

COMPARATIVE SEISMIC HAZARDS STUDY OF WESTERN MONTANA

H. H. Waldron (I)

R. W. Galster (II)

Presenting Author: H. H. Waldron

SUMMARY

Previously much of the seismicity in the Northern Rocky Mountains of western Montana was believed to be related to an intraplate boundary zone of seismicity extending from southern Utah into northwestern Montana. A review of the seismotectonics of western Montana, however, suggests that this zone of seismicity is not continuous in Montana, but is disrupted by a major, intraplate crustal discontinuity, the Lewis and Clark Line. Owing to significant differences in seismotectonic characteristics north and south, of and within this discontinuity, the seismic hazard potential also differs between them.

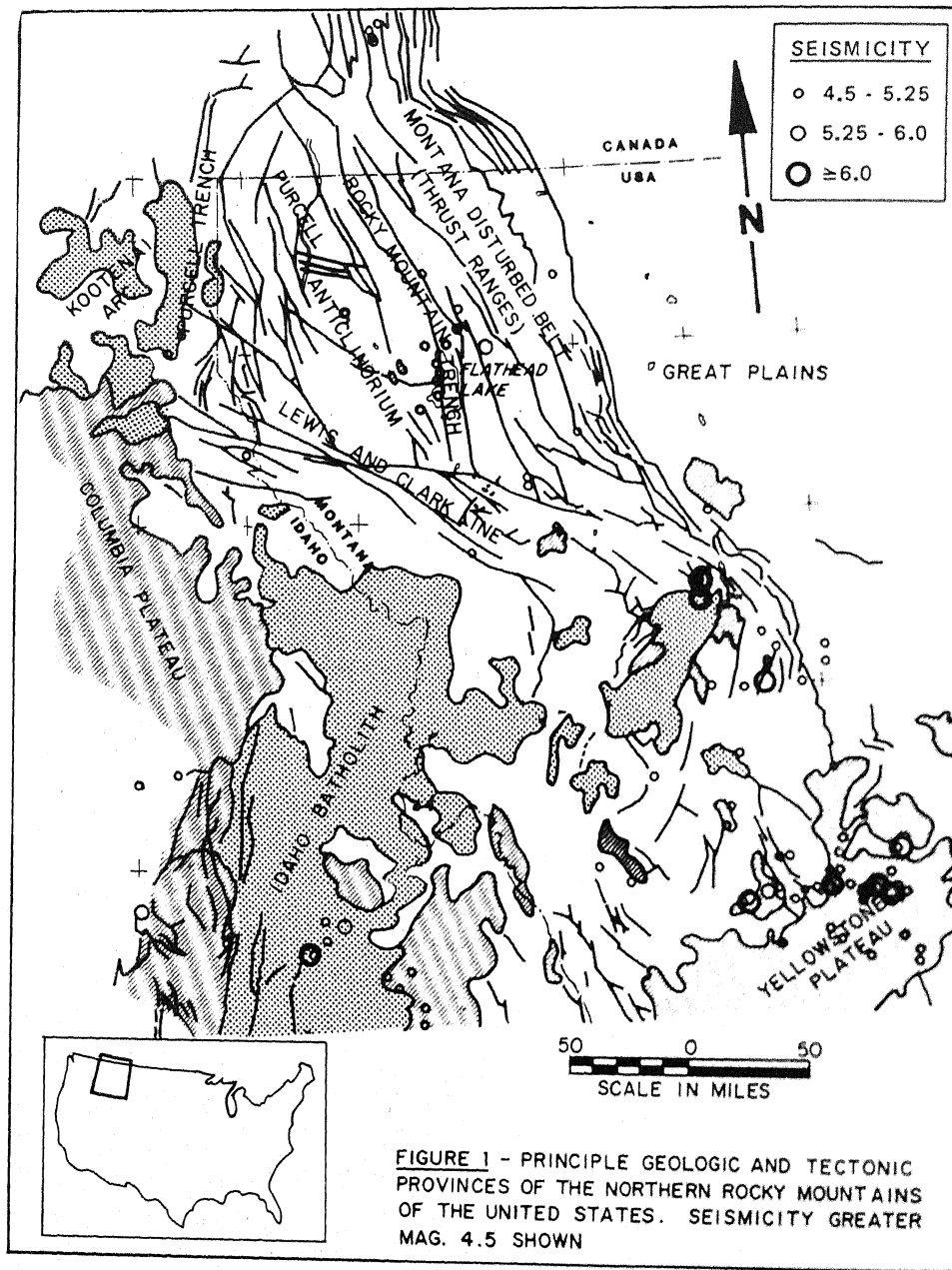
INTRODUCTION

This paper discusses the seismotectonics of western Montana and adjoining areas and its bearing on the earthquake hazard potential of the region. Particular attention is given to the tectonic characteristics of the region. The probable influences of these characteristics on the past earthquake history and on the seismic potential for the region are also discussed.

REGIONAL GEOLOGY AND TECTONICS

Western Montana is in the Northern Rocky Mountains, a region characterized by a series of structurally controlled, linear, north- to north-northwest-trending mountain ranges and intervening narrow valleys. Relief in the area is commonly several thousand feet. Slicing midway through the region is a 15- to 50-kilometer-wide zone of transverse structure trending west-northwest known as the Montana Lineament or Lewis and Clark Line (LCL). Parts of the region have been modified by both continental and alpine glacial erosion and deposition. The effects of continental glaciation, however, is restricted largely to north of about latitude 48° (Fig. 1).

-
- (I) Staff Consultant, Geology, Shannon & Wilson, Inc., Seattle,
Washington, USA
- (II) Chief, Geology Section, U.S. Army Corps of Engineers, Seattle,
Washington, USA



Western Montana is predominantly underlain by a very thick sequence of low-grade metasedimentary rocks of the late Precambrian Belt Supergroup. The sequence consists largely of fine-grained clastic rocks and minor amounts of carbonate rocks. The rocks were deposited in a broad, subsiding basin, called the Belt Basin, which formed as a re-entrant in the North American craton along the eastern edge of the Cordilleran miogeocline during late Precambrian time (Ref. 1). The Belt rocks are overlain by a variety of Paleozoic and Mesozoic sedimentary rocks and, locally, by Cretaceous and Tertiary volcanic rocks. The Belt and Paleozoic rocks have been intruded by a variety of granitic rocks, mainly in the southern part. Thick deposits of Tertiary and Quaternary sediments occur in the trenches and basins throughout the region.

The tectonic development of western Montana began in the late Precambrian and has continued intermittently until today. The tectonic record for Belt time is meager but generally indicates a broad, slowly-sinking, south-southeast-trending basin. Crustal discontinuities, which developed in or near this basin during Belt time, appear to have significantly affected many subsequent tectonic events in the region (Ref. 2). The limited data available suggest that only very gentle folding accompanied by some faulting occurred in the Belt rocks during Paleozoic and early Mesozoic times. This prolonged period of relative quiescence, however, was radically altered by major tectonic-magmatic activities beginning in the Jurassic and culminating during the Laramide orogeny, which extended from Late Cretaceous to early Tertiary time. Later Cenozoic activity was dominated by periods of crustal relaxation, during which extension tectonics produced the major, north-trending trenches, such as the Rocky Mountain and Purcell trenches.

Tectonically the Northern Rocky Mountains in western Montana may be divided into two distinct provinces or blocks of the earth's crust (Fig. 1), each with contrasting tectonic styles and separated by a major intraplate crustal discontinuity, the Montana Lineament or Lewis and Clark Line (LCL). This Line is a structurally complex linear zone of west-northwest-trending faults and folds that extends from the vicinity of Helena on the east to northeastern Washington on the west. The zone is 15-50 kilometers wide and essentially coincides with the ancient axis of a deeper zone of sedimentation formed in the Belt basin in early to mid-Belt time (Ref. 2). Folding and faulting along the Line apparently began in late Precambrian time, and various parts of it have been affected by stresses at different times since then. The faults exhibit both dip-slip and right-lateral strike-slip components; latest movements appear to have involved some westward movement and clockwise rotation of the southern block in Tertiary time. A change in the tectonic characteristics of the Montana thrust ranges, or Disturbed Belt, also occurs at its intersection with the Line. Near Helena, the Disturbed Belt changes from a northwest-trending, moderately-dipping zone of imbricated thrusts on the north to a single, more gently-dipping thrust with an arcuate trend curving around the eastern end of the Line (Ref. 3). The Line may continue eastward into the Lake Basin fault zone of en echelon faults in central Montana.

Geophysical data support the interpretation of the Line as a major and long-lived tectonic boundary (Ref. 4). Both the magnetic and gravity data exhibit regionally higher values north of the Line. The Line is expressed as a nearly continuous gravity gradient that separates predominantly northwest-trending anomalies on the north from predominantly northeast trends to the south. The magnetic data shows strongly aligned contours along the Line. Also, like all of the structures north of the Line, a prominent, linear gravity high, which trends southward from Canada into western Montana, terminates abruptly at the Line (Ref. 5).

The tectonic province north of the LCL consists of three sub-elements--a relatively stable central core, the Purcell anticlinorium, which is flanked on the east by the Montana Disturbed Belt and on the west by the Kootenai Arc/Mobile Belt (Fig. 1). The anticlinorium which is underlain by Belt rocks, consists of a series of subparallel, broad, open, northerly-trending folds. Major fault trends are parallel or subparallel to the folds. Most of the faults have been interpreted to be high-angle normal and reverse faults with small to large displacements. Recent studies, however, have suggested that many of these may be west-dipping thrust faults, similar to those occurring farther north in Canada (Ref. 6).

The Kootenai Arc/Mobile Belt extends from the Purcell Trench westward to the eugeosynclinal rocks of the Omineca Crystalline Belt (Ref. 1). About half of the Mobile Belt is underlain by intrusive rocks with the remainder underlain by Precambrian and younger sedimentary rocks. Structures within the Mobile Belt range from simple, broad folds to complexly folded and faulted areas. Folds commonly trend from north to northeast, and the faults both parallel and cross-cut the folds.

The Montana Disturbed Belt consists of a linear belt of multiple overthrust slices that extends from the vicinity of Helena northwestward into Canada. This Disturbed Belt is characterized by numerous subparallel, westward-dipping, moderate- to low-angle thrusts. The thrust plates involve Precambrian rocks as well as Paleozoic and Mesozoic rocks. The genesis of this Disturbed Belt is not well understood, but apparently it has been relatively inactive since early Tertiary time.

The tectonic province south of the LCL is dominated by extensive batholithic terranes (including the Idaho and Boulder batholiths), by low-angle thrust plates, and by typical basin and range structures in the eastern part. Large parts of the remainder of the original Belt terrane are buried by younger rocks or consist of complexly deformed high-grade metamorphic rocks. Pre-Beltian crystalline basement rocks, which also crop out in this southern province, are not exposed in the northern province. Structural trends in the southern province tend to be less persistent and more diverse than in the northern province.

SEISMICITY

Although the recorded earthquake history of western Montana is relatively brief, extending back only to 1869, it shows that seismic activity throughout most of the region has consisted of relatively infrequent and scattered events of low to moderate intensities or magnitudes (Ref. 7). The record also shows that three areas in the region have had intermittent but significant activity throughout most of historic time. These seismogenic zones include: 1) the Flathead Lake area in the northern tectonic province; 2) the Helena area at the eastern end of the LCL zone of deformation; and 3) the Intermountain Seismic Belt (ISB) in the basin-range part of the southern tectonic province, extending from the Yellowstone Plateau northward to the eastern end of the LCL (Fig. 1).

Seismicity in the northern tectonic province, with the exception of the Flathead Lake seismogenic zone, has consisted only of infrequent and scattered events with low intensities or magnitudes (Fig. 1). The seismic hazard potential for this province, as a whole, is considered to be relatively low; i.e., events exceeding a magnitude of 5.0 or intensity of MM VI are not expected. The Flathead Lake seismogenic zone is largely confined to the Rocky Mountain Trench, a prominent, linear structural depression that separates the Purcell Anticlinorium from the thrust ranges of the Montana Disturbed Belt on the east. On the north, the Trench continues into Canada for more than 1,000 kilometers. On the south, however, like other tectonic elements in the northern province, it terminates at the LCL. Although this area has been the center of considerable historic earthquake activity, no large shocks have occurred there--the largest a magnitude 5.0 (MM VII)--and no active faults have been identified in the area. A significant part of this activity has occurred in swarms in the vicinity of the intersection of a west-northwest-trending fault and the Trench. The structural trend of the trench also changes in this area from southeasterly to southerly. The occurrence of numerous earthquakes in swarms suggests a possible relation to geothermal phenomena in the area. However, because the activity is largely confined to the Rocky Mountain Trench, and because it is occurring in the vicinities of both the intersection of an easterly-trending fault and a change in the structural trend of the Trench, the activity more likely may be due to the relief of remnant stresses rather than to the relief of any contemporary tectonic stress build-up occurring in the area. Fault-plane solutions in the area predominantly show east-west extension (Ref. 8), which could be the result either of post-kinematic relief of remnant stress in this area or of oblique shear occurring on the LCL. The seismic hazard potential for this seismogenic zone is considered to be moderate; i.e., events exceeding a magnitude of 5.5 to 6.0 are not to be expected.

The Helena area seismogenic zone appears to be confined to the LCL in an area of complex geologic and tectonic features, including the presence of abnormally high heat flow, and the intersection of the strike-slip translation of the LCL and low-angle thrusts of the Montana Disturbed Belt. Fault-plane solutions in the area show both strike-slip and normal,

northwest-trending fault mechanisms (Ref. 9). Numerous small shocks and several larger events, including the 1935 magnitude 6.25 shock, have occurred in the vicinity of Helena and northwestward along the trend of the LCL to about longitude 113.5°. Traces of active faults capable of producing a large earthquake also have been reported in this seismogenic zone (Ref. 7). The presence of active faults, coupled with the occurrence of larger earthquakes, indicates that seismicity in the area is due to the relief of contemporary tectonic stresses probably related to continued intermittent right-lateral movements occurring along the LCL. Events with magnitudes as large as 6.5 are estimated to be possible in this seismogenic zone. Earthquake activity along the remainder of the Line west of longitude 113.5° during historic time has been very infrequent and of low intensity or magnitude.

The most pronounced seismic activity in western Montana has been in the southern tectonic province in the basin-range area that extends from the Yellowstone Plateau northward along the Intermountain Seismic Belt (ISB) to its termination by the LCL near Helena. The remainder of the province exhibits relatively less frequent and scattered events of low to moderate intensities or magnitudes. The ISB in southwestern Montana is part of a broad zone of seismicity that extends from southern Utah northward into Montana (Refs. 10 and 11). This belt of seismicity has been interpreted to represent an intraplate boundary oblique to the motions between the North American and Pacific plates, while the more abundant seismicity and overall subplate motions in the vicinity of Yellowstone Park have been attributed to radial stresses overlying a mantle plume (Ref. 11). Fault-plane solutions in this seismogenic zone of southwestern Montana predominantly show northeast-southwest extension, in contrast to those in the other two seismogenic zones (Ref. 12). The presence of active faults and the occurrence of several large earthquakes, including the Clarkston, 1925, magnitude 6.75, and the Hegben Lake, 1959, magnitude 7.1 events indicate that high strain rates exist in this zone, and that significant relief of tectonic stress is occurring. The seismic hazard potential for this seismogenic zone is estimated to be very high. Earthquakes with magnitudes ranging from 6.5 up to 7.5 might be expected in this zone.

CONCLUSIONS

Based on the seismotectonic study conducted of western Montana, the authors present the following conclusions:

- 1) Western Montana consists of two major tectonic provinces separated by a major tectonic intraplate boundary zone, the Lewis and Clark Line.
- 2) Because each province and the intervening boundary zone exhibit unique geologic, tectonic, and seismic characteristics, their seismic hazard potentials also differ significantly.

3) The Intermountain Seismic Belt does not extend to the Flathead Lake area but is terminated by the tectonic discontinuity of the Lewis and Clark Line.

4) Three seismogenic zones are identified in the region--one in each tectonic province, and one in the boundary zone between the two.

5) The seismic hazard potential in the northern province ranges from low ($M=5$, or less) throughout most of the province to moderate ($M=5.5-6.0$) in the Flathead Lake seismogenic zone.

6) Seismic potential in the LCL ranges from low on the west to relatively high ($M=6.5$) on the east near Helena.

7) Seismic hazard potential in the southern tectonic province ranges from low throughout most of the province to the highest in western Montana ($M=6.5-7.5$) along the ISB in the basin-range area of southwestern Montana.

REFERENCES

1. Harrison, J. E., 1972, Precambrian Belt basin of northwestern United States--Its geometry, sedimentation, and copper occurrences: Geol. Soc. America Bull., v. 83, no. 5, p. 1215-1240.
2. Harrison, J. E., Griggs, A. B., and Wells, J. D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S. Geol. Survey Prof. Paper 866, 15 p.
3. Bregman, M. L., 1976, Change in tectonic style along the Montana thrust belt: Geol. Soc. America Geology, v. 4, no. 12, p. 775-778.
4. Reynolds, M. W., and Kleinkopf, M. D., 1977, The Lewis and Clark line, Montana-Idaho: A major intraplate tectonic boundary: Geol. Soc. America Abstracts with Programs, v. 9, no. 6, p. 1140-41.
5. Kleinkopf, M. D., 1977, Regional geophysical studies of the Northern Belt basin, Montana: Geol. Soc. America Abstracts with Programs, v. 9, no. 6, p. 738.
6. Harrison, J. E., Kleinkopf, M. D., and Wells, J. D., 1980, Phanerozoic thrusting in Proterozoic rocks, northwestern United States: Geol. Soc. America Geology, v. 8, no. 9, p. 407-411.
7. Qamar, A. I., and Stickney, M. C., 1983, Montana earthquakes, 1869-1979, Historical seismicity and earthquake hazard: Montana Bur. Mines & Geol. Memoir 51, 80 p.

8. Qamar, A. I., Kogan, J., and Stickney, M. C., 1982, Tectonics and recent seismicity near Flathead Lake, Montana: Seismol. Soc. America Bull., v. 72, no. 5, p. 1591-99.
9. Freidline, R. O., Smith, R. B., and Blackwell, D. D., 1976, Seismicity and contemporary tectonics of the Helena, Montana area: Seismol. Soc. America Bull., v. 60, no. 1, p. 81-96.
10. Sbar, M. L., Barazangi, M., Dorman, J., Scholz, C. H., and Smith, R. B., 1972, Tectonics of the intermountain seismic belt, western United States: Microearthquake seismicity and composite fault plane solutions: Geol. Soc. America Bull., v. 83, no. 1, p. 13-28.
11. Smith, R. B., and Sbar, M., 1974, Contemporary tectonics and seismicity of the western United States, with emphasis on the intermountain seismic belt: Geol. Soc. America Bull., v. 85, no. 8, p. 1205-1218.
12. Smith, R. B., and Lindh, A. G., 1978, Fault plane solutions of the western United States: A compilation, in Smith, R. B., and Eaton, G. P., Cenozoic tectonics and regional geophysics of the western Cordillera: Geol. Soc. America Memoir 152, p. 104-109.