EARTHQUAKE HAZARDS OF THE GRAND TETON NATIONAL PARK EMPHASIZING THE TETON FAULT

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Abstract

The Teton normal-fault zone extends for over 80 km along the eastern front of the Teton Range. Mapping and profiling of Quaternary fault scarps shows that the scarps are nearly continuous for 55 km with scarp heights varying from about 10 m to 40 m. The largest scarps occur adjacent to the topographically highest parts of the Teton range. The scarps locally offset glacial moraine crests in a left-lateral sense. On a regional scale the scarps exhibit a right-stepping, en echelon geometry that is also consistent with a component of left-lateral displacement.

The Teton fault is structurally subdivided into three segments. One prominent geometrical segment boundary occurs just south Taggart Lake, where the range front bends through an angle of 23° and a major structural boundary extends through the hanging wall basin, as inferred by gravity data. This boundary may have influenced the history of Quaternary earthquake occurrences because vertical offset across faults scarps is greater to the north of the boundary, than to the south. The lengths of the proposed segments and scarp size are consistent with M7 to 7.5 earthquakes for the Teton fault zone.

Research Objectives

This is a preliminary report of the results of the first years research of the University of Utah project "Earthquake hazards of The Grand Teton National Park emphasizing the Teton Fault", as of 15 December 1987. The principal research objectives of the first year of this project were: 1) to map the location and extent of the Teton fault, 2) to investigate the extent of fault-zone segmentation, and 3) to assess the "likely" sites of future large events on the basis of the fault zone data. Additional research topics that are currently being pursued based on this years data are: 1) an evaluation of the geometry of possible subsurface faulting on the Teton fault, 2) modeling of observed and theoretical surface deformation on the valley of Jackson Hole from large earthquakes.

Introduction

The east face of the Teton Range is one of the most dramatic topographic escarpments of North America with 2.2 km of relief. The eastern margin of the range is bounded by the Teton fault scarps extend for 55 km along the range front and In a 3 month summer 1987 field season, the Teton fault was mapped in detail and topographic profiles of the scarps were acquired by electronic distance measurements of elevations. Additional data from gravity surveys, seismic refraction studies, seismicity, topography and geomorphology are integrated to evaluate the geometry, and segmentation of the fault zone. The preliminary results of this work are compared with data from other large normal fault zones and recent earthquakes in the Intermountain region.

REGIONAL TECTONICS

The structural evolution of the Teton Range has been influenced by four major tectonic events (Figure 1):1) Mesozoic-Early Tertiary, east-west compression accompanying the development of the Wyoming-Idaho thrust belt and the foreland province to the east, 2) Late Tertiary epeirogeny and extension of the Basin and Range province, 3) Cenozoic volcanism of the nearby Snake River Plain, and 4) extensive volcanism and faulting associated with the Quaternary, Yellowstone volcanic plateau. The Teton fault system is an eastern extension of Basin-Range tectonic regime and is superimposed on folds and thrusts of the older Laramide foreland and thrust belt structures (Lageson, 1987; Royce, et al, 1975; Love and Montagne, 1956).

The Teton Range is a westward tilted, Precambrian-cored fault block that extends north-south for about 70 km. Precambrian gneisses, diabases and quartz monzonites make up the core of the range (Reed, 1973) and are intensely deformed and metamorphosed. West dipping Paleozoic sedimentary rocks overlie the core of the range and extend across its north and south ends (Love and Reed, unpublished map). Quaternary rhyolites of the Yellowstone silicic system are exposed at the northern end of the Teton range and in the northern Jackson Hole area.

The youthful Quaternary Yellowstone silicic volcanic plateau is located 20 km north of the Teton Range. Here extensive rhyolite flows, ring fractures and radial fracture systems in the northern Teton region are associated with the 600,000 yr. explosive eruptions and collapse of the Yellowstone caldera. The ancestral Teton fault system likely extended north in the Yellowstone region but was covered by Quaternary rhyolite flows. The buried fault system may still impart a tectonic grain to the regional stress field.

Seismically, the Teton fault system is located within the Intermountain Seismic Belt, an 800 km long N-S zone of normal faulting and crustal extension that extends from western Montana to southern Utah (Smith and Sbar, 1974). Large earthquakes have occurred within 90 km of the Teton

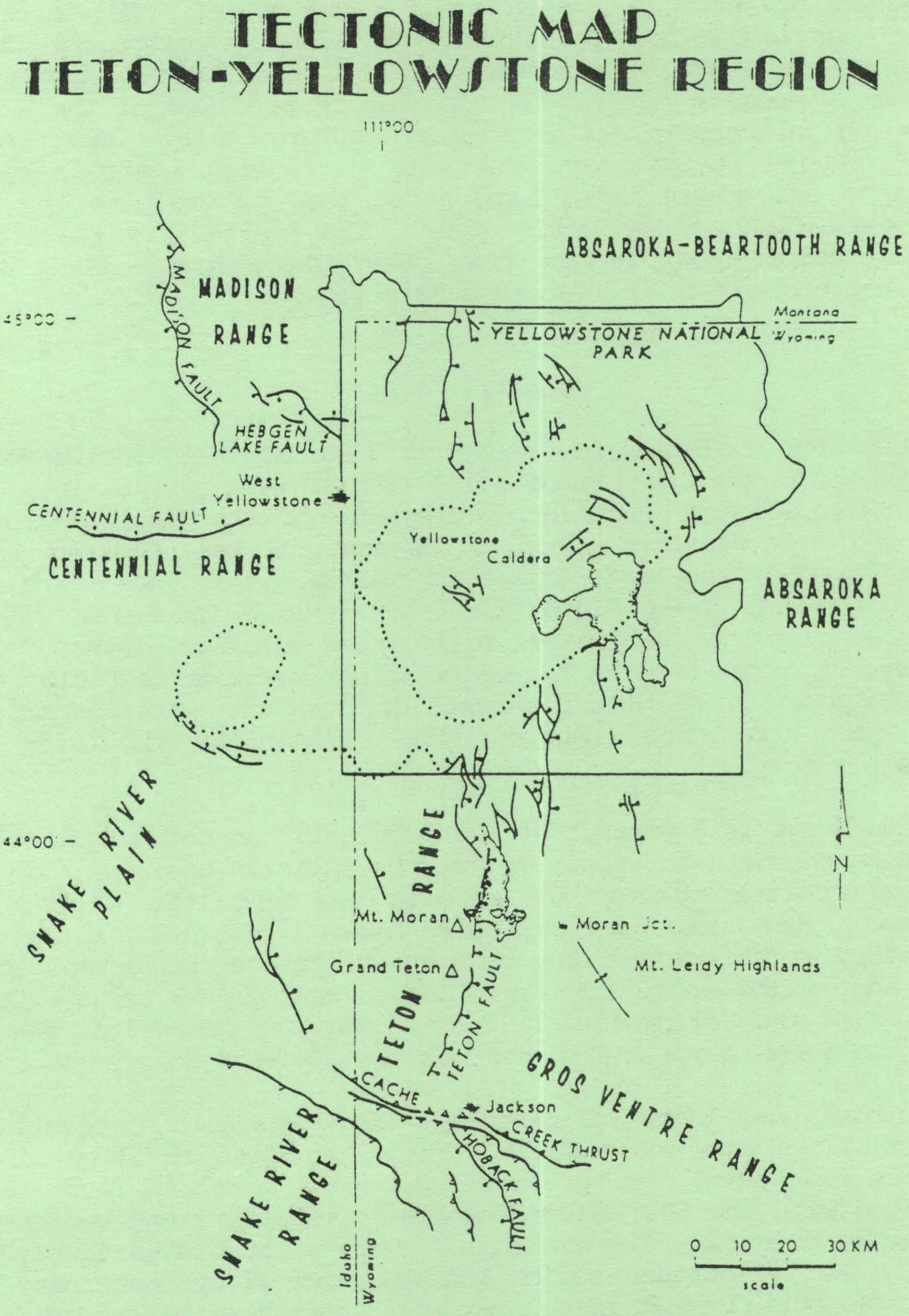

Figure 1: General tectonic map of the Teton fault zone and the Jackson Hole area.

fault zone in Yellowstone National Park and in the Hebgen Lake, Montana area, the site of the magnitude Ms 7.5, 1959, Hebgen Lake earthquake, the largest historic earthquake in the Rocky Mountains.

In historic time there has been an apparent quiessence of seismicity along the Teton fault (Figure 2) in spite of evidence for extensive Quaternary faulting and surrounding regional seismicity (Doser and Smith, 1983). Dispersed earthquake activity has been mapped in the footwall block of the Teton range, on the east side of the Jackson Hole Valley in the Mount Leidy highlands, and in the Gros Ventre Range (Figure 3).

THE TETON FAULT ZONE

The Teton fault zone extends north-south for 80 km and bounds the eastern flank of the Teton Range. Love and Reed (1971) show a generalized map of the trace of the Grand Teton National Park region (Love and Reed, 1975, unpublished map). Gilbert et al. (1983) of the U.S. Bureau of Reclamation conducted a seismotectonic assessment of the earthquake hazards of the Jackson Lake Dam and made a reconnaissance map of the fault by air photo interpretations and field examinations. In that study, several individual fault scarps were mapped, however scarps in dense vegetation, in difficult logistical areas, and in areas not related to their dam safety objectives were not included in their work.

In our study, the Teton fault zone was examined in detail by mapping most of its entire length during 3 months of field work in the summer 1987. Fault scarps were mapped on air photos at a scale of 1:16,000 then compiled to a detailed strip map of the Teton fault zone shown in Figure 4. Criteria for identifying and delineating fault scarps included: 1) scarp slope angles greater than 10°, 2) scarps heights larger than 1 m, 3) linearity of scarps across geomorphic and topographic features, and 4) by identification of deformation and brecciation of adjacent footwall blocks.

Based on this study, Quaternary fault scarps were identified for 55 km along the Teton range front. Examinations of the south end of the fault zone, near Wilson, did not reveal Quaternary fault scarps south of that area. At the north end of the fault zone the fault displacement decreased rapidly beyond Colter Canyon, however because of time limitations we were unable to map in detail any northward extension of the fault beyond Webb Canyon

Scarps of the Teton fault exhibit a generally linear pattern parallel to the topography of the range front to the north, but showed a distinct right-stepping, en-echelon pattern and a change of trend south of Taggart Lake (Figure 4). Small grabens with 1-2 m of displacement on boundary faults were mapped at Taggart Lake, Lupine Meadow, Colter Canyon and String Lake (Figure 4).

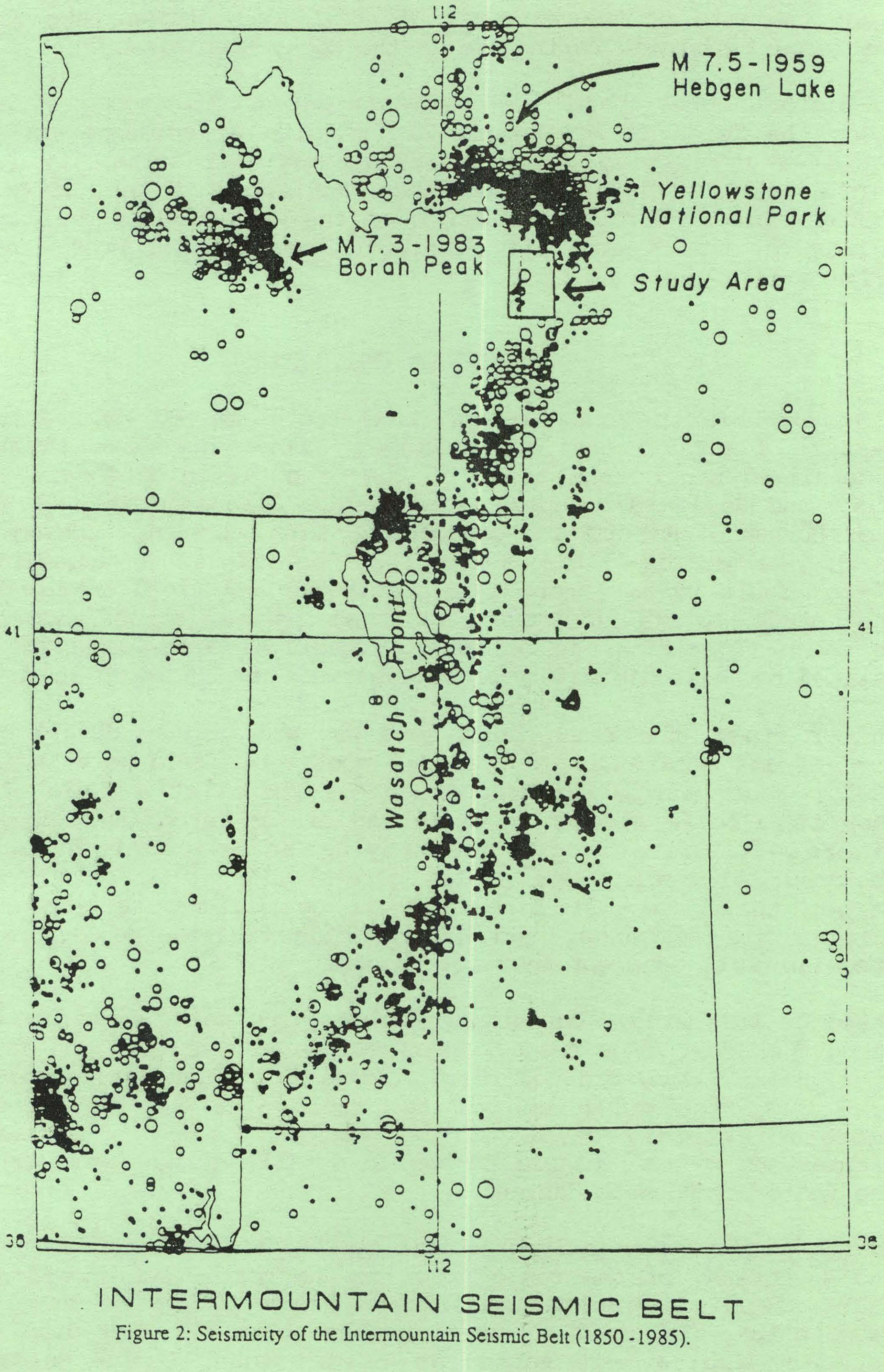

Figure 2: Seismicity of the Intermountain Seismic Belt (1850 -1985).

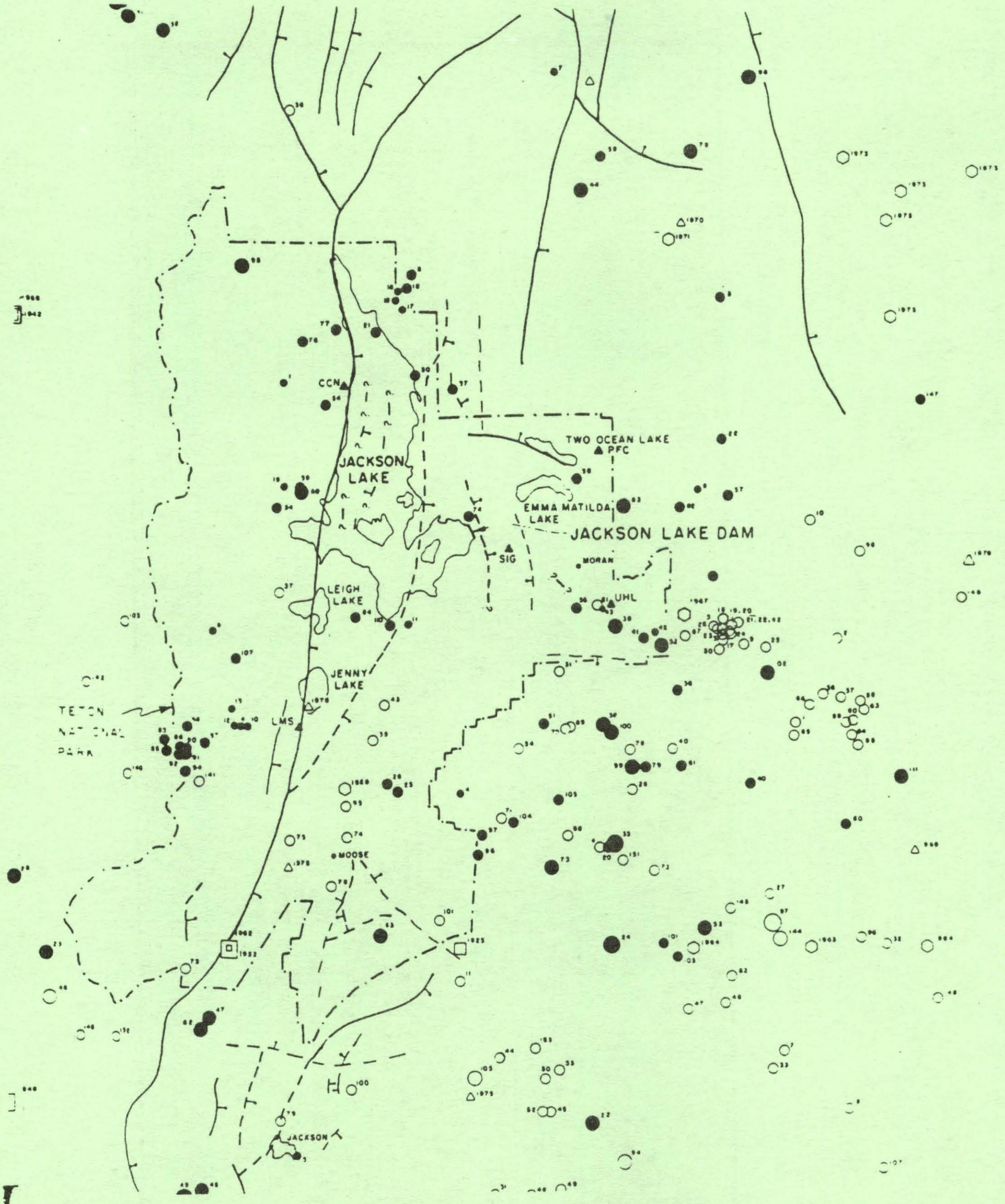

Figure 3 Detailed seismicity map of Teton and Jackson Hole region for period, 1962 to 1986. Data taken from University of Utah and the U.S.Bureau of Reclamation.

Figure 4: Fault strip map of the Teton fault zone compiled from detailed field mapping at 1: 16,000 scale.

Quaternary fault scarps along the Teton fault are not however, continuous along the entire range front. Gaps of hundreds of meters in scarp continuity coincided with lakes along the range front, along areas of steep topography, and at areas of rock avalanches.

Bathymetric maps of the lakes along the range front were examined for possible lake-bottom scarps. Topographic scarps were identified in Jenny and Leigh lakes (P. Hayden, 1987, unpublished NPS maps) as bathymetric slope breaks that were tentatively identified as fault scarps. Additionally, divers from the U.S. Bureau of Reclamation identified as small fault scarp in the bottom of Jenny Lake (J. Gilbert, personal communication) that confirmed these interpretations.

Other notable terminations in Quaternary fault scarps on the Teton fault may be due to gaps in earthquake surface ruptures. For example, surface ruptures of the 1983, Ms 7.3, Borah Peak, Idaho earthquake (Crone and Machette, 1984) and the 1959, Ms 7.5, Hebgen Lake earthquakes (Myers and Hamilton, 1964) were discontinuous with gaps of up to 6 km suggesting the possibility that secondary or buried faults accommodated the fault displacement.

At several locations the Teton fault cuts Pinedale age lateral moraines at the mouths of the canyons and provides estimates of ages of faulting. The maximum of age of the Pinedale glaciation in the northern Rocky Mountains is estimated to be about 35,000 years (Ken Pierce, USGS, personal communication, 1987). The high stand of the Pinedale glaciation occurred approximately 20,000 to 22,000 years ago with final deglaciation occurring about 11,000 to 14,000 years ago (Madole and Shroba, 1979; Pierce, 1979). We infer a maximum age of about 35,000 years for the faulting that cut the moraines. If these lateral moraines were deposited at the high stand of the glaciation, the maximum age of the fault scarps may be about 20,000 years.

Evidence of Lateral Displacement--Morphologically, the east-west tending lateral moraines at the mouths of the canyons are sharp linear features. When cut by a fault, the moraines can be used as piercing points to evaluate the sense of slip on the fault. In this study, extensive mapping including preparation of detailed contour maps at scales of 1:500 was made of lateral moraine crests cut by the Teton fault using an electronic distance measuring (EDM) device.

The detailed study areas included Stewarts Draw (Figure 5) and Avalanche Canyon (Figure 6). The moraine crests are marked by dashed lines on the figures and show left-lateral offset of 26 m at Stewarts Draw and 8 m at Avalanche Canyon. The dip-slip component is 32 m at the Stewarts Draw moraine and 9 m at Avalanche Canyon. These horizontal displacements document a significant component of oblique slip, especially near the southcentral part of the fault zone.

Evidence for left lateral displacement is amplified by the geometry of

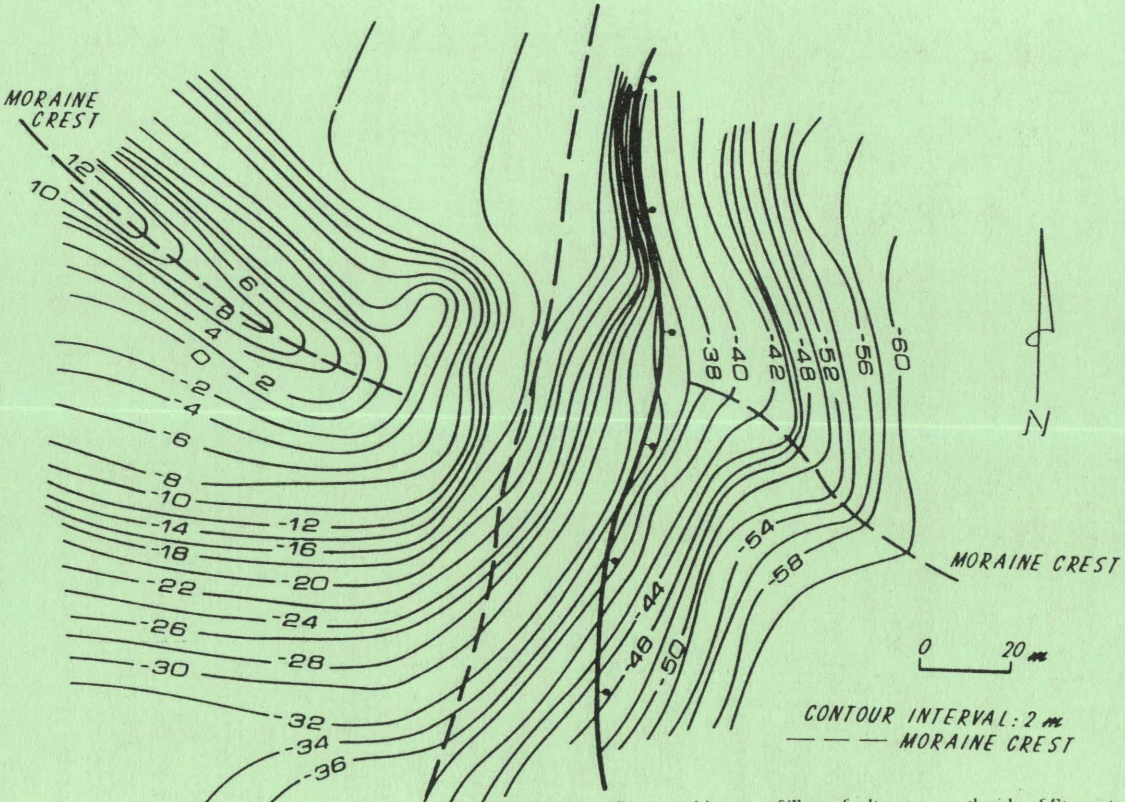

Figure 5 Topographic map of Teton fault scarp, south side of Stewarts Draw. Teton fault is shown in heavy line with downthrown block to the east. Left lateral displacement of 26 m is based on extrapolation of the trace of the moraine crest on the upthrown block into the fault trace.

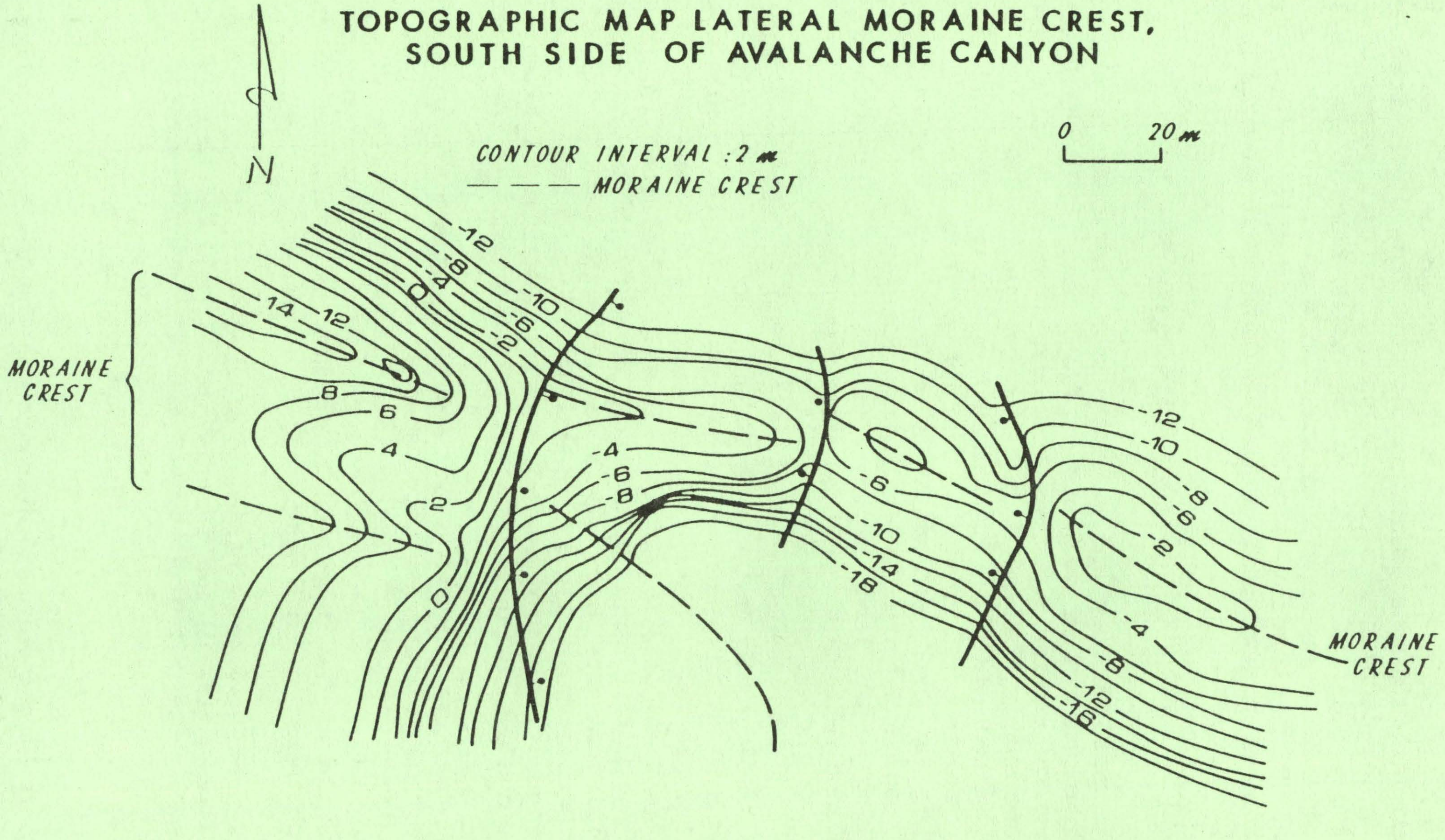

Figure 6: Topographic map of Teton fault scarp, south side of Avalanche Canyon. Teton fault is shown in heavy line with downthrown block to the east. Left lateral displacement of 9 m is based on extrapolation of the trace of the moraine crests on the upthrown block into the fault trace.

the scarps relative to the steep slopes of the moraine crests. For example, left-lateral oblique slip on an east-west trending moraine will produce larger displacements on the left side of the moraine crests and smaller displacements on the right. For this reason the scarps are relatively small (0 to 2 m) on the north side of the Avalanche canyon lateral moraine while on the south side scarp heights are as large as 10+m. This geometry was useful in identifying the large lateral displacement components at Avalanche Canyon and Stewarts Draw.

FAULT SCARP PROFILES

The scarp morphology and geometry of fault zones can be used to date and delineate active segments of fault zones. In the Basin-Range, the morphology of fault scarps has been used to examine the Quaternary displacement histories of large normal faults (Wallace, 1977; Bucknam and Anderson, 1979). Bucknam and Anderson (1979) noted that higher fault scarps have steeper faces for a given age. In areas of arid climates the scarps degrade systematically resulting in decreasing scarp slope angles with increasing age. However, the application of scarp profiling to the Teton region must be made with caution because of its cooler and wetter climate than the Basin-Range

Seventeen topographic profiles of the Teton fault were surveyed with a Zeiss 3 Electronic Distance Measuring theodolite to evaluate topographic variations in displacement along strike of the fault zone (detailed profiles are on file at the University of Utah and will be included in the final report). Profile sites were selected for their relative position along the fault zone, quality of scarp indicators, and visibility at the site. Care was taken to avoid areas of slumps and areas modified by alluvial processes and landslides. Several profiles (see Figure 7 for profile locations) included multiple en echelon fault scarps and antithetic faults that formed grabens in the hanging wall.

Surface materials, vegetation, and slope aspect are important variables in scarp degradation and were noted at each site. The surface materials generally consisted of glacial till, alluvium and colluvium from sand to boulder size. The vegetation varied from sagebrush meadows to spruce-fir forest. The directional exposure of the profiled scarps varied from southeast to northeast.

Scarp profiles were initially plotted without vertical exaggeration. The slope angles varied from 24° to 46° and the heights ranged from 11 to 48 m. Steep fault scarps generally suggest more recent faulting, while large scarp heights i.e. in excess of 10m, are most likely indicative of multiple faulting events (Nash, 1984; Bucknam and Anderson, 1979).

The scarp height versus distance along the fault was plotted in Figure 7 to examine systematic variations in the displacement history of the fault. Vertical lines in Figure 7 are the locations of the profiles

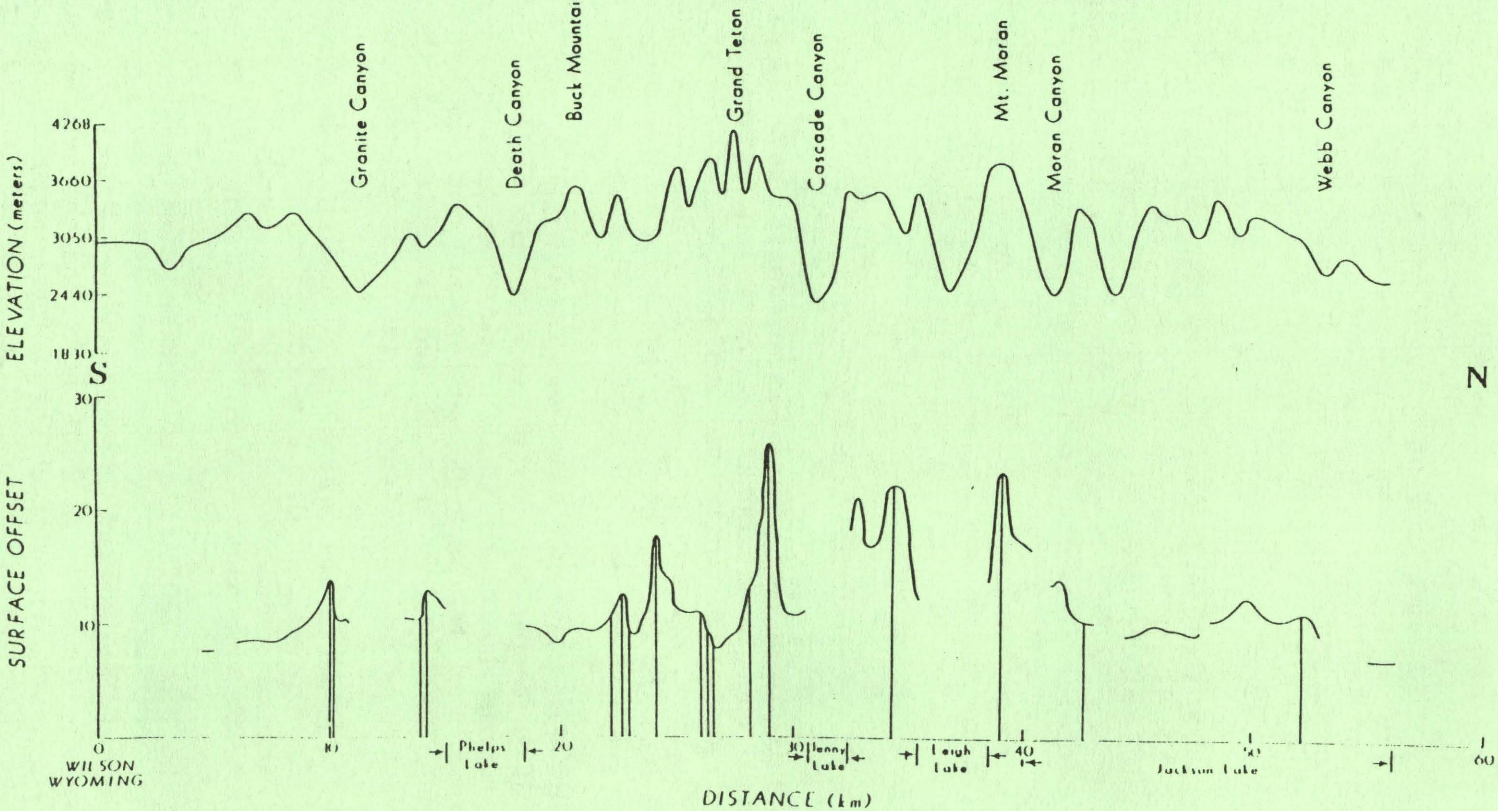

Figure 7: Plot of surface displacement and topography of the footwall block of the Teton fault zone. Note correlation of maximum topographic relief with areas of greatest surface displacement. Topographic profile locations are indicated by vertical lines.

used in this study. Gaps in the displacements indicate that fault scarps were not visible and thus not mapped in these areas. The surface displacements in Figure 7 can be divided into three domains, or segments, based on the magnitude of surface offset. Assuming that the surface offset is an expression of the displacement history of the fault, the Teton fault zone appears to have three segments with different average displacement histories (Figure 8). Also note the comparison of the similar fault parameters for the 1959, M7.5, Hebgen earthquake fault (Figure 9).

Figures 7 and 8 show that fault offsets vary considerably within each of the segments of the Teton fault. Variations in surface offset within an individual fault segment are quite common and may be a function of earthquake rupture mechanics and changes in materials along strike (Crone and Machette, 1984). For example, the scarp height of the 1959, M7.5 Hebgen Lake earthquake varies from 0 to 5.5 m along strike (Figure 9). The scarp height of the 1983, M7.3, Borah Peak earthquake varied from 0 to 2.7 m in height and averaged 0.8 m and the maximum surface throw of 2.7 m occurred in alluvial material (Crone et. al, 1987).

FAULT ZONE SEGMENTATION

Large normal fault zones such as the Wasatch fault, have been subdivided into individual rupture segments that have lengths corresponding to earthquakes of a characteristic magnitude (Schwartz and Coppersmith, 1984). For example 12 segments have been proposed for the Wasatch fault zone in Utah (Machette, et. al., 1987) where the largest segment corresponds to a maximum or characteristic earthquake of magnitude 7.

Variations in the topography of mountain ranges have also been correlated with segmentation of the large normal faults. Significant breaks in the topography of the Wasatch Range correlate with the ends of individual segments of the Wasatch fault zone. The highest topography of the Wasatch Range coincides with the segments with the youngest Holocene displacements and most frequent return times (Machette, 1986).

Individual fault segments are defined by similarities in geomorphologic and topographic expression, displacement histories, geometry of the hanging wall basins, seismicity and fault zone bending, and branching (Scott, et al, 1985; King and Yielding, 1984; Bruhn, et al, 1987; Susong and Bruhn, in press, Vita-Finzi and King, 1985). These parameters were evaluated for the Teton fault zone to examine possible segmentation.

Based on the scarp displacements, shape of the regional gravity field, local earthquake patterns, projected fault zone geometry and topography of the footwall block we propose three fault segments for the Teton fault zone: the South, Middle, and North segments (Figure 8). Each segment likely has a different displacement history that may be correlated to individual earthquake ruptures. Scarps with large heights and uniform slope angles form separate domains that suggests each domain

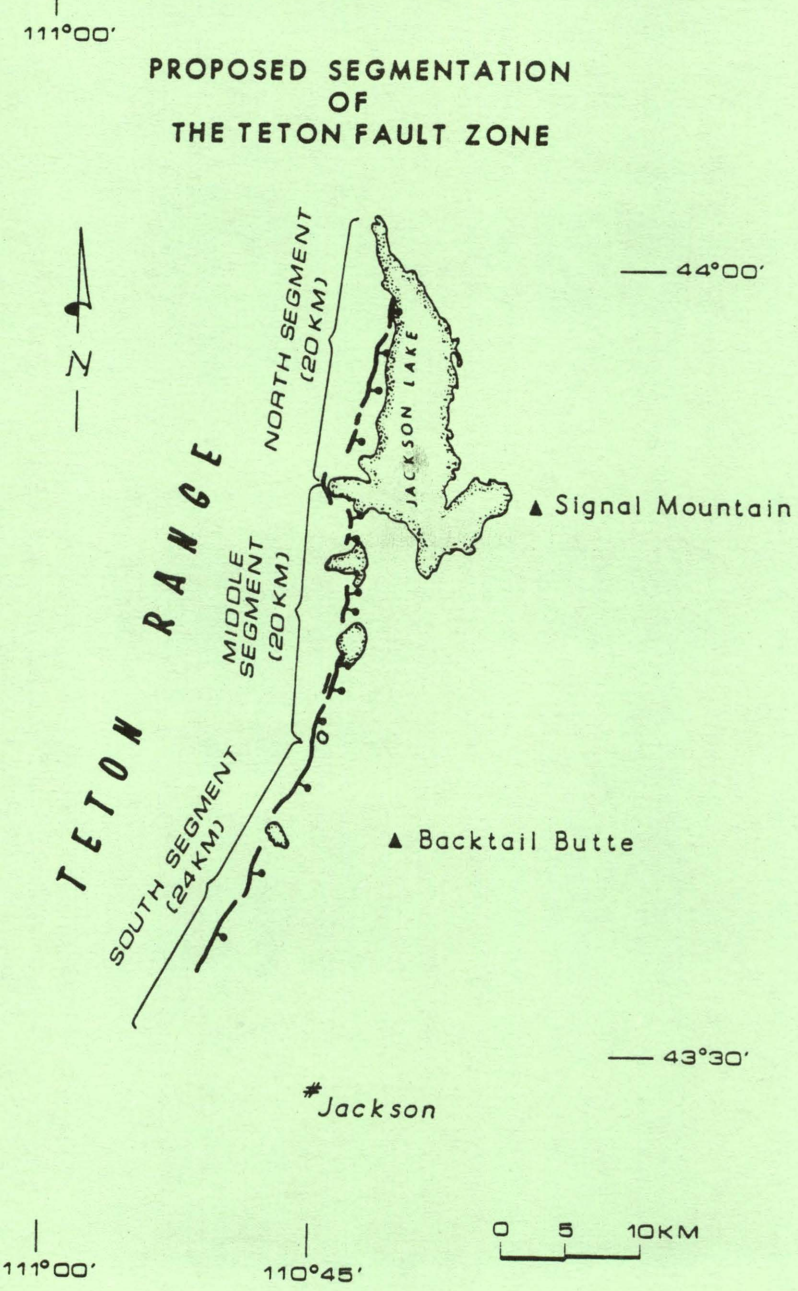

Figure 8: Map showing proposed segmentation of the Teton fault zone.

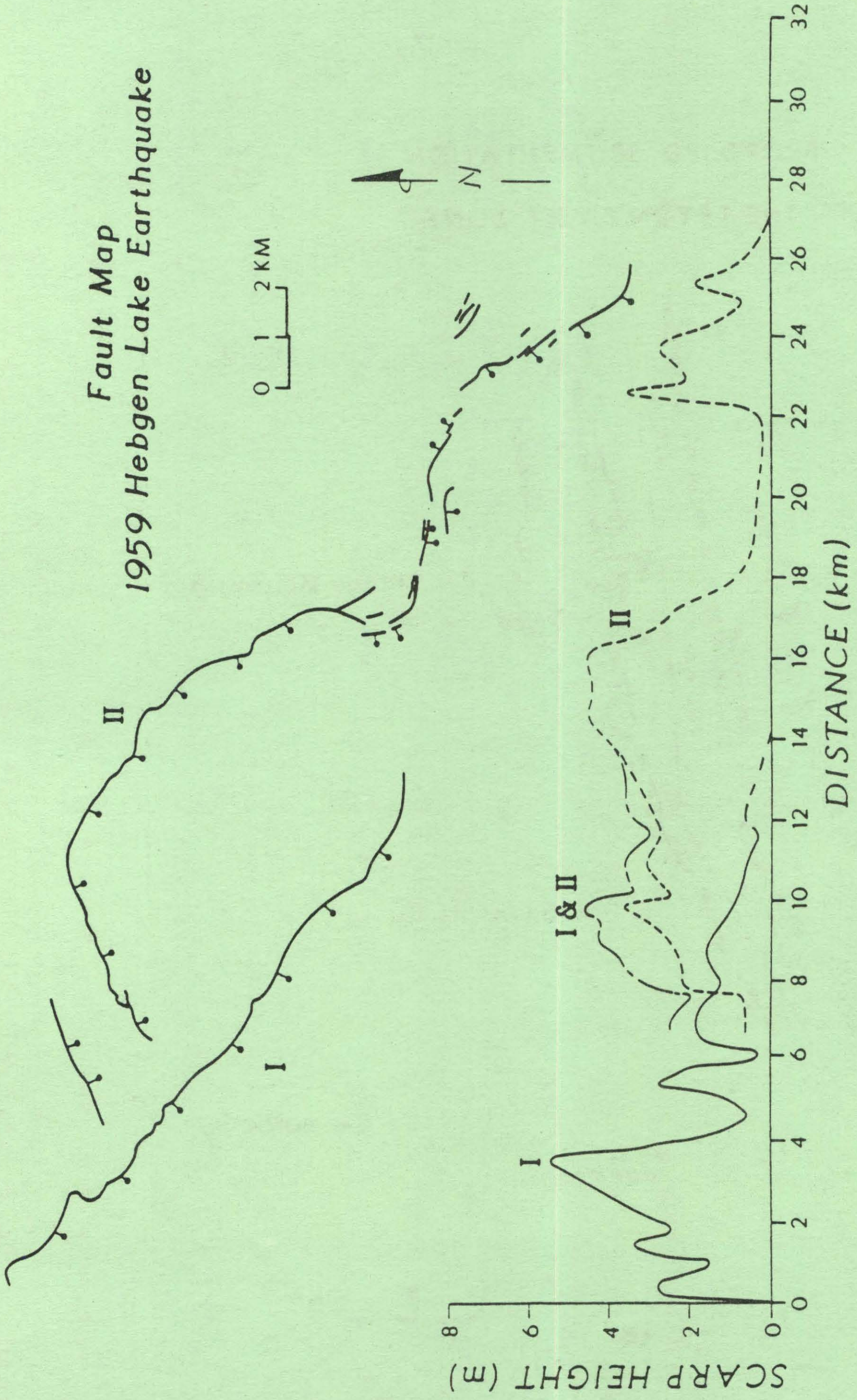

Figure 9: Fault strip map of the Hebgen Lake, Montana, fault zone (upper diagram). Variation of fault offset associated with the M7.5,1959; Hebgen Lake earthquake (lower diagram).

may have a different displacement history.

Using these criteria, the three domains of average topography were identified for the Teton fault (Figures 7 and 8) that corresponds to the three segments. The Southern segment extends for 24 km from Wilson to the vicinity of Taggart Lake. In this segment the fault trends N 20° E., has an average offset of less than 10 m and the topography in the footwall averages less than 3000 m. Beginning at Taggart Lake, the Middle segment is characterized by a marked increase in displacement, a 24° change in strike from 23° to 359° (Figure 4), and the location of the large left lateral offset scarps. The Middle segment also corresponds to the area of highest topography of 3810 to 4200 m and the area of maximum Quaternary fault offset of 24 to 48 m. The Northern segment extends for 20 km from Moran Bay to north of Webb Canyon. At Moran Bay, the Teton fault zone jogs with one portion diverging into bay and the other segment continuing on the north side of the bay (Figure 4). This segment has correspondingly lower topography and smaller surface offset (Figure 7). Overall, the segments and topography correlate quite well with geometrical changes in the Teton fault zone. This uniformity of segmentation suggests that the characteristic earthquake and maximum magnitude model can be considered as a criteria for earthquake hazards evaluation.

King and Nabelek (1984) and Susong and Bruhn (1987, in review) have suggested for large strike-slip and normal faulting earthquakes, respectively, that bends in fault zones have an important role in initiating and terminating earthquake ruptures. Bends in fault zones are considered geometrical boundaries between fault segments and can be barriers to earthquake rupture propagation. Branches in fault zones can play similar roles in controlling earthquake ruptures (Bruhn, et al, 1987). Thus, the segments and their boundaries are considered important in defining the likely locations of future large earthquakes and the segment lengths may also give a conservative estimate of the maximum earthquake magnitude.

Changes in the downdip extension of a normal fault should also be expressed in the shape of the adjacent basin. For instance, changes in direction of the fault zone may be expressed as a structural highs in the footwall and hence should produce a shoulder of higher density material that extends into the basin. Applying this concept to the eastward dipping Teton fault, that is interpreted to underlie Jackson Hole, we would expect changes in the shape of the basin to reflect geometrical changes in the fault zone.

The Bouguer gravity map of the Jackson Hole area (Figure 10) depicts the general shape and thickness of the unconsolidated valley fill versus the higher density bedrock of the Teton Range in relationship to the Teton fault. The gravity map shows that Blacktail Butte is located in the center of a gravity high (Behrendt and others, 1968). The gravity high is interpreted to correspond to a structural high that extends from the range eastward beneath the basin. The gravity high is located east of

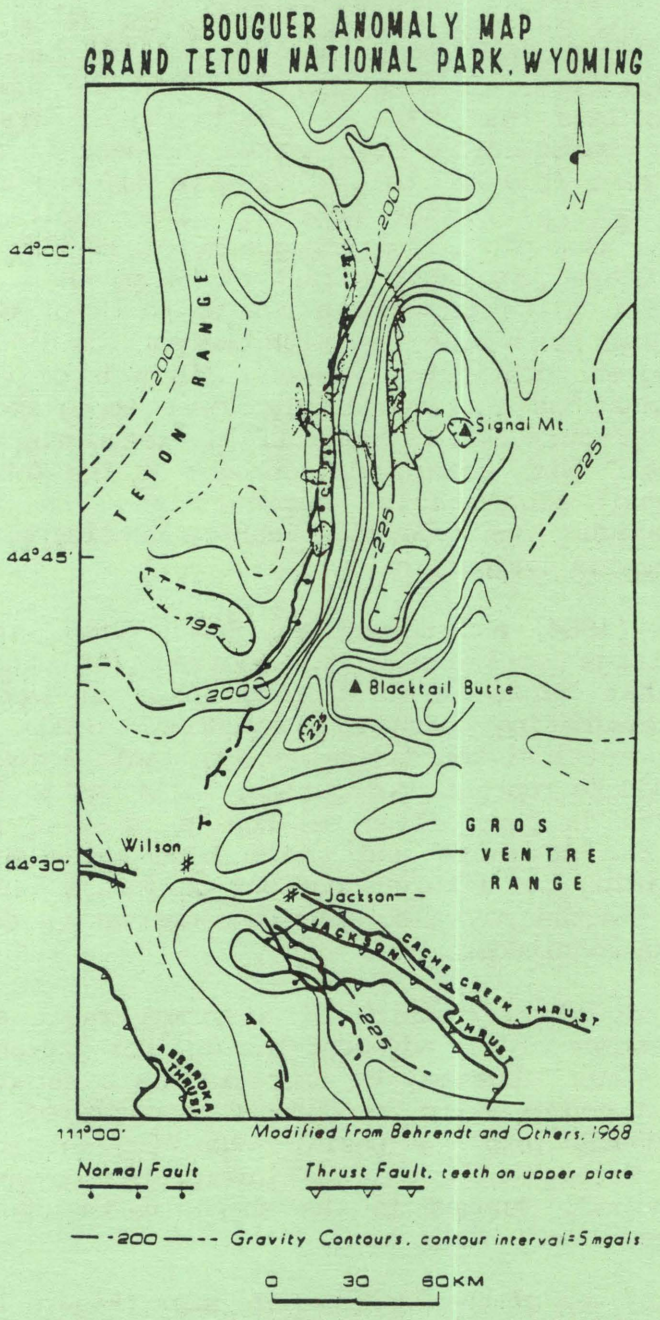

Figure 10: Teton fault and Bouguer gravity anomaly map, Teton region, Wyoming. Note the relative gravity high that extends across the Jackson Hole valley at Blacktail Butte.

the prominent 24° bend in the Teton fault zone and lies on the projection of the bend into the subsurface. This geometry implies an eastward extension of the high density footwall material as a segment boundary. We suggest that the basin shape thus reflects deformation that is occurring in the bend of the Teton fault zone. Susong and Bruhn (in press) observed a similar structure at a major segment boundary in association with a 45° bend in the Lost River fault zone in Idaho.

The gravity field of the hanging wall basin (Figure 10), however, does not reflect branching of the Teton fault at Moran Bay. This suggests that: 1) branching or offset of the fault zone occurs in the footwall thus not effecting the gravity field, or 2) branching or offset of the fault does not produce a structural high in the basin.

The subsurface projection of the Teton fault my be associated with the diffuse seismicity of the east side of the Jackson Hole valley (Figure 3). Local seismicity surveys by the University of Utah and the U.S. Bureau of Reclamation show a diffuse pattern of background seismicity in the area of Mt. Leidy, the east Moran area, and in the eastern Gros Ventre Mountains (Figure 3, US Bur Rec unpublished data, 1987; Doser and Smith, 1983). Interestingly, there is a cluster of events on the east side of the valley that lies on the subsurface projection of the 24° bend in the fault zone. These earthquakes may reflect deformation in the bend of the Teton fault zone at depth.

Segmentation of the Teton fault is shown in a perspective view in Figure 11. The strike of Quaternary fault scarps is used for the orientation of the fault segments and the fault planes are shown dipping at 45°. The strikes are reasonably well constrained while the dip of the fault could vary from 30° to 60°. We depict the Teton fault as a planar structure dipping 45° to the east. While we do not have any direct evidence for this geometry from the large normal faulting events in the immediate Teton region, it provides a hypothetical working model for earthquake nucleation on the Teton fault. Focal mechanisms and geodetic data for the M7.5, 1959, Hebgen Lake and the M7.3, 1983, Borah Peak earthquake indicate that these large earthquakes occurred on planar faults dipping 45 to 60° (Doser, 1985; Richins, et al, 1987, Smith and others, 1985) and nucleates at mid crustal depths of 15 km.

This planar fault model however may not be applicable to the Teton fault. Royce (1983) and Lageson (1987) suggest on the basis of surface mapping that the Teton fault has a listric geometry soling into a ramp on the Cache Creek thrust. However, our data do not suggest, as yet, this geometry.

Doser and Smith (1983) and Gilbert and others (1983) suggest that the maximum credible earthquake for the Teton fault zone is a magnitude Ms 7.5 with down-dip displacements of 2 to 3 m per event. Maximum credible earthquakes can be estimated from displacement rates, seismic moment rates, Quaternary fault lengths, and statistical relations among earthquake magnitude, surface rupture length, and fault displacement

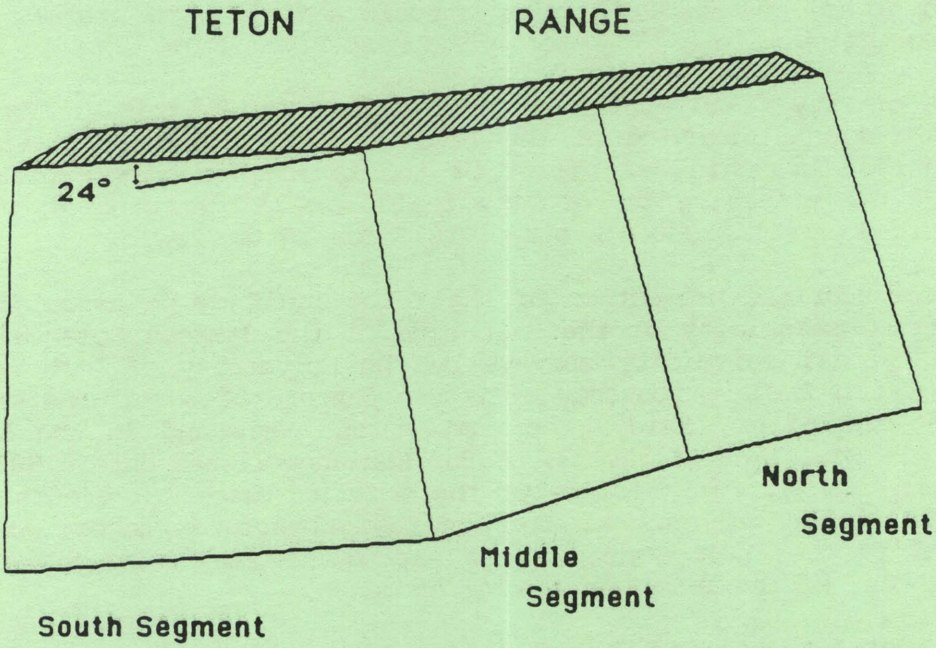

Figure 11: **Perspective drawing of segmentation of the Teton Fault zone.**

(Bonilla, et al., 1984; Peity et al, 1986). For the Teton fault segment lengths of 20 to 25 km correspond to earthquake magnitudes of Ms 6.9 to 7.1 with surface displacements of 1 to 1.5 m. However, larger surface displacements of 8 to 26 m for a maximum magnitude of Ms 7.5 on the Teton fault zone are plausible if two or more segments broke in a single event.

The single-earthquake rupture characteristics of the three proposed segments have not yet been defined. The surface scarps presumably developed by displacement during multiple earthquakes. The measured variations in offset across the scarps may reflect different segments, variations in the number of earthquakes that have occurred in the segments, or both. The characteristic earthquake model, in which repeated earthquakes of essentially the same rupture dimension and magnitude occur within a specific fault segment may apply to the Teton fault zone, but the data are not sufficient yet to reach such a conclusions. The observed variations in multiple-event scarp offset could arise from a more complex rupture behavior, in which the segment boundaries near Taggart Lake and Moran Bay stopped some earthquake ruptures but not others. Information on the single-earthquake rupture history of each segment will be required to allow a conclusion to be drawn between these two hypothetical rupture scenarios.

TREE-RING DATING ALONG FAULT ZONE

Recently tree-ring dating of trees located on or near faults has been applied to estimating ages of fault displacement along the San Andreas fault by Gordon Jacoby and his associated a Columbia University. This method was applied to the Teton fault zone by Jacoby's group in 1987 as part of our project. In this effort tree-ring cores were obtained from several of the large fir and spruce trees in the Taggart and Stewarts Draw areas. The cores were then taken to Columbia University for study and dating. The preliminary results indicate that most of the older trees were uniformally, not older than 130 years. It is suspected that the large forest fires of the late 1800's burned the entire region, thus precluding the use of the older 300 to 500 year old trees to estimate fault offset during that time.

Conclusions

Detailed mapping of the Teton fault zone has identified Quaternary fault scarps along 55 km of the 80 km trace of the fault. The fault scarps cut glacial moraines of Pinedale age, 11,000 to 35,000 years B.P., and display varying amounts of vertical, 11 to 48 m, and left-lateral, 0 to 26 m offset. Displacements are largest in the central portion of the Teton fault and appear to diminish at the southern and northern ends of the fault. Quaternary scarps are not present south of Teton Village, and are inconspicuous north of Colter Canyon. The fault zone was not mapped north of Webb Canyon. Topographic relief in the footwall block also varies along the length of the fault zone, with the greatest relief corresponding to those areas with the largest Quaternary fault scarps.

Three segments of the Teton fault zone were identified, the South, Middle, and North. These segments are inferred to have different displacement histories, and their boundaries are interpreted to have an important role in the initiation and termination of earthquake ruptures. These boundaries are also inferred to be the likely locations of future large earthquakes (Figure 12).

Application of a planar fault model to the Teton fault suggests that potential epicentral locations for future large earthquakes are on the east side of Jackson Hole valley (Figure 12). These sites are located on a planar fault dipping 45^{o} to 60^{o} to the east with a nucleation depth of 15 km. Based on the depths of large historic normal faulting earthquakes in the Basin-Range at depths of 10-15 km (Smith and Bruhn, 1984). Note that the potential nucleation sites are located 9 to 15 km from the trace of the Teton fault zone and coincide with the segment boundaries. Surface displacements associated with earthquakes of M 6.9 to 7.5 would result in significant westward tilting of the valley floor. Modeling of the effects of large earthquakes on the Jackson Hole area is ongoing as a part of this study.

If the planar model for large normal faulting earthquakes ascertained from the large historic earthquakes of the Basin-Range is appropriate, then future large earthquakes on the Teton fault will likely be associated with the individual segments. The three segment boundaries that we propose for the Teton fault zone maybe important areas for rupture initiation and termination. The southern end of the Teton fault zone intersects a series of thrust faults that could form a barrier for rupture propagation and concentrate stresses. The boundary between the Northern and Middle segments corresponds to the location of Jackson Lake dam, a structure now reconstruction due to poor earthquake resistant earthquake design. While the north end of the fault zone splays into a series of faults in southern Yellowstone which may distribute displacement on the Teton fault.

References Cited

Behrendt, J. S., B. L. Tibbetts, W. E. Bonnini, and P. M. Lavin. 1968. A geophysical study in Grand Teton National Park and vicinity, Teton County, Wyoming. U.S. Geol. Surv. Prof. Paper, 516-E, 23 p.

Bruhn, R. L., P. R. Gibler, and W. T. Parry. 1987. Rupture characteristics of normal faults: example from the Wasatch fault zone Utah, in Continental Extensional Tectonics, ed. Coward, M. P., Dewey, J. F., and P. L. Hancock. Geol. Soc. London, 28, 337-353.

Figure 12: Map of possible zones of earthquake nucleation for a magnitude 6.9 to 7.5 event on the Teton fault. Model assumes a planar fault, dipping 45° to 60° to the east and a nucleation depth of 15 km. Stars indicate nucleation points, stippled pattern represent full fault failure surface for individual segments.

Bucknam, R. C., and R. E. Anderson. Estimation of fault-scarp ages from scarp-height slope angle relationship. Geol. 7:11-14.

Crone, A. J., and M. N. Machette. 1984. Surface faulting accompanying the Borah Peak earthquake, central Idaho. Geol. 12:664-667.

Crone, A. J. M. N. Machette, M. G. Bonnilla, J. J. Lienkaemper, K. L. Pierce, W. E. Scott. Surface faulting accompanying the Borah Peak earthquake. Bull. Seis. Soc. Amer. 77:739-770.

Doser, D. I. 1985. Source parameters and faulting processes of the 1959 Hebgen Lake, Montana earthquake sequence. J. Geophys. Res. 90:4537-4555.

Doser, D. I., and R. B. Smith. 1983. Seismicity of the Teton-southern Yellowstone region, Wyoming. Bull. Seis. Soc. Amer. 73:1369-1394.

Doser, D. I., and R. B. Smith. 1985. Source parameters of the October 28, 1983, Borah Peak, Idaho earthquake from body wave analysis. Bull. Seis. Soc. Amer. 75:1041-1051.

Gilbert, J. D., D. Ostenna, and C. Wood. 1983. U.S. Bureau of Reclamation Seismotectonic Report 83-8. Seismotectonic study Jackson Lake Dam and Reservoir. Minidoka Project, Idaho-Wyoming, 123 p.

King, G. and G. Yielding. 1984. The evolution of a thrust fault system: process of rupture initiation, propagation and termination in the 1980 El Asnam (Algeria) earthquake. Geophy. J. Roy. Astr. Soc. 7:915-933.

King, G., and J. Nabelek. 1985. Role of fault bends in the initiation and termination of earthquake ruptures. Sci. 228:984-987.

Lageson D. R. 1987. Laramide uplift of the Gros Ventre Range and implications for the origin of the Teton fault, Wyoming. WY Geol. Assoc., 38th Ann. Field Conf. Guidebook. 78-89.

Love, J. D., and J. Montagne. 1956. Pleistocene and recent tilting of Jackson Hole, Teton County, Wyoming. WY Geol. Assoc. 11th Ann. Field Conf. Guidebook. 169-178.

Love, J. D., and J. C. Reed Jr. 1971. Creation of the Teton landscape-the geological story of Grand Teton National Park: Grand Teton Nat. Hist. Assoc. 120 p.

Machette, M. N., S. F. Personius, and a. R. Nelson. 1987. Quaternary geology along the Wasatch fault zone: Segmentation, recent investigations, and preliminary conclusions. U.S. Geol. Surv. Open File Rept. (in press)

Madole, R. F., and R. R. Shroba. 1979. Till sequence and development in the north St. Vrain drainage basin, east slope, Front Range, Colorado, ed. Ethridge, F. G. Geol. Soc. of Amer. Rocky Mountain Section, Guidebook, 32nd Annual Meeting. p. 124-178.

Myers, W. B., and W. Hamilton. 1964. Deformation accompanying the Hebgen Lake earthquake, August 17, 1959, in the Hebgen Lake, Montana, earthquake of August 17, 1959. U.S. Geol. Surv. Prof. Paper. 435, p. 55098.

Nash, D. B. 1984. Morphologic dating of fluvial terrace scarps and fault scarps near West Yellowstone, Montana. Geol. Soc. of Amer. 95:1413-1424.

Piety, L. A., C. K. Wood, J. D. Gilbert, J. T. Sullivan, and M. H. Anders. 1986. Seismotectonic study for Palisades Dam and Reservoir. Palisades Project, U.S. Bur. Reclam. Seismotectonic Rept. 86-3. p. 198.

Pierce, K. L. 1979. History and dynamics of glaciation in the northern Yellowstone National Park area. U.S. Geol. Surv. Prof. Paper 729-f. 90 p.

Reed, J. C. 1973. Geologic Map of the Precambrian Rocks of the Teton Range, Wyoming. U.S. Geol. Surv. Open File Rept. 73-230.

Richins, W. D., J. C. Pechmann, R. B. Smith, C. J. Langer, S. K. Goter, J. E. Zollweg, and J. J. King. 1987. The 1983 Borah Peak Idaho, earthquake and its aftershocks. Bull. Seis. Soc. Amer. 77:694-723.

Smith, R. B., W. D. Richins, D. I. Doser, and L. L. Lew. 1987. The 1983 Borah Peak, Idaho earthquake: Regional seismicity, fault kinematics and extensional mechanism. Bull. Seis. Soc. Amer. (in press)

Richmond, G. M. 1979. Pleistocene stratigraphy and chronology in the mountains of western Wyoming, in W. E. Maheny, ed. Quaternary stratigraphy of North America. Dowden, Ross, Hetchinson, Stroudsburg, PA. 353-380.

Royce, F. Jr., M. A. Warner, and D. L. Reese. 1975. Thrust belt structural geometry and related stratigraphic problems Wyoming-Idaho-Northern Utah, in Bolyard, D. W., Deep drilling frontiers of the central Rocky Mountains. Rocky Mtn Assoc. of Geologists, Denver. 41-54.

Schwartz, D. P., and K. J. Coppersmith. 1984. Fault behavior and characteristic earthquakes; Examples from the Wasatch and San Andreas fault zones. J. Geophys. Res., 89, 5681-5698.

Scott, W. E., K. L. Pierce, and M. H. Hiat, Jr. 1985. Quaternary tectonic setting of the 1983 Borah Peak earthquake, central Idaho, in Proceedings of Work XXVIII on the Borah Peak, Idaho Earthquake, edited by R. Stein and R. C. Bucknam. U.S. Geol. Surv. Open File Rept. 85-290. p. 43-58.

Smith, R. B., J. R. Pelton, and J. D. Love. 1977. Seismicity and the possibility of earthquake-related landslides in the Teton-Gros Ventre-Jackson Hole area, Wyoming. WY Geol. Assoc. Contrib. WY Geol. 14:57-64.

Smith, R. B., Field Conference, Guidebook, Rocky Mountain Thrust Belt Geology and Resources, Teton Village, Wyoming. Sept. 14-17, 1977, p. 603-610.

Smith, R. B., W. D. Richins, and D. I. Doser. 1985. The 1983 Borah Peak, Idaho, earthquake: regional seismicity, kinematics of faulting, and tectonic mechanism in Proceedings of work XXVIII on the Borah Peak, Idaho Earthquake, edited by R. Stein and R. C. Bucknam. U.S. Geol. Surv. Open File Rept. 85-290. p. 43-58.

Smith, R. B., and M. L. Sbar. 1974. Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain Seismic Belt. Geol. Soc of Amer. Bull. 85(8):1205-1218.

Smith, R. B. and R. L. Bruhn. 1984. Intraplate extensional tectonics of the western U.S. Cordillera: Inferences on structural style from seismic reflection data, regional tectonic and thermal-models of brittle-ductile deformation. J. Geophys. Res. 89:5733-5762.

Susong, D. and R. L. Bruhn. 1987. Structure of an earthquake rupture segment boundary in the Lost River fault zone, Idaho; Implications for rupture propagation during the 1983 Borah Peak earthquake, (paper in review)

Susong, D. D., R. B. Smith, and R. L. Bruhn. 1987. Quaternary Faulting and Segmentation Of The Teton Fault Zone, Grand Teton National Park, Wyoming. EOS Trans. Amer. Geoph. Union.

Vita-Finzi, C. and G. C. P. King. 1985. The seismicity, geomorphology and structural evolution of the Corinth area of Greece. Phil. Trans. R. Soc. Lond. A. 314:379-407.

Wallace, R. E. 1977. Profiles and ages of young fault scarps. North-Central Nevada: Geol. Soc. of Amer. 88:1267-1281.