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

Robert B. Smith
John O. D. Byrd
Ronald L. Bruhn
Department of Geology and Geophysics
University of Utah
Salt Lake City

Detailed Geologic Mapping Of The Teton Fault

Documentation of the location, age and relationship of surface trace of the Teton fault zone to other geologic features is a prerequisite to a full understanding of seismic hazards associated with the fault. The University of Utah's mapping by David Sussong during the summer of 1987 documented the central portion of the fault trace. However, the northern and southern ends of the fault zone still required detailed mapping. Determination of the character of the fault in the areas south of Phillips Canyon and north of Webb Canyon can help to evaluate how movement on the fault would effect these areas, i.e., better evaluation of the relative seismic risk.

Unfortunately, the extreme fire situation (the Huck fire started at the location of mapping) and the excessive time demands of the surveying reduced the amount of field mapping that we had planned for detailed geologic mapping. John Byrd, however, was able to do reconnaissance mapping in the Steamboat Mountain and Lizard Point area. In this area there is good evidence for the existence of several faults that are most likely splays of the Teton fault, that cross Jackson Lake and extend northward on the east side of the valley. Additional mapping is planned in this area next year.

Establishment and Surveying Of 1st-Order Level Line Across The Teton Fault

A leveling array, 21 km-long, was established across the Teton normal fault in summer, 1988, by John Byrd and Chuck Meertens. The array comprises 42-permanent bench marks in an irregular line having a total length of 21,123 m(Fig. 1). It commences at the south end of Antelope Flat where the flat overlooks Deadman Bar on the Snake River, it proceeds westward about 10 km along an unimproved dirt road to the south end of Jenny Lake, thence west and north about 5 km via a horse trail around the south and west shore of Jenny Lake, thence west about 2 km via a horse trail across the fault scarp, and then about 4 km into Cascade Canyon (Fig. 1). A topographic profile of the line is shown in Figure 2.

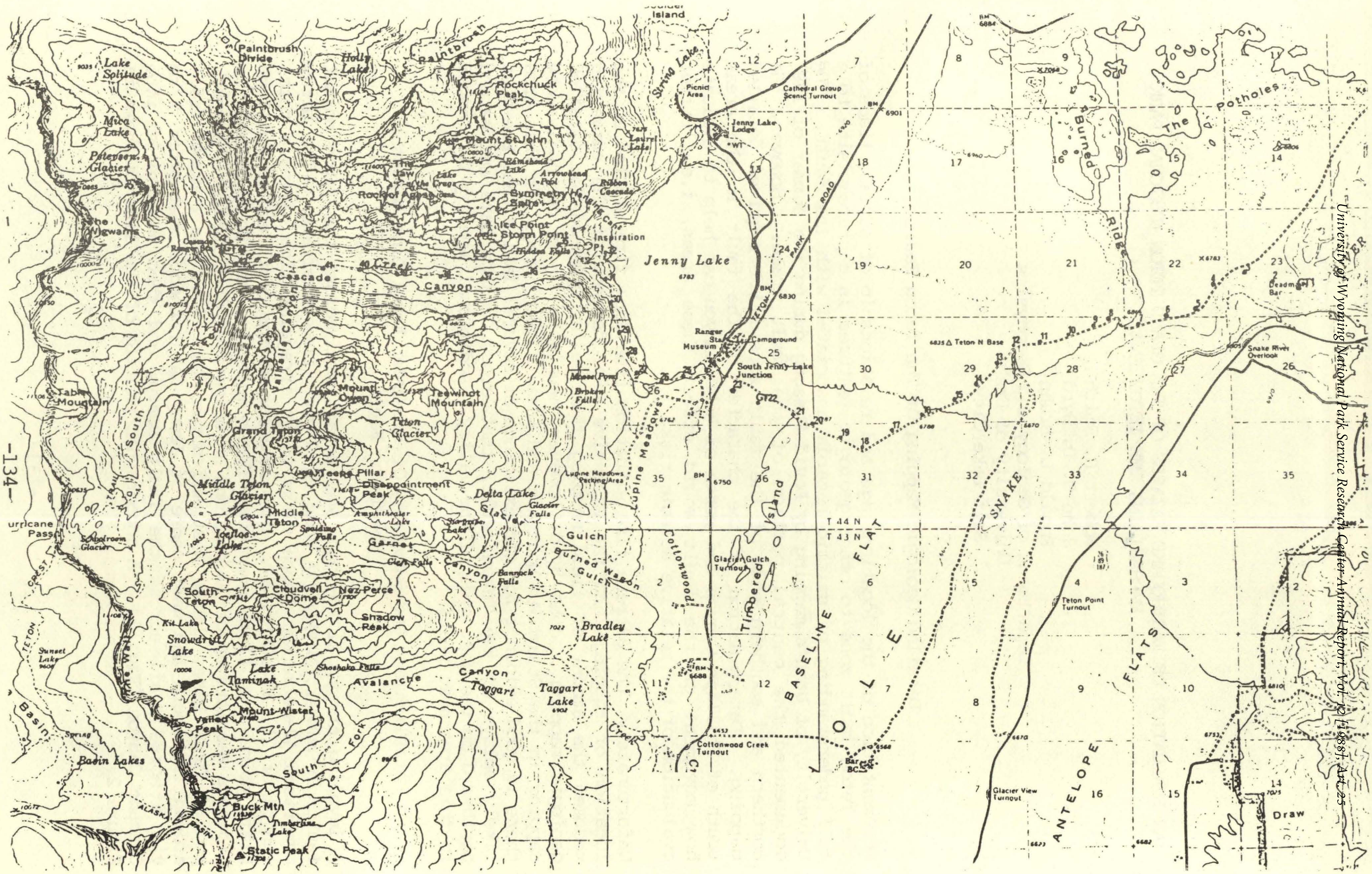

Figure 1. Location of permanent bench marks, GTNP.

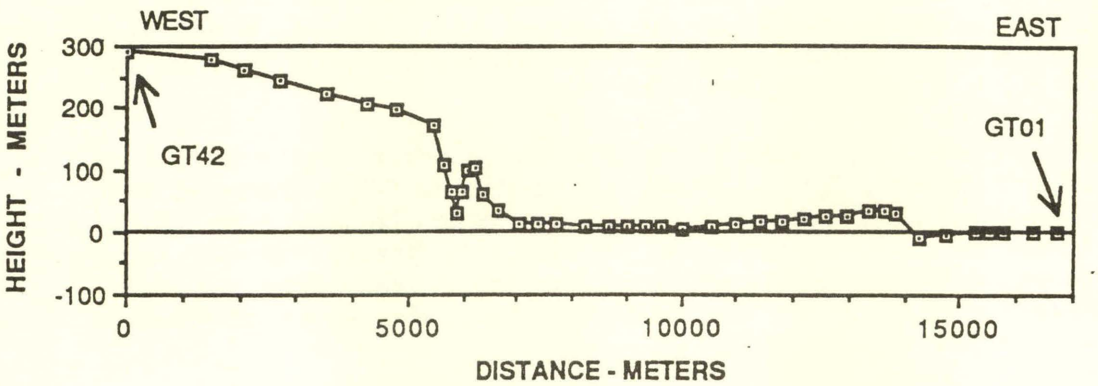

Figure 2. Grand Teton topographic profile.

Benchmarks

Bench marks are of two types: Class B rod marks (Floyd, 1978) which are coupled 2 cm-diameter steel rods, driven to refusal; and 4 cm-diameter, stainless steel plugs cemented into holes drilled in bedrock or large boulders which are embedded in alluvium, moraine, or ancient landslide deposits (Sylvester, 1984). Minimum length of the Class B rod marks in 1 m, and the maximum length is 5 m. Each of the Class B rod marks is tipped by a 4 cm-diameter stainless steel rod, 10 cm long, which is screwed firmly to the top of the steel rod and cemented with Loctite[TM]. The top of each rod is nearly flush with the ground surface and is encased by a 0.5 m-long PVC[TM] pipe; the space between the rod and the pipe is backfilled with gravel to the base of the stainless steel tip. The top of each kind of bench mark is rounded, so that the base of the leveling rod makes a point contact with it.

Bench marks are generally about 500 m from one another, but some are as close as 254 m (between GT33 and GT34) and as far as 847 m (between GT37 and GT38). As many as 40 turning points were needed between some of the permanent bench marks where the leveling route is steep, such as along the west shore of Jenny Lake, and along the horse trail from the shore of Jenny Lake to the top of the fault scarp in the mouth of Cascade Canyon.

Equipment and Methods

Two crews separately leveled segments of the line, and the results of each segment were combined to yield height differences among all of the bench marks together with a total closure error.

One crew used a Wild N3 tilting level in conjunction with a matched pair of strut-supported Wild GPL-3 leveling rods, serial numbers 6477 A and B. The other crew used a Wild NAK2 automatic level with optical micrometer in conjunction with a matched pair of strut-supported Wild GPL-3 leveling rods, serial numbers 4003 A and B. Leveling rods 4003 A and B have been calibrated annually by laser interferometry since 1976 at the U.S. Navy Gage and Standards Laboratory, Pomona. Leveling rods 6477 A and B were new. The instruments were shaded at all times during the field work. Personnel were apportioned so that there were two rodmen, and instrumentman, and a recorder who doubled as an umbrella man.

All leveling was double run with balanced sights. Length of shots from instrument to rod were no more than 21 m. Left rod readings were permitted to deviate from the right rod reading by no more than 0.010 cm, else the observation was repeated.

The leveling data were adjusted only to the extent that the closure error was apportioned by standard procedures throughout the leveled segment. Thus the data in Table 1 represent observed data; they are not

Table 1. Heights of bench marks, Teton fault crossing line, Grand Teton National Park.

BENCHMARK	1988 Height (METERS)	CUMULATIVESTADIA DISTANCE (METERS)
GT01	0.0000	0.0
GT02	0.2107±0.24mm	387.7±0.5m
GT03	0.0901	868.2
GT04	0.3822	1353.9
GT05	-1.7289	1850.0
GT06	-4.7299	2343.3
GT07	-9.5027	2882.2
GT08	30.3473	3541.4
GT09	32.3067	3982.2
GT10	31.2007	4445.3
GT11	26.7274	4794.7
GT12	24.3251	5207.4
GT13	22.0535	5631.1
GT14	17.5125	6106.9
GT15	14.2787	6658.1
GT16	10.7486	7176.8
GT17	7.1596	7739.1
GT18	4.7937	8273.6
GT19	6.3748	8729.2
GT20	9.2408	9263.9
GT21	7.0981	9598.8
GT22	6.9338	10,172.6
GT23	8.7628	10,489.1
GT24	13.5791	11,103.8
GT25	9.8745	11,580.4
GT26	13.4957	12,006.9
GT27	34.5644	12,333.8
GT28	60.7141	12,845.3
GT29	100.6850	13,304.1
GT30	97.0293	13,790.2
GT31	62.9240	14,250.1
GT32	29.1352	14,774.8
GT33	62.5362	15,451.4
GT34	108.1390	15,705.9
GT35	172.3880	16,420.9
GT36	197.8720	16,849.0
GT37	207.3890	17,553.9
GT38	223.0730	18,400.9
GT39	243.0340	19,023.6
GT40	261.4630	19,606.3
GT41	278.4630	20,232.4
GT42	292.1530	21,123.1

GT01 is arbitrarily assigned a height and distance of 0.0.

corrected for temperature, rod error, or other kinds of systematic and non-systematic errors. Our acceptable closure error for tectonic precision is 1 mm x D-1/2 where D is the one-way length of the line in kilometers. In an extensive series of tests, we routinely achieve a precision of a few parts in 10^{-7} in our observed data (Sylvester, 1984).

This Survey

The leveling typically commenced about 7:30 AM and terminated about 5 PM. Temperatures ranged from $5^{\circ}C$ in the early morning to $32^{\circ}C$ in the mid-afternoon. The sky was generally cloudless. The air was hazy on some days because of smoke from the Yellowstone fires. The air was usually calm each morning, but a strong gusty wind picked in the early afternoons of the last few days of the survey.

Personnel for the August 1988 survey were as follows: A. G. Sylvester, John Byrd, Ross McNeil, Ken Perez, Noel Howe, Allan Smith, Gail Cekada, and Michael Deacon.

Results

Adjusted heights and cumulative stadia distances of bench marks relative to GT01 are presented in Table 1. GT01, which is the easternmost bench mark and, thus, farthest from the fault trace, is arbitrarily assigned a height and distance of zero.

Table 2 presents the closure errors, leveling precision, length, and date for the surveys of the segments. Segment lengths were chosen on the basis of what could be double-run in a day or one-half of a day between two permanent bench marks, and so that no segment had more than 51 total permanent and temporary points.

Closure errors in Table 2 represents the misclosure between the foreward and backward runs of a segment. The allowable closure error for "tectonic precision" is 1 mm x D-1/2 where D is the one-way length of the line in kilometers, whereas "first order precision" is 2 mm x D-1/2, and "second order precision" is 5 mm x D-1/2 (Federal Geodetic Commission, 1984).

We achieved "tectonic precision" in 15 of the 23 segments, "first order precision" in seven of the segments, and "second order precision" in one segment - that between GT24 and GT26. Misclosure exceeded the allowable error by 1 mm. That particular segment was run across vegetated ground, rather than along a road or horse trail as all other segments were run. In fact, it was rerun after second order precision was achieved the first time, with a similar result. We believe that the survey was plagued by settlement of the rods and the instrument in the relatively soft, vegetated ground. We recommend that a route be taken along the horse trail in future surveys to minimize this problem.

Table 2. Closure errors and leveling precision of leveled segments.

LEVELING SEGMENT	LENGTH (METERS)	OBSERVED CLOSURE (mm)	ALLOWABLE CLOSURE (mm)*	PRECISION (PMM)	ORDER	SURVEY DATE
GT01-03	867.2	-0.364	0.931	-0.4198	TEC 1st	Aug 31
GT03-06	1475.1	0.734	1.214	0.4977	TEC 1st	Aug 31
GT06-08	1198.1	1.514	1.095	1.2633	1st	Aug 31
GT08-09	440.8	-0.110	0.664	-0.2499	TEC 1st	Aug 30
GT09-12	1226.2	0.895	1.107	0.7302	TEC 1st	Aug 30
GT12-15	1450.7	0.379	1.204	0.2611	TEC 1st	Aug 30
GT15-18	1615.5	-1.463	1.271	-0.8830	1st	Aug 30
GT18-21	1325.2	0.629	1.151	0.4749	TEC 1st	Aug 22
GT21-24	1505.0	-1.222	1.227	0.8118	TEC 1st	Aug 23
GT24-26	903.1	1.931	0.950	2.1379	2nd	Aug 24
GT26-27	326.9	0.289	0.572	0.8834	TEC 1st	Aug 25
GT27-28	511.9	0.508	0.716	0.9934	TEC 1st	Aug 25
GT28-29	458.8	0.516	0.677	1.1238	TEC 1st	Aug 26
GT29-30	486.1	0.359	0.697	0.7382	TEC 1st	Aug 26
GT30-32	985.6	1.875	0.993	1.9021	1st	Aug 25
GT32-33	675.6	0.314	0.822	0.4651	TEC 1st	Aug 23
GT33-34	254.5	0.661	0.496	2.3580	1st	Aug 24
GT34-35	714.4	1.035	0.845	1.4480	1st	Aug 24
GT35-37	1133.6	1.070	1.065	0.9439	1st	Aug 28
GT37-38	846.0	1.775	0.920	1.2078	1st	Aug 28
GT38-39	622.7	0.010	0.789	0.0162	TEC 1st	Aug 28
GT39-40	582.7	0.470	0.763	0.8063	TEC 1st	Aug 29
GT40-42	1516.8	0.640	1.232	0.4218	TEC 1st	Aug 29
TOTAL	21.123.1 m	12.336 mm	4.596 mm	0.5892 ppm		

*Allowable closure for "tectonic first order"= 1 mm x $D^{1/2}$ where D = one way segment length in kilometers.

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A precision of one part per million is equivalent to "tectonic first order" precision, and is considered the minimum acceptable level of precision to document tectonic movement by geodetic techniques. This survey achieved a precision of 5.89 x 10^{-7} (Table 2), which qualifies it for "tectonic first order" in spite of the lower order of some of the segments, especially the segment between GT24-26 which was second order.

Conclusions

This survey was concluded in a timely and geodetically rigorous manner. The high degree of precision attained for the entire line, 6 x 10^{-7} assures us that we shall be able to document tectonic movement having a movement of a few parts in 10^{-6} which is equal to an offset across the fault of about 25 mm. Between any pair of bench marks, however, we should be able to detect as little as 3 mm of movement. At a geologic slip rate of 1 mm/yr, it will require considerable time before sufficient slip accumulates to be detected confidently through the entire line length. On the other hand, if the slip is faster, or if slip occurs along the fault episodically in earthquakes as the geologic evidence indicates, then we shall be able to quantify the location and amount of slip or tilt with considerable confidence.

Paleomagnetic Study Of Deformation of the Teton Fault

Paleomagnetic analysis of oriented and dated rock samples in the footwall and hanging wall of a fault is a geophysical technique used to assess ground deformation that may be related to past paleo-earthquakes. In 1988, 43 locations, with 7 to 15 cores at each location, were sampled in units of the Huckleberry Ridge tuff during the week of July 8-15. This stratigraphic marker is 2.0 million years old and will be used as a means of assessing the amount of tilt in the hanging wall/footwall due to repeated earthquakes in the past 2 million years on the Teton fault. Sample sites (see attached map) were located within Grand Teton National Park, and the Bridger-Teton and Grand Targhee National Forests. Dr. John Geissman, University of New Mexico, assisted with the sampling program, and will also assist with the analyses of the cores in his laboratory.

Preliminary results from locations at Signal Mountain, east of the Teton fault, and the Grand Targhee area on the west side of the range, suggest that westward tilting in the Signal Mountain area may be entirely due to tectonic movement on the Teton fault. Results from the Grand Targhee area are equivocal, and suggest that the Huckleberry Ridge tuff may have undergone a rather complex cooling history in this area. Additional analyses of other sample locations on the west side of the Tetons are necessary in order to better evaluate these results.

Figure 3. Locations of (1) Teton fault zone (▬ ▬ ▬); (2) paleomagnetic samples (●); and (3) first-order level line (▬▬▬), GTNP & vicinity.

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