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GEOLOGICAL SURVEY CIRCULAR 898

Summary of Workshops Concerning Regional Seismic Source Zones of Parts of the Conterminous United States, Convened by the U.S. Geological Survey 1979–1980, Golden, Colorado

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Edited by Paul C. Thenhaus

GEOLOGICAL SURVEY CIRCULAR 898

1983

United States Department of the Interior
WILLIAM P. CLARK, *Secretary*

Geological Survey
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Free on application to the Branch of Distribution, Eastern Region, U.S. Geological Survey, 604 South Pickett Street, Alexandria, VA 22034

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Summary of workshops concerning regional seismic source zones of parts of the conterminous United States, convened by the U.S. Geological Survey, 1979-1980, Golden, Colorado

Edited by Paul C. Thenhaus

ABSTRACT

Workshops were convened by the U.S. Geological Survey to obtain the latest information and concepts relative to defining seismic source zones for five regions of the United States. The zones, with some modifications, have been used in preparation of new national probabilistic ground motion hazard maps by the U.S. Geological Survey.

The five regions addressed are the Great Basin, the Northern Rocky Mountains, the Southern Rocky Mountains, the Central Interior, and the northeastern United States. Discussions at the workshops focussed on possible temporal and spatial variations of seismicity within the regions, latest ages of surface-fault displacements, most recent uplift or subsidence, geologic structural provinces as they relate to seismicity, and speculation on earthquake causes.

Within the Great Basin region, the zones conform to areas characterized by a predominance of faults that have certain ages of latest surface displacements. In the Northern and Southern Rocky Mountain regions, zones primarily conform to distinctive structural terrane. In the Central Interior, primary emphasis was placed on an interpretation of the areal distribution of historic seismicity, although geophysical studies in the Reelfoot rift area provided data for defining zones in the New Madrid earthquake area. An interpretation of the historic seismicity also provided the basis for drawing the zones of the New England region.

Estimates of earthquake maximum magnitudes and of recurrence times for these earthquakes are given for most of the zones and are based on either geologic data or opinion.

INTRODUCTION

By P. C. Thenhaus and F. A. McKeown

Under the Earthquake Hazards Reduction act of 1977 (Public Law 95–124, Executive Office of the President, 1978) the U.S. Geological Survey has been given the responsibility for producing earthquake hazard and seismic risk maps on both a regional and national scale. The maps are intended to aid in the mitigation of the short-term earthquake hazard to buildings of standard construction. The preparation of these maps requires completion of three major tasks: (1) delineation of seismic source zones, (2) analysis of the recurrence interval of earthquakes in each of the zones, and (3) calculation of cumulative probability distributions of expected acceleration exceedences for points in the region. A major part of the first task in the preparation of the new maps is to incorporate the most recent information and ideas related to the seismicity, geology, and geophysics of various parts of the country. This report is primarily a description of the first task—the delineation of seismic source zones.

In an effort to utilize the most recent, pertinent information from a variety of disciplines and for a variety of areas across the country, informal workshops were convened by the U.S. Geological Survey in Golden, Colo., in late 1979 and early 1980. The number of workshops convened was limited by budget considerations. A difficult decision, therefore, was to determine which regions of the United States would benefit greatest from these workshops. Seismic source zoning of the east and west coasts had been addressed in studies completed just prior to the planning of the 1979–1980 seismic source zone workshops (Perkins and others, 1979; Perkins and others, 1980; Thenhaus and others, 1980). A predecessor to the 1979–1980 workshops was convened in September 1978 at the U.S. Geological Survey's office in Woods Hole, Mass., to gather recent information that might have a bearing on seismic source zones for the eastern United States. Source zones defined as a result of information acquired at that meeting are discussed by Perkins and others (1979). Because source zones for the east and west coasts incorporated the most recent information available as of 1978–1979, they were excluded from consideration in planning the 1979–1980 workshops. Throughout the remaining part of the United States, the general governing principle was to choose those regions where geological, geophysical, and seismological research of the past 5 years contributed

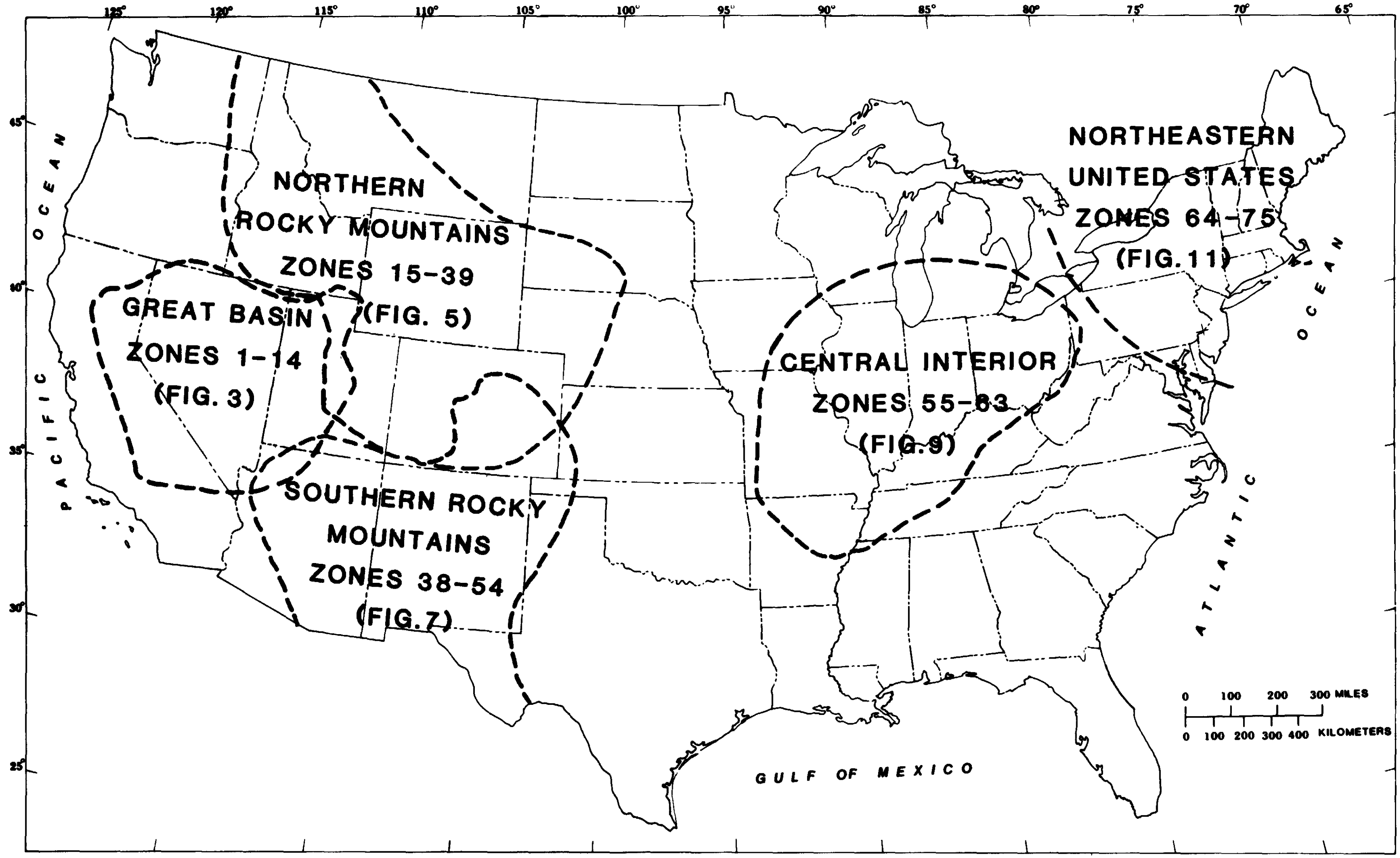

FIGURE 1.—Five regions of the conterminous United States discussed at seismic source zone workshops convened by the U.S. Geological Survey, 1979–1980. Numbered zones are shown on figure indicated in parentheses.

significantly to the understanding of the seismotectonics of the region. The regions chosen were the (1) Great Basin, (2) Northern Rocky Mountains, (3) Southern Rocky Mountains, (4) Central Interior, and (5) northeastern United States (fig. 1).

The workshops provided a forum for (1) presenting and discussing current research, some of which is in a formative stage, (2) speculating on the nature of the earthquake-generating process operating on a regional scale, (3) voicing concerns and recommendations for various seismic source zones, and (4) suggesting various treatments of these zones in application to probabilistic hazard maps.

Prior to each workshop, participants were asked to ponder a number of considerations in relating geological, geophysical, and seismological information to seismic source zones. These considerations are enumerated here as they were the focus of the discussions at the workshops.

1. A clear distinction should be drawn (or at least attempted) between estimating ground motion in the short term (say 50 years) and the long term (say 10,000 years). To what extent can our present understanding of regional seismotectonics be applied to this problem?
2. Will the spatial distribution of earthquake activity in the region remain stationary or change in the next 50 years, or in the next 10,000 years? If there are changes, what will be the directions and rates? Is the Neogene tectonic history of use to predict changes in the distribution of earthquake activity?
3. With regard to the previous question, will large shocks recur within that zone in the next 10–500 years or will other areas become active? What other areas might become active?
4. To what extent is it now possible to estimate frequency of occurrence of earthquakes in a region by means other than the magnitude distribution of earthquakes (for example, by using data on average rates of slip on faults)?
5. Can a relationship be drawn between the age of mapped faulting in various parts of a region and (1) current seismicity, (2) seismicity in the next 50–500 years, and (3) seismicity in the next 10,000 years? Is there a difference in the preceding relationships for (1) earthquakes of magnitude $M<6.5$, and (2) earthquakes $M>6.5$?
6. Can faults in different parts of the region be characterized by differences in style, such as, in length, continuity, mode of displacement, or in location with respect to range fronts or within basins, and so forth? If differences can be recognized, is there any relationship to seismicity patterns or size of earthquakes?
7. Is there strong evidence that various structural, tectonic, or geophysical features, including average elevation, heatflow, gravity or magnetic gradients, or volcanic centers, are correlative with seismicity and, therefore, indicate constraints on the distribution of seismicity?

Zones resulting from these considerations are shown in figures 3, 5, 7, 9, and 11. The zones are numbered consecutively (1 through 75) in accord with the chronological order of the workshops for easy reference to the source zone descriptions. Some source zones are duplicated among workshop summaries and tables 1, 2 and 3 because of the overlap of the three western United States regions (see fig. 1). Information requested from the workshops, other than outlines of source zones, were estimates of maximum magnitude and recurrence of large events for the zones. This information is summarized in tables 1 through 5. Geologic data that support these estimates are available for some zones; for other zones for which little or no pertinent data are available, estimates of the magnitude and recurrence are made relative among the zones. Outside the Basin and Range and the New Madrid regions, these estimates, although intuitive, still are informative when made by a group of knowledgeable researchers. Interestingly, an opinion as to the reasonableness of areas belonging to the same (or different) zones commonly is based on an intuitive distinction of both maximum magnitude and earthquake recurrence among different areas.

We must point out that the zones derived from the workshops are not necessarily the zones used in the national seismic hazard maps (Algermissen and others, 1982). A brief description of those zones accompanies the maps.

The configurations of the source zones in this report represent current thinking in seismic regionalization and can be expected to change in the future as research pertinent to the subject evolves. Therefore, just as important as the exact zone configurations outlined here, is the need to indicate the current trends in thinking. Discussions at the workshops covered a wide scope, ranging from detailed accounts of geologic data about earthquake occurrences on a particular fault to relatively unconstrained speculation on regional tectonics and underlying earthquake causes. Indeed, participants were encouraged to range as far as they could to construct a reasonable hypothesis. The detailed, better founded hypotheses are represented in the source zone maps and are documented in the accompanying source zone descriptions. They are, as would be expected, the information that the groups were comfortable using as a basis for zoning. Many other ideas that related to uncertain geologic associations with seismicity, or ideas that may have involved speculative causal mechanisms are not represented in the source zone maps. However, each idea has some degree of merit, and, limited as it might be at present in scope or application, with further study may result in a useful zoning principle. Accordingly, the "Workshop Summary" sections in this report reflect the nature of these more speculative ideas and discussions.

The source zones described herein represent solely the views of the various committees. They do not represent the authors' viewpoints nor are they to be interpreted as an official position of the U.S. Geological Survey.

ACKNOWLEDGMENTS

Thanks are due to all the participants of the workshops for their contribution in this effort, particularly for their willingness to supply or to discuss unpublished data and ideas. Their unselfishness in this respect has led to the use of the most up-to-date information for delineation of seismic source zones. The following workshop summaries and zone descriptions have been excerpted, either in part or in whole, from workshop summaries prepared by the Recorder of each workshop. The Recorders' extra efforts are greatly appreciated as are the efforts of Frank McKeown for organizing the workshops.

A special thanks is extended to Frank McKeown, Porter Irwin, Otto Nuttli, John Bell, Michael Stickney, Yngvar Isachsen, Gabriel Leblank, William Diment, Anthony Qamar, Allan Sanford, S. T. Algermissen, and David Perkins for helpful comments during the preparation of this text.

GREAT BASIN SEISMIC SOURCE ZONES—SUMMARY OF WORKSHOP CONVENED OCTOBER 10–11, 1979

By R. C. Bucknam and P. C. Thenhaus

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WORKSHOP SUMMARY

A substantial part of the workshop was spent discussing the significance of spatial and temporal variation of seismicity along both the Nevada Seismic Zone (NSZ) and the Wasatch fault (see fig. 2 for location). Ryall (1977) argued two points that were reiterated at the workshop: (1) that, based on the distribution of late Quaternary faulting in Nevada, the seismic activity in the western Great Basin migrates with time, and (2) that the sites of large historic events are probably the least likely areas to have large events in the future based on the distribution and recurrence characteristics of recent seismicity in the vicinity of the past large events. A clear division of opinion existed as to whether the present state of knowledge of the seismotectonics in the western Great Basin allows delineation of areas where seismic activity could be expected to increase in the future as opposed to areas where seismicity could be expected to decrease. Seismologic data indicate a decreasing rate of low-magnitude seismicity along faults that have had historic rupture, indicating that perhaps the microseismicity is part of a waning aftershock pattern. Also, clusters of seismicity are prominent at the ends of certain faults that have late Quaternary but not historic displacement. Other late Quaternary faults, however, have moderate levels of seismicity along their length, perhaps indicating stress accumulation on these

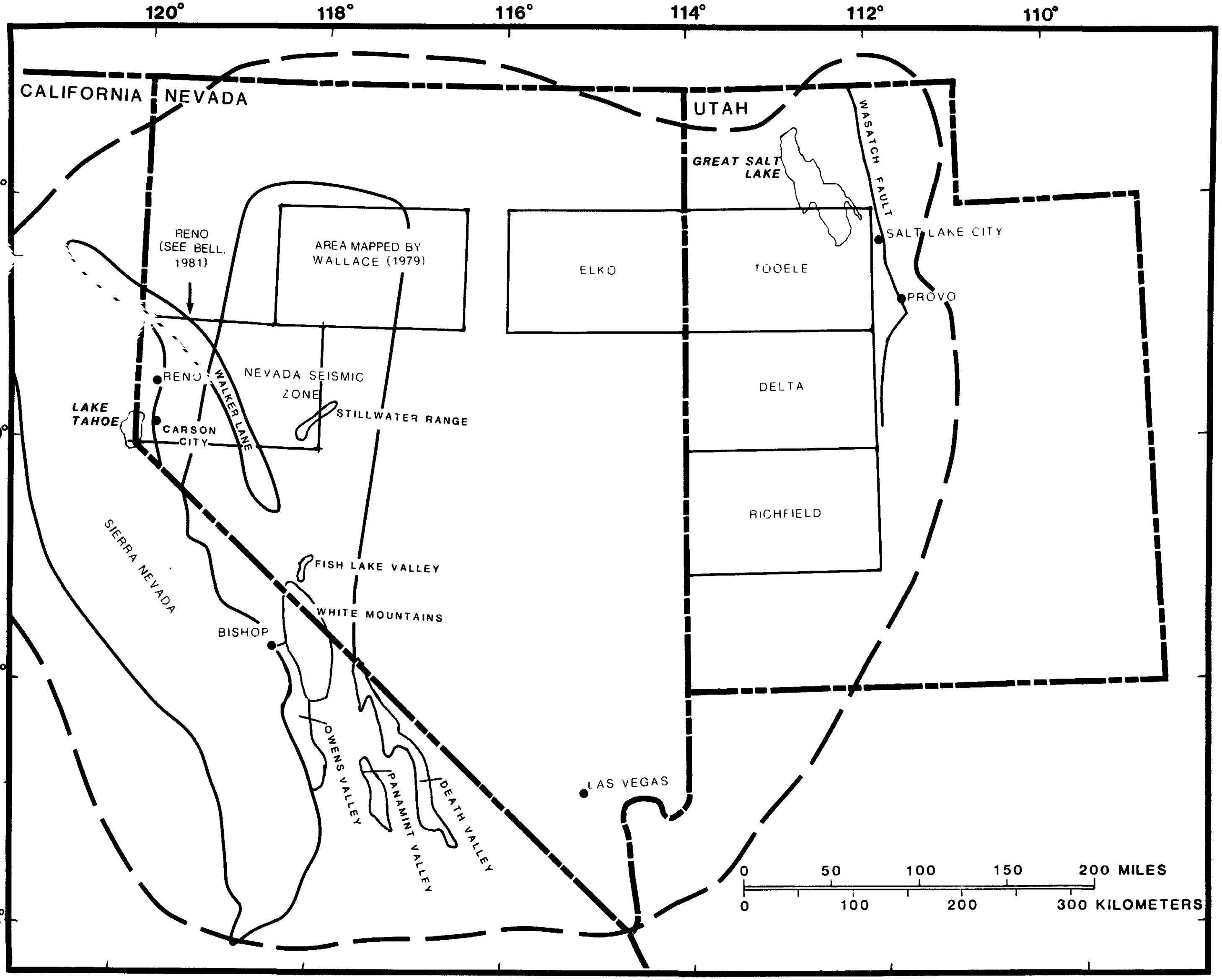

FIGURE 2.—Index map of the geographic region addressed at the Great Basin seismic source zone workshop showing selected topographic, geologic, and geographic features that are referenced in the text. Two-degree topographic quadrangles shown are those in which Quaternary faults have been mapped. Dashed line indicates geographical extent of the region considered in the workshop.

particular faults and possibly impending fault rupture. Although the concept generally was accepted as having merit, the unclear nature of the seismotectonic cycle in the western Great Basin precluded its use in a form of detailed zoning of individual faults. The high incidence of historic faulting in the NSZ is apparently without precedent in Holocene time, indicating perhaps that rather broad zones in the western Great Basin are "uniformly" activated but only for geologically short periods of time. The concept of zones of reactivation that contain a number of faults involves still other considerations for determining temporal and spatial variation of seismicity. A suggestion was made that perhaps the NSZ has run the course of a seismic cycle in the western Great Basin and, therefore, that large earthquakes should not be expected there in the future. An objection was that large events could not be precluded on range-bounding faults next to those faults that have ruptured in historic time. Also, how likely are areas outside the NSZ but still within the area of Holocene faulting to be reactivated in the near future? Discussions at the workshop did not resolve any of the myriad questions raised through considerations of spatial and temporal variations of seismicity in the western Great Basin. The source zones (fig. 3) do not represent any special consideration along the Nevada Seismic Zone.

Along the Sierra Nevada–Great Basin boundary zone (SNGBZ), west of the Nevada Seismic Zone, Ryall and Van Wormer (1980) noted that existing seismic hazard maps do not show as high a hazard as fault-scarp studies, rate of uplift, and instrumental seismicity indicate (see Slemmons and others, 1979; Bell and Slemmons, 1979; Sanders and Slemmons, 1979). This area is of considerable significance as it includes the Reno–Carson City area which is the most heavily populated area in western Nevada. Ryall and Van Wormer (1980) have demonstrated reasonably the low estimation of ground acceleration hazard along the SNGBZ in existing hazard maps (Algermissen and Perkins, 1976; Applied Technology Conference, 1978) and therefore have called for a reconsideration of these hazard maps for that region.

The Wasatch fault at the east margin of the Basin and Range province in Utah poses two problems that were discussed at the workshop. First, the entire fault zone has evidence of late Quaternary displacement, and at two sites shows evidence of repeated Holocene movement (Swan and others, 1980). These Holocene displacements reasonably can be inferred to represent $M>7$ events, yet in historic times no earthquake larger than $M=5.5$ has occurred on the fault (Arabasz and others, 1980). Second, two areas along the fault show anomalously low instrumentally detected seismic activity (Arabasz and others, 1980; Smith and Sbar, 1974; Smith, 1972) but these same areas have geologic evidence of repeated Holocene movement (Swan and others, 1980). The implication is that seismicity is periodic along the fault. Pavlis and Smith (1980) have suggested that the Wasatch fault is segmented and bounds independent crustal blocks along its length. Possibly, block adjustments could control the spatial character of the seismicity along the Wasatch fault.

Arabasz and others (1980) provided an excellent discussion of considerations involving seismic "gaps" along the Wasatch fault. They distilled the arguments down to the fact that if seismicity is periodic along the Wasatch fault, the seismic cycle has yet to be defined with any confidence. Available geologic data are not adequate to determine whether seismic potential is increasing or decreasing along individual segments of the fault.

The primary seismic zonation of the Basin and Range region has been on the basis of broad regions that are relatively homogeneous with respect to the age of most recent surface faulting within certain broad age categories (Holocene, no Holocene/late Pleistocene, no late Quaternary). The zones can be inferred to represent distinctive regional variations in the rate of occurrence of large ($M>7$) earthquakes as averaged over thousands of years (Bucknam and others, 1980). The approach used does not preclude the presence of a younger fault within a region of predominantly older faults. Individual faults can be defined as source zones where the details of their late Quaternary history are known well enough to assign a specific magnitude and recurrence interval to them. The recurrence estimates in table 1 are minimum estimates. The recurrence estimates of events assumed to be $M>7$ are made on what is thought to be a nearly complete record of these events to the extent that the events are preserved in the geologic record as fault scarps.

DESCRIPTION OF INDIVIDUAL SOURCE ZONES

For documentation of the ages of faulting in western Utah and northeastern Nevada, the reader is referred to figure 2 on which is outlined areas of 1°×2° topographic quadrangle maps in which morphometric scarp studies have been made (Bucknam and Anderson, 1979b; Anderson and Bucknam, 1979; R. L. Dodge and others, written commun., 1980; T. P. Barnhard and R. C. Bucknam, written commun., 1980; Bell, 1981). The seismic source zones as defined at the workshop are shown in figure 3. Table 1 lists estimated

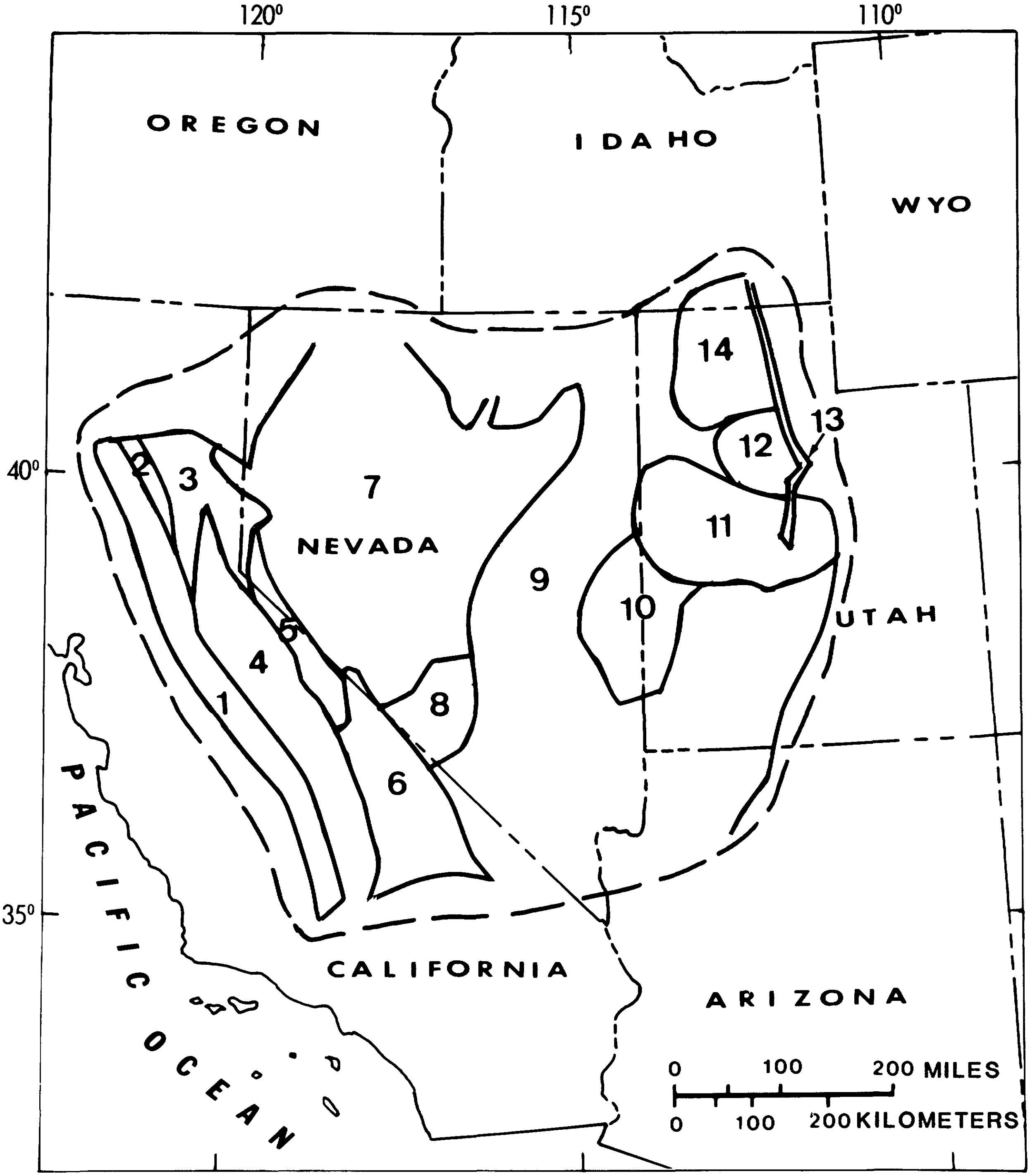

FIGURE 3.—Seismic source zones of the Great Basin. Numbers refer to descriptions of seismic source zones given in text. Unconnected lines indicate that boundary continues beyond the area considered at the Great Basin workshop. Dashed line indicates geographical extent of the region considered in the workshop.

TABLE 1.—*Estimated maximum magnitudes and recurrence rates from geologic data for earthquakes $M_s>7$ in the Great Basin seismic source zones*

[M_s, surface wave magnitude; leaders (---) indicate that no value was given at the workshop]

Zone No. (from fig. 3)	Estimated maximum magnitude (M_s)	Estimated geologic rate for earthquakes $M_s \geq 7.0$ given as number of events per 10^4 years per 10^4 square kilometer
1	6.5	---
2	---	---
3	7.0	---
4	---	---
5	7.5	---
6	8.0	---
7	7.5	[1]1.7; [2]3.4
8	---	---
9	7.5	[1]0.7
10	---	---
11	7.5	[1]2.4
12	---	---
13	7.75	---
14	---	---

[1]For western Utah zones from Bucknam and others (1980).

[2]For Wallace (1977) study area shown on figure 1.

maximum magnitudes and geologic recurrence rates for events M>7.0 in the zones.

Zone 1.—A zone of late Quaternary faulting located along the western flank of the Sierra Nevada.

Zone 2.—A zone of no late Quaternary faulting.

Zone 3.—A zone of late Quaternary faulting north of the Sierra Nevada.

Zone 4.—Central Sierra Nevada zone. Late Cenozoic deformation in this zone is restricted to broad uplift and westward tilting in the northern part with more intense warping and tilting in the southern part (Christiensen, 1966).

Zone 5.—This zone trends northerly along the Sierran front along a series of en-echelon warps and faults to the vicinity of Reno, Nev. A basis for the western boundary was poorly defined; in a general way, the zone encloses the western extent of the en-echelon segments. The northwestern and southeastern boundaries of the zone were supplied by J. W. Bell (written commun., 1981).

Zone 6.—This zone includes Owens Valley, Panamint Valley, and Death Valley. The boundary within the Sierran block has been drawn along the "frontal fault" to the vicinity of Bishop, Calif. From Bishop north, the Sierran front diverges from a linear north-northwest trend and steps westerly on a series of warps and en-echelon faults. (See Bateman, 1965, for a good account of the structural style in this area.) The northern part of the boundary extends to the west side of the White Mountains and then joins the northern end of Fish Lake Valley.

Zone 7.—This zone includes the Nevada Seismic Zone (NSZ) which, except for the historic activity, does not appear to have been more active in Holocene or late Quaternary time than the rest of the region. The zone boundary represents a region within which Holocene faulting is widely distributed. Note, though, that determination of faulting as Holocene outside the region studied by Wallace (1979; see fig. 1) is largely subjective and is not well documented. The rate of occurrence of magnitude 7–7.5 events within Wallace's study area is $3.4/10^4$ yr/10^4 km^2. Wallace believed that the density of Holocene age scarps in his study area is at least as great, or perhaps greater, than that of the entire region. The rate of faulting, therefore, may represent an upper bound. The small branch of zone 7 extending from western Nevada into northeastern California includes the Walker Lane in zone 7. Holocene age faulting is recognized along the Walker Lane (J. W. Bell, written communs., 1981, 1982).

The significance of the Nevada Seismic Zone received considerable discussion but was not resolved definitively. Ryall argued that the occurrence of major events in the NSZ has lowered the likelihood of large earthquakes in the rupture zones of these events (Ryall, 1977; Ryall and Van Wormer, 1980). In general, the group believed that the concept was of merit but some would prefer to show some indication of the high rate of historic seismicity. One participant believed that large events cannot be precluded on other major faults adjacent to the zone of large historic events, such as the west side of the Stillwater Range. The point clearly was not resolved, although there was not strong pressure to show the Nevada Seismic Zone as a separate zone. The map was left with much of western Nevada as a single zone.

Zone 8.—A zone of no late Quaternary faulting.

Zone 9.—This zone is defined on the basis of widespread faults of late Quaternary age. Holocene faulting is not known but may be present. Faults here tend to be short; Wallace believed that the maximum magnitude expected for this region should be less than that of zone 6 to the west.

Zone 10.—A zone of no late Quaternary faulting. (Zones 10 through 14 are from Bucknam and others, 1980.)

Zone 11.—A zone of Holocene faulting.

Zone 12.—A zone of no Holocene, but late Pleistocene faulting.

Zone 13.—Wasatch fault, multiple Holocene movement.

Zone 14.—A zone of Holocene faulting.

NORTHERN ROCKY MOUNTAINS SEISMIC SOURCE ZONES—SUMMARY OF WORKSHOP CONVENED DECEMBER 6–7, 1979

BY F. A. McKeown, D. C. Ross, and P. C. Thenhaus

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WORKSHOP SUMMARY

Systematic regional mapping of Quaternary faults in the Northern Rocky Mountains region has not been done. However, Witkind (1975a, b, 1976) has summarized information from many sources on late Cenozoic faulting. Pardee (1950) mapped displacements of range-bounding faults in western Montana of late Tertiary to recent age, but many of these scarps need to be reevaluated in light of the new understanding of fault-scarp morphology and methods of study (Wallace, 1977; Bucknam and Anderson, 1979a, b). If a systematic search were made for young faults, probably many more would be found, and ages of faulting could be revised on a number of known faults.

Because of this lack of regional faulting information, workshop participants adopted a zoning rationale based on information on the age of youngest faulting within regions of similar tectonic setting and structural style. This approach is not zoning on the spatial extent of different ages of latest displacements as is true for the Basin and Range province. Instead, the spatial extent of a particular age of faulting (known from specific faults within a distinctive structural region) is inferred by assuming that the age of faulting is characteristic of a region of similar structure. Emphasis is placed on the spatial distribution of historic activity in drawing only one zone—zone 21. The remaining zones generally conform to distinctive structural terranes under the assumption that distinctive structural terranes also have different seismotectonic characteristics that govern present-day seismicity.

Considerable discussion was devoted to the significance of the Lewis and Clark line (fig. 4). Features defining the lineament are the St. Marys fault trend and parallel faults to the south. These faults extend across western Montana and into Idaho (Witkind, 1977). There is evidence of right lateral movement of Pleistocene age on the St. Marys fault; sand boils and faulted talus cones are evident along its trace. Some strike-slip movement of similar age on faults paralleling the St. Marys trend is suspected. The zone bends to the south near Helena where there has been historic seismicity (Eppley, 1965; Stickney, 1978). The 1935 earthquake had a strike-slip focal mechanism (Smith and Sbar, 1974) and is consistent with geologically inferred type of fault movement. Pardee (1950) stated that the 1935 series of earthquakes (M=6.25, M=6.7) at Helena, Mont., probably were associated with a fault at the south end of Prickly Pear basin as indicated by surface effects and locations from instrumental records. He noted, though, that no surface displacement was found from the earthquakes. Pardee (1926) located the 1925 event (M=6.75) 80 km southeast of Helena. This location coincides with a projection of the St. Marys trend to the southeast. Freidline and others (1976) defined a northwest-trending zone of seismicity between Helena and Marysville that had both strike-slip and normal faulting indicated by focal mechanisms. They suggested an association on a regional scale between seismicity and northwest-trending zones of weakness in the basement. One such zone, the Lake Basin lineament, coincides with a possible extension of the Lewis and Clark line to the southeast and reasonably might extend the structure into the northern parts of Wyoming. Stickney (1978) also noted a northwest trend in earthquakes of magnitude

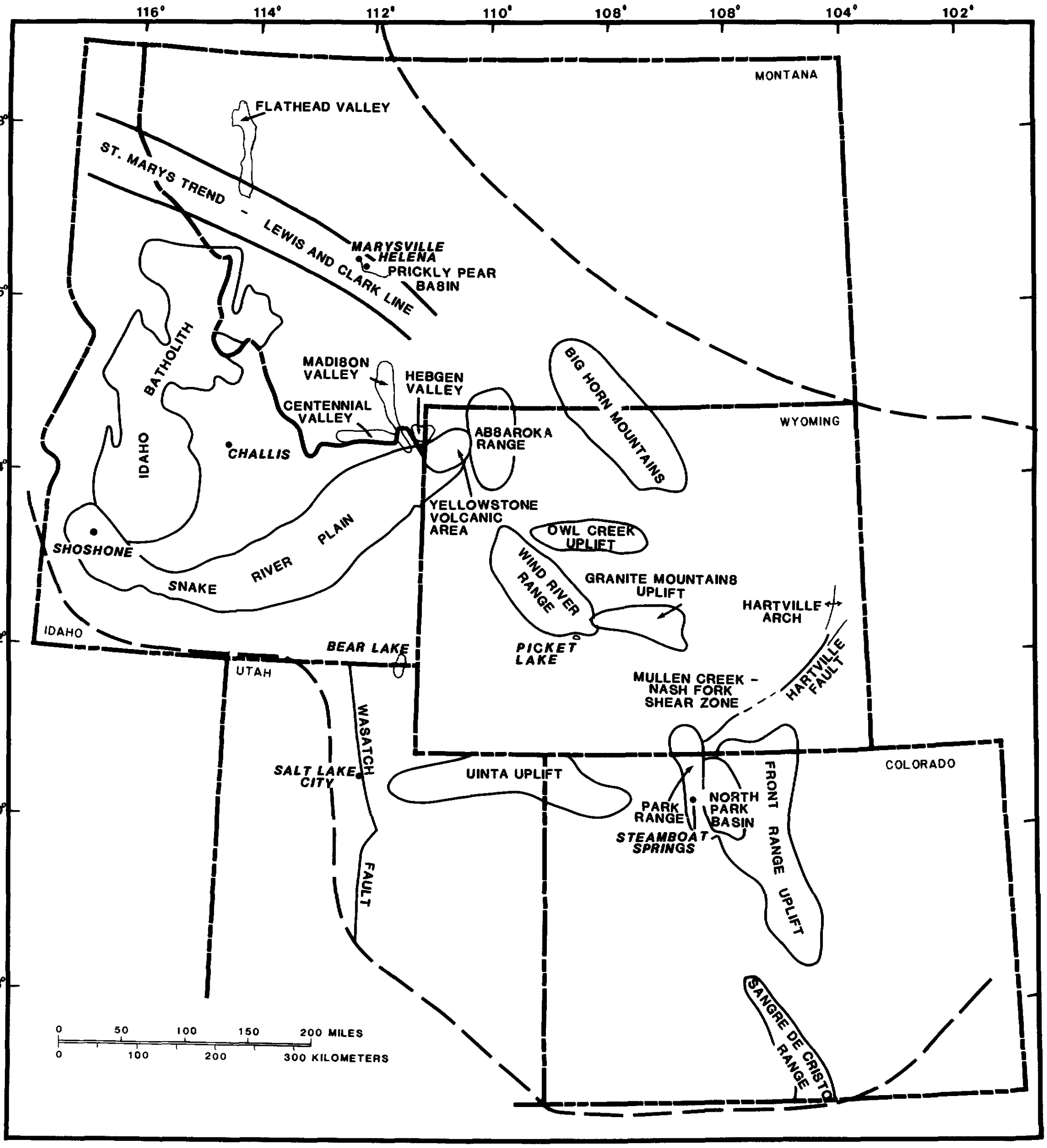

FIGURE 4.—Index map of the geographic region addressed at the Northern Rocky Mountains seismic source zone workshop showing selected topographic, geologic, and geographic features that are referenced in the text. Dashed line indicates geographical extent of the region considered in the workshop.

greater than 2.5 recorded between July, 1974, and March, 1977. The trend is about 80 km wide and extends from Helena, Mont., to Flathead Valley. Fault-plane solutions and hypocenter distributions in that part of the trend covered by the Helena seismograph array indicate earthquake swarms on northwest-trending normal faults and northeast-trending oblique-slip faults. He noted that the lengths of active, continuous faults are short (less than 10 km), which suggests faulting along preexisting zones of weakness that bound crustal blocks.

The committee considered the possibility of the Lewis and Clark line being a separate source zone. The lack of late Quaternary faults north of the line suggests that faults there are less recently active than are those near Helena; although extensional tectonism has affected both areas north and south of the line, it is much more impressive to the south. Also, gravity and magnetic signatures differ on either side of the line. An interesting fact is that the Marysville geothermal area lies along the Lewis and Clark line near Helena. Such geothermal anomalies may be indicative of a deep crustal flaw that provides an avenue for the ascent of hydrothermal fluids. However, the lineament itself is not clearly a primary source for historic earthquakes. Areal rates of seismic activity to the north in western Montana appear to be higher.

Other topics of significant discussion were the Snake River Plain, the Uinta Mountains, and the seismic source zones of Wyoming.

In southeast Idaho, formation of the Snake River Plain has progressed from southwest to northeast since Miocene time, and perhaps is related to the gross movement of the North American plate over a mantle thermal anomaly (Suppe and others, 1975; Smith, 1978; Christiansen and McKee, 1978; Armstrong, 1978). The Yellowstone area now forms the advancing front of tectonism to the northeast. Strong northwest-oriented gravity gradients in the older, thicker western part of the plain indicate that perhaps the plain has been superimposed over older northwest-trending Basin and Range structures. These structures are evident both north and south of the basalt cover of the plain. Holocene "pull-apart" structures form an arcuate pattern across the plain so as to follow the grain of the Basin and Range structures to the north and south (Prinz, 1970). These "pull-aparts" show no apparent lateral or vertical displacement across them (M. A. Kuntz and H. R. Covington, oral commun., 1979). The relatively warmer, younger, eastern part of the Snake River Plain has been aseismic in historic time. The aseismicity may be due to the young crust being unable to store enough elastic energy for the generation of earthquakes. The older western part of the plain, however, has a thicker crust (see Hill and others, 1961; LaFehr and Pakiser, 1962; Hill, 1963; Hill and Pakiser, 1967). At Shoshone, Idaho, on the western part of the plain, (fig. 4) an intensity VII was felt from an event occurring on November 11, 1905. Greensfelder (1976) indicated that the epicenter probably was located within 24 km of Shoshone. Not known is what structure may have been the earthquake source. In the workshop there was a general consensus that the western part of the plain has a higher potential for earthquakes than the eastern part because of the different crustal rheologies.

Discussion of the Uinta trend centered around its eastern margin. The structure has an anomalous east-west strike as compared with the northwest trends of Laramide-age structures. Geophysical evidence indicates that there is a distinct difference in crustal thickness north and south of the trend; therefore, the Uinta trend may be a fundamental crustal structure. Geophysically, the Uinta trend can be traced eastward into Colorado to the south end of the Park Range, near Steamboat Springs. There, the Neogene-age structures of the northern extension of the Rio Grande rift swing west along the Uinta trend (Tweto, 1979), indicating perhaps a fundamental influence on younger tectonism. Quaternary faulting has been noted on a north-south oriented uplift extending south from the Uinta extension in Colorado (M. West, oral commun., 1980). Although the Uinta trend apparently has influenced the structure of northeastern Utah and northwestern Colorado for a long span of time, its influence on present-day seismicity is unclear. Lack of seismological and other supporting evidence precludes the identification of any obvious relationship.

Other discussions centered around the source zones of Wyoming. Witkind (1975a) has noted that ages of latest displacements of east-trending faults in central Wyoming are Pliocene. Similar east-trending faults occur in the southern Bighorn Mountains and in the Owl Creek Mountains. Zones 26 and 27 were drawn on this basis, although there was considerable argument as to whether a Pliocene age of latest displacements is significant to present-day seismicity. One point of view holds that, regardless of the ages of tectonism, the area of most recent tectonism in a region should be considered the most hazardous. Another point of view holds that any tectonism older than Quaternary is, by itself, irrelevant to the relative hazard among areas. The argument was not resolved clearly, although the zones defined by Pliocene faulting were retained.

An alternative zoning procedure suggested by some committee members was that the large Laramide-age basins be separated from a large zone encompassing the central Rocky Mountain region.

R. B. Smith (written commun., 1979) recommended an east-trending zone from Norris Geyser Basin in Yellowstone National Park west to Hebgen. This zone would include the Centennial Valley frontal faults and other east-trending tectonic features along the southern Montana State line.

DESCRIPTIONS OF INDIVIDUAL SOURCE ZONES

The following seismic source zones are shown in figure 5. Table 2 lists estimated maximum magnitudes and estimated relative recurrence times of the maximum magnitudes of earthquakes for the individual zones.

Zone 15.—This zone is ambiguous as it is defined primarily by its contrast with the surrounding zones. On the southwest, the zone boundary is drawn along the north edge of the Columbia Plateaus province. On the west, the boundary separates this zone from the Cascade Mountains of north-central Washington.

Zone 16.—This zone encompasses a northwest-trending group of faults that had pre-middle Pleistocene movement. It coincides with an area of Basin and Range type normal faulting that may be a continuation of the Rocky Mountain trench into Montana (Mudge, 1970).

Zone 17.—The disturbed belt of western Montana. The zone is characterized by large imbricate thrust sheets of the Northern Rocky Mountains (Mudge, 1970).

Zone 18.—Idaho batholith exclusive of the Challis geothermal area (zone 21).

Zone 19.—This zone has a structural style similar to that of zone 20 and similarly, has Quaternary faults. However, the rate of seismic activity is noticeably lower than in zone 20 to the east, or in zone 16 to the north.

Zone 20.—This zone is characterized by mixed east-, north-, and northwest-trending structure and both normal and strike-slip focal-plane solutions (Smith and Sbar, 1974; Qamar and Hawley, 1979).

Zone 21.—Challis geothermal area. This region is characterized by swarm events that typify areas of high geothermal anomalies. Faults are present in Eocene volcanics. The petrology of the volcanic and plutonic rocks is similar to that of the rocks in the Yellowstone area and may indicate that the Challis area is an old analog to the Yellowstone area.

Zone 22.—Trenching studies in this zone (Malde, 1971) indicated faulting from Pleistocene to at least 10,000 years before the present.

Zone 23.—This zone is the volcano-tectonic area of Yellowstone National Park. The zone has a high heat flow and may have a low maximum magnitude.

Zone 24.—Western Snake River Plain. The western plain has an older, thicker surface than the eastern part of the plain.

Zone 25.—Eastern Snake River Plain. The surface is generally 20,000–50,000 years old (based on studies of undisturbed loess) and has young volcanic features superimposed upon it. Limited breakage consisting of pull-apart structures with no apparent displacement (Prinz, 1970; M. A. Kuntz, and H. R. Covington, oral commun., 1979) is evident on this surface. The breaks form an arcuate pattern across the plain (Printz, 1970). The aseismicity may be attributable to a warm, thin sialic crust incapable of sustaining earthquake stresses.

Zone 26.—This zone encompasses the Bighorn Mountains, Absaroka Range, Wind River Range, and the Owl Creek uplift of northwestern Wyoming. The zone excludes the east-trending faults that terminate each of these ranges to the south.

Zone 27.—This zone includes the east-trending faults of central Wyoming that cut late Pliocene but not Pleistocene sediments in the Picket Lake area. Faults in the southern Bighorns and the Owl Creek area have much the same pattern. The area of east-trending faults may be potentially more hazardous than the rest of Wyoming (see previous discussion), even though youngest documented movement is Pliocene.

Zone 28.—The boundary of this zone is poorly constrained, but structural style here is different from that of the Snake River Plain to the north. The north-northwest-trending faults in the zone apparently had no late Quaternary movement.

Zone 29.—Faults in this area have the same Basin and Range character as those north and south of the Snake River Plain. Southeast Idaho has well-developed extensional tectonic features. This north-south-trending, normal extensional faulting extends south past the west end of the Uinta Mountains in Utah.

Zone 30.—No distinction was made in this zone between age of faulting or tectonic style.

Zone 31.—Bear Lake area (Utah). Age of faulting is Holocene. On the basis of scarp heights of more than 1 m and on lengths of fault segments, magnitude 7+ earthquakes can be expected in this zone.

Zone 32.—Wasatch fault zone. Multiple Holocene offsets are evident along the fault.

Zone 33.—Uinta Mountains. Geophysical data

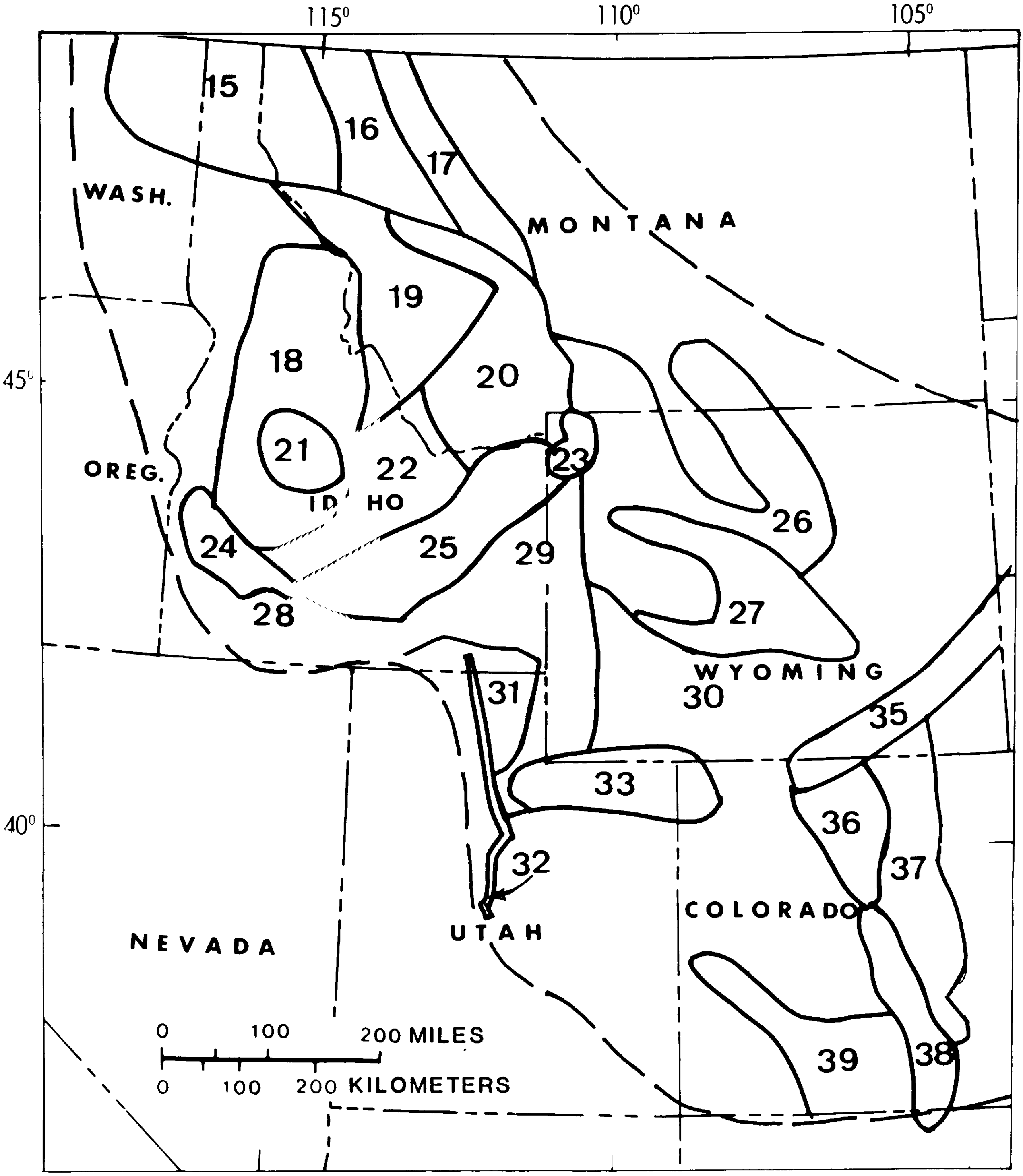

FIGURE 5.—Seismic source zones of the Northern Rocky Mountains region. Unconnected lines indicate a continuation of the boundary beyond the area considered at the workshop. Dashed line indicates geographical extent of the region considered in the workshop.

TABLE 2.—*Estimated maximum magnitudes (M_s) and estimated relative recurrence of maximum magnitude events for the source zones of the Northern Rocky Mountains region*

[M_s, surface wave magnitude; leaders (---) indicate that no value was given at the workshop]

Zone No. (from fig. 5)	Estimated maximum magnitude (M_s)	Estimated relative recurrence[1]	Zone No. (from fig. 5)	Estimated maximum magnitude (M_s)	Estimated relative recurrence[1]
15	6.0	C	28	---	---
16	6.5-7.0	B	29	6.5-7.0	B
17	6.0	C	30	6.0	D
18	5.0	D	31	7.0+	A
19	7.0	B	32	7.75	A+
20	7.5	A	33	7.0	C
21	6.0-6.5	B	34	6.5-7.0	A-
22	7.5	B	35	6.5	C-D
23	6.5	A	36	6.5	C
24	6.5	C	37	6.5	C
25	6.0	C-D	38	7.0-7.5	A-B
26	6.0	C	39	6.5	---
27	6.0	C			

[1]A relative scale agreed upon by committee. A+ is assigned to the Wasatch fault zone as the zone of highest likelihood of seismic events of maximum estimated magnitude during a 50-year exposure time. Decreasing in likelihood are categories A, B, C, and D. The following numerical values were assigned by committee consensus: A=40, B=10, C=3, and D=1. In other words, a zone rated A would have 40 times higher likelihood of a maximum estimated magnitude earthquake than a zone rated D within the return period.

indicate different crustal thickness north and south of an eastward extension of the Uinta Mountains. Also, Neogene structures bend westward along an extension of the Uinta Mountains to the south end of the Park Range in Colorado. The Rio Grande rift structures to the south terminate at this eastward extension. Historic seismicity provides no compelling evidence that these features control present-day seismicity.

Zone 34.—This zone encompasses a north-south-trending group of normal, extensional faults that terminate the Colorado Plateaus to the northwest. The faults extend beyond the west end of the Uinta trend.

Zone 35.—This zone is defined by the Mullen Creek–Nash Fork shear zone (Houston and McCallum, 1961) that juxtaposes strongly contrasting Precambrian rocks. This feature is a fundamental basement trend that may represent an old plate boundary. The zone includes a possible extension of the feature to the northeast, the Hartville fault (Droullard, 1963).

Zone 36.—This zone is a subdivision of the Park Range at the north end of the Sangre de Cristo Range. Quaternary-age fault displacements are evident in the zone.

Zone 37.—This zone is the Front Range of the Northern Rocky Mountains. Quaternary-age fault displacements are evident in the zone.

SOUTHERN ROCKY MOUNTAINS SEISMIC SOURCE ZONES—SUMMARY OF WORKSHOP CONVENED JANUARY 23–24, 1980

By R. E. Anderson, W. P. Irwin, and P. C. Thenhaus

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WORKSHOP SUMMARY

As in the Northern Rocky Mountains, systematic morphometric studies of fault scarps have not been made throughout the Southern Rocky Mountains. The age-of-faulting information that is available has been assumed to hold throughout distinctive tectonic areas, the boundaries of which included consideration of basin and mountain blocks, alinements of volcanic centers, possible buried magma chambers, basement configuration, and physiography.

Expression of late Paleogene and Neogene tectonic movements in reactiviated older structures is widespread in the Southern Rockies (Tweto, 1979; Kirkham and Rodgers, 1978, 1981). The most impressive tectonic movements, however, are associated with the formation of the Rio Grande rift (see fig. 6 for location). The structure of the Rio Grande rift and its associated seismicity therefore dominated the discussions of seismic source zones in this region.

Although significant faulting has occurred within the rift in late Quaternary time, the low level of recent seismicity within the rift does not appear to represent sustained long-term regional tectonic activity. This observation has prompted Cordell (1978) and Sanford and others (1979) to suggest that the current low level of seismicity is not representative of the long-term trends. From microseismic data collected in recent years, Sanford and others (1979) noted that the current seismicity level in the rift is comparable to those levels of the neighboring Colorado Plateaus and High Plains provinces. Sanford and others (1979) have related much of the current microseismicity to movement of magma in the crust. However, they noted that the historic record of earthquakes from 1849 through 1961 indicates that the Rio Grande rift was by far the most active area in New Mexico. Their listing of six intensity VII events shows that all these events occurred within the rift. Earthquakes of this large size probably are reported completely from 1869 and therefore should be free of biased reporting due to nonuniform population density. The period 1962–1977 is one of low seismicity compared with the seismicity of previous years. Sanford and others (1979) concluded that the seismicity in the rift is episodic, related perhaps to episodic spreading of the rift.

Sanford and others (1981) noted that on the Colorado Plateau in New Mexico, seismic activity is relatively high along the eastern and northwestern margins of the San Juan basin. Also, an epicentral trend crosses the southern part of the Colorado Plateau and extends through the Rio Grande rift into the High Plains of northeastern New Mexico. The trend is coincident with a trend of Pliocene to Pleistocene volcanic centers that define the Jemez lineament.

DuBois and Smith (1980) recently have published the results of their investigation of the 1887 (estimated M=7.2) Sonoran earthquake. The epicenter was about 60 km south of Douglas, Ariz., in the State of Sonora, Mexico. Surface rupturing extended about 50 km north of the epicentral area. A critical task for seismic zoning is to define the area over which a similar event might reasonably be expected in the future. Sumner (1976) has noted a seismicity trend that extends from the area of the Sonoran event northwestward across the San Francisco volcanic field and into the western Grand Canyon region of Arizona (fig. 6). However, it remains to be established that seismic potential is similar along the entire seismicity trend that includes such a diversity of geologic structure. The workshop participants chose a geologic approach to zoning this area as described in the following descriptions of source zones.

DESCRIPTION OF INDIVIDUAL SOURCE ZONES

The seismic source zones as they were defined at the workshop are shown in figure 7. Table 3 lists maximum estimated magnitudes and relative recurrence estimates of the maximum magnitudes for the zones of the Southern Rocky Mountain region.

Zone 38.—Sangre de Cristo Range. The zone contains the Sangre de Cristo fault that bounds the San Luis Valley on the northeast. The fault may be potentially active (Kirkham and Rogers, 1978, 1981).

Zone 39.—Uncompahgre Plateau and San Juan volcanic field. The northeastern and southwestern

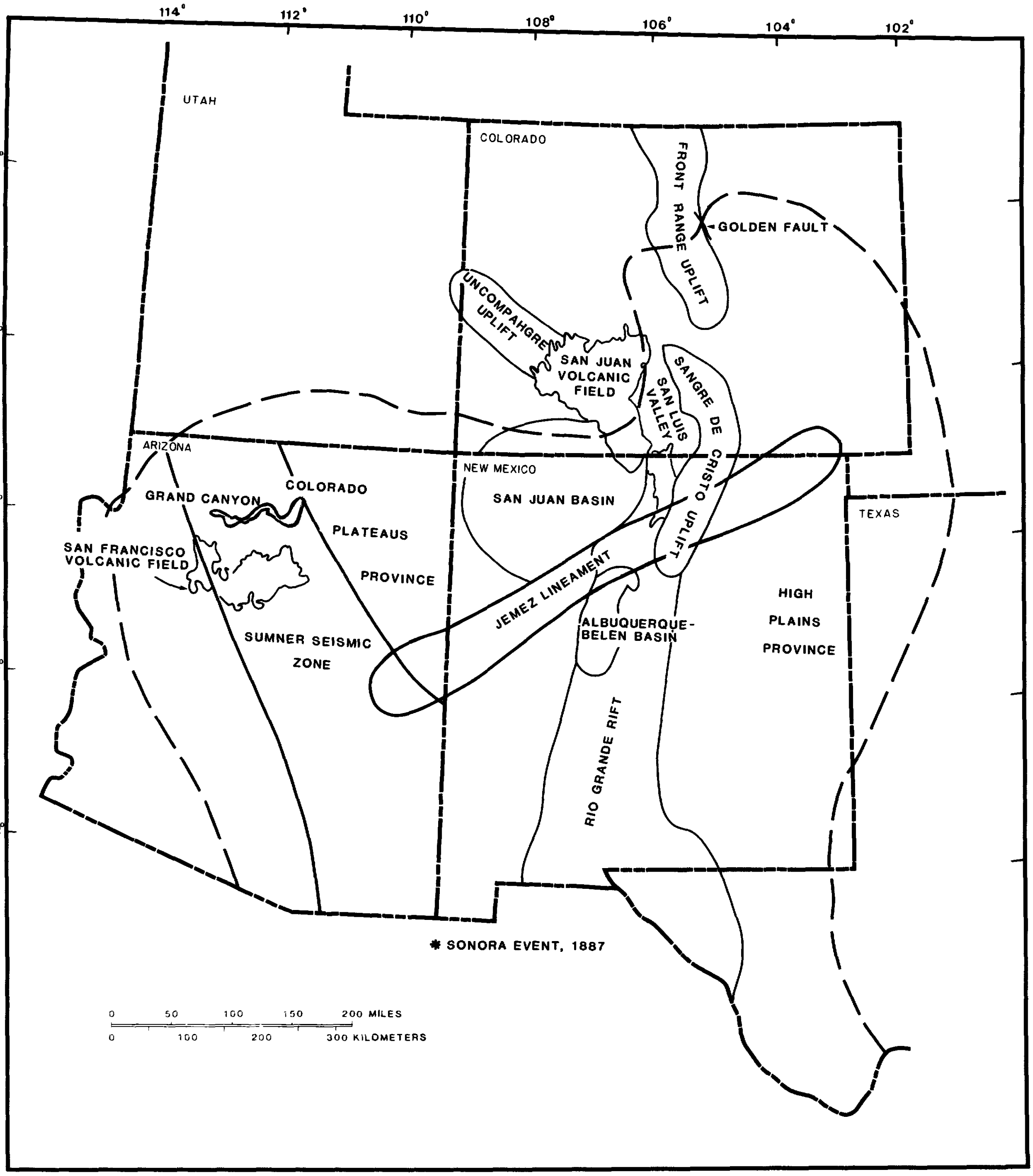

FIGURE 6.—Index map of the geographic region addressed at the Southern Rocky Mountains seismic source zone workshop showing selected topographic, geologic, and geographic features that are referenced in the text. Dashed line indicates geographical extent of the region considered in the workshop.

flanks of the Uncompahgre Plateau are structurally complex. On the northeast flank, only one fault can be proved to have moved in Quaternary time (Kirkham and Rogers, 1978) although other faults are suspect. Quaternary faults also exist on the southwestern flank (Kirkham and Rogers, 1978).

Zone 40.—Golden fault. Kirkham (1977) documented evidence of recurrent Quaternary displacement on the fault. If the small size of the

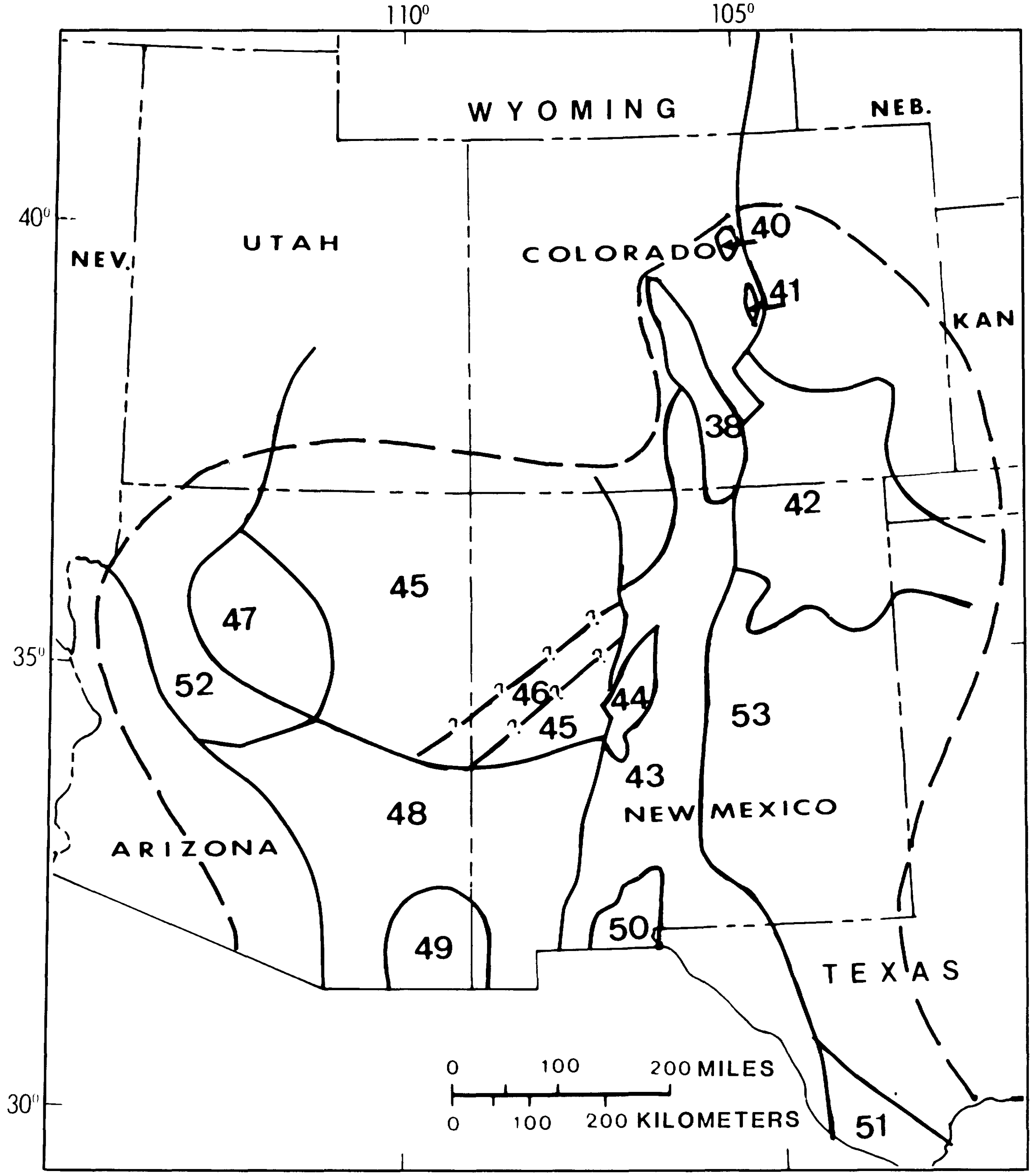

FIGURE 7.—Seismic sources zones of the Southern Rocky Mountains region. Unconnected lines indicate that boundaries extend beyond the area considered at the workshops. Queried lines indicate uncertainty that the zone is a significant seismic source. Dashed line indicates geographical extent of the region considered in the workshop.

zone limits its usefulness to seismic zoning, it could be deleted in favor of a larger zone of Quaternary faulting that covers all the Colorado Front Range.

Zone 41.—Rampart Range fault. Delineation of this zone is based on evidence of Quaternary displacement along the fault (Kirkham and Rogers, 1978, 1981).

TABLE 3.—*Estimated maximum magnitudes (M_s) and estimated relative recurrence of maximum magnitude events for the source zones of the Southern Rocky Mountains region*

[M_s, surface wave magnitudes; leaders (---) indicate that no values were given at the workshop]

Zone No. (from fig. 7)	Estimated maximum magnitude (M_s)	Relative recurrence rate[1]
38	7.0-7.5	A
39	6.5	D
40	---	---
41	---	---
42	6	C
43	7.0-7.5	B
44	7.0-7.5	A
45	---	---
46	6.0	C
47	6.0	C
48	---	---
49	7.0-7.5	A
50	7.0-7.5	A
51	7.0-7.5	D
52	6.5-7.0	B
53	5.5-6.0	D
54	6.0	D

[1]Relative recurrence is based on a dimensionless scale and indicates a subjective likelihood of a zone having the maximum magnitude earthquake take place in a 50-year period of interest.

Zone 42.—Jemez lineament, east of the Rio Grande rift. The zone includes the Cimarron and Raton-Clayton-Capulin volcanic fields. In terms of magnitude and frequency of earthquakes, this zone is inferred to be similar to zone 48.

Zone 43.—This is an elongate zone that follows the trend of the Rio Grande rift and includes the Trans-Pecos area of west Texas. Evidence for late Quaternary faulting does not exist everywhere in this zone, but in some parts the evidence is widespread. In the Albuquerque-Belen basin, Bachman and Machette (1977) have identified a widespread geomorphic surface that is $5–6\times10^6$ years old. This and younger surfaces are displaced by perhaps a hundred faults including scarps along about 50 km of fault trace at the eastern margin of the Albuquerque basin. Detailed studies by Machette (1978) indicated at least four displacement events during Quaternary time on a single fault in the northern Albuquerque basin. Although systematic morphometric studies have not been made, widespread, easily recognized scarps in the Trans-Pecos area (Muehlberger and others, 1978) suggest late Quaternary faulting there also. Justification for the placement of the zone boundaries comes, in part, from recognition of the Rio Grande rift as a series of structurally integrated basins that have an overall integrity and continuity imposed across a wide variety of older structures. The boundaries of the Trans-Pecos part of the zone are determined by the distribution of a coherent system of north- and northwest-trending scarps. Linear dry lakes in that region parallel the scarp trends and suggest perhaps a Holocene structural control—possibly by faulting.

Zone 44.—Evidence for Holocene faulting in this zone is mainly from studies by Michael Machette who has found evidence for offset of Holocene deposits of as much as 6 m on the La Jencia fault—a major basin-margin structure. The fault shows evidence of young rupture for 35 km but not all the rupture may be related to a single seismic event (Machette, 1980). A. R. Sanford (oral commun., 1980) noted that seismic activity has not been detected along the La Jencia fault and that a geodetic network installed across the fault by J. Savage showed no indication of extension.

Zone 45.—Delineation of this zone is based on a lack of evidence for late Cenozoic faulting in the central part of the Colorado Plateaus province.

Zone 46.—This zone is the Jemez lineament west of the Rio Grande rift. The zone is drawn on an alinement of Pliocene-Holocene volcanic centers that extends diagonally across Arizona and New Mexico.

Zone 47.—Delineation of this zone is based on evidence of minimal faulting in Pleistocene lavas in the San Francisco volcanic field (E. Wolfe and G. Ulrich, unpub. data). A few faults in the northern part of the volcanic field may have moved during late Quaternary time, but they average only about 2 km in surface trace and have small displacement. In general, there is a conspicuous lack of large-magnitude faulting associated with volcanism in the San Francisco field. Infrequent large seismic events probably have an upper-bound magnitude of 5.5–6.0.

Zone 48.—Delineation of this zone is based on a lack of evidence for late Quaternary faulting within a tectonic province that was deformed by late Cenozoic faulting.

Zone 49.—A recently published study by DuBois and Smith (1980) examined about 90 percent of the historic record of the 1887 Sonoran earthquake (estimated M=7.1). The earthquake produced surface breakage over a distance of about 50 km. Studies of young faulting in that area are in progress. Geomorphic evidence suggests the possibility of four events on the 1887 earthquake fault, but whether a prehistoric Holocene event occurred is not known. The zone is extended into Arizona on the basis of the possibility of Holocene surface faulting in southeasternmost Arizona according to R. C. Bucknam and S. M. DuBois (oral commun., 1980).

Zone 50.—Evidence for Holocene faulting in this zone is based mainly on unpublished studies by L. Gile, who first demonstrated the presence of mid-Holocene faulting, and by Machette (1980) who has found evidence for 3–4 m of displacement where the Cox Ranch fault trace crosses Holocene fans. The mid-Holocene scarp is locally 9–10 m high and the fault shows evidence of breakage for at least 25 km (W. Seager, written commun., 1980). Faults other than the La Jencia and Cox Ranch in zones 44 and 51 have "reported" but undocumented Holocene displacement.

Zone 51.—This zone includes an area of the Trans-Pecos, Texas, for which no fault scarps cutting Quaternary units have been identified but which has major late Cenozoic faults cutting rocks of early Oligocene age and older. It is similar to zone 49.

Zone 52.—This zone includes the terrane commonly referred to as the western Grand Canyon region in the transition zone between the Basin and Range and Colorado Plateaus provinces. The location of the boundary is not narrowly constrained. Evidence for Quaternary faulting relates to (1) Quaternary lava flows that are offset by widely spaced normal faults in the western Grand Canyon region (Hamblin, 1970; Koons, 1945; Anderson, 1978), (2) offset of Quaternary alluvium in northwestern Arizona (I. Lucchitta, written commun., 1980), and (3) displacement of Quaternary alluvium in Chino Valley (I. Lucchitta, oral commun., 1976).

Zone 53.—Delineation of this zone is based on lack of evidence for late Cenozoic faults.

Zone 54.—Delineation of this zone is based on lack of evidence for Quaternary faulting, although the area was deformed in late Cenozoic time.

CENTRAL INTERIOR SEISMIC SOURCE ZONES—SUMMARY OF WORKSHOP CONVENED JUNE 10–11, 1980

By F. A. McKeown, D. P. Russ, and P. C. Thenhaus

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WORKSHOP SUMMARY

A consensus was that the central United States zones should be defined on patterns of historical seismicity except those areas for which geological or geophysical knowledge allow delineation of zones on the basis of deep structure. Recent analysis of reflection profiles by USGS investigators has resulted in the identification of several deeply buried faults believed to be active. For the most part, however, little is known about buried faults in the central United States. Therefore, diverse factors such as gravity, aeromagnetics, and geologic province boundaries also were used to delineate seismic source zones.

A substantial part of the committee's discussions was on the characteristics of source areas and possible causes of earthquakes of the central United States. Subjects considered include the following:

1. The relation of seismicity to ancient rifts and aulacogens.

2. The relation of seismicity to plutons. Several investigators have suggested that stress is concentrated near the contacts of plutons with country

rock because of differences in their elastic properties.

3. The relationship of the Mississippi Embayment gravity field to thick masses of post-Paleozoic sediments indicates perhaps that during late Mesozoic time there were widespread intrusions of magma because of mantle upwarping. As these masses cooled, they contracted and subsided causing downwarping of the embayment. Loading by post-Paleozoic sediments caused further tectonic perturbations. Questionable, however, is if contraction on cooling would be sufficient to produce the net subsidence and if the isostatic phenomenon could operate in such a short time to produce the observed geology (W. J. Hinze, oral commun., 1980).

4. The enigma of the lack of moderate-size earthquakes on large fault zones such as the Ste. Genevieve (see fig. 8 for location). Some of these fault zones seem to be suitably oriented to the east-west stress field to have movement occur in them. Perhaps the question should not be why the northwest-trending structures are inactive, but rather, why only the northeast-trending structures are active. Although both directions are conjugate to an east-west stress field (and therefore theoretically would have an equal opportunity to be active), the northeast-trending structures may have a preferred structural fabric or other physical characteristic that make them preferentially active.

5. The suggestion of block uplift and tilting of the Ozarks as revealed by terrain relief studies. These studies suggest that the Ozarks may behave as a block bounded by northwest-trending faults. Uplift and tilting about a northeast-striking axis would depress the Mississippi Embayment, generating and concentrating stress along preexisting structural elements. Thus, modern stresses in the embayment may be related more closely to the tectonics of the Ozarks than to ambient stresses associated with a drifting continental plate. Interestingly, a projection of the lineament bounding the southwest edge of the inferred block is approximately coincident with the southwestern terminus of seismicity within the Reelfoot rift zone.

6. A possible relationship between seismicity and the intersection of the rift and the Pascola arch.

DESCRIPTION OF INDIVIDUAL SOURCE ZONES

The seismic source zones are shown in figure 9. Maximum estimated magnitudes and recurrence estimates of the maximum magnitudes are listed in table 4.

Zone 55.—This zone is the area of the largest earthquakes to affect the central United States (Nuttli, 1973, 1979; Nuttli and Herrmann, 1978). It is also the area of most frequent moderate seismicity (Stauder, 1982). Although there is little evidence for surface faulting within the zone (Russ, 1979), subsurface faults, believed to be seismogenic, have been found recently (Zoback and others, 1980). The zone has been assigned a maximum estimated magnitude (m_b) of 7.5 (see Nuttli, 1973) and a recurrence time of 600–700 years (see Nuttli, 1974; Russ, 1979; Algermissen, 1969, 1972). Zone 55 is defined as being generally coincident with the Reelfoot rift as identified by Hildenbrand and others (1977) and Hildenbrand and others (1980) on the basis of aeromagnetic anomalies. The northwest and southeast boundaries of the zone are drawn on differences in the pattern and intensity of the magnetic field and are believed to be the location of the border faults of the rift. Concealed plutons lie along these boundaries and may control the occurrence and distribution of nearby seismicity (Kane, 1977; McKeown, 1978). The southwest and northeast boundaries of the zone are not identified easily. Although most of the seismicity associated with zone 55 does not extend south of about Marked Tree, Ark. (lat 35°30′ N.) (Stauder, 1982), the rift continues its geophysical expression to at least lat 34°30′ N. At this location, the rift boundaries become poorly defined and gravity data show a northwest-trending zone of many areally small but intense highs that are tentatively interpreted to be plutons. The northeast boundary of the gravity highs is nearly coincident with what traditionally has been mapped as the buried Ouachita front. The change in the character of the gravity is used as the southwestern boundary of seismic source zone 55 because recent studies throw doubt upon the existence of the so-called buried Ouachita front (a boundary previously suggested as the southwestern limit of modern seismicity). The implication is that large earthquakes can occur along the entire length of the rift. The rift initially continued farther south than lat 34°30′ N. but burial or tectonism has masked or destroyed the structure

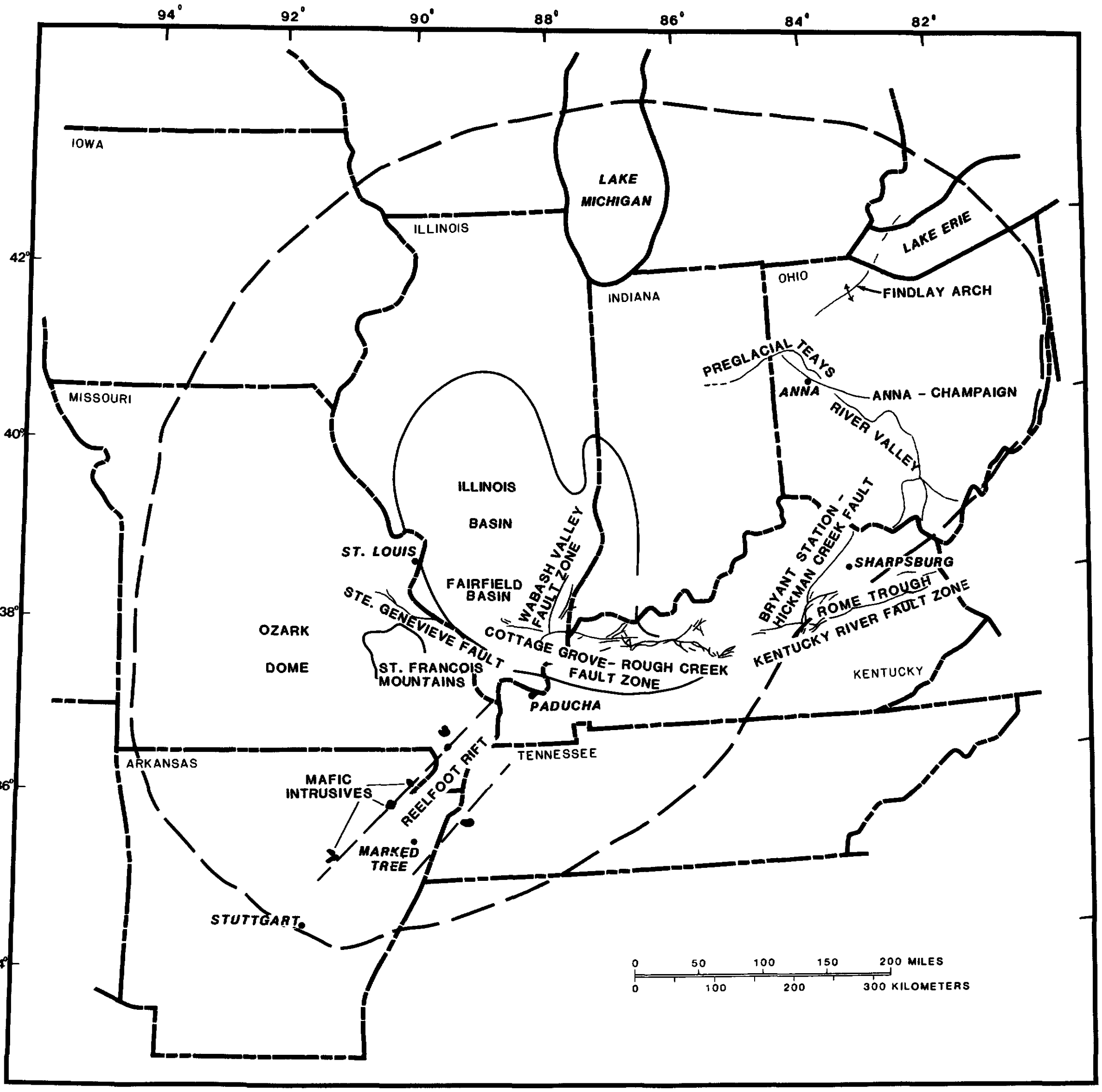

FIGURE 8.—Index map of the geographic area addressed at the Central Interior seismic source zone workshop showing topographic, geologic, and geographic features that are referenced in the text. Dashed line indicates geographical extent of the region considered in the workshop.

south of this location. The extension of the zone to the southwest invoked dissenting opinions because the southwestern part has been much less active in historic times relative to the northeastern part. An alternative might have been to divide the zone into two parts, both having the same estimated maximum magnitude, but with the southwestern part having a recurrence time about double the 600- to 700-year estimate for the northeastern part. The cause of the cessation of seismicity just south of Marked Tree, Ark., is unknown. Whether it marks a change in subsurface structure or is the result of spatial variation in seismic activity within the zone (that is, the zone presently is quiescent, but periodically may be active) remains to be determined. Because of these uncertainties and because the rift structure with which many of the earthquakes seem to be associated extends at least to the vicinity of Stuttgart, Ark., the committee decided that zone 55 should be retained as drawn. The northeastern boundary of zone 55 is defined as the southwesternmost of a series of prominent northwest-trending aeromagnetic anomalies that truncate the rift

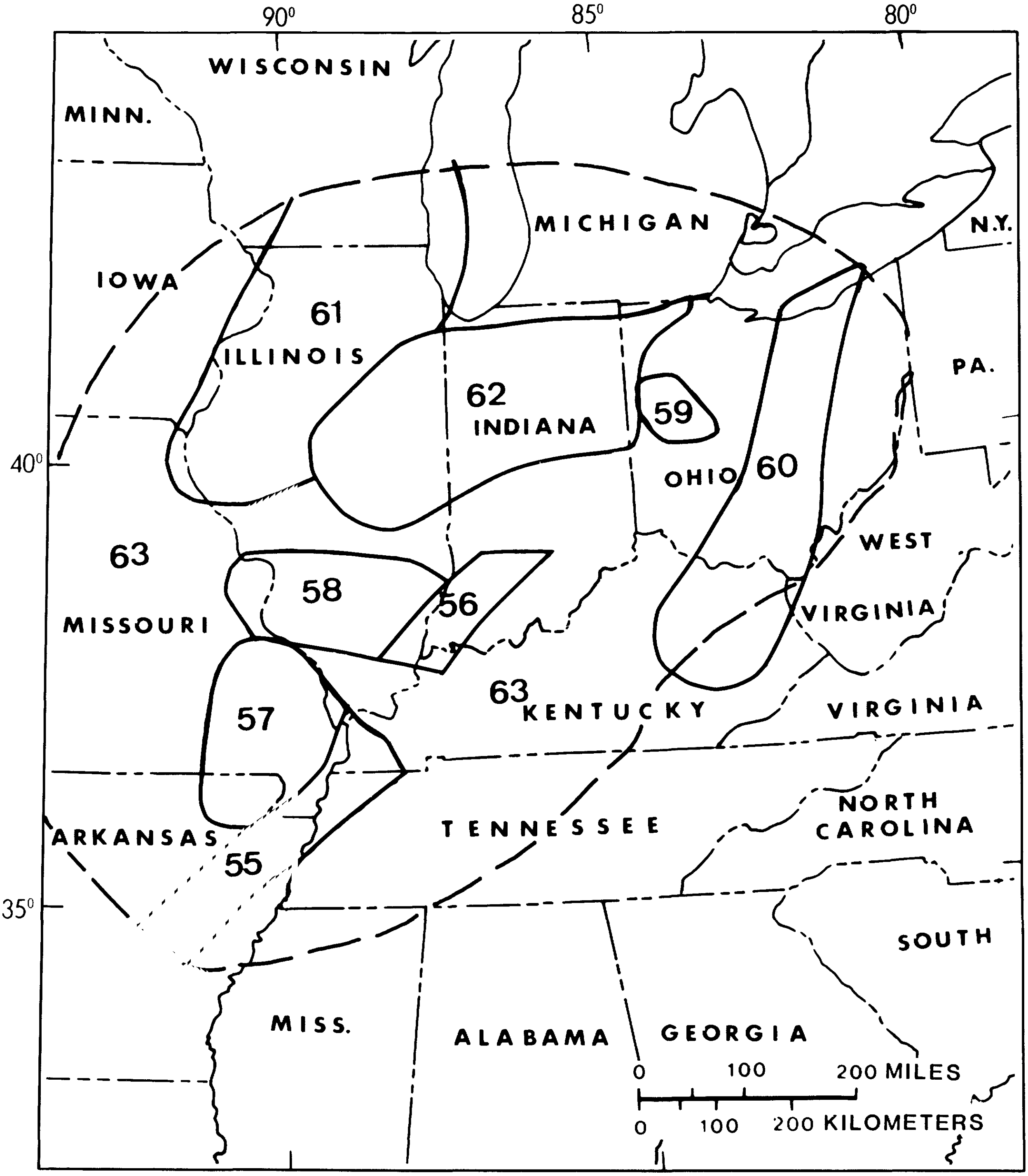

FIGURE 9.—Seismic source zones of the Central Interior. Unconnected lines extend beyond the region considered at the Central Interior workshop. Dashed line indicates geographical extent of the region considered in the workshop.

about 15 km southwest of Paducah, Ky. The southwesternmost anomaly is believed to be along the subsurface extension of the Ste. Genevieve fault zone. Although Hildenbrand and others (1980) projected the rift a short distance northeast of the anomalies, the anomalies have been selected

TABLE 4.—*Estimated maximum magnitudes (m_b) and estimated recurrence rates for maximum magnitude events for the seismic source zones of the Central Interior region*

[m_b, body wave magnitude; leaders (---) indicate that no values were given at the workshop]

Zone No. (from fig. 9)	Estimated maximum magnitude (m_b)	Estimated recurrence (in years)
55	7.5	[1]600–700
56	6.5	[2]1000
57	6.5	[2]1000
58	6.5	[2]2000
59	5.5–6.0	---
60	---	---
61	---	---
62	---	---
63	---	---

[1]From Russ (1979).
[2]From Nuttli and Herrmann (1978).

as the source zone boundary because they represent a prominent shift in the orientation and character of deep geologic structure and because the areas of intense modern seismicity are southwest of the anomalies.

Zone 56.—This zone is identified on the basis of aeromagnetic, gravity, crustal-seismic, and basement-rock studies. As with zone 55, zone 56 is a relatively narrow northeast-trending feature characterized by subdued magnetic relief within the zone and greater magnetic relief outside the zone. Magnetic highs interpreted to be plutons bound the northwest and southeast margins of the feature. Braile and others (1980) suggested that the feature may be an offset continuation of the structure inferred to be a rift (Reelfoot rift) in the Mississippi Embayment. The southwest boundary of the zone is expressed geologically by the east-southeast-striking Cottage Grove–Rough Creek fault zones and geophysically by a prominent east-southeast-trending magnetic lineament. The northeast boundary of the zone is set arbitrarily at about lat 39° N. where geophysical expression of the feature is lost. The Wabash Valley fault zone is situated in the southern half of source zone 56, which geologically is part of the Illinois basin. The Wabash Valley faults strike obliquely to the trend of zone 56. No Holocene surface offsets have been reported in the fault zone. Earthquakes in this zone frequently are deeper (>15 km) than those to the south in zone 55. Some of these earthquakes are along the margin of the Fairfield basin (a flexural zone) and are not on Wabash Valley faults. The estimated maximum magnitude (m_b) for earthquakes in zone 56 is 6.5 and the recurrence time is 1000 yr (see Nuttli and Herrmann, 1978).

Zone 57.—This zone encompasses the St. Francois Mountains and surrounding regions. Its boundary, however, is not based upon physiography or structure but rather on the spatial pattern of seismicity which takes the form of a ring surrounding the mountains (Nuttli, 1979). Earthquakes in the center of the ring are not as common as those along the perimeter. The southern part of the zone has been extended to the south in order to include a number of events in northeast Arkansas with $4.0<m_b<4.9$. Zone 57 has been assigned a maximum estimated magnitude (m_b) of 6.5 and a recurrence time of 1000 years (Nuttli and Herrmann, 1978).

Zone 58.—This zone includes the St. Louis, Mo., area and much of south-central Illinois. It is situated on the deepest part of the Illinois basin. The zone is delineated, however, solely on the basis of seismicity. Several events with $5.0<m_b<5.9$ have occurred here. The north-central boundary of the zone has been shifted slightly to the north in order to include two events with $5.0<m_b<5.9$ (Nuttli, 1979). According to Nuttli, the largest earthquakes generally occur in the eastern half of the zone. Zone 58 has been assigned a maximum estimated magnitude of 6.5 (Nuttli and Herrmann, 1978) and a recurrence time of 2000 yr.

Zone 59.—This zone embraces the area of the Anna, Ohio, earthquakes. Several faults have been mapped in zone 59, and those striking northwest appear to be the active ones. A number of the earthquakes have occurred near the Anna-Champaign fault (Mauk and others, 1979). Presently unclear is whether the faults are related to the Findlay arch or to the buried glacial Teays River valley. Two earthquakes (m_b=3–3.4) have been recorded in the zone in the past 6 years. Most of the larger earthquakes (MM VII–VIII) occurred in the 1930's.

Zone 60.—This zone is a north-northeast trending area of seismicity in central and eastern Ohio and northeastern Kentucky that has had earthquakes with magnitudes between $3<m_b<5.3$. The northern part of the zone is parallel with the regional strike of Paleozoic rocks; the southern part includes elements of the Kentucky River fault zone, the Bryant Station–Hickman Creek fault and the Rome trough. The zone has been extended to the south to include the area of the Sharpsburg, Ky., earthquake sequence of July–August, 1980.

Zone 61.—Delineation of this zone is based entirely on seismicity and includes most of northern Illinois and a small part of southern Wisconsin. Earthquakes of $3.0 < m_b < 5.9$ have occurred in the area in historic times. The eastern boundary was drawn arbitrarily through the center of Lake Michigan. There is no apparent reason, however, for separating the events of zone 61 from the events of zone 63.

Zone 62.—This zone is distinguished on the basis of its lack of seismicity. According to Nuttli (1979), no earthquakes with $m_b > 3.0$ have occurred in this region in historic times. Zone 62 includes east-central Illinois, northern Indiana, and part of western Ohio.

Zone 63.—This zone is a background zone that encompasses the area included in the Central Interior United States study area not designated a formal seismic source zone. Earthquakes occur in the area, although most have $m_b < 4.0$ (Nuttli, 1979). Nuttli (1979) stated that the maximum estimated magnitude (m_b) for earthquakes in this area is 5.5. Nuttli adds, however, that the larger earthquakes probably are associated with minor active structures and that in regions not associated with these minor structures the maximum-magnitude earthquake may be reduced to 4.5. Probably the most questionable part of this zone is the wedge-shaped area in southern Illinois and western Kentucky. Much of this particular area lies within the highly faulted Kentucky fluorspar district (New Madrid system of Heyl and Brock, 1961; and Heyl and McKeown, 1978) and along strands and splays of the Cottage Grove–Shawneetown–Rough Creek fault zones. These structures generally have been included as part of the 38th Parallel lineament. Although these faults are some of the longest and most prominent in the Central Interior United States, they have not been grouped into a designated source zone because there have been no historic large earthquakes on or near them (Nuttli, 1979). Nevertheless, the potential for earthquakes may be significant. The wedge-shaped area separates by only a small amount the two most hazardous zones in the region. Faults within the Kentucky fluorspar district have the same optimal orientation to the modern stress field (to permit movement) as faults in zone 55. However, faults in zone 55 may not be related genetically to those in the wedge-shaped area. Zone 55 faults are associated with the Reelfoot rift (Zoback and others, 1980) whereas faults in the Kentucky fluorspar area may have formed during the uplift and subsidence of a regional dome in Pennsylvanian time (Heyl and Brock, 1961; Krausse and Treworgy, 1979). The prominent northwest-trending structural elements in the wedge-shaped area probably separate or uncouple faults in zone 55 from those in zone 56, and from those in the wedge-shaped area itself. A difference in opinion did exist at the workshop as to whether the wedge area should be deleted in favor of connecting zones 55 and 56.

NORTHEASTERN UNITED STATES SEISMIC SOURCE ZONES—SUMMARY OF WORKSHOP CONVENED SEPTEMBER 10–11, 1980

By W. H. Diment, F. A. McKeown and P. C. Thenhaus

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WORKSHOP SUMMARY

The committee consensus was to zone the region primarily on the distribution of historic seismicity. We noted that the spatial distribution of seismicity in the Northeast during last two decades was essentially the same as that revealed by the compilations of W.E.T. Smith (1962, 1966), except that some of the recent epicenters seem to be more closely bunched in areas of high seismicity. The closer bunching can be explained easily by imperfections in the earlier record. For small magnitude events, Dewey and Gordon (1980) noted that about half of the instrumentally recorded earthquakes that they have studied are in persistent source zones whereas the remainder are more than 20 km from other earthquakes.

Temporal changes in activity have been noted in some areas. For example, the seismicity in eastern Massachusetts in recent years was low with respect to that of the historic record. In examining the seismicity of southern New England, Shakal and Toksoz (1977) found that the seismicity was higher in the period 1725–1824 than in the following 100 years. Also, there was little activity prior to the Attica, N.Y. earthquake (I_0=VIII) of 1929. In this sense, the border (PQ/ME) earthquake of 1973 (Wetmiller, 1975) also was something of a surprise.

Problems with focal depths and focal-plane solutions were reviewed. The problems pose a severe handicap in relating seismicity to geologic structure. Measurements of focal depths, and, to a somewhat lesser extent, focal-plane solutions are of questionable reliability except in those areas covered by dense networks, such as the Ramapo fault area (Aggarwal and Sykes, 1978) (see fig. 10 for location), Blue Mountain Lake (Sbar and others, 1972; Sbar and Sykes, 1977), Attica, sometimes (for example, Fletcher and Sykes, 1977; Herrmann, 1978), and La Malbaie (Leblank and Buchbinder, 1977). For a seismotectonic interpretation of seismicity in New England, the depth of the foci must be known—whether it is 1 or 10 km or even deeper. Depths of hypocenters make a difference as to which structures might be causal. Ratcliffe (1971) outlined the intricate history of deformation in the area of the Ramapo fault system, and, at the workshop, stressed the wide range of structures that could be seismogenic in the 1–10 km depth interval in which earthquakes have been observed (Aggarwall and Sykes, 1978).

A good illustration of the importance of reliable depth determinations comes from the studies of Bollinger and his collegues in Giles County, Va. Their detailed network reveals focal depths between 5 and 25 km (Bollinger and Wheeler, 1980). Moreover, the trend of epicenters is north-northeast which is in accord with the structural grain to the north of the region but which is discordant with the northeast structural trends in the vicinity of the earthquakes. The suggestion is that the seismicity is controlled by older and deeper structures that have little manifestation at the surface (Wheeler and Bollinger, 1980).

Another aspect of the association of geologic conditions with seismicity is that earthquakes appear to occur in crystalline rock; that is, in highly metamorphosed or igneous rocks. This association seems to be so in the northeast, except where solution mining of salt in the overlying sediments is involved (Fletcher and Sykes, 1977) or where there are other manmade perturbations. A rationale (for example, Diment, 1980) is that the sediments are too thin, too soft, or too decoupled from the basement for sufficient strain to accumulate within them to produce significant earthquakes. Basement is exposed in much of the northeast including the Adirondack Mountains and most of New England and appears to be peppered with shallow earthquakes, judging from instrumental determinations and the prevalence of earthquake sounds which some would attribute to shallowness of foci (Sbar and others, 1972; Anderson and Fletcher, 1976). The fact remains, however, that some earthquakes seem to be of mid-crustal depth or deeper. Some have suggested (for example, Sbar and Sykes, 1977; Acharya, 1980) that these are the regions where large earthquakes are likely to occur. This suggestion is plausible but one that remains to be evaluated more fully. A hypothesis was suggested relating seismicity to residual pore pressure and higher porosity in alkalic intrusives compared with rocks of normal alkali content.

DESCRIPTION OF INDIVIDUAL SOURCE ZONES

The seismic source zones for the northeastern United States are shown in figure 11. Table 5 lists the estimated maximum magnitudes assigned to the zones. No recurrence estimates of these maximum magnitudes were made due to a lack of geologic data to support such estimates.

Zone 64.—Offshore zone. The northwestern boundary of this zone corresponds roughly to the western edge of zone 3 in a report of seismic hazard for the east coast of the United States by Perkins and others (1980). The boundary roughly coincides with the western edges of deep Jurassic ba-

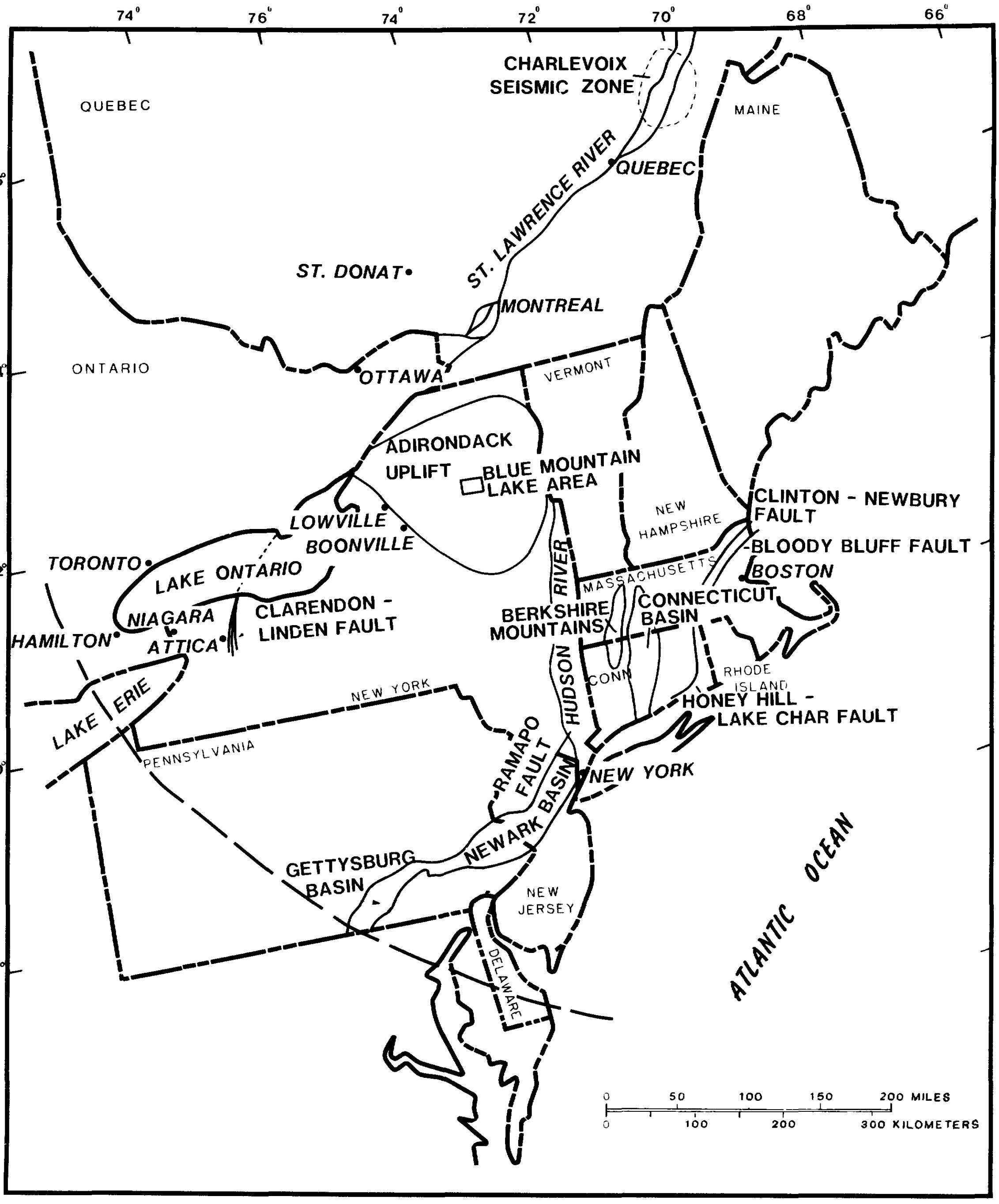

FIGURE 10.—Index map of the geographic area addressed at the Northeastern seismic source zone workshop showing selected topographic, geologic, and geographic features referenced in the text. Dashed line indicates geographical extent of the region considered in the workshop.

sins (Klitgord and Behrendt, 1979) that underlie the continental shelf and slope.

Recent earthquakes near the Bermuda Rise (Nishenko and Kafka, 1980) are a reminder that the oceanic plate is not inactive. Indeed, the Grand Banks earthquake of 1929, which occurred about 700 km to the east of the area covered by the map, was east of the western edge of the Jurassic basins. This earthquake was assigned a magnitude of 7.2. Intensity IV effects were felt

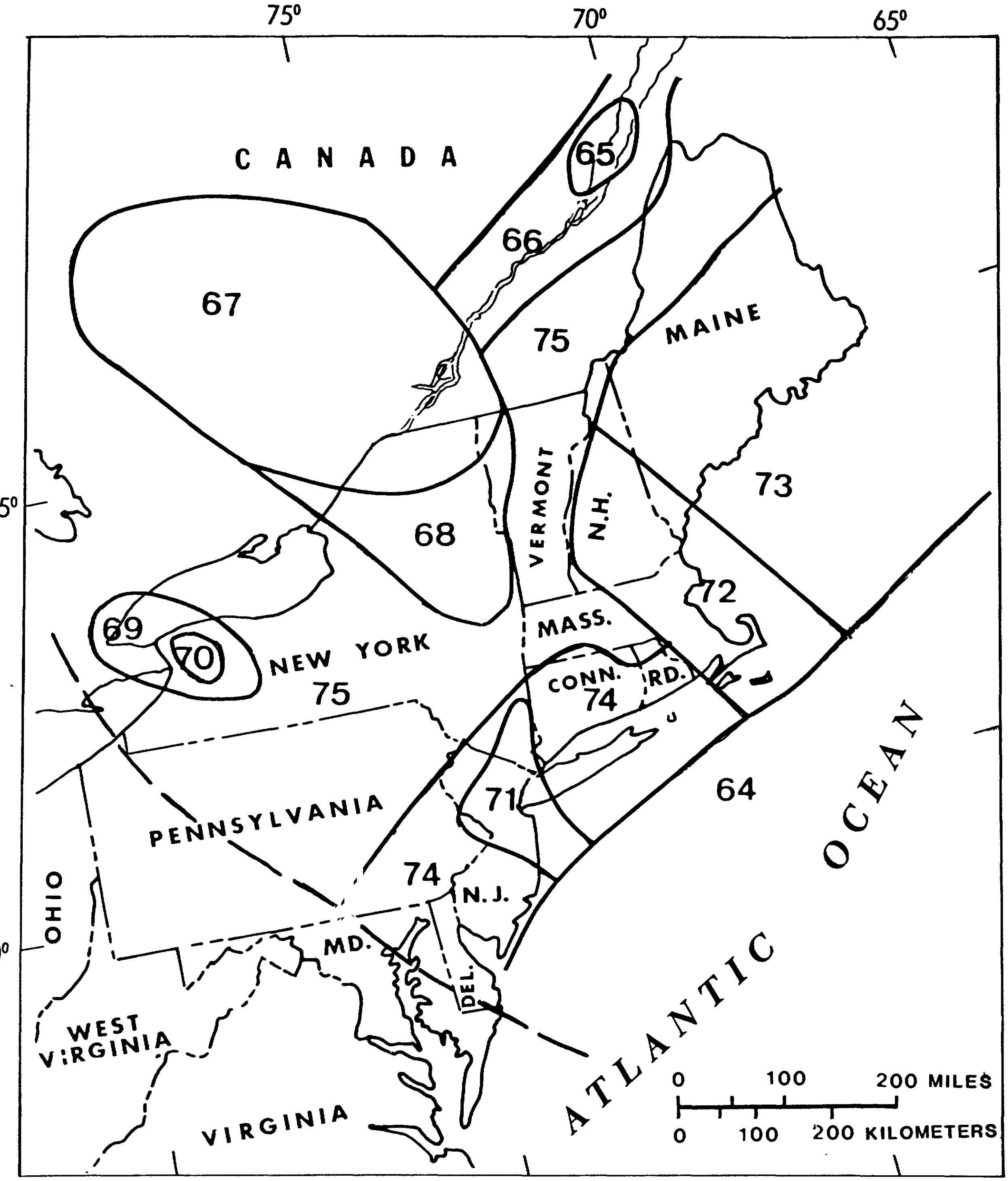

FIGURE 11.—Seismic source zones of the northeastern United States and adjacent Canada. Unconnected lines indicate that boundaries continue beyond the area considered at the workshop. Dashed line indicates geographical extent of the region considered in the workshop.

in the United States about 1,000 km from the epicenter.

Zone 65.—Charlevoix zone. Earthquakes estimated to have equalled or slightly exceeded Richter magnitude 7 have occurred in this zone. The zone's historical and instrumental seismicity is as high as, or maybe exceeds, that of the New Madrid region of the Mississippi Embayment. The

TABLE 5.—*Estimated maximum magnitudes for seismic source zones of the northeastern United States and adjacent Canada*

[Leaders (—) indicate that no value was given at the workshop]

Zone No. (from fig. 11)	Estimated maximum magnitude[1]
64	---
65	7.5
66	6.0
67	7.0
68	6.0
69	5.5
70	6.5
71	6.5
72	6.5
73	6.0
74	6.0
75	5.0

[1]Magnitude scale not specified at the workshop

zone is drawn essentially as presented by Basham and others (1979). They noted that if the zone was drawn on the basis of distribution of microearthquakes (Leblank and others, 1973; Leblank and Buchbinder, 1977) the zone would be smaller. The microearthquakes extend to depths of about 20 km and appear to be confined to the Precambrian crystalline rocks that dip southeasterly under Paleozoic sediments and metasediments. Microearthquake data obtained during the past 4 years confirm the earlier observations. Stevens (1980) reassessed the locations of the larger instrumentally recorded earthquakes (1924–1978) and found them to fall largely in the zone of microseismicity (70 km long) with concentrations at both ends. On the basis of Dewey and Gordon's (1980) instrumental relocations, the major shocks tend to occur near the northeastern end of the zone.

Basham and others (1979, table 3) and Weichert and Milne (1979, table 2) both used a maximum magnitude of 8.0 for their probabilistic studies. At the workshop, a maximum magnitude of 7.5 was suggested, apparently to represent more recent thinking about the maximum size of intraplate earthquakes and to bring the value more in line with those assigned in the central United States.

Zone 66.—St. Lawrence River zone. There are regions along the St. Lawrence River valley, both to the northeast and southwest of the Charlevoix zone, that are considerably less seismic than the Charlevoix zone. However, these regions probably are considerably more seismic than the background zones to the northwest and southeast. Thus, a zone has been introduced that extends on the northeast from the lower St. Lawrence zone (Basham and others, 1979), (off fig. 12 to the northeast) to the southwest through the Charlevoix zone to the western Quebec zone.

Zone 67.—Western Quebec–northern New York zone. This zone is drawn essentially as outlined by Basham and others (1979) who were careful to state that the zone is "simply intended to encircle concentrations of seismicity."

Basham and others (1979, fig. 11) defined a zone of higher seismicity within the western Quebec zone (as they did within the Charlevoix zone) and call it the "Gatieau Triangle" (from Forsyth, 1977). Near the United States border it is about half the width of the western Quebec zone.

The northwestern edge of the western Quebec zone could be extended far to the northwest on the basis of the known seismicity and in accordance with the highly speculative notions of Diment and others (1980) and Muller and others (1980). These authors suggested that zones of high seismicity may occur along, or may be bounded by, certain northwesterly trending lineaments on gravity and magnetic maps.

The western Quebec zone is terminated in northern New York near the northern edge of the high Adirondack Mountains.

Some of the earthquakes in the western Quebec zone are rather deep. The Manisaki earthquake of 1975 was assigned a depth of 17 km (Horner and others, 1978) and the St. Donat earthquake of 1978 a depth of 7 km (Horner and others, 1979). Moreover, a systematic change of focal depth has been suggested across the western Quebec zone from upper-crustal depth north of Montreal to mid-crustal depth north of Ottawa (Horner and others, 1979). The focal depths of some northern New York earthquakes are thought to be of mid-crustal depth (Aggarwal and Yang, 1977).

Zone 68.—The Adirondack Mountains and environs. Until recently the seismicity of the Adirondacks has been portrayed as low, perhaps because of the low density of population and because most of the seismicity is distributed around the margins of the Adirondacks. Recent studies indicate an abundance of small earthquakes in the Adirondack

Mountains (Aggarwal and Sykes, 1978) although the principal anorthosite bodies tend to be aseismic (Aggarwal and Yang, 1977).

No large earthquake has been attributed to this region, nor have any been attributed to its periphery, except to the north, which falls in the western Quebec zone. A maximum magnitude of 6 seems appropriate.

Serious attempts have been made to relate seismicity to geologic structure in this region (for example, Isachsen and McKendree, 1977a–d; Pomeroy and Fakundiny, 1976). So far the results are most interesting, but rather equivocal. The maximum compressive stress, however, has been shown to have an east-northeast direction (Sbar and Sykes, 1973, 1977) as it seems to have in those regions west of the Ordovician suture (for example, Sykes, 1978), however it might be defined.

The southwestern limit of seismicity falls close to a northwesterly trending lineament constructed by Diment and others (1980) and Muller and others (1980) on the basis of terminations of gravity and magnetic features in the region. This lineament has not been examined in detail as yet. The Lowville earthquake of 1853 (Coffman and von Hake, 1973) and the Booneville earthquake of 1980 (Kafka and others, 1980) appear to occur along it. Moreover, the focal-plane solution for the Boonville earthquake suggests a northwesterly trending plane with northeasterly directed compressive stresses, as do most earthquakes in the Adirondacks.

Some earthquakes in the Adirondacks are known to be shallow (<3.5 km) as at Blue Mountain Lake (for example, Sbar and others, 1972; Anderson and Fletcher, 1976), but they cannot be related unequivocally with geologic structure (Isachsen and Geraghty, 1979).

Zone 69.—Niagara-Attica Zone. Basham and others (1979) defined a zone of diffuse seismicity extending from the Niagara peninsula to Attica and a little beyond. Because the zone is delineated mainly on the basis of historical seismicity, its possible extent into Lake Ontario and Lake Erie is not well known, although results from the LDGO net do show epicenters in the western part of Lake Ontario (Sykes, 1978). Because many of the small earthquakes near Hamilton and Toronto and on the Niagara peninsula were the result of shallow pop-ups, the zone might be restricted to western New York.

The intensity VIII Attica earthquake of August 12, 1929 is the largest earthquake of the region. Street and Turcotte (1977) assigned an m_b=5.2. Herrmann (1978) found focal depths between 2 and 3 km for two more recent events (1966 and 1967) near Attica and suggested that the anomalously high intensity of the 1929 shock also might be the result of such shallow focal depth.

Zone 70.—The Clarendon-Linden fault. The north-northeast-trending Clarendon-Linden fault is close to Attica and the 1929 earthquake could have occurred along one of its strands, but this is not entirely clear. Certainly, the small earthquakes (1972–1975) induced by solution mining of salt did occur along a strand of the Clarendon-Linden system but they ranged in depth from 0.5 to 1.1 km (Fletcher and Sykes, 1977, fig. 8). A focal mechanism with thrust motion on a nodal plane nearly parallel to the fault was obtained from these earthquakes (Fletcher and Sykes, 1977). The mechanisms obtained from the 1966 and 1967 events also yield a north-northeast-trending nodal plane, but require approximately equal components of right-lateral and reverse faulting along this nodal plane (Herrmann, 1978).

The Clarendon-Linden fault falls on the west flank of a pronounced gravity and magnetic feature that extends north-northeast to northeast across Lake Ontario (Diment and others, 1974; Bothner and others 1980). This geophysical anomaly must owe its presence to contrasts primarily within the Precambrian basement. However, the Precambrian structures may have influenced the development of the Paleozoic Clarendon-Linden fault.

Many earthquakes in the zone clearly are not related to the Clarendon-Linden fault. An east-west trend has been noted by many, a northwest trend by some (Diment and others, 1980), an association of earthquakes with mafic plutons as revealed by gravity and magnetic anomalies (Kane, 1977), and an association of earthquakes with edges of blocks as defined by geophysical and stratigraphic studies (Fakundiny, this workshop). The Precambrian basement of northwestern New York appears somewhat anomalous with respect to the surrounding region in that local but intense gravity and magnetic highs are more common (Revetta and Diment, 1971). The character of the signatures appears to extend northward into Lake Ontario.

Zone 71.—Southeastern New York and northern New Jersey. This zone was drawn on the basis of historical and recent instrumental seismicity (Aggarwal and Sykes, 1978; Sykes, 1978; Chiburis and Ahner, 1980). The seismicity in a part of the zone appears to be closely related to the northeasterly trending Ramapo fault (Triassic-Jurassic) or to earlier faults that may date back to late Precambrian time. However, there are many historic as well as instrumentally recorded earthquakes in the general area that are well outside the Ramapo zone (W.E.T. Smith, 1962, 1966; Sykes, 1978; Chiburis and Ahner, 1980). Indeed, some epicenters extend a considerable distance offshore. Thus, the zone has been extended offshore to the arbitrary offshore boundary of zone 64 (see previous discussion). Perhaps it extends farther into the ocean where it might be associated with transform faults, although which of the many faults may be seismogenic is not clear from the maps of Klitgord and Behrendt (1979). The southern termination of the zone corresponds to the change in structural trends from southwest to west-southwest, and to a reduction in seismicity. The northern termination corresponds to the intersection of the northeasterly structural trends with the more northerly trends of the Berkshire Hills, and to a reduction in seismicity. There is evidence for significant minor seismicity along the Hudson River valley and the zone might be extended to the north, perhaps to join with the areas of moderate seismicity in, and peripheral to, the southern and central Adirondack Mountains (Pomeroy and Fakundiny, 1976).

Zone 72.—The Boston-Ottawa trend. Over the years, several suggestions have been made that link a diffuse northwesterly trending zone of seismicity (W.E.T. Smith, 1962, 1966) that extends from offshore through eastern Massachusetts, southeastern New Hampshire and into Canada in the region of Montreal and Ottawa, with an ill-defined zone of Mesozoic alkaline magmatism (Diment and others, 1972; Sbar and Sykes, 1973; McHone and others, 1976; McHone, 1977; Sykes, 1978). Although the notion may have some merit, it has some significant imperfections: (1) there is a gap in seismicity in Vermont, although results from recently established stations indicate that this area may not be aseismic (Chiburis and Ahner, 1980); (2) if the orientation of the principal compressive stress in the coastal zone (west-northwest) is correct, and, if the orientation of this compressive stress is east-northeast in the Canadian Shield, the Adirondack Mountains, and the Appalachian platform, there is a zone in which the orientation of the stress directions must change. The zone of change must intersect the Boston-Ottawa trend, probably in Vermont in the region of relative low seismicity. There was little discussion of these ideas and uncertainties among the participants. However, some participants insisted that the seismicity in southern New Hampshire and northeastern Massachusetts is higher than in adjacent areas along the coast to the north and to the south.

Zone 73.—Northeastern New England. This large zone could be subdivided if we had more information and greater insight, but at this moment it would be difficult to subdivide with a systematic rationale. A number of comments were made about the seismicity of the region and its possible relation to geologic structure, but time was short and the comments were brief and sometimes conflicting.

1. Although the historic seismicity near the coast is somewhat high relative to that of the interior (W.E.T. Smith, 1962, 1966; Coffman and Von Hake, 1973; Stover and others, 1977), the contrast may be due to the fact that the interior was settled late (U.S. Geological Survey, 1970) and remains sparsely populated.

2. The border (PQ, ME) earthquake of 1973 of magnitude $m_b \approx 5$ (Wetmiller, 1975) was something of a surprise and is a principal reason for extending the zone so far to the northwest.

3. Recent focal mechanisms for this zone (Graham, 1978; Pulli and Toksoz, 1980) are sufficiently different that they do not necessarily support the notion of uniform west-northwest-trending compressive regime but rather suggest a complex stress pattern along coastal New England.

Zone 74.—Southeastern New England. Seismic activity seems to be clustered loosely in the vicinity of the Triassic-Jurassic grabens, but areal distribution may be higher a little to the east in southern Connecticut, which might raise the question of the relation of seismicity to strands of the Lake Char and Honey Hill fault zones or possibly to the northeasterly trending lineaments in this region.

Zone 75.—Zone of background seismicity. Large areas have been assigned to this category (m_b=5) of low historic and instrumental seismicity. An enumeration of ideas expressed at the workshop and in the literature may be useful:

1. Many believed that earthquakes in the zone

are attributed to shallow phenomena and have been expunged from the record. However, many quarry blasts remain unculled from the record (an important problem inasmuch as they outnumber natural events by more than a hundred to one in some regions). Moreover, some earthquakes caused by collapse of subsurface workings, pop-ups due to natural unloading or quarrying (Pomeroy and Fakundiny, 1976), and solution mining or reinjection of wastes remain in the record.

Although most of these earthquakes are consequences of man's activities, some actually are indicators of high stress levels near the surface. The latter may be regional in extent and should not be ignored entirely in seismic zoning.

2. The aseismicity of certain regions may be due to the presence of shallow sediments that are so soft or so decoupled that they cannot accumulate sufficient strain to produce shallow earthquakes (for example, Diment, 1980). However, this does not mean that deeper earthquakes might not occur in such regions.

3. Within the zones of background seismicity are areas that are more seismic than others, but that are not recognized as such because consideration of larger variations obscures them. Sometimes these subtle variations of seismicity within "background regions" represent extensions of more obvious trends into regions where seismogenic structures are present at greater depths (for example, the possible extension of the Attica zone to the southeast).

SUMMARY

By P. C. Thenhaus

The procedures used in delineating seismic source zones are ill defined. No single standard exists by which source zones across the nation can be drawn, primarily because of the nonuniform level of pertinent seismological, geological, and geophysical information available for areas of vastly differing tectonic and geologic settings. The equivocal association of seismicity with geologic structure throughout most of the United States compounds the problem. The zones described herein, resulting from a general consensus of each of the committees, illustrate three useful approaches in defining regional seismic source zones. Each of the approaches represents the different level of understanding of seismotectonics in any one of the regions. They are: (1) zoning on individual faults, or areal extent of faulting where the faults have geologically young displacements, or have distinct association with seismicity; (2) zoning primarily on regional structural style, particularly where regional seismicity is associated strongly with distinctive structural terrane; and (3) zoning on areal distribution of historic seismicity. Typically, some combination of the three approaches is used to best define the zones of a region; however, one approach usually predominates.

Comparing the regions discussed in this report, much more recent faulting information is available on the Great Basin region than on either the Northern or Southern Rocky Mountain regions. This detailed information allows geologic estimates of earthquake recurrence for high-magnitude events. These estimates have high uncertainty, but are informative and useful for comparison with statistically derived estimates of recurrence.

Where recency of faulting information was available for the Rocky Mountain regions (primarily in the Rio Grande rift and the Intermountain Seismic Belt), it has been taken into account in defining zones. Large areas exist, though, that have not been studied in this respect. The zoning philosophy, therefore, has been modified for the Rocky Mountain regions to include zones defined by similar structural or tectonic setting. The available data on ages of latest faulting has been assumed to hold throughout a distinctive structural region. Note that this second approach is different from that used in the Basin and Range where the zone boundaries conform to areas characterized by certain ages of latest fault displacements.

In contrast to the western United States, throughout most of the eastern United States specific seismotectonic structures are unknown. Also, the diversity of geologic and tectonic terrane is not nearly as marked as in the west. These facts pose major handicaps in attempting to define zones primarily on geologic information. Accordingly, in the Central Interior and the northeastern United States, a third approach for developing source zones is used that has primary emphasis on the spatial distribution of historic seismicity.

Considerations for defining seismic source zone boundaries within regions parallel those for devising a zoning technique for the region. Within a region, a nonuniform level of pertinent information exists among source zones being considered under a single zoning technique. This fact bears on the certainty of the zone boundaries within each region. Illustrating this intraregion variation, the given zone boundaries within the Basin and Range have a higher degree of certainty at the eastern and western margins than in the central area. The reasons for this are obvious: (1) the margins of the Basin and Range are the most seismically active, and (2) the hazard threatens the population which is more densely concentrated at these margins. Therefore, more research effort has been concentrated in these areas. This effort results in more and better quality data on ages of latest displacements.

In contrast, certainty of zone boundaries defined under the remaining two techniques of zoning (use of structural provinces and spatial distribution of seismicity) can be assessed only according to the extent that they appear to reasonably organize historic seismicity. Because these techniques are not based on geologic effects of earthquakes (that is, number and size of fault scarps), their certainty cannot be assessed in terms of completeness or quality of a particular kind of quantitative data set. Judgments on both the tectonics of an area and the historic record of events are involved. It is because of these judgments that the source zones represent a general but qualified consensus on the part of the workshop participants. There usually exists dissenting opinions on the part of a few as to the reasonableness of some zones.

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