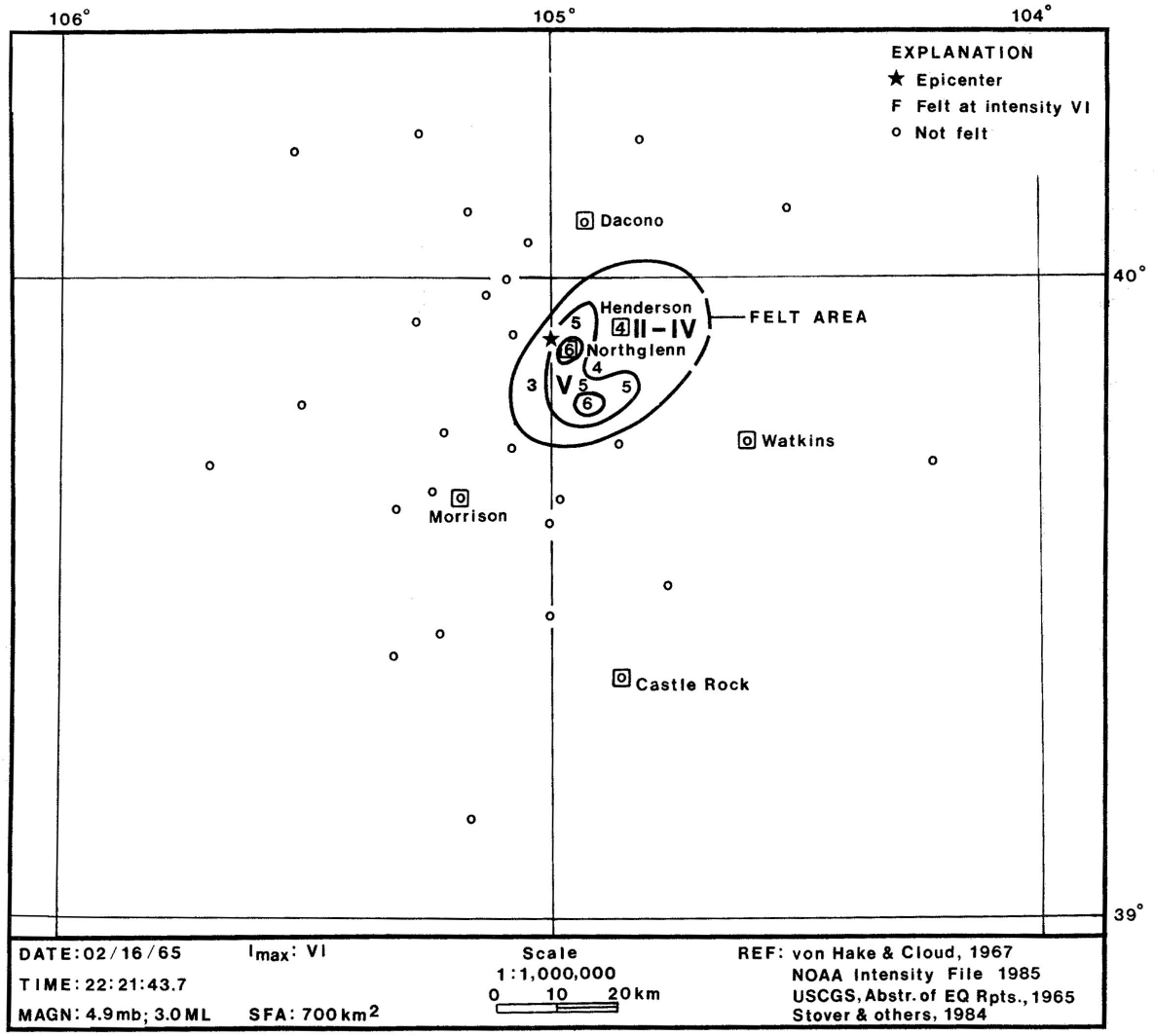


Figure 26. Isoseismal map for the February 16, 1965 earthquake.

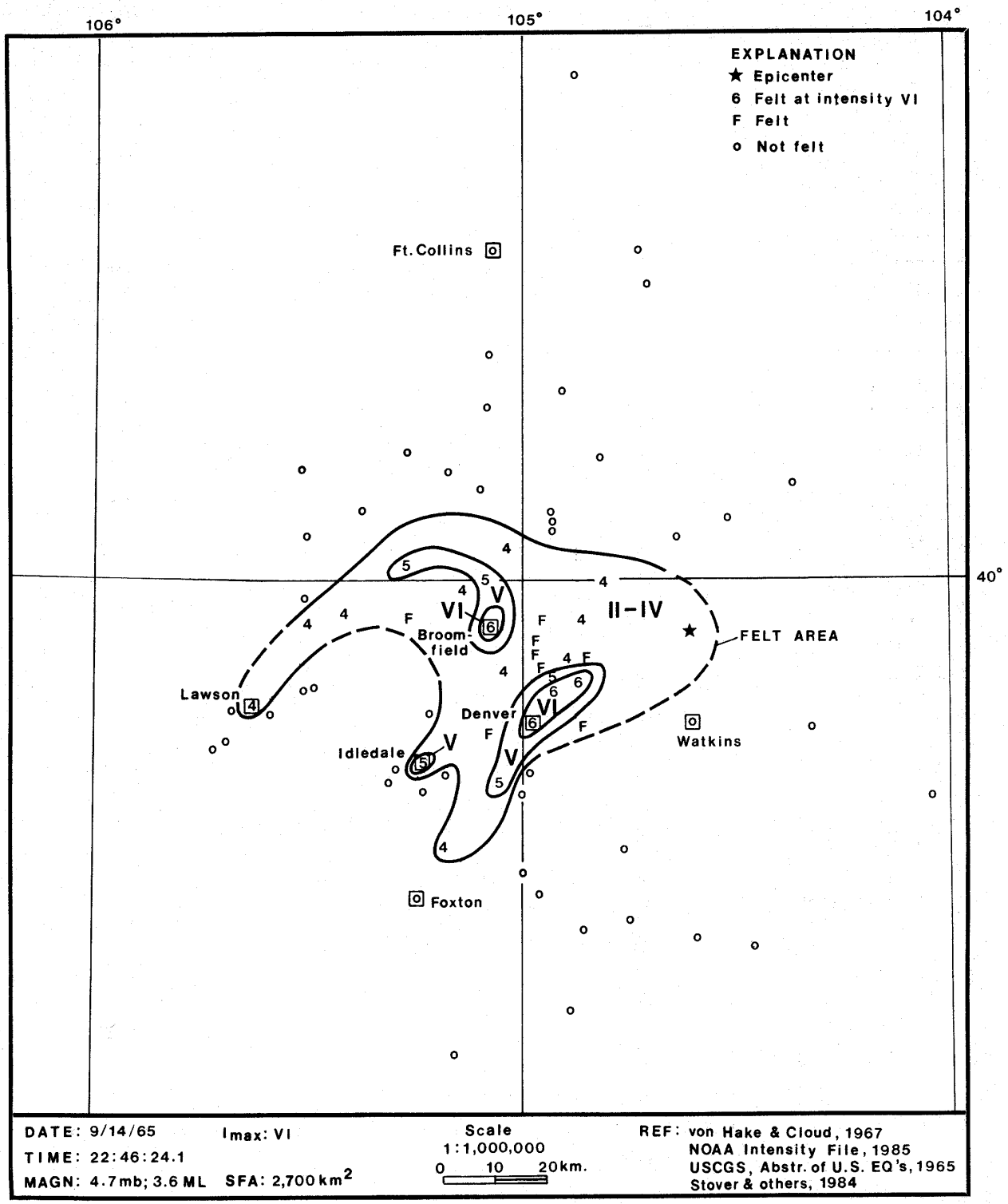


Figure 27. Isoseismal map for the September 14, 1965 earthquake.

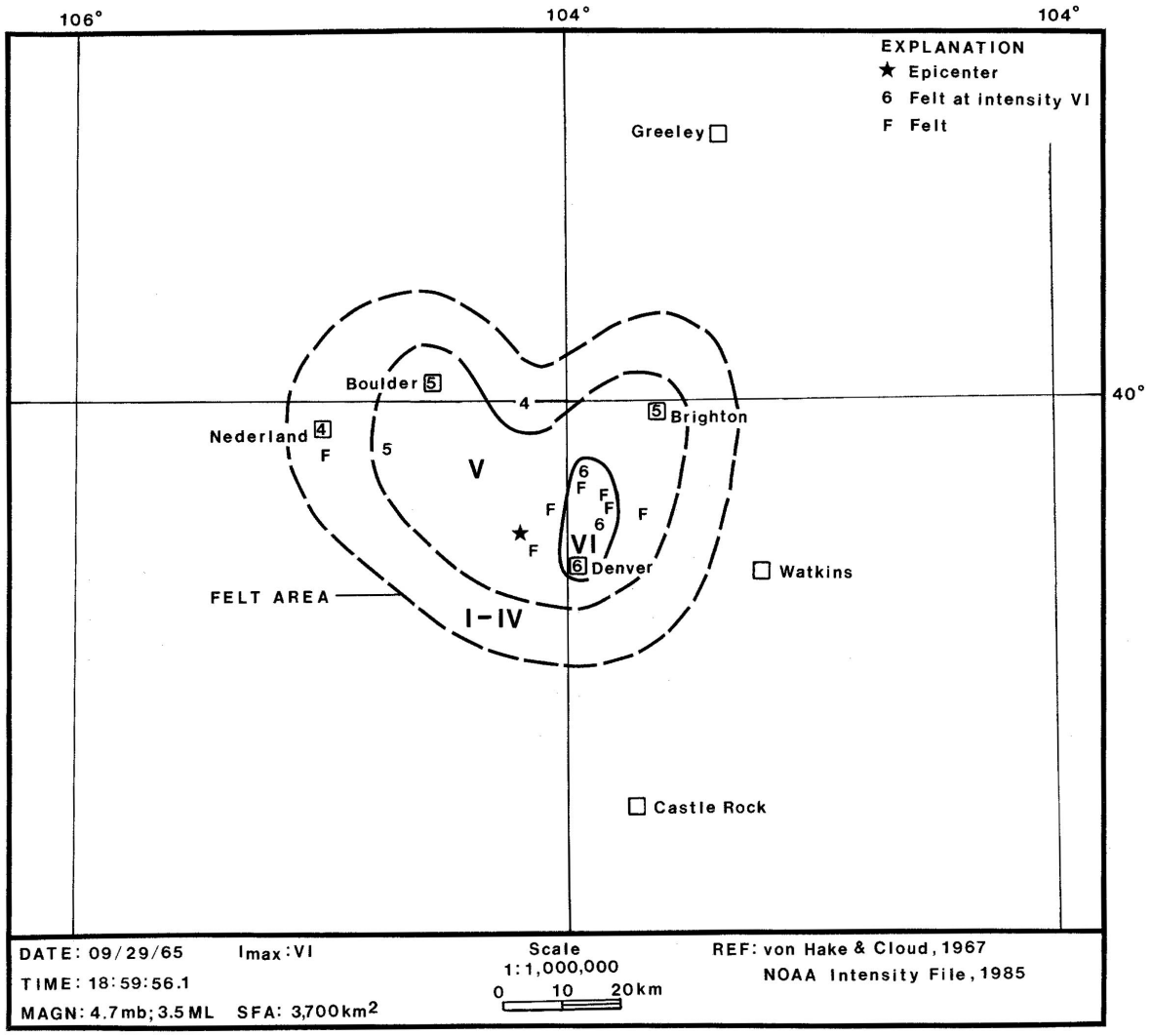


Figure 28. Isoseismal map for the September 29, 1965 earthquake.

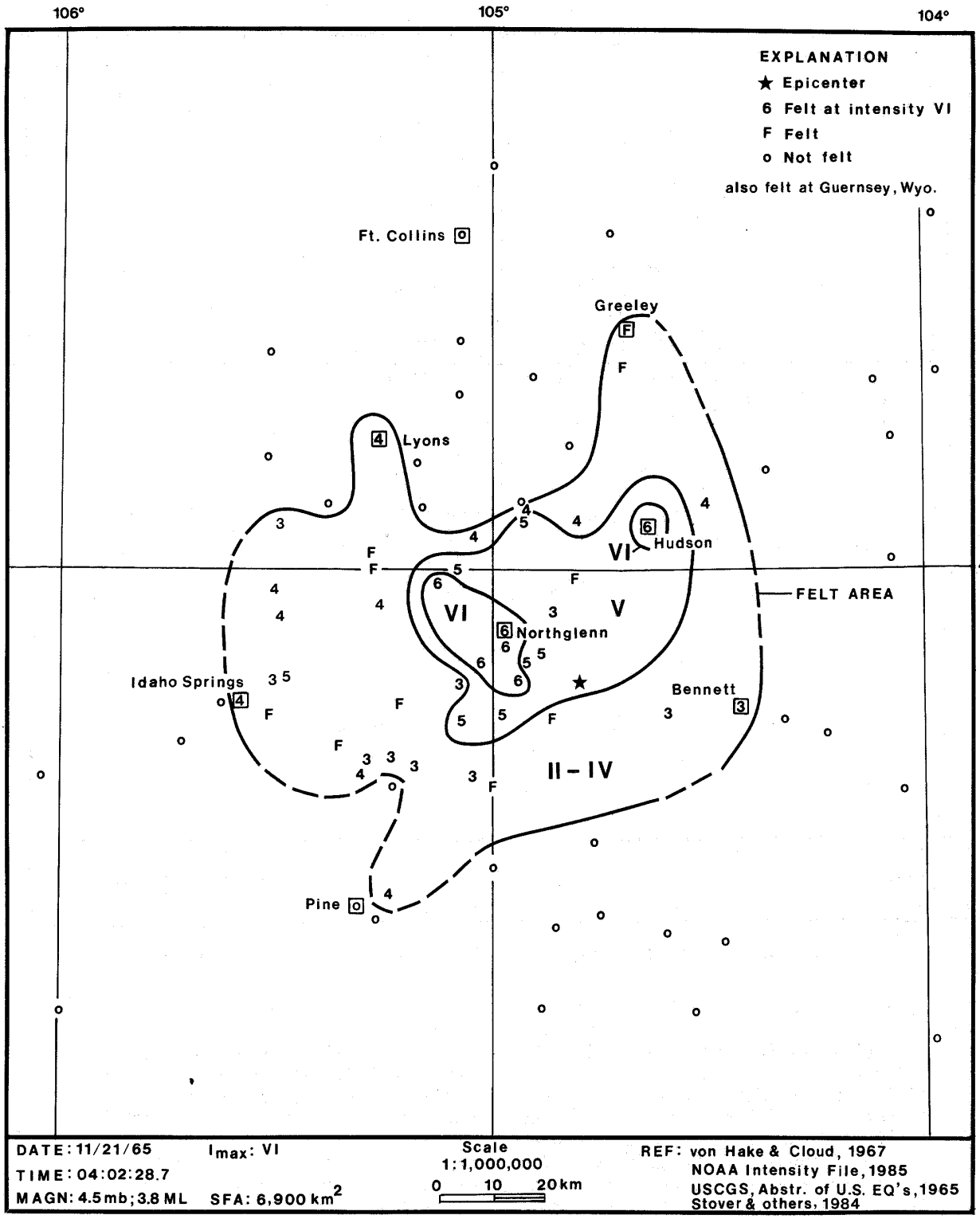


Figure 29. Isoseismal map for the November 21, 1965 earthquake.

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 ML 3.5 **(Major and Simon, 1968)** and mb 4.7 **(von Hake and Cloud, 1967)**. **Hadsell (1968)** suggested the felt area was larger, being about 10,400 km^2.

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 for this quake is around 6,900 km^2 based on Figure 29. Other estimates of the felt area included 41,400 km^2 **(Hadsell, 1968)**, 15,500 km^2 **(Docekal, 1970)**, and 7,800 km^2 **(von Hake and Cloud, 1967)**. A ML 3.8 was assigned by **Major and Simon (1968)** and mb 4.5 by **von Hake and Cloud (1967)**.

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 ML 3.4 for the tremor, while von Hake and Cloud (1968) described it as mb 5.0. 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.

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 intensities for 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.

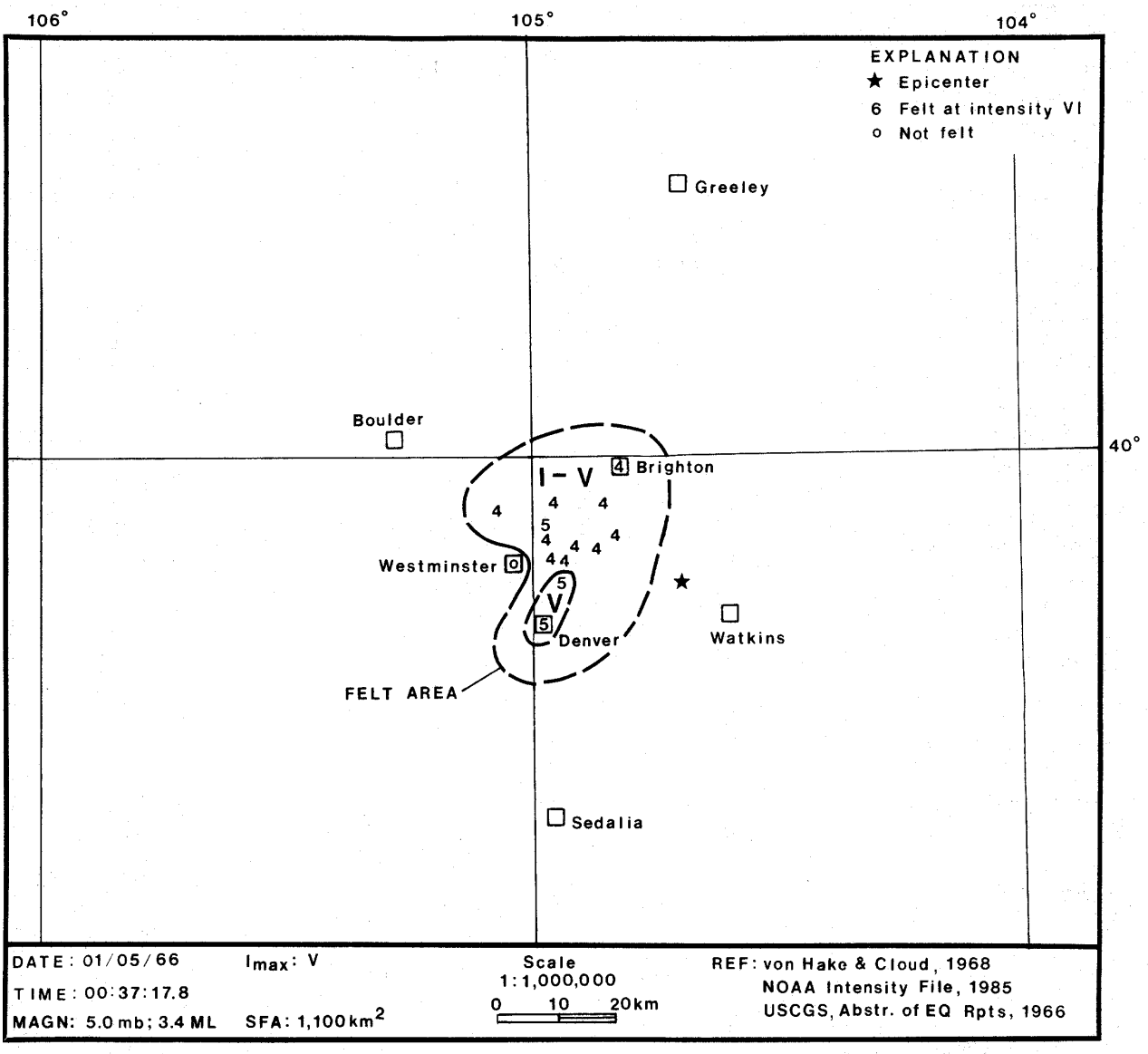


Figure 30. Isoseismal map for the January 5, 1966 earthquake.

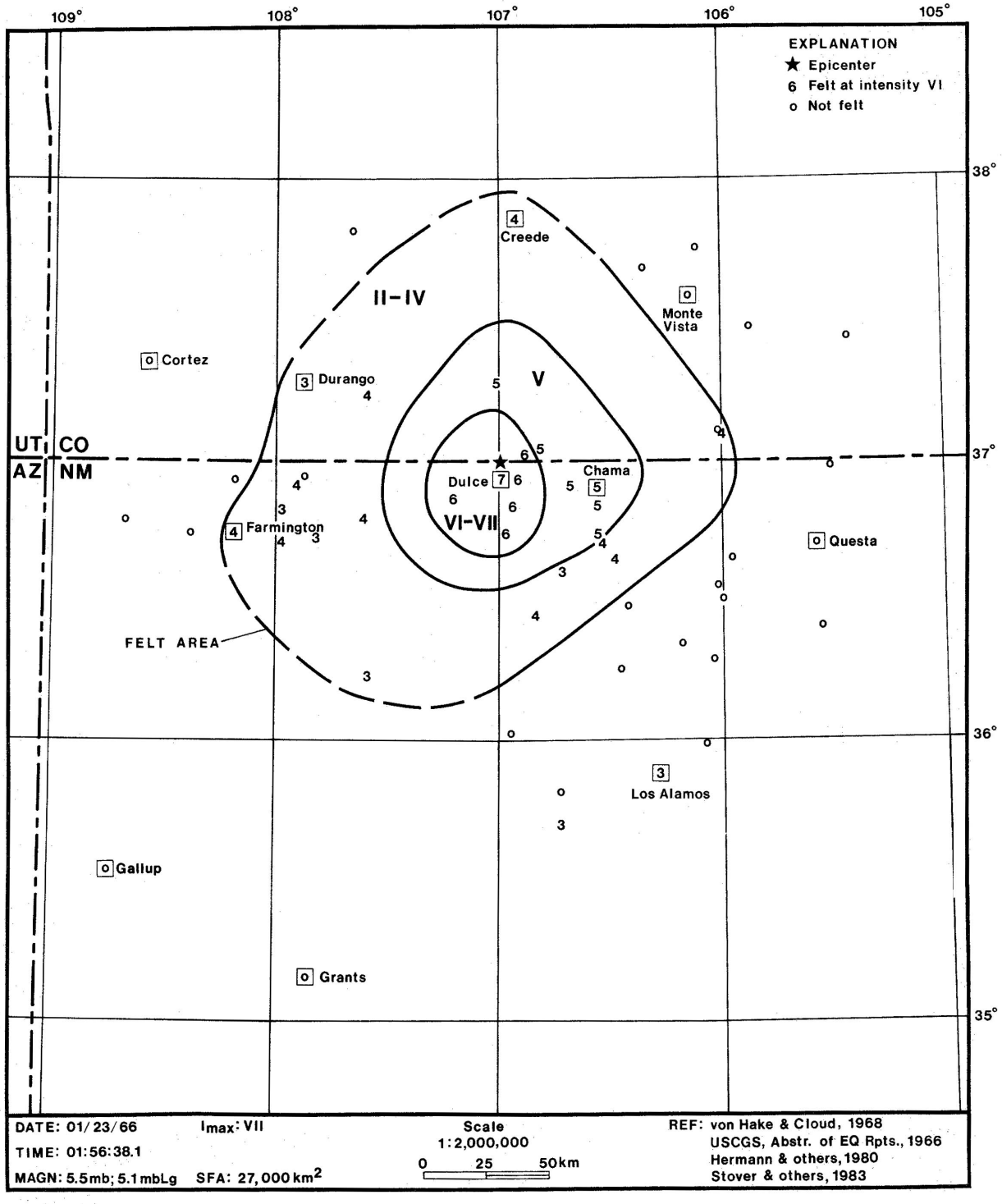


Figure 31. Isoseismal map for the January 23, 1966 earthquake.

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. There are discrepancies in the epicentral locations for many of the aftershocks following the Dulce earthquake in the various catalogs. We have attempted to include in Table 1 all events that occurred within Colorado or on the border with New Mexico.

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 mb 5.5. Later studies by **Herrmann and others (1980)** reported a magnitude of mbLg 5.1 magnitude for the main shock.

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 3, 1966 earthquake mentioned that some residents of 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 mb 4.1. **Stover, Reagor, and Algermissen (1983)** later published magnitudes of mb 3.8 and ML 2.7 for the quake.

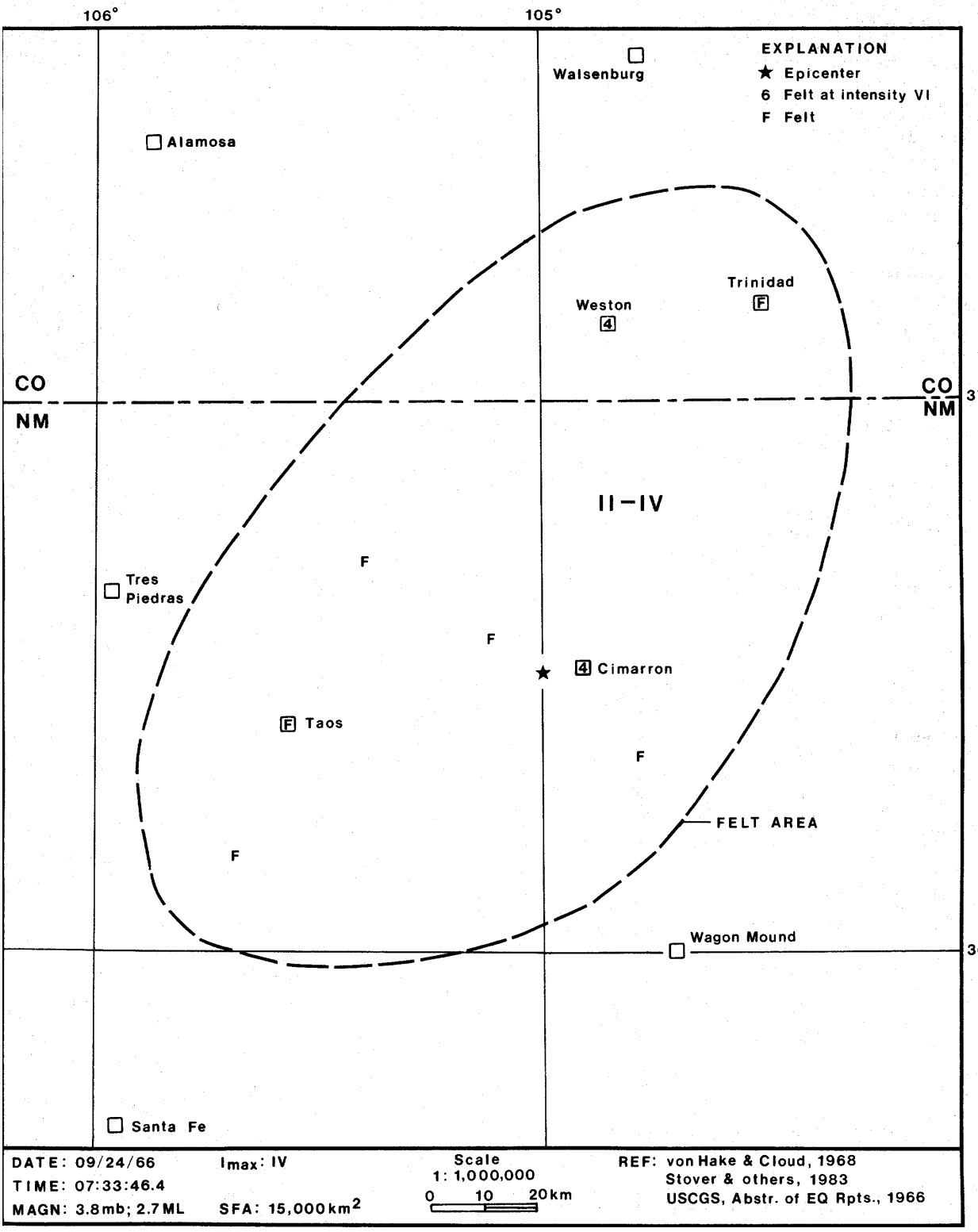


Figure 32. Intensity map for the September 24, 1966 earthquake.

October 3, 1966

The Colorado-New Mexico border region experienced another earthquake on October 3, 1966. This event was apparently centered 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 mb 4.5 was described for this quake by **von Hake and Cloud (1968)**, and **Stover, Reagor, and Algermissen (1984)** listed the magnitude at ML 4.6.

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. Reports from Eastlake also were 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 mb 4.1, while **Stover, Reagor, and Algermissen (1984)** report magnitudes of mb 4.4 and ML 3.5.

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;

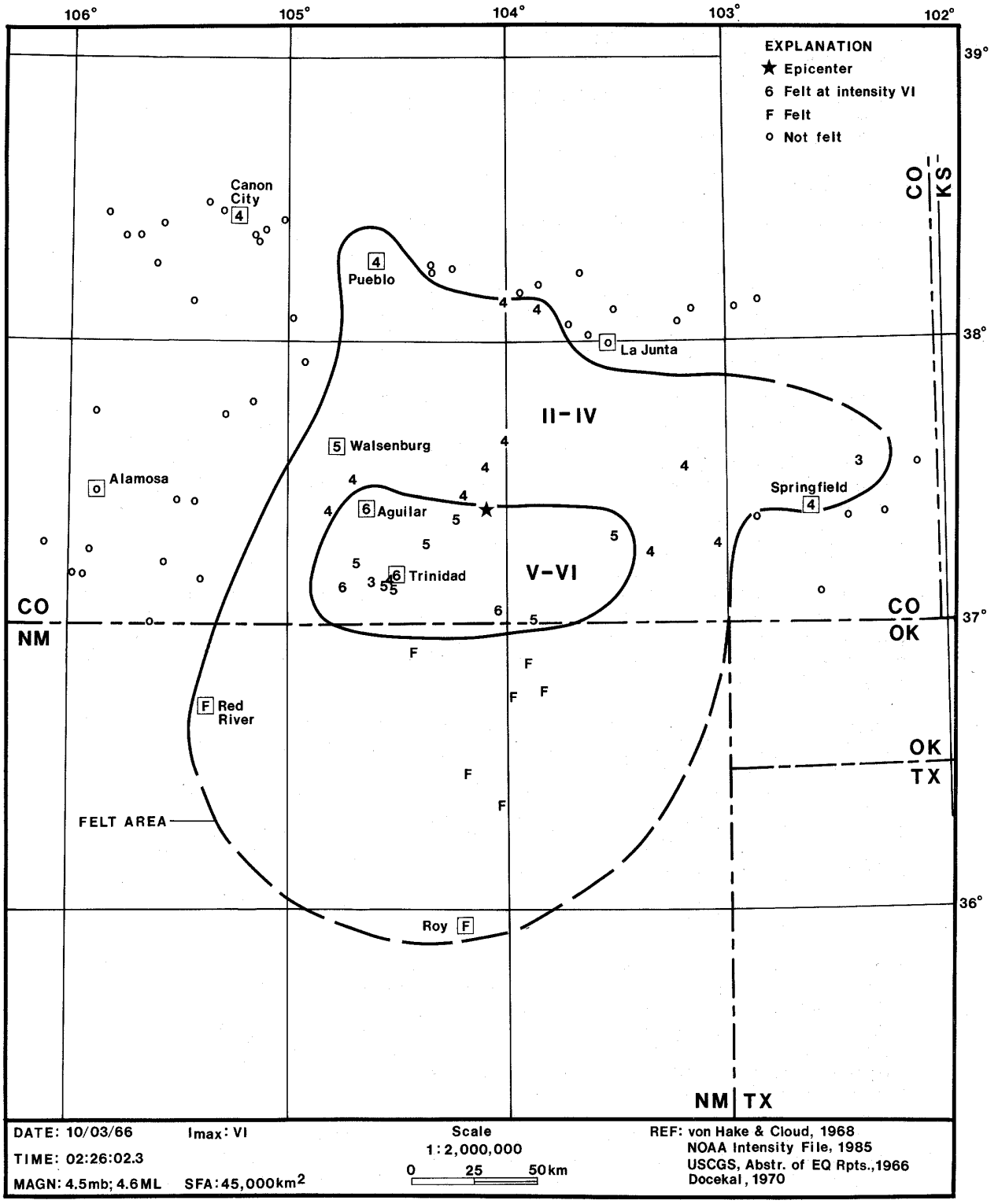


Figure 33. Isoseismal map for the October 3, 1966 earthquake.

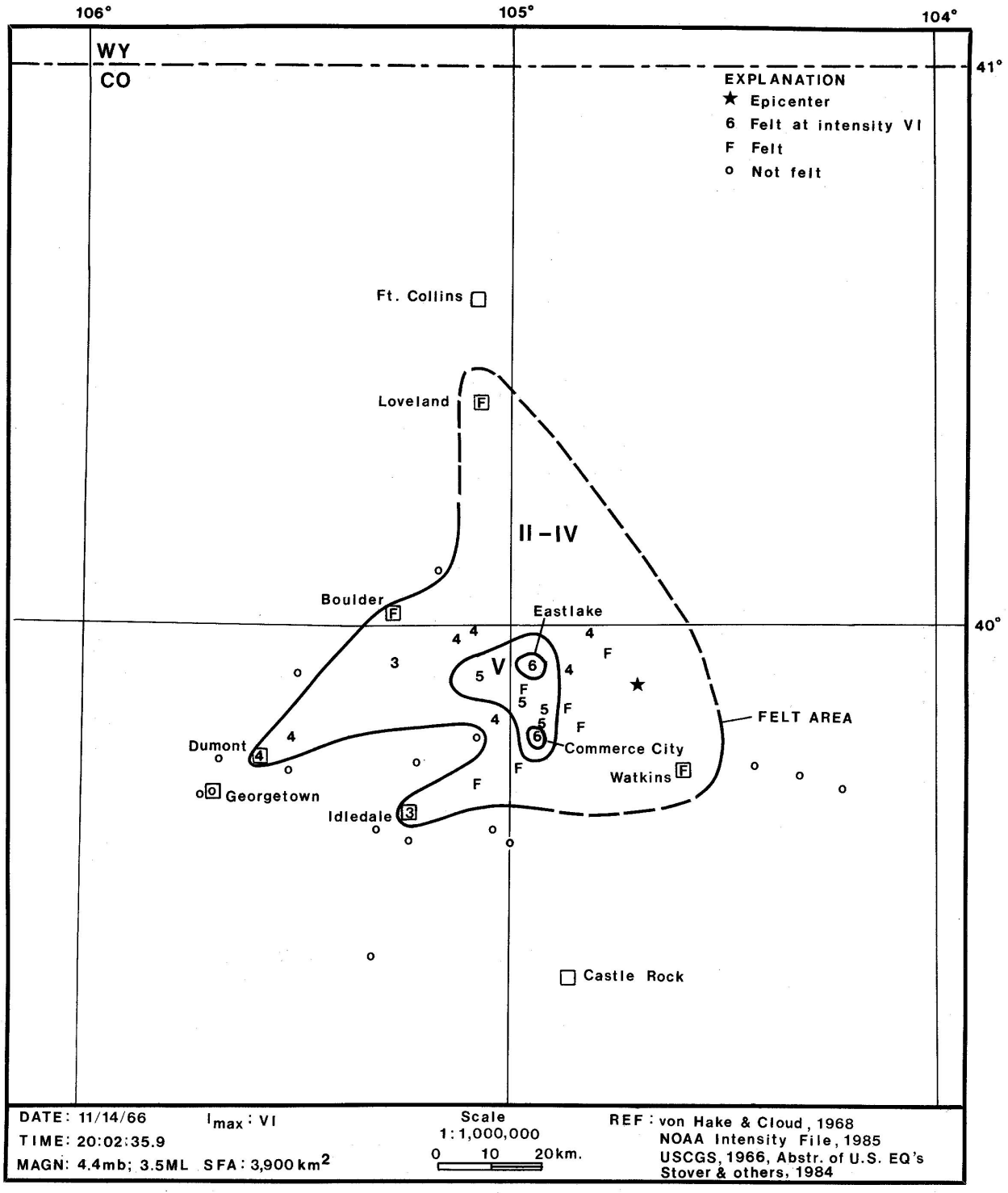


Figure 34. Isoseismal map for the November 14, 1966 earthquake.

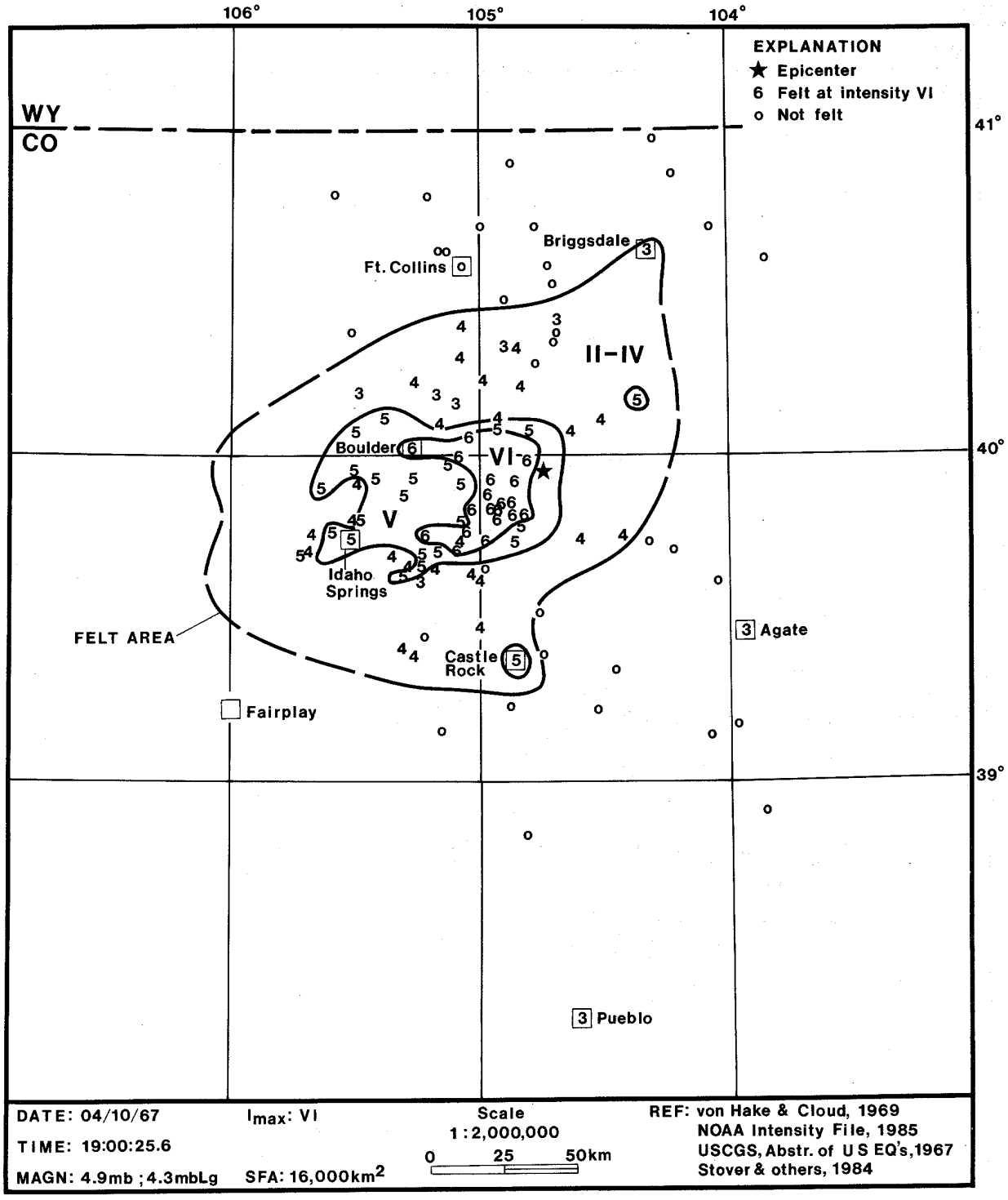


Figure 35. Isoseismal map for the April 10, 1967 earthquake.

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 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 mb 4.8 was initially published by **von Hake and Cloud (1969)**, but **Stover, Reagor, and Algermissen (1984)** reported a mb 4.9. **Herrmann and others (1981)** estimated the magnitude of this earthquake at mbLg 4.3 ± 0.2 and suggested the focal depth was 4 km.

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 mb 4.4 by **von Hake and Cloud (1969)** and mb 4.5 and ML 3.8 by **Stover, Reagor, and Algermissen (1984)**.

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 to be about 50,000 km^2. **Von Hake and Cloud (1969)** proposed a size of 39,000 km^2, while **Hadsell** indicated it was felt over 117,000 km^2. **Docekal (1970)** reported a felt area of 52,000 km^2. A magnitude of mb 5.3 was calculated for this earthquake by **von Hake and Cloud (1969)**, whereas **Nuttli and others (1974)** calculated an mbLg of 4.9. **Herrmann and others (1981)** suggested a focal depth of 3 km for this event.

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.

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 **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 mb 5.2, while **Stover, Reagor, and Algermissen (1984)** report an mbLg of 4.6.

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 mb 4.4 to the quake.

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 mb 4.4 by **von Hake and Cloud (1973)** and ML 3.8 by GOL **(Stover, Reagor, and Algermissen, 1984)**.

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 ML 2.7 for this event.

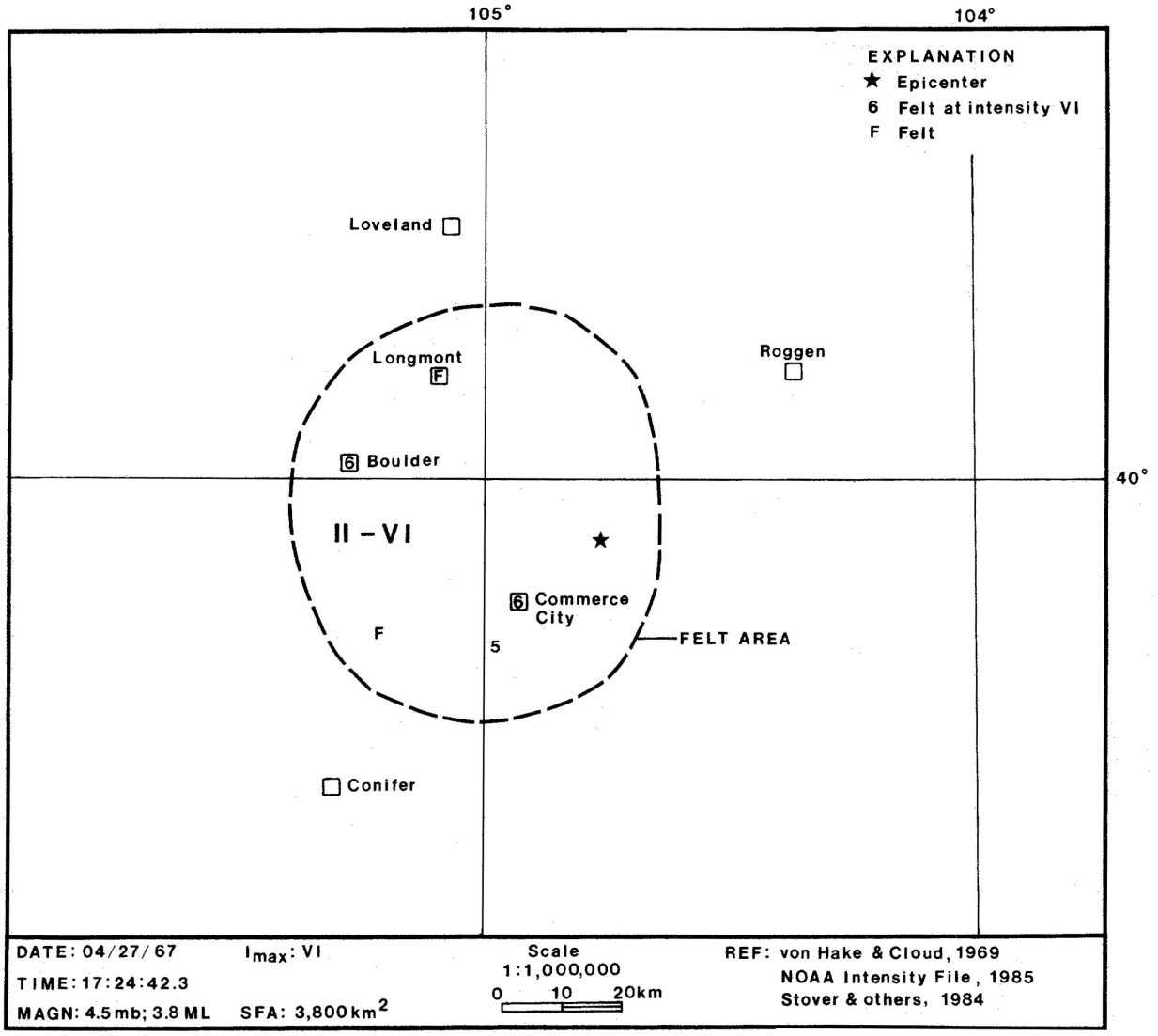


Figure 36. Intensity map for the April 27, 1967 earthquake.

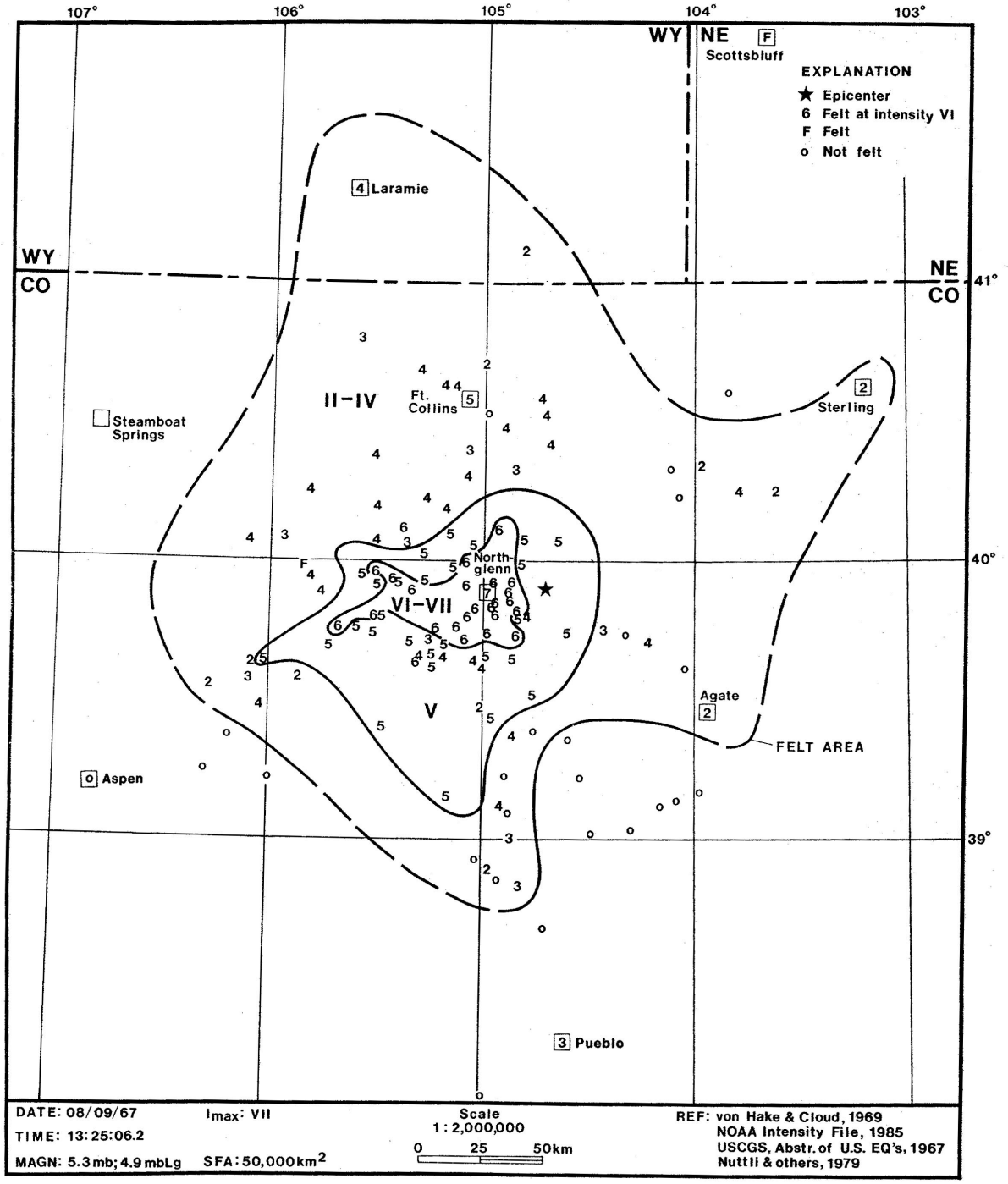


Figure 37. Isoseismal map for the August 9, 1967 earthquake.

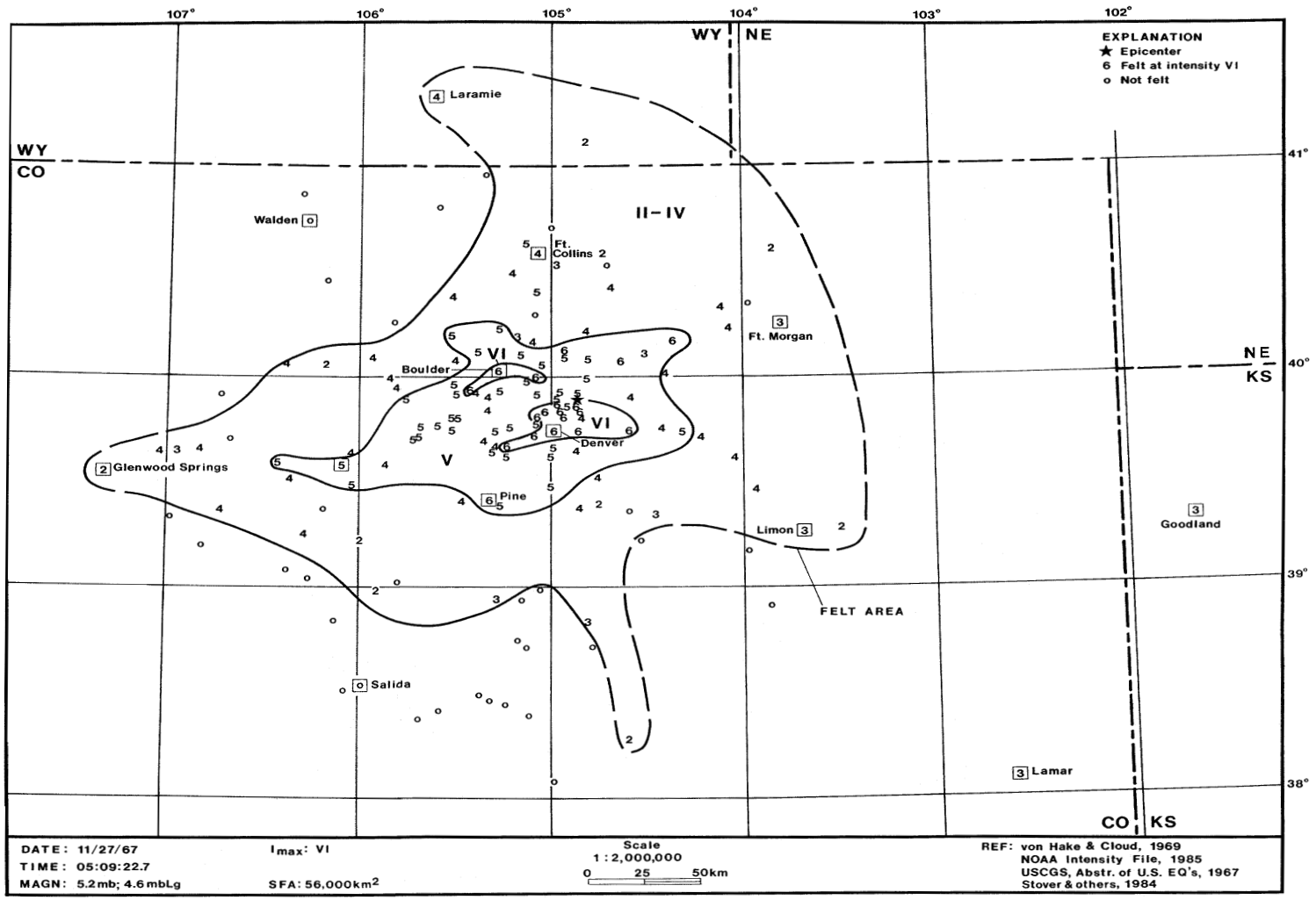


Figure 38. Isoseismal map for the November 27, 1967 earthquake.

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 across a 5,000 km^2 area 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 mb 4.4 and ML 3.7 **(Stover, Reagor, and Algermissen, 1984)**.

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 for the tremor was reported at 115,000 km^2 by **Simon and others (1978)**. Earthquake magnitude was mb 5.0 and ML 4.6, while its depth was estimated at 25 km. A slightly different epicentral location is given by **Wong and others (1984)**. They indicated this event occurred at the significantly greater depth of 40.5 ± 6.5 km.

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 mb 4.6 and ML 4.2 at a depth of 22 km. **Wong and others (1984)** report a slightly different epicentral location and a much greater depth (43.6 ± 3.6 km).

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 from the epicentral area, reported shaking as a strong or stronger than the epicentral area. **Stover and others (1979)** estimate the magnitude at mb 5.0 and ML 5.1 and the depth at 5 km.

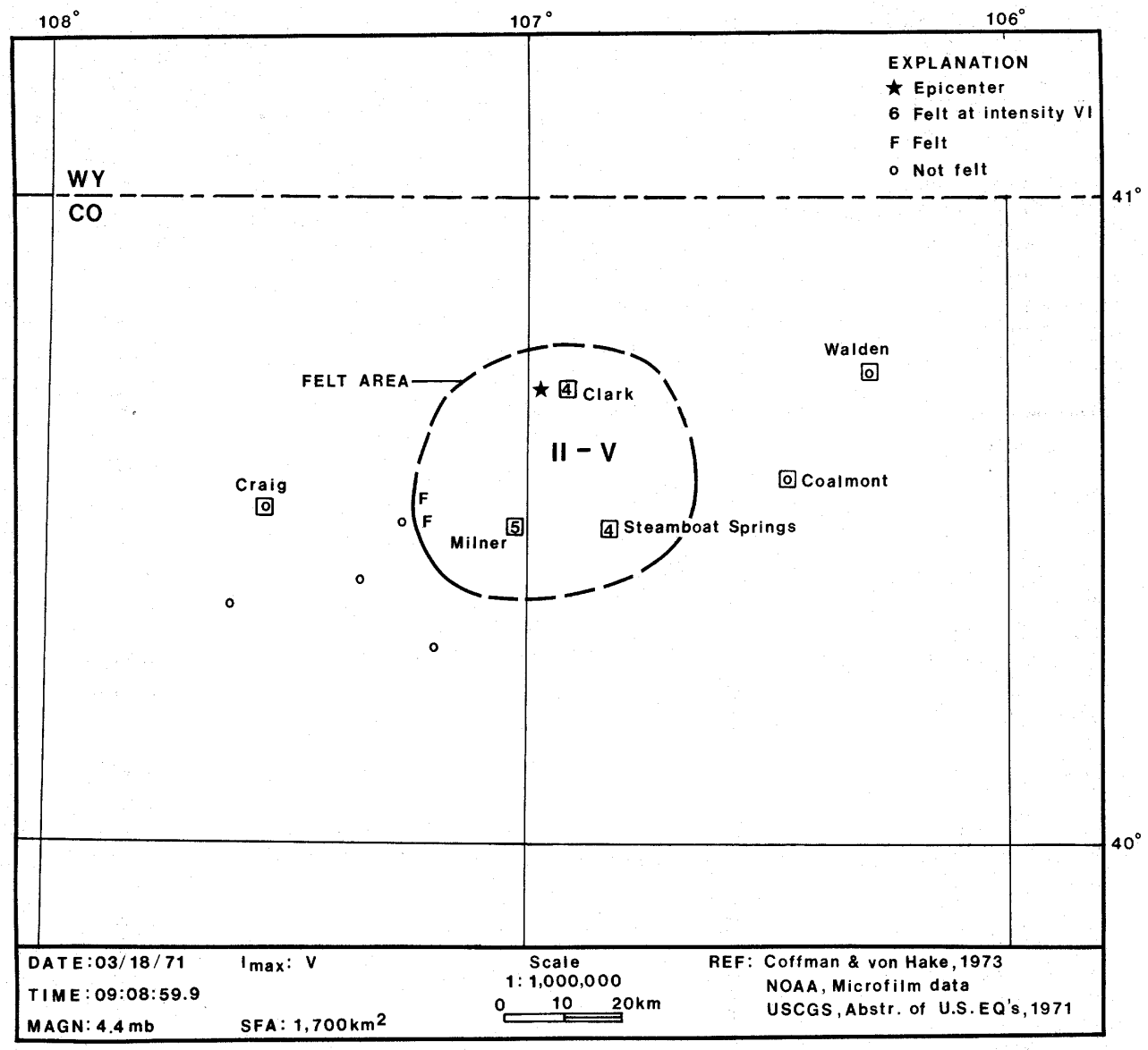


Figure 39. Intensity map for the March 18, 1971 earthquake.

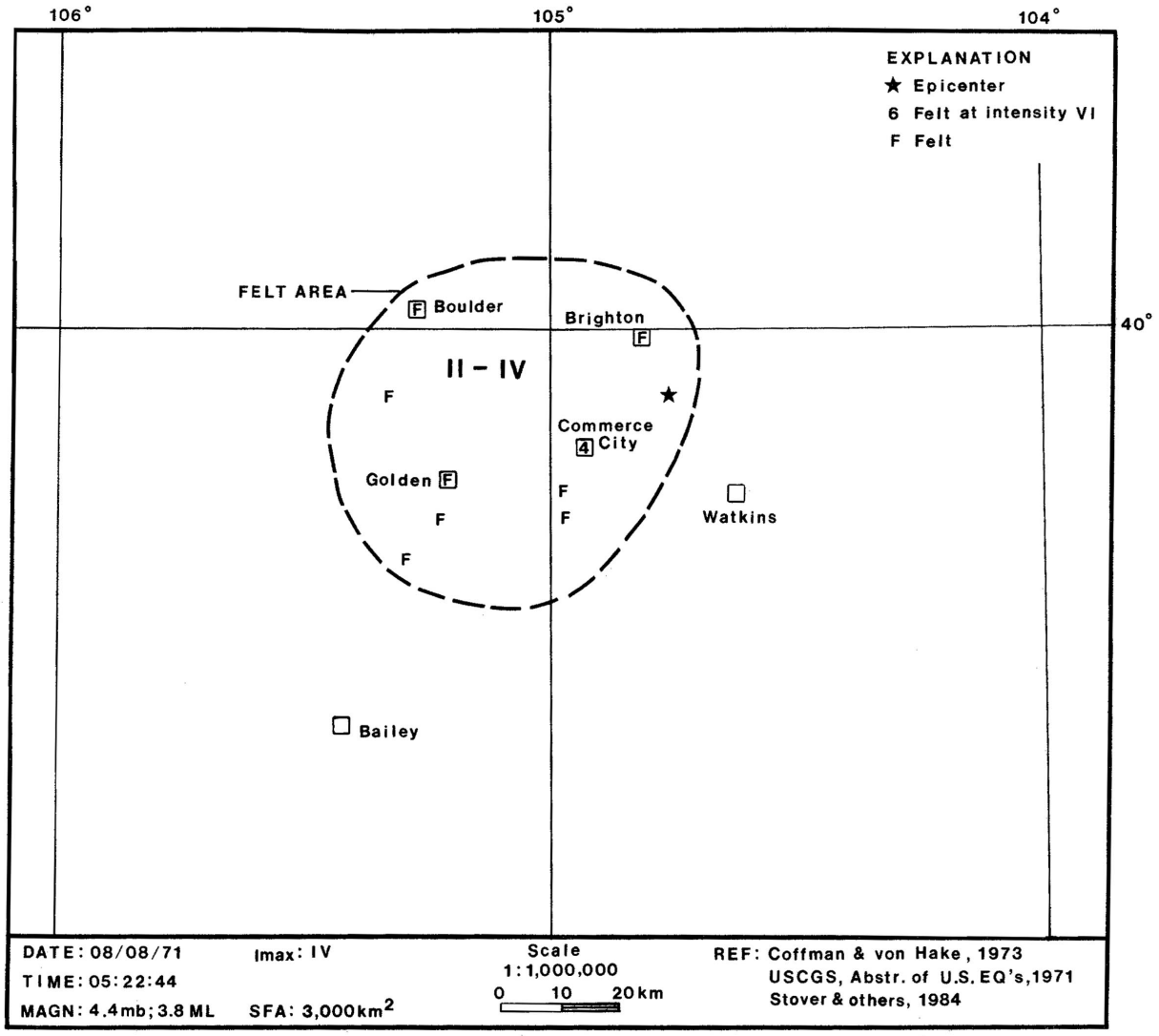


Figure 40. Intensity map for the August 8, 1971 earthquake.

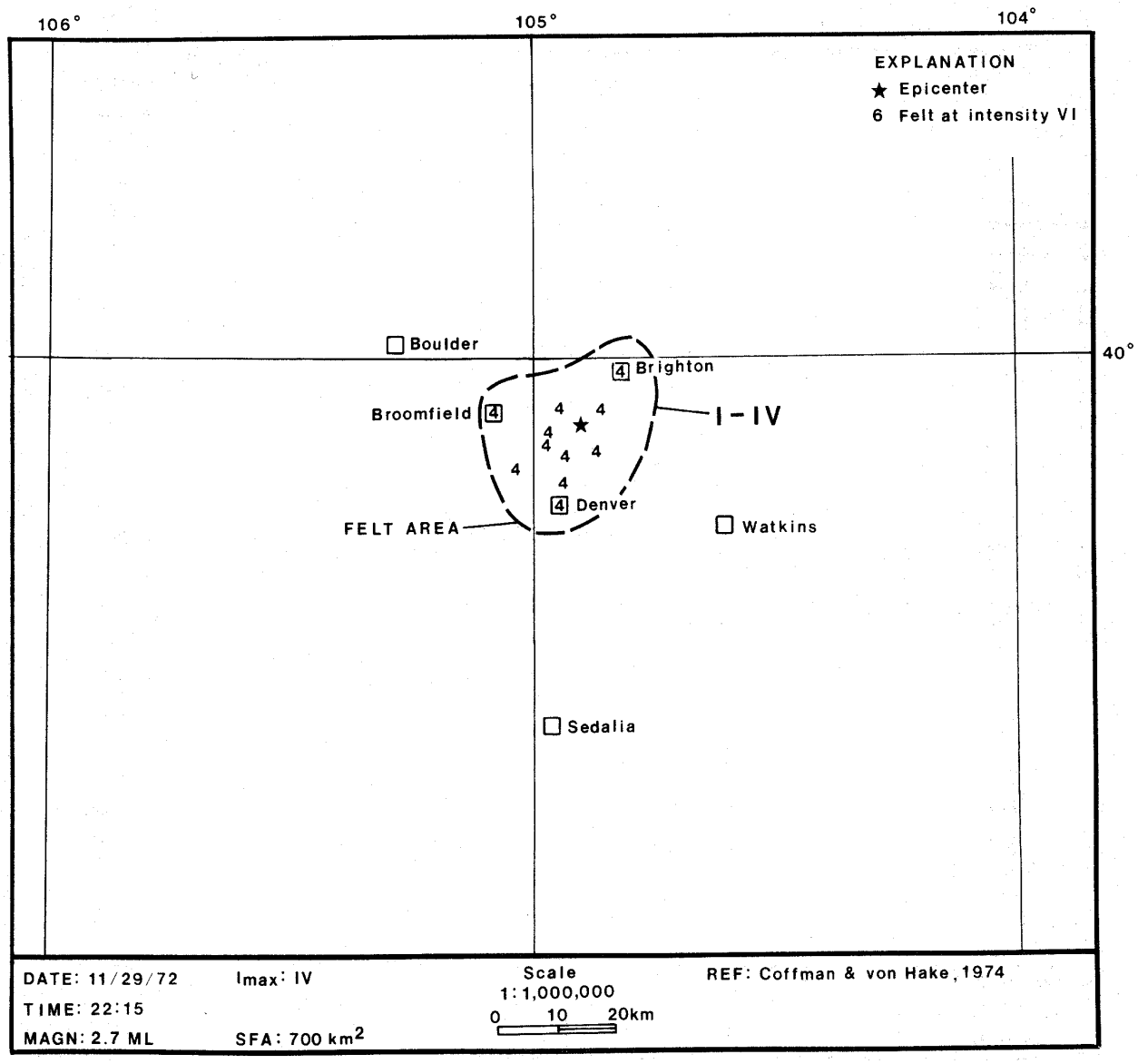


Figure 41. Intensity map for the November 29, 1972 earthquake.

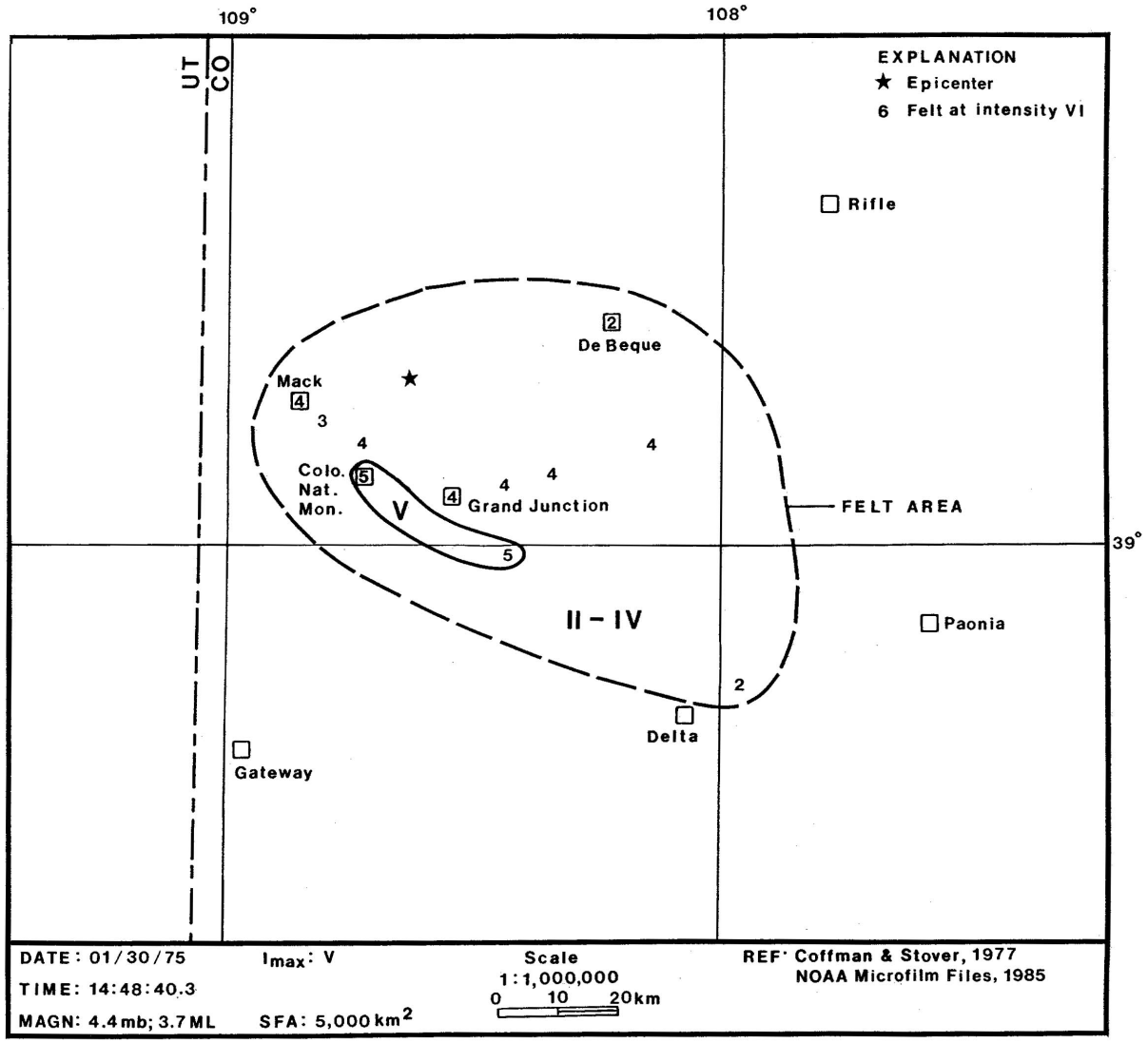


Figure 42. Intensity map for the January 30, 1975 earthquake.

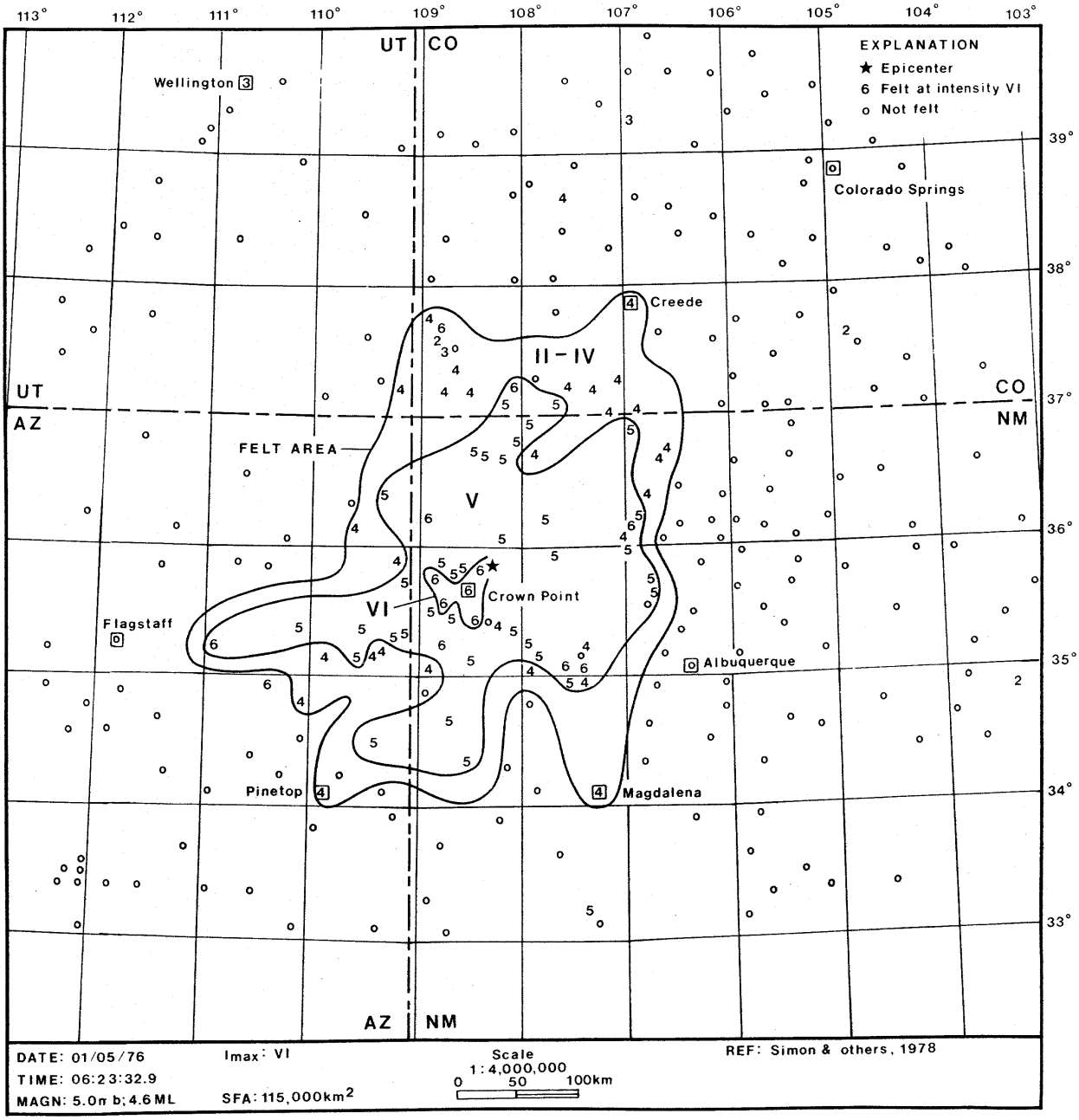


Figure 43. Intensity map for the January 5, 1976 earthquake.

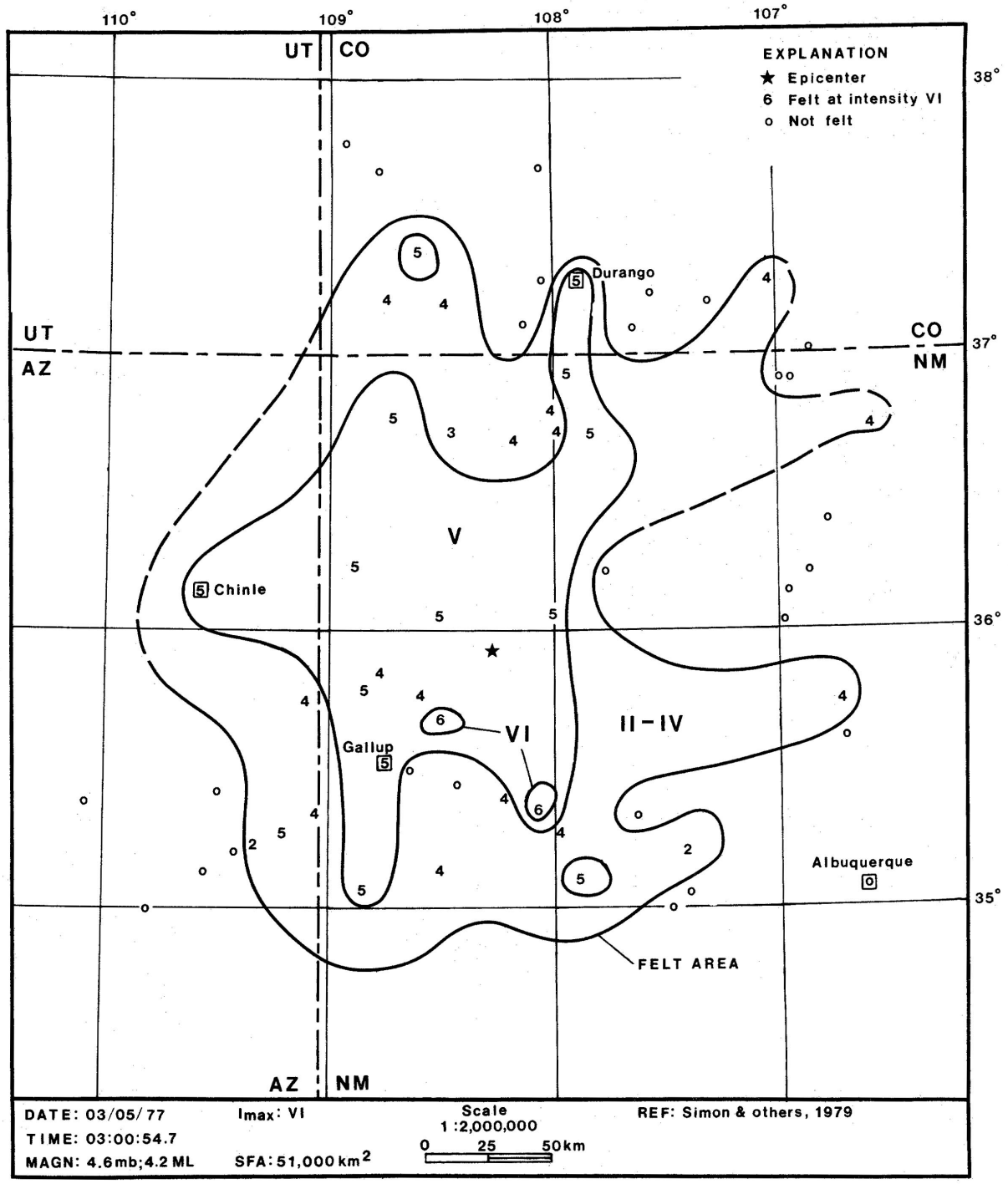


Figure 44. Intensity map for the March 5, 1977 earthquake.

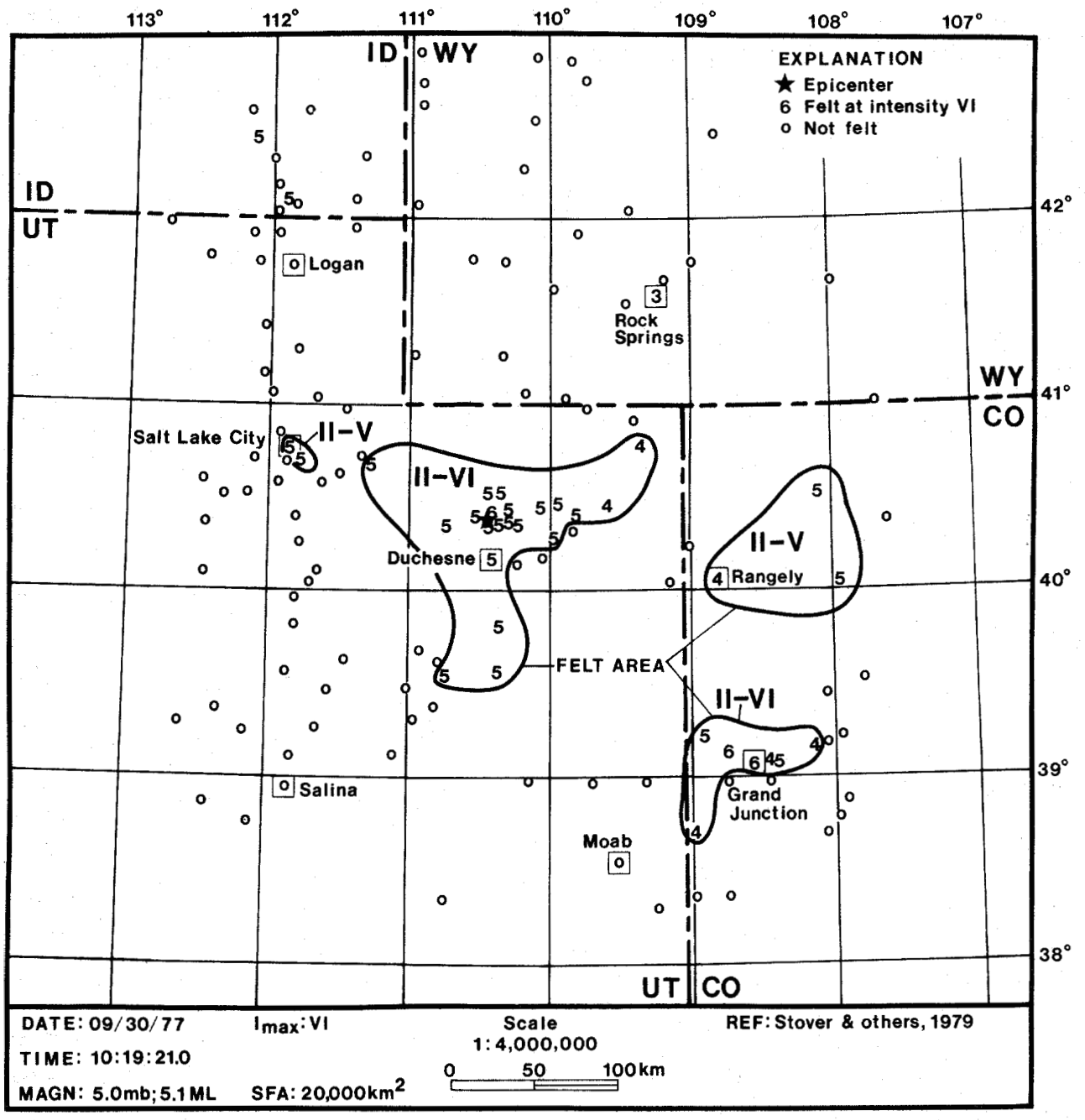


Figure 45. Intensity map for the September 30, 1977 earthquake.

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. 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. Based on their own canvass of the felt area, **Butler and Nicholl (1985a; 1986b)** report a much smaller felt area of only 1,800 km^2. Earthquake magnitude was listed at ML 2.9 and mbLg 3.3 by **Stover and von Hake (1981)**, and hypocentral depth was given as 5 km. Audible effects associated with the earthquake led **Butler and Nicholl (1985a; 1986b)** to conclude the hypocentral depth was less than 5 km.

April 2, 1981

On April 2, 1981 an earthquake shook 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 included mb 4.3, ML 3.8, and Mn 4.5, while the hypocentral depth was reported at 9 km **(Stover, and others, 1982a)**.

The April 2 event was preceded by a magnitude ML 2.8 foreshock on March 24 and followed by six small aftershocks between April 4 and 7 **(Bollinger and others, 1983**; **Unruh and others, 1996)**. The aftershocks occurred in the same zone as the 1966 to 1967 earthquakes that were relocated by **Herrmann and others (1981)**.

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. An isoseismal map prepared by **Butler and Nicholl (1985b; 1986a)** is reproduced as **Figure 49**. Both the USGS and MicroGeophysics epicenters are shown. This map suggests the felt area was only 1,000 km^2. **Stover and others (1982b)** reported magnitudes of ML 2.8 and Mn 3.1 for this earthquake, and their hypocentral location is near or on the Kennedy Gulch Fault. **Butler and Nicholl (1985b; 1986a)** suggest a slightly different location that places the epicenter between the Kennedy Gulch and Floyd Hill Faults.

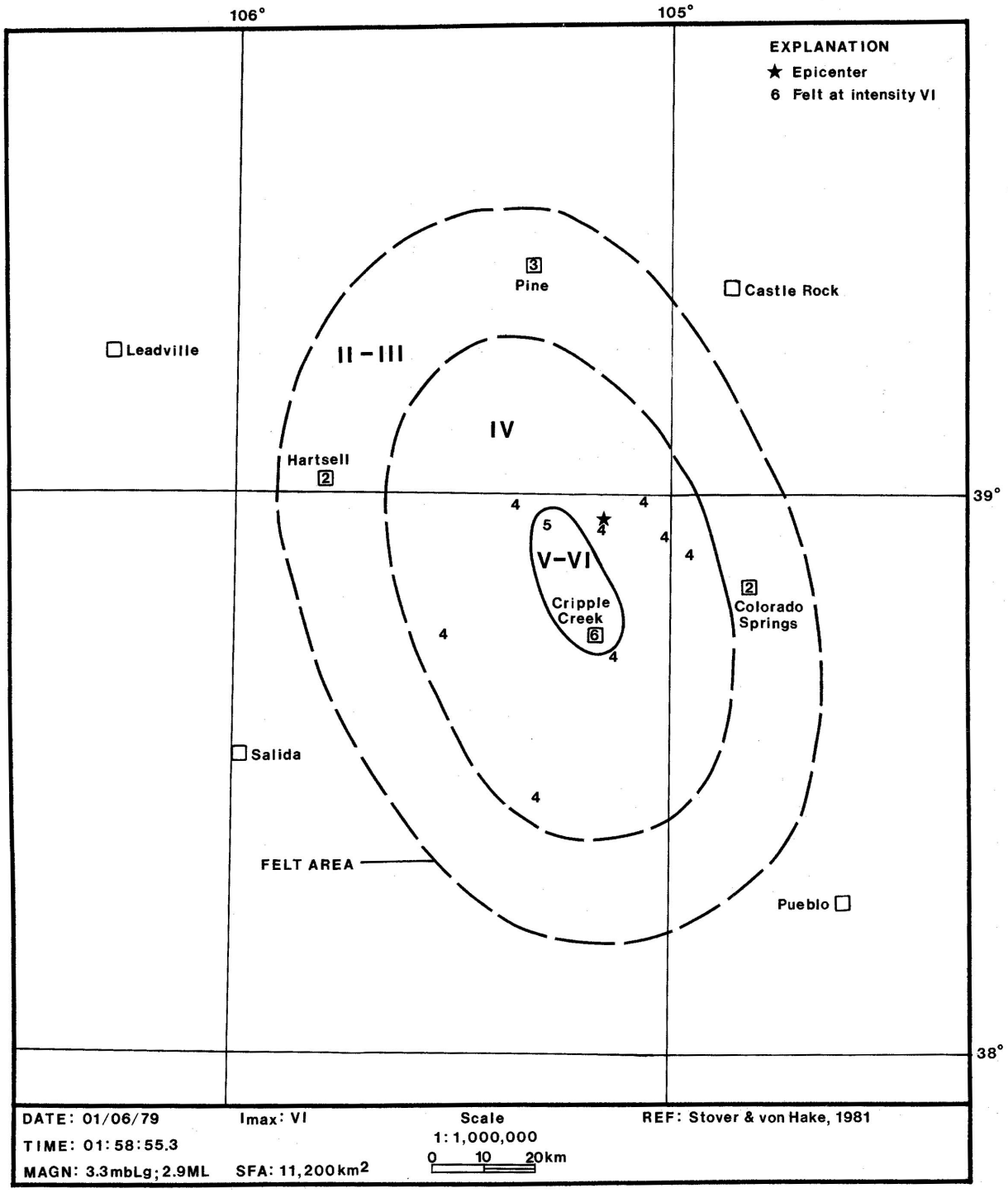


Figure 46. Intensity map for the January 6, 1979 earthquake.

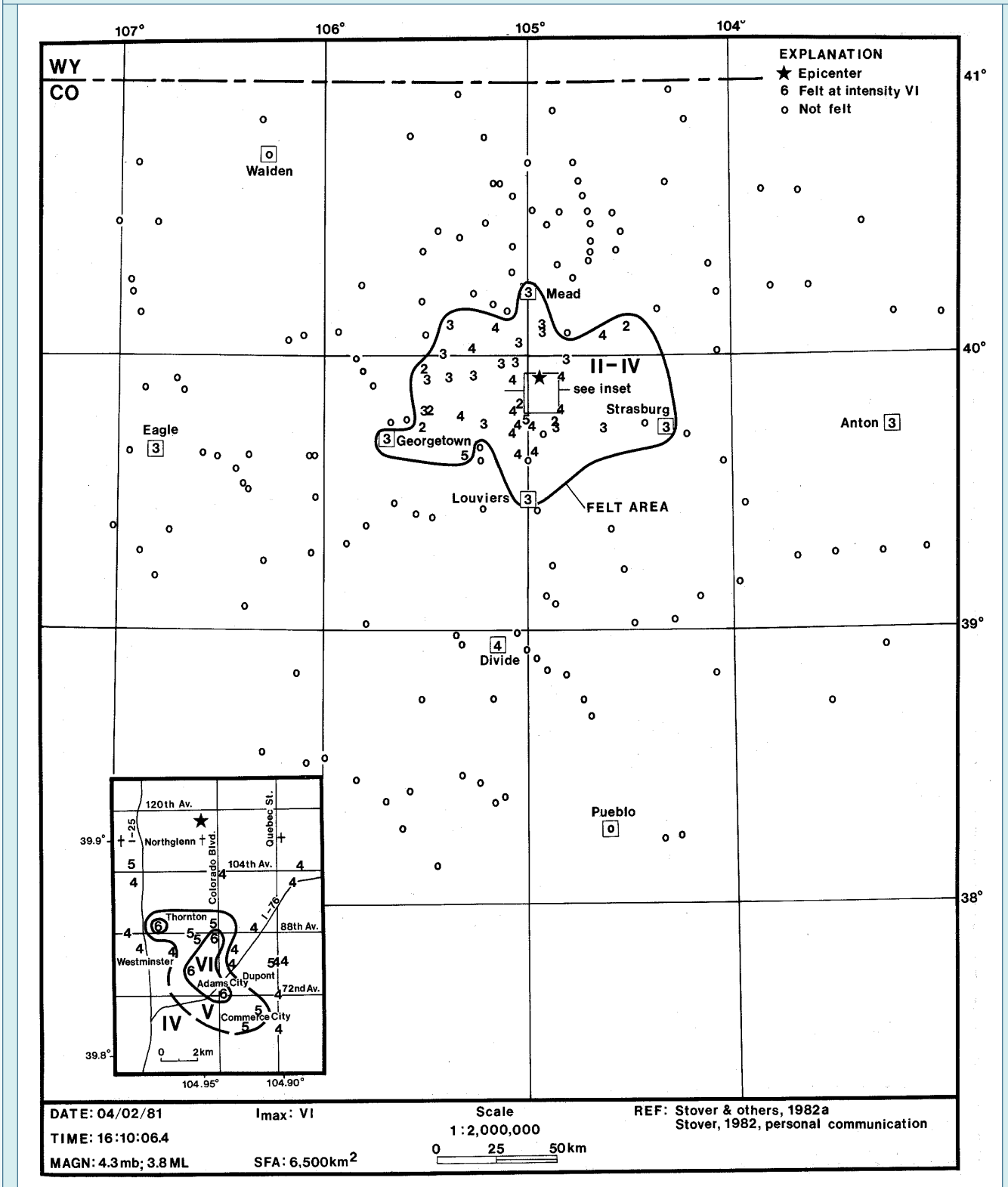


Figure 47. Intensity map for the April 2, 1981 earthquake.

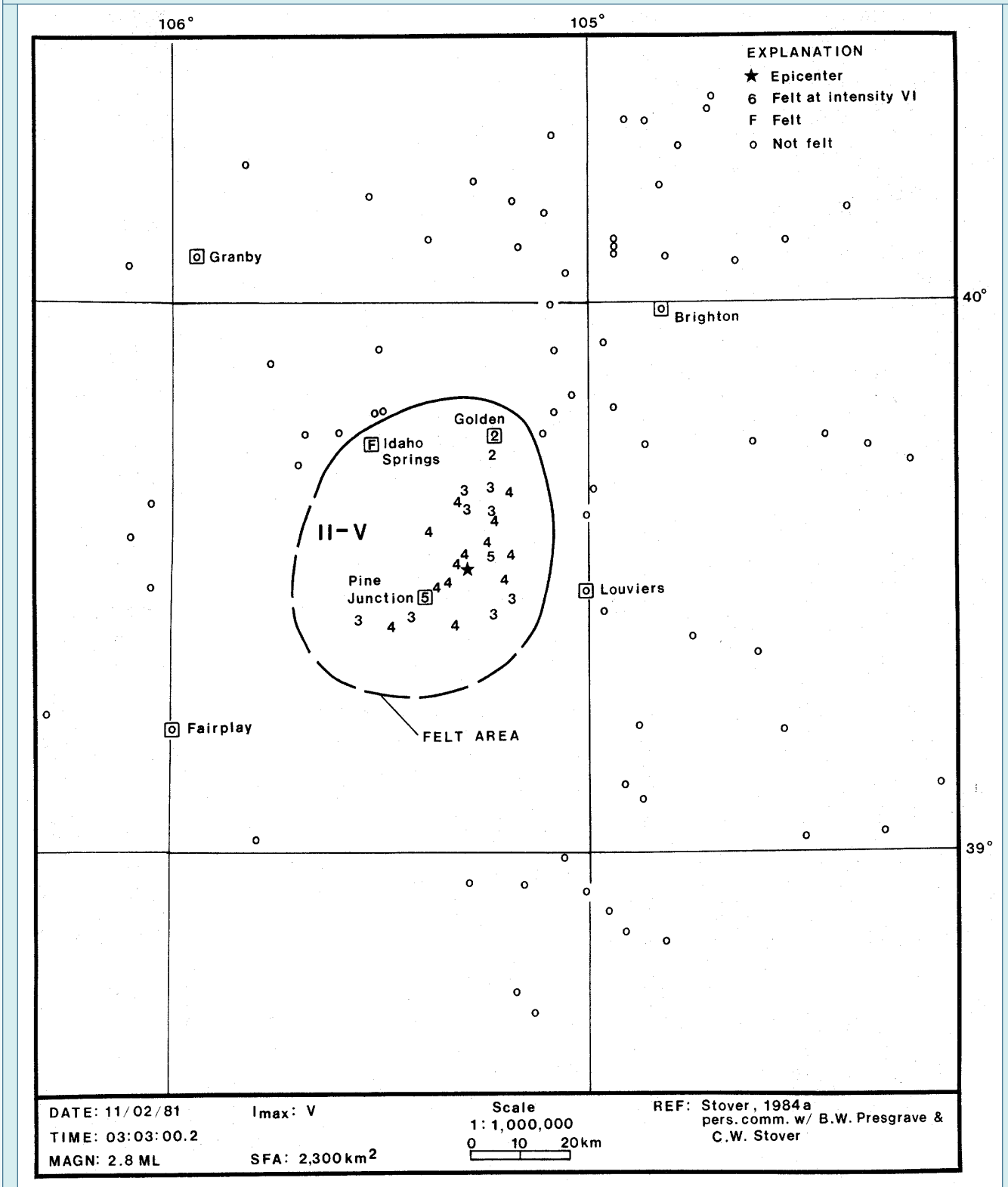


Figure 48. Intensity map for the November 2, 1981 earthquake.

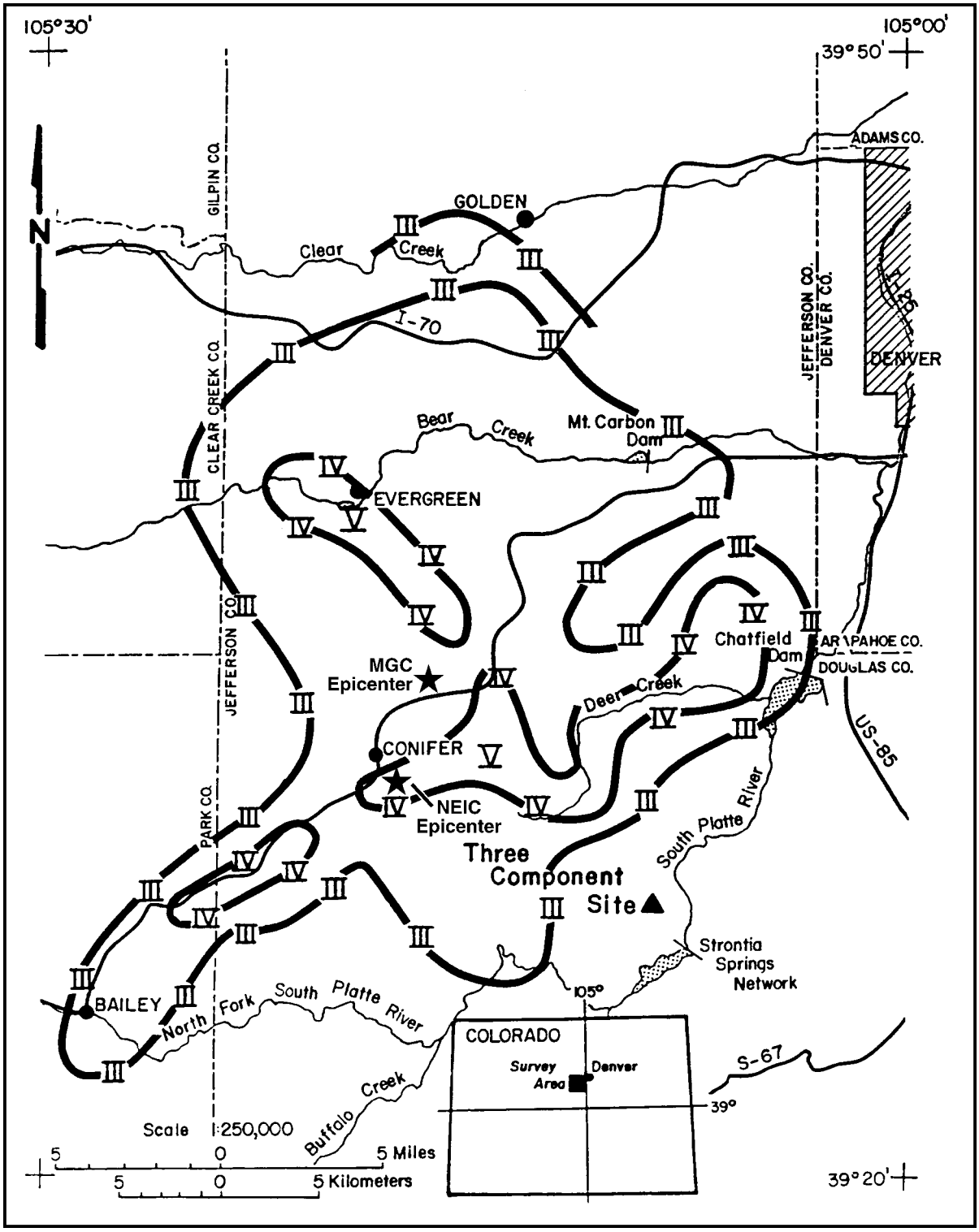


Figure 49. Isoseismal map for the November 2, 1981earthquake (modified from Butler and Nicholl, 1986a).

August 14, 1983

On August 14, 1983, a small earthquake of magnitude ML 3.4 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".

April 12 to May 31, 1984

A swarm of small earthquakes south-southwest of Carbondale began with a magnitude ML 2.2 event on April 12, 1984. Over the next four weeks the USGS-NEIC located seventeen more earthquakes in this region that ranged from magnitude ML 1.9 to 3.2. These events are listed in Table 1. The largest event occurred on May 14, had a magnitude of ML 3.2, and caused intensity IV effects in Carbondale. On May 16 the USGS deployed a nine-station, portable seismic network **(Goter and others, 1986; 1988)**. Revised hypocentral locations resulting from this work are described in Table 1. While fully operational from May 17 to 31, seventeen additional earthquakes ranging from ML 1.3 to 2.6 were recorded by the portable network. Refer to **Goter and others (1988)** for data on these events. Using a joint hypocenter determination technique, **Goter and others (1988)** found that most earthquakes plotted along or at the north end of the Elk Mountain Anticline at depths of 2.3 to 6.5 km (**Figure 50**). **Unruh and others (1993)** suggest that these earthquakes may be related to salt diapirism.

Goter and others (1988) constructed two composite focal mechanisms from local first-motion data. A focal mechanism based on five earthquakes at the northeast end of the zone of seismicity indicated normal faulting associated with northeast-southwest extension. A second focal mechanism composited from three earthquakes located one to two km south of those events used for the first focal mechanism suggested reverse faulting.

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 51**.

The earthquake was felt over 287,000 km^2, an unusually large area for an event rated at mb 5.3, MS 5.1, and ML 5.5. **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.

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 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 **(Stover, 1988)**, 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.

About 24 hours after the mainshock, **Langer and others (1991)** installed a temporary network of seismographs to monitor aftershock activity. Forty-seven events were located by the array. They occurred in a tight cylindrical cluster about 4 km in diameter at depths of 20 to 25 km (Langer and others, 1991).

This earthquake provides insight into the November 8, 1882 earthquake. **Oaks and others (1985)**, **Kirkham and Rogers (1986)**, and **Spence and others (1996)** describe possible implications of the Laramie Mountains quake on what is widely believed to be Colorado's greatest historic earthquake.

March 16, 1985

On March 16, 1985 a small earthquake shook the Salida area. The quake was felt over 2,200 km^2 (**Figure 52**), with intensity V reported at Salida and Texas Creek. The magnitude was determined at ML 3.2 by NEIC and ML 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, personal commun.). Felt effects associated with this earthquake appear to follow the Arkansas River Valley.

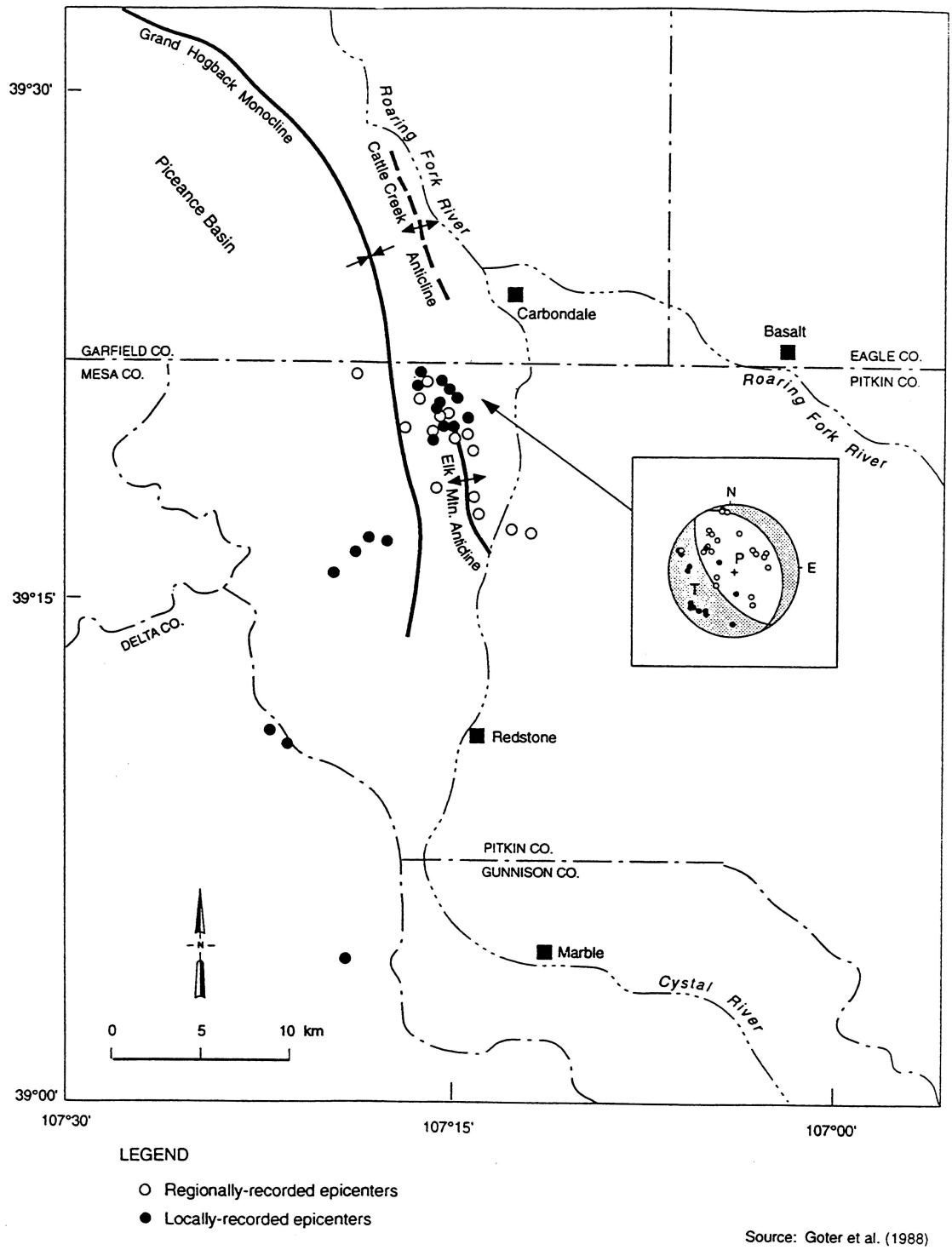


Figure 50. Epicenter map for the 1984 Carbondale earthquake swarm (data from Goter and others; 1988, figure from Unruh and others, 1993).

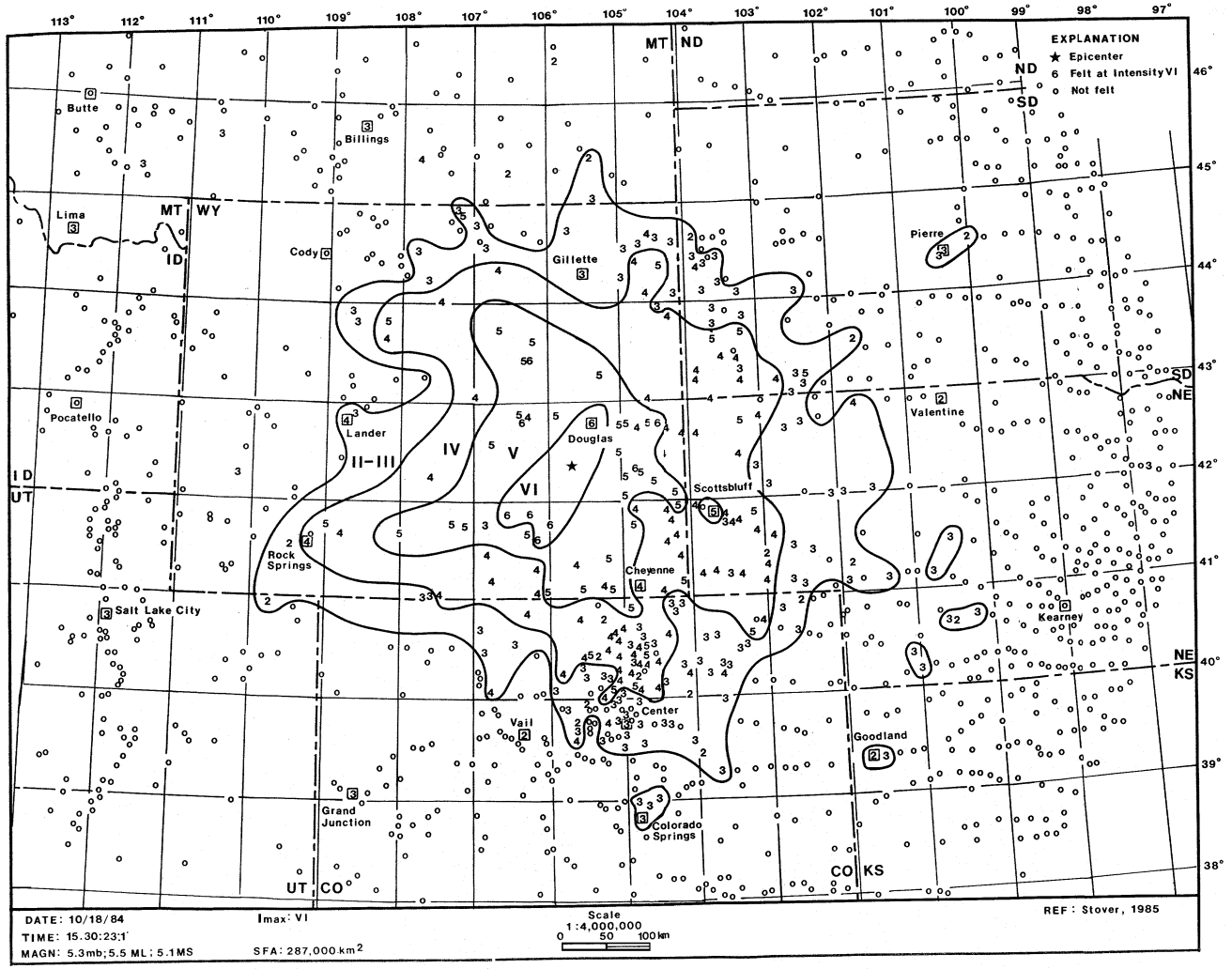


Figure 51. Isoseismal map for the October 18, 1984 earthquake.

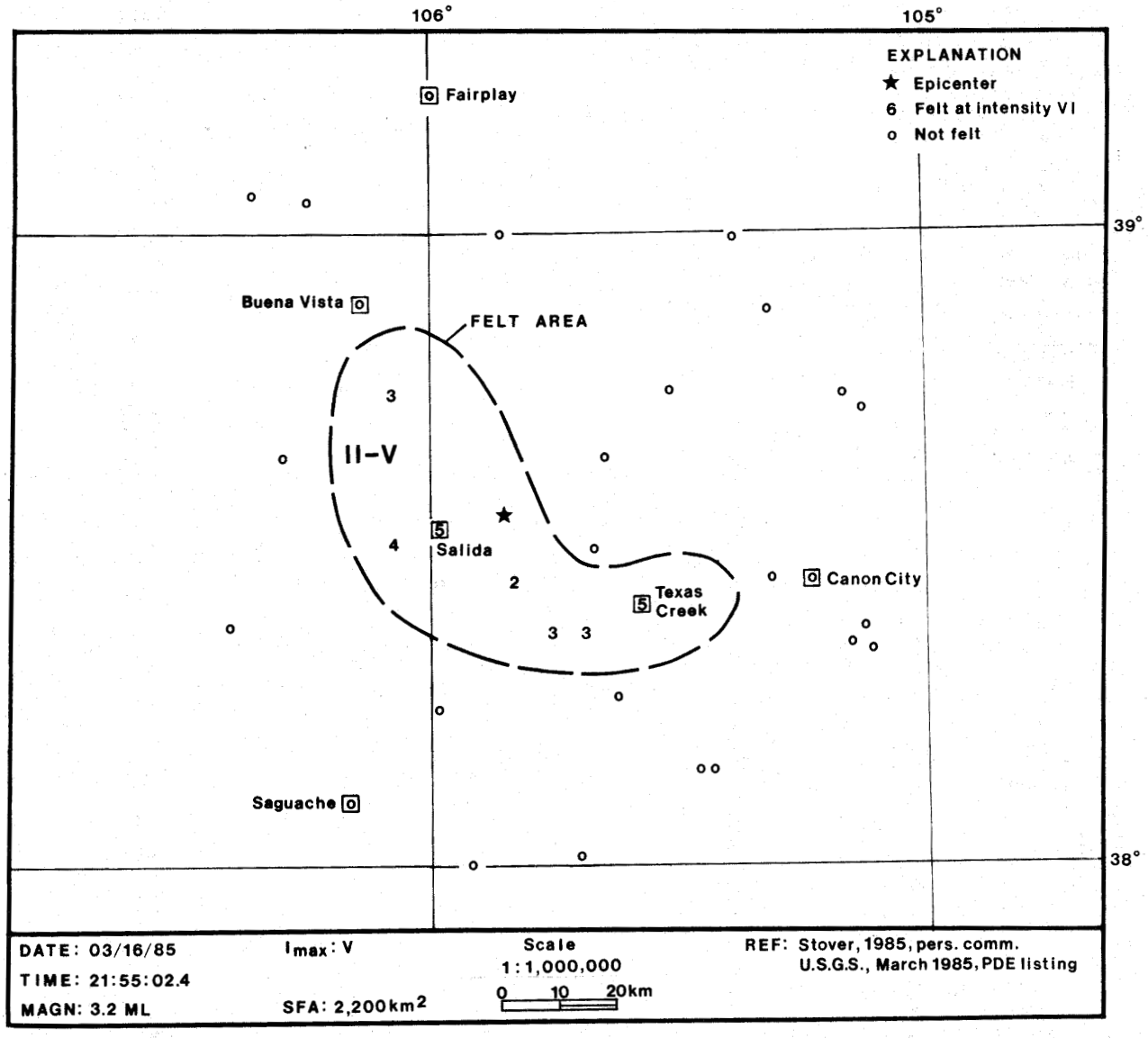


Figure 52. Intensity map for the March 16, 1985 earthquake.

December 6, 1985

A small earthquake of ML 2.9 occurred on the southwestern flank of the Uncompahgre Uplift on December 6, 1985. This earthquake and several others that centered in this area shortly before and after it were recorded on the 17-station Paradox Basin network in southeast Utah, the 10-station Paradox Valley network, and the 6-station Ridgway Dam network **(Ely and others, 1986)**. Only the main event is listed in Table 1. Refer to **Ely and others (1986)** for information on the other earthquakes. A focal mechanism for the mainshock prepared by **Ely and others (1986)** indicates normal faulting. They suggest it may have occurred on the Ryan Creek Fault, but recognize that other structures in the area could also be the causative structure.

August 13 to September 3, 1986

The 1986 Crested Butte earthquake swarm began on August 13 and continued through September 3, 1986. It was preceded by two quakes, a ML 2.9 earthquake on April 11 and a ML 2.7 event on May 9, and it was followed by a sporadic series of earthquakes that initiated on September 18 and continued through December 13 **(Bott and Wong, 1995)**. Thirty events equal to or greater than ML 1.6 were located by NEIC; these events are listed in **Table 1**. The parameters for these earthquakes that are described in **Table 1** are based on data from **Stover and Brewer (1994)**, **Bott and Wong (1995)**, and the NEIC earthquake database. Sixteen of the quakes were reported felt, including the largest earthquake, a ML 3.5 event on September 3. It caused intensity V effects at Crested Butte, where a few glassware or dishes broke.

Over 200 events with coda duration magnitude 0.5 and greater related to this earthquake sequence were recorded by the Ridgway Dam and Paradox Valley regional networks. A portable seismographic network was installed by the USGS and MicroGeophysics Corporation near the epicentral area for a seven-day period **(Bott and Wong, 1995)**. Unfortunately, the remote and rugged location prevented deployment of the instruments uniformly across the epicentral area. Several events recorded by the portable array were also recorded by several regional stations, which allowed for station corrections to be developed for both the regional and portable networks **(Bott and Wong, 1995)**.

As shown on **Figure 53**, nearly all of the 78 earthquakes located by the portable network during the swarm centered in a 6-km-long, northwest-trending zone near Treasure Mountain northwest of Crested Butte **(Bott and Wong, 1995)**. The earthquakes occurred between depths of 2 to 11 km in a zone that dipped steeply northeast. The hypocentral locations and focal mechanisms for the earthquakes led **Bott and Wong (1995)** to conclude that predominantly normal slip on the Treasure Mountain Fault was likely responsible for the earthquakes.

August 14, 1988

A magnitude mb 5.5 (ML 5.3) earthquake centered near Ferron, Utah shook parts of Utah, Colorado, and Wyoming on August 14, 1988. A unpublished isoseismal map for the event prepared by L.R. Brewer for the USGS is shown in **Figure 54** (J.W. Dewey and M.G. Hopper, 1996, written commun.). The earthquake was felt over an area of about 113,000 km^2. Several towns in Utah near the epicenter experienced intensity VI shaking; damage included cracked foundations and chimneys (unpublished data in USGS-NEIC files). The earthquake was felt at intensity V at Gateway, Colorado and across parts of western Colorado at intensity II to IV.

September 12, 1990

On September 12, 1990 a ML 3.0 earthquake caused intensity V shaking in Vail, Frisco, and Minturn (NEIC data provided by W.K. Smith, 1996, written commun.). It was also felt at intensity III at Silverthorne. The NEIC epicentral location for this event places it on the east flank of the Gore Range.

October 21, 1990

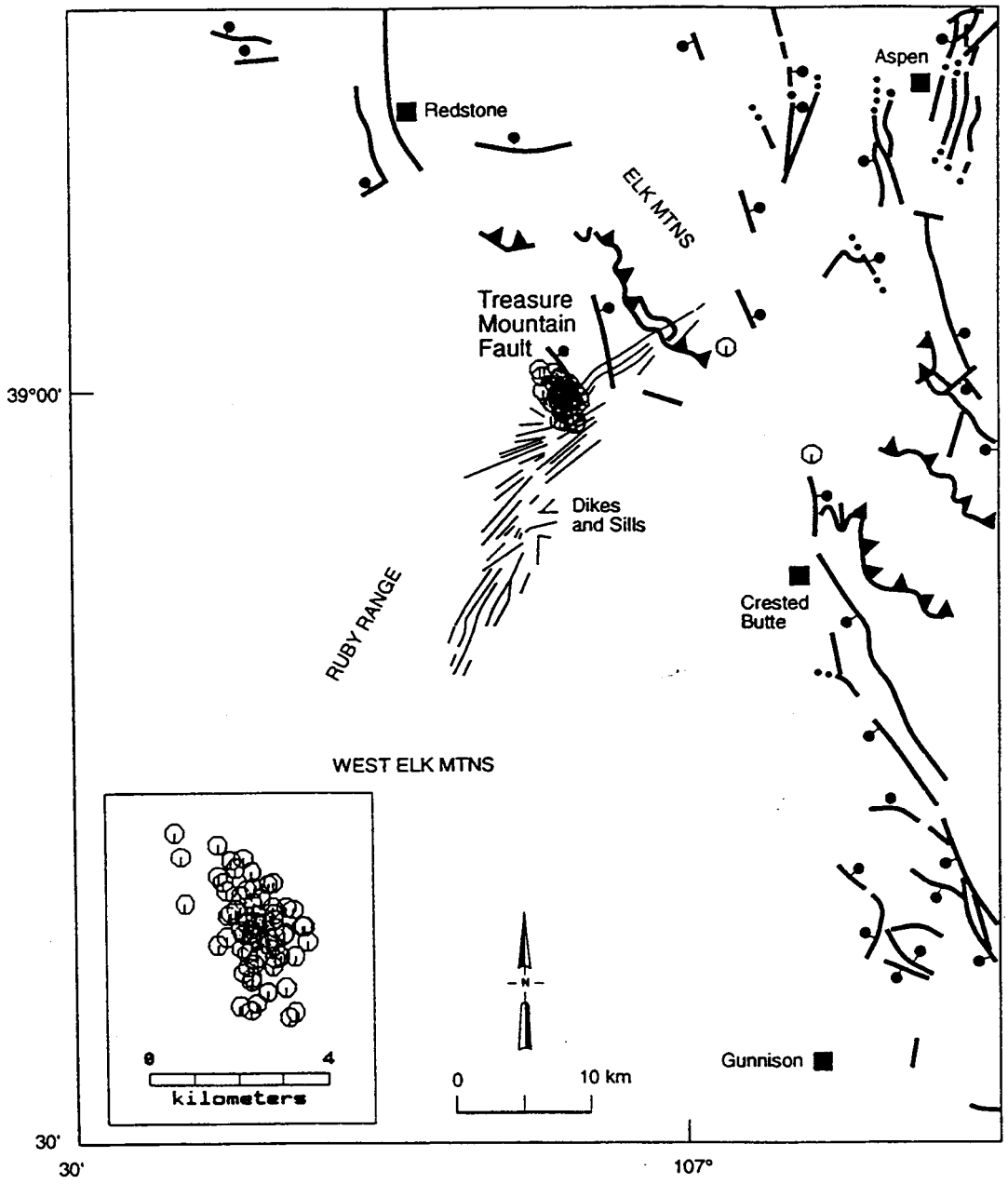
A few windows cracked and a few dishes and knickknacks were broken in Palisade (intensity V), while Clifton and Whitewater reported intensity III shaking during the October 21, 1990 earthquake (NEIC data provided by W.K. Smith, 1996, written commun.). Earthquake magnitude was ML 2.7, and its epicentral location was near Grand Mesa about 18 km north of Delta (NEIC data).

April 15, 1992

A ML 3.2 earthquake was felt across a small part of south-central Colorado on April 15, 1992. Intensity V shaking was reported at Aguilar, where a few objects were overturned (NEIC data provided by W.K. Smith, 1996, written commun.). Gulnare experienced intensity IV shaking, while reports from Walsenburg were assigned a rating of intensity III. According to the NEIC epicentral location, this event occurred in the foothills about 13 km southwest of Aguilar, near Gulnare.

September 13, 1994

A large part of west-central Colorado felt the effects of the September 13, 1994 earthquake. Magnitude of the event was reported as ML 4.6 and mb 4.4 by NEIC, and their location places it on the southeast end of the Uncompahgre Uplift about 20 km south-southwest of Ridgway. An isoseismal map prepared from felt reports collected by the USGS-NEIC (J.W. Dewey, 1996, personal commun.) for this earthquake is shown in **Figure 55**. The strongest ground shaking was in Norwood, where minor cracking was reported in exterior and interior walls, indicative of intensity VI shaking. Olathe, Ridgway, Telluride, Ophir, and Placerville all reported intensity V effects. The quake was felt over an area of about 17,300 km^2. The USGS September 1994 Preliminary Determination of Epicenters indicates the earthquake was also felt in Grand Junction and Moab, Utah, however the USGS-NEIC file on felt reports does not corroborate this.



Note: Faults are from Tweto (1979) and dikes from Godwin and Gaskill (1964)
Fault labelled Tv/Q from Kirkham and Rogers (1981).

Figure 53. Epicenter map for the 1986 Crested Butte earthquake swarm (from Unruh and others, 1993).

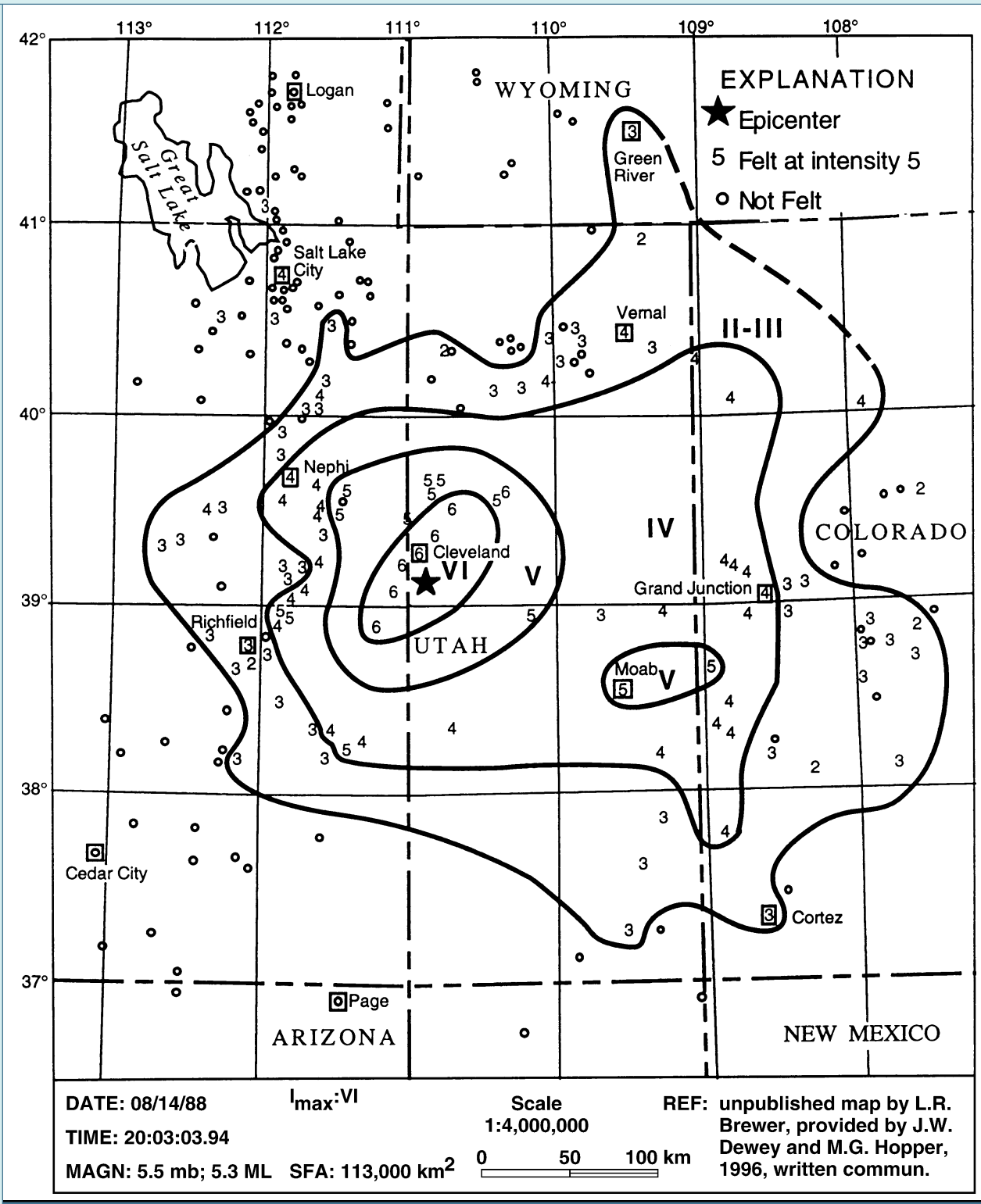


Figure 54. Isoseismal map for the August 14, 1988 Utah earthquake (unpublished USGS map prepared by L.R. Brewer; provided by J.W. Dewey & M.G. Hopper, 1996, written commun).

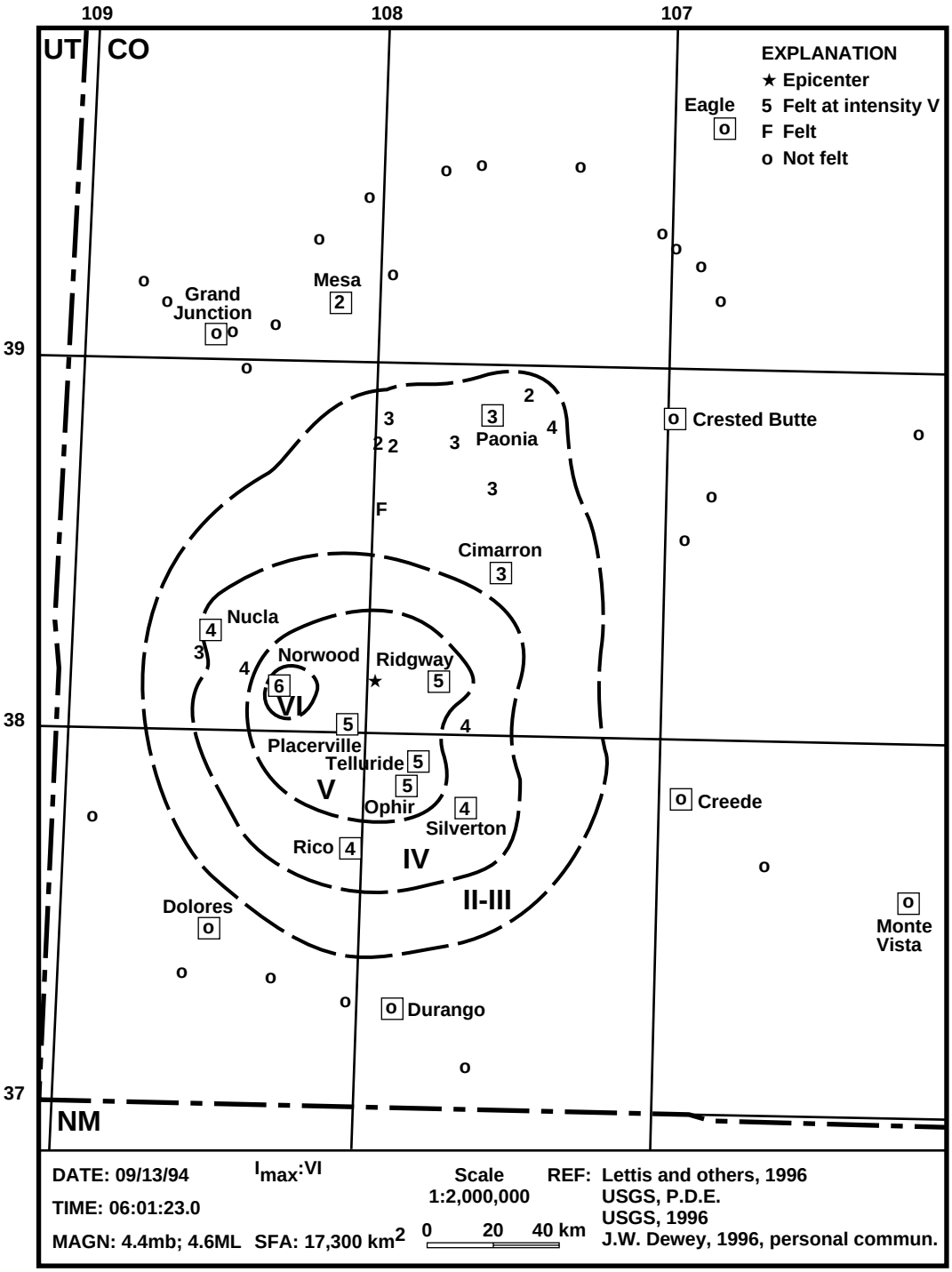


Figure 55. Isoseismal map for the September 13, 1994 earthquake.

Vetter and others (1995), based on data from regional networks in the area, located the event west of the east-west-trending Ridgway Fault. Aftershocks outlined a northwest-striking zone 2 km wide by 2 km long that dipped northeast at about 60°. A relatively well constrained focal mechanism for the mainshock suggested normal faulting along a north to northwest-striking fault plane and a N50°E direction of extension **(Vetter and others, 1995)**. The trend of the aftershocks and the focal mechanism led them to conclude that the event did not occur on the Ridgway Fault.

December 25, 1994

On Christmas day of 1994, Palmer Lake and Larkspur experienced intensity V shaking during a magnitude Mn 4.0 earthquake. The NEIC database reported an epicentral location about 9 km southeast of Castle Rock. **MicroGeophysics Corporation (1995)** relocated the earthquake using additional arrival times from other seismographs, including the regional stations which they operated, and reported its location to be about 4 km north of Perry Park along the mountain front at a depth of 23.5 km. Their hypocentral location is given in Table 1. **Figure 56** is an isoseismal map for the event prepared from felt reports collected by the USGS-NEIC (J.W. Dewey, 1966, personal commun.). The earthquake was felt over an area of 1,700 km^2, which is somewhat small considering its magnitude. **MicroGeophysics Corporation (1995)** noted that this event occurred in an area where small earthquakes had previously been recorded by the Front Range network.

March 20, 1995

Parts of northwest Colorado and northeast Utah reported an earthquake on March 20, 1995. It was felt at intensity V at Rangley and Dinosaur, Colorado and at III at Jensen, Utah. Based on the NEIC epicentral location, the earthquake occurred about 10 km southeast of Dinosaur.

December 23, 1995

A magnitude Mn 3.6 (mb 3.5) earthquake occurred near Manitou Springs on December 25, 1995. Epicentral coordinates in the NEIC database suggest a location near the east flank of the Rampart Range about 13 km north of Manitou Springs. The earthquake was felt at intensity IV at Victor, Cripple Creek, and Manitou Springs.

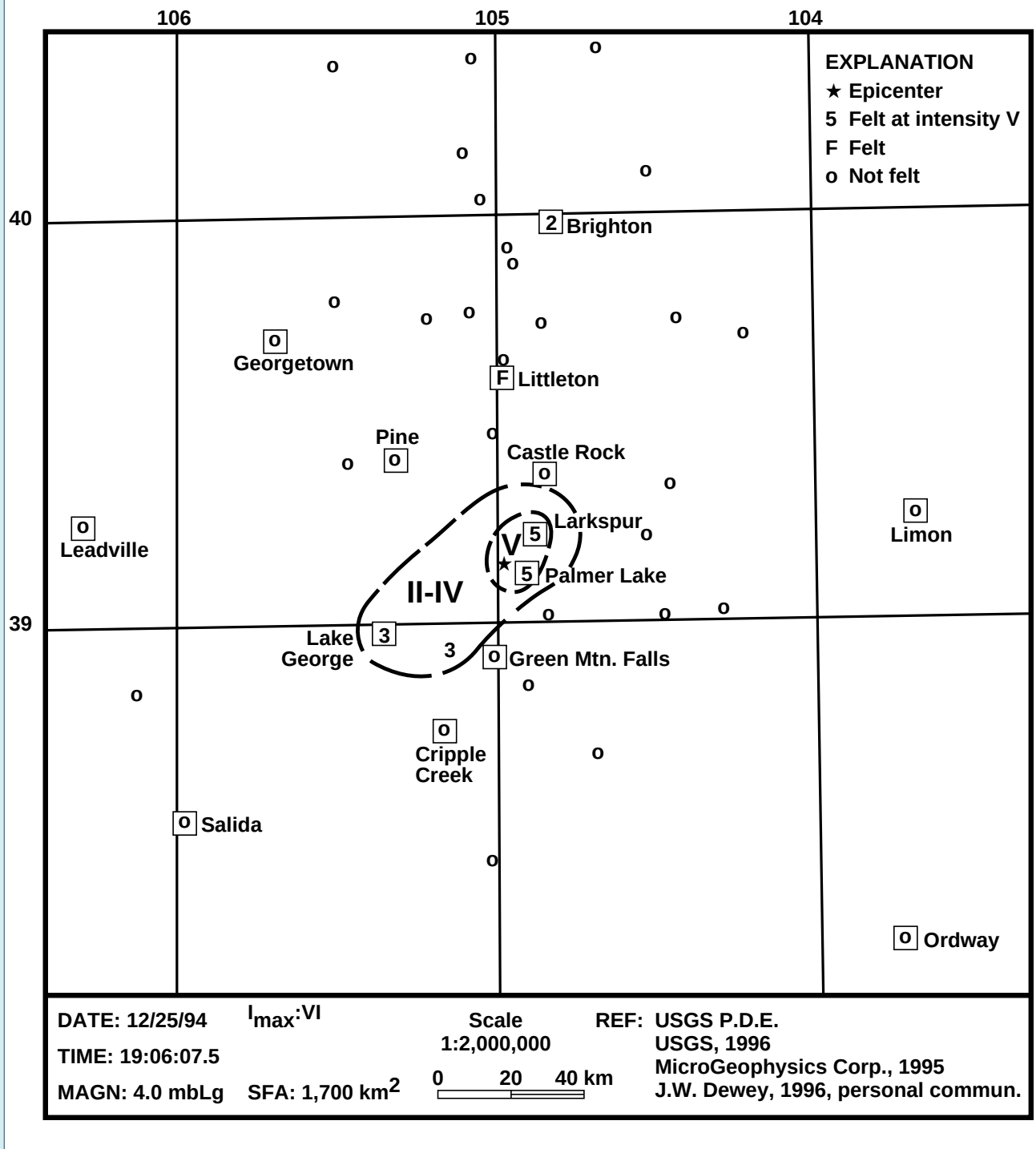


Figure 56. Isoseismal map for the December 25, 1994 earthquake.

REGIONAL SEISMOGRAPHIC NETWORKS

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During the past thirteen years, three long-term, multi-station seismic arrays have operated in Colorado, vastly improving knowledge of the distribution and character of seismicity in parts of Colorado. Between 1977 and 1983 the Denver Water Department contracted with MicroGeophysics Corporation to conduct several short duration, microearthquake surveys of Strontia Springs Dam site **(MicroGeophysics Corporation, 1993)**. Beginning in 1983, MicroGeophysics Corporation undertook at the request of the Denver Water Department the operation of a long-term seismic network to monitor seismicity in much of the central and southern Front Range. This network is generally referred to as the Front Range network. Data from the Front Range network has been released in a number of annual, unpublished reports from MicroGeophysics Corporation to the Denver Water Department. The 1993 annual summary report **(MicroGeophysics Corporation, 1993)** contains a listing of all events recorded throughout the life of the network, while a synopsis of the data and conclusions derived from it are in **MicroGeophysics Corporation (1995)**.

A total of 2,292 local events were identified by the Front Range network during 3,931 days of monitoring between 1983 and 1993 **(MicroGeophysics Corporation, 1993)**. Monitored seismic activity occurred as clusters of events and as diffuse seismicity across much of the area. Swarms of earthquakes were recognized near Round Mountain (7 km northwest of the town of Lake George), between the south end of Elevenmile Reservoir and Saddle Mountain in the southeast part of South Park, and beneath the South Platte River Canyon near the confluence of the North Fork and South Fork of the South Platte River **(MicroGeophysics Corporation, 1995)**.

Unruh and others (1996) prepared an epicentral map and series of cross sections using seismicity recorded by the Denver Water Department's Front Range network. One of the more interesting features of their map, which is shown in **Figure 57**, is the broad zone of seismicity that is parallel to and generally west of the mountain front. The cross sections of **Unruh and others (1996)** are reproduced as **Figure 58**; they suggest that some earthquake clusters coincide with known Neogene faults (potentially active faults of **Kirkham and Rogers, 1981**).

Figure 57. Microseismicity located by the Front Range network (1983 to 1993); operated by MicroGeophysics Corp. for the Denver Water Dept. (from Unruh & others, 1996).

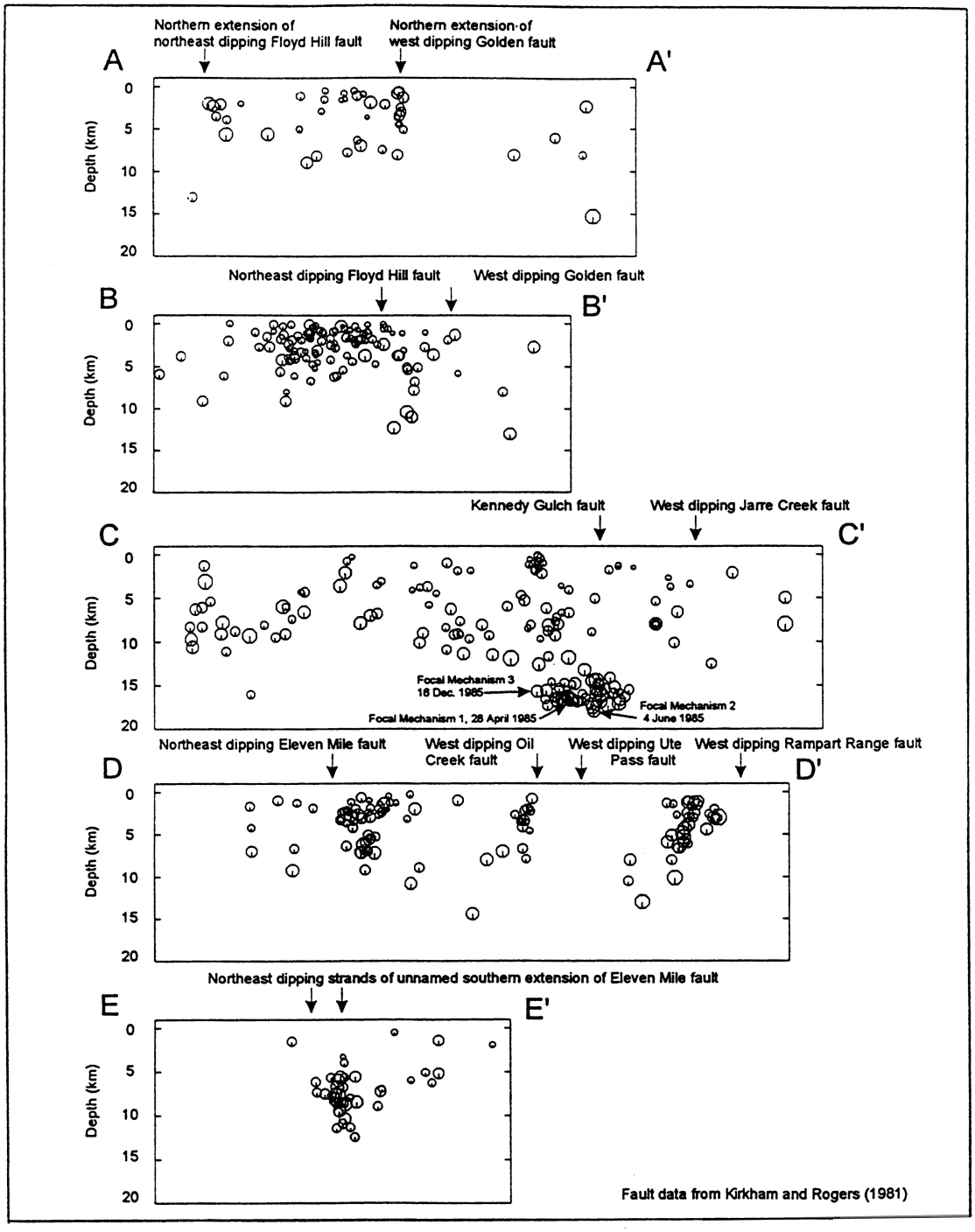

Figure 58. Cross sections across the Front Range showing microseismicity recorded by the Front Range network and spatial relationships to Neogene faults. Refer to Figure 57 for locations of cross sections. (from Unruh and others, 1996)

The U.S. Bureau of Reclamation, in cooperation with the USGS, has monitored seismicity in Paradox Valley since 1983 and near Ridgway Dam since 1985, in part due to concern about fluid-induced seismicity (**Unruh and others, 1993**; **Lettis and others, 1996**). **Vetter and others (1993)** report that seismicity near Ridgway Dam increased about seven-fold subsequent to reservoir filling, a large number of which they believe are associated with north-trending branch faults of the Ridgway Fault. The most persistent seismicity observed in the region occurs near Cimarron Ridge, an area that includes the 1960 magnitude ML 5.5 event. Refer to the section on the September 13, 1994 earthquake for a description of their work on the 1994 Norwood earthquake. Data and interpretations from the networks in Paradox Valley and at Ridgway Dam has been described in **Martin and Spence (1986)**, **Wong and Humprey (1986)**, **Ely and others (1986)**, **Wong (1991)**, **Unruh and others (1993)**, **Ake and others (1994)**, **Bott and Wong (1995)**, **Vetter and others (1995)**, **Unruh and others (1996)**, and **Lettis and others (1996)**. One of the more interesting observations of the Ridgway studies is the relationship between seismicity and faults (**Figure 59**). There is good correlation between several of the faults and the recorded seismicity in this region.

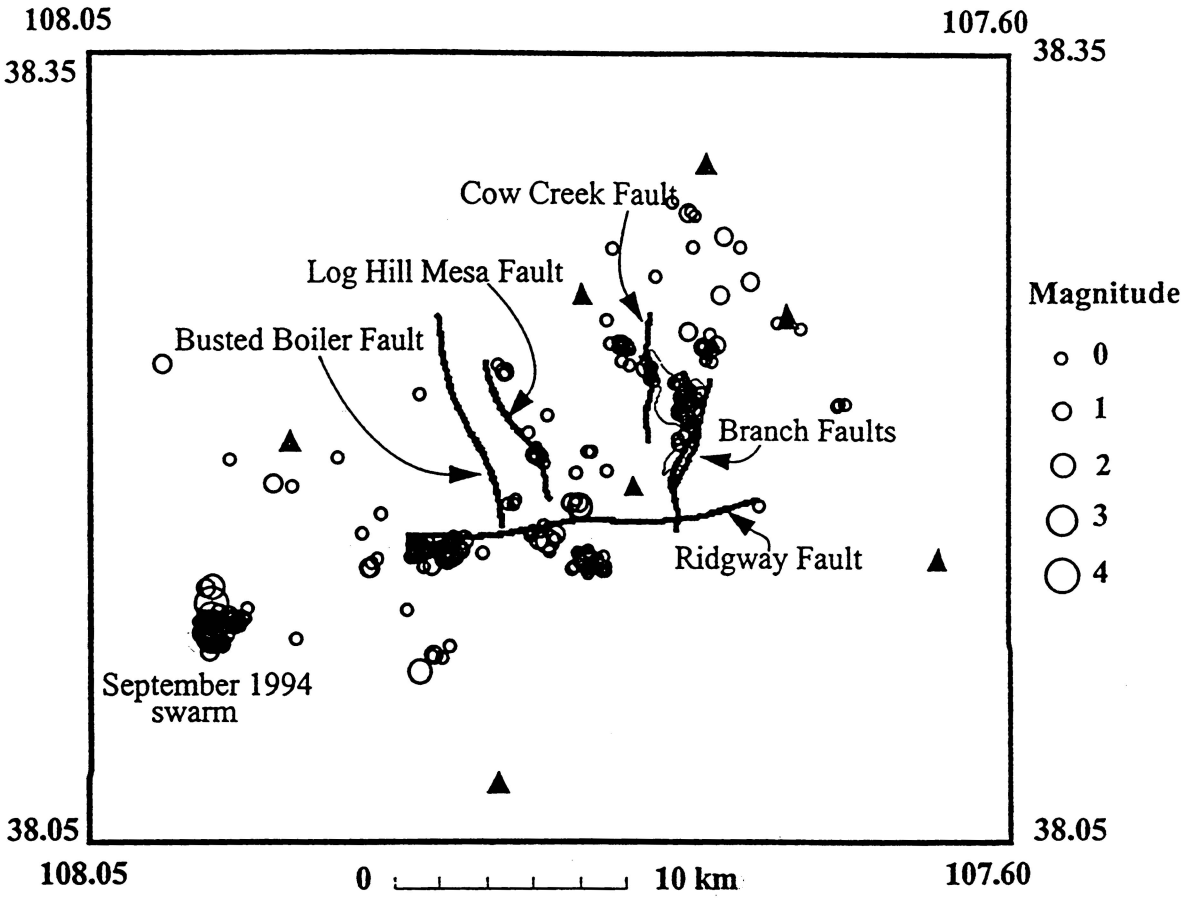

Figure 59. Seismicity and faults in the vicinity of the U.S. Bureau of Reclamation's Ridgeway seismic network (after Lettis & others, 1996). Shaded triangles indicate seismograph stations.

FOCAL MECHANISMS

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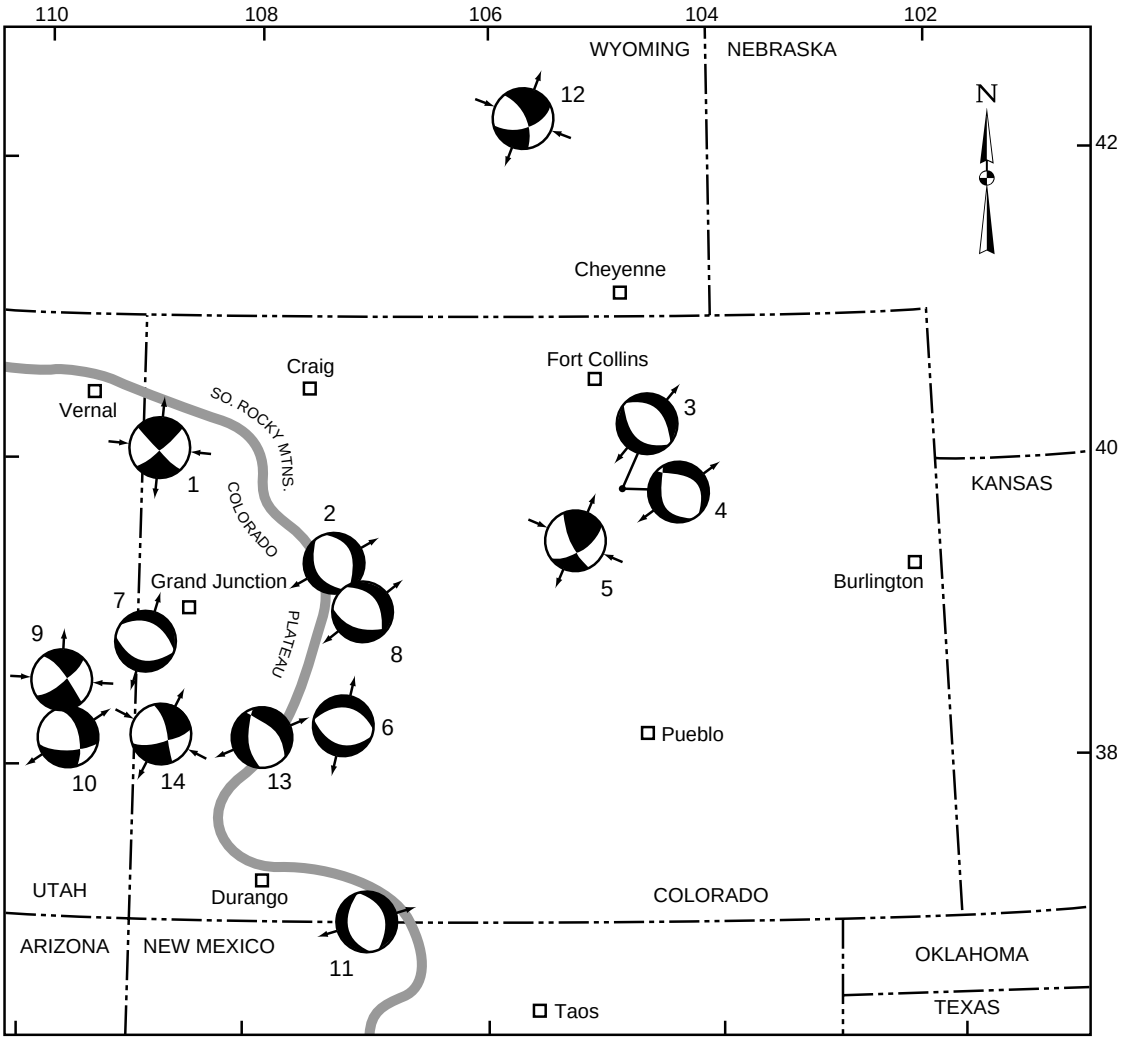
An integral part of the modern analysis of earthquakes involves focal mechanisms, also sometimes called fault-plane solutions, which yield information about the stress regime for earthquakes. **Zoback and Zoback (1980)** originally defined four stress provinces within Colorado based on a limited number of stress indicators available at that time: 1) the Rio Grande Rift province in south-central Colorado, 2) the Colorado Plateau province in the western part of the state, 3) the Southern Great Plains province in central and southeast Colorado, and 4) the Midplate province in northeastern Colorado. Focal mechanisms have since been determined for several earthquakes in and near Colorado. Based in part upon the new data **Zoback and Zoback (1989)** restricted the Colorado Plateau stress province to westernmost Colorado; the central part or Southern Rocky Mountain region of the state was placed into the newly defined Cordilleran extensional province.

Wong (1986) published one of the earliest summaries on focal mechanisms in and near Colorado and presented them in an informative figure which was later modified by **Unruh and others (1993; 1996)** and **Lettis and others (1996)**. A modified version of these focal mechanism maps is shown in **Figure 60**.

Most focal mechanisms within the Southern Rocky Mountains suggest normal faulting with minor oblique slip, a result of NE-SW, NNE-SSW, or ENE-WSW extension. An obvious exception to this trend is the strike-slip faulting for the Conifer earthquake **(Butler and Nicholl, 1986a)**. An additional 13 focal mechanisms in the Front Range have been determined by **MicroGeophysics Corporation (1993)**. Most but not all indicate strike-slip faulting; however their stress orientations vary widely. A poorly constrained fault-plane solution for the Christmas 1994 earthquake near Palmer Lake suggests strike-slip movement with a slight oblique component and a SW-directed tension axis **(MicroGeophysics Corporation, 1995)**. **Unruh and others (1996)** report a SE-directed tension axis for this earthquake based on a poorly constrained fault-plane solution.



Data Sources:

1. Rangely (Raleigh and others, 1972)
2. Carbondale (Goter and others, 1986)
3. Rocky Mountain Arsenal (Herrmann and others, 1981)
4. Rocky Mountain Arsenal (Herrmann and others, 1981)
5. Conifer (Butler and Nicholl, 1986)
6. Cimarron (Wong and Humphrey, 1986)
7. Gateway (Ely and others, 1986)
8. Crested Butte (Wong, 1991; Unruh and others, 1993)
9. Canyonlands (Wong and Humphrey, 1989)
10. Glen Canyon (Wong and Humphrey, 1989)
11. Dulce (Herrmann and others, 1980)
12. Laramie Mountains (Langer and others, 1991)
13. Ridgway (Vetter and others, 1995; Lettis and others, 1996)
14. Paradox (Ake and others, 1994; Lettis and others, 1996)

Figure 60. Focal mechanisms in and near Colorado (modified from Wong, 1986; Unruh & others, 1996; Lettis & others, 1996).

Focal mechanisms for earthquakes within the Colorado Plateau, such as those at Rangley **(Raleigh and others, 1972)**, Canyonlands and Glen Canyon **(Wong and Humphrey, 1989)**, and Paradox **(Lettis and others, 1996)**, are predominantly strike slip. However, those for the Gateway earthquake **(Ely and others, 1986)** and for several near Ridgway **(Lettis and others, 1996)** indicate normal faulting.

EARTHQUAKE INTERPRETATIONS

EARTHQUAKE EARTHQUAKE

The largest historical earthquake in Colorado occurred in 1882. Controversy continues regarding the location and magnitude of this event. Recent investigations by **Kirkham and Rogers (1986)** and **Spence and others (1996)** report an epicentral location somewhere in the northern Front Range or southern Laramie Mountains, whereas **Risk Engineering, Inc. (1994)** suggested the epicenter may have been anywhere in north-central or northwest Colorado, southern Wyoming, or northeastern Utah. Most estimates of the local magnitude of the 1882 earthquake fall in the range of ML 6.2 to 6.6 **(Dames and Moore, 1981**; **Kirkham and Rogers, 1986**; **Risk Engineering, Inc., 1994**; **Spence and others, 1996)**. Various factors have led other researchers to suggest magnitudes as low as ML 5.0 ± 0.6 **(Hadsell, 1968)** or moment magnitude (Mw) 5.0 ± 0.4 **(Risk Engineering, Inc., 1994)** for the 1882 quake and as high as ML 6.7 ± 0.6 ML **(Hadsell, 1968)** or Mw 6.9 ± 0.2 **(Risk Engineering, Inc., 1994)**.

Seismicity Patterns

Earthquakes occurring in Colorado during the historical period are plotted on **Plate 1**. Most recorded earthquake activity in the state has been concentrated in the northeast Denver area. These events are thought to have been initiated by fluid injection at the Rocky Mountain Arsenal, but they have continued long since injection ceased, suggesting the more recent quakes may be “natural” seismicity. Over 200 earthquakes have centered in the north and northeast Denver area. Most of these events were less than magnitude 4.0, but several were magnitude 4.0 to 4.9, and three were magnitude mb 5.0 or greater.

Much of the remaining historic seismicity occurs along a broad, poorly defined zone that generally coincides with the boundary between the Colorado Plateau and Rocky Mountains **(Plate 1)**. Discrete areas of seismicity within this broad zone include the Montrose–Ridgway area, Glenwood Springs–Aspen area, Rangley–Craig area, and Dulce, New Mexico area. The Montrose–Ridgway area has had a relatively high rate of seismicity during the historic period when compared to most of Colorado. At least three moderate-sized events have occurred in this region, including one magnitude mb 5.5 earthquake.

The Glenwood Springs–Carbondale–Aspen–Crested Butte area also has had a relatively high rate of historic seismicity. Earthquake activity has been reported in this region throughout the historical period, including the recent swarms near Carbondale in 1984 and Crested Butte in 1986. Part but not all of this seismicity may be related to diapirism, flowage, and dissolution-induced collapse associated with evaporitic rocks that underlie this region.

The Rangely–Craig 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. Several pre-instrumental earthquakes appear to roughly coincide with the Axial Basin Arch, which separates the Piceance Basin from the Washakie Basin.

The series of earthquakes on the Colorado–New Mexico border south of Pagosa Springs were related to a mainshock at Dulce, New Mexico in 1966 and its sequence of aftershocks. Seismic activity at Dulce may possibly be related to the Archuleta Anticlinorium, a structure which forms the eastern margin of the Colorado Plateau.

A number of earthquakes have occurred around the margins of the Uncompahgre Uplift. The Steamboat Springs region has experienced several earthquakes, as has the Trinidad–Aguilar area. Geologic evidence indicates that the Rio Grande Rift is an area where earthquakes should be expected, yet only a few felt earthquakes have been reported in the upper Arkansas Valley part of the Rio Grande Rift and in the San Juan Mountains west of San Luis Valley.

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) northern and eastern San Luis Valley. The geologic characteristics of northeastern Colorado support the lack of seismicity in that region, but late Pleistocene fault ruptures have been well documented along the Sangre de Cristo and Villa Grove Faults in northern and eastern San Luis Valley. Perhaps this latter region is presently within the midst of a relatively aseismic period that separates major fault ruptures.

Maximum Historical Earthquake Intensities

Figure 61 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 felt reports were utilized from earthquakes for which we do not have an isoseismal or intensity map. Maximum felt Modified Mercalli 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, but these reports are not definitive. The 1966 Dulce earthquake possibly caused intensity VII damage along the Colorado-New Mexico border, but no documented reports have been received.

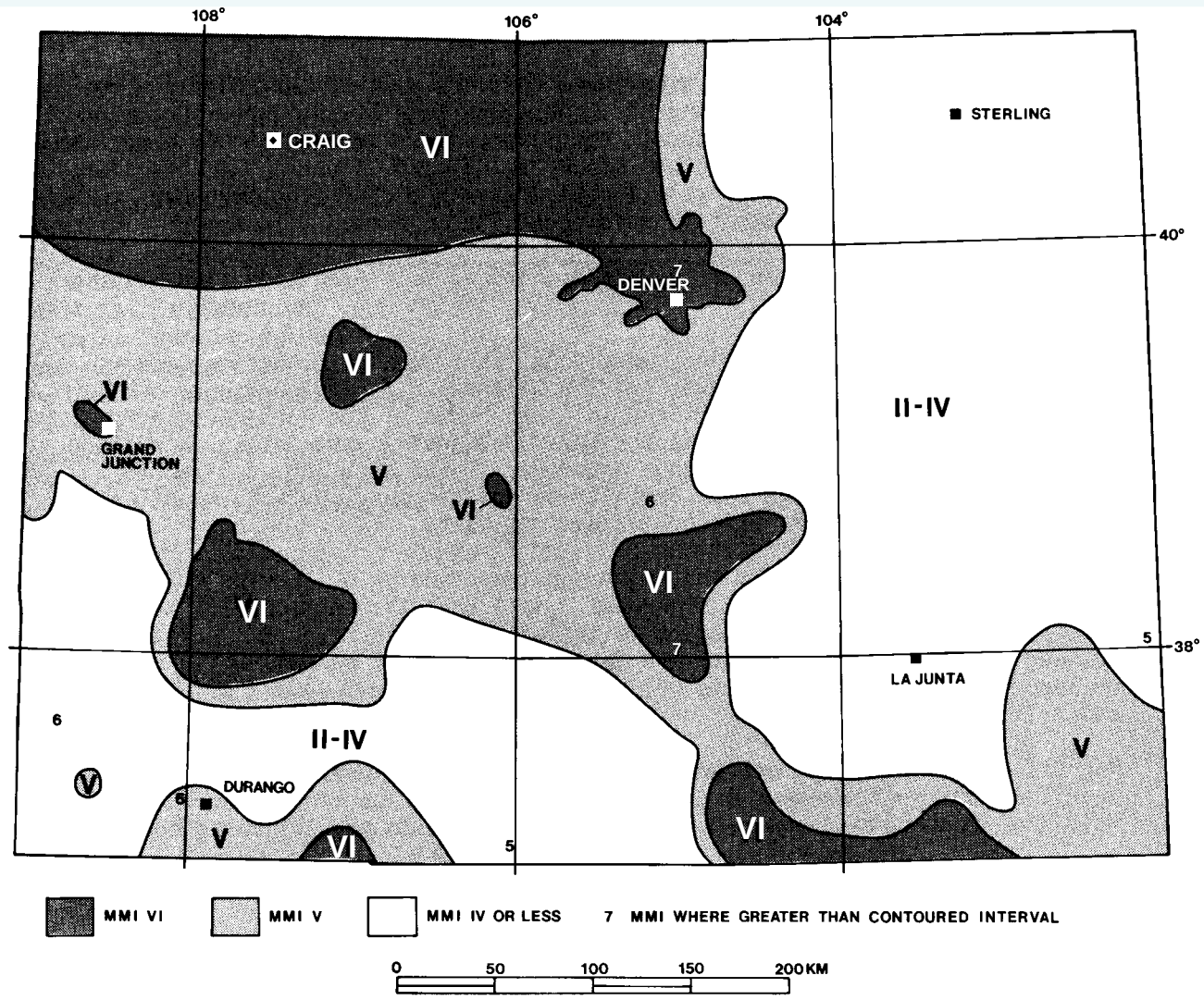


Figure 61. Maximum historical earthquake intensities in Colorado.

Intensity VI damage has occurred over several areas of the state. Much of northwestern and north-central Colorado have experienced intensity VI shaking. Other areas that have reported historic intensity VI effects include the Montrose–Ridgway–Ouray–Norwood 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 region.

Much of the Plains region of northeastern and east-central Colorado has experienced only intensity IV or less during the period of historic record. 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 intensity patterns shown in southeastern Colorado. The series of earthquakes during the 1960's affect intensity contouring in the Denver area, while the November 11, 1913, September 9, 1944, August 3, 1955, October 11, 1960, and September 13, 1994 earthquakes generated the maximum historic intensities in the Norwood–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.

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 larger earthquakes felt in Colorado through 1996. **Table 3** presents similar information for earthquakes centered in other parts of the Rocky Mountain region that were not felt in Colorado. 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 62 and **63** are graphs that plot magnitude (mb or ML) versus felt area size using the data in **Tables 2** and **3**. Note that the surface wave magnitude for the 1983 Borah Peak earthquake is included with the ML data. Relationships between magnitude and intensity for this data set are shown in **Figures 64** and **65**, while the graph on **Figure 66** illustrates the relationship between maximum reported intensity and felt area size.

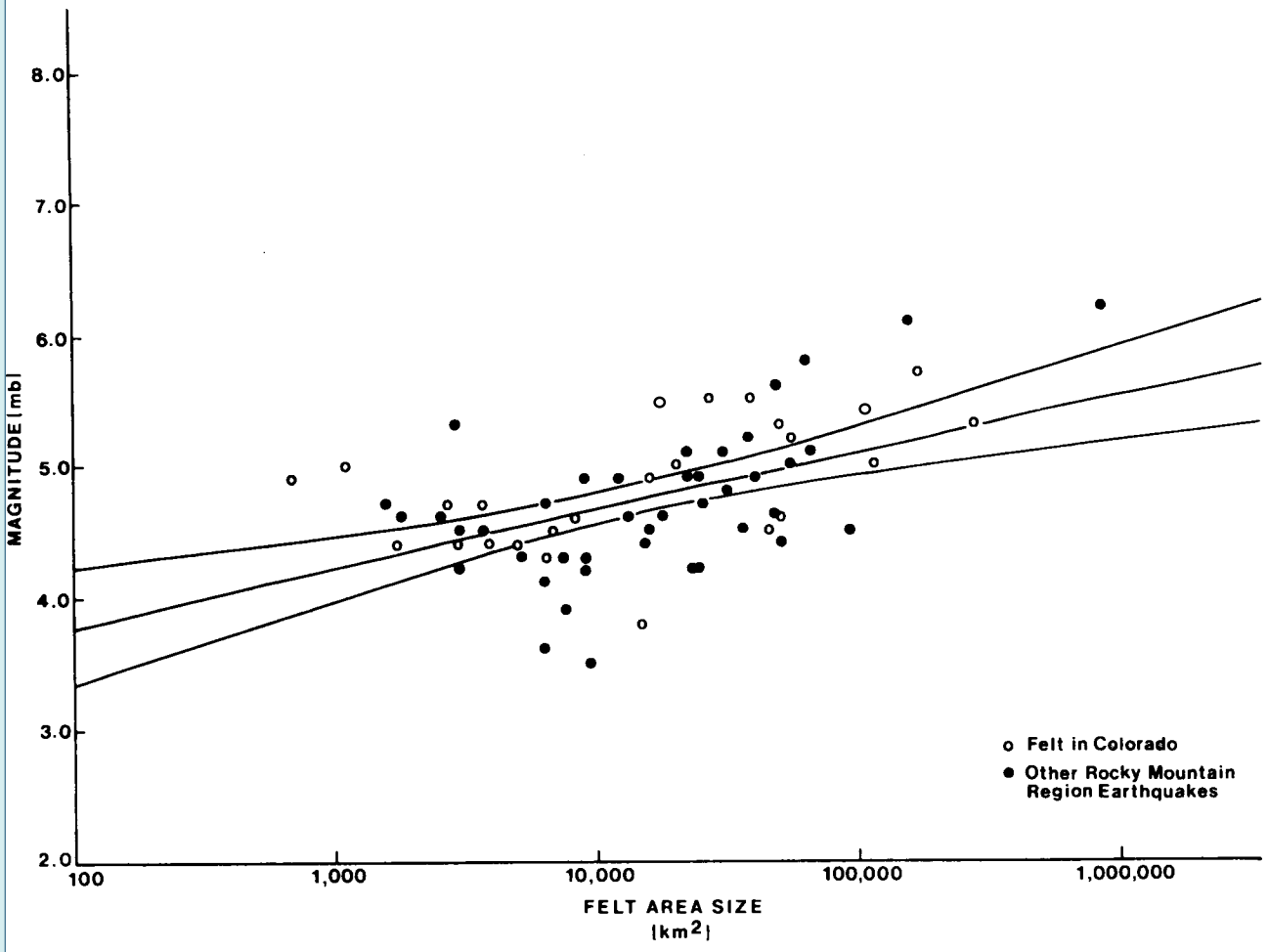


Figure 62. Magnitude (mb) versus felt area size for all Rocky Mountain region earthquakes.

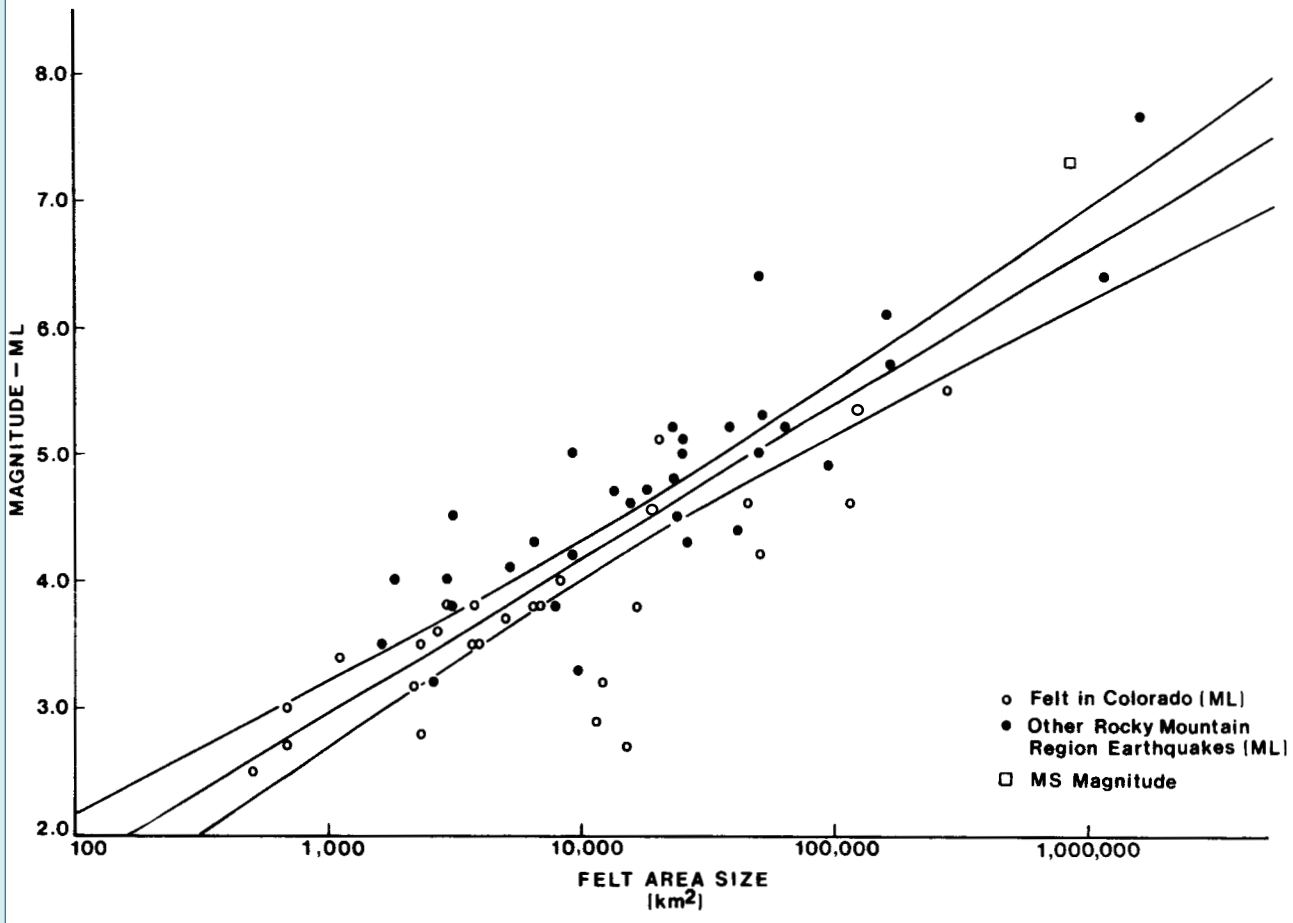


Figure 63. Magnitude (ML) versus felt area size for all Rocky Mountain region earthquakes.Note that the surface wave magnitude for the 1983 Borah Peak earthquake is included in this graph.

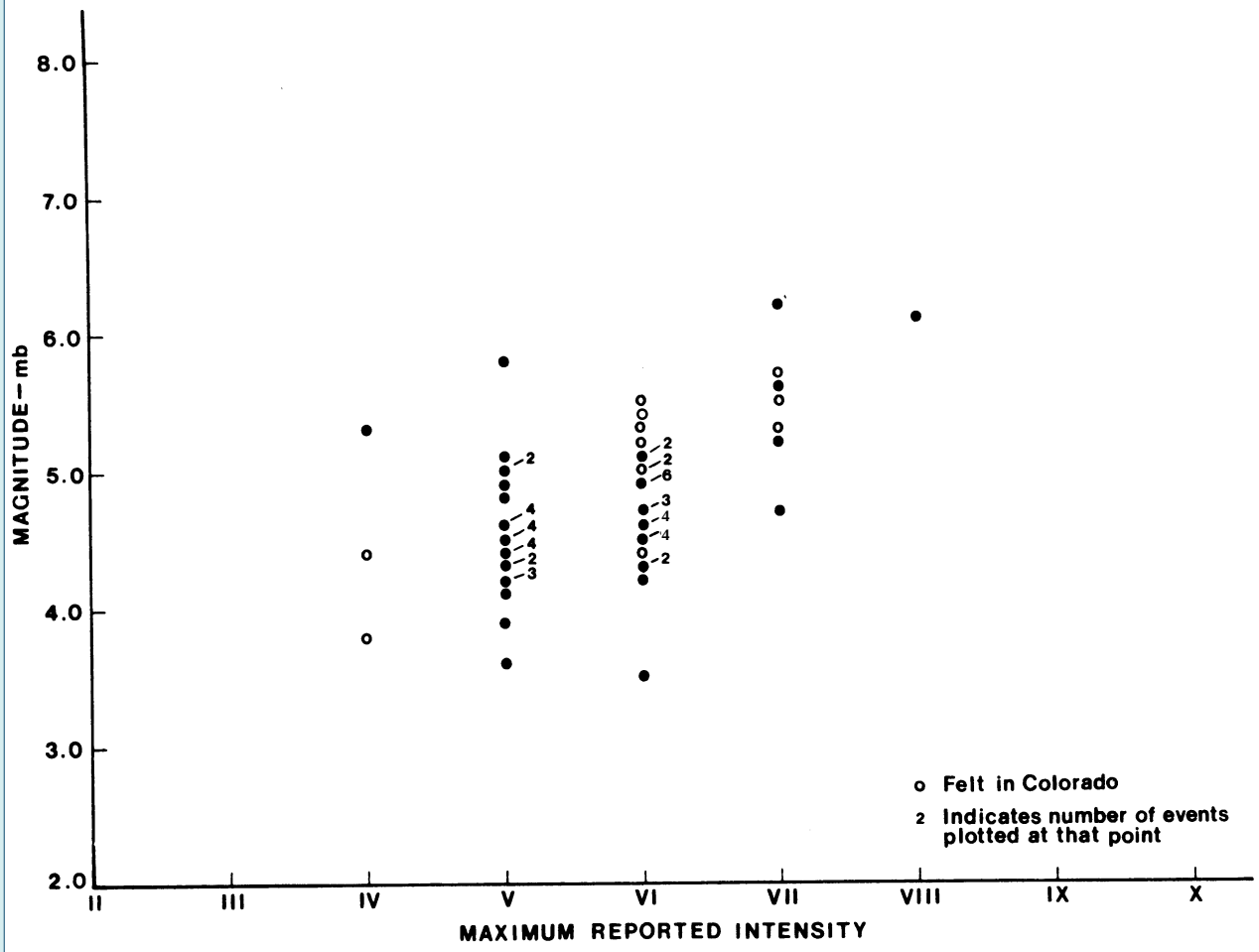


Figure 64. Magnitude (mb) versus maximum intensity for all Rocky Mountain region earthquakes.

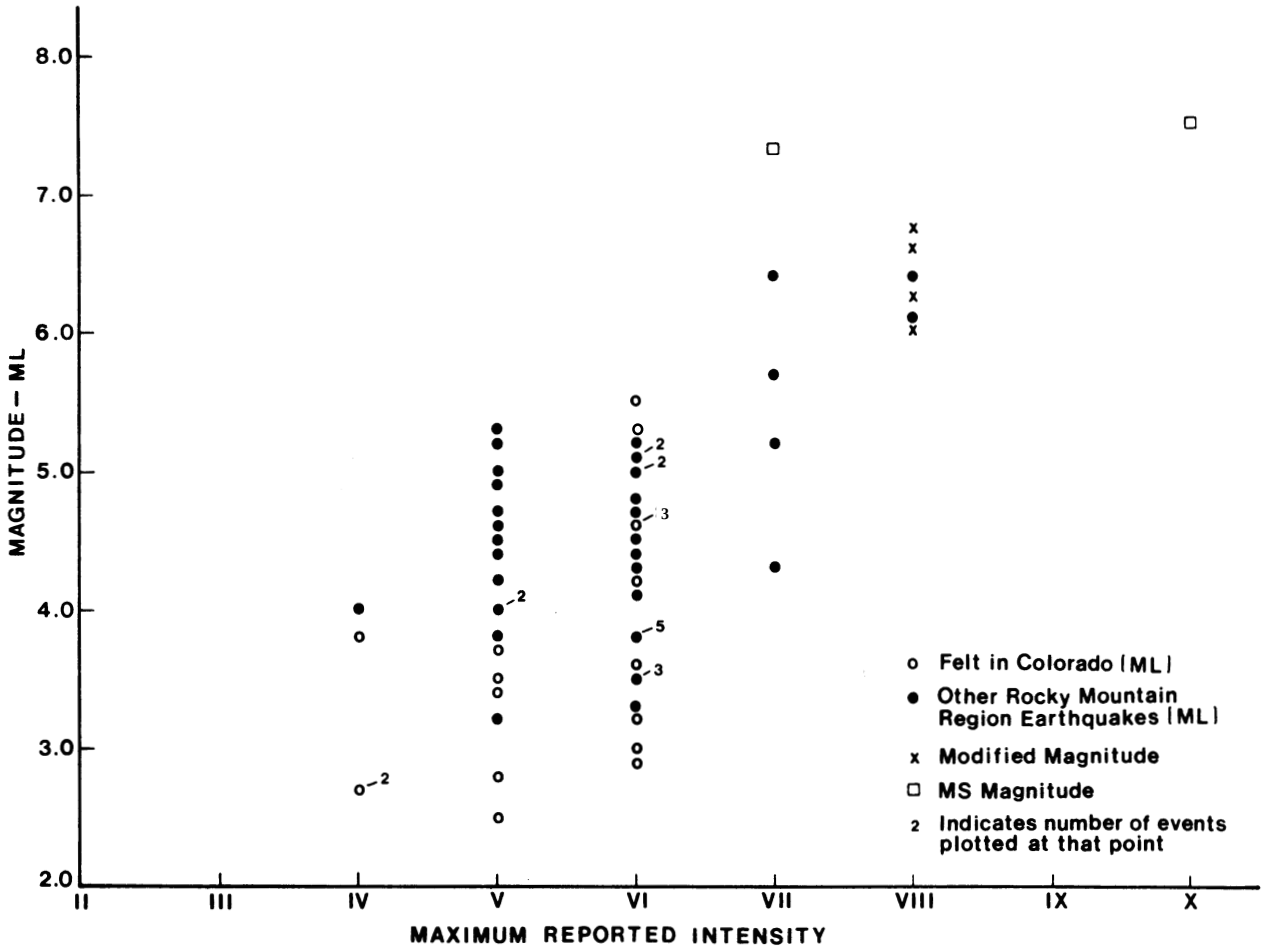


Figure 65. Magnitude (ML) versus maximum reported intensity for all Rocky Mountain region earthquakes.

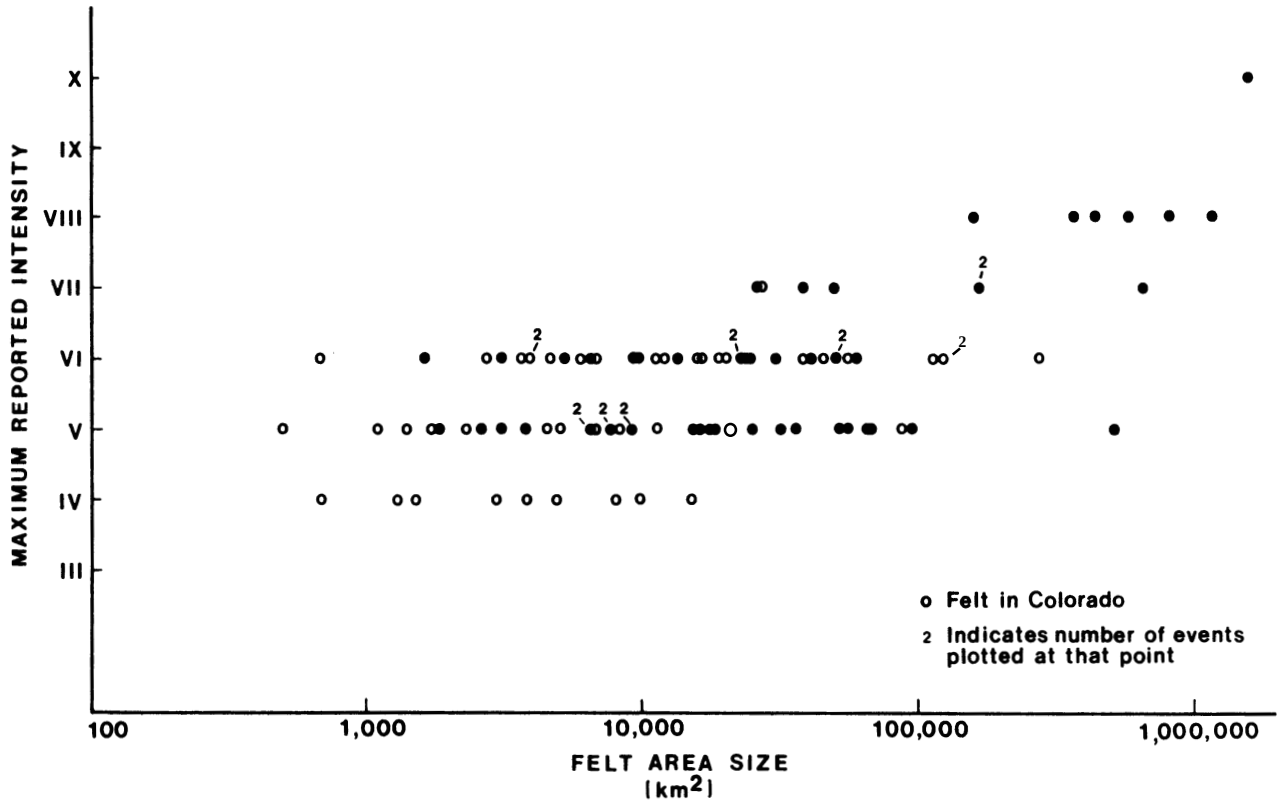


Figure 66. Maximum reported intensity versus felt area size for all Rocky Mountain region earthquakes.

Regression analyses reported in **Kirkham and Rogers (1985)** defined the relationship of local Richter magnitude (ML) or body-wave magnitude (mb) as a function of the log of the felt area size for the earthquakes listed in **Tables 2** and **3**. 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 were significant and could be used to estimate earthquake magnitudes if the size of the felt area of an earthquake was known. Testing indicated that at a 95% confidence level a strong linear relationship existed between the log of the felt area size and Richter magnitude (ML), whereas a barely significant linear relationship existed between the log of the felt area size and body-wave magnitude (mb). 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.

Observations Related to Intensity Patterns and Reported Felt Effects

A fascinating 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 contour 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 distribution or by 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 inhomogeneity in the 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 the Denver Basin, a major Laramide age structural basin filled with thousands 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, energy-attenuating sedimentary cover for hundreds of kilometers. This phenomena may also explain the limited number of felt reports east of the Front Range urban corridor for the November 8, 1882 earthquake.

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. During this 5.1 ML earthquake the Grand Junction area, which was over 100 km from the epicenter, experienced ground motion equal to or stronger than the epicentral area (Figure 48). A similar situation developed for the January 18, 1950 tremor (Figure 10). The felt areas of many of the larger regional earthquakes have “dog legs” that 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.

Table 2. Data for larger 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	4.6 ML				
10/03/66	TRINIDAD	4.5 mb	4.6 ML		IV	15,00	18
11/14/66	NE DENVER	4.4 mb	3.5 ML		VI	45,000	10
04/10/67	NE DENVER	4.9 mb		4.3 mbLg	VI	3,900	5
04/27/67	NE DENVER	4.5 mb	3.8 ML		VI	16,000	5

Table 2. (continued)

DATE(UTC)	LOCATION	MAGNITUDE			INTENSITY	FELT AREA	DEPTH
08/09/67	NE DENVER	5.3 mb		4.9 mbLg	VI	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	NORTHEAST 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	
08/14/88	CLEVELAND, UT	5.5 mb	5.3 ML		VI	113,000	
09/13/94	NORWOOD	4.4 mb	4.6 ML		VI	17,300	10
12/25/94	PALMER LAKE			4.0 mbLg	VI	1,700	24

Table 3. Data for larger 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	
11/02/72	CENTRAL MT	4.2 mb 4.5 ML	V	3,100	

Table 3. (continued)

DATE(UTC)	LOCATION	MAGNITUDE				INTENSITY	FELT AREA (sq. km)	DEPTH (km)
02/15/74	TX PANHANDLE	4.5 mb			4.6mbLg	V	37,000	
02/04/75	NORTHWEST 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	SOUTHEAST ID	4.6 mb	4.7 ML			V	18,000	4
10/14/82	SOUTHEAST 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

* Mod. Mag. = Modified Magnitude from Gutenberg and Richter (1954)

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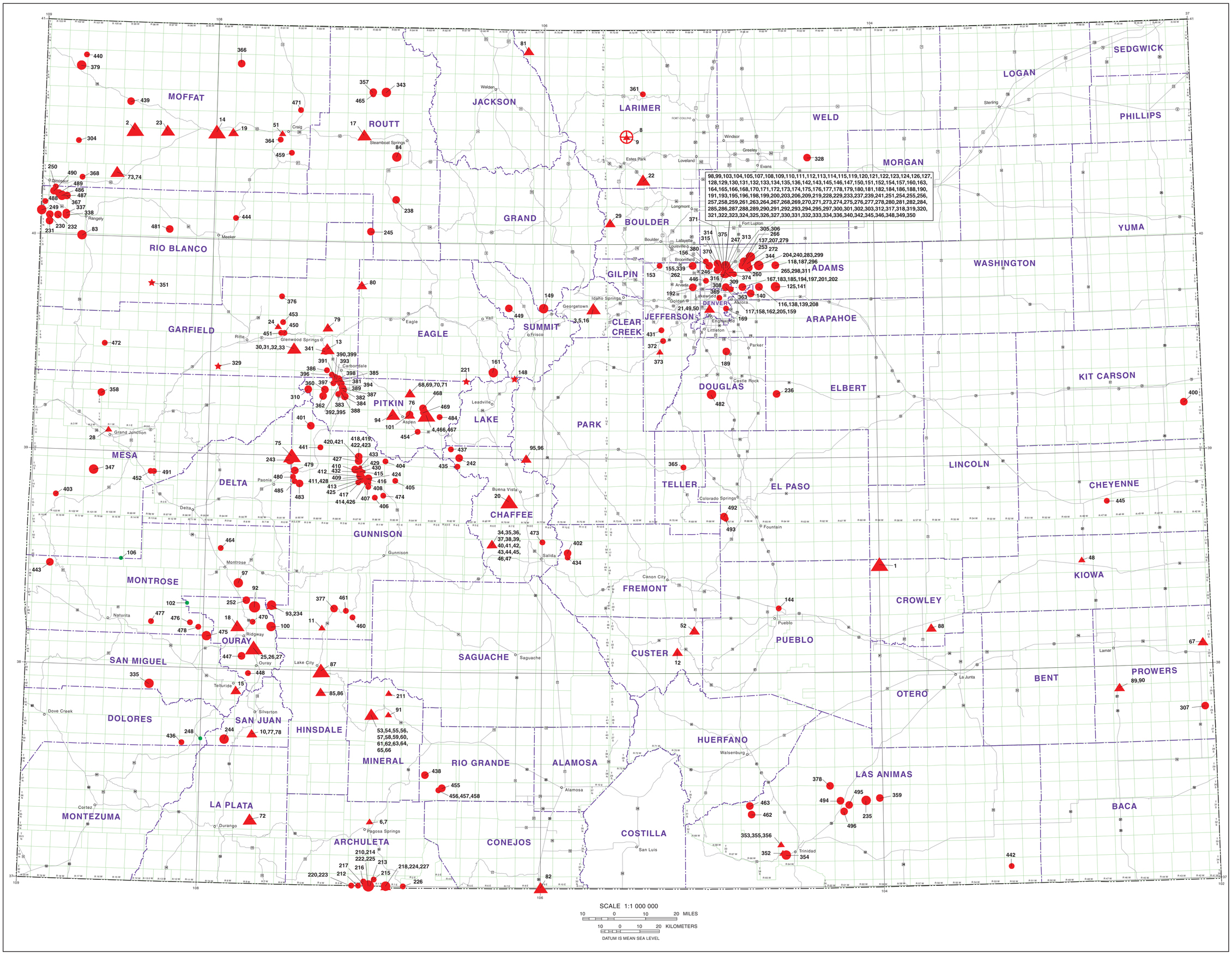
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

COLORADO EARTHQUAKES, 1867 THROUGH 1996

By Robert M. Kirkham and William P. Rogers

BULLETIN 52
PLATE 1
1999



EXPLANATION

Each earthquake has a unique identification number assigned to it that is keyed to Table 1 in the text. To view the line in Table 1 that corresponds to a particular earthquake, left click on the identification number for that earthquake.

More than one earthquake may plot at the same epicentral location. Where this occurs the identification numbers for all earthquakes that have the same epicentral location are shown, and the symbol size corresponds to the largest magnitude or highest intensity.

Refer to Table 1 in the text for the latitude and longitude of the epicenter and size or type of

401 Epicentral location of instrumentally located earthquake. Size of dot indicates magnitude.

- 1.0 1.9
- 2.0 2.9
- 3.0 3.9
- 4.0 4.9
- 5.0 5.9

23 Approximate epicentral location of pre-instrumental earthquake. Size of triangle indicates the modified Mercalli intensity.

- F, I, II, III
- IV
- V
- VI

8 Approximate location of the November 8, 1882 (Universal Coordinated Time) earthquake. The location and magnitude of this pre-instrumental earthquake has been estimated by several researchers using felt reports. The location used herein is that reported by Kirkham and Rogers (1986) and Spence and others (1996) and is probably accurate to only 0.5 to 1 degree of latitude or longitude. Recent studies report magnitudes that range between 6.0 and 6.8 for the earthquake.

278 Epicentral location of instrumentally located earthquake for which neither magnitude nor intensity are available.

351 Location of earthquake generated by blast from mining operations or underground nuclear testing.

GIS and Digital Cartography by
Cheryl Brchan and Matt Morgan